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New constraints on Arctic Ocean Mn stratigraphy from radiocarbon dating on planktonic foraminifera

Pin-Yao Chiu [a], Weng-Si Chao [a], Richard Gyllencreutz [b], Martin Jakobsson [b], Hong-Chun Li [a], Ludvig Löwemark [a, *], Matt O'Regan [b]

[a] Department of Geosciences, National Taiwan University, P.O. Box 13-318, 106, Taipei, Taiwan
[b] Department of Geological Sciences, Stockholm University, 106 91, Stockholm, Sweden

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ABSTRACT

Variations in the abundance of manganese (Mn) in Arctic Ocean sediments are used as a tool to identify glacial and interglacial periods. This study aims to provide new insight into the applicability of Mn as a stratigraphic tool in the topmost sediment and to investigate the occurrence of Mn peaks in sediments within the range of radiocarbon dating. In combination with variations in ice-rafted debris (IRD), radiocarbon dating is used to better constrain the stratigraphic occurrence of Mn peaks, and the synchroneity between multiple records, especially during the late glacial and the Holocene. We find that a hiatus spanning MIS 2 is widely observed in most of our cores, resulting in a merging of Mn peaks of Holocene age and the later part of MIS 3. The Holocene Mn peak is usually high amplitude but short, while the MIS 3 Mn peak has a lower amplitude and is protracted. Where preserved, MIS 2 sediments form a 2–3 cm thick layer characterized by a light color, low Mn content, sparse IRD and low foraminiferal abundance. IRD variations provide a powerful tool to identify the boundary of the Holocene and late MIS 3 in cores with a MIS 2 hiatus. Because the IRD content displays a general increment from the start of MIS 3, and both the Holocene and MIS 2 show small IRD variations, the end of MIS 3 can be pinpointed to the point of decrease in IRD. The hiatus of MIS 2 is widely observed in our cores, suggesting extensive persistent sea ice coverage during the peak of the last glacial cycle, with sharply reduced sedimentation throughout the Arctic Ocean. Identifying similar events during previous glacial periods may be an important step towards constructing longer and more accurate chronologies for Arctic Ocean sediments.

1. Introduction

The Arctic Ocean plays an important role in the global climate system. The melting and freezing of land and sea ice affects the freshwater balance and surface water salinity, albedo, air and water temperatures, and heat transfer (Stein, 2008). Paleoceanographic changes in the Arctic Ocean are important for understanding the global climate system. In order to better understand the Arctic Ocean's role in the climate system, chemical, physical and biological proxies have been used to provide insight into its paleoceanography. For example, planktonic foraminiferal assemblages are used to reconstruct surface water and sea-ice conditions. Nørgaard-Pedersen et al. (2007) suggested that the increased percentage of the subpolar species *Turborotalita quinqueloba* indicated reduced sea-ice cover during MIS 5 in certain areas. Furthermore, high abundances of ice rafted debris (IRD) have been widely observed in sediments deposited during deglacial periods, which are related to major continental deglaciations and associated iceberg discharge (Jakobsson et al., 2001; Spielhagen et al., 1997; Stein et al., 2012). Although these proxies can provide information on paleoenvironmental conditions and processes, they require reliable age models to place these observations in a meaningful context.

Age control in Arctic Ocean deep sea sediments is impeded by several obstacles (Alexanderson et al., 2014; Backman et al., 2004). About 10% of the riverine freshwater input to the World oceans is entering directly into the Arctic Ocean (Holmes et al., 2002; Stein et al., 2004). This large amount of fresh water strongly bias oxygen isotope ratios recorded in calcareous foraminifera shells. Furthermore, cold and corrosive bottom water cause poor

* Corresponding author.
E-mail address: loewemark@gmail.com (L. Löwemark).

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preservation, or complete dissolution, of calcareous micro- and nannofossils. This prevents the establishment of a continuous oxygen isotope record that could be used for age control (Sellén et al., 2010). Severe sea-ice conditions have affected biological productivity in some regions, even during interglacial periods. Owing to the low light and food influx, the central Arctic Ocean is one of the least productive regions in the world, especially during glacial periods (Sakshaug, 2004; Wassmann, 2011). Furthermore, paleomagnetic variations in central Arctic Ocean sediments are complex, and do not appear to correlate with known excursions and reversals in the geomagnetic polarity timescale (O'Regan et al., 2008). This may be the result of post-depositional changes (Channell and Xuan, 2009), or may reflect the true nature of the Earth's magnetic field at high latitudes (St-Onge and Stoner, 2011).

Despite these obstacles, clear cyclostratigraphic signals are present in many lithologic parameters of Quaternary Arctic sediments that can be used to outline periods of glacial and interglacial deposition (Löwemark et al., 2014; O'Regan et al., 2008). One of the first cyclostratigraphic approaches to dating central Arctic Ocean sediments was based on the recurrent downcore abundances of manganese during interglacial and interstadial periods of the Quaternary (Jakobsson et al., 2000). The initial assumption by Jakobsson et al. (2000) was that darker colored sediment units enriched in Mn represent interglacial conditions thus permitting correlation to the low-latitude $\delta^{18}O$ record, a proxy for glacial-interglacial cycles (Bassinot et al., 1994; Lisiecki and Raymo, 2005). Commonly, enhanced Mn concentrations occur in fine-grained, biotubated intervals of central Arctic sediments. The input of Mn is attributed to coastal erosion and riverine particulate MnOx, which in turn is controlled by glacial-interglacial variations in sea ice and ice sheet conditions (Macdonald and Gobeil, 2012; Löwemark et al., 2014). Glacial and stadial periods are defined by coarser grained, IRD-enriched intervals that lack evidence of bioturbation, and are sometimes finely laminated and tend to be devoid of microfossils. Hence, the distribution of Mn and coarse fraction abundances are primarily controlled by glacial and interglacial variability (Jakobsson et al., 2000; Löwemark et al., 2014; Macdonald and Gobeil, 2012; Nørgaard-Pedersen et al., 2007; O'Regan et al., 2008; Stein, 2008; Stein et al., 2012). Therefore, the downcore Mn and IRD patterns in Arctic Ocean sediments indicate the cyclicity of glacial and interglacial climate shifts. High Mn content is related to warm interglacial and interstadial periods, while low Mn content can indicate cold glacial periods (Löwemark et al., 2008).

High-resolution downcore records of Mn abundance can be rapidly acquired using XRF-scanning techniques. Together with the Ca pattern, which can indicate the abundance of microfossils (Hanslik et al., 2013), the Mn pattern can be used as a preliminary proxy to identify MIS stages. The typical late Quaternary Mn patterns show a peak in the top of the core, corresponding to the present interglacial. Downcore, several additional Mn peaks corresponding to MIS 3, MIS 5.1, 5.3, 5.5, and sometimes MIS 7, 9, and 11 can be identified, which are separated by clear Mn minima, believed to represent glacial or stadial intervals. Consequently, a first correlation between Arctic cores can often be based on the corresponding Mn peaks from top to bottom (Fig. 1).

The Holocene Mn peak usually has a high amplitude, but is thin, while the Mn peak of MIS 3 has a low amplitude and is protracted. Some studies also indicate that the Mn peaks of MIS 5 can be separated into three distinct peaks of MIS 5.1, 5.3 and 5.5 (Jakobsson et al., 2001; Löwemark et al., 2016), and the thickness of the individual peaks in MIS 5 are also greater than MIS 1. Therefore, Mn variations can potentially be used not only to correlate between different cores, but also provide a basic tool for general age control.

However, while the Mn peaks can be efficiently used to distinguish warm interglacial or interstadial periods, to identify which interglacial period requires further correlation with other cores and the application of additional age control markers. The application of Mn variations as a stratigraphic tool in Arctic sediment cores still faces several limitations in spite of its convenience and availability. For instance, core top sediment lost during coring may bias the Mn variation as a correlation tool. Furthermore, the hiatus often observed in MIS 2 (Jakobsson et al., 2014a; O'Regan et al., 2008) may also sometimes be overlooked, resulting in a downward offset in the correlation of Mn peaks. The MIS 2 hiatus is often indistinguishable without other proxies such as lithology (e.g. sediment color), foraminifera abundance, or IRD content.

The aim of this study is to investigate the occurrence of Mn peaks, and IRD abundances within the range of radiocarbon dating, to better constrain their stratigraphic occurrence and synchroneity between multiple records, especially for the period covering the transition from the last glacial to the present interglacial period – from late MIS 3 to the Holocene. We calculate the IRD content of the sediment, providing another proxy for differentiating the interstadial period MIS 3 from the Holocene in cores where the MIS 2 hiatus exists. To correctly identify glacial intervals in the records, even if extremely thin, is important to perform downcore correlations between sedimentary archives from different regions of the Arctic. Partially or completely overlooked glacial intervals may introduce propagating stratigraphic errors that render any paleoenvironmental interpretations invalid.

2. Material and methods

2.1. Core materials

The core material used in this study is mainly from the Lomonosov Ridge off Greenland (LOMROG) expeditions in 2007, 2009, and 2012 (Fig. 2). Additional cores from the Arctic Ocean 1996 (AO96) cruise are included (Table 1).

X-radiographs were produced from sediment slabs at MARUM, Bremen University, or the Institute of Oceanography at National Taiwan University (IONTU) (cf. Werner, 1967; Löwemark and Werner, 2001). The high resolution XRF- profiles for most cores were obtained using the ITRAX-XRF scanner at Stockholm University, while some of the ITRAX-XRF scanning was performed on the radiograph core slabs at the National Taiwan University ITRAX lab. The XRF results of Mn and Ca were used to select intervals for AMS ^{14}C dating. A total of 18 cores were selected for AMS dating in the upper 25 cm. Samples were deemed to contain the Holocene and/or MIS 3 period, based on the occurrence of one or two diagnostic brown layers identified during core description. The selected cores were subsampled at 1 cm continuous intervals. Samples were freeze dried and wet-sieved through a mesh size of 63 μm. The fraction of the sediment >63 μm was dried at 50 °C. The coarse fractions of the sediment were used to determine the ice rafted debris (IRD) content and to pick foraminifera for AMS ^{14}C dating. Here, the IRD was defined as coarse grains larger than 250 μm that were transported by either sea ice or icebergs (Nørgaard-Pedersen et al. (2007).

2.2. Laboratory analysis

In this study, AMS ^{14}C dating was conducted on monospecific samples of the polar planktonic foraminifera *Neogloboquadrina pachyderma* (sinistral). For AMS dating, 0.01 ± 0.003 g of tests were picked from each sample. The foraminifer tests were ultrasonicated with methanol in order to physically remove any nannofossils or organic material attached to the porous surface, and washed 3 times with deionized water. The tests were immersed in

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