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Variable uplift rate through time: Holocene coral reef and neotectonics of Lutao, eastern Taiwan

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ABSTRACT

Significant discrepancies have existed regarding rate and timing of the uplift of Lutao (Green Island), located at the border of the ongoing collision between the Eurasia continental plate and the Philippine Sea Plate. To document its neotectonic history, two cores were drilled into Holocene coral reefs exposed at the southeastern coast of Lutao. Twelve pristine fossil corals, nine taken from cores and three on the surface, were ^{230}Th dated. The results show that the coral reefs started to develop at 8,736 ± 56 yr BP (before 1950 CE) with uplift rate varying from 3.6 mm/yr during 8.7–6.0 kyr BP to 1.2 mm/yr in the past six thousand years. Our study strongly suggests that the uplift rate can vary significantly on millennial time scale. Caution should be used when extrapolating uplift rate estimates based on Mid-late Holocene corals to early times for tectonic active locations, such as Lutao.

1. Introduction

Fossil corals have been used to reconstruct tectonic histories for decades. Many studies acquired fossil corals from outcrops, followed by the use of coral age and elevations to calculate a simple mean uplift rate (Chappel, 1974; Wang and Burnett, 1990; Liew et al., 1993; Ota et al., 1993; among others). However, regional tectonic history could have been oversimplified by such an approach. Recent observations and fossil coral studies using more detailed sampling, for example, in Sumatra and the Solomon islands (e.g., Taylor et al., 2005 (which showed a complete reversal of vertical directions and acceleration of uplift rates); Briggs et al., 2006; Sieh et al., 2008; Meltzner et al., 2015; Philibosian et al., 2016; Thirumalai et al., 2015) have shown that displacement and deformation histories and rates can be very complex and variable overtime along convergent plate boundaries.

Holocene sea level in the tropical western Pacific reached its maximum around six to four thousand years ago (Pirazzoli, 1991; Dickinson, 2004; Rashid et al., 2014; Khan et al., 2015). Corals taken from emerged Holocene reef outcrops represent that time span when sea level in that region was higher than present. Few early Holocene corals can be sampled on the surface because they are either covered by mid-late Holocene reef deposits or still submerged. Reconstruction of detailed history over the entire Holocene is therefore hindered by the paucity of early Holocene samples. Coring of Holocene reefs has been demonstrated to successful access and sample early Holocene corals to constrain sea level before the mid-Holocene (Montaggioni, 1976; Easton and Olson, 1976; Davies et al., 1979; Marshall and Jacobson, 1985; Fairbanks, 1989; Camoin and Montaggioni, 1994; Shen et al., 2010; Gong et al., 2013; Siringan et al., 2016, also see review by Montaggioni, 2005). This approach should also be as helpful in neotectonic studies.

Lutao (Green Island) is a volcanic island off eastern Taiwan, situated at the boundary of an ongoing arc-continent collision between the Eurasian plate and the Luzon Arc that sits on the Philippine Sea plate (Fig. 1). Lutao is located at a critical location to document the deformation and crust shortening of the arc-continent collision (Wang and Burnett, 1990; Chen and Liu, 1992; Liew et al., 1993; Vita-Finzi, 2000; Ota and Yamaguchi, 2004; Yamaguchi and Ota, 2004; Inoue et al., 2011; Shyu et al., 2011). However, those studies have significant differences in timing and rate of uplift. Wang and Burnett (1990) reported that Lanyu-Lutao area had an average uplift rate of 2.2 ± 0.2 m/kyr after correction for paleosea level. Chen and Liu (1992) proposed that the Holocene uplift rate ranged from 0.9 to 3.3 m/kyr in the past 6 kyr based on beach deposits and encrusting algae limestone. Vita-Finzi (2000) estimated an uplift rate at 5 m/kyr from 9 to 5 kyr BP and cessation of uplift after 5 kyr BP.

Most of the previous studies did not use a consistent datum to compare sample elevations, such as the living water-depth of corals or

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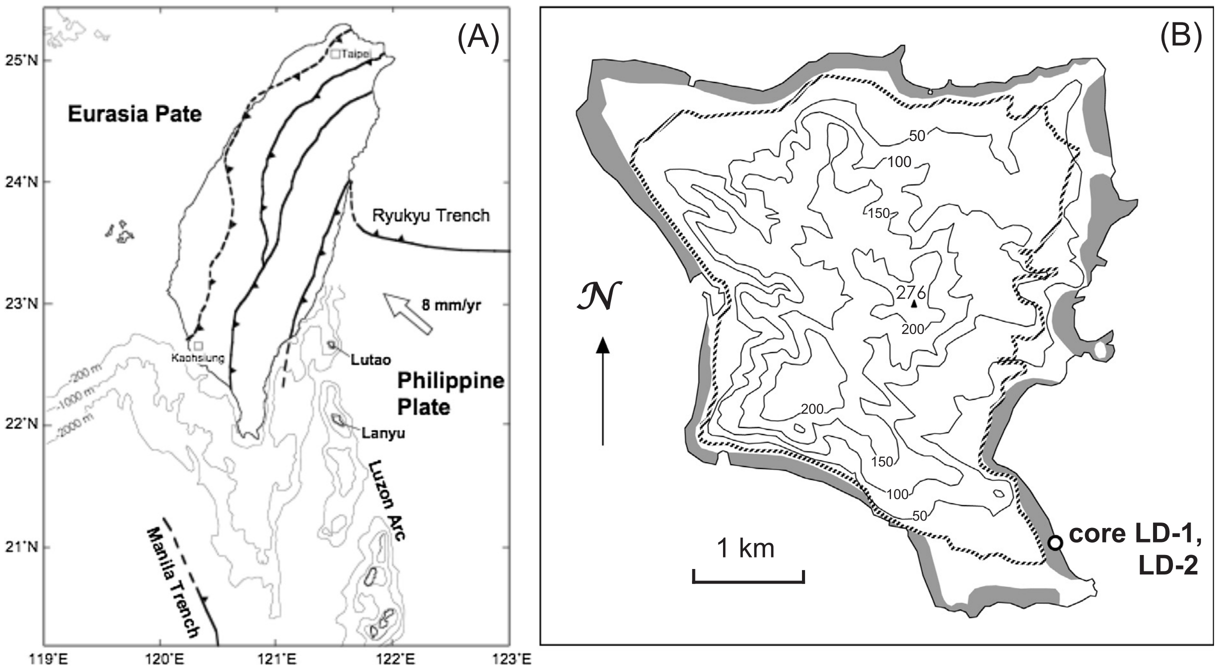

Fig. 1. (A) Location and tectonic setting of Taiwan. Bathymetry data from Taiwan Ocean Research Institute (TORI) database. (B) Topography of Lutao and distribution of Holocene coral reefs, compiled from Chen and Liu (1992), Inoue et al (2011) and our own investigation. A small circle denotes the drill core location.

mean lower low tide. The lack of consistent reference to a datum that allows comparison within and between studies prevents precise estimates and comparisons of uplift rate. Inoue et al (2011) were the first to consider the factor of living water-depth of corals. They identified the *Isopora palifera*, as well as *Acropora digitifera* and *A. gemmifera* as an indicator of paleosea level. This approach made their estimate of uplift rate more reliable than previous studies. Inoue et al (2011) proposed an uplift rate at 1.2 mm/yr since 5,749 cal yr BP, less than the values suggested by previous studies (Wang and Burnett, 1990; Chen and Liu, 1992; Vita-Finzi, 2000). They concluded that uplift was continuous uplift, rather than episodic as other studies had proposed (Liew et al., 1993; Yamaguchi and Ota, 2004).

The objective of our study is to establish the Holocene history of coral-reef development and tectonic uplift of Lutao. To accomplish this objective, we drilled two cores in the Holocene reefs and acquired a continuous record of upward reef growth to explore the relative sea-level history and to interpret the tectonic history of Lutao prior to 6 kyr BP when the sea level was still rising. We demonstrate that the uplift rate may vary through time and subsurface sampling is essential to acquire necessary samples to bridge time gaps and address possible varying uplift rates over a longer time span.

2. Study site

Lutao, with an area of 16.2 km^2, is located about 34 km east of Taiwan and 70 km north of Lanyu, another volcanic island on the same trend as Lanyu Island and a submarine ridge of the Luzon arc off eastern Taiwan (Fig. 1). Lutao is comprised of Pliocene and late Pleistocene andesitic volcanic agglomerates (Juang and Chen, 1990). The Philippine Sea plate, on which Lutao and the inactive Luzon arc is colliding obliquely with the Eurasia plate at ~8 cm/yr (Yu et al., 1997), and the boundary is moving southwards at 9 cm/yr (Suppe et al., 1987). The ongoing collision has been deforming the Coastal Range of eastern Taiwan. Lutao is on the margin of the Philippine Sea plate, and anticipated to collide with Eurasia plate (Teng, 1990; Shyu et al., 2005).

Lutao has a subtropical climate with an annual temperature ranging from 23.3 to 23.9 °C, averaging 23.6 °C, and annual rainfall from 2030 to 3280 mm, averaging 2600 mm during 2005-–2014. The mean tidal range of the island is 0.95 m. Dai et al. (2004) estimated about 300 species of stony coral in the Lutao-Lanyu area. *Isopora palifera*, mostly in encrusting form, and *Acropora digitifera* are observed abundantly in the exposed Holocene reefs. The species *I. palifera* was found to occur extensively from 0.5 to 1.5 m below mean sea level (MSL) in Lanyu, and is very rare at greater depths. No other corals were observed living in shallower water depth (Inoue et al., 2011). Coral *I. palifera* is, therefore, a reliable water-depth indicator in the study area.

Emerged Holocene reef terraces have developed along the coasts of Lutao (Fig. 1B). Most of the emerged reef are less than 2.5 m above MSL, and were named the "lower reef terrace" in Inoue et al. (2011). At the southeastern coast of Lutao, the emerged Holocene reef is well exposed and measures 140 m in width perpendicular to the coastline (Fig. 2). A rampart of 1.8 m in elevation occurs at the seaward edge with a broad, incised depression behind it. The surface elevation increases to about 1.8 m at the landward edge, and then terminates at a narrow beach (Fig. 2).

3. Material and methods

Two cores, LD-1, and LD-2 were drilled on the emerged Holocene coral reef near the seaward margin at the southeastern coast (Figs. 1b, 2). Core LD-1 is a vertical core of 12.9 m in depth drilled from 1.5 m above MSL. Core LD-2 is a 16.1 m in length inclined 45-degree seaward (11.3 m in vertical depth,), drilled from 1.4 m above MSL (Fig. 1b).

Cores were split, photographed and described and thin sections were made to aid core examination. Three additional *I. palifera* corals

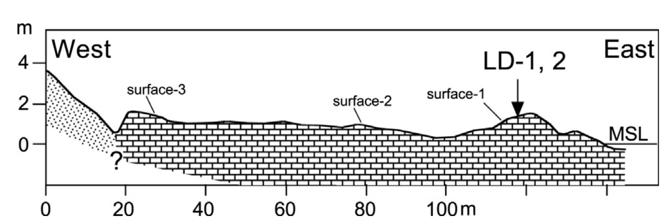

Fig. 2. Topographic profile of the study site, Lutao. Mean sea level (MSL) is based on tide gauge of Central Weather Bureau at Lutao. Locations of cores LD-1 and LD-2 and surface samples are marked.

were taken at the surface of the emerged reef (Fig. 2). Subsamples of one gram were taken from each fossil corals oriented in growth position and relatively large in size, and gently crushed into fragments and physically cleaned in an ultrasonic bath if distilled water. Their pristine aragonitic compositions were confirmed by X-Ray diffraction. Fragments, 0.1 g each, were picked for U-Th chemistry (Shen et al., 2003) and ^{230}Th dating (Shen et al., 2008, 2012).

U-Th isotopic compositions of fossil corals, physically cleaned with ultrasonic methods (Shen et al., 2008), were determined on a multi-collector inductively-coupled plasma mass spectrometer (MC-ICP-MS) with single secondary electron multiplier protocols in the High-precision Mass Spectrometry and Environment Change Laboratory (HISPEC), Department of Geosciences, National Taiwan University (Shen et al., 2012). The developed MC-ICP-MS technique offers an accurate determination of U-Th isotopic ratios and contents with a precision of ± 1–2‰ (2σ) for abundance determinations of 50–200-fg ^{234}U (1–4-ng ^{238}U) or ^{230}Th (Shen et al., 2012). Half-lives of U-Th nuclides used for ^{230}Th age calculation are given in Cheng et al. (2013). Uncertainties in the U-Th isotopic data and ^{230}Th dates, relative to 1950 CE are calculated at the 2σ level or two standard deviations of the mean ($2\sigma_m$) unless otherwise noted.

4. Results

4.1. Rock types

The two cores are well lithified for Holocene coral reefs and core recovery was almost 100% (Figs. 3 and 4). Several rock types are identified in the cores and summarized in lithocolumns (Fig. 4): (1) algal-coral boundstones, (2) bioclastic calcarudites, (3) bioclastic-volcanic arenites, and (4) volcanic rocks. Lithofacies delineation was based on bioclastic and lithologic components and rock fabric.

The algal-coral boundstones, light tan to beige in color, consist of predominantly encrusting or thick branching coral *I. palifera* (Fig. 3A, B) since the beginning till the end of reef growth with occasional massive corals such as *Leptoria, Favia* and *Favites* spp. The boundstones often alternate with encrusting red algae, and granule- to sand-sized bioclastics and andesitic sediments filling in space between the coral frameworks (Fig. 3A, B). In modern coral reefs, *I. palifera* typically occurs as encrusting plate at the edge of reef flat or upper reef slope in localities with strong waves (Dai and Horng, 2009; Inoue et al., 2011).

The bioclastic calcarudites are light tan to beige in color and comprise pebble- to sand-sized bioclastics with granule- to sand-sized volcanic sediments in matrix. Most of the bioclastic pebbles are rounded and in rudstone fabric. Some are coated or partly binded by encrusting red algae.

The bioclastic-volcaniclastic arenites, grayish in color, are composed of volcanic sands mixed with bioclastics, partially with bioclastic pebbles in floatstone fabric, and occasionally encrusted by calcareous red algae. The percentage of volcanic sands increase downward from about 20% at 7–8 m to 70% at 11.2 m of LD-1 (Figs. 3 and 4); the grain size of the volcanic sediments also increase from sand to granule size toward the bottom. As a result, the color gradually changes from gray to dark gray downward.

The volcanic rocks, black in color, occur at the bottom of the two cores below carbonate sediments. They represent the volcanic basement on which the Holocene coral reef developed (Fig. 4).

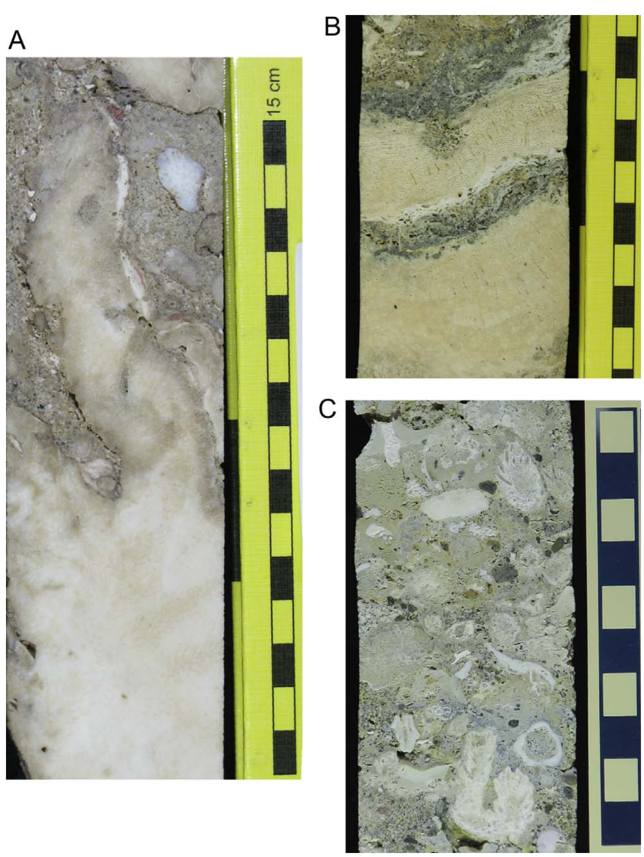

Fig. 3. Photographs of rock types in the Lutao cores. (A) Algal-coral boundstone at 1.6 m of core LD-2. (B) Encrusting *Isopora palifer* at 8.2 m of core LD-1. (C) Bioclastic calcarudite at 9.6 m of core LD-1.

4.2. Coral ages

Fossil coral U-Th measurement results are summarized in Table 1 and the determined ages are also given in Fig. 4. The absence of secondary carbonates in the intra-skeletal structure, the ^{238}U levels of 1128–3060 ppb, and the initial δ^{234}U values of 141-–147‰ as in modern corals, suggest that the selected coral samples are well preserved. The oldest sample is dated as 8,736 ± 56 yr BP at a depth of 11.9 m of core LD-2, and youngest 5,376 ± 25 yr BP at 0.8 m of core LD-1.

The ages and lithology indicate that coral-reef of Lutao started at least as early as 8.7 kyr BP on a volcanic rocky substrate in a fringing reef mode. The reef accreted vertically till 5.4 yr BP without significant change in coral composition.

5. Discussion

5.1. Holocene reef growth at Lutao

The coral ages and thickness of LD-1 and LD-2 shown in Fig. 4 indicate that the reef grew upward at a surprisingly fast rate of 11.2 m/kyr from 8 to 7.5 kyr BP. *I. palifera* remained as the dominant species during this period suggesting that reef growth kept up with the sea-level rise. Considering Lutao was uplifted during the period, the sea-level rise must have been at faster rate than the reef growth to accommodate newly formed reefs. The growth rate decreased to 2.3 m/kyr from 7.5 to 5.7 kyr BP. The rate of deglacial sea-level rise slowed down about 7 kyr BP (Montaggioni, 2005). Such slowdown in sea-level rise would result in decreased rate of increased accommodation space and slowdown in upward reef growth. Coral reefs ceased to grow when they reached paleosea level at 5.7 kyr BP and emerged as a result of tectonic uplift.

All our dates older than 7 kyr BP were acquired from subsurface samples. The oldest coral collected at outcrop is 6,759 ± 31 kyr BP. The results demonstrate that sampling the subsurface part of Holocene reefs is critical for reconstructing the early Holocene tectonics of Lutao.

5.2. Paleosea-level reference

Coral-reef growth is controlled not only by sea-level change, but

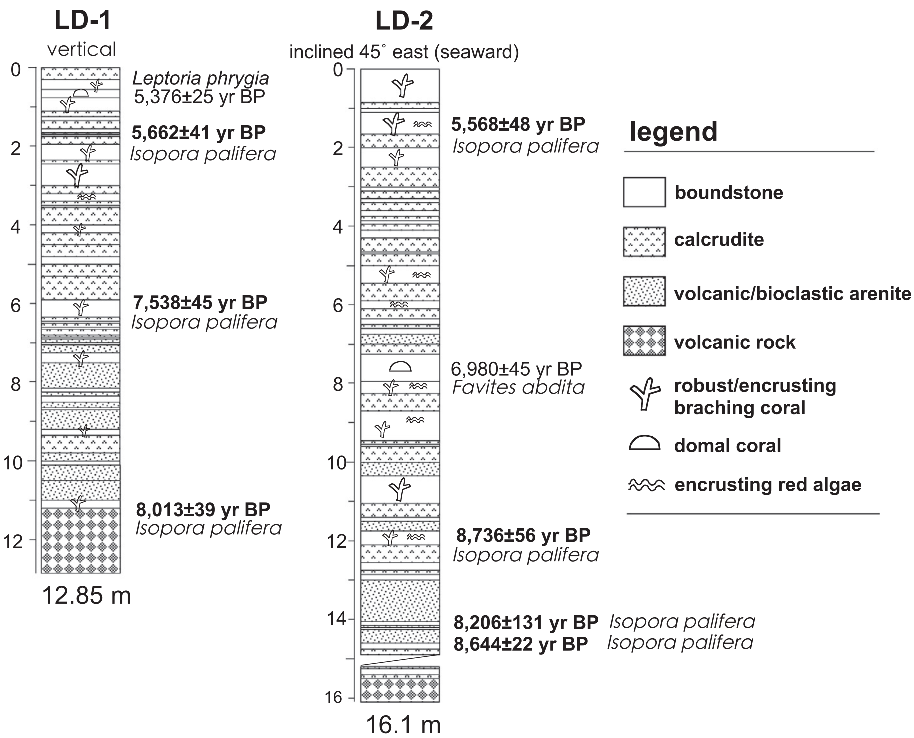

Fig. 4. Lithocolumn and ^{230}Th ages of fossil corals of the Lutao cores. Depths are below the ground surface. The elevation of LD-1 is 1.5 m and LD-2 is 1.4 m above MSL. The depth of LD-2 is apparent depth as the core inclined 45° seaward (east). Ages of *I. palifera* used in Fig. 5 are in bold.

also by vertical tectonic displacement (Chappel and Polach, 1991; Rostami et al., 2000). If eustatic sea level is known, then it can be subtracted from the relative sea level record so that the vertical tectonic history can be inferred. While the volume of ice meltwater is the primary control of deglacial sea level rise, regional variations of paleosea level are also affected by two other factors. First, seawater moved from far-field sites to subsiding forebulge near the deglaciation centers or "equatorial ocean siphoning" (Mitrovica and Peltier, 1991; Mitrovica and Milne, 2002) that is mainly determined by the distance of the study site from ice sheet. The second factor is spatial variations of hydro-eustatic adjustment or rheological behavior of earth crust caused by water loading (Nakada, 1986; Nakada and Lambeck, 1989). Oceanic and continental crusts respond differently to water loading. In addition, oceanic islands of different sizes also have different responses (Nakada, 1986; Grossman et al., 1998). Spatial variations in rheological behavior result in various accommodation spaces for seawater, and consequently modify local sea levels (Peltier, 2002; Mitrovica and Milne, 2002; Milne and Mitrovica, 2008). It has been shown that continental margins and large islands typically exhibited mid-Holocene sea level 1–3 m higher than present, while volcanic islands in oceanic basins tend to have undergone less mid-Holocene emergence (Nakada and Lambeck, 1989; Grossman et al., 1998; Camoin et al., 2004).

To reconstruct neotectonic history of Lutao faithfully requires a reference of paleosea level record that could be considered the same or similar to that of Lutao. Holocene sea-level records of Tahiti and Ishigaki Island are depicted in Fig. 5. The two sites are small volcanic

Table 1
Uranium and Thorium isotopic compositions and ^{230}Th ages of the Lutao fossil corals.

NTU ID	Weight g	^{238}U ppb		^{232}Th ppt		δ^{234}U measured[a]		[^{230}Th/^{238}U] activity[c]		[^{230}Th/^{232}Th] ppm[d]		Age uncorrected		Age corrected[c,e]		δ^{234}U$_{initial}$ corrected[b]	
Surface 1	0.100	3006.3	± 3.0	485.9	± 7.2	142.4	± 1.5	0.05992	± 0.00040	6122	± 99	5877	± 41	5812	± 41	144.8	± 1.6
Surface 2	0.098	1918.6	± 2.1	136.0	± 7.1	140.9	± 1.7	0.06734	± 0.00023	15,691	± 822	6636	± 26	6573	± 26	143.6	± 1.8
Surface 3	0.105	2718.6	± 2.6	413.3	± 6.7	142.1	± 1.5	0.06926	± 0.00029	7523	± 125	6824	± 31	6759	± 31	144.8	± 1.6
LD-1 0.7 m	0.094	1323.1	± 1.3	14.4	± 7.4	144.2	± 1.7	0.05563	± 0.00023	84,473	± 43,485	5437	± 25	5376	± 25	146.5	± 1.7
LD-1 1.6 m	0.086	2008.6	± 1.9	57.6	± 8.1	147.2	± 1.4	0.05864	± 0.00041	33,777	± 4757	5723	± 41	5662	± 41	149.6	± 1.4
LD-1 5.9 m	0.082	2432.8	± 2.5	903.1	± 8.9	141.6	± 1.9	0.07693	± 0.00042	3422	± 38	7608	± 44	7538	± 45	144.7	± 1.9
LD-1 11.2 m	0.086	2530.8	± 2.5	4079	± 11	142.3	± 1.4	0.08189	± 0.00032	838.9	± 3.9	8112	± 35	8013	± 39	145.6	± 1.5
LD-2 1.6 m	0.105	2821.2	± 2.3	302.0	± 6.8	146.8	± 1.4	0.05770	± 0.00047	8900	± 212	5631	± 48	5568	± 48	149.2	± 1.4
LD-2 7.7 m	0.109	1128.0	± 1.1	41.4	± 6.4	145.3	± 1.6	0.07161	± 0.00043	32,220	± 4976	7042	± 45	6980	± 45	148.2	± 1.6
LD-2 11.9 m	0.083	2343.4	± 2.0	310.7	± 8.5	142.3	± 1.5	0.08859	± 0.00053	11,032	± 307	8800	± 56	8736	± 56	145.9	± 1.5
LD-2 14.1 m	0.091	2006.3	± 1.8	19,380	± 78	143.0	± 1.4	0.08563	± 0.00067	146.4	± 1.3	8491	± 69	8206	± 131	146.4	± 1.4
LD-2 14.3 m	0.090	3060.4	± 2.8	801.8	± 7.8	144.2	± 1.5	0.08786	± 0.00017	5537	± 55	8711	± 21	8644	± 22	147.8	± 1.6

Analytical errors are 2σ of the mean.
[a] $\delta^{234}U = ([^{234}U/^{238}U]_{activity} - 1) \times 1000$.
[b] $\delta^{234}U_{initial}$ corrected was calculated based on ^{230}Th age (T), i.e., $\delta^{234}U_{initial} = \delta^{234}U_{measured}\ X\ e^{\lambda 234 * T}$, and T is corrected age.
[c] $[^{230}Th/^{238}U]_{activity} = 1 - e^{-\lambda 230T} + (\delta^{234}U_{measured}/1000)[\lambda_{230}/(\lambda_{230} - \lambda_{234})](1 - e^{-(\lambda 230 - \lambda 234)\ T})$, where T is the age. Decay constants are 9.1577×10^{-6} yr^{-1} for ^{230}Th, 2.8263×10^{-6} yr^{-1} for ^{234}U (Cheng et al., 2000), and 1.55125×10^{-10} yr^{-1} for ^{238}U (Jaffey et al., 1971).
[d] The degree of detrital ^{230}Th contamination is indicated by the [^{230}Th/^{232}Th] atomic ratio instead of the activity ratio.
[e] Age corrections were calculated using an estimated atomic ^{230}Th/^{232}Th ratio of 4 (± 2) ppm (Shen et al., 2008), and calibrated to yr BP (before 1950 CE).

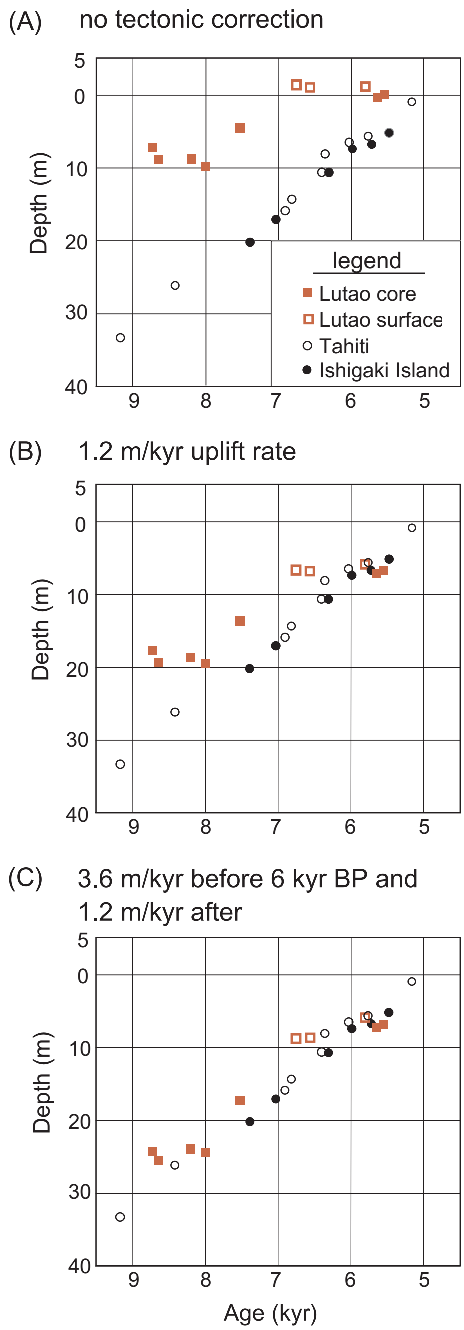

Fig. 5. Comparison of sea-level records between Lutao, Tahiti (Bard et al., 1996) and Ishigaki Islands (Hongo and Kayanne, 2010). Depths are corrected to vertical depths with respect to MSL. Tahiti data were corrected using subsidence rate of 0.2 m/kyr after Bard et al. (1996). No correction for Ishigaki Islands. (A) Lutao data without tectonic correction. (B) Lutao data corrected by uplift at 1.2 m/kyr. (C) Lutao data corrected by uplift at 1.2 m/kyr after 6 kyr BP and 3.6 m/kyr before 6 kyr BP.

islands sitting on oceanic crust and considered to have undergone hydro-eustatic adjustment similar to Lutao (Nakada, 1986; Grossman et al., 1998; Milne and Mitrovica, 2008).

Sea-level records of Ishigaki Island were mostly based on *Acropora digitifera* and *Montastrea curta* that are considered to live from 2 to 5 m in water depth from core IB-3 at Ibaruma reef, Ishigaki Island (Hongo and Kayanne, 2010). No tectonic correction was needed due to the absence of vertical tectonic displacement over the past 118.5 kyr (Hongo and Kayanne, 2010). The inferred paleosea level should be 3.5 ± 1.5 m above the corals. At Taihiti, *Acropora danai* and *Acropora robusta* were used for paleosea level as they live at 0–6 m below sea surface (Bard et al., 1996; Cabioch et al., 1999). Tahiti sea level was estimated to be at 3 ± 3 m above dated coral after correcting for tectonic subsidence 0.2 m/kyr (Bard et al., 1996). As shown in Fig. 5A, the paleosea level records at Tahiti and Ishigaki Island match very well and are considered to be trustworthy references for small oceanic islands.

5.3. Uplift rate of Lutao

Plots of depth versus age for all dated corals in Fig. 5A show a history of coral growth through time. This figure represents a relative paleosea level curve, which is estimated to be 1.0 ± 0.5 m above coral depth (Inoue et al., 2011). Fossil corals of Lutao are at much shallower depth than those of Tahiti and Ishigaki Island (Fig. 5A). This discrepancy is evidently caused by tectonic uplift of Lutao, which can be estimated by comparing the apparent sea-level records of Lutao to the reference sea level of Tahiti and Ishigaki Island.

Lutao corals younger than 6 kyr BP match the Tahithi and Ishigaki sea-level records by correction of 1.2 m/kyr uplift as suggested by Inoue et al (2011) (Fig. 5B), but those older than 6 kyr BP are still significantly shallower than Tahiti and Ishigaki corals by 5–10 m. This offset suggests higher uplift rate before 6 kyr BP. Using an uplift rates of 3.6 m/kyr before 6 kyr BP and 1.2 m/kyr after 6 kyr BP produces the best match between Lutao corals and paleosea-level based on Ishigaki/Tahiti corals (Fig. 5C), assuming *I. palifera* of Lutao living at 1 ± 0.5 m and those corals of Ishigaki/Tahiti living at 1–4 m below sea level. If using a fixed uplift rate between 1.2 and 3.6 m/kyr to correct the tectonic effect, either the older Lutao corals would still be too shallow, or the younger corals would be too deep to match paleosea-level.

Previous studies reported two samples older than 9 kyr at Lutao. A coral, located 1 m above present sea level, was dated to be 9455 ± 165 cal yr BP and (sample LT76-03, Wang and Burnett, 1990) and the other "paleoshoreline" sample, 1.3 m above present sea level, was dated to be 9055 ± 505 cal yr BP (UCL-438, Vita-Finzi, 2000). Tahiti paleosea level record indicates that sea level was −32 m at 9 kyr BP. If those two samples were indeed paleosea-level indicators, the long-term average uplift rate of Lutao would be 3.5 and 3.7 m/kyr, respectively. Assuming 1.2 m/kyr as the uplift rate for the past 6 kyr (Inoue et al., 2011), the uplift rate from 9 to 6 kyr would have had to be 7.4 m/kyr using Wang and Burnett (1990) data, or 8.7 m/kyr using the Vita-Finzi (2000) data. Unfortunately, Wang and Burnett (1990) only described the sample as "coral" without providing either field occurrence or taxonomy information. Vita-Finzi (2000) didn't explain what his "paleoshoreline" sample was. We cannot comment on the reliability of their data. Nevertheless, a higher uplift rate before 6 kyr BP is consistent to our results.

6. Conclusions

1. Holocene reefs of Lutao off eastern Taiwan developed in an overall aggradation mode from 8,736 ± 55 to 5,376 ± 25 yr BP during deglacial sea-level rise. The vertical growth rate of Lutao reefs was as high as 11.2 m/kyr from 8 to 7.5 kyr BP, and then decreased to 2.3 m/kyr after 7.5 kyr BP concurrent to slowing down of deglacial sea-level rise.
2. Ages and depths of Lutao fossil corals indicate a lower rate of 1.2 m/kyr after 6 kyr BP, as proposed by Inoue et al (2011), but suggest a high uplift rate of 3.6 m/kyr before 6 kyr BP.
3. Using corals collected from outcrops to estimate uplift rate has its limitations for Holocene studies. Sampling the subsurface sequence and choosing the proper paleosea-level reference are important not only for sea-level reconstruction but also for neotectonic studies.

Conflict of interest

The authors declared that there is no conflict of interest.

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