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1B Reef response to sea-level and environmental changes

Seismic profiling survey of submerged coral reefs near Okinawa Island

Kohsaku Arai, Tomoyuki Sato, Takahiko Inoue

Institute of Geology and Geoinformation, Geological Survey of Japan-AIST, Central 7, Higashi 1-1-1, Tsukuba, Ibaraki, 305-8567, Japan
Corresponding author: ko-arai@aist.go.jp

Abstract. A shallow seismic profiling and bathymetric surveys recorded mounds, interpreted as submerged coral reefs and reefal sediments, to the southwest of Okinawa Island, in the center of the Ryukyu Island Arc. High-resolution seismic data were collected using a 2800 LLX (491.6 cm^3) cluster gun with a 16 channel digital streamer cable, and a parametric sub-bottom profiler system. Images of the mounds, about 40 m high and 30–50 m wide, revealed erosional surfaces, possibly formed during the last glacial period. The base of the mounds are in a water depth of about 140 m, and the topographic profile is very similar to the modern reef crest to upper slope area around the Ryukyu Island Arc (at 0–50 m water depth). Such high-resolution seismic profiles, accompanied by detailed bathymetric mapping, of the reefal area may be an effective indicator of not only the paleoenvironment development of the coral reef, but also the tectonic setting of the offshore area.

Key words: Seismic profiling survey, Ryukyu Island Arc, Submerged Coral reef, Okinawa Island, Northwestern Pacific.

Introduction

The Ryukyu Island Arc extends 1200 km, from Kyushu to Taiwan, along the Ryukyu Trench where the Philippine Sea Plate is subducting beneath the Eurasian Plate (Fig. 1). The Okinawa Trough is a back-arc basin that formed behind the Ryukyu Island Arc in the late Pliocene to early Pleistocene (Sibuet et al. 1998; Park et al. 1998; Shinjo 1999). The formation of the Okinawa Trough is intrinsically linked to the tectonic development of the Ryukyu Island Arc, and caused the complicated uplift and/or subsidence of the Islands.

The Geological Survey of Japan (AIST) conducted geological mapping around Okinawa Island, which is located in the center of the Ryukyu Island Arc, between 2008 and 2010. Part of the survey area, southeast of Okinawa Island, is on the upper fore-arc slope of the Ryukyu Island Arc system. Seismic reflections from the upper fore-arc slope show a distinct reflector that may represent an erosional unconformity. This reflector dips to the southeast and is overlain by stratified sediments. No obvious deformation, such as folding or faults parallel to the Ryukyu Trench axis, was found under the upper fore-arc slope. In contrast, active faults perpendicular to the Ryukyu Trench axis (NW–SE) were observed (Arai et al. 2010). The most conspicuous fault system, known as the Kerama Gap, is located southwest of Okinawa Island in an active tectonic area where water depths reach approximately 1,800 m (Fig. 1).

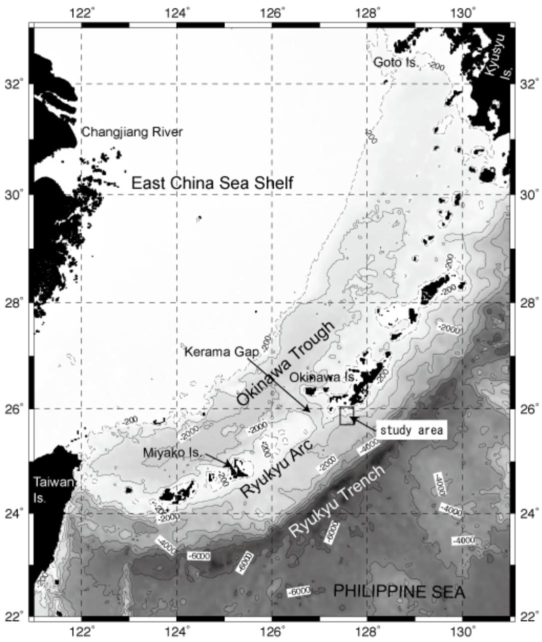

Figure 1: Bathymetric map of Ryukyu Island (data from JTOPO30).

In this study, we present high-resolution seismic profiles of the area southwest of Okinawa Island. These profiles show a clear erosional unconformity, overlain by stratified sediments and mound-shaped structures with acoustically chaotic properties, which we interpret as submerged coral reefs and reefal sediments.

Material and Methods

The Geological Survey of Japan completed three research cruises around Okinawa Island: GH08 (July 28 to August 29, 2008), GH09 (July 16 to August 17, 2009) and GH10 (October 27 to November 25, 2010). More than 6,800 nautical miles of multi-channel high-resolution seismic profiles were acquired during these cruises using a GI gun (5,817 cm^3) or a cluster gun (2 × 491.6 cm^3) system with a 16 channel digital streamer cable (Fig. 2). The shot interval of the GI gun was about 25 m, and for cluster gun it was about 12.5 m. The spacing interval of the streamer cable was 12.5 m. The recording length was 5.9 s for the GI gun, and 3.9 s for the Cluster-gun. The data was recorded in a SEG-D format and processed onboard.

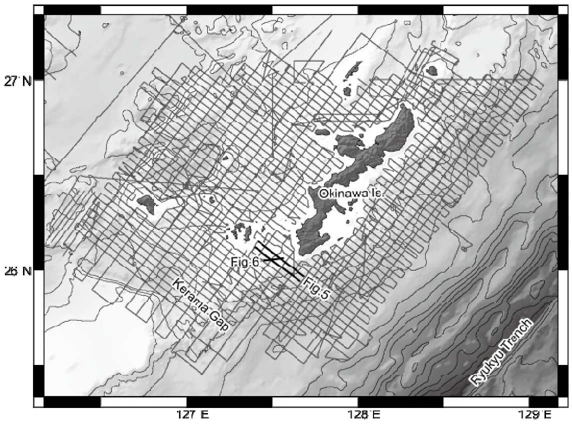

Figure 2: Seismic survey lines around Okinawa Island covered more than 6,800 nautical miles and 16 channel seismic and SBP profiles were acquired.

Multi-narrow-beam bathymetric mapping using a Hydrosweep DS, and parametric SBP (sub-bottom profiler) surveys using a TOPAS PS18 were also completed along the seismic survey line (Fig. 2).

Results

The bathymetric map (Fig. 3) shows the mounds observed at water depths of 120–140 m, southwest of Okinawa Island. The tops of the mounds were up to 15m above the sea floor (mound of center in Fig. 3). Samples were collected from the mounds during the cruises using a grab, and a rock core sampler (e.g., Itaki et al. 2010). The surface of the mounds was well indurated (Fig. 4), and only algal carbonate blocks, which encrusted the well-indurated surface, were recovered.

High-resolution seismic profiles show an acoustic basement dipping to the southeast, and traceable under the wide area to the south of Okinawa Island (Fig. 5). The basement is covered by sediment. A distinct and irregularly undulating reflector was observed at the top of the sediments. This reflector may correspond to an erosional surface, and is overlain by a thin layer of stratified sediments. The maximum thickness of sediment above the distinct reflector was 0.07 s TWT (two-way travel time), but it could not be traced beyond the southeastern shelf margin.

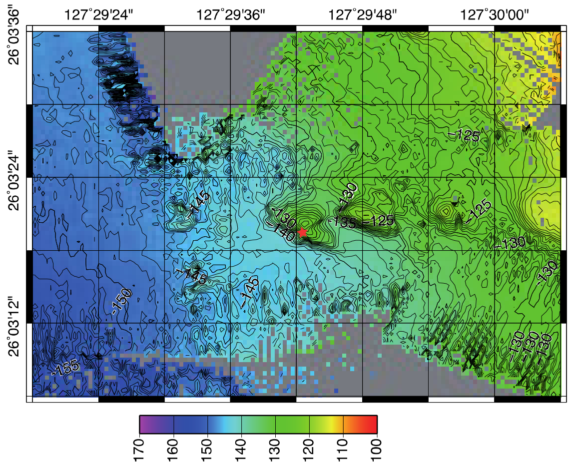

Figure 3: Bathymetric map showing the topography of sea-floor mounds in the area southwest of Okinawa Island.

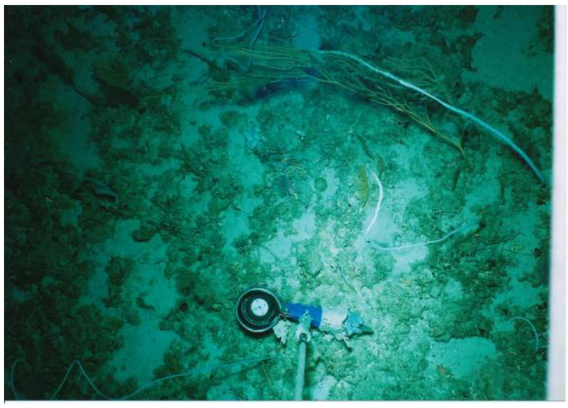

Figure 4: Image of the subsurface of the mounds. For scale, the compass is about 45 cm long. Location is shown as a red star in Fig. 3.

The seismic profiles show small mounds, which are outlined by strong reflections, but have internally chaotic reflections (Fig. 5). The mounds cover the distinct reflector, and are onlapped by the thin layer of stratified sediment. The maximum height of the mounds reaches 0.055 s TWT from the base of the reflector, which is equivalent to 41 m (velocity of sound = 1,500 m/s). The width of the mounds was approximately 30–50 m.

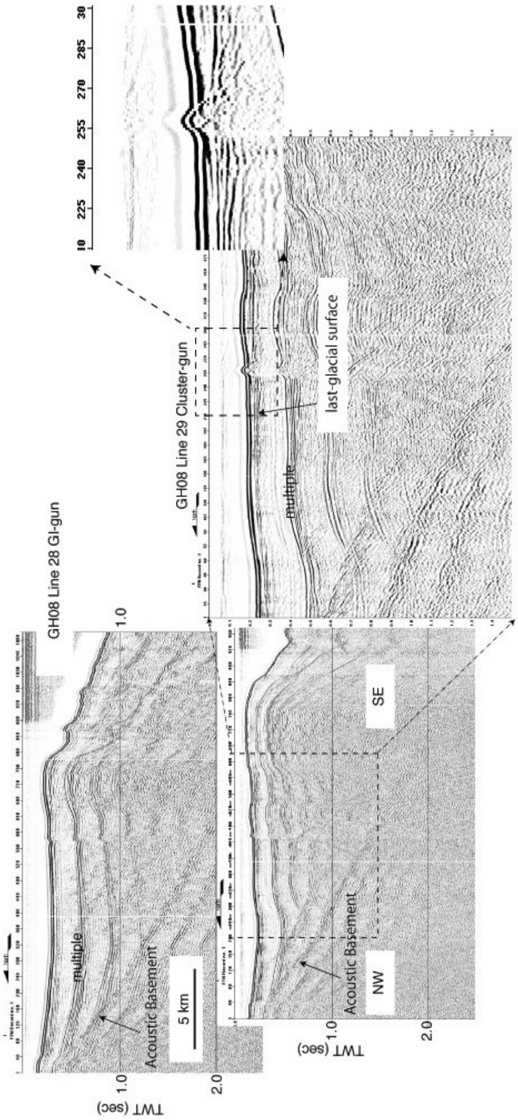

Figure 5: Seismic profiles south of Okinawa Island. Right panel is a close-up of the high-resolution image of the last glacial unconformity. Left panel shows the Mound-shaped structures along two seismic lines.

Discussion

Erosional Surface and Stratified Sediment

The thickness and characteristic features of the seismic reflector, including its distinctly irregular undulations, suggests that it represents an erosional surface formed during last glacial maximum (last-glacial surface in Fig. 5, upper panel). The thin layer of stratified sediment overlying the reflector accumulated during the period of deglaciation. The mound-shaped structures above the erosional surface cannot be attributed to volcanism, because the base boundary is cut reflector as erosional surface. In other words, the mound-shaped structure may form above the erosional surface. Similar mound-shaped structures, with acoustically chaotic properties, were reported from the shelf off Irabu Jima, in the Southern Ryukyu Island Arc system (Obata & Tsuji 1992). Sasaki et al. (2006) dated samples collected from an isolated mound-shape structure and confirmed it was a lowstand coral reef. Matsuda et al. (2011) also record submerged reefal deposits, near the present-day northern limit of coral reef formation in the northern Ryukyu Island Arc. Consequently, we conclude that the mound-shape structures are submerged coral reefs, and reefal deposits, that developed following the last glacial maximum. Itaki et al. (2009) report that coarse- to medium-grained modern carbonate sediments are widely distributed, except on the indurated mound-shaped structures. These results are consistent with our seismic profiles.

SBP Topography

The SBP profile images are topographically very similar to the present-day morphology of the island shelf off the middle and southern Ryukyu Island Arc (Hori and Kayane 2000). The distinctive morphological features of the island shelf were classified (in descending order) as: inner break, outer break, inner shelf, and shelf break. The mound-shaped structures may correlate with the section above the inner break, and show spurs and grooves just off the reef crest. Arai et al. (2008) obtained topographic images of recent spurs and grooves in the northern Ryukyu Island Arc, and their base is at a water depth of less than 50 m. The spurs and grooves in this study were about 40 m high, which is slightly larger than the modern equivalent. This may be caused by reef growth possibly keeping pace with sea-level rise during the first stage of deglaciation.

Depth of Mound-shaped Structure

The water depth to the base of the mounds was 140 m, and the top of the mounds was at about 110–120 m (Fig. 6). Hori and Kayane (2000) report that the distinctive topographic features of coral reefs are not found off the inner break (ca. 50 m water depth), and suggest that reef accumulation began after 10–11 kyr B.P. on the middle to south Ryukyu Island Arc. Since the last glacial maximum, sea level has risen in a non-linear way (Fairbanks, 1989); reef backstepping and the ages of drowned reefs can be interpreted as successive cycles of reef-growth and drowning in the low latitude areas of the world (e.g., Blanchon and Shaw 1991). We have no absolute chronology for the mound-shaped structures; however, their depth indicates that coral reef development began around the time of the last glacial maximum. This suggests that the climate may have been warm enough, even in the central Ryukyu Island Arc, to support the development of reefs and reefal sediments during the last glacial period.

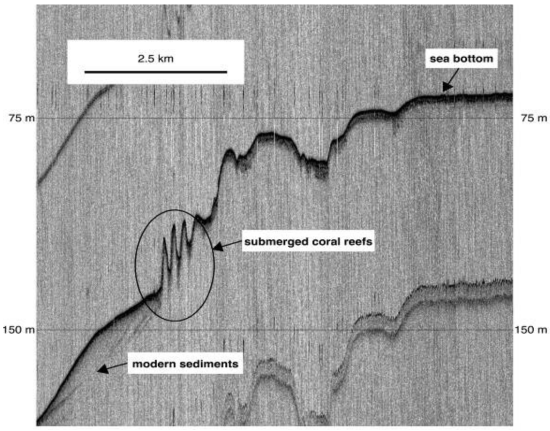

Figure 6: SBP profile south of Okinawa Island. Mound-shaped structures are clearly imaged and may correspond with modern reefal topography.

Subsidence southwest of Okinawa Island

The most conspicuous fault system was located southwest of Okinawa Island; i.e., the Kerama Gap, which is an important tectonic boundary between the south and middle Ryukyus (e.g., Konishi 1965). The Kerama Gap trends NW–SE, perpendicular to the axis of the Ryukyu Trench and the Ryukyu Island Arc, and the water depth in the Gap is approximately 1,800 m. Topographically, it is characterized by steep slopes on its southwestern side, but more gentle slopes to the northeast.

Our study area is in the upper section of the gently sloping northeastern side of the Gap, and seismic profiles show that subsidence accompanies many of the normal faults here. The base of the mounds formed at 140 m water depth, which is deeper than other mounds in the Ryukyu Island Arc (Obata and Tsuji 1992; Matsuda et al. 2011). A more detailed seismic survey, and the recovery of sample cores from the mound-shaped structures, are required to establish the subsidence rate and detailed deformation history of the Kerama Gap.

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