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Recognizing cryptic environmental changes by using paleoecology and taphonomy of Pleistocene bivalve assemblages in the Oga Peninsula, northern Japan

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ABSTRACT

Multivariate analyses applied to Pleistocene bivalve assemblages from the Oga Peninsula (northern Japan) discriminate three distinct assemblages. The assemblages and their taphonomy were used to recognize environmental settings and changes. The *Astarte–Cyclocardia–Glycymeris* assemblage indicates shelf environment (below the storm wave base) where gravels and shells are transported from shallower settings. Supply of the exotic coarse sediment probably enabled epifaunal bivalves to inhabit the sea floor. The *Glycymeris* assemblage is characterized by dominance of *G. yessoensis* and represents current-swept shoreface environment (above the storm wave base). The *Moerella* assemblage is characterized by bivalves inhabiting bay to open-marine conditions and diverse deposit-feeders, indicating a moderately land-locked environment, such as an open bay or a bay mouth. Fine-grained substrata rich in organic matters in the bay were probably suitable for the deposit-feeders. Ordination also shows the assemblages along two environmental gradients, a bathymetrical one and the other related to open-marine and bay conditions. The environmental changes are explained mainly by glacio-eustatic sea-level changes and alternation of coastal geomorphology caused by local crustal movements. This study also suggests that fossil assemblages can be a powerful tool to reconstruct environments and depositional dynamics even in intensely bioturbated sedimentary facies.

Introduction

Paleoecology and taphonomy have been frequently used for reconstructing environmental and sedimentological conditions. Since the appearance of sequence stratigraphy, analyses in fossil assemblages have been high-resolution (systems tract and finer scales), and recurrences of shell beds and fossil assemblages have been explained mainly by sea-level fluctuations and related changes in environment and sedimentation (Kidwell, 1991; Brett, 1995, 1998; Kondo et al., 1998). Recently, many studies have demonstrated that multivariate analyses can empirically recognize interpretable fossil assemblages and extract environmental gradients in Europe (e.g., Dominici, 2001; Scarponi and Kowalewski, 2004; Zuschin et al., 2007), America (e.g., Holland et al., 2001; Daley, 2002; Leonard-Pingel et al., 2012) and New Zealand (e.g., Abbott and Carter, 1997; Hendy and Kamp, 2004, 2007). In addition, recent taphonomic studies on modern marine environments have suggested that taphonomic features (e.g., abrasion, encrustation, fragmentation of shells) as well as fossil assemblages can be used to characterize ancient environmental settings and changes (e.g., Tomašových and Zuschin, 2009; Powell et al., 2011; Brett et al., 2013).

For Quaternary fossil assemblages in particular, knowledge of the environmental distributions of extant relatives can be used to reconstruct environment (e.g., absolute water depth and salinity) through taxonomic uniformitarianism (e.g., Scarponi and Kowalewski, 2004; Dominici et al., 2008; Carboni et al., 2010). In addition, environmental changes inferred from fossil assemblages refine sedimentary dynamics and sequence stratigraphy (e.g., Abbott, 1997; Abbott and Carter, 1997). Furthermore, environmental conditions also provide important information for paleobiology and paleoecology (e.g., evolution and biotic interaction) since changes in shell morphology and predator–prey interaction (e.g., location of predatory drillhole on prey skeleton) may be induced by environmental changes (e.g., Daley, 2002; Daley et al., 2007). However, environmental reconstructions on the basis of macrofossil assemblages and their taphonomy are relatively rare in Japan partly because of scarcity of a continuous outcrop and limited variation in the macrofossil assemblages.

The Oga Peninsula is a type locality for Quaternary sediments of Japan Sea side of northern Japan (Kano et al., 2011). In particular, the Oga Peninsula bears continuous shallow-marine successions that have been uplifted above present sea-level as a result of crustal movements (Shirai and Tada, 2002). In addition, the successions are rich in well-preserved

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mollusk fossils (Ogasawara et al., 1986), making these successions suitable for the study of mollusk assemblages and environmental reconstructions. Many studies have described the mollusk fossils for each formation (e.g., Takayasu, 1962; Huzioka et al., 1970; Watanabe, 2004). However, no high-resolution quantitative study of the mollusk fossils has been performed, despite the potential importance of the mollusk fossils as an archive for environmental changes. Although, Shuto et al. (1977) have reported mollusk fossil assemblages from the Anden Coast (1 in Fig. 1C), they have not reconstructed environments using the mollusk assemblages. In addition, relationships between the mollusk assemblages and sedimentary facies remain unexplored. This is because of the scarcity of knowledge of recent mollusks (e.g., geographic and bathymetric distributions) and lack of sequence stratigraphic framework. After the Shuto et al.'s (1977) pioneer work, knowledge of recent mollusks has been accumulated and updated around the Japanese Islands (Okutani, 2000; Japanese Association of Benthology, 2012), and sequence stratigraphy has been established (Shirai and Tada, 1997, 2000). It is, therefore, timely to re-analyze the mollusk fossil assemblages.

Here, we quantitatively examined the Pleistocene mollusk fossil assemblages in the Oga Peninsula. We hypothesize that the mollusk assemblages indicate fluctuations in water depth, as sedimentary facies of the shallow-marine succession reflect glacio-eustatic sea-level changes (Shirai and Tada, 1997, 2000). In addition, available literature on sedimentary successions from tectonically active regions shows that basin tectonics as well as glacio-eustatic sea-level changes affect water depth and sedimentation (e.g., Ito et al., 1999; Zecchin, 2005). Because the Oga Peninsula is characterized by active crustal movements during the Quaternary period (Shirai and Tada, 2002), we expect the crustal movements cause environmental changes. If so, the environmental changes caused by crustal movements can be recognized by looking at composition of the mollusk assemblages, as they can be sensitive to the environmental changes (e.g., Dominici, 2001). The aims of this study are (1) to describe bivalve assemblages using multivariate techniques, (2) to reconstruct environments, (3) to explore relationship between the bivalve assemblages and sedimentary facies and (4) to refine interpretation of depositional dynamics in the Oga Peninsula.

Geology and stratigraphy

Cenozoic sedimentary and volcanic rocks are well exposed in the Oga Peninsula, Akita Prefecture, northern Japan (Kano et al., 2011). The late Cenozoic strata in the Oga Peninsula dip eastward and become younger to the east, from Miocene to Holocene (Fig. 1C). The Quaternary sediments are divided into the Kitaura, Wakimoto, Shibikawa, Katanishi, Iriai, Hakoi and Hashimoto formations, in ascending order (Kano et al., 2011). The depositional environments of these formations change from continental slope (the Kitaura Formation) through shelf and nearshore (the Wakimoto, Shibikawa and Katanishi formations) to non-marine (the Iriai, Hakoi and Hashimoto formations) (Kitazato, 1975; Shirai and Tada, 2000; Shiraishi, 2000).

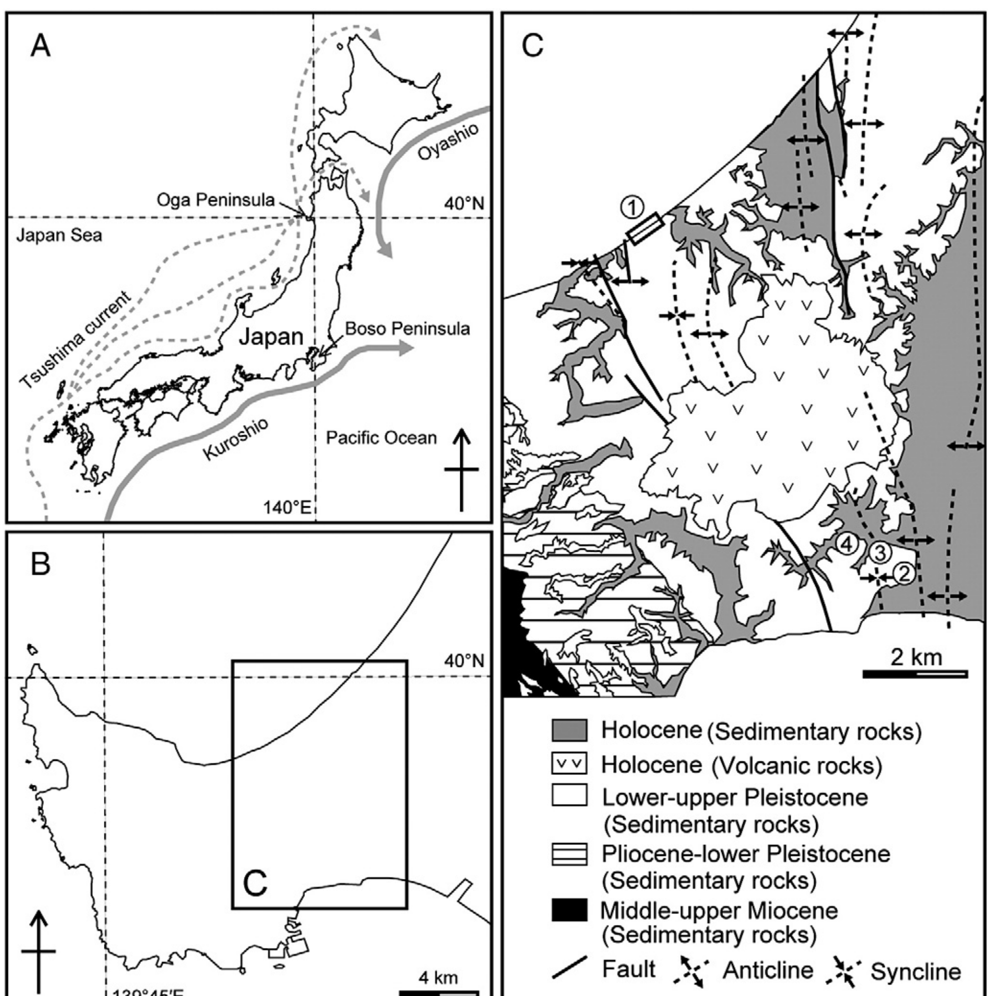

Figure 1. A–B. Map showing location of the Oga Peninsula, Akita Prefecture, northern Japan. Generalized recent current systems around the Japanese Islands are shown (after Kitamura et al., 2000). C. Geologic map of eastern part of the Oga Peninsula. Locations of outcrops (1: Anden Coast, 2: Wakimoto-1, 3: Wakimoto-2, 4: Tayasawa) are shown. The base map from Kano et al. (2011).