100. *An Early Wisconsin Reef on the Daito Ridge, North Philippine Sea*

Isotopic Evidences

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Coralline radiometry by uranium-series has successfully located ancient strand lines during the Last Interglacial State and the following intra-Wisconsin Interstadials, the datum levels to estimate the amount and rate of vertical displacement resulting from local as well as regional neotectonism (e.g. Fig. 8 of Konishi *et al.*, 1974) Together with the celebrated Kita-daito (North Borodino Island) (Sugiyama, 1934, 1936; Hanzawa, 1940), Minami-daito (South Borodino Island) of the Daito Islands represents an emergent dolomitized atoll capping above the otherwise submarine Daito Ridge which is one of the oldest remnant arcs in the Philippine Sea (Konishi *et al.*, 1973).

Because of its unique geomorphic configuration and geotectonic location in front of the Ryukyu Trench, this paper reports the occurrence of an emergent fringing reef of the earliest intra-Wisconsin Interstadial (ca. 100,000 years B.P.) from the elevated atoll, Minami-daito, and discusses Late Quaternary tectonic history of the remnant arc. The dating was done by the newly proposed ^{226}Ra-^{238}U method (Komura *et al.*, 1978), the result of which was supported with ^{14}C dates for the same specimens. It is further complemented with oxygen isotopic analysis of the associated gastropods. In spite of the contemporaneous aseismic activity, the observed elevation of the earliest intra-Wisconsin reef at the island suggests a steady slow rate (ca. 0.25 mm per year) of uplift of that part of the Daito remnant arc in the Philippine Marginal Sea for the last 100,000 years, or possibly as long as its two-times of the duration.

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Geology. The dolomitized reef complexes on Minami- and Kita-daito which were hitherto denominated Daito Limestone (Aoki, 1931) are better redefined and named as Minami-daito and Kita-daito Dolostone, respectively. They have been correlated micropaleontologically with the Pleistocene Riukiu Limestone of the Ryukyus to the north and west, and the Mariana Limestone of the Marianas to the east (Hanzawa, 1956).

The Minami-daito reef complexes can be geomorphologically divided into five units, of which the earlier two stages are believed to represent atoll environment, whereas the subsequent three periods are of fringing reef (Motoya, 1976 MS). The latest fringing reef complex is preserved as coralliferous calcirudites forming the lowest terrace which crops out between the mean water level and 11 m above it. The complex unconformably overlying the Minami-daito Dolostone is characterized with two lithofacies; a landward facies of reefoid biolithites merges gradually into the seaward fore-reef facies of allochthonous coralline gravels associated with abundance of gastropods, as observed at Kaigunbo, the east-south-east end of the island (Fig. 1). Thin veneer of the similar stratigraphic context has been

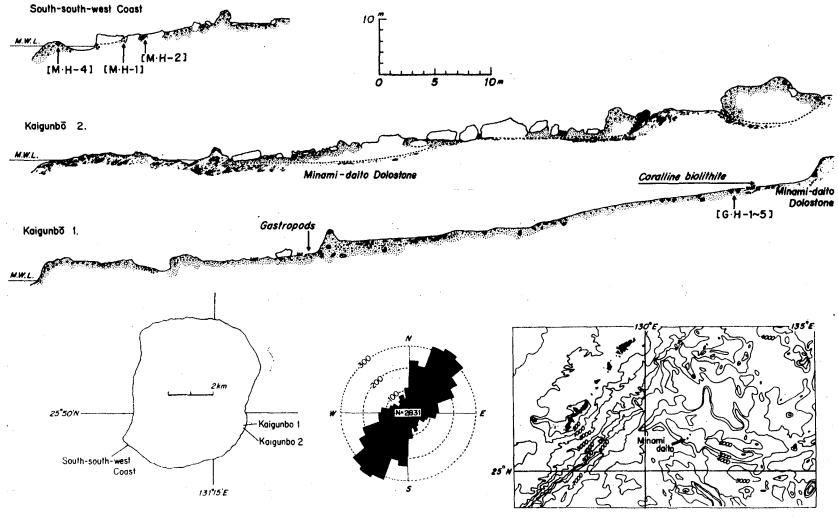

Fig. 1. Maps and cross-sections that show the location of measured traverses and dated corals on them at Minami-daito-jima. Diagram at the central bottom indicates percentage of 2831 fissures and lineaments that have been observed in Minami-daito Dolostone.

mapped in the crenuated grooves along the southwestern coast.

In contrast with the older four units forming the Minami-daito Dolostone, the youngest reefoid sediments, for which the Kaigunbo Limestone is named hereafter, has been escaped from dolomitization and still retain the original mineralogy, both aragonite and magnesian calcite almost entirely. Dolomite is found only as detrital blocks and grains. Matrix of the calcirudites consists of detrital grains of skeletal origin, which are feably cemented with magnesian calcite.

Radiometric dating. Six hermatypic corals in growth position were collected from the two traverses perpendicular to the coast line, the one at Kaigunbo, the type locality of the Kaigunbo Limestone, and the other at the southwest end of the island (Fig. 1). As shown in Table I, all the six specimens were dated by the "non-destructive" ^{226}Ra-^{238}U gamma-spectrometry at Low Level Radioactivity Laboratory of Kanazawa University, and five of them were double-checked with ^{14}C proportional gas counting method at Japan Radioisotope Association (Tokyo).

Although the specimens came from two localities, they gave a consistent date within the range from 87,500±5,000 years B.P. to 110,000±14,000 years B.P. If a statistical error be considered, these values are close enough to the established dates for the earliest intra-Wisconsin Interstadial (100,000 years B.P.).

The discrepancy as this between ^{14}C and uranium-series ages like ^{226}Ra-^{238}U, ^{230}Th, ^{231}Pa and ^{234}U dates is not uncommon for the specimens older than 25,000 years B.P., because even a very small amount

Table I. Radiometric dates and geochemical data of fossil corals from Minami-daito

Sample	Taxa	^{238}U (ppm)	^{226}Ra (dpm/g)	$^{226}Ra/^{238}U$ ratio (% equil.)	^{14}C age*	$^{226}Ra/^{238}U$ age (×1000 y)
KK75042801 (=GH-1, N-2151)	*Porites* sp.	3.14±0.12	1.61±0.04	69.7±4.0	41600^{+4600}_{-3000}	105±11
KK75042803 (=GH-3, N-2152)	*Hydrophora* sp.	2.71±0.22	1.42±0.02	71.3±5.8	27500± 700	110±14
KK75042804 (=GH-4, N-2153)	*Goniastrea* sp.	3.38±0.10	1.58±0.04	63.7±2.5	39100^{+3200}_{-2300}	91± 6
KK75042805 (=GH-5)	*Porites* sp.	3.47±0.17	1.64±0.05	63.3±3.7	——	90± 9
KK75050101 (=MH-1, N-2154)	*Goniastrea* sp.	3.30±0.09	1.54±0.04	63.5±2.4	34300^{+1700}_{-1400}	91± 6
KK75050102 (=MH-2, N-2155)	*Favites* sp.	3.38±0.12	1.53±0.03	61.6±2.5	40500^{+2900}_{-2200}	87.5± 5

* Calculated with the half-life of 5730 years (by Ms. T. Hamada).

of contaminant of modern carbon into such an old specimen easily results in an apparent age far younger than the real one. The ^{14}C ages of this nature should be taken as the minimum ages.

Oxygen isotope analysis. Thirteen gastropod specimens comprising four species from the Kaigunbo Limestone were analyzed for their oxygen and carbon isotope ratios with Nier-McKinney-type mass-spectrometer (HITACHI RM61-model) at Department of Earth Sciences, Faculty of Science, Kanazawa University. The obtained values expressed in the conventional $\delta^{18}O_{SMOW}$ and $\delta^{13}C_{PDB}$ are shown in Table II, together with those of the present-day analogues of the same specimens collected at the shoal of Minami-daito. The fossil gastropods ranges from -1.60 to -0.10‰ in $\delta^{18}O$ and from $+0.76$ to $+3.07$‰ in $\delta^{13}C$, both of which coincide with those of the present-day specimens so closely that, together with the mineralogy, this can be accepted as a supporting evidence to assign the Kaigunbo Limestone to either the earliest intra-Wisconsin Interstadial or the preceding Last Interglacial Stage, when the sea level stood close to the present.

Table II. Oxygen and carbon isotope ratios of Late Pleistocene and Present-day gastropods from Minami-daito

Species	Present-day		Kaigunbo Limestone		
	$\delta^{18}O_{SMOW}$(‰)	$\delta^{13}C_{PDB}$(‰)	$\delta^{18}O_{SMOW}$(‰)	$\delta^{13}C_{PDB}$(‰)	Locality
Ravitrona caputserpentis reticulum	−1.69	+2.86	−1.33	+2.46	Kaigunbo
	−1.63	+2.82	−0.82	+2.36	Kaigunbo
	−1.75	+1.77	−0.63	+2.80	Kaigunbo
			−1.60	+0.76	Kaigunbo
			−0.89	+3.07	East of Kameike-ko
Trochus maculatus	−0.75	+1.98	−0.42	+2.33	Kaigunbo
			−1.30	+2.56	Kaigunbo
			−0.10	+2.42	Southwest coast
			−0.74	+2.27	Southwest coast
			−0.90	+2.78	Southwest coast
Turbo (Lunatica) marmoratus	−1.07	+2.04	−0.93	+2.38	Kaigunbo
	−1.32	+2.75	−0.91	+2.56	Kaigunbo
			−0.42	+2.67	Kaigunbo
Chelyconus catus	−1.10	+1.98	−0.96	+2.56	Kaigunbo
Barbatia tenella	−1.39	+2.70			
	−0.91	+2.33			

A very slight positive shift in the oxygen isotopic ratio of the Kaigunbo gastropods against the present-day counterparts may even suggest the Interstadial time, when the maximum sea-level is believed to have stood about 15 m below the present one.

Discussion. Our knowledge on the development of the Daito Ridge and neighboring regions has been advanced lately through the extensive surveys by submarine geology and geophysics (e.g. Mizuno *et al.*, 1978), including two cruises of DSDP Leg 31 in 1973 (Ingle *et al.*, 1975) and IPOD Leg 58 in 1977–78 (Klein *et al.*, 1978). The uniqueness of Minami-daito on the Daito Ridge in terms of geotectonic framework in the Northwestern Pacific is summed in two aspects; 1) an elevated Pleistocene atoll underlain by thick reefoid column of upper Eocene (?), upper Oligocene, Lower and Upper Miocene and Pliocene, and 2) one of the oldest remnant arcs with continental basement rocks (Mizuno *et al.*, 1976), which has been drifted northwards about 1000 km from the equatorial region over the last 52 Ma (Klein *et al.*, 1978).

Subsurface drilling of Kita-daito in 1934 and 1936 suggests that Minami-daito had also changed the tectonic history to uplift sometime in Pleistocene after a slow (0.05 mm/y or less than 0.1 mm/y) subsidence of almost 30 Ma, with possible interruption of Early Oligocene and Middle Miocene. The other evidence of neotectonism on and around Minami-daito comes directly from the conspicuous fissures and lineaments cutting through the Minami-daito Dolostone as clearly observed in the field as well as on aerial photographs along the coast of the island. Some fissures are traceable across the island. They scatter mostly in trend between N20°E and N50°E with the mode of N35°E for 2831 measurements (Fig. 1), which coincides with the general trend of the Ryukyu Trench to the west. The formation of these fissures should have antedated a deposition of the Kaigunbo Limestone, hence perhaps of Middle Pleistocene, as the limestone fills one of the fissures at the southwest coast, but no such fissures have been delineated within the limestone. It is noteworthy that either the mid-Holocene or Middle and Late intra-Wisconsin emergent reefs, which can be taken as a firm evidence of a severe neotectonic uplift after the Last Interglacial, have not been exposed on Minami-daito.

The present elevation at Minami-daito appears to be 20 to 25 m higher than the proposed elevation (−10 to −15 m) of sea level for the earliest intra-Wisconsin. This may imply a steady uplift of the island with the average rate of 0.25 mm/y for the last 0.1 Ma. If we extrapolate this rate back into Middle Pleistocene, the maximum elevation of the atoll crest at Minami-daito, 55 mm, might suggest

that the island has undergone to tectonic upheaval, at least, for the last 0.20 to 0.25 Ma.

Thus, the find of an Earliest intra-Wisconsin reef on the raised atoll of Minami-daito adds to our knowledge on the Quaternary history of the Daito Ridge. The ridge experienced by no means a uniform tectonic history throughout Pleistocene, but reversed from the prolonged steady slow subsidence to a moderate rate of uplift causing the emergence of both atoll and fringing reef after Late Pleistocene or possibly late Middle Pleistocene. If the subsidence of the Daito remnant arc for almost 52 Ma was accompanied with the northward horizontal drift of the Philippine plate on which the Daito Ridge rests, this change into the upheaval can be attributed to an "upward bulge" (Dubois *et al.*, 1977) forming the outer ridge of the Philippine plate close to its subduction at the Ryukyu Trench.

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