TOPOGRAPHICAL FEATURES OF PHYSIOGRAPHIC UNIT
BORDERS ON REEF FLAT IN FRINGING REEFS

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Abstract In coral reef ecosystem spatial structure of $10^1$-$10^3$ m scale provide very important aspect in coral reef conservation. Nakai (2007) showed that physiographic unit (PGU) could be set as well as zonation on reef flat of fringing reef. The borders of PGUs delimiting it from the open sea or an adjacent PGU are constituted by landforms such as reef crest or channels. In this article the landforms becoming the borders of PGUs were discussed and the PGU property was clarified.

Key words: coral reef, fringing reef, spatial structure, physiographic unit, PGU

1. Introduction

In coral reef ecosystem zonation has been studied about spatial structure of $10^1$-$10^3$ m scale (e.g., Ladd 1950; Wells 1957). While Nakai (2007) showed that physiographic unit (it is called PGU as follows) could be set as well as zonation on reef flat of fringing reef by a topographical study of Yoron Island. The unit is a basic inorganic environmental system reminding an ecosystem where however the process and geographical features are driven by the seawater movement of the system. Grasp of such a PGU leads to understanding space characteristic of real coral reefs ecosystem deeply. Furthermore, it plays an important role for coral reef conservation.

The borders of PGUs delimiting it from the open sea or an adjacent PGU are constituted by landforms such as reef crest or channels. The development of those landforms presents a differential setting at each area. The difference of development of each landform gives place to the borders of the PGU and produces variable properties in their respective features. The property is mainly the identifiable attributes or patterns found in seawater movement which are independent from the PGU itself. In this article, I will discuss about landforms becoming the borders of PGUs and examine the changing process of a PGU property and its corresponding landform changes. For these discussions two coral reefs will be shown as examples in the Ryukyu Islands. One is the reef of the eastern part of Yoron Island; another one is Henoko Reef is located in the East Coast of the central part of Okinawa Island (Fig. 1).

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Fig. 1 Location of Yoron Island and Henoko Reef.

Fig. 2 Physiographic units (PGU) in the coral reefs of Yoron Island.
1: Reef edge, 2: Reef crest, 3: Moat, 4: Land,
5: PGU border, 6: Dominant seawater movement

2. Landforms as the borders of PGUs

1) Reef crest
The typical characteristic of coral reef landform in the eastern part of the reefs of Yoron Island is the excellent development of reef crest. This reef crest has high level and high continuity. It is a fringing reef of a crest-moat type which Mezaki et al. (1977) described in detail. Fig. 2 showed PGUs in Yoron Island (Nakai 2007). These PGUs was set by seawater movement patterns clarified by aerial
photo reading and landform investigation. Because of the physiographic features developed by this reef crest, the seawater which entered into the moat cannot return to the open sea easily. The seawater then, flows through a direction parallel to the shoreline toward the moat.

The Fig. 3 generated from a combination of aerial photo interpretation, local observation and other existing documents (Japan Defense Facilities Administration Agency 2003; Nature Conservation Society of Japan 2006) describes the coral reefs environment of Henoko Reef. Base on these methods, distribution of reef crest was represented on Fig. 3. In Henoko Reef, the development of reef crest revealed that continuum is fragmentary. Furthermore, seawater movement patterns generally match the landscape patterns on reef flat which appeared on aerial photos.

As a result of the aerial photos processing and analysis, three PGUs were found in these coral reefs (Fig.3). However, they differ from each other in character since the driven factors of their physiography vary. At first, in the Unit 1, reef crest develops continually to some extent. Therefore, as the top of the reef flat of Yoron Island, seawater flows to a-like determined direction which is parallel to a shoreline in moat. However, in the Unit 2, the development of the reef crest presents a very bad shape. Therefore the seawater which entered the open sea just comes back to it almost like a rip current without drifting in a parallel course along a shoreline. The Unit 2 is independent from adjacent PGU, but its independency toward the open sea is not relative. And then this unit is a fringing reef non crest-moat type which Mezaki et al. (1977) described.

In each of the cases of well developed reef crest (crest-moat type) or undeveloped reef crest (non crest-moat type), seawater movement patterns displayed it in a schematic view (Fig. 4). The former is

![Diagram](image)

**Fig. 3** Physiographic unit (PGU) in Henoko Reef.
1: Coast line, 2: Seagrass bed, 3: Coral head zone, 4: Reef crest, 5: Land, 6: Reef edge, 7: Micro landform pattern, 8: Channel, 9: Artificial channel, 10: Dominant seawater movement, 11: PGU border.
closed to seawater movement system which is independent from the open sea in some degree because of the presence of a reef crest. Seawater comes into the reef flat ahead of the crest from the open sea, but does not pass through. In contrast, the latter is a much opened system which has active water changes between open sea and the reef flat because of the absence of a reef crest.

As above, reef crest constitute the PGU border with an entrance of seawater from the open sea. Therefore, the degree of seawater exchange and closure to the open sea depends on the importance of the PGU development.

![Fig. 4 Schematic view of seawater movement patterns in two landform types.](image)

2) Channel

In coral reefs, a bay and a channel cutting reef flat are often found. Such landforms were formed by geological structure such as fault and river erosion during the glacial age. The stream usually appeared to have cut a semi-deep channel through the well developed reef flat all the way out to the reef crest.

In the north East of Henoko reef, namely the northeastern side of Unit 3, the reef flat does not develop at all (Fig. 3). This is mainly attributed to Ooura Bay which is deeply indented. The reef flat, then, is completely cut, and seawater which moved on reef flat flows out all the way to the bay. Because of the absence of an adjacent PGU, its border appears clearly on the aerial photos. Besides, there was also evidence of few inflows of seawater due perhaps to severe wave scouring since we are in presence of a bay and not reef edge facing the open sea. Accordingly, a discharge effect took place as a large seawater exit makes it at the border. In Unit 3, though the development of reef crest is not so good, evidence of current paralleling the shore is found. This may explain the existence of a very large discharge effect at one of the PGU borders. In other words, the seawater which entered the open sea is
pulled towards an exit and moves all the way out to the reef flat. This process drives the currents flowing parallel to the shoreline.

However, channels cut on a reef flat may also have a discharge affect at such type of exits (Fig. 3). The southwest of Unit 1 is cut by a clear deep channel through the well developed reef flat. In Unit 1, seawater shows very clearly a movement pattern parallel to the shoreline which makes the channel develops as well as a reef crest. Thus, the seawater moving this way goes through the channel and flows out to the open sea. Meanwhile, there is reef flat in the southwestern side of the channel which can set another PGU. Similarly, the seawater moving in the PGU also flows through the channel and go out toward to the open sea. In this channel, seawater comes over from two adjacent PGUs in two completely reversal directions. However, because the channel is clearly cut, and its discharge effect is large, currents flowing from a PGU into another one are obviously rare. When a channel is deep, and its width wide, the vector driving the motion process grows large towards the open sea.

In Yoron Island the border between Unit 2 and Units 3 is a PGU border with a drainage function. This PGU border represents a rift of the reef crest rather than a channel because that part lacks consecutive reef crest. In the coral reefs where reef crest develops very well, the area where reef crest does not develop well is regarded as a channel cutting factor. However, that part is indistinct as a border.

Consequently, a channel should be qualify as a PGU border playing the role of the exit where seawater flows from the reef to the open sea. The development of a channel may influence two processes. One is the power and features of the current which move parallel to the shoreline in reef flats. Indeed, whenever the development of the channel is good, it triggers the motion of a current. Another process is its independency toward an adjacent PGU. If the development of channel is good, the seawater movement of one PGU does not influence the movement in the adjacent PGU.

3) Cape

The existence of a cape may determines the seawater movement pattern too. In Fig. 2, the PGU border between Unit I and Unit II is a cape and the width of reef flat gets narrower than the outskirts. The seawater which entered from the open sea flows toward a larger cross-section. Therefore courses of the current are different around the border of the cape. A cape is a border standing as a dividing ridge in a land drainage system. If a cape develops well, and the width of the reef flat becomes narrow, the border of the PGU becomes clear. In the northern limit distribution area of coral reefs in high latitude, reef flat does not develop on the front of a cape, but spreads between capes (Nakai 1990). In this case, reef flats developing next to each other across a cape completely become separated with the PGUs.

4) Land

Because of the presence of a land close to the reef flat, the cape serves as a dividing ridge in a land. This is a problem of landform developed in a scale of 10^3-10^4 levels. In other words, such physiography is related to the geomorphological features of the types of coral reef (fringing reef,
barrier reef, atoll, etc.). In this study we will focus our analysis on a fringing reef where reef flat develops close to a land.

Because it is a fringing reef, the seawater which flows in the reef flat changes the direction of the current along the shoreline of the land. In that case a cape of the land serves as a dividing ridge. However, in the case of an atoll where there is no land inward or barrier reef which has a wide and deep lagoon between land and reef flat, current paralleling the shoreline does not occur. In a land drainage system, the rain which fell is divided by a ridge and flows to the sea.

However, in this case, it seems rain falls directly into the sea. Therefore, if there is not the land in a neighborhood of reef flat, PGU cannot be set. But PGU may be set in a reef flat when there is sand cay on reef flats of a barrier reef or atoll. And fringing reef sometimes develops in the most landside of barrier reef; such cases may give allow the development of a PGU.

Table 1 shows relations between geomorphologic coral reef types and spatial structures.

<table>
<thead>
<tr>
<th>Table 1 Geomorphological types of coral reefs and spatial structure</th>
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<tbody>
<tr>
<td><strong>Direction of Seawater Movement</strong></td>
</tr>
<tr>
<td>(to Coast Line)</td>
</tr>
<tr>
<td>Barrier Reefs / Atolls</td>
</tr>
<tr>
<td>Fringing Reefs</td>
</tr>
<tr>
<td>Non Crest-Moat Type</td>
</tr>
</tbody>
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: confirmed, △: occasionally confirmed, ×: not confirmed

3. Conclusion

For a landform to be qualifying as a PGU border, the typical features are to be found in reef crest, channel, cape, land. These landforms are distributed regarding a gradient of functions as follows.

1. A border standing as an entrance of seawater....reef crest
2. A border standing as an exit of seawater........... channel
3. A dividing ridge standing as a border.................cape, land

These landforms appear with various pairs in real coral reefs. Besides, the degree of the development is different from place to place. For example, the Yoron Island is a very simple example. Consecutiveness of reef crest is high, and the number of channels is extremely limited. But, in the Henoko Reef, reef crest is not well developed and it appeared to be cut in several places by channels. These typical landforms have possibility to develop into a PGU border. However, with regard to the function that these landforms have at each place, the strength of an effect is different accordingly to the
development, degree, position and relations with other landforms. Therefore landform developing all the way to a PGU border has been really limited cases.

Moreover the difference of the development degree in each landform which becomes a PGU border affects to relations of an interval between PGU next to each other. The landform where the development degree is high, the border of the PGU clearly cut. In other words, there's no seawater movement sitting astride an adjacent PGU, and each other's independency is clearly set. On the contrary, if the development degree is low, the seawater movement which sat astride in an adjacent PGU is easy to be generated although it is a PGU border and their independent characteristics are lower. Each other's independency then becomes lowers and naturally their relationships are strong. The possibility of a Super Unit comes through the analysis of the relations between such kinds of PGUs.

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References


(*: in Japanese, **: in Japanese with English abstract)