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Sea-level changes and water structures between 3.5 and 2.8 Ma in the central part of the Japan Sea Borderland: Analyses of fossil Ostracoda from the Pliocene Kuwae Formation, central Japan

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Abstract

Middle Pliocene ostracode assemblages were examined in the lower to middle parts of the Kuwae Formation, central Japan (ca. 3.5–2.8 Ma). This formation accumulated in the Japan Sea, which is an enclosed marginal sea between the Eurasian continent and the islands of Japan, and is now connected to the open sea through its northern and southern straits. Q-mode factor analysis shows that paleobathymetric changes occurred in orbital obliquity cycles of about 41 kyr. At least seven cycles of sea-level changes were found in the lower to uppermost parts of the study section. From ca. 3.2 to 3.0–3.1 Ma, there was no inflow of temperate intermediate waters due to cooling in Japan, even in the periods of high interglacial sea levels. Cyclic changes in the dominance of shallow-water ostracodes and deep cool-water ostracodes living at a bottom-water temperature of 2–5 °C are apparent in this interval. From ca. 3.0–3.1 to 2.8 Ma, temperate intermediate waters entered the Japan Sea during each interglacial period. The Tsushima Warm Current, less than 60 m thick, certainly flowed into the Japan Sea from the southern strait to a small extent during at least 2.88–2.95 Ma, which is possibly equivalent to marine oxygen-isotope stage G15, reflecting high global sea levels. *Krithe antisawanensis*, which lives abundantly in muddy bottoms at water temperatures of about 6–20 °C, flourished. In these interglacial periods, the water temperatures in the lower sublittoral to upper bathyal zones of the Japan Sea were higher and the thermal gradients there were gentler than they are today, suggesting no development of the homogeneous cold water mass like the Japan Sea Intermediate–Proper Water in these periods. Stable deep-water ostracode species were strongly influenced by the inflows of the temperate intermediate waters.

Keywords: middle Pliocene; Ostracoda; Q-mode factor analysis; Tsushima Warm Current; Japan Sea

1. Introduction

The middle Pliocene (ca. 3.5–3.0 Ma) was warmer (mid-Pliocene climatic optimum) than it is today and the Arctic ice sheets were probably reduced (e.g., Cronin et al., 1993; Dowsett et al., 1994, 1996; Barron, 1995; Raymo et al., 1996). A sea level 50 m higher than it is today was estimated by Haq et al. (1987). The reduced sea ice present during this time in the Northern Hemisphere allowed marine animals to migrate throughout the Arctic Ocean (Cronin et al., 1993). Warm-water

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molluscs living in warm–temperate waters have been reported even along the Pacific side of northern Japan (Masuda et al., 1990). The intensification of Northern Hemisphere Glaciation (NHG) has been recorded throughout the world between 3.1 and 2.5 Ma on the basis of various micropaleontological, sedimentological, and geochemical studies (e.g., Rea and Schrader, 1985; Raymo et al., 1992; Krissek, 1995; Shackleton et al., 1995; Maslin et al., 1998). The progressive increase in obliquity amplitude during those intervals as well as the formation of the Isthmus of Panama was a direct trigger for the formation of the Northern Hemisphere ice sheet, and extensive glacio-eustacy occurred in orbital cycles of 41 kyr (e.g., Haug and Tiedemann, 1998; Maslin et al., 1998). In the northwest Pacific, a dramatic increase in ice-rafting debris is observed at 2.75 Ma (Maslin et al., 1995).

There have been few studies of oxygen isotopes in foraminiferal tests in Eastern Asia. However, recently some studies have been conducted in the South China Sea (e.g., Jian et al., 2003; Huang et al., 2003). These studies have shown, on the basis of foraminiferal proxies and isotopes, that the intensification of the Asian winter monsoon began 3.2 Ma. Surface-water cooling events have also been identified at 2.73 or 2.74 Ma (Huang et al., 2003). Sato et al. (2004) showed a dramatic change in the relative abundance of calcareous nannofossils at 2.75 Ma (originally 2.74 Ma). This horizon is datum plane A of Sato and Kameo (1996). It is recognized widely in northeastern to central Japan as an increase in the relative abundance of the typical cold-water species *Coccolithus pelagicus* and is useful for correlations. Sato and Kameo (1996) suggested that this floral change was related to the onset of heavy glaciations around the marginal seas in the North Pacific Ocean. An age of 2.75 Ma is assigned to marine oxygen-isotope stage (MIS) G6 of Shackleton et al. (1995).

The Japan Sea is an enclosed marginal sea between the Eurasian continent and the islands of Japan (Fig. 1). It is now connected to the East China Sea through the Tsushima Strait at a water depth of ca. 130–140 m at its southern margin, to the Pacific Sea through the Tsugaru Strait at a water depth of ca. 130–140 m, and to the Okhotsk Sea through the Soya Strait at a water depth of

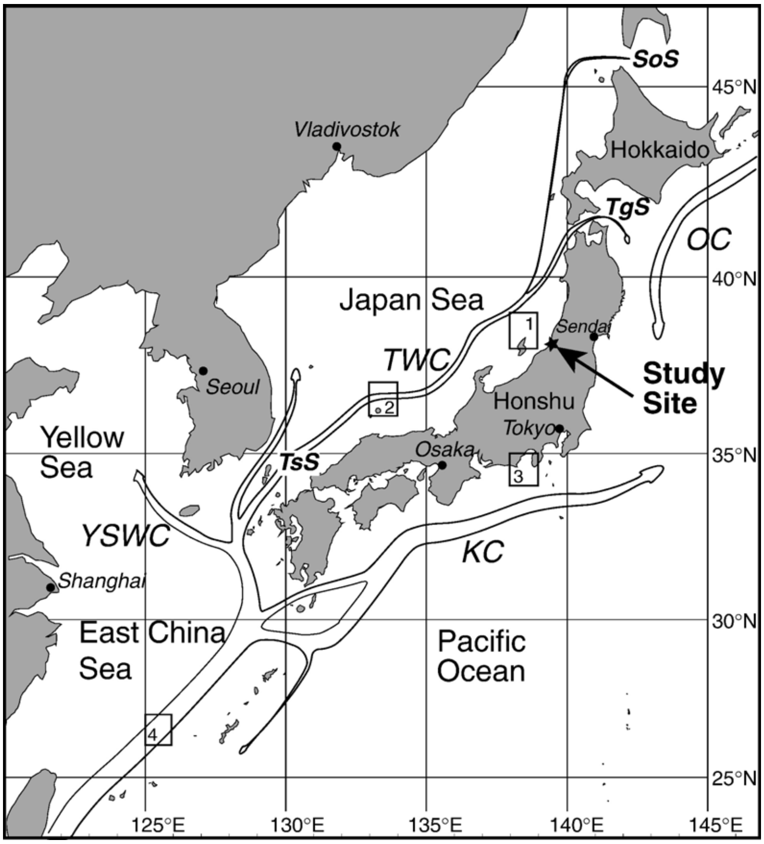

Fig. 1. Index map of the study site. OC: cold Oyashio Current, KC: warm Kuroshio Current, TWC: Tsushima Warm Current, YSWC: Yellow Sea Warm Current, SoS: Soya Strait, TgS: Tsugaru Strait, TsS: Tsushima Strait. See Fig. 10 for rectangle areas with numerals (1–4).