Deep-Sea Research II 125-126 (2016) 184–190

Contents lists available at ScienceDirect

Deep-Sea Research II

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

Late Quaternary changes of the oxygen conditions in the bottom and intermediate waters on the western Kamchatka continental slope, the Sea of Okhotsk

A. Matul [a,]*, A. Abelmann [b], T. Khusid [a], M. Chekhovskaya [a], A. Kaiser [c], D. Nürnberg [c], R. Tiedemann [b]

[a] P.P. Shirshov Institute of Oceanology, Nakhimovsky Prospect 36, 117997 Moscow, Russia
[b] Alfred Wegener Institute for Polar and Marine Research, Postfach 120161, 27515 Bremerhaven, Germany
[c] Leibniz-Institut für Meereswissenschaften, IFM-GEOMAR, Wischhofstr. 1-3, 24148 Kiel, Germany

ARTICLE INFO

Available online 14 March 2013

Keywords:
Late Quaternary
Micropaleontology
Water oxygen conditions
Sea of Okhotsk

ABSTRACT

Microfossil data on the foraminifers and radiolarians in the sediment core KOMEX LV28-44-3, the Kamchatka slope in the eastern Sea of Okhotsk, exhibit the changes in the water oxygen conditions during the last 146 ky. The paleoenvironmental proxies are the radiolarian species *Cycladophora davisiana* as indicator of the upper intermediate water ventilation, and the benthic/planktonic foraminifers as indicators of the bioproductivity and bottom water oxygenation. In case of sediment core LV28-44-3, the bottom water represents the lower intermediate one, so that conclusions on paleoenvironments are applicable for the most range of the local intermediate water. The well-oxygenated intermediate and near-bottom waters existed in the area of study during the penultimate glaciation of MIS 6, Early Weichselian initiation of the last glaciation within MIS 5b–d, and last glacial stages of MIS 3–2. The intervals of the short low-O_2 bottom events with suboxic conditions (dissolved O_2 in water 0.3–1.2 ml/l) occur during the last interglacial MIS 5e (Eemian stage) 125 to 113 ka, and during the last deglaciation 17.5 to 6.5 ka. Eemian low-O_2 bottom events are associated with the high bioproductivity of the subsurface water but poor ventilation on the upper intermediate depths. The low-O_2 bottom events during the last deglaciation occurred at the high bioproductivity of the subsurface water and active ventilation on the upper intermediate depths.

1. Introduction

The subarctic hydrological and biological structures of the modern Sea of Okhotsk, the semi-isolated marginal basin of the North Pacific, may have similarities with the Quaternary paleoenvironmental situation in the high-latitude glacial ocean (Hays and Morley, 2003). A distinct feature of the Sea of Okhotsk is the well-ventilated cold intermediate water (SOIW) on depths of 200–1000 m which represents a major source for the ventilation of the intermediate water over the North Pacific (Talley, 1991). The Pleistocene environments in the North Pacific could be affected in a large degree by the changes in the paleo-SOIW production and properties. During the last two decades, the high-resolution micropaleontological studies of the Sea of Okhotsk sediment cores documented the prominent paleoenvironmental changes on the different timescales during the Pleistocene to Holocene (e.g., Morley et al., 1991; Chekhovskaya and Basov, 1999; Khusid, 2000; Shiga and Koizumi, 2000; Barash et al., 2001; Matul and Abelmann, 2001; Gorbarenko et al., 2002a; Okazaki et al., 2003; Nürnberg and Tiedemann, 2004; and others). An increasing number of recent works discuss the paleoreconstructions of the deep to intermediate water formation (ventilation) during the Late Pleistocene in the North Pacific and its marginal seas to discover its regional and global implications using both micropaleontological and isotopic/geochemical parameters (Ohkushi et al., 2003; Shibahara et al., 2007; Bubenshchikova et al., 2010; Cartapanis et al., 2011; and others). Keigwin (1998), based on the isotopic data, suggested that during the last glacial time there was more modern-like watermass or/and better ventilated watermass at intermediate depths in the far northwestern Pacific including the Sea of Okhotsk. However, e.g., Ohkushi et al. (2003), and Tanaka and Takahashi (2005), who analyzed the available data on the radiolarian SOIW marker *Cycladophora davisiana*, excluded the Sea of Okhotsk as an area of SOIW production during the Last Glacial Maximum. Our paper presents a micropaleontological study of the

* Corresponding author. Tel.: +7 499 129 21 72; fax: +7 499 124 59 83.
E-mail address: amatul@mail.ru (A. Matul).

0967-0645/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.dsr2.2013.03.023

foraminifers and radiolarians from the Late Pleistocene to Holocene sediments on the western continental slope of the Kamchatka regarding the story about the oxygen conditions in the bottom and intermediate waters during last glacial cycle. We analyze the sediment core KOMEX LV28-44-3, which is located on the water depth of 684 m within the domain of SOIW; therefore, the local bottom water represents the lower SOIW. Conclusions about the changes in paleo-SOIW properties are based on the comparative discussion of variations in the bioproductivity (indication from the total microfossil content, and abundances of the planktonic foraminiferal species *Globigerina bulloides*), and water oxygen conditions (indication from the benthic foraminiferal oxygen index, and abundances of the radiolarian species *C. davisiana*).

2. Regional setting

A cyclonic water circulation in the Sea of Okhotsk, complicated by the different-scale eddies, gyres, local fronts, and upwellings, complies the general, large-scale circulation in the Subarctic Pacific (Uda, 1963; Verkhunov, 1997). Major sources of the coming water are the cold Oyashio current from the northwestern Subarctic Pacific, and the seasonal warm Soya current from the Japan Sea as a far extension of the subtropical Tsushima current. The principal vertical hydrological structure in the sea (Fig. 1) consists of (1) the uppermost warm, mixed layer in the summer, (2) the subsurface cold (dichothermal) layer on depths of 50 to 150–200 m as a remnant of the strong winter cooling, (3) the cold well-ventilated layer on depths of 150–200 to 600–1000 m as the Sea of Okhotsk Intermediate Water (SOIW) formed predominantly by mixing of the Okhotsk dense shelf water with the intermediate water from the Northwest Pacific, (4) the deep, warmer and poorly ventilated water of the Pacific origin distributed deeper than 600–1000 m or on depths of the oxygen minimum zone (e.g., Yasuoka, 1967; Kitani, 1973; Yang and Honjo, 1996). The area of our study off the western Kamchatka is under the general influence of the well-ventilated SOIW with the dissolved oxygen values of 2–3 to 5–6 ml/l on the depths of 200 to 600 m, and ca. 2 ml/l at the bottom (World Ocean Atlas 2001—Conkright et al., 2002).

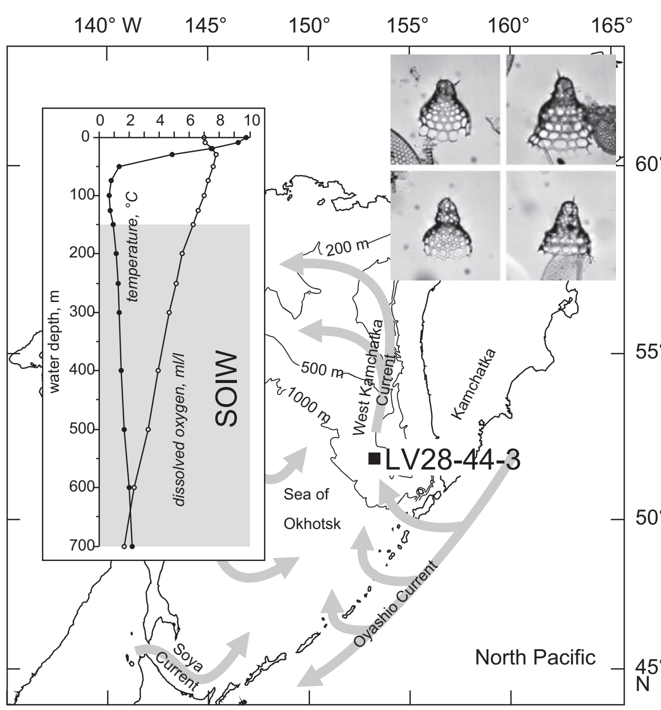

Fig. 1. Location of the core LV28-44-3. Bathymetry in the eastern Sea of Okhotsk: 200, 500, and 1000 m isobaths according GEBCO data, ⟨http://www.gebco.net⟩. Modern hydrology: gray arrows as main water streams on the surface according to Verkhunov (1997), vertical profile of the temperature and dissolved oxygen at the coring point according World Ocean Atlas 2001 (Conkright et al., 2002). Microphotographs in the upper right corner of the figure: radiolarian species *Cycladophora davisiana* (core LV28-44-3, sample 208–209 cm) as an indicator of the upper Sea of Okhotsk intermediate water. Computer tools PanPlot and PanMap, ⟨http://www.pangaea.de⟩, are used to draw the map and graphs.

3. Material and methods

We studied the microfauna (planktonic/benthic foraminifers and radiolarians) in the sediments of the KOMEX core LV28-44-3 (Biebow and Hütten, 1999) located in the eastern central Sea of Okhotsk on the Kamchatka continental slope (52°02.514′N, 153°05.949′E; water depth 684 m; recovery 1116 cm) (Fig. 1). The weakly to moderately bioturbated sediments are composed of the intermittent layers of the terrigenous silty–sandy–clayey muds, diatomaceous oozes, and silty–clayey muds enriched of diatoms; the latter layers compose most of the core sequence (Fig. 2). Two large clearly defined biogenous (diatomaceous) units of 0–353 cm and 837–932 cm contain increased amounts of the foraminifers, coccoliths, and radiolarians. A total of 117 samples for foraminifers, and 136 samples for radiolarians were analyzed in 5–10 cm sampling intervals. We analyzed foraminifers from the available sediment fraction >125 μm, and radiolarians from the fraction 40 to 500 μm. A preparation of radiolarian slides followed the method described in Abelmann (1988) and Abelmann et al. (1999). Almost all samples had enough microfossils for the counting. Preservation of both foraminiferal and radiolarian tests was moderate to good through the core.

Paleoenvironmental proxies in our study indicate changes in the bioproductivity and water oxygen conditions. Proxies for bioproductivity: (1) an occurrence of the diatomaceous oozes in the core sequence, and maxima of the total microfossil abundances (foraminifers and radiolarians) in sediments as indicators of the bioproductivity increase during the interglacial intervals in the Sea of Okhotsk (Nürnberg and Tiedemann, 2004), (2) the abundance peaks of the dysoxic benthic foraminifers, which include genera *Globobulimina*, *Bulimina*, *Bolivina*, etc., associated with high bioproductivity on the continental margins (Kaiho, 1999), (3) the planktonic foraminiferal species *G. bulloides* as indicator of the subsurface bioproductivity (Bé and Tolderlund, 1971). Proxies for water oxygenation: (1) the benthic foraminiferal oxic, suboxic, and dysoxic groups as indicators of the specific bottom oxygen conditions (Kaiho, 1991); the quantification of levels of the bottom oxygenation groups is expressed through the benthic foraminiferal oxygen index (Kaiho, 1999), (2) the radiolarian species *C. davisiana* as indicator of the proper ventilation in the upper intermediate water of the Sea of Okhotsk (Abelmann and Nimmergut, 2005).

An interpretation of the bottom oxygen conditions follows a method elaborated by Kaiho (1991) for the analysis of the benthic foraminiferal assemblages. Kaiho (1999) calculated the Benthic Foraminiferal Oxygen Index (BFOI) based on the quantitative relation of different groups of the benthic foraminifers, which are divided into dysoxic (habitat at 0.1–0.3 ml/l of dissolved O_2 in the water), suboxic (0.3–1.2 ml/l), and oxic (>1.2 ml/l) indicators. Description of BFOI equations was given by Kaiho (1994). The correlation coefficient R^2 of 0.81 exhibits a strong direct correlation between BFOI and dissolved-oxygen levels in overlying water (Kaiho, 1999). Six ranges of dissolved oxygen in the bottom water can be recognized using the BFOI: index <−55 means anoxic oxygen condition (0–0.1 ml/l of dissolved O_2 in the water), from −55 to −40 is dysoxic (0.1–0.3 ml/l), from −40 to 0 is suboxic (0.3–1.2 ml/l), from 0 to 15 is low oxic (1.2–2.0 ml/l), from 15 to 50 is