NEW RESEARCHES AT CORAL MINAMIDAITO ISLAND (NANSEI ARCHIPELAGO, SOUTHEAST JAPAN)

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ABSTRACT

Minamidaito Island is located on the Philippine plate. It lies about 360 km southeast of Okinawa. There were three karstification periods on Minamidaito. The first karstification occurred during the Pliocene between the Lower and the Upper Daito Layer. The top surface of the lower Daito Layer was karstified and soils formed. During the Pleistocene, karstification continued from 1.6 Ma until the last glacial period. Coral biointrasparite limestone and coral dolomitized biointrasparite limestone were identified. The calcimetric analyses showed that the distribution of limestone and dolomite in individual locations differed from that previously described. The rock transitions from limestone to dolomite in areas are today out of reach of even the highest waters but under constant impact of seawater spray. The line between the limestone lying below and the dolomite lying above probably corresponds to the line between the Lower and Upper Daito formations. Although the characteristics of coral limestone and dolomitized limestone put a distinctive stamp on the rock relief, it remains an important trace of the formation and development of this unique karst landscape. The rock is often heavily perforated in three dimensions during the subsoil phase, and when the subsoil formation is followed by denudation, and ultimately when it suffers corrosion due to seawater spray. The coral composition of the rock is distinctly reflected in rock relief forms. The rock is relatively smooth only in places hollowed by the erosive and corrosive action of waves and subsoil processes; rock exposed only to rain is less dissected than that exposed to seawater spray as well.

The unique features of the rocky shoreline are dictated by the erosive power of the sea, especially during periodic typhoons.

INTRODUCTION

Numerous studies have been done on the formation of Minamidaito Island and even more studies have dealt with the Kitadaito atoll located 12 km away (Suzuki et al. 2006). Their proximity explains a number of parallel characteristics and the same or very similar development and processes. The studies included coral limestone and dolomitized limestone and calcimetric analyses. Rock from Kaigunbo and several other locations on the island was described in detail.

The composition of the coral rock significantly influences the formation of the rock relief of karst features on the surface and in the caves on the island. Coral rock is mostly composed of larger whole or fragmented coral with fragile connections. This not only affects the surface of the rock and its relief but also its shape. The traces of rock formation by the factors characteristic of the environment are clearly visible.

The island has been karstified since the Pleistocene. The present study of Minamidaito Island examines the karstification periods during which the layers developed into their present state and
provides measured solution values of the limestone tablets studied (Urushibara-Yoshino 2003). Dating data on dolomitized limestone obtained by previous studies is used to estimate the age of karstification.

Figure 1. Coral Minamidaito island, Nansei Archipelago, Southeast Japan (Photo: NPO Dongosabows).

THE STUDY AREA

Minamidaito Island (Figure 1) is located on the Philippine plate and lies about 360 km southeast of Okinawa Island. This island is shifting toward the Ryukyu subduction zone at a speed of about 4 to 5 cm/year. Shown in Figure 2, the location of the island is 25° 50’ 47” N and 131° 14’ 24” E. Its north-south axis stretches 6.54 km, and its east-west axis, 5.78 km. The island was named Borodino Island in 1820 by the Russians.

PREVIOUS STUDIES

The bedrock layers of Kitadaito Island, located 12 km northeast of Minamidaito Island, have been thoroughly studied by geologists. According to their findings, it was possible to approximate data for the bedrock layers of Minamidaito Island (Ota et al. 1991, Omura and Ota 1992, Ohde and Elderfield 1992, Inagaki and Iryu 1998, Nanbu et al. 2003, Suzuki et al. 2006, Urushibara-Yoshino et al. 2009).

Borehole studies to a depth of —431.6 meters were made on Kitadaito Island (Sugiyama, 1934, 1936; Hanzawa, 1940). These studies reported pure limestone accumulation since the early Miocene. The upper parts (ca. 100 m) of the accumulation layer contain dolomitized limestone. The age of the layer was reported as Pliocene to Pleistocene. The geology was explained as follows: “Kitadaito and Minamidaito islands moved from the equatorial region to the present region, and these islands arrived at an uplifting zone as they neared the subduction zone about 1 Ma” (Hanzawa, 1940). Ohde and
Kitano (1982) and Ohde (1987) attempted to explain the dolomite of the Pleistocene layer, concluding that it is proto-dolomite formed in the lagoonal area of the atoll.
GEOLOGY

The profile on the eastern coast of the island (Kaigunbo) was studied in detail (Figure 3), rock in South Port, North Port and West Port and at some other locations (Figure 2).

The geological description of the profile at Kaigunbo (Figures 3 and 4) covers the distance from the water table to the top of the ridge in a southeast-northwest direction. The rock is moderately to thickly layered with layers between 10 centimeters and several meters thick. The dip of the beds changes along the profile, primarily running toward the northwest and ranging between 5° in 20°. Macroscopically, the upper planes of the beds in the lower section of the profile and in the cross sections contain numerous smaller and larger remnants of coral. The largest examples are several tens of centimeters in diameter.

The rock is covered by a microbial biofilm that accounts for the almost entirely grey surface of the rock. The only exceptions are individual areas where stronger waves reach higher on a shelf inclined at a 10° average whose highest part is about ten meters above the level of the sea. These areas reveal the true white colour of the rock because the frequent movement of the numerous pebbles and boulders (some up to several cubic meters in size) polishes the surface (Figure 4). Primary porosity is observed everywhere. Rock fissuring is not distinctive but predominantly subvertical faults and fissures in all directions can be traced. The thickness of the studied profile totals 40 meters. The age of the rock ranks it in the Daito formation (Urushibara-Yoshino 2003).

The description of the profile was divided into two areas. The first area occupies the almost 70-meter wide limestone rock shelf where the rock is periodically in contact with seawater. The lower section of the shelf lies between high and low tides while the slightly inclined and roughly 50-meter long upper section is only reached by high waters during typhoons and severe storms a few times a year. The second area is the almost vertical dolomitized cliff above the level shelf that is affected by the more or less constant spray of seawater.

At the beginning of the profile, at the limestone shore platform, the rock is biointramicrosparite to biointrasparrarite limestone (grainstone to boundstone and bafflestone to framestone). Calcite minerals dominate, and only occasionally do we find dolomite clasts fringing the fenestrae inside the sample limestone. Euhedral to subhedral dolomite crystals of one generation do not exceed 45 µm and only occasionally fringe the interior edge of fenestrae. Dolomite crystals comprise around 5%, insoluble residues a few percent (mostly between 1% and 4%), and the rest is calcite. The samples contain numerous whole corals and coral fragments but these do not exceed 10% of the total mass. Well sorted micrite and microsparite intraclasts dominate, usually between 0.14 and 0.45 mm in diameter. Among the orthochems, calcite drusy mosaic cement with grains that do not exceed 45 µm dominates. Porosity is primarily intragranular to fenestral and partly framework porosity and estimated at 5% to 10%. Secondary porosity is not observed, and there are no calcite veins.

The beds where dolomitized cliff area starts are composed of biointramicrosparite to biointrasparrarite dolomite (bafflestone to framestone). The transition between limestone and dolomite or between the limestone bed and the dolomite bed is sharp. In terms of minerals, dolomite dominates while the rest is calcite filling individual fenestrae that are 0.15 to 0.45 mm in diameter. Most of the fossils in the bed are corals in situ and their numerous fragments with some ostracod plankton and uniserial and biserial foraminifera as well. The cement is composed of unimodal dolomite euhedral to subhedral crystals
and occasional anhedral crystals. The porosity is primarily intragranular to fenestral and partly framework porosity and is estimated at less than 5%.

Figure 3. Kaigunbo bay on the eastern coast.

Figure 4: Traces of the erosion action of the sea water.
COASTAL KARREN

The karren that stretches to the top of the ridge encircling the island can be divided into that within direct reach of seawater and that shaped by various amounts of sea spray and rain. The former are shaped by seawater most of the time or just periodically by high waters or large waves (Figure 5).

![Sea pans](image)

Figure 5: Sea pans.

This study is focused primarily on the specific features in the formation of the coast (Figure 5) in the unique environment of Minamidaito Island.

There is a rock shelf at sea level that in places is several tens of meters wide. It is either completely submerged or only along its outer section and usually slopes gradually upward toward the island. It is flooded by high waves that carve notches where they touch the wall. A vertical wall up to ten meters high typically rises above the shelf and ends in a steep rim. Above this is another rock shelf, tens of meters in width, ending in another steep wall. This is repeated one more time but less distinctly before the top of the ridge. The surfaces of the first two ledges are bare but the topmost ledge is overgrown.
It is possible to describe generally the most characteristic cross sections of coastal karren. The width of shore platforms at sea level varies. They are usually dissected by pans that are often co-shaped by erosion. The steep cliffs along the coast, especially those behind narrower shore platforms, have distinct longitudinal notches. On the tops above them, the rock is heavily dissected by pinnacles and solution pans due to seawater spray. The lower section of the gradually rising erosional ramp is relatively smooth. In the area of constant wave activity, the rock is dissected by smaller solution pans and below the cliff it is dissected by larger ones, as a rule arranged in a longitudinal series. The higher parts lying five to ten meters above sea level are dissected by the relatively distinct seawater spray that is the dominant factor. These parts of the shelf are only occasionally flooded. However, the power and impact of the floods is huge, especially during the long-lasting activity of typhoons when the wind reaches speeds as high as 280 km/h. These parts also have erosion-polished rock surfaces and combined rock forms. These features are most distinct in lower, especially crosswise notches. Larger belts are covered by sand, pebbles, and boulders whose diameter on exposed positions can exceed one meter. Higher-lying surfaces are dissected primarily by seawater spray and are often covered in lichen. The immense erosive power of the sea in earlier periods is also demonstrated by the erosion caves in the cliffs above old shelves located five and more meters above the current water level. They can be several meters in length and their circumferences are polished by erosion.

Higher up the ridge on the top platform, the rock is thickly overgrown. Subsoil recesses in the coral rock are filled with soil and crisscrossed by roots. The previously described rock forms are found below the soil, and the rock is rounded and relatively smooth. Often soil is only found deeper in the pockets, and there are plants growing on the surface of the rock in their upper parts. The surface layer of bare rock is distinctly perforated and dissected according to its composition.

The coral rock is most distinctly dissected on steep parts of the slope at the top of the ridge that are mostly denuded. There are often more hollow areas than areas of solid rock since the rock has disintegrated to become scree at the foot of the cliffs. The rock is shaped by the seawater spray and rainwater that washed away the soil and exposed the subsoil-dissected rock.

CONCLUSION

The geological studies were also augmented with results of studies from the Kitadaito atoll located 12 kilometers to the northeast (Suzuki et al. 2006). Their proximity and locations make it reasonable to believe that the two islands share very similar or even identical formation and development processes. Numerous rock samples from different parts of Minamidaito Island were studied in detail and subjected to calcimetric analyses. Coral biointrasparite limestone (framestone and bafflestone with transitions to grainstone) and coral dolomitized biointrasparite limestone (framestone and bafflestone) with around 75% dolomite in the total carbonate content were identified. The calcimetric analyses showed that the distribution of limestone and dolomite in individual locations differed from that previously described (Ohde & Kitano, 1982). The rock transitions from limestone to dolomite in areas out of reach of even the highest waters but under constant impact of seawater spray. The line between the limestone lying below and the dolomite lying above probably corresponds to the line between the Lower and Upper Daito formations that formed in the Pliocene.

The coral composition of the rock is distinctly reflected in rock relief forms. The rock is relatively smooth only in places hollowed by the erosive and corrosive action of waves and subsoil processes; rock exposed only to rain is less dissected than that exposed to seawater spray as well. The unique features of the rocky shoreline are dictated by the erosive power of the sea, especially during periodic
typhoons. This periodic character is evident in the dominant proportion of features created by the corrosive activities of seawater, biocorrosion, and biocrust and the state of erosion forms found several meters inland, on shore platforms, or in walls. The surface of the interior of the island was formed under the soil; only the denuded sections of karren are transformed by rain. The rock relief of caves reveals their formation in the phreatic zone and the more or less distinct oscillation of the water level in them, the filling of passages by fine-grained sediment and the deposit of smaller quantities of fine-grained sediment on the circumference, and the distinctly porous rock of the ceiling and the heightening of passages due to its decomposition.

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