Late Holocene Shorelines and Sea Level in Miyako Island, the Ryukyus, Japan*

Toshio KAWANA** and Paolo A. PIRAZZOLI***

The present sea level in Miyako Island is the highest recorded during the Holocene, determined by systematic investigation of marine notches and beachrocks occurring along the coast. The elevations of the retreat points of the notches are consistent with the present tidal range and exposure. All beachrocks which are known to be due solely to tidal conditions are situated at an intertidal or almost intertidal zone. Near-intertidal beachrocks have been dated 425±70 and 1520±60 y. B.P. (Loc. 13), and 2120±75 y. B.P. (Loc. 31), showing a relative stability of sea level during at least the past 2100 years. This situation clearly differs from the Late Holocene emergence prevailing in most of the major axial islands in the Ryukyu Frontal Arc. Such a difference can be ascribed to recent crustal movements.

I. Introduction

The Ryukyu Islands form a tectonically active island arc stretching about 1,200 km between Kyushu and Taiwan (Figure 1). The area shown in Figure 1 is divided into eight geomorphological zones from the Asian Continent (west) to the Philippine Sea (east): Tunghai Shelf, Senkaku Island Arc, Ryukyu (Okinawa) Trough, Ryukyu Volcanic Arc, Ryukyu Frontal Arc, Fore-arc Slope, Ryukyu Trench, and Philippine Basin (KONISHI and Sudo, 1972). The Ryukyu Frontal Arc consists of the major axial islands: Amami, Okinawa, Miyako, Ishigaki Islands, etc. (west), and of the trenchward islands: Kikai Island, etc. (east) (KONISHI et al., 1974). Miyako is a relatively flat island (maximum altitude: 114.6 m), fringed with coral reefs and surrounded by three small islets: Ögami, Ikema, and Kurima (Figure 2). Quaternary Ryukyu Limestone of Miyako Island unconformably overlies the Uppermost Miocene–Lower Pleistocene Shimajiri Group consisting of mudstone, sandy mudstone and alternate beds of mudstone and sandstone (Ujité and Oki, 1974). Unconformity between these layers inclines westwards. Thus, the boundary between two layers occurs at high altitude on the scarps along the northeast coast of the island, while along the south and northwest coasts, only Ryukyu Limestone is exposed. Three levels of marine terraces have been recognized (OTA and Hori, 1980); none of them however is dated. Wall-like ridges of limestone extend along the northwest-southeast normal faults. Such landforms are similar to the ones named "limestone wall" in Okinawa by FLINT et al. (1953), who considered them to be the case-hardening of steep exposures of the limestone, followed by differential erosion. The east and south coasts of the island have abrupt cliffs, some climbing to more than 90 m, although most are generally smaller. Sea-corrosion notches have frequently been cut into the cliffs, but they have developed only in the mid-littoral zone corresponding to the present sea level (KAWANA and NISHIDA, 1980). Intertidal or almost intertidal beachrocks are common, especially along the northeast coast.

The tide in Miyako is of the mixed type, usually two high and two low a day, although the high and low tides are not of the same magnitude (diurnal inequality). The tidal data for Miyako are shown in Table 1.

* A contribution to IGCP Project No. 200 (Sea-level correlations and applications).
** Department of Geography, College of Education, University of the Ryukyus. 1 Senbaru, Nishihara, Okinawa 903-01, Japan.
Figure 1. Location map of the Ryukyu Islands.

Figure 2. Distribution of beachrocks and notches investigated along the coasts of the Miyako Islands.
Each number corresponds to the locality number of a beachrock or a notch. Distribution of the beachrocks at Loc. 11, 12 and 22 is determined from aerial photographs only because of inaccessibility. It is assumed that the beachrock at Loc. 42 was hidden by an embankment. The position of limestone walls has been determined from aerial photographs. (see also Figures 5 and 6.)
Table 1. Tidal values in Miyako Island.
The levels are related to the local datum at Hirara Port, Miyako Island.

<table>
<thead>
<tr>
<th>Tidal Level</th>
<th>Value (cm)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>MHHWSL (mean highest high water spring level)</td>
<td>+182</td>
<td>(1)</td>
</tr>
<tr>
<td>MHWSL (mean high water spring level)</td>
<td>+174</td>
<td>(2)</td>
</tr>
<tr>
<td>MHWL (mean high water level)</td>
<td>+156</td>
<td>(2)</td>
</tr>
<tr>
<td>MSL or MTL (mean sea level or mean tide level)</td>
<td>+102</td>
<td>(1)</td>
</tr>
<tr>
<td>MLWL (mean low water level)</td>
<td>+50</td>
<td>(2)</td>
</tr>
<tr>
<td>MLWSL (mean low water spring level)</td>
<td>+31</td>
<td>(2)</td>
</tr>
<tr>
<td>MLLWSL (mean lowest low water spring level)</td>
<td>+6</td>
<td>(1)</td>
</tr>
</tbody>
</table>

(1): Mean values compiled from data from the Okinawa branch of the Japanese Meteorological Association (1981). The MHH(LI)WLSL corresponds to the average highest (lowest) level reached at each spring tide.
(2): The average annual and spring values have been calculated from the tide tables of the year 1981 (see the above reference).

This paper is based on a systematic survey and measurement of beachrocks and marine corrosion notches, which are the most frequent indicators of sea levels occurring along the coasts of Miyako and the adjacent islands.

II. Characteristics of recent sea level indicators

1. Beachrocks

Beachrocks are very numerous in the area investigated (Figure 2). Their distribution was determined from colored aerial photographs and confirmed by a field survey. The vertical and horizontal sizes of each beachrock were measured and their relation to the tidal range was observed.

Three shell specimens Nos. 1–3 collected in the beachrocks at Loc. 13 and Loc. 29 (Figure 2) were identified by Moritoshi CHINEN (Naha High School, Okinawa) and were radiocarbon-dated by the Japan Radioisotope Association, with a half-life of carbon 14 of 5568 years (LIBBY’s value). The shell specimen No. 4 analyzed in a previous study (KAWANA, 1981) is also used in this study.

a) Specimen No. 1 at Loc. 29 (Figure 3)
Locality: 24°43′30″ N, 125°26′30″ E
Elevation: about 225 cm above the local datum
Age of the specimen: Modern
Laboratory number: N-4167
Taxon of the specimen: Tridacna (Flodacna) squamosa (Lamarck)

This beachrock, about 300 m long and 20 m wide, is intertidal in the western part, but its level rises in the east, where it reaches an elevation of about 365 cm above the local datum. A cross-section made in the eastern part of the beachrock and the position of the sampled specimen are shown in Figure 3. The dated shell was collected just below the surface of the beachrock, at an elevation of +225 cm, which is higher than the MHHWSL (+182 cm). Landward, the shore is bordered by a 40 m high cliff, the upper part consisting of Ryukyu Limestone, the lower part of the Shimajiri Group. A small spring issues from the cliff and disappears into the beach sands near the place where the beachrock is highest.

b) Specimen No. 2 at Loc. 13 (Figure 4)
Locality: 24°50′00″ N, 125°18′30″ E
Elevation: about 170 cm above the local datum
Age of the specimen: 425±70 y. B.P.
Laboratory number: N-4168
Taxon of the specimen: Tridacna (Flodacna) squamosa (Lamarck)

c) Specimen No. 3 at Loc. 13 (Figure 4)
Locality: 24°50′00″ N, 125°18′56″ E

Figure 3. Cross section of Loc. 29.
(1): sampling locality (2): beachrock (3): sand and gravel
Loc. 13 is situated in the northeastern part of the island. An extensive beachrock, about 400 m long 70 m wide, occupies most of a former small embayment. This is one of the largest beachrocks on the island. Inland from the beachrock there is a cliff of 20-30 m in height, composed mostly of the Shimajiri Group and capped by Ryukyu Limestone.

Figure 4 is a cross-section of the beachrock at Loc. 13, and indicates the sampling position of specimens No. 2 and No. 3. The surface of the beachrock shows a typical microcuesta-like topography; the outer layer, from which specimen No. 2 was sampled, is slightly lower than the inner layer containing specimen No. 3. Nevertheless, the beachrock at Loc. 13 lies entirely within the mid-littoral zone.

d) Specimen No. 4 at Loc. 31
Locality: 24°40'17" N, 125°21'34" E
Elevation: about 180 cm above the local datum
Age of the specimen: 2120±75 y.B.P.
Laboratory number: N-3825
Taxon of the specimen: *Tridacna (Flodacna) squamosa* (Lamarck)

The elevation of the beachrocks is shown in Figure 5 in comparison with the tide levels and the geology of the nearby cliffs. Beachrocks occur along almost all the coasts of Miyako, but they are especially extensive along the northeast coast of the island. There seems to be a close relationship between the presence of the beachrocks and the geological formations.

In general, the age of a specimen in a beachrock is older than that of the formation of the beachrock. The ages of the corals in the beachrock of Toku Island suggest however that the corals were conveyed to the shore shortly after their death (Takahashi and Koba, 1980). Moreover, it is known that beachrock can lithify rapidly, as evidenced by the incorporation of some materials in the beachrock (Milliman, 1974). We presume therefore that the tridacnic shells in the beachrocks in Miyako are not much older than the formation of the beachrocks.

Beachrock is formed in an intertidal and sea spray zone (Bricker, 1971; Milliman, 1974). All the beachrocks except one have developed within a range corresponding to the present mid-littoral zone (Figure 5). According to the
Late Holocene Sea Level in Miyako Island

Elevations and the radiocarbon ages obtained for the beachrocks, they all have been formed at sea level stand similar to the present one which has existed for at least the past 2100 years.

2. Notches

Notches cut by sea corrosion in limestone coasts yield very precise sea-level indications which have often been used for the reconstruction of former sea levels. The most important indicator is the retreat point, or vertex of the notch, which corresponds to the area of strongest attack on the limestone. This area is usually situated near the mean sea level on a sheltered shore (FOCKE, 1978).

Numerous sea-corrosion notches cutting the base of limestone cliffs are found around Miyako and the adjacent islands. Their distribution is shown in Figure 2. The elevations of the retreat points and their relation to the tidal range are plotted in Figure 6. This completes and updates the results of a previous investigation (KAWANA and NISHIDA, 1980). All the retreat points are clearly situated between MSL and MHWL. Even if the seasonal variations in MSL and local exposure to regular wave action are taken into account, all the notches investigated in Miyako clearly belong to the "tidal type" (PIRAZZOLI, in press) and correspond to a sea level very similar to the present one. In addition, vertical profiles of the notches, almost symmetrical to the retreat points, suggest stability of the sea level.

On the other hand, the depth of most notches ranges from about one to two meters. According to the rates of sea corrosion usually assumed for notch development in a tropical limestone area (1 mm per year on an average) (KAYE, 1959; HODGKIN, 1964; PIRAZZOLI, in press), it can be inferred that the notches in Miyako have been deepening for approximately the past two thousand years.

III. Discussion and conclusion

The notably high altitude of the beachrock at Loc. 29 is probably affected by the small spring in the nearby cliff. The cementation of the upper part of the beachrock is probably caused by fluctuations in the water table. The beachrock at Loc. 29 is Modern in age; therefore, its altitude does not indicate a former sea-level stand higher than the present one.

OTA and HORI (1980) have discussed Late Quaternary tectonic movements in the Ryukyu Islands, and ascribed the formation of the lowest terrace on Miyako Island, +10 m in elevation, to Holocene times. After investigation of the corrosion notches cut in the cliffs around the island, KAWANA and NISHIDA (1980) inferred that the sea level must have remained near its present elevation during a certain period in the Late Holocene.

The present investigation confirms that there is no evidence in Miyako of Holocene shorelines higher than the present one. The beachrock at Loc. 13, the depth of the intertidal notches measured along the shores of the island, and
the datings obtained from Loc. 13 and Loc. 31, all suggest that the local sea level seems to have remained almost stable in Miyako during at least the past 2100 years.

On the basis of all these data, we estimated the local sea level changes in Miyako as shown in Figure 7.

The recent sea-level stand in Miyako Island is in striking contrast to the situation prevailing in other major axial islands in the Ryukyu Frontal Arc, most of which show evidence of Holocene higher sea level stands at different levels (Pirazzoli, 1978; Koba et al., 1982). This contrast probably results from differences in crustal movements in the Ryukyu Islands, the active tectonic boundary where the Philippine Sea plate is being subducted beneath the Eurasia plate.

What should be emphasized is that Miyako is one of the few islands in the Ryukyus where Holocene emerged shorelines are completely absent. A sea-level rise prevailed in Miyako during the Holocene; however, since at least 2100 years ago, the relative sea level seems to have been almost stable.

Acknowledgments

This investigation was carried out in the framework of the French-Japanese co-operative studies in Earth Science ("Ryukyu Shorelines" project). Field work was supported in part by the Centre National de la Recherche Scientifique (France) and the Japan Society for the Promotion of Science. The invitation and assistance in 1981 of Professor Torao Yoshikawa (University of Tokyo) and Professor Koshiro Kizaki (University of the Ryukyus) are gratefully acknowledged. Facilities were provided by the Department of Geography of the University of Tokyo, the Department of Geography of the Yokohama National University, and by the Department of Marine Sciences of the University of the Ryukyus. We would like to express our gratitude to Dr. Moritoshi Chinen of Naha High School for the identification of the shell specimens. We are indebted to Professor Michihiro Miyagi, Dr. Shigekazu Mizaki of the University of the Ryukyus, and Dr. Motoharu Koba of the Ariake Technical College for their comments on an earlier version of the manuscript and for their many helpful suggestions. For revisions of the English text, we are grateful to Dr. Karen J. Lupidus (University of the Ryukyus) and Ms. Mary Delahaye (Institut Océanographique, Paris). Thanks are also due to the Japan Radioisotope Association for the age determination of the shell specimens, and to Mr. Kazuo Shimoz of the Shichifuku-so Inn who kindly provided facilities during the field work.

(Received September 29, 1983)
(Accepted April 28, 1984)

Notes

1) The mid-littoral zone is characterized by intermittent immersion by tide or waves. In sheltered sites, this zone covers approximately the tidal ranges (=intertidal zone). In regularly exposed sites the vertical range of the surf (surf or swash zone) must be added to the tidal amplitude.

2) The monthly MSL is at a maximum in August-September and at a minimum from December to February. The seasonal difference in elevation is about 35 cm.

References


---

**琉球列島, 宮古島の後期完新世海面変動**

河名俊男* ・ Paolo A. **Pirazzoli****

琉球列島の宮古諸島に分布するノッチおよびビーチロックの調査により、現海面が完新世の最高海水準を示すとの結論を得た。ノッチの後退点高度は潮間帯に位置し、ビーチロックは潮間帯あるいは、ほぼ潮間帯ビーチロックを示す。潮間帯ビーチロックの2カ所から、425±70年 B.P., 1520±60年 B.P. (Loc. 13) および 2120±75年 B.P. (Loc. 31) の年代値が得られた。以上のビーチロックおよびノッチの諸特性より、宮古諸島における後期完新世の海面は少なくとも2100年前より現在まで、現海面にはほぼ近い位置に存在していたと推察される。上記の海面変動は、琉球列島の他の主軸諸島に見られる後期完新世の高海水準を示す海面変動と対照的である。以上の対照性は、後期完新世に宮古諸島が他の主軸諸島と異質の地殻変動地域であった可能性を示唆する。

---

* 〒903-01 沖縄県西原町字千原 1　琉球大学教育学部地理学教室
** C.N.R.S., "INTERGEO". 191, Rue Saint Jacques, 75005 Paris, France