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A newly discovered submerged reef on the Miyako-Sone platform, Ryukyu Island Arc, Northwestern Pacific

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ABSTRACT

Bathymetric echosounder mapping and seafloor observations using a remotely operated vehicle were conducted on the Miyako-Sone platform, located northeast of Miyako-jima, Ryukyu Islands, northwestern Pacific Ocean. This study aims to unravel the origin and development of the Miyako-Sone platform, a key field to reconstruct the biogeographic evolution and the geologic history of the Ryukyu Islands. The resulting high-resolution bathymetric map reveals details of the seafloor geomorphology, including the spatial distribution of submerged terraces on the platform. We report herein the discovery of a submerged reef (the Miyako-Sone reef) on the platform whose top is at a water depth of 56 m, extending in a north–south direction for up to 1 km and with a minimum width of 500 m. The reef consists of a central depression and a concentric marginal ridge; topographic features analogous to "spurs and grooves" are recognized along the outer margin of the marginal ridge. The Miyako-Sone reef was drowned during a period of global postglacial sea-level rise between ~11–12 ka which may coincide with MWP-1B at ~11.5 ka. The increase in sea surface temperature in the Ryukyu Islands at ~11 ka shows that the Miyako-Sone reef formed during the final stage of the cooler postglacial period. Part of the Miyako-Sone platform was likely a land bridge for the migration of terrestrial organisms from Okinawa-jima to Miyako-jima during low sea-level stands after the deposition of the Ryukyu Group.

1. Introduction

The Ryukyu Island Arc, which extends for over 1200 km along the east coast of Asia from Kyushu to Taiwan, and the associated Ryukyu Trench are products of the subduction of the Philippine Sea Plate beneath the Eurasian Plate (Fig. 1). The Okinawa Trough, a back-arc basin located landward of the Ryukyu Island Arc, formed in the Late Miocene (Gungor et al., 2012) or the Late Pliocene–Early Pleistocene (Sibuet et al., 1998; Shinjo, 1999); its formation is a key geologic event associated with complex tectonic movements and changes in the topographic configuration of the Ryukyu Islands. The 'coral sea' of the Ryukyu Islands is thought to have formed after the opening of the Okinawa Trough and the subsequent influx of the Kuroshio Current. Because the Kuroshio Current is a source of warm oligotrophic water, its influx into the Okinawa Trough was important for the evolution of modern oceanographic conditions in the northwest Pacific and climate conditions in Far East Asia (Iryu et al., 2006; Gallagher et al., 2015).

No islands are present along the Ryukyu Island Arc between Okinawa-jima and Miyako-jima, a distance of 290 km (Fig. 1), and along this stretch, the sea floor is broad, flat, and relatively shallow, with a water depth of <500 m (Ujiié, 1980). This broad flat surface is bounded by steep slopes of the Kerama Gap (Miyako Depression) to the northeast and the Miyako Saddle to the southwest. The Kerama Gap, which reaches a maximum depth of 1800 m, is one of distinctive geological boundaries, separating the South Ryukyus from the Central Ryukyus (Konishi, 1965). Biomolecular data indicate that a land bridge existed between Okinawa-jima and Miyako-jima during the Middle-Late Pleistocene (e.g., Ota, 1998). This land bridge appears to have enabled animals characteristic of the Central Ryukyus to migrate to the South Ryukyus. However, Arai et al. (2014) showed that since the Middle Pleistocene, the environment along the northwestern margin of the Miyako-Sone platform has been continuously marine and has not been subjected to episodic subaerial exposure or associated

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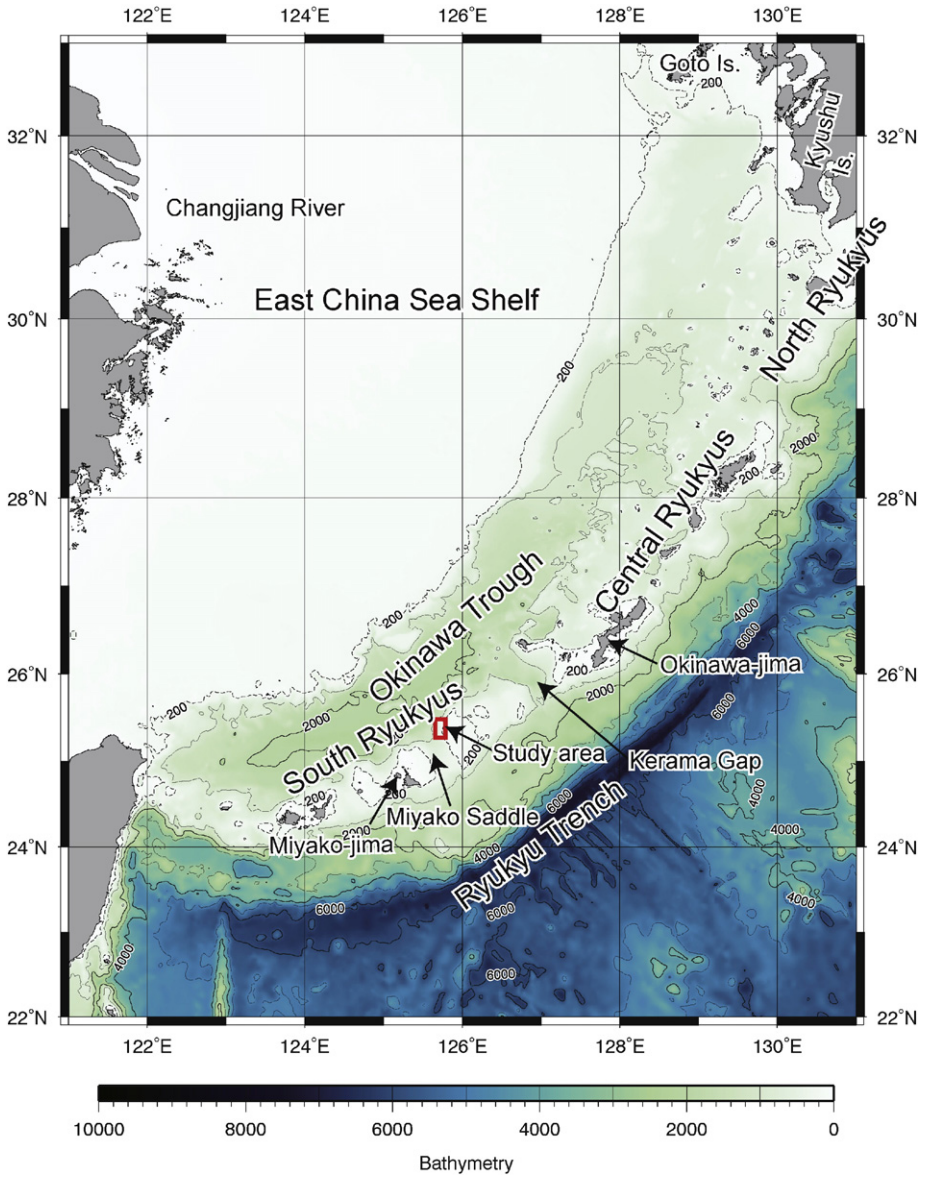

Fig. 1. Bathymetric map of the Ryukyu Island Arc (bathymetric data are from ETOPO1 Global Model; Amante and Eakins, 2009). The study area is located to the northeast of Miyako-jima.

meteoric diagenesis. They suggested that, as the platform is shallowest on the Zyuho-Tai Bank (Fig. 2), located to the south of their study area, this bank and its environs are the most likely candidate for the presumed land area.

Many studies have examined the morphology of modern coral reefs in the Ryukyu Islands (e.g., Hori, 1977; Hori and Kayanne, 2000). Hori and Kayanne (2000) reported that in the Central to South Ryukyus, topographic features distinctive of coral reefs are not found below the inner break (i.e., water depths greater than ~50–55 m). However, submerged coral reefs have been discovered on continental shelves and on island margins in many tropical and subtropical areas worldwide. Sea-level rise since the last glacial maximum has been non-linear (Fairbanks, 1989). Reef backstepping and reef drowning are markers of rapid sea-level rise (e.g., Blanchon and Shaw, 1995). Paleowater-depth interpretation of fossil reef organisms and their radiometric dating are used to constrain the amplitude and timing of sea-level changes (e.g., Bard et al., 1996). Investigations off Barbados (Peltier and Fairbanks, 2006), Hawaii (Webster et al., 2004), Papua New Guinia (Edwards et al., 1993), Tahiti (Camoin et al., 2006; Deschamps et al., 2012), the Great Barrier Reef (Beaman et al., 2008; Abbey et al., 2011), the Sunda Shelf (Hanebuth et al., 2000), and the Maldives (Fürstenau et al., 2010) have confirmed the significance of these reefs as unique archives of postglacial global sea-level rise.

Here, we document the detailed topography of the Zyuho-Tai Bank on the northwestern margin of the Miyako-Sone platform, and show the existence of drowned reef whose top is at a water depth of 56 m. The results contribute to our understanding of coral reef formation and the response of coral reefs to postglacial sea-level rise in a relatively high-latitude area in a coral reef province. This study also provides important data for reconstructing the paleogeographic evolution of the Ryukyu Islands, which is essential to the interpretation of island biogeography in this area.

2. Regional setting and methods

The study area is located 50–60 km northeast of Miyako-jima on the northwestern margin of the Miyako-Sone platform (Fig. 2). The platform is ~70 km from north to south and ~50 km from east to west; it is bounded on the west by steep slopes of the Miyako Saddle, and water depths on the eastern outer edge reach 120–170 m (Hamamoto et al., 1979). The platform comprises five isolated banks: the Kita-Zyuho-Tai, Zyuho-Tai, Hozan-Sone, Minami-Hozan-Sone, and