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764. URANIUM-SERIES AGES OF SOME SOLITARY CORALS FROM THE RIUKIU LIMESTONE ON THE KIKAI-JIMA, RYUKYU ISLANDS*

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Abstract. $^{230}Th/^{234}U$ ages averaging 82,000±2,000 years old were determined for three species of ahermatypic solitary corals (*Trochocyathus hanzawai, Micrabacia japonica* and *Flabellum rubrum*) from the Riukiu Limestone of grainstone facies in the northern area of Kamikatetsu, Kikai-jima, Ryukyu Islands. It is most likely that this type of limestone was deposited at the water depth of 120 m or less as a forereef sediment, in front of the reef which has been elevated up to 184 m in present altitude by the vertical tectonic movement and is now forming a marine terrace developing to the south of Gusuku. The surface of terrace including the dated grainstone is thought to be partly constructional and partly erosional. Because two types of limestone, coralline limestone and this grainstone formed separately during times of two interstadial high sea stands (approximately 60,000 and 82,000 years ago, respectively), are recognized in the terrace deposit distributed at the same altitude.

Introduction

$^{230}Th/^{234}U$ ages for some solitary corals from the Riukiu Limestone on the Kikai-jima, Ryukyu Islands, are dealt with in this paper. These are not only the first dates from the other type of limestone than that formed as a reef itself, but also one of the most valuable informations to reconstruct the paleoenvironment under which a coral reef was developed and to discuss the tectonic history of the island.

The staircase morphology of the Kikai-jima is essentially due to the mutual relationship between the construction of coral reefs during times of Pleistocene high sea stands and the tectonic movement, vertical displacement up to the present time. The Pleistocene reefs are occurred landward, developing five or probably more marine terraces bounded by the remarkable terrace scarps, while the Holocene reefs are surrounding the whole island in the maximum width of about 1.2 km, forming topographically distinctive four terraces. They have been chronologically studied in some detail by means of the uranium-series dating techniques like $^{230}Th/^{234}U$ and $^{231}Pa/^{235}U$ methods and the radiocarbon method of dating, as shown in works of Konishi *et al.* (1974) and Ota *et al.* (1978).

So far, the Pleistocene limestone (Riukiu Limestone of Hanzawa, 1935) on the Kikai-jima has been thought to be an assortment of several reef complexes, each of which was dated to be 35,000—45,000, 55,000—65,000, 80,000—100,000 and 120,000—130,000 years (Konishi *et al.*, 1974). The individual reef complex has been correlated with the elevated Pleistocene reefs in other areas, *e.g.* Barbados, West Indies

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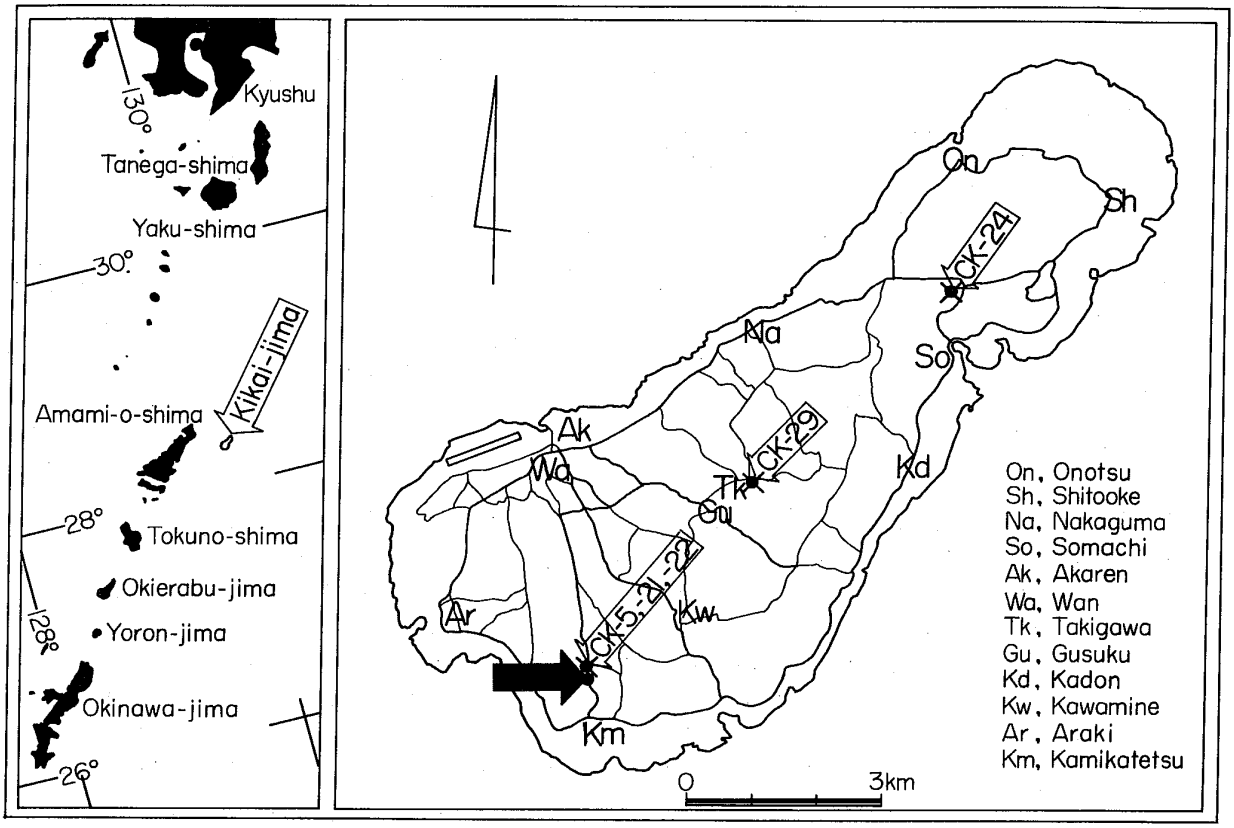

Fig. 1. Index map showing the localities of samples stated in the present paper. (Black arrow shows the sampling site of solitary corals examined in this study. See text for details.)

(Bender *et al.*, 1979; and others) and the Huon Peninsula, New Guinea (Bloom *et al.*, 1974; and others). However, details of stratigraphic relations among those reef complexes and their distribution remain still equivocal. The major reasons of it seem to be that only hermatypic corals from the reefy limestone have been dated before and that stratigraphy has not been completely resolved, because of limited numbers of outcrops on the island.

Radiochemical analyses for uranium and thorium isotopes were carried out on three species of ahermatypic solitary corals, *Trochocyathus hanzawai*, *Micrabacia japonica* and *Flabellum rubrum*, selected out of many species from an outcrop along a road which lies approximately 650 m north of Kamikatetsu (Fig. 1). The locality is situated at a height of about 40 m in lat. 28°17.1′ N. and long. 129°57.2′ E. Because of its unique lithologic nature, the limestone near by the sampling site has been attracted the notice of some paleontologists and/or geologists since the 1930s. It is moderately sorted, unconsolidated to weakly cemented, and grain-supported limestone made up of a wide variety of small-sized (less than 10 cm in diameter) bioclastics. This limestone can be regarded as the typical grainstone defined by Dunham (1962). Foraminifers, brachiopods, bryozoans, molluscs, echinoids, solitary corals and fragmental calcareous algae are included as main bioclastic components, while larger bioclastics such as hermatypic corals and coralline algae in growth position are seldom or never seen in this grainstone facies. The bryozoan and coral faunas in this type of limestone were studied by Kataoka (1961) and Yabe and Eguchi (1932). They found conclusions independently upon each full description that this grainstone was probably deposited at a depth of from 40

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to 100 m or approximately 100 m, respectively.

The details of separation and purification methods for uranium and thorium isotopes in carbonate samples are omitted here. The overall chemical yields of uranium and thorium isotopes were checked by using two kinds of ^{232}U-^{228}Th spikes (Table 1), as yield tracers in the repeated analyses for each sample, separately. Alpha spectrometries were employed by a 4096 channel multichannel analyzer coupled with four solid-state silicon detector systems.

Table 1. ^{232}U concentration and $^{228}Th/^{232}U$ activity ratio of the ^{232}U-^{228}Th spikes used as yield tracers for checking overall chemical yield of uranium and throium isotopes. (Measurements were carried out on August 26, 1981.)

Name of Spike	^{232}U (dpm/g)	$^{228}Th/^{232}U$ (activity ratio)
"Harwell"	22.53±0.20	0.990±0.010
"KU (Kanazawa Univ.)"	17.30±0.10	0.999±0.012

X-ray powder diffraction patterns revealed that all of the samples examined in this study are free of the secondary calcite. This evidence suggests that they have not been altered mineralogically throughout their diagenetic history.

Results of the alpha spectrometries are presented in Table 2, in which the $^{230}Th/^{234}U$ age of each sample also is shown. The quoted errors are standard deviation derived from counting statistics.

The following equation and half-lives ($T_{1/2}$) of objective radionuclides, which were arranged in the Uranium-Series Intercomparison Project (USIP; Harmon *et al.*, 1979), were used here in order to calculate the $^{230}Th/^{234}U$ age:

$$^{230}Th = {}^{238}U\,[1 - \exp(-\lambda_0 t)] + ({}^{234}U - {}^{238}U)\,[\lambda_0/(\lambda_0 - \lambda_4)]\,[1 - \exp(\lambda_4 t - \lambda_0 t)]$$

^{238}U : $T_{1/2} = 4.468 \times 10^9$ years
^{234}U : $T_{1/2} = 2.48 \times 10^5$ years
^{232}U : $T_{1/2} = 7.2 \times 10^1$ years
^{230}Th : $T_{1/2} = 7.52 \times 10^4$ years
^{228}Th : $T_{1/2} = 1.913$ years
^{224}Ra : $T_{1/2} = 3.64$ days

Table 2. Isotopic composition and $^{230}Th/^{234}U$ ages of fossil solitary corals from the Riukiu Limestone on the Kikai-jima.
(*T.h., *Trochocyathus hanzawai*; M.j., *Micrabacia japonica*; F.r., *Flabellum rubrum*: For the same sample, the results in upper and lower rows were obtained by use of "Harwell" and "KU" spikes, respectively.)

Material*	Isotope Concentration				Activity Ratio		$^{230}Th/^{234}U$ Age ($\times 10^3$ yrs)
	^{238}U (ppm)	^{234}U (dpm/g)	^{232}Th (ppm)	^{230}Th (dpm/g)	$^{234}U/^{238}U$	$^{230}Th/^{234}U$	
T. h.	3.56 ± 0.08	2.92 ± 0.06	<0.02	1.57 ± 0.03	1.10 ± 0.02	0.521 ± 0.015	79 ± 4
	3.46 ± 0.06	2.92 ± 0.05		1.49 ± 0.03	1.11 ± 0.02	0.521 ± 0.014	79 ± 3
M. j.	4.42 ± 0.12	3.72 ± 0.10		1.91 ± 0.05	1.13 ± 0.02	0.513 ± 0.020	77 ± 4
	4.46 ± 0.11	3.69 ± 0.09		1.99 ± 0.04	1.09 ± 0.02	0.539 ± 0.017	83 ± 4
F. r.	3.77 ± 0.10	3.22 ± 0.08		1.78 ± 0.04	1.15 ± 0.02	0.553 ± 0.014	85 ± 5
	4.34 ± 0.08	3.59 ± 0.06		1.94 ± 0.04	1.11 ± 0.02	0.540 ± 0.014	83 ± 3

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where λ_0 and λ_4 are decay constant of ^{230}Th and ^{234}U, respectively.

The $^{230}Th/^{234}U$ activity ratios in Table 2 are characterized by the limited range of 0.513 ±0.020 to 0.553±0.014, and accordingly the $^{230}Th/^{234}U$ ages are in agreement within the statistical error. The mean age is calculated to be 82,000±2,000 years.

This $^{230}Th/^{234}U$ age is most reliable for some reasons itemized below:

(1) All samples are entirely free of recrystallization, as shown by the absence of the secondary calcite.
(2) It can be safely assumed from the reproducibility in the analyses repeated by using two sorts of ^{232}U-^{228}Th spikes that all of the analytical values in the table are truthworthy.
(3) ^{238}U concentration of each sample almost equals those which have appeared in literature for ahermatypic corals to date.
(4) The assumption of negligible initial ^{230}Th is supported by the observation that ^{232}Th concentration does not exceed the analytical limitation (0.02 ppm in this study).
(5) The average $^{234}U/^{238}U$ activity ratio of 1.12±0.01 is consistent with the mean value of $^{230}Th/^{234}U$ ages.

The $^{230}Th/^{234}U$ age of 82,000 years fits in the time of an interstadial phase after the last interglacial stage. The reef complex including the grainstone facies is correlative with the terrace deposit composed of the Barbados terrace I of Mesolella (1968) and the Worthing terrace of Bender *et al.* (1979) on Barbados, West Indies, and with the reef complex V on the Huon Peninsula in New Guinea (Bloom *et al.*, 1974). Konishi *et al.* (1974) proved the existence of the reef which was formed at that time and stratigraphically separated it as the Middle Limestone Member from their former Younger Limestone Member of Riukiu Limestone (Konishi *et al.*, 1970), because the same $^{230}Th/^{234}U$ dates were obtained from two hermatypic coral samples (CK-24, *Favia* sp., 81,000±3,000 yrs.; CK-29, *Porites* sp., 86,000±4,000 yrs.). However, the details of this uplifted reef complex on the island, namely the distribution and the lithologic nature of its forereef sediment, are not yet definitely solved.

The Riukiu Limestone of the grainstone facies can be traced also in the eastern area of the locality where the samples analyzed in the present study were collected. The maximum height of the area is about 70 m. The present elevation of the reefy limestone dated as approximately 80,000 years old is 184 m at the maximum. The difference in distributing height between the reefy limestone and the grainstone of the same age is 114 to 144 m. Assuming that both facies have undergone the vertical displacement of the same extent up to the present time, this difference may be roughly taken as the depth of water where the grainstone was deposited. The actual depth of sedimentation, however, may be less than 120 m, because of local difference in vertical displacement expected from the existence of some faults as seen in the geologic map of Konishi *et al.* (1974). Such an inference seems to be well-matched with the conclusions drawn from the faunal analyses for bryozoans and solitary corals by Kataoka (1961) and Yabe and Eguchi (1932), respectively. In any case, there is very little doubt that the Riukiu Limestone near by the locality, where the samples dated here were collected, was deposited as a forereef sediment.

Besides the grainstone, some different types of limestone are occurred as the terrace deposits on the same terrace. In other words, the lateral change of limestone facies is obviously recognized in the terrace deposit. The $^{230}Th/^{234}U$ ages of 55,000 to 65,000 years have been previously reported on two hermatypic corals (CK-5, *Acanthastrea echinata*, 59,000±5,000 yrs.; CK-21, *Cyphastrea* sp., 54,000±2,000 yrs.) from the coralline limestone (Younger Limestone Member of Riukiu Limestone) by Konishi *et al.* (1974). The author also has once dated a fossil hermatypic coral sample (CK-22, *Porites* sp.) and got the respective $^{230}Th/^{234}U$ and $^{231}Pa/^{235}U$ ages of 52,000±3,000 and 61,000±3,000 years. Those samples were collected at the spot which is very close to the locality of the solitary coral samples examined in this study and which is

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of the same height, 40 m above sea level. All such dates are in accord with the age of another interstadial phase, being represented by the reef complex IV on the Huon Peninsula, New Guinea (Bloom *et al.*, 1974).

The evidence stated above may imply that a couple of limestone units formed separately during times of two interstadial high sea stands are now seen on the same terrace. The sea level of 55,000 to 65,000 years B.P. is thought to have been apparently attained up to 40 m or more in present altitude, regardless of the subsequent tectonic movement. A part of the terrace surface, therefore, appears to have been eroded at that time or in process of upheaval to the present elevation. After all, it can be safely said that the surface of terrace extending to the north of Kamikatetsu is partly constructional and partly erosional.

In conclusions, the author can briefly summarize as follows:

(1) Six $^{230}Th/^{234}U$ ages, the mean of which is 82,000±2,000 years, were obtained for three species of ahermatypic solitary corals from the Riukiu Limestone of grainstone facies distributed in the northern area of Kamikatetsu, Kikai-jima, Ryukyu Islands.

(2) Such a grainstone was deposited as the forereef sediment while the reefy limestone occurred in Gusuku and its vicinity was formed during a time of interstadial high sea stand, about 82,000 years ago.

(3) The surface of terrace, which is extending at a height of 40 m to the north of Kamikatetsu, is very likely to be partly constructional and partly erosional.

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喜界島の琉球石灰岩より産出した単体サンゴの放射年代：喜界島の更新統琉球石灰岩のうち，上嘉鉄の北方約 650 m・高度 40 m の地点付近に分布するものは，その特徴的な岩相（典型的な Dunham, 1962, の grainstone）と，保存のよい多くの種類の単体サンゴを産することなどで，古くから注目されてきた。本研究では，それらの中から 3 種（*Trochocyathus hanzawai*, *Micrabacia japonica* および *Flabellum rubrum*）を選んで，$^{230}Th/^{234}U$ 法による放射年代測定を試み，平均 82,000±2,000 年の年代値を得た。この値は，世界各地（例えば，西インド諸島 Barbados 島やニューギニア Huon 半島など）で，その存在が確認されている一亜間氷期の年代と一致する。

一方，当時の礁石灰岩は，現在城久南部に発達する海成段丘の構成物として，すでに確認されている（Konishi *et al.*, 1974）。すなわち，城久南部にみられる礁石灰岩がサンゴ礁として形成されていた当時，上述の grainstone はその礁前縁相として堆積したものと考えられる。そして，この grainstone と礁石灰岩との現在の分布高度差（114～144 m）は，もし両者がこれまでに等量の構造運動（垂直変動）をうけてきたとすれば，大よそ grainstone の堆積深度を示しているといえる。しかし，島内で確認される断層から局地的な変動量の違いも考慮しなければならず，実際の堆積深度は 120 m 以浅と推定される。この推定値は，単体サンゴおよび蘚虫類の研究から Yabe and Eguchi (1932) や Kataoka (1961) によって推定された grainstone の堆積深度と決して矛盾しない。また，以前 Konishi *et al.* (1970, 1974) が報告した 55,000～65,000 年前の Younger Limestone Member of Riukiu Limestone の礁性サンゴに富む石灰岩の分布地点が，この grainstone の分布地域と近接し，形成時代と堆積深度が全く異なると思われる両者が段丘構成物としてみられることから，上嘉鉄北方に広がる高度 40 m の平坦面は，一部が堆積面一部が侵食面であると考えられる。　大村明雄

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