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沖縄島と平安座島の上に位置する海中道路 沖の埋没化石マイクロアトール群

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Buried fossil microatolls off the Kaichu-Doro Causeway, between Okinawa and Henza Islands

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Abstract. On sandy tidal flats about 1 km south of the “Kaichu-Doro” Causeway (26°19’34”N, 127°55’58”E), we discovered many fossil microatolls up to 5 m in diameter, which were buried in sandy sediments. Radiocarbon ages of the outermost top of microatolls indicated that the massive *Porites* corals were dead at ca. 3700 to 4000 Cal BP. These buried fossil microatolls suggest that a shallow-water back reef moat environment existed in this area ca. 4000 years ago.

Record

Microatolls are intertidal coral colonies with dead, relatively flat, upper surfaces surrounded by an annular rim of living coral (Smithers 2011). We discovered fossil microatolls (i.e., those in which no living polyps survive but the colony morphology is preserved), located about 1 km south of the “Kaichu-Doro” Causeway connecting Okinawa Main Island and Henza-jima Island (26°19’34”N, 127°55’58”E; Fig. 1). The fossil microatoll zone ranges about 300 m from east to west, and about 200 m from south to north (Fig. 2). The east end is truncated sharply, while the west end is bounded by sand banks with large limestone blocks. The north side is connected to a sand flat zone, while the south side is connected to an exposed reef crest, where many *in situ* dead branching and table corals were found. The area is completely exposed during low tides.

The fossil microatolls are up to 5 m in diameter, with most approximately 1 m in diameter (Fig. 3). Since these fossil microatolls were buried with sand and gravel, their colony height is not clear. All microatolls were originally massive colonies of *Porites* spp. (possibly mixed populations of the species *Porites lobata* Dana, 1846, *P. lutea* Quoy & Gaimard, 1833, and *P. australiensis* Vaughan, 1918). Their morphologies were classified as the



Fig. 1. A photograph of a tidal flat off south side of the “Kaichu-Doro” Causeway, showing fossil microatolls (white arrows) buried in sediment.

図 1. 海中道路南側沖に広がる干潟で発見された埋没化石マイクロアトール群 (白い矢印).

“classical” form according to Hopley (1982), with a relatively flat plane on the top. The number of fossil microatolls is estimated to be more than 1000 colonies within the area, based on the average counts of two to three microatolls per unit of area (100 m²) multiplied by the total area (approximately 50,000 m²).

Radiocarbon ages of the outermost top of three microatolls were determined by accelerator mass spectrometry (AMS) analysis. Conventional ¹⁴C



Fig. 2. Distribution of buried fossil microatolls off the south side of the “Kaichu-Doro” Causeway (within white dotted lines).

図 2. 海中道路南側沖における埋没化石マイクロアトール群の分布 (白い点線内).

ages were calibrated using the Marine 13 dataset (Reimer et al. 2013), a ΔR value of -85 ± 75 years, and the calibration software OxCal v4.2.3 (Ramsey 2009). The ΔR used in this study was a weighted mean of ΔR values ($n = 10$) from corals and molluscs around the Ryukyu Islands (data from 14CHRONO Marine Reservoir Database; Reimer and Reimer 2001). Results of calibrated ages showed that all the three massive *Porites* corals were no longer alive after ca. 3700 to 4000 Cal BP (Table 1).

Large *Porites* colonies are commonly found in protected reef zones such as back reefs and fore-reef slopes. *Porites* species are generally tolerant of wide ranges of seawater temperature and light intensity. Some species found on reef flats can cope with exposure to full sunlight and air temperature during low tides for several hours. *Porites* species are also tolerant of high salinity and fine particle sedimentation (Pichon 2011). Nevertheless, fossil *Porites* microatolls buried in sediment suggest that these *Porites* corals suffered extreme stress conditions such as longer-term exposure to air and/or sudden burial by high rates of sedimentation. Further research needs to specify the causes of *Porites* deaths, but their deaths are likely related to a relative sea-level fall during late Holocene around Okinawa Island (e.g., Kawana 2002).

Although coastal ecosystems on tidal flats along the Kaichu-Doro Causeway are now degraded possibly due to reduction in water flow caused by the construction of the causeway (Reimer et al. 2015), these fossil microatolls also suggest that a shallow-water, back reef moat environment with abundant *Porites* microatolls existed in this area ca. 4000 years ago. These buried fossil microatolls are,



Fig. 3. Some examples of buried fossil microatolls off the south side of the “Kaichu-Doro” Causeway. **A** sample M01, longest diameter = 132 cm; **B** sample M08, longest diameter = 485 cm; **C** sample M09, longest diameter = 130 cm.

図 3. 埋没化石マイクロアトールのいくつかの例 (**A** 試料 M01, 長軸直径 = 132 cm; **B** 試料 M08, 長軸直径 = 485 cm; **C** 試料 M09, 長軸直径 = 130 cm).

therefore, important for understanding the history of the formation of the tidal flats and their ecosystems.

Table 1. Radiocarbon dating results of microatoll-forming *Porites* corals off the south side of the “Kaichu-Doro” Causeway.

表 1. マイクロアトールを形成するハマサンゴ属サンゴの放射性炭素年代測定結果

Sample ID	Beta Analytics ID	Coral	Location		Calcite	$\delta^{13}\text{C}$ (‰)	Conventional ^{14}C age (yr BP)	Calibrated age (Cal BP)	
			Latitude (N)	Longitude (E)				Median	2 σ range
OK-Ka-M04	364417	<i>Porites</i> sp.	26° 19' 34"	127° 55' 59"	Not detected	-3	3920 ± 30	4018	3801–4267
OK-Ka-M08	364418	<i>Porites</i> sp.	26° 19' 34"	127° 56' 01"	Not detected	-0.8	3780 ± 30	3828	3615–4060
OK-Ka-M10	364419	<i>Porites</i> sp.	26° 19' 33"	127° 56' 03"	Not detected	-1.4	3700 ± 30	3727	3516–3948

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要旨. 沖縄島と平安座島の上に位置する海中道路の南へ約 1 km の砂質干潟 (26°19'34"N, 127°55'58"E) において、砂質堆積物に埋もれた、直径が数 m に及ぶ化石マイクロアトール群を発見した。マイクロアトールの頂部最外縁部を放射性炭素年代測定した結果、マイクロアトールを形成する塊状ハマサンゴ属サンゴは約 3700–4000 年前まで生きていたことを示す。これらの埋没化石マイクロアトール群は、浅い礁原 (礁池) 環境が約 4 千年前までこの海域に広がっていたことを示唆する。

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