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# Paleoceanographic history of the Northwest Pacific Ocean over the past 740 kyr, discerned from radiolarian fauna

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ABSTRACT

The Northwest Pacific Ocean is characterized by a strong mixing of water masses, due to the interplay of three distinct currents, i.e., the Kuroshio, the Tsugaru, and the Oyashio. The C9001C drill core site, located east of the Shimokita Peninsula and directly influenced by the Tsugaru warm current and the Oyashio subarctic current was used here to reconstruct the paleoceanographical history of this region, especially focusing on the Mid-Brunhes Event (MBE) and its consequences. This core provides a continuous record from marine isotope stage (MIS) 18 (740 ka) to the present. Polycystine radiolarian assemblages were analyzed to highlight paleoceanographic and sea surface temperature changes at this site. Based on the radiolarian fauna, seven time periods are defined, which coincide with changes in the dynamics of the Tsugaru and Oyashio currents, respectively. The oldest time interval covered by our analysis (i.e., VII: 740–621 ka) was marked by generally sluggish ocean circulation. The Tsugaru Current influence increased during the following Interval VI (621–478 ka) which encompasses interglacials MIS 15 and 13, while the Oyashio Current strengthened during the Interval V (478–337), i.e. from glacials MIS 12 to 10. These latter intervals (VI to V) constitute a long climatic transitional period where Tsugaru Current and Oyashio Current influences are strengthened. In the time period from Interval IV to Interval I (0–337 ka), the warming intensity of interglacials (MIS 9, MIS 5) appears to be close to the modern one. However, several unusually warm glacials, associated with a relatively strong Tsugaru Current flow, were identified during this interval (e.g., MIS 8 and MIS 6). Radiolarian productivity data suggest that during Intervals VII to V, deep water masses are rich in nutrient content. However, a high vertical mixing event is recorded after Interval IV, when high nutrient concentrations appear to shift to the surface layer.



## 1. Introduction

Glacial/interglacial climate oscillations have driven major paleoceanographical changes during the Quaternary, with especially the last 800 kyr being characterized by strong warmings in the tropical and monsoonal regions and severe coolings at high latitudes (Ruddiman, 2003, 2006). This intra-hemispheric climatic contrast was enhanced after the Mid-Brunhes events (MBE) which constitute a transitional interval between periods dominated by relatively cold vs. extremely warm interglacials. The MBE is generally considered to have taken place between MIS 13 and MIS 11 (374–533 ka) (EPICA, 2004). Recently, Yin and Berger (2011) and Yin (2013) claimed that a very high concentration of greenhouse gases caused the MIS 11 warming; however, the reasons why the greenhouse gas concentration increased remain unknown. Recent works have also contributed to a more complex picture of the effect of this period on Earth climate. In fact, several mid-latitude regions seem to have not been affected by the MBE, as the tropical west Pacific for instance (Meckler et al., 2012). In the North Atlantic, only high latitude domains (>56°N) were affected by higher intensity interglacials as specific to the MBE (Candy and McClymont, 2013). On the other hand, depending on the location, the intensification of interglacials occurred earlier. The East China Sea region presents intensification of interglacials since MIS 15 or 13, while in other regions this event occurred late in MIS 11 (Lang and Wolff, 2011).

The Shimokita region represents a key location for understanding the evolution of the Northwest Pacific Ocean, as it is located at the convergence of two modern major surface currents: the warm Tsugaru Current (wTgC) and the cold Oyashio Current (cOC, Fig. 1). This

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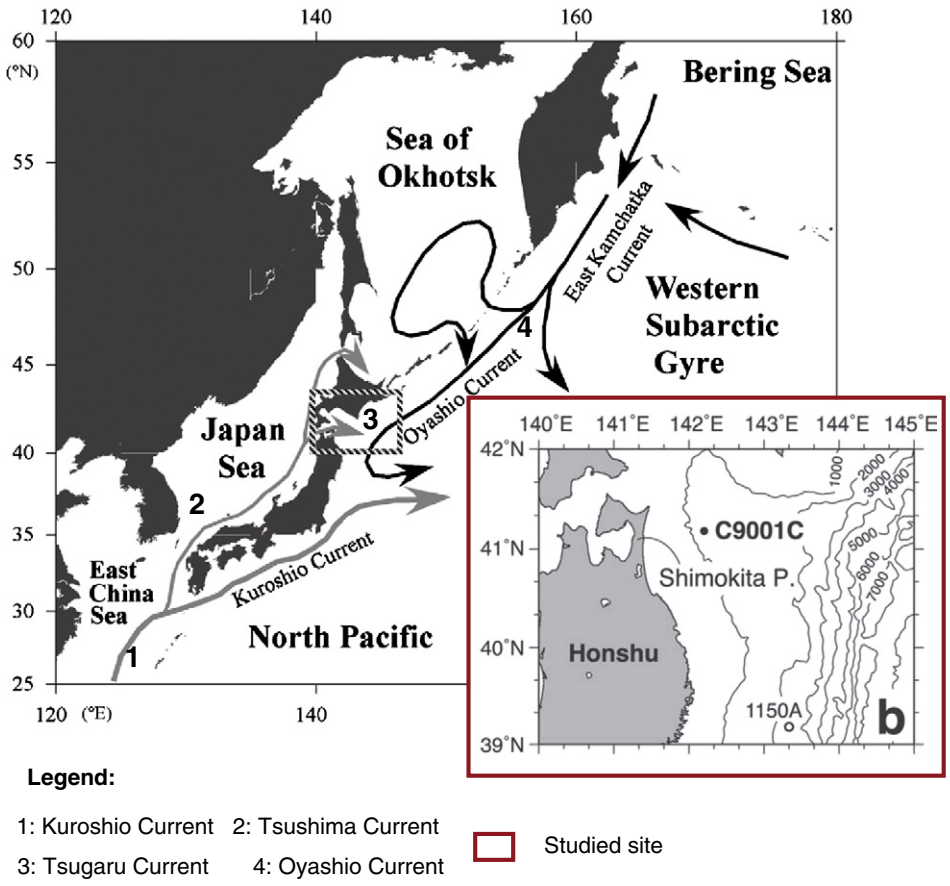


**Fig. 1.** Location of Hole C9001C in the northwestern Pacific Ocean and the main currents in the Shimokita region: the Tsugaru warm current, the Oyashio Current and the Kuroshio Current.

oceanographic setting at present generates a complex hydrographic pattern with a high mixing of water masses and high intra- and inter-annual variability, causing the occurrence of upwelling phenomena and ensuing transient primary productivity events (Kawai, 1972; Talley, 1991; Yasuda, 1997; Koizumi and Yamamoto, 2005). Past studies (Morley and Heusser, 1997; Koizumi et al., 2004, 2006; Kuroyanagi et al., 2006) have shown that the relative influence of these currents changed in response to the late Quaternary climatic shifts. In this context, drastic changes in response to the MBE can be expected.

Several paleoceanographic studies based on microfossil assemblages from the Northwest Pacific have been accomplished under the CLIMAP project for the Late Pleistocene (Koizumi et al., 2004, 2006; Kuroyanagi et al., 2006). Those studies illustrate the responses of diatom and planktic foraminifera populations to the Last Glacial Maximum sea level changes, and to Milankovitch cycles. However, few studies encompassed the period older than 300 kyr (Heusser and Morley, 1997; Morley and Heusser, 1997; Bordiga et al., 2013), with the latter two studies documenting the sea surface temperature (SST) evolution for the last 350 kyr in relation to East Asian Monsoon intensity changes.

The here studied core C9001C, drilled off the Shimokita Peninsula, displays high sedimentation rates (20–90 cm/kyr) and covers the last 740 kyr (Domitsu et al., 2011). Based on the onshore report focusing on diatoms, this core presents high diatom productivity levels in the upper part while the lower parts is richer in terrigenous sediments (Aoike et al., 2010). In this study, we have analyzed another siliceous proxy: polycystine radiolarians. The latter are widely distributed from surface to deep oceanic waters (Lombari and Boden, 1985; Boltovskoy et al., 2010). They produce siliceous skeletons and are therefore used as proxy of oceanographic conditions. The objective of the present study was to document the evolution of polycystine radiolarian assemblages off Japan over a long (last 740 kyr) and high-resolution paleoceanographic record from the North Pacific margin. These data were used to reconstruct past radiolarian-based SST (rSST), using Q-mode Factor Analysis (Imbrie and Kipp, 1971). Our study thus represents the first existing long term and quantified oceanographic reconstruction for the last 740 kyr in the Japanese Pacific margin, and allowed us to discuss the coupled history of climate and hydrography along this time interval, with a particular focus on the MBE.

## 2. Oceanic setting

The studied core was obtained from Hole C9001C (41°10′38.28″ N, 142°12′04.86″ E) and retrieved from a depth of 1180 m during the D/V CHIKYU shakedown cruises of CK05-04 Leg 2 and CK06-06. The site is located close to the margin of the Shimokita Peninsula in front of the Tsugaru Strait (Fig. 1). The Northwestern Pacific region hosts one of the main components of oceanic circulation for the Pacific: the Western Subarctic Gyre (WSG). The WSG is a large counter-clockwise gyre that circulates water through the western Bering Sea, the Sea of Okhotsk, and the subarctic western Pacific including the East Kamchatka Current (EKC) and the cOC (Talley, 1991). The EKC is a subarctic current marked by low temperature, low salinity, and high-density water. This current originates in the Bering Sea and flows southwestward past the Kuril Islands. The cOC is characterized by low temperatures and salinities and it is formed by the mixing of waters from the EKC and the Sea of Okhotsk gyre (Talley, 1991).

The Tsugaru Strait is dominated by the outflow of the wTgC, a branch of the Tsushima Warm Current that flows into the Japan Sea through the Tsushima Strait. Waters carried by the wTgC are of relatively high temperatures (>15 °C) and high salinities (33.7–34.2) (Hanawa and Mitsudera, 1986). The wTgC transports waters to the subarctic Pacific and plays an important role in the WSG circulation (Talley et al.,