Quaternary Science Reviews 191 (2018) 406–430

Contents lists available at ScienceDirect

Quaternary Science Reviews

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

Paleoclimatic and paleoceanographic records through Marine Isotope Stage 19 at the Chiba composite section, central Japan: A key reference for the Early–Middle Pleistocene Subseries boundary

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ARTICLE INFO

Article history:
Received 4 April 2017
Received in revised form
6 April 2018
Accepted 23 April 2018

Keywords:
Marine Isotope Stage (MIS) 19
Oxygen isotope ($\delta^{18}O$) stratigraphy
Pollen

ABSTRACT

Marine Isotope Stage (MIS) 19 is an important analogue for the present interglacial because of its similar orbital configuration, especially the phasing of the obliquity maximum to precession minimum. However, sedimentary records suitable for capturing both terrestrial and marine environmental changes are limited, and thus the climatic forcing mechanisms for MIS 19 are still largely unknown. The Chiba composite section, east-central Japanese archipelago, is a continuous and expanded marine sedimentary succession well suited to capture terrestrial and marine environmental changes through MIS 19. In this study, a detailed oxygen isotope chronology is established from late MIS 20 to early MIS 18, supported by a U-Pb zircon age and the presence of the Matuyama–Brunhes boundary. New pollen, marine microfossil, and planktonic foraminiferal $\delta^{18}O$ and Mg/Ca paleotemperature records reveal the complex interplay of climatic influences. Our pollen data suggest that the duration of full interglacial conditions

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https://doi.org/10.1016/j.quascirev.2018.04.022

Foraminifera
Calcareous nannofossils
Radiolarians
Mg/Ca
Matuyama–Brunhes boundary
Chiba composite section (CbCS)
Lower–Middle Pleistocene boundary

during MIS 19 extends from 785.0 to 775.1 ka (9.9 kyr), which offers an important natural baseline in predicting the duration of the present interglacial. A Younger Dryas-type cooling event is present during Termination IX, suggesting that such events are linked to this orbital configuration. Millennial- to multi-millennial-scale variations in our $\delta^{18}O$ and Mg/Ca records imply that the Subarctic Front fluctuated in the northwestern Pacific Ocean during late MIS 19, probably in response to East Asian winter monsoon variability. The climatic setting at this time appears to be related to less severe summer insolation minima at 65N and/or high winter insolation at 50N. Our records do not support a recently hypothesized direct coupling between variations in the geomagnetic field intensity and global/regional climate change. Our highly resolved paleoclimatic and paleoceanographic records, coupled with a well-defined Matuyama–Brunhes boundary (772.9 ka; duration 1.9 kyr), establish the Chiba composite section as an exceptional climatic and chronological reference section for the Early–Middle Pleistocene boundary.

List of abbreviations

AP	arboreal pollen
CbCS	Chiba composite section
EAWM	East Asian winter monsoon
IODP	International Ocean Discovery Program/ Integrated Ocean Drilling Program
LAD	last appearance datum
MAT	Modern analogue technique
MIS	marine isotope stage
MJS	Montalbano Jonico succession
M–B boundary	Matuyama–Brunhes boundary
NIPR	National Institute of Polar Research
ODP	Ocean Drilling Program
PTI	pollen temperature index
SST	sea-surface temperature
T_{ann}	mean annual temperature
T_{inf}	Mg/Ca paleothermometry
VPDB	Vienna Pee Dee Belemnite

1. Introduction

The Earth experienced fundamental changes in oceanic and atmospheric circulation, ice sheet distributions, and biotic evolution during the transition from the Early to Middle Pleistocene (e.g., Head and Gibbard, 2005; Head et al., 2008; Head and Gibbard, 2015a). Known previously as the "mid-Pleistocene Revolution" or "mid-Pleistocene (climate) Transition" (e.g., Maasch, 1988; Mudelsee and Stattegger, 1997; Mudelsee and Schulz, 1997; Raymo et al., 1997; Clark et al., 2006; Elderfield et al., 2012), it is now more properly known as the "Early–Middle Pleistocene transition" (Head and Gibbard, 2015a). A progressive increase in the amplitude of climate oscillations, the shift from a 41-ky to quasi-100 ky rhythm, increasing long-term average global ice volume, and the establishment of strong asymmetry in global ice volume cycles, all occurred during this interval (Head and Gibbard, 2015a). Significant progress has been achieved over recent decades in collecting and analyzing a wide range of climate records from terrestrial sites, marine sediment cores, and Antarctic ice cores extending back to 800 ka, and this allows us to understand how minor differences in external forcing mechanisms can lead to a wide range of responses for each glacial–interglacial cycle (e.g., Lang and Wolff, 2011; Berger et al., 2016).

The EPICA Dome C ice core record (Fig. 1a) shows that a small optimum in the δD and CO_2 signal in Marine Isotope Stage (MIS) 1 might place it within the same group of interglacials as MIS 5e, 7e, 9e, and 19c (e.g., Berger et al., 2016). Notwithstanding the influence of atmospheric CO_2 concentrations (Ganopolski et al., 2016), MIS 19 is thought to be the closest analogue for evaluating the timing, duration, and variability of the present interglacial, given the similar astronomical parameters (phasing between obliquity and precession) (e.g., Pol et al., 2010; Tzedakis, 2010; Tzedakis et al., 2012; Yin and Berger, 2012). The lowered amplitude of the 400-ky eccentricity cycle and the consequent suppression of precessional forcing are very similar for the two stages. The phasing of the obliquity maximum with the precession minimum is also similar, although obliquity increased more rapidly at the beginning of MIS 1 than of MIS 19. Detailed climatic reconstructions have revealed a cooling event at the transition from MIS 20 to MIS 19 (Termination IX) that is similar to the Younger Dryas cooling that interrupted the Last Glacial Termination (Termination I). This event appears in at least one record from the North Atlantic (IODP Site U1308; Hodell et al., 2008), at Lake Baikal (Prokopenko et al., 2006), in paleolake sediments within the Mediterranean area (Sulmona; Giaccio et al., 2015), and at the Montalbano Jonico succession (MJS) in southern Italy (Maiorano et al., 2016; Simon et al., 2017) (Fig. 1a). However, the timing, duration, and variability of the interglacial and Termination IX, including the nature of the Younger Dryas-type cooling event, are still poorly understood.

Continuous deep-ocean records across this climatic transition are common, but constructing links between atmospheric circulation, terrestrial environmental change, and biotic evolution have been hampered by the rarity of sedimentary records from nearshore areas. Therefore, continuous and highly-resolved marine records that capture both terrestrial and marine environmental signals with strong chronological controls are needed to improve our understanding of the Earth's climate system. Geomagnetic field reversal events are additional important datums as they provide useful near-synchronous time lines that are independent of astrochronology.

The Japanese archipelago is geographically well suited for various kinds of paleoclimatic and paleoceanographic studies. Located at the easternmost margin of the Eurasian Continent and facing the Pacific Ocean, its marine sedimentary record preserves the interplay of terrestrial and marine climatic and environmental changes relating to the westerly jet, East Asian monsoon, and North Pacific Gyre (subtropical and subpolar) (Fig. 1). The Chiba composite section (CbCS), in the east-central part of the Japanese archipelago, spans most of the Pleistocene (Kazaoka et al., 2015) including a well-exposed and continuous marine sedimentary record across MIS 19. The Matuyama–Brunhes (M–B) magnetostratigraphic reversal, which is the primary chronological datum for the Lower–Middle Pleistocene Subseries boundary (Head et al., 2008), occurs immediately above a widespread tephra bed, the Ontake-Byakubi (Byk-E), in the CbCS of the Kokumoto Formation,