Deep-Sea Research II 125-126 (2016) 177–183

Contents lists available at ScienceDirect

Deep-Sea Research II

journal homepage: www.elsevier.com/locate/dsr2

Surface ocean cooling in the subarctic North Pacific during the late Pliocene suggests an atmospheric reorganization prior to extensive Northern Hemisphere glaciation

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ARTICLE INFO

Available online 11 May 2015

Keywords:
TEX_{86}
U^K_{37}
ODP Site 882
The subarctic North Pacific
Pliocene
Pleistocene
Northern Hemisphere glaciation

ABSTRACT

This paper presents records of TEX^L_{86}- and U^K_{37}-derived sea-surface temperatures (SSTs) from Ocean Drilling Program Site 882 in the subarctic North Pacific over the last 5.8 million years. The TEX^L_{86}-derived SST record shows a cooling trend from 17 °C at 3.6 Ma to 8 °C at 2.3 Ma. This cooling preceded the onset of extensive Northern Hemisphere glaciation (NHG) at 2.7 Ma, coinciding with the intensification of the East Asian winter monsoon, surface cooling in the North Atlantic, and the gradual development of NHG. The results of this study suggest that the reorganization of atmospheric circulations in the northern high latitudes from 3.6 to 2.3 Ma was associated with the early-stage development of the ice sheets and sea ice in the arctic and subarctic regions, inducing the cooling of the North Atlantic and the subarctic North Pacific and the intensification of the East Asian winter monsoon.

1. Introduction

The subarctic North Pacific contains a closed subarctic gyre system that is characterized by counterclockwise surface water circulation (Fig. 1; Dodimead, 1963). The subarctic gyre system is divided into two sub-gyre systems: the Alaskan gyre and the western subarctic gyre (Dodimead, 1963). The spatial distribution of sea surface temperature (SST) in this region is governed by the intensities of the Aleutian Low and the Siberian High, which are linked to the Arctic Oscillation (Thompson and Wallace, 2001) and El Niño-Southern Oscillation (Wallace and Gutzler, 1981).

At present, a permanent halocline exists between depths of 100 and 200 m in the subarctic Pacific Ocean (Conkright et al., 2002). Records of biogenic opal and nitrogen isotopes from Ocean Drilling Program (ODP) Site 882 suggested that that this halocline was established at 2.7 Ma, coincident with the onset of extensive Northern Hemisphere glaciation (NHG: Haug et al., 1999; Sigman et al., 2004). Haug et al. (2005) showed that at 2.7 Ma the alkenone $U^K_{37'}$- and diatom $\delta^{18}O$-derived temperatures abruptly increased, and the foraminiferan $\delta^{18}O$-derived temperature decreased in ODP Site 882. They proposed that enhanced seasonality of SST in the subarctic Pacific Ocean triggered the initiation of NHG by providing water vapor to northern North America. Shimada et al. (2009) showed a drastic change in diatom assemblage in ODP Sites 883 and 887 in the subarctic North Pacific at 2.7 Ma, being attributed to severe cooling and/or a change in nutrient regime at the onset of NHG.

In this study, we present records of TEX^L_{86}-and and U^K_{37}-derived temperatures from ODP Site 882 in the subarctic North Pacific over the last 5.8 million years (Fig. 1). These data are compared with previously reported U^K_{37}-derived temperatures obtained by a different method. The new established record shows a similar pattern to records of the East Asian winter monsoon and North Atlantic SST. The timing of the SST change is discussed in the context of NHG. This is the first application of TEX_{86} paleotemperature estimation to the paleoceanography of the subarctic North Pacific.

2. Samples and methods

2.1. Study site and age-depth model

The study site, ODP Site 882, is located at 50°22′N, 167°36′E with a water depth of 3244 m on the western flank of the Detroit Seamount at the northern end of the Emperor Seamount Chain in the North Pacific Ocean (Rea et al., 1993; Fig. 1). This site is situated along the path of the East Kamchatka Current. The maximum SST near the core site (50.5°N, 167.5°E) is 10 °C in August and September, and the minimum is 2 °C in March (Fig. 2; Conkright et al., 2002).

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http://dx.doi.org/10.1016/j.dsr2.2015.03.005
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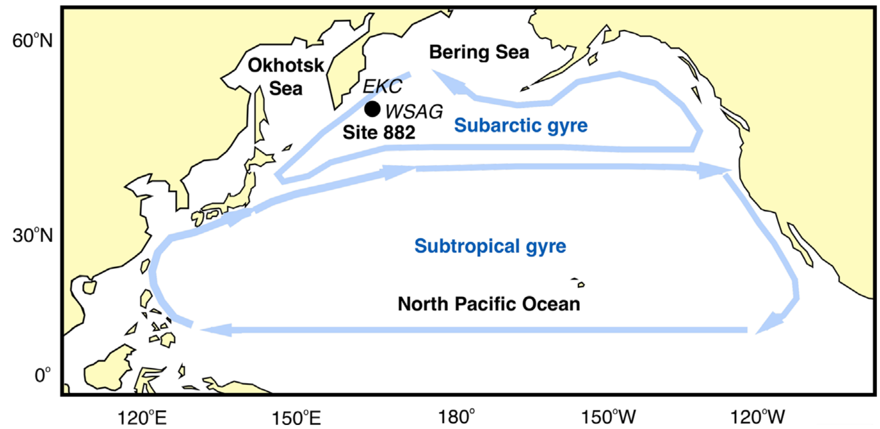

Fig. 1. Surface current systems in the North Pacific Ocean (simplified after Dodimead, 1963) and the location of ODP Site 882. WSAG=Western Subarctic Gyre, EKC=East Kamchatka Current.

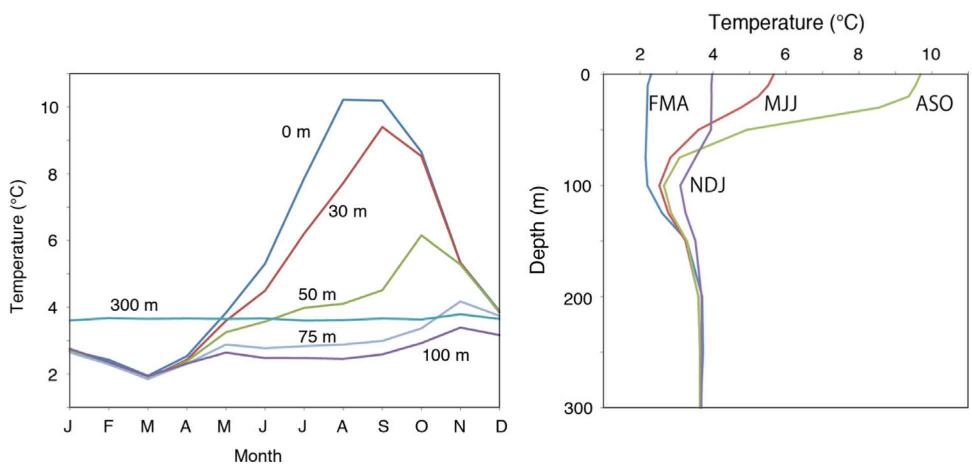

Fig. 2. Seasonal and monthly mean water temperatures at different depths at the study site (Data from Conkright et al., 2002). "J" to "D" indicate January to December. FMA=February to April, MJJ=May to July, ASO=August to October, NDJ=November to January.

The sediments of cores from Site 882 were divided into two lithological subunits. Quaternary sediments (0–105 mbsf) consisted of diatom ooze with ash, clay, and dropstones. Pliocene to late Miocene sediments consisted of diatom ooze with accessory nannofossils and sponge spicules (Rea et al., 1993). Compared to the Pliocene to late Miocene sediments, the Quaternary sediments were characterized by a higher influx of both volcanic ash and terrigenous material in the form of clay and dropstones.

The age-depth model of Site 882 was generated by magnetostratigraphy before 4 Ma and an astronomically calibrated stratigraphy for the last 4 Ma based on fine-tuning the gamma ray attenuation porosity evaluation (GRAPE) density oscillations in the precession band of the summer insolation at 65°N (Fig. 3; Tiedemann and Haug, 1995). The sedimentation rate decreased at 2.7 Ma, resulting from an abrupt decrease in opal accumulation rate (Haug et al., 1999). TEX_{86} was analyzed for a total of 97 samples (each 2 cm thick) from cores between 2 and 395 mbsf (0–5.9 Ma, average 61 ky interval).

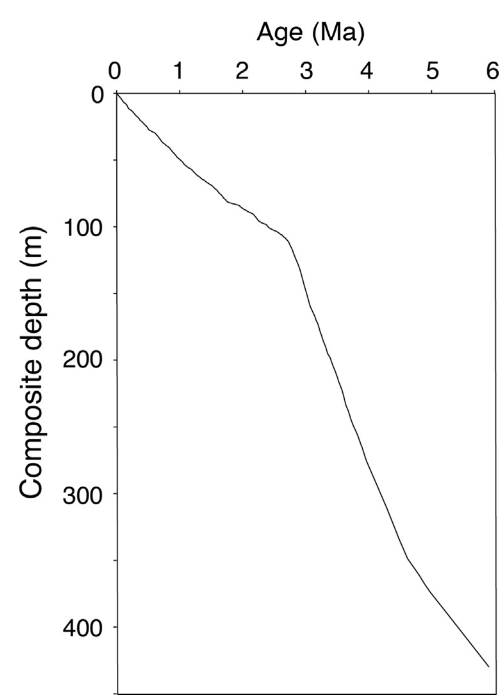

Fig. 3. Age-depth model of the ODP Site 882 (Tiedemann and Haug, 1995).

2.2. Analytical methods

Alkenones and glycerol dialkyl glycerol tetraethers (GDGTs) were analyzed following Yamamoto et al. (2000) and Yamamoto and Polyak (2009), respectively.

Lipids were extracted (3 ×) from a freeze-dried sample using a DIONEX Accelerated Solvent Extractor ASE-200 at 100 °C and