OS31A-0976, 2014 AGU Fall Meeting - Ocean Sciences Section: New Perspectives on Seafloor Morphology from High-Resolution Ocean Mapping

Submerged Humid Tropical Karst Landforms observed by High-Resolution Multibeam Survey in Nagura Bay, Ishigaki Island, Southwestern Japan

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Abstract

Submerged tropical karst features were discovered in Nagura Bay on Ishigaki Island in the South Ryukyu Islands, Japan. This is the first description of submerged humid tropical karst using multibeam bathymetry. We conducted a broadband multibeam survey in the central area of Nagura Bay (1.85 × 2.7 km) and visualized the high-resolution bathymetric results with a grid size of 1 m over a depth range of 1.6–58.5 m. Various types of humid tropical karst landforms were found to coexist within the bay, including fluviokarst, doline karst, cockpit karst, polygonal karst, uvalas, and mega-dolines.

We assume that Nagura Bay was a large karst basin in which older limestone remained submerged, thus preventing corrosion and the accumulation of reef sediments during periods of submersion, whereas the limestone outcropping on land was corroded during multiple interglacial and glacial periods. Based on our bathymetric result together with aerial photographs of the coastal area, we conclude that the submerged karst landscape has likely developed throughout the whole of Nagura Bay, covering an area of ~6 × 5 km. Accordingly, this area hosts the largest submerged karst in Japan.

We also observed abundant coral communities during our SCUBA observations. The present marine conditions of Nagura Bay are characterized by low energy (calm sea) and low irradiance owing to the terrestrial influence. Such conditions have been strengthened the effect by the presence of large undulating landforms, which cause decreases in wave intensity and irradiance with depth. These characteristics created unique conditions compared to other coral reef areas in the Ryukyu Islands. It may play an important role in supporting the regional coral reef ecosystem.

1. Introduction

The geomorphology of shallow coastal regions has been modulated by repeated subaerial and submarine processes during glacio-eustatic sea-level change. However, in contrast to the vast knowledge that has been accumulated regarding terrestrial landforms, few previous studies have dealt with shallow seafloor landforms, which represent former terrestrial landscapes modified by present marine processes, from a geomorphological perspective.

2. Study Area

Ishigaki Island is one of the Ryukyu Islands located in the northwestern Pacific (Fig. 1A). The warm Kuroshio Current originates from the Western Pacific Warm Pool flows through the Ryukyu Islands. Fringing reefs are developed around the islands under the humid tropical climate. We conducted MBES survey in a rectangular area spanning 1.85 × 2.7 km in the central part of Nagura Bay located on the western coast of Ishigaki Island (Fig. 1B, C).

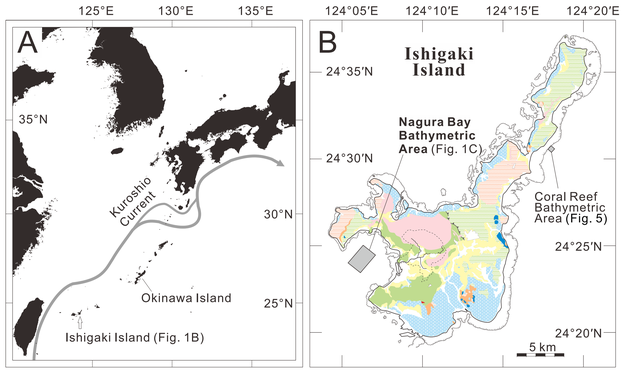
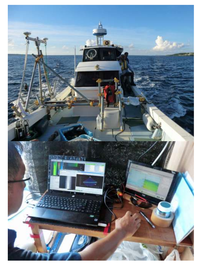


Fig. 1 (A) Location and (B) lithology of Ishigaki Island, showing surveyed area (C).

Coastal geomorphology with reference to the bathymetric results in Nagura Bay. The aerial photograph was provided by Pasco Co. Ltd.



3. MBES Methodology

A broadband multibeam echosounder (Sonic 2022, R2 Sonic, LLC) and its accessory system were introduced to the first author's laboratory. The Sonic 2022 has a variable ultrasonic frequency of 200–400 kHz, 256 ultrasonic beams and selectable swath coverage of 10–160°. The typical ultrasonic beam widths parallel and orthogonal to the direction of travel are within one degree of each other when an ultrasonic frequency of 400 kHz is selected. We used a VS111 GPS compass system with A20 and A30 antennas (Hemisphere Inc.) combined with a dynamic motion sensor (DMS-10, Teledyne TSS Ltd.), a sea surface sound velocity sensor (miniSVS, Valeport Ltd.), a sound velocity profiler (MicroSVP, AML Oceanographic Ltd.).

In general, the ultrasonic frequency of 400 kHz was selected for bathymetric survey, however, we adopted 200 kHz in the southwestern (i.e., oceanward) third of the Nagura Bay area owing to the occurrence of occasional weak reflections produced by partially distributed soft bottom sediments and to increase swath width. Overlap of at least ~20% (typically ~50%) was implemented throughout the bathymetric survey to ensure 100% coverage of the surveyed area. The depth of the surveyed area is within the range 1.6–58.5 m. The HYPACK2010 software was used for both hydrographic survey and data processing. IVS3D Fledermaus was used for three-dimensional visualization with a grid size of 1 m.

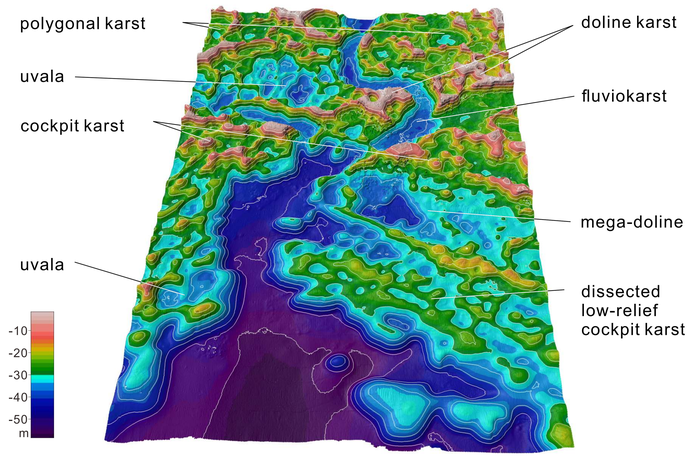


Fig. 2 Multibeam bathymetry of Nagura Bay.

A bird's-eye view of our bathymetric results, visualized with a horizontal grid size of 1 m. Contours indicate 5 m isobaths. Vertical exaggeration is times 3.

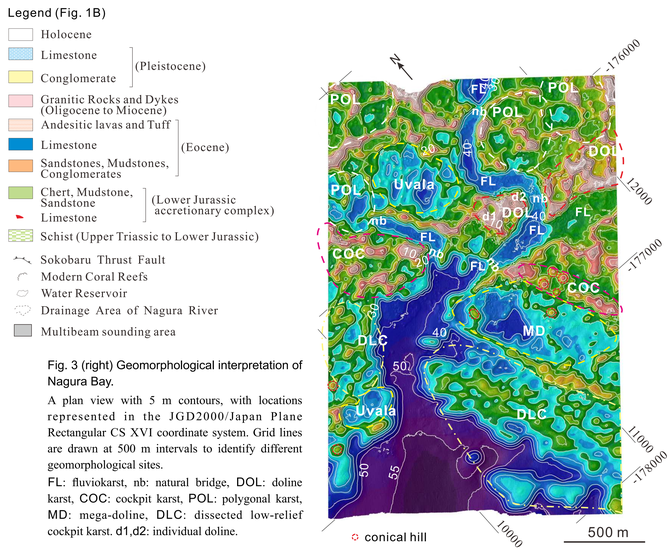


Fig. 3 (right) Geomorphological interpretation of Nagura Bay.

A plan view with 5 m contours, with locations represented in the JGD2000/Japan Plane Rectangular CS XVI coordinate system. Grid lines are drawn at 500 m intervals to identify different geomorphological sites.

FL: fluviokarst, nb: natural bridge, DOL: doline karst, COC: cockpit karst, POL: polygonal karst, MD: mega-doline, DLC: dissected low-relief cockpit karst. d1,d2: individual doline.

4. Seafloor landforms

The terrestrial karst landscapes break up the integrated and scalable patterning typical of fluvial systems by encouraging the development of small centripetal drainage basins and closed depressions exhibiting irregular patterning[1]. The seafloor landforms of Nagura Bay are characterized by large, frequent undulations (~30 m) with numerous depressions (represented by closed contours in the figure). It resembles that associated with the typical terrestrial karst landforms and may be attributed to a submerged karst that developed during a sea level lowstand (Figs 2 and 3). The undulations decrease in the seaward (i.e., southwestward) direction, such that a flat seafloor without closed depressions appears below 40 m.

An aerial photograph (Fig. 1D) illustrates that the submarine plateaus observed in our bathymetric result extend to the shallow coastal area of Nagura Bay. Many closed depressions can also be seen in this photograph. Based on our bathymetric result together with aerial photographs of the coastal area, we conclude that the submerged karst landscape has likely developed throughout the whole of Nagura Bay, covering an area of ~6 × 5 km. This area hosts the largest submerged karst in Japan.

Because the the karst landforms are covered by a thick postglacial reef complex, the host rock remains unknown. In general, cockpit karsts are typically developed in pure and hard carbonate strata. The Pleistocene limestone in the Ryukyu Islands is porous reef limestone with high permeability. In Ishigaki Island, conical hills are developed on the Eocene limestone. We assume that the hard Eocene limestone is the host rock of the submerged karst landscape in Nagura Bay.

[1] Jennings, J. N., 1985. Karst Geomorphology. Basil Blackwell, Oxford, UK, 293pp.

5. Difference from coral reef geomorphology

Figure 5 illustrates a 500 × 500 m area of coral reef morphology along the northeastern coast of Ishigaki Island. Distinct spurs and grooves have developed with long axes parallel to wave orthogonals. In contrast to the reef geomorphology, the bathymetric map of Nagura Bay is characterized by large geomorphological units with gently curved isobaths and large undulations (Fig. 3).

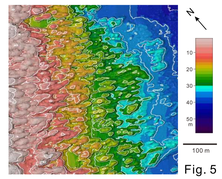


Fig. 5

MORE INFORMATION in the following paper:

Kan, H., Urata, K., Nagao, M., Hori, N., Fujita, K., Yokoyama, Y., Nakashima, Y., Ohashi, T., Goto, K., Suzuki, A., (2014) Submerged karst landforms observed by multibeam bathymetric survey in Nagura Bay, Ishigaki Island, southwestern Japan. *Geomorphology*, (in press) DOI: 10.1016/j.geomorph.2014.07.032

OPEN ACCESS at: http://www.sciencedirect.com/science/article/pii/S0169555X14003973

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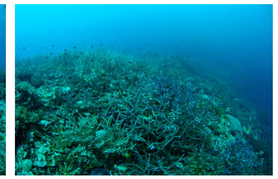
Edge of the submarine plateau where branching coral rubble forms talus creeps that extend toward the fluviokarst valley (depth: 10 m).

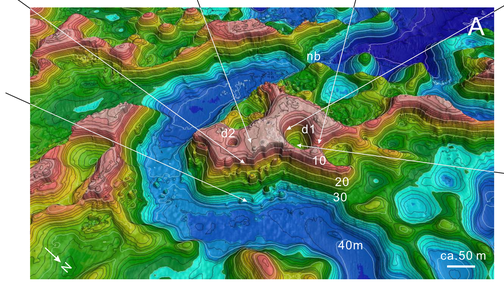
Top surface of the submarine plateau covered by living solitary and branching corals (depth: 5 m).



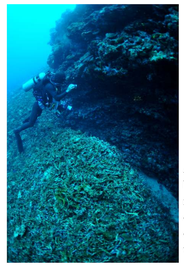
Branching *Acropora* thicket on a saddle between two dolines (depth: 12 m).

Foliaceous corals in the middle of an interior slope of doline d1 (depth: 15 m).

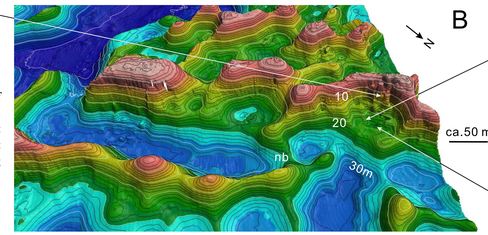
A huge block and fine sediment at the bottom of the fluviokarst valley (depth: 32 m).

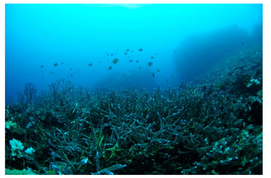


Living coral head at the bottom of doline d1 (depth: 23 m).



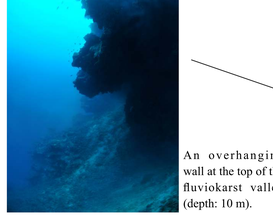
Accumulation of branching coral rubble with height of ~1.5 m at the foot of an overhanging wall (depth: 15 m).



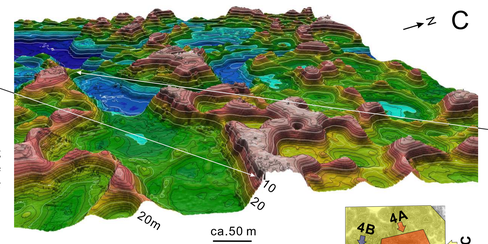


Thicket of branching *Acropora* sp. (depth: 25 m).

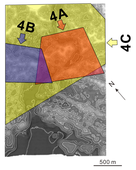
Monospecific communities of laminar corals. (depth: 25 m).



An overhanging wall at the top of the fluviokarst valley (depth: 10 m).



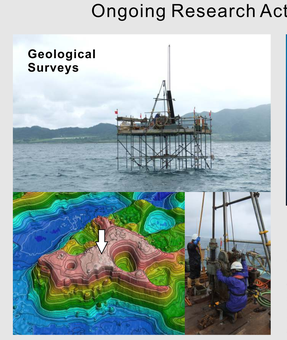
Large thicket of branching *Acropora* sp. (depth: 25 m).



The left map shows the areas of Figs. 4A (red), 4B (blue), and 4C (yellow) overlaid on a plan view corresponding to Fig. 3. Arrows indicate the direction of three-dimensional views.

Fig. 4 Three-dimensional views of submerged karst and SCUBA diving observations in Nagura Bay. (A) doline karst and fluviokarst viewed from the northeast, (B) polygonal karst (right) and fluviokarst (left) viewed from the northeast, and (C) fluviokarst viewed from the southeast. Contours indicate 5 m (white) and 1 m (black) isobaths. d1 and d2: dolines corresponding to Fig. 3, nb: natural bridge. Vertical exaggeration is times 3. All photographs were taken by H. Kan in November 2011.

Ongoing Research Activities in Nagura Bay



Left: Our drilling down to 60 m depth is, to date, the only source of borehole information for the entire Nagura Bay area.

Above: We started biological and ecological surveys including coral distribution and coverage in Nagura Bay with Frederic Sinniger, Rian Prasetia and Saki Harii.