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NOTES AND CORRESPONDENCE

Finding of Probable Tsunami Boulders on Jiupeng Coast in Southeastern Taiwan

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ABSTRACT

We find three coral boulders (approx. 5 m across) resting on the Holocene coral terrace on the Jiupeng coast of southeastern Taiwan. Three exotic corals on the outer part of the boulders are dated at ca. 5000 yr BP which is similar to that of in situ corals composing the Holocene terrace. We interpret that these boulders were broken off from the coral terrace and were transported by tsunami waves, although the timing of the paleotsunami is not determined at this stage.

Key words: Tsunami boulder, Radiocarbon age, Southeastern coast of Taiwan

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1. INTRODUCTION

Taiwan is located upon an active plate boundary and has suffered from many kinds of natural hazards related to large earthquakes, such as coseismic surface rupture, coastal uplift, and landslides. Tsunami can be one of the hazards in Taiwan. However, only a few tsunamis have been documented in the written history of Taiwan, for example, they were reported at Tainan in September 1721, Kaoshung on 9 August 1792, and Keelung on 18 December 1867 (Ma and Lee 1997; Mak and Chan 2007; Lau et al. 2010).

Recently, large earthquakes have resulted in catastrophic disasters, including tsunamis, in tectonically active coastal areas (e.g., the 2004 Sumatra earthquake and the 2011 off the Pacific Coast of Tohoku Earthquake). In addition, past tsunami hazards have been known from historical documents and geological records in many areas. For example, the giant earthquake of 1700 AD on the Cascadian coast was reconstructed by a detailed sedimentary study of late Holocene coastal deposits (e.g., Atwater 1987; Atwater et al. 2005). Huge coral boulders on the marine terraces in the Ryukyu Islands are interpreted as being of tsunami origin (Makino 1968, on Ishigaki Island; Ota et al. 1985, on Hateruma Island). Kawana and Nakata (1994) and Goto et al. (2010) estimated the occurrence of multiple tsunamis in the last several thousand years based on the age of tsunami boulders distributed on several islands of the Ryukyus. Huge tsunami boulders were also observed in the 2011 off the Pacific Coast of Tohoku Earthquake. For example, huge tsunami boulders are found at 23 m above sea level at the small bay-head of Raga, Iwate Prefecture (personal communication by Tsuji, Earthquake Research Institute, University of Tokyo). Nevertheless, despite the subduction tectonics of the east coast of Taiwan, the possibility of tsunami occurrence has not been considered by previous studies.

The similarity of the tectonic situation between eastern Taiwan and the Ryukyu Islands suggests that tsunamis would have occurred in east Taiwan in the past. Analysis of past tsunami evidence is one of the important tools for paleoearthquake reconstruction. In this regard, we carried out two approaches: 1) the excavation of Holocene sediments and 2) the examination of tsunami boulders. The former was done at Chenggong on the eastern coast of the Coastal

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Range in March 2009 and 2010, and three tsunami events during the past 3000 years were found (Matta et al. 2010a, b). The latter was done on huge coral boulders lying on a Holocene terrace in the Hengchun Peninsula in 2009 - 2011. This brief report is focused on the latter approach, investigating coral boulders that were found on the southeastern coast of Taiwan.

2. LOCALITY

The study area is located along the southern part of the east coast the Central Range, east of Mt. Jiupeng (351.6 m above sea level), from Bitou to north of Nanrenbi Port (Fig. 1). The narrow (about 200 to 300 m in width) Holocene coral terrace fringes the steep eastern slope of the Central Range and is underlain by Miocene sandstone .

Holocene coral limestone is exposed on the east side of a coastal road that runs parallel to the coast line. The inner margin height of the coral terrace is ca. 5 m above sea level (Fig. 2). Two in situ coral samples from the northern part of the study area (the profile location is shown in Fig. 1) are dated at 5320 - 5220 and 5200 - 5120 cal yrs BP (Table 1).

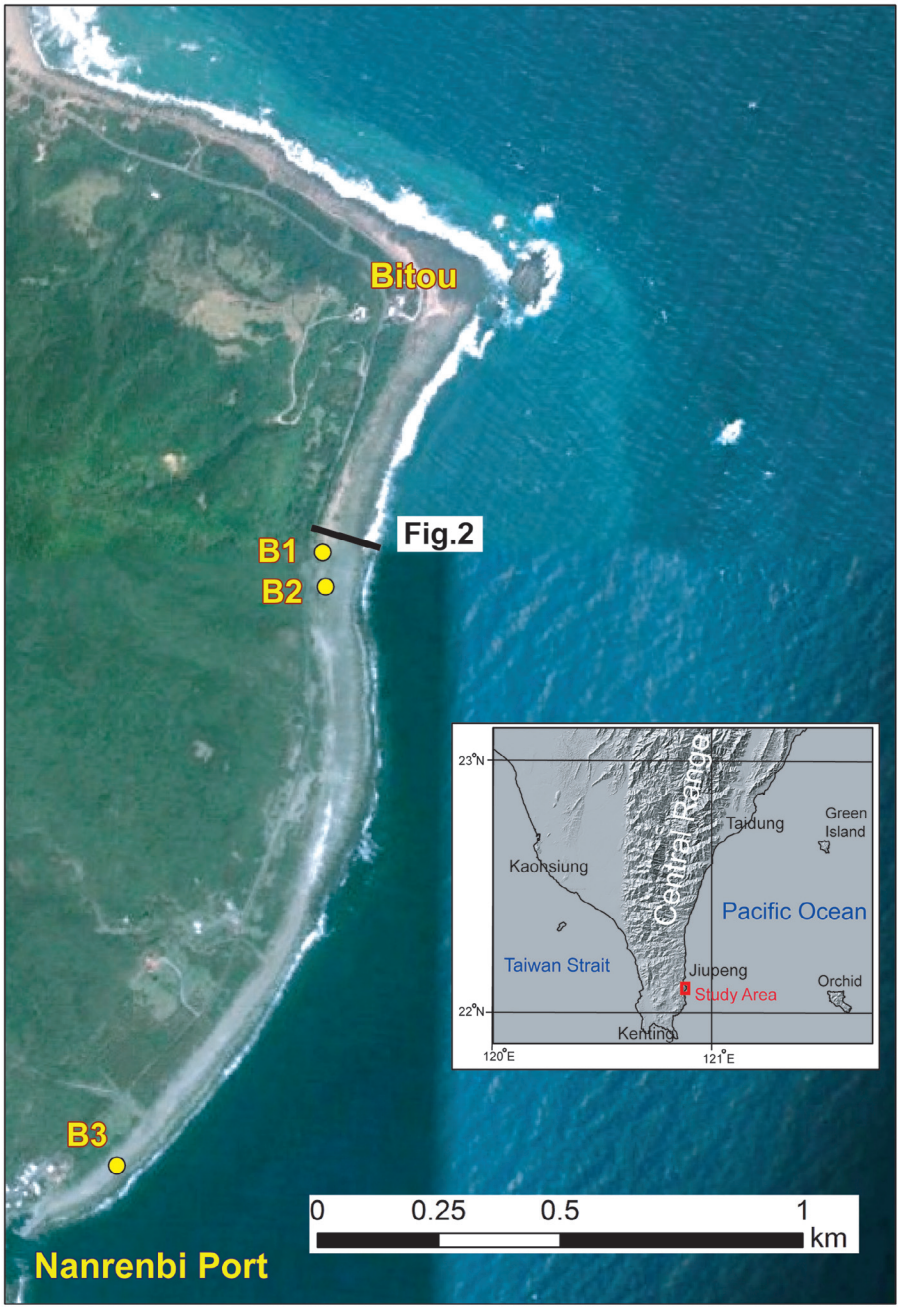

Fig. 1. Map showing the location of study area, three boulders (B1, B2, B3) and profile location. The base map is from Google Earth.

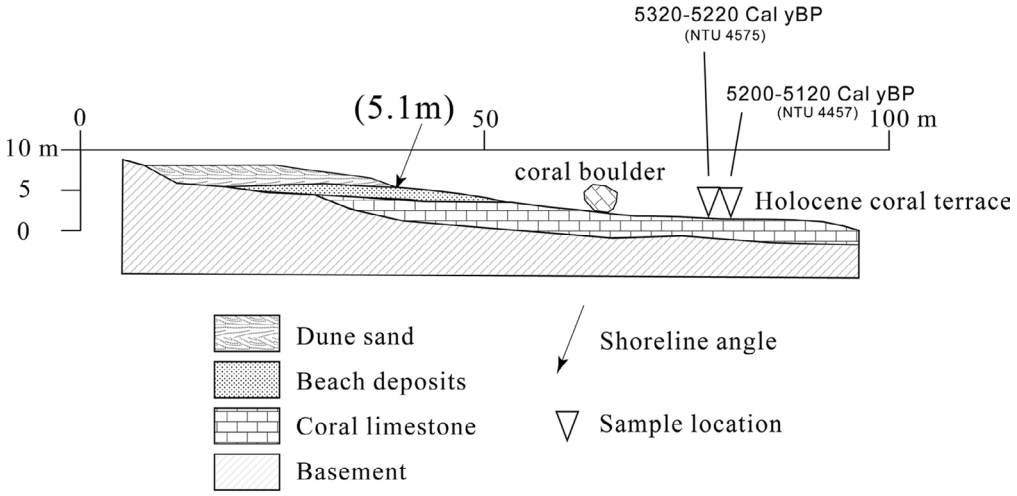

Fig. 2. Topographic profile and geologic section through the Holocene terrace. Locations for ^{14}C dates from Holocene terrace and tsunanmi boulders (B1 and B2) are projected into the profile.

Table 1. Location and size of coral boulders.

Boulder	Maximum diameter (m)	Height of the top of boulder above the coral terrace (m)	Distance from the present shoreline (m)
B1	5.5	1.8 - 2.2	76.5
B2	4.2	3.6	48.4
B3	5.5	1.2 - 1.6	ca. 30

Thus the Holocene uplift rate is estimated to be 1 m ka^{-1}, assuming that the sea level height ca. 5000 yrs BP was the same as at present. This uplift rate is rather low, compared with the very high uplift rate of the east coast of the Coastal Range (see Liew et al. 1990; Yamaguchi and Ota 2004; Hsieh and Rau 2009). Beach deposits and dune sand overlie the Holocene coral limestone on the west side of the road. Much drift wood is found on the beach deposits, indicating that storm waves can wash up on the beach deposits.

3. CORAL BOULDERS

Along the 3 km long coast, we confirmed the presence of three huge coral boulders on the Holocene coral terrace on the coastal side of the road. We label them B1, B2 and B3 (Figs. 1, 3). Despite our detailed observation of the coast, no other boulders were found. Sizes of the coral boulders are shown in Table 2. Our observation is summarized as follows: 1) Boulders are up to 5.5 m across, very similar to tsunami boulders from the Ryukyu Islands and those from the 2011 earthquake along the Tohoku coast. 2) They are entirely composed of corals with overturned growth structure. 3) They are resting on the Holocene coral terrace with distinct discontinuity to the underlying Holocene coral terrace. 4) There is no coral limestone on the hill behind the Holocene terrace. Therefore, we are quite sure that these boulders do not represent the relief within the Holocene coral terrace, and also are not derived from the hill as fallen blocks. They must have been transported from the seabed by strong sea waves. Two ways of transporting the huge boulders are possible, waves by storms and by tsunami. Frequent typhoons have struck the Taiwanese coast, but the presence of coral boulders is limited to only three. Thus we consider that a tsunami is acceptable as the cause of transportation of coral boulders B1, B2, and B3 that we observed.

4. AGE OF CORAL BOULDERS AND INTERPRETATION

We took samples from the outer part of the boulders for ^{14}C dating. The ages obtained (Table 2) are 4860 - 4570 cal yr BP from B1, 4910 - 4620 and 5490 - 5250 cal yr BP from B2. The sample from B3 was not suitable for dating because of recrystallisation. There is no significant difference between the ages of the boulders, considering some dating errors and the uncertain value for the marine reservoir effect (32 - 390 years, Yamaguchi et al. 2004). The obtained ^{14}C ages from B1 and B2 are close to those of the in situ corals composing the underlying Holocene terrace (Table 2). Thus we suppose the coral boulders originated from the Holocene coral terrace and were broken and transported landward by very strong tsunami waves upon the marine terrace. We can infer that these coral boulders provide at least one tsunami event after the formation of the coral terraces. It is impossible to estimate the date of the tsunami based on currently available data.

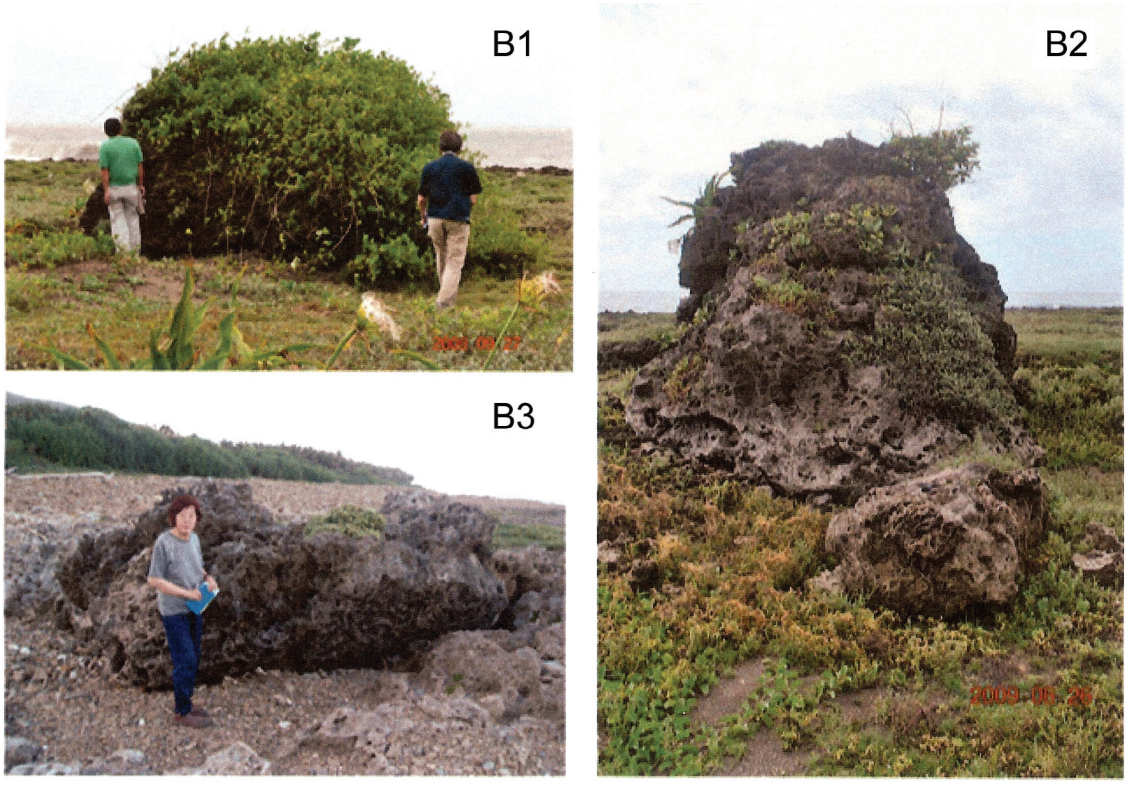

Fig. 3. Photograph of three boulders. Locations of B1, B2 and B3 are shown in Fig. 1. See Table 2 for the size of the boulders.

Table 2. Radiocarbon age from the Holocene coral terrace and coral boulders.

Sample occurrence	Sample no.	Lab no.	^{14}C age yr BP	Cal yr BP
in situ coral	20051015-4	NTU-4457	5270 ± 50	5320 - 5220
in situ coral	950702-08	NTU-4575	5160 ± 49	5220 - 5120
coral boulder (B1)	J-1	NTU-5331	4530 ± 50	4860 - 4570
coral boulder (B2)	J-2	NTU-5365	5000 ± 50	5490 - 5250
coral boulder (B2)	J-3	NTU-5338	4570 ± 50	4910 - 4620

Our observation is incapable of estimating the location of the tsunamigenetic earthquake. It is necessary to extend the study area for any reconstruction of a paleoearthquake. Actually, similar huge boulders are found on the east coast of Green Island, based on our preliminary observation. We hope this first report on the presence of probable tsunami boulders can be an opportunity for a further study of paleotsunamis.

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