Quaternary International xxx (2015) 1–7

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Holocene Antarctic melting and lithospheric uplift history of the southern Okinawa trough inferred from mid- to late-Holocene sea level in Iriomote Island, Ryukyu, Japan

Yusuke Yokoyama [a, e, *], Yasuo Maeda [b], Jun'ichi Okuno [c], Yosuke Miyairi [a], Takeharu Kosuge [d]

[a] *Atmosphere and Ocean Research Institute, University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba 277-8564, Japan*
[b] *Institute of Environmental Science, University of Hyogo, Kobe, Hyogo 651-2197, Japan*
[c] *National Institute of Polar Research, Tachikawa, Tokyo 190-8518, Japan*
[d] *International Society for Mangrove Ecosystems, c/o Faculty of Agriculture, University of the Ryukyus, Nishihara, Okinawa 903-0219, Japan*
[e] *Department of Biogeochemistry, Japan Agency for Marine-Earth Science and Technology, 2-15 Natsushima-Cho, Yokosuka 237-0061, Japan*

A R T I C L E   I N F O

Article history:
Available online xxx

Keywords:
Sea level
Ryukyu
Antarctica
Holocene
Tectonics
Glacio hydro isostasy

A B S T R A C T

Relative sea level deduced from fossil oysters and mangroves are reported for Iriomote Island, Ryukyus, southwestern Japan. Radiocarbon-dated fossil oysters, as well as previously analyzed mangrove muds, are compared to geophysical and glacio-hydro-isostatic adjustment (GIA) models that describe Earth deformation due to changing surface loading. The Holocene-high-stand (HHS) inferred from oyster fossils (*Saccostrea echinata* and *Saccostrea malaboensis*) is 2.7 m at ca. 3500 years ago, after which sea level gradually fell to present level. The HHS magnitude attributed to GIA for the last ca. 4000 is between 1 and 1.5 m above present day sea level, and the residual indicates the long-term lithospheric uplift rate of the island. The timing of peak HHS also indicates that late Holocene melting mainly from Antarctica ceased by approximately 4000 years ago.

1. Introduction

Observations of sea level change, relative to present, provide geophysical and climatological information. Directly, sea level change is due to exchange of water between the oceans and the ice sheets. At sites distant from major ice sheets, the deformation of the ocean basins due to water loading/unloading in a process called glacio-hydro-isostatic adjustment (GIA), can also cause apparent changes in sea level (Yokoyama et al., 2001a; Milne et al., 2009; Yokoyama and Esat, 2011). Global sea level has increased by as much as 120–130 m (Hanebuth et al., 2000; Yokoyama et al., 2000, 2001b) since the end of the last glacial maximum (LGM: ca. 19,000 years ago) causing re-distributions of surface loading due to complementary changes in ice and seawater volume (Lambeck et al., 2003).

The Japanese archipelago is located far away from former ice sheets, such as those of North America and Scandinavia, hence any changes in relative sea level (RSL) during the last deglaciation are limited to changes in ocean volume and the loading of seafloor and additionally due to possible crustal deformation caused by tectonic activities. The relative rise in sea level, for example from 7000 years ago, can be monitored from such locations and can be used to understand the geophysical structure of the lithosphere and the mantle as well as to quantify the melting history of ice sheets, in particular, the response of the Antarctic ice sheet to deglacial climate change (Yokoyama and Esat, 2011; Yokoyama et al., 2012).

At many coastal sites, peak Holocene RSL is often above the present day sea level due to GIA and is called the Holocene High Stand (HHS). The height and the timing of the HHS depend on local geophysical properties and whether the site is immune from tectonically-derived lithospheric movements. Therefore, systematic RSL observations during the Holocene combined with GIA modeling have been used to constrain lithospheric thickness and mantle viscosity (Nakada and Lambeck, 1987; Mitrovica and Milne, 2002).

Comparisons of sea level observations from far-field sites indicate that 3–4 m sea level equivalent (SLE) ice melting occurred during the mid- to late-Holocene, likely from Antarctica (Nakada and Lambeck, 1987; Fleming et al., 1998). Subsequent studies

* Corresponding author. Atmosphere and Ocean Research Institute, University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba 277-8564, Japan.
E-mail addresses: yokoyama@aori.u-tokyo.ac.jp, yokoyama@eps.s.u-tokyo.ac.jp (Y. Yokoyama).

http://dx.doi.org/10.1016/j.quaint.2015.03.030
1040-6182/

confirmed such melting which ceased at about 4 to 2 ka (Lambeck, 2002; Peltier, 2002; Yokoyama et al., 2012), though detailed behavior of Antarctic ice sheet is still under debate (Gehrels, 2010). Accurate determination of HHS timing is important to deconstruct the GIA induced lithospheric deformation (Yokoyama et al., 2012). A larger magnitude of crustal uplift is expected if the cessation of melting occurred earlier during the Holocene, e.g. 6 ka. Conversely, no HHS above present level would be expected if ocean volume continuously increased due to constant melting since the LGM (Yokoyama et al., 2012). Therefore, precise determination of peak HHS timing is required clearly understand Holocene Antarctic ice sheet behavior.

Iriomote Island is located in the southern Ryukyus where the Okinawa trough is expanding northward and the Philippines Sea Plate (PSP) is subducting in the south (Fig. 1). Global positioning system (GPS) measurements indicate northward movement of the PSP at up to 8 cm/year (Gripp and Gordon, 2002). The status of plate coupling (strong or weak) in the region is not well understood, which has implications for the likelihood of future large thrust-related earthquakes (Mw > 8) (Kao et al., 1998; Wei and Seno, 1998; Ando et al., 2009). In 1771 AD, a tsunami in the southern Ryukyus caused approximately 12,000 casualties, but no other devastating tsunami of similar size are recorded in historical documents (Watanabe, 1985). However a number of large boulders casted onshore by tsunamis (tsunami boulders) have been dated by both radiocarbon and Uranium series methods (Suzuki et al., 2008; Araoka et al., 2010), indicating a recurrence time of 150–400 years over the last 2400 years in the southern Ryukyu (Araoka et al., 2013).

Past RSL indicators are often not well preserved (Yokoyama and Esat, 2015). Fossil oysters are a good indicator of paleo sea level along the Pacific coast (Pirazzoli, 1991; Yokoyama et al., 1996) that can accurately indicate sea level rise (Rodriguez et al., 2014). Combined observations on corals and oysters together with geomorphological sea level features (i.e. notches) along tectonically stable Palawan coast, Philippines, suggest that oyster beds precisely indicate past sea level (Maeda et al., 2004). Here we present relative sea level data based on oyster beds found in a coastal cave shielded from wave action, which protected the relatively fragile shells from mechanical erosion. These were radiocarbon dated, and, together with previously reported mangrove data, the results compared to a GIA model to further illuminate Holocene Antarctic melting history, as well as regional tectonic activity.

2. Methods

Iriomote Island is located 190 km east of Taiwan and 20 km west of Ishigaki Island in the southern Ryukyu arc (Fig. 1). The basement of the island consists of shallow marine and/or terrestrial facies of early Miocene sandstone to mudstone (Nakagawa et al., 1982). Uplifted marine terraces were recognized from analyses of aerial photos, and the elevations of the last interglacial terraces are identified by Ota and Hori (1980) at 40 m above sea level (asl) or by Machida (2001) at 30–60 m asl. Assuming the last interglacial shoreline was formed at 125 ka, long-term linear uplift rate of this island is between 0.24 and 0.48 m/ky.

Coastal areas of Iriomote Island were surveyed to locate marine caves that contain well-preserved oyster beds (Fig 2). Radiocarbon dating was conducted following standard protocols described elsewhere (Yokoyama et al., 2007, 2010). The radiocarbon ages were converted to calendar ages using the Marine13 calibration data set (Reimer et al., 2013) with local reservoir ages (ΔR) of 10 ± 37 years (Araoka et al., 2010).

Lithospheric deformation of the solid earth due to re-distribution of the surface loading since the LGM was calculated

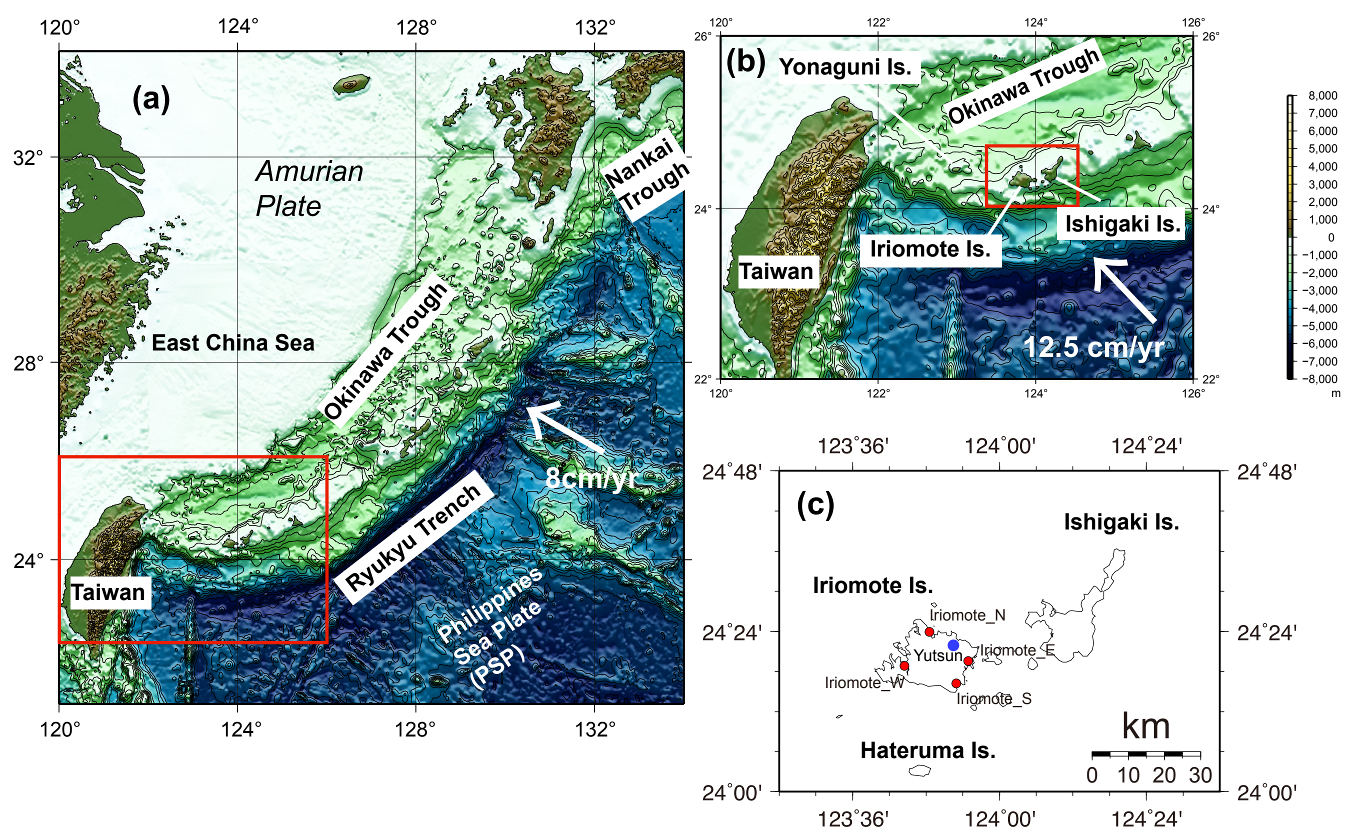

Fig. 1. Location of Iriomote Island and tectonic settings of Ryukyu islands.

Please cite this article in press as: Yokoyama, Y., et al., Holocene Antarctic melting and lithospheric uplift history of the southern Okinawa trough inferred from mid- to late-Holocene sea level in Iriomote Island, Ryukyu, Japan, Quaternary International (2015), http://dx.doi.org/10.1016/j.quaint.2015.03.030