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Paleoenvironments and relative sea-level changes caused by regional tectonics during the last 4500 years in Kumihama Bay, northern Kyoto Prefecture, central Japan

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A B S T R A C T

Ostracode assemblages were examined, and the grain size and chemistry of sediments were analyzed with the aim of clarifying paleoenvironmental and relative sea-level (RSL) changes relating to regional tectonics in Kumihama Bay, central Japan. Overall, 21 genera and 38 species of ostracode were identified from two cores taken in the northwestern and southeastern parts of the bay. The analysis of sedimentary facies, ostracode assemblages and geochemical records of sediments revealed the following environmental changes. A closed bay, with an area smaller than that of today, existed between 4500 and 4300 cal BP. A gradual increase in seawater influence in the bay was caused by an RSL rise between 4300 and 2000 cal BP with highest RSL occurring at 2000 cal BP. Between 4000 and 2500 cal BP, the RSL in Kumihama Bay has shifted from −3.8 m to −2.0 m at a rate of 1.2 mm/yr. This rate is inconsistent with the predicted RSL trend in surrounding regions, suggesting the occurrence of a subsidence in Kumihama Bay during the Late Holocene. The trend in tectonic movement and their rate are common in the San'in shear zone, implying that this subsidence might be related to the subducting of the Philippine Sea Plate.

1. Introduction

The relative sea-level (RSL) changes during the Holocene were affected by glacio-hydro-isostatic adjustment additions to eustasy and regional tectonics (e.g., Nakada et al., 1991; Lambeck et al., 2004). The eustatic sea-level curve has been reconstructed based on observations in tectonically stable regions such as those in Australia, Tahiti and the Seychelles (e.g., Nakada and Lambeck, 1989; Fleming et al., 1998; Woodroffe et al., 2015). Furthermore, recent improvements in the models for prediction of sea-level curves induced by glacio-hydro-isostatic adjustments and eustasy could isolate tectonic movement contributions from the observed RSL (Bradley et al., 2011; Lambeck et al., 2014). However, a few topics are still to be determined, such as the eustatic sea level during the Holocene, the time at which the Antarctic ice sheet melting contribution ended and which model is the best for reconstructing the sea-level changes during the Holocene. Further, small-amplitude sea-level changes relating to Holocene climate changes were observed (Mayewski et al., 2004). To clarify the uncertainties above and to validate the predicted sea-level curves, a comparison between the observed and predicted sea-level changes is required.

Various methods have been applied for the calculation and reconstruction of RSL changes from the observations during the Holocene, including sedimentary facies (Tanabe et al., 2009), peat sediments (Brain et al., 2015), diatoms (Sato, 2014; Mourelle et al., 2015), oysters (Yokoyama et al., 2016), archaeological evidence (Lambeck et al., 2004; Mastronuzzi et al., 2017), beach rocks and beach ridge deposits (Stattegger et al., 2013), etc. The Japanese Islands are located in a far field, where a large volume of seawater

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induced by ice melting caused deformation of the seafloor. In Japan in particular, regional tectonics related to the subduction of oceanic plates and seismic activities are strongly associated with the RSL (Yokoyama et al., 2012). Based on models, subtracting local tectonics, the highest RSL would be observed at 6 ka during the Holocene, then the RSL decreased to the present level around the Japanese Islands (Nakada et al., 1991; Lambeck et al., 2004). It is accepted that the RSL trend during the Holocene reached its maximum at 6–7 kyr BP and decreased to that of the present level based on observed sea-level variations in the Japanese archipelago (e.g., Sato, 2008). However, most of these records were obtained from the coastal area in the Pacific Ocean, which is a forearc basin. In addition, the amplitude of the highest sea-level and the rate of predicted sea-level changes differed between the side on the Sea of Japan, which is a back-arc region, and the coastal area on the Pacific Ocean (Okuno et al., 2014). Further, another peak termed the “Yayoi regression” was recognized between 2000 and 3000 cal BP in some regions (e.g., Kawase, 1998; Tanabe and Ishihara, 2013; see details in Tanabe et al., 2016). Thus, the predicted sea-level changes and tectonic movements around the Japanese Islands during the Holocene are yet not fully understood.

Because earthquakes occur frequently on the Japanese Islands, the history of regional tectonic activities is important for disaster prevention. Since the 2011 Tohoku–Oki earthquake, numerous investigations have been carried out to understand the mechanism and cyclic intervals of earthquakes in Japan (e.g., Goto et al., 2011; Szczuciński et al., 2012). Earthquakes that occur at relatively shallow depths along the Japanese Islands might cause significant destruction on the ground surface and these have also been investigated recently in addition to earthquakes induced in the subduction zone (Sawazaki et al., 2009; Kato et al., 2016). The San'in region, that is the area located along the Sea of Japan in south-western and central Japan, is a shear zone where at least six huge shallow earthquakes have occurred during the last 100 years (Nishida, 2007). In the Tango Peninsula, in central Japan, the Yamada and Gomura active fault zones extend NE–SW and NNW–SSE, respectively, and are thought to be conjugated with each other (Tsukuda et al., 1993, Fig. 1). A slip fault on the ground surface that relates to these faults was identified in the 1927 Kita-Tango earthquake (Izuno, 2012). The regional uplift and subsidence during the Holocene were also deduced from the difference in terrace elevation among the areas along the northern coast of the

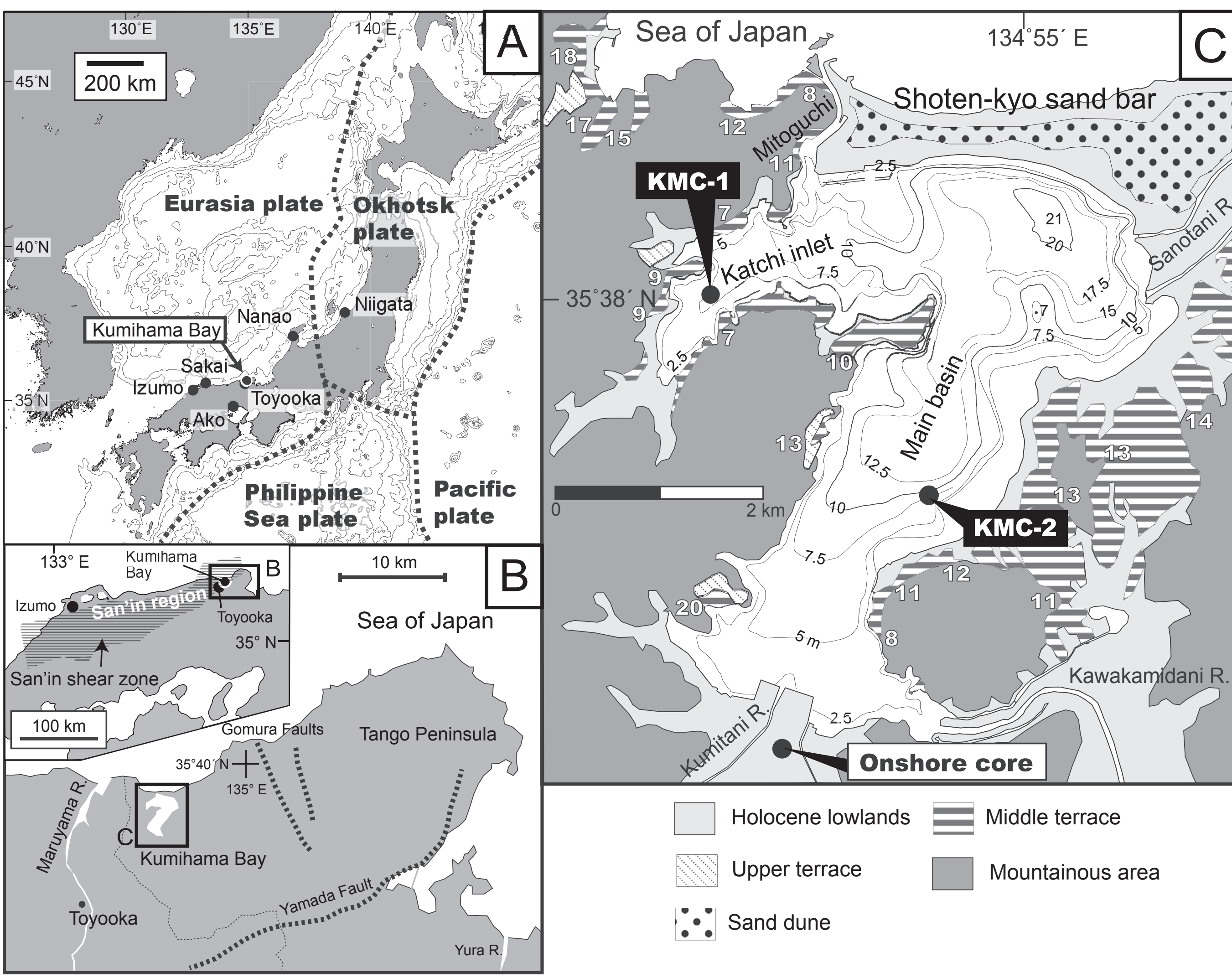

Fig. 1. Maps showing the location of Kumihama Bay (A and B) and the core sites (C). The San'in shear zone suggested by Nishimura and Takada (2017), Yamada and Gomura faults, Izumo and Toyooka cities, and the location of the inland core taken in the south of Kumihama Bay are also represented. Dotted lines in map A indicate plate boundaries. The topographic elements surrounding the Bay and outlined numbers showing the present elevation of the middle terrace were modified after Uemura (1994).

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