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Diatom distributions in northern North Pacific surface sediments and their relationship to modern environmental variables

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ABSTRACT

In order to map the modern distribution of diatoms and to establish a reliable reference data set for paleoenvironmental reconstruction in the northern North Pacific, a new data set including the relative abundance of diatom species preserved in a total of 422 surface sediments was generated, which covers a broad range of environmental variables characteristic of the subarctic North Pacific, the Sea of Okhotsk and the Bering Sea between 30° and 70°N. The biogeographic distribution patterns as well as the preferences in sea surface temperature of 38 diatom species and species groups are documented. A Q-mode factor analysis yields a three-factor model representing assemblages associated with the Arctic, Subarctic and Subtropical water mass, indicating a close relationship between the diatom composition and the sea surface temperatures. The relative abundance pattern of 38 diatom species and species groups was statistically compared with nine environmental variables, i.e. the summer sea surface temperature and salinity, annual surface nutrient concentration (nitrate, phosphate, silicate), summer and winter mixed layer depth and summer and winter sea ice concentrations. Canonical Correspondence Analysis (CCA) and other analyses indicate 32 species and species groups have strong correspondence with the pattern of summer sea surface temperature. In addition, the total diatom flux data compiled from ten sediment traps reveal that the seasonal signals preserved in the surface sediments are mostly from spring through autumn. This close relationship between diatom composition and the summer sea surface temperature will be useful in deriving a transfer function in the subarctic North Pacific for the quantitative paleoceanographic and paleoenvironmental studies.

The relative abundance of the seaice indicator diatoms *Fragilariopsis cylindrus* and *F. oceanica* of >20% in the diatom composition is used to represent the winter sea ice edge in the Bering Sea. The northern boundary of the distribution of *F. doliolus* in the open ocean is suggested to be an indicator of the Subarctic Front, while the abundance of *Chaetoceros* resting spores may indicate iron input from nearby continents and shelves and induced productivity events in the study area.

1. Introduction

Reliable data sets of diatom species composition in ocean surface sediments are widely used for paleoceanographic reconstruction in the Southern Ocean (e.g. Zielinski and Gersonde, 1997; Crosta et al., 1998; Zielinski et al., 1998; Esper and Gersonde, 2014) and in the North Atlantic Ocean (e.g. Koç Karpuz and Schrader, 1990). In contrast, only a few investigations were published in the North Pacific decades ago (Kanaya and Koizumi, 1966; Jousé et al., 1971; Sancetta, 1979, 1981, 1982). Recent studies are either based on sparse samples (e.g. Kazarina and Yushina, 1999) or focus on minor regions (e.g. Shiga and Koizumi, 2000 and Tsoy et al., 2009 on the Sea of Okhotsk; Lopes et al., 2006 on coastal North America). The pioneer statistical analysis based on diatom species from surface samples of the entire North Pacific was done by Sancetta (1979). However, only few samples from the Bering Sea, especially from the Bering Shelf, which is covered by sea ice seasonally, were included in her study. Later work expanded the data set in the marginal seas (Sancetta, 1981) and the subarctic Pacific (Sancetta and Silvestri, 1986).

As one of the High Nutrient Low Chlorophyll (HNLC) regions, the North Pacific plays a role in controlling the glacial–interglacial atmospheric CO_2 concentration variability by plankton productivity shifts, which are limited by iron availability, and by ocean stratification, which may reduce CO_2 leak from deep ocean to atmosphere (Sigman et al., 2004; Haug et al., 2005; Jaccard et al., 2005). Furthermore, the atmospheric vapor and water flow from the North Pacific through the

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Bering Strait to the Arctic and hence the North Atlantic may stabilize the global climate variability by the salinity and heat balance (Keigwin and Cook, 2007). Thus, in order to understand the North Pacific's role in shaping global climatic and oceanographic changes, the history of paleo-sea-surface-temperature and winter sea ice distribution is of vital importance (e.g. Gebhardt et al., 2008; Max et al., 2012). Therefore, a high quality and comprehensive diatom based data set is needed for paleoceanographic reconstruction, due to the restricted occurrence of calcareous fossils and hence reconstructions based on corresponding geochemical proxies in this area.

In this paper, we present the diatom distribution in northern North Pacific sediments, including the Sea of Okhotsk and the Bering Sea. In total 422 surface samples, including 263 samples from Sancetta and Silvestri (1986) are studied here, covering the Subarctic Front system (Fig. 1a). Statistical analysis, such as Q-mode analysis and Canonical Correspondence Analysis, is applied to the diatom data set, in order to reveal the relationships between the diatom distribution and the environmental variables (e.g. sea surface temperatures, sea ice concentration, salinities, nutrients, mixed layer depths) and to detect the primary factors which determine the diatom species and their abundance distributions in the North Pacific.

2. Regional setting

2.1. North Pacific open ocean

The northern North Pacific open ocean can be subdivided by the Subarctic Front into the Subarctic Gyre (Dodimead et al., 1963) and

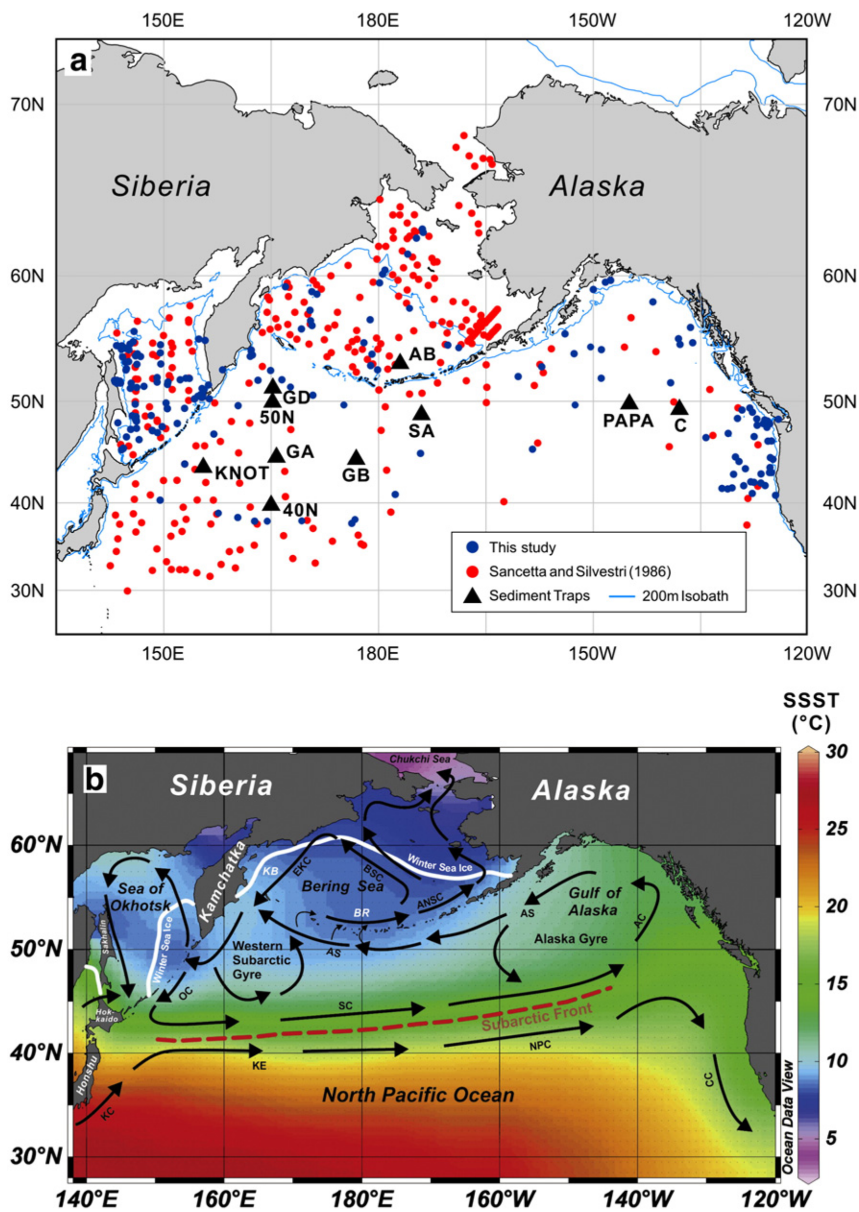

Fig. 1. a) Distribution map of 422 surface samples in the North Pacific Ocean (blue and red circles). Black triangles indicate the sediment traps mentioned in the Discussion. b) Current system in the North Pacific Ocean (black arrows). The winter sea ice edge (March of 1982–1991; Reynolds et al., 2002) and the Subarctic Front (Aydin et al., 2004) are indicated by the solid white and dashed red lines, respectively. The summer sea surface temperature from WOA94 is indicated as a background (Levitus and Boyer, 1994). Currents system: AC: Alaska Current; ANSC: Aleutian North Slope Current; AS: Alaska Stream; BSC: Bering Slope Current; CC: California Current; EKC: East Kamchatka Current; KC: Kuroshio Current; KE: Kuroshio Extension; NPC: North Pacific Current; OC: Oyashio Current; SC: Subarctic Current. Topography: BR: Bowers Ridge; KB: Komandorsky Basin.