

Late Pleistocene coral reef sediments and their U-series ages in Kikai Island, central Ryukyus, Japan : implications for sea-level change and tectonic movements

メタデータ	言語: eng 出版者: 公開日: 2017-10-05 キーワード (Ja): キーワード (En): 作成者: メールアドレス: 所属:
URL	http://hdl.handle.net/2297/14611

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学位の種類	博士 (学術)
学位記番号	博甲第 783 号
学位授与の日付	平成 18 年 3 月 22 日
学位授与の要件	課程博士 (学位規則第 4 条第 1 項)
学位授与の題目	Late Pleistocene coral reef sediments and their U-series ages in Kikai Island, Central Ryukyus, Japan: Implications for sea-level change and tectonic movements (喜界島に分布する後期更新世サンゴ礁堆積物とそのウラン系列年代)
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ABSTRACT

New α -spectrometric $^{230}\text{Th}/^{234}\text{U}$ dates for 60 colonial and solitary corals collected from both terraces and careful observations of lithofacies reveal new depositional history of Pleistocene terraces on Kikai Island. Fossil corals from the Hyakunodai Terrace (HT) show Mid- to Late Pleistocene dates ranging from 154.8 ± 6.4 to 83.2 ± 2.4 ky (2σ statistical error) corresponding to Marine Isotope Stage (MIS) 6 to 5a combining their distributions and lithofacies, and Middle Pleistocene age (> 450 ky). Coral assemblage dated as MIS 5c at the outcrop *ca.* 195 m above present sea level (apsl) indicate depositional depth ranging from 5 to 15 m. The elevation of the samples and the depth range of the corals put the relative sea level position during MIS 5c between 200 – 210 m, higher than the position of the HT. These facts reveal that the highest terrace was formed during MIS 5c. Solitary corals from the lowest Pleistocene terrace (LPT) sediments provided reliable dates ranging from 96 ± 2.8 to 56.7 ± 2.2 ky, corresponding to MIS 5c to 3, which can be divided into four age groups taking error into account. The lithofacies and dates suggest that this sediment was deposited on the insular shelf during both relatively high and low sea stands. Additionally, corals obtained from the proximal location of the LPT tend to show older ages, while corals from the distal site show younger dates. Coral limestone is also sporadically distributed on LPT, which the youngest date was 40.2 ± 1.2 ky. These results indicate that the LPT was formed in different depositional environments between MIS 5b and 3 with the fall of relative sea level: from the insular shelf where fore-reef sediments were deposited to the shallow water environment where coral reefs were formed. No Pleistocene coral reef sediments, younger than about 40 ky, are exposed on the surface of Kikai Island.

Introduction

Coral reef terraces record many information about sea level change and paleoclimate. Kikai Island, Central Ryukyus, Japan is an actively rising island, where Pleistocene and Holocene terraces are developed. Pleistocene marine terraces in generally have three steps. They consist of mainly thick Middle Pleistocene and thin

Upper Pleistocene sediments. The Hyakunodai Formation composed of coral limestone is distributed on the higher two steps called the Hyakunodai Terrace. The lowest terrace extensively developed southwest of Kikai island overlies a detrital limestone called the Wan Formation composed of well-preserved biogenic remains.

In this study, I report new and precise α -spectrometric U-series dates of fossil corals collected from Late Pleistocene coral reef sediments on each Pleistocene terraces in Kikai Island, determine the age of each terraces in combination with lithofacies and previously reported Pleistocene dates from Kikai Island and reconstruct the history of depositional environment accompanied by sea level change and climate changes.

Results and Discussions

Solitary and colonial corals collected from the Hyakunodai Terrace and the lowest Pleistocene terrace were used for α -spectrometric $^{230}\text{Th}/^{234}\text{U}$ dating. Fifty-six fossil corals were dated, six were re-dated yielding a total of 60 dates.

The Hyakunodai Terrace

Fossil corals from the Hyakunodai Terrace show Mid- to Late Pleistocene dates ranging from 154.8 ± 6.4 to 83.2 ± 2.4 ky (2σ statistical error) and Middle Pleistocene age (> 450 ky). These ages, combined with their distributions and lithofacies, can be divided into age groups correlated to MIS 6, pre-MIS 5e, MIS 5e, late-MIS 5e, 5d, 5c and 5a. Coral assemblage dated as MIS 5c at the outcrop *ca.* 195 m above present sea level (apsl) indicate depositional depth ranging from 5 to 15 m. The elevation of the samples and the depth range of the corals put the relative sea level position during MIS 5c between 200 – 210 m, higher than the position of the Hyakunodai Terrace. These facts reveal that the highest terrace was formed during MIS 5c. The appearance of MIS 6 sediments implies that sea level fluctuation occurred before MIS 5.

The uplift rate of Kikai Island has been reported to be 1.8 m/ky (Ota and Omura, 1992). Since it is confirmed that the top of this island was formed during MIS 5c, the uplift rate previously reported must be reexamined. Potter *et al.* (2004) reported that the MIS 5c sea level at 101 ky was at -14 ± 4 m. Using this value and assuming constant uplift, the uplift rate since MIS 5c is estimated to be 2.1 – 2.3 m/ky. I tested the value of 2.1 – 2.3 m/ky by comparing to the uplift rate after the last interglacial and Holocene. Consequently, the uplift rate since the last interglacial, Holocene and Holocene high stand (HHS; 7 ky) are calculated to be 1.8 – 2.2 m/ky, 2.0 – 3.0 m/ky and 0.9 m/ky, respectively. There is no significant difference between each estimated uplift

rate except after HHS, which suggests that faults action has not been large since the last interglacial.

The Lowest Pleistocene terrace

Solitary corals from the lowest Pleistocene terrace sediments provided reliable dates ranging from 96 ± 2.8 to 56.7 ± 2.2 ky, corresponding to MIS 5c to 3. These can be divided into four age groups taking error into account. The lithofacies and dates suggest that this sediment was deposited on the insular shelf during both relatively high and low sea stands. Correlation between the age and elevation of samples; show that the oldest sample occurred at *ca.* 40 m, the youngest at *ca.* 18 m apsl. In addition, corals obtained from the proximal location of the lowest terrace tend to show older ages, while corals from the distal site show younger dates. Coral limestone is also sporadically distributed on this terrace. The youngest date obtained was 40.2 ± 1.2 ky from a sample collected at the southwest end of the terrace, about 25 m apsl. Dates of three other samples from the same site are comparable within the margin of error; the average was calculated to be 41.2 ± 0.8 ky. These results indicate that the lowest Pleistocene terrace was formed in different depositional environments between MIS 5b and 3 with the fall of relative sea level: from the insular shelf where fore-reef sediments were deposited to the shallow water environment where coral reefs were formed. Thus, no Pleistocene coral reef sediments, younger than about 41 ky (MIS 3), are exposed on the surface of Kikai Island.

Conclusions

New sixty $^{230}\text{Th}/^{234}\text{U}$ dates of colonial and solitary corals and careful investigations of lithofacies make it possible to reconstruct more precisely the history of Kikai Island during Mid to -Late Pleistocene. The results are the following:

1. Middle and Mid- to Late Pleistocene (*ca.* 154 to 82 ka, corresponding to MIS 6 to 5a) coral reef sediments are distributed on the Hyakunodai Terrace. They can be divided into 6 age sediments correlated to MIS 6, pre-MIS 5e, MIS 5e, late MIS 5e, MIS 5d, 5c and 5a based on age, elevation and lithofacies.
2. Relative sea level position during MIS 5c can be put between 200 and 210 m apsl based on coral assemblage and elevation of the corals. This estimate is higher than the position of the highest terrace suggesting that Hyakunodai Terrace was submerged during MIS 5c.
3. MIS 5e, pre- and late MIS 5e coral limestones have been found on the highest plane which was interpreted to be formed during MIS 5e by previous studies. This fact

indicates that the relative sea level position during MIS 5e would be higher than the top of present Kikai Island.

4. Sediments formed during MIS 6 was confirmed from Kikai Island for the first time. The appearance of MIS 6 deposits at the highest plane may suggest that sea level fluctuation occurred before MIS 5.
5. The uplift rate of Kikai Island after MIS 5c was calculated to be 2.1-2.3 m/ky. This value is consistent with that of MIS 5e and Holocene. This suggest that faults action has not been large since the last interglacial.
6. On the lowest Pleistocene terrace, detrital limestones containing solitary corals are extensively distributed. Solitary corals show ages ranging from *ca.* 93 to 56 ka, corresponding to MIS 5b to 3. They can be divided four age groups, $93.9 \pm 2.8 \sim 87.6 \pm 2.8$ ky, $77.2 \pm 2.2 \sim 76.1 \pm 2.0$ ky, $70.4 \pm 2.0 \sim 68.5 \pm 2.4$ ky and $63.4 \pm 1.6 \sim 56.7 \pm 2.2$ ky indicating deposition at four different durations. On the other hand, colonial corals in distal part of the terrace show age of around 50 ky.
7. The ages and distribution of sediments on the lowest Pleistocene terrace indicate that this terrace was formed in different depositional environments between MIS 5b and 3 with the fall of relative sea level: from the insular shelf where fore-reef sediments were deposited to the shallow water environments where coral reefs were formed.
8. No Pleistocene carbonate sediments, younger than about 41 ka (MIS 3), are exposed on the surface of Kikai Island.

学位論文審査結果の要旨

平成 18 年 1 月 30 日の学内委員による審査会と、2 月 10 日の口頭発表会終了後全審査員が出席して開催した第 2 回審査会における協議の結果、以下の結論に達した。

本論文は、南西諸島喜界島に発達するサンゴ礁段丘の $^{230}\text{Th}/^{234}\text{U}$ 法による年代測定、構成物の岩相解析及び精密地形測量等により、後期更新世以降の海面変化と垂直変位に関する多くの新知見を得たが、それらの中でも、以下の 3 点は特筆すべき成果といえる。①上記年代測定法の高精度化により、喜界島から初めて酸素同位体ステージ 6 (MIS-6) 相当の年代値 ($142.7 \pm 5.8 \sim 154.8 \pm 6.4$ ky) を得、後期更新世初頭にも相対的高海面期が存在した事を実証した。②これ迄 MIS-5e (約 125ka) とされていた最高位段丘の形成期を MIS-5c (約 105ka) に修正し、それ以降の島の隆起速度を 2.1 ~ 2.3m/ky とした。そして、③後期更新世段丘を 2 分し、高位段丘が、MIS-5 初頭から MIS-5a 迄の約 5 万年間における少なくとも 4 回の相対的高海面期に堆積したサンゴ石灰岩を含み、低位段丘は、単体サンゴ化石の年代測定、岩相及び生相解析から、MIS-5b (約 94ka) ~ MIS-3 (約 41ka) 迄の連続した相対的高海面低下期を通して形成された事を明らかにした。

以上、本研究は、喜界島のサンゴ礁段丘に関する従来の研究で論じられた氷河性海面変化や地殻変動に関する定説をくつがえす成果を挙げており、博士 (学術) の学位に十分値するものと認定した。