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Fine structure of dark layers in the central Japan Sea and their relationship with the abrupt climate and sea level changes over the last 75 ka inferred from lithophysical, geochemical and pollen results

S. Gorbarenko [a,*], X. Shi [b], Y. Rybiakova [a], A. Bosin [a], M. Malakhov [c], J. Zou [b], J. Liu [b], T. Velivetskaya [d], A. Ignatiev [d], A. Derkachev [a], Y. Wu [b], F. Shi [b]

[a] V.I. Il'ichev Pacific Oceanological Institute, 43 Baltiyskaya St., Vladivostok 690041, Russia
[b] First Institute of Oceanography, SOA, Xian-Xia-Ling Road, 6, Qingdao 266061, China
[c] NEISRI FEB RAS, North-East Interdisciplinary Science Research Institute FEB RAS, Portovaya St., 16, 685000 Magadan, Russia
[d] Far East Geological Institute FEB RAS, Pr. 100 let Vladivostoku, 159, Vladivostok 690022, Russia

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A B S T R A C T

High resolution of the color lightness, productivity proxies (TOC, chlorin, $CaCO_3$, Ba-bio, Mo and U), and lithological description defined alternation of dark layers (DLs) and light layers in sediment core LV53-23 recovered from the central Japan Sea (west Yamato Rise) over the last 75 ka. Age model was constructed by AMS 14C data, tephrochronology, $\delta^{18}O$ of planktonic foraminifera record, and the correlation of DLs with lightness of Japan Sea core MD01-2407 and with millennial interstadials recorded in the Greenland ice cores and East Asia stalagmites. Regional interstadials were also independently established and dated by vegetation amelioration of the surrounded land, inferred from the pollen results. Correlation of the DLs with millennial scale climate and sea level changes indicate that both interstadial warming and sea level fluctuations influence on its formation providing their individual features. During MIS 3, with sea level above −90 m, DL was formed mostly consistent with the Tada et al. (1999)'s hypotheses. During MIS 2 and 4, when sea level was nearly and below −90 m, sea level descending led to water column stratification, oxygen depletion in bottom water and facilitates the DLs formation. High-resolution lightness and productivity proxies defined the subtle structure of pronounced interstadials 14 and 12.

1. Introduction

High-resolution paleoclimatic records were often obtained from ice cores (Dansgaard et al., 1993; NGRIP Members, 2004), deep-sea sediments (Hendy et al., 2002; Harada et al., 2008), cave stalagmites (Wang et al., 2001, 2008) and the terrestrial sites (An and Porter, 1997; Demske et al., 2005), and they can indicate rapid oscillations in climate occurred on millennial time scales during the last glacial–interglacial period. Each Dansgaard-Oeschger (DO) cycle corresponds to: (1) a relatively gradual cooling of about 5–10 °C (at the altitude of the Greenland ice sheet) that lasted about 600–2000 years; (2) a subsequent, more rapid decline of 5–10 °C into peak stadial conditions, lasting another 300–700 years (DO stadial); and (3) a very abrupt return (3–5 °C warming per century) to DO interstadial conditions (DOI) (Thomas et al., 2009). Episodes of accelerated ice rafted detritus (IRD) accumulation were found in North Atlantic deep-sea sediments, which was characterized by abrupt massive discharge of icebergs associated with intense periodic cooling events that termed as Heinrich events (Heinrich, 1988). With intensive investigation following that, it was suggested that millennial-scale climate changes observed in the Greenland ice core, China cave stalagmites, marine sediments and terrestrial sites had occurred synchronously in the North hemisphere (Voelker, 2002; Rohling et al., 2003). However, some marginal seas, such as the semi-closed Japan Sea, were characterized by specific evolution features owing to its location in the East Asia monsoon system, shallow straits – Tsushima and Tsugaru, and surface water freshening during low sea level period (Gorbarenko, 1983; Oba et al., 1984, 1991, 1995; Matsui et al., 1998). Very important features of the Late Quaternary Japan Sea environment and sedimentation development were centimeter to meter-scale alternation between dark parallel-laminated layers (or thinly lamination layers, TLs) and light layers (Tanaka, 1985; Nakajima et al., 1996). Initially, it is suggested that the deposition of the dark layers (DLs) was synchronous and reflected basin-wide

* Corresponding author.
E-mail address: gorbarenko@poi.dvo.ru (S. Gorbarenko).

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events (Ichikura and Ujiie, 1976), which was confirmed by subsequent site-to-site correlation studies of the DLs in the Japan Sea (Oba et al., 1991; Tada et al., 1999; Itaki et al., 2004; Kido et al., 2007; Ikehara and Itaki, 2007; Yokoyama et al., 2007; Khim et al., 2009). Tada et al. (1999) has commented on the geochemical and lithological studies, saying "The centimeter to decimeter-scale alternations reflect millennial-scale variations which are possibly associated with Dansgaard-Oeschger cycles, with each dark layer appearing to correspond to an interstadial. The increased influence of the lower-salinity, nutrient-enriched East China Sea coastal water reduced deep water ventilation and enhanced the surface productivity, leading to the development of anoxic bottom waters and deposition of the dark layers". Owing to the basin synchronicity, the dark layer sequence became a tool for establishing the late Quaternary stratigraphy in the Japan Sea sediments (Tada et al., 1999; Kido et al., 2007; Khim et al., 2009, 2012). However, several important problems remain in applying the TLs sequence to the paleoceanography and chronostratigraphy in Japan Sea. There are several approaches on numbering the dark layers (above the Aso-4 ash layer), from D-16 to D-1 (Nakajima et al., 1996) or from TL-21 to TL-1 (Tada et al., 1999), and therefore their ages. Watanabe et al. (2007) demonstrated specific individual peculiarities of dark layer accumulation by reconstructing 5 sediment fabric types. The Japan Sea sediment dating is often beyond the AMS ^{14}C method limit. In addition, specific $\delta^{18}O$ of planktonic and benthic foraminifera records result difficulties in correlate those records with the SPECMAP curve. The reconstruction of the paleointensity of Earth magnetic field in the Japan Sea sediment and its correlation with dated sediments are still problematic up to present due to intensively diagenetic processes in the Japan Sea sediments (Hayashida et al., 2007).

Here we present ultra-high resolution records of color lightness (CL), productivity proxies (TOC, chlorin, Ba-bio and $CaCO_3$ content), trace metals (Mo and U), $\delta^{18}O$ and $\delta^{13}C$ planktonic foraminifera curves and DLs sequence defined by sediment description in the core sediment recovered in the central Japan Sea. Firstly, according to the hypothesis proposed by Tada et al. (1999), the AMS ^{14}C data and the tephrochronology, we synthesized all proxies of environment and sedimentation that have been determined in the studied core and correlated them with millennial-scale climate changes recorded in the Greenland ice core (NGRIP Members, 2004) and China cave stalagmite (Wang et al., 2001, 2008) over the last 75 ka. Other purpose of this paper is to clarify the linkages between the DO cycles observed in the Japan Sea sediments and the surrounded land vegetation/regional climate changes forced by the global climate fluctuations on millennial-scale. Based on the surrounded land vegetation/regional climate changes constructed by pollen records in the same core (independent age model) and various eustatic sea level records, we partially correlated the abrupt environmental changes in Japan Sea derived from pollen and the DLs formed in the studied core with pronounced Greenland/Chinese Interstadials (GI/CI) and sea level changes. The ultra-high resolution records of Japan Sea and the highly sensitive basin environment corresponding to abrupt climate and sea level changes allow us to reveal new subtle structure of pronounced GI/CI cycles imprinted in the Japan Sea sediment and re-evaluate the dominant factors on DL formation during the base of Marine isotope stage (MIS) 3.

2. Oceanographic setting of the Japan Sea

The Japan Sea, a semi-enclosed marginal sea in the northwestern (NW) Pacific Ocean, is located between East Asia and the Japanese Island and connects with the East China Sea, the NW Pacific Ocean and the Okhotsk Sea through four shallow straits: Tsushima (130 m), Tsugaru (130 m), Soya (55 m) and Tartar (12 m) Straits (Fig. 1). Among them, the southwestern Tsushima Strait and the northeastern Tsugaru Strait are two deepest straits with sill depths of ~130 m. The shallow sills of straits imply that major paleoceanographic changes were strongly influenced by glacio-eustatic sea level oscillations during the Late Quaternary. At present, the Tsushima Current, a branch of warm, saline Kuroshio Current, extension of the Taiwan Current and affected by the East China Sea coastal water, enters the Japan Sea through the Tsushima Strait and flows out through Tsugaru and Soya Straits (Fig. 1). The deep water below water depths of 200–300 m is called the Japan Sea Proper Water (JSPW), which is characterized by high dissolved oxygen concentrations, and it is originated in the northwestern part of the Japan Sea during winter cooling and freezing of surface water (Gamo, 1999). Japan Sea surface water is divided by temperature into two water masses at latitudinal boundary that forms a subpolar front near 40°N.

In this study, we examined sediment Core LV53-23 recovered during joint Russian-Chinese cruise 53 at R/V "Academic Lavrent'jev" at northwestern part of the Yamato Rise. The coordinates were 40°18′N and 134°19′E, and the water depth was 1282 m (Fig. 1). The sampling site is located in northern boundary of south warm water masses in the vicinity of northern branch of warm Tsushima Current (Fig. 1).

3. Methods and materials

According to lithological description, the sediment of core LV53-23 is characterized by typical alternation of light layers (LL, 10GY5/2) and dark layers (DL, 5GY5/2); mostly LL downward in core gradually become darker and continuously transform into DL which have sharp low boundary with underlying LL. Three of them have thinly laminated structure (Fig. 2). Traces of bioturbation often happened in the studied core.

Several isotope-geochemical, lithological and micropaleontological methods were applied for the environmental reconstruction of the Japan Sea in the past. Total carbon content and total inorganic carbon were measured with 2-cm resolution through core depth by coulometry using an AN-7529 analyzer (Gorbarenko et al., 1998). Total organic carbon (TOC) content was determined by the difference of total and total inorganic carbon. Chlorin content was determined at 1-cm resolution using a Shimadzu UV-1650PC spectrophotometer after 24-hour extraction in acetone at 4 °C, which is a modified method of Harris et al. (1996) (Zakharkov et al., 2007). The contents of Mo, U and Ba in sediment were determined at a resolution of 5 cm using ICP-MS (Zou et al., 2012). The biogenic Ba (Ba_bio) content was calculated from Ba values according to Goldberg et al. (2007).

Monospecies planktonic *Neogloboquadrina pachyderma* (s.) from fractions 125–250 μm and benthic foraminifera *Uvigerina auberiana* and *U. parvocastata* (fraction 250–350 μm), with weight of 2–10 mg, were dated at National Ocean Science Accelerator Mass Spectrometry Facility at Woods Hole Oceanographic Institute (Woods Hole, USA).

All radiocarbon ages were converted into calibrated 2-sigma calendar age ranges using the calibration software CALIB REV 7.0.1 (Stuiver and Reimer, 1993) with the Marine 13 calibration curve (Reimer et al., 2013) (Table 1). We accepted the constant reservoir age of the Japan Sea surface water to be equal to modern value of 400 years (Yokoyama et al., 2007) throughout the studied time period.

$\delta^{18}O$ and $\delta^{13}C$ in planktonic foraminifera *N. pachyderma* (sin.) from the 125–250 μm size fraction were measured with a Finnigan-MAT 252 mass spectrometer without preliminary oven drying, which is a standard analytical method with modified