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Surface water hydrography of the Kuroshio Extension during the Pliocene–Pleistocene climate transition

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ABSTRACT

The Pliocene–Pleistocene climate transition offers an opportunity to study the effect of glaciation on the ocean–climate system. We present a *Globigerinoides ruber* $\delta^{18}O$ record from Ocean Drilling Program Site 1208 (Kuroshio Current Extension; KCE). This exclusively (sub)tropical foraminifer, a summer/fall mixed-layer dweller at the KCE, affords the first long (3.0 Ma to 1.8 Ma) orbital-scale (2.5-kyr time step) account of the sea surface in this area. The section's temperature-corrected benthic foraminiferal $\delta^{18}O$ record constrains global changes in ice volume, yielding a $\Delta\delta^{18}O$ record that primarily reflects summer/fall KCE hydrography (temperature and salinity). A 0.3‰ decrease in $\Delta\delta^{18}O$ values at 2.7 Ma coincides with the onset of Northern Hemisphere glaciation, indicating as much as 1.5 °C warming during the summer/fall to suggest that the subtropical North Pacific sea surface provided heat and moisture for expanding ice sheets. On the orbital scale, the 41-kyr cycle that dominates high-latitude climate is absent from the $\Delta\delta^{18}O$ record, indicating a stable surface water hydrographic regime on this time scale. Rather, the $\Delta\delta^{18}O$ record varies at and is coherent with the 19-kyr precessional component of the regional insolation curve, supporting a direct response to subtropical insolation and insensitivity to extra-regional forcing factors, such as ice sheets.

1. Introduction

The early Pleistocene offers an attractive laboratory for understanding natural variability of the ocean–atmosphere system in two important ways. First, it was colder than the preceding Late Pliocene, this later interval's climate characterized by the 2.7-Ma advent of widespread Northern Hemisphere glaciation (NHG; Jansen and Sjøholm, 1991; Haug et al., 1995; Balco et al., 2005; Harris, 2005; Lisiecki and Raymo, 2005). Second, development of an east–west sea surface temperature (SST) gradient in the early Pleistocene (~2 Ma), which characterizes the modern equatorial Pacific, marks the end of perennial El Niño-like conditions (Cannariato and Ravelo, 1997; Chaisson and Ravelo, 2000; Wara et al., 2005; Lawrence et al., 2006; Ravelo et al., 2006, 2007; Etourneau et al., 2010).

The Kuroshio Current system, the western boundary current of the North Pacific subtropical gyre, is an integral part of the North Pacific climate system. This warm-water jet efficiently transports heat from the western Pacific warm pool to the cool mid-latitude atmosphere. Changes in meridional heat transport potentially explain obliquity's dominant pacing of ice volume during this time (Philander and Fedorov, 2003; Raymo and Nisancioglu, 2003), perhaps providing moisture for the formation of the Northern Hemisphere (NH) ice sheets (e.g., Haug et al., 2005). Furthermore, changes in heat transport in the Kuroshio Current system may have been closely related to the cooling in the eastern equatorial Pacific and the end of persistent El Niño-like conditions during the early Pleistocene (Philander and Fedorov, 2003).

Here, we explore the applicability of a planktic foraminiferal $\delta^{18}O$ record from Ocean Drilling Program (ODP) Site 1208, located at the Kuroshio Current Extension (KCE; Fig. 1), to reconstruct surface-water hydrography spanning the Plio/Pleistocene climate transition. The planktic foraminifer, *Globigerinoides* (*Gs.*) *ruber*, represents the first long surficial record (3.00–1.76 Ma) from the region to span the Pliocene–Pleistocene boundary at the orbital timescale (2.5-kyr time step). We use the section's benthic foraminiferal $\delta^{18}O$ record, smoothed to minimize deep-water temperature changes (after Sosdian and Rosenthal, 2009), as a measure of global ice-volume changes. By subtracting it from the *Gs. ruber* $\delta^{18}O$ record we obtain a $\Delta\delta^{18}O$ record that primarily reflects surface-water hydrography (temperature and salinity).

We argue that the residual $\Delta\delta^{18}O$ record is primarily a surface water temperature signal. This is because the evaporation/precipitation balance, which affects surface water $\delta^{18}O$ values, remains relatively constant throughout the year in the modern ocean (e.g., salinity varies only between 34.4 and 34.5, Fig. 2b). Spatially, too, regional surface-water $\delta^{18}O$ values are relatively constant across a broad area of the northwestern Pacific (Schmidt, 1999; Bigg and Rohling, 2000). Thus,

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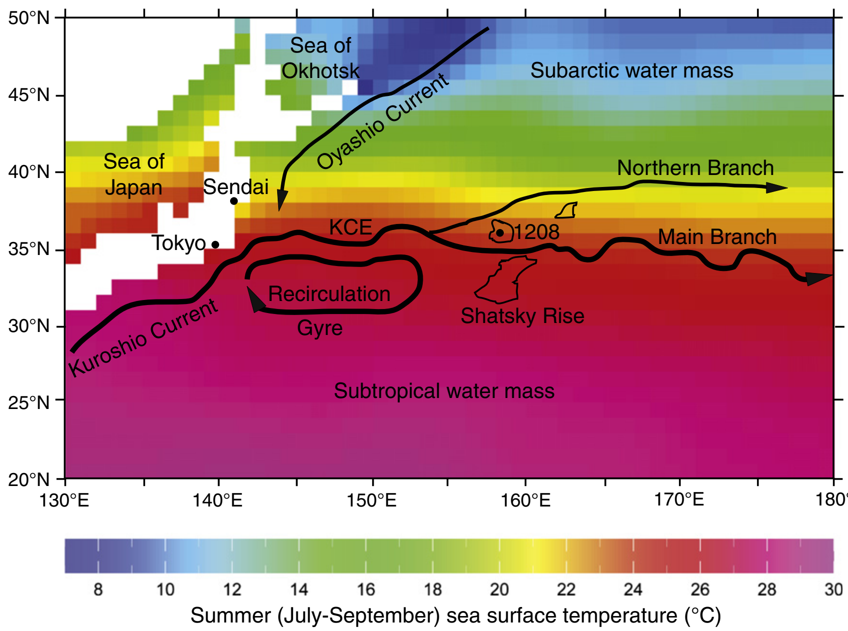

Fig. 1. ODP Site 1208 on Shatsky Rise (Shipboard Scientific Party, 2002). Surface currents are sketched after Mizuno and White (1983), Sainz-Trapaga et al. (2001), Qiu (2002), and Yasuda (2003). The base map shows summer (July–September) sea surface temperatures averaged in a 1°×1° grid (Locarnini et al., 2010) generated with the web application at http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NODC/.WOA09/.

we do not anticipate large changes in the hydrographic regime to have introduced large changes in surface water $\delta^{18}O$ values.

Specifically, we propose that these temperature changes approximate conditions during the summer/fall season. Plankton tows indicate that *Gs. ruber* is restricted to waters warmer than 15 °C and prefers temperatures of >20 °C (Bradshaw, 1959), i.e., the mixed layer in the northwest Pacific (Kuroyanagi and Kawahata, 2004; Fig. 2a). Regional sediment-trap studies confirm that this species inhabits the KCE predominantly during summer and fall (Eguchi et al., 2003; Mohiuddin et al., 2004). Thus, the *Gs. ruber* $\Delta\delta^{18}O$ record resolves the response of summer/fall mixed-layer hydrography to the growth of NHG during the Plio/Pleistocene climate transition.

2. Regional setting

The warm Kuroshio Current system transports a large volume of water (as much as 45 Sverdrup; Sv), with an additional 90 Sv in the associated recirculation gyre (Wijffels et al., 1998), forming the northwestern boundary of the North Pacific anticyclonic subtropical gyre (Reid, 1997; Fig. 1). The northeastward-flowing Kuroshio Current converges with the southwestward-flowing subarctic Oyashio Current in the offshore region east of Japan, northeast of Tokyo (35.7°N) and southeast of Sendai (38.1°N; Yasuda, 2003). The high kinetic energy of mesoscale eddies in this region introduces meanders into the Kuroshio (Wyrtki et al., 1976) as it continues east between 33°N and 37°N as the

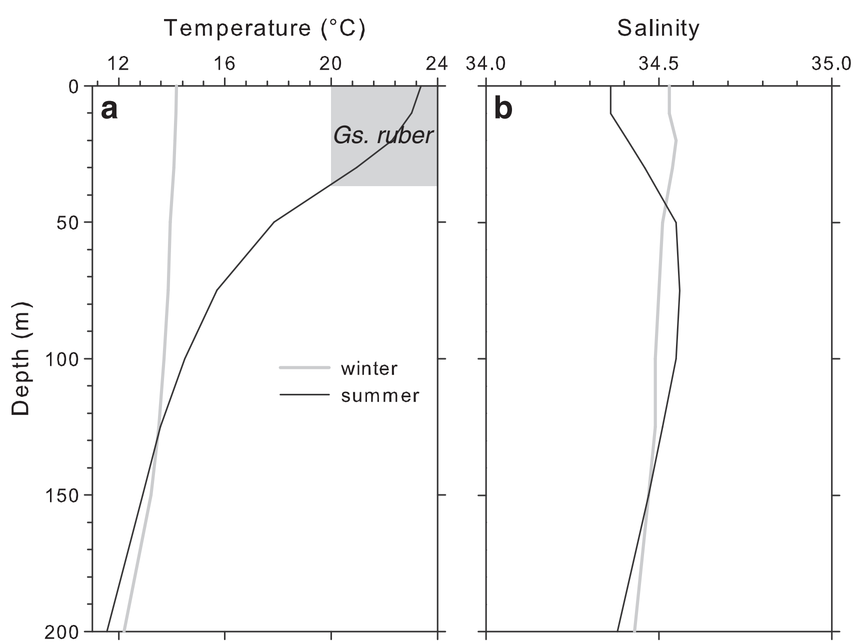

Fig. 2. Temperature (a) (Levitus and Boyer, 1994) and salinity (b) (Levitus et al., 1994) versus depth at Site 1208 during winter (January, February, and March) and summer (July, August, and September). The shaded area in panel (a) indicates *Globigerinoides ruber*'s preferred habitat.