Quaternary Geochronology xxx (2016) 1–17

Contents lists available at ScienceDirect

Quaternary Geochronology

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

Using tephrostratigraphy and cryptotephrostratigraphy to re-evaluate and improve the Middle Pleistocene age model for marine sequences in northeast Japan (Chikyu C9001C)

Tabito Matsu'ura [a, *, 1], Jun-Ichi Kimura [b], Qing Chang [b], Junko Komatsubara [c]

[a] Japan Nuclear Energy Safety Organization (JNES), Toranomon Towers Office, 4-1-28 Toranomon, Minato-ku, Tokyo 105-0001, Japan
[b] Japan Agency for Marine-Earth Science and Technology (JAMSTEC), 2-15 Natsushima-cho, Yokosuka, Kanagawa 237-0061, Japan
[c] Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (AIST), 1-1-1 Site 7 Higashi, Tsukuba, Ibaraki 305-8567, Japan

ARTICLE INFO

Article history:
Received 13 February 2016
Received in revised form
7 November 2016
Accepted 14 November 2016
Available online xxx

Keywords:
Tephra
Glass shard chemistry
Marine isotopic stage
Deep-sea core
Middle Pleistocene
Northeast Japan

ABSTRACT

We refine the tephrostratigraphy and cryptotephrostratigraphy of the Middle Pleistocene deep-sea sediments in the C9001C cores and reconstruct the age model of the cores to provide a standard stratigraphy for the NW Pacific Ocean area. In the lower half of the cores (corresponding to marine isotopic stages [MISs] 9–18), we newly identify nine concentrations (spikes) of glass shards (numbered G17–G25 from top to bottom) below sixteen previously reported spikes (numbered G1–G16) in the upper half of the cores (MISs 1–9). We correlated two spikes (both cryptotephras) with known widespread tephras: G18 with Naruohama-IV (MIS 10d; 357 ka) and G19 with Kasamori 5 (MIS 12b–c; 434–458 ka). Although the two cryptotephra spikes cannot be distinguished by the major- and trace-element compositions of glass shards, these correlations are based upon their stratigraphic occurrence within separate glacial periods (MISs 10 and 12) as indicated by the $\delta^{18}O$ stratigraphy of the C9001C sequence. Based on the stratigraphic positions of the Naruohama-IV and Kasamori 5 tephras, we assign the sediment units corresponding to MISs 10, 11, and 12, and revise the previous assignment of core segments corresponding to MISs 7, 8, and 9. The resulting tephra-based age model is consistent with the last occurrence of *Proboscia curvirostris*, but it is inconsistent with the first occurrence of *Emiliania huxleyi*. According to the new age model, the sedimentation rate during MISs 18–2 has ranged from 0.21 m/ky (during MIS 17) to 0.74 m/ky (during MISs 8 and 9), however, the sedimentation rate was never as high as the rate of 1.1 m/ky indicated by an earlier age model.

1. Introduction

Deep-sea sediments, in some places, contain continuous records of $\delta^{18}O$ fluctuations, which provide a high-temporal-resolution proxy record of cyclic climatic changes since 5000 ka or earlier (Lisiecki and Raymo, 2005). The $\delta^{18}O$ stratigraphy of such sediments is a useful age indicator, particularly when used in combination with magnetostratigraphy, biostratigraphy, and tephrostratigraphy. The amplitudes of $\delta^{18}O$ fluctuations during the Brunhes chron are higher than those during the Matuyama and earlier chrons (Shackleton and Opdyke, 1973; Zachos et al., 2001; Siddall et al., 2010). Therefore, continuous $\delta^{18}O$ records for the Brunhes chron in deep-sea sediment cores have a temporal resolution of about 20 kyears and can resolve substages within marine isotope stages (MISs).

Along the northwestern Pacific rim, several deep-sea sediment cores with continuous $\delta^{18}O$ records have been reported, including MD01-2422, off Shikoku Island, Japan (from MIS 10 to the present; Ikehara et al., 2006), MD01-2398, Ryukyu Islands (from MIS 12 to the present; Ujiie and Ujiie, 2006), and the V21–146 cores, northwestern Pacific Ocean (from MIS 13 to the present; Hovan et al., 1991). Furthermore, the deep-sea sediments of the C9001C cores, obtained from the continental slope off Shimokita Peninsula, northeastern Japan, by D/V *Chikyu* during its 2006 shakedown

* Corresponding author.
E-mail address: tabito_matsuura@nsr.go.jp (T. Matsu'ura).
[1] Now at Regulatory Standard and Research Department, Secretariat of Nuclear Regulation Authority (S/NRA/R), 1-9-9 Roppongi, Minato-ku, Tokyo 106-8450, Japan.

http://dx.doi.org/10.1016/j.quageo.2016.11.001
1871-1014/

Please cite this article in press as: Matsu'ura, T., et al., Using tephrostratigraphy and cryptotephrostratigraphy to re-evaluate and improve the Middle Pleistocene age model for marine sequences in northeast Japan (Chikyu C9001C), Quaternary Geochronology (2016), http://dx.doi.org/10.1016/j.quageo.2016.11.001

cruise for the Integrated Ocean Drilling Project, contain $\delta^{18}O$ records from MIS 18 to the present (Fig. 1b) (Aoike, 2007; Kobayashi et al., 2009). The C9001C core sediments have been correlated with MISs by magnetostratigraphic, biostratigraphic, and tephrostratigraphic analyses, as well as by using $\delta^{18}O$ of benthic foraminifera (Domitsu et al., 2011; Matsu'ura et al., 2014). Thus, the C9001C cores can provide a reference stratigraphy for the northwestern Pacific Ocean area, spanning almost the entire duration of the Brunhes chron.

The initial age model for the C9001C cores, proposed by Aoike (2007), was subsequently revised by new biostratigraphic findings (Domitsu et al., 2010, 2011). The 2011 revised age model for the upper half of the cores is very strongly constrained by the occurrence of a nannofossil, namely, the first appearance datum (FAD) of *Emiliania huxleyi* (250 ka: Domitsu et al., [2010]). Recently, the 2011 nannofossil-stratigraphy-based age model for the period from MIS 9 to the present was revised again on the basis of tephrostratigraphy and cryptotephrostratigraphy (Matsu'ura et al., 2014). Tephrostratigraphy and cryptotephrostratigraphy have proved to be a powerful tool for refining the age model of these cores, but they have not yet been applied to the older half of the cores (corresponding to MISs 9–18).

Vitric tephra layers and cryptotephras detected as glass shard concentrations in sediments are usually widespread tephras from distant volcanoes (e.g., Machida and Arai, 2003; Lowe, 2011). Such tephras are fairly well preserved in deep-sea sediments, but petrographically similar tephras occasionally occur at several stratigraphic positions in a core. As a result, it may be difficult to judge whether they represent primary tephra layers or tephras that have been reworked by post-emplacement processes such as bioturbation (Reineck and Singh, 1980) or redeposition (Lowe, 2011; Cassidy et al., 2014), or tephras that have been duplicated by tectonic folding and faulting or turbidity flows, or even by duplicate sampling of the same horizon during coring (Allan et al., 2008). In fact, several pairs of petrographically similar tephras actually occur in the C9001C cores; thus, to improve the age model, the cores must be carefully examined by integrating data from tephrostratigraphy, $\delta^{18}O$ stratigraphy, magnetostratigraphy, and biostratigraphy studies. An improved age model for these cores will be useful for assigning robust ages to Middle Pleistocene tephras and cryptotephras in NE Japan and for establishing the history of volcanic eruptions and chronology of terraces in the same area. Moreover, the techniques presented in this paper are applicable to deep-sea sequences in other regions of the world where tephras are common.

In this study, we investigate the C9001C cores, focusing on the lower half of the cores corresponding to MISs 18–9, to refine their tephrostratigraphy and cryptotephrostratigraphy. We identify tephra and cryptotephra horizons by examining concentrations of glass shards and heavy mineral grains in the cores. Then we analyze the glass shard chemistry to identify juvenile tephras and establish the tephrostratigraphy by correlating the juvenile tephras with tephras described in sedimentary sequences on the Japanese Islands. As a result, we detect and identify several important cryptotephras, which we use to reassess the age model of the C9001C cores.

2. Regional setting of the study area

The drilling site of the C9001C cores is on the continental slope off northern Honshu at 1180 m water depth (41.177300°N, 142.201350°E; Aoike, 2007, Fig. 1b). Although the site lies in the non-volcanic forearc, it also lies within the westerly wind belt, therefore many volcanoes are upwind of the site and it has received tephras from both nearby and distant volcanoes during the Quaternary (Suzuki et al., 2012; Hasegawa et al., 2014; Matsu'ura et al., 2014). We consider nearby volcanoes to be those on northern Honshu (Osore, Kita-Hakkoda, and Towada volcanoes) or Hokkaido Island (Shikotsu and Toya volcanoes) (Fig. 1b) and distant volcanoes to be those on central Honshu (Shiobara volcano), Kyushu Island (Aso volcano) or on the Asian continent (Baekdushan volcano; also spelled Baegdusan) (Fig. 1a).

3. Description of the C9001C cores

The C9001C cores record a 365 m long continuous marine sedimentary succession that covers almost the entire Brunhes chron (Kobayashi et al., 2009; Aoike et al., 2010). The cores have

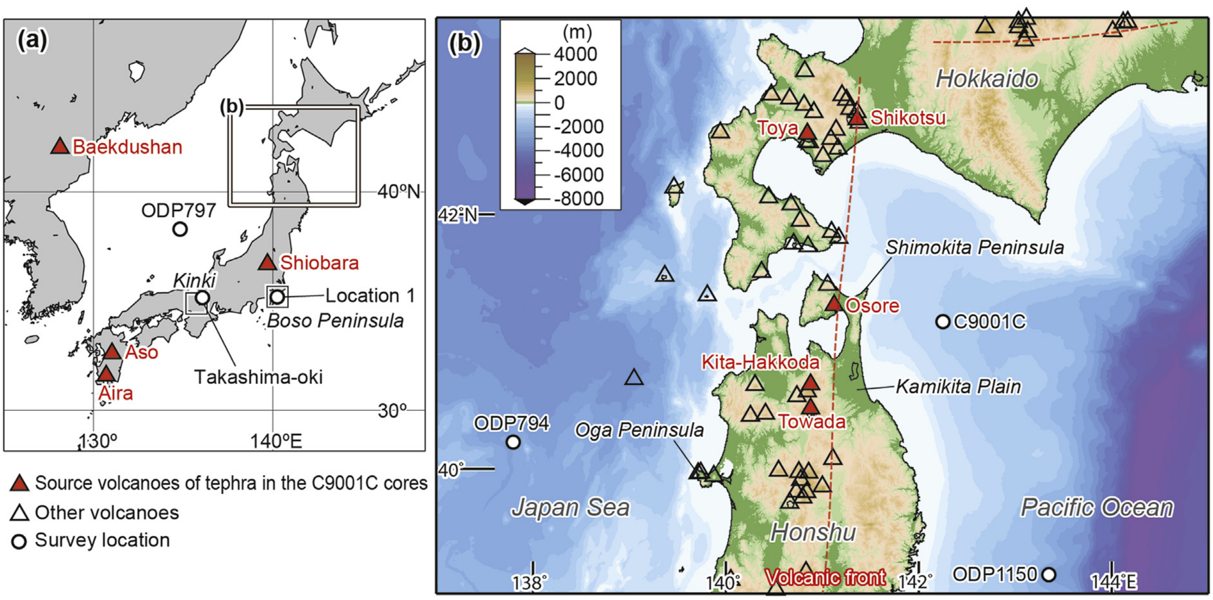

Fig. 1. Maps showing the locations of volcanoes and ocean drilling sites (a) in and around Japan and (b) in northern NE Japan. The locations of the Takashima-oki in the Kinki area and location 1 outcrop on the Boso Peninsula are also shown in (a).

Please cite this article in press as: Matsu'ura, T., et al., Using tephrostratigraphy and cryptotephrostratigraphy to re-evaluate and improve the Middle Pleistocene age model for marine sequences in northeast Japan (Chikyu C9001C), Quaternary Geochronology (2016), http://dx.doi.org/10.1016/j.quageo.2016.11.001