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Variability of neodymium isotopes associated with planktonic foraminifera in the Pacific Ocean during the Holocene and Last Glacial Maximum

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ABSTRACT

The deep Pacific Ocean holds the largest oceanic reservoir of carbon which may interchange with the atmosphere on climatologically important timescales. The circulation of the deep Pacific during the Last Glacial Maximum (LGM), however, is not well understood. Neodymium (Nd) isotopes of ferromanganese oxide coatings precipitated on planktonic foraminifera are a valuable proxy for deep ocean water mass reconstruction in paleoceanography. In this study, we present Nd isotope compositions (ε_{Nd}) of planktonic foraminifera for the Holocene and the LGM obtained from 55 new sites widely distributed in the Pacific Ocean. The Holocene planktonic foraminiferal ε_{Nd} results agree with the proximal seawater data, indicating that they provide a reliable record of modern bottom water Nd isotopes in the deep Pacific. There is a good correlation between foraminiferal ε_{Nd} and seawater phosphate concentrations ($R^2 = 0.80$), but poorer correlation with silicate ($R^2 = 0.37$). Our interpretation is that the radiogenic Nd isotope is added to the deep open Pacific through particle release from the upper ocean during deep water mass advection and aging. The data thus also imply the Nd isotopes in the Pacific are not likely to be controlled by silicate cycling. In the North Pacific, the glacial Nd isotopic compositions are similar to the Holocene values, indicating that the Nd isotope composition of North Pacific Deep Water (NPDW) remained constant (−3.5 to −4). During the LGM, the southwest Pacific cores throughout the water column show higher ε_{Nd} corroborating previous studies which suggested a reduced inflow of North Atlantic Deep Water to the Pacific. However, the western equatorial Pacific deep water does not record a corresponding radiogenic excursion, implying reduced radiogenic boundary inputs during the LGM probably due to a shorter duration of seawater–particle interaction in a stronger glacial deep boundary current. A significant negative glacial ε_{Nd} excursion is evident in mid-depth (1–2 km) cores of the eastern equatorial Pacific (EEP) which may suggest a stronger influence of NPDW return flow to the core sites and decreased local input in the EEP. Taken together, our Nd records do not support a dynamically slower glacial Pacific overturning circulation, and imply that the increased carbon inventory of Pacific deep water might be due to poor high latitude air–sea exchange and increased biological pump efficiency in glacial times.

1. Introduction

Neodymium isotopes have been widely used as a water mass source proxy, as the $^{143}Nd/^{144}Nd$ ratio varies systematically in different water masses (Goldstein and Hemming, 2003). Nd isotopic composition is expressed as ε_{Nd} and compared to the Chondritic Uniform Reservoir (CHUR) composition ($^{143}Nd/^{144}Nd = 0.512638$; Jacobsen and Wasserburg, 1980): $\varepsilon_{Nd} = [(^{143}Nd/^{144}Nd)_{measured}/(^{143}Nd/^{144}Nd)_{CHUR} - 1] * 10000$. The relatively short residence time (360–700 yr) of Nd in the ocean (Rempfer et al., 2011; Siddall et al., 2008; Tachikawa et al., 2003) does not allow Nd isotopes to be homogenized throughout the deep ocean, but enables its signatures to be transported by deep currents. A global compilation of seawater Nd isotope composition (Lacan et al., 2012) shows a gradual ε_{Nd} increase of intermediate and deep water masses from the Northwest Atlantic, via the Southern Ocean to the Indian and the Pacific oceans, demonstrating the useful-

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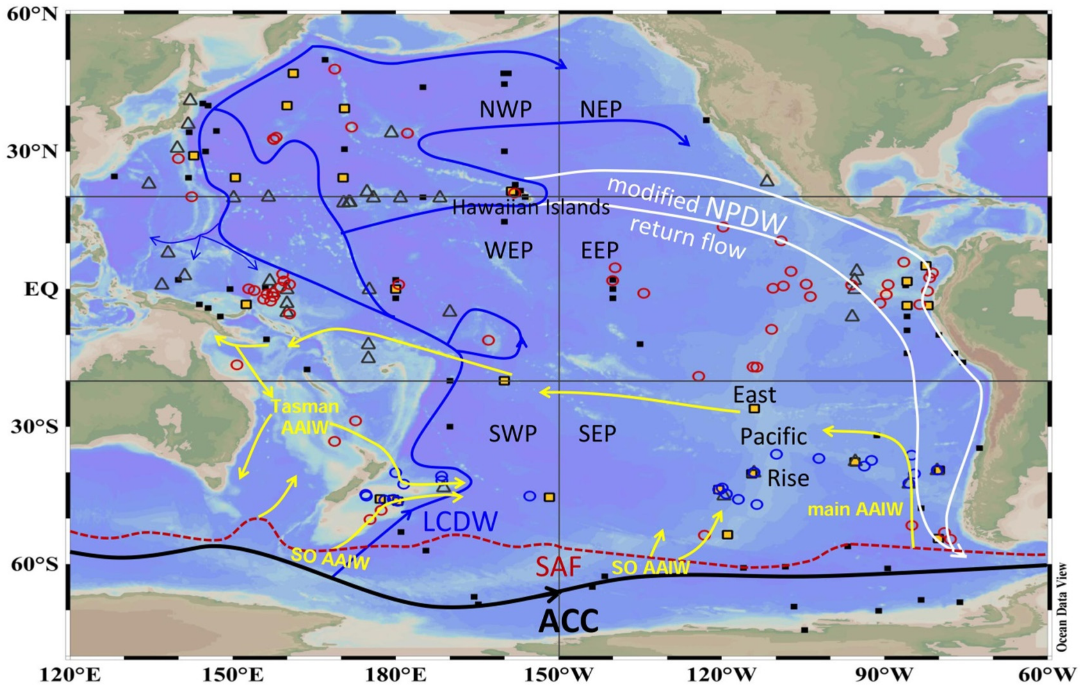

Fig. 1. Locations of the samples in oceanographic setting with schematic flow patterns (modified from Kawabe and Fujio, 2010). Red open circles: foraminifera samples from this study; blue open circles: previously published foraminifera samples (Elderfield et al., 2012; Molina-Kescher et al., 2014b; Noble et al., 2013); grey open triangles: previously published fish debris samples (Basak et al., 2010; Horikawa et al., 2011; Molina-Kescher et al., 2014b); black/orange filled squares: seawater stations with reported Nd isotopes (Amakawa et al., 2013; Basak et al., 2015; Carter et al., 2012; Grasse et al., 2012; Grenier et al., 2013; Jeandel et al., 2013; Lacan et al., 2012 and references therein; Molina-Kescher et al., 2014a); orange squares with black rim are those seawater stations used for core–top Nd isotope calibration (Fig. 4). Red dashed line represents the modern Subantarctic Front (SAF). Black bold line: Antarctic Circumpolar Current (ACC); blue line: Lower Circumpolar Deep Water (LCDW); yellow line: Antarctic Intermediate Water (AAIW); white line: modified North Pacific Deep Water (NPDW) return flow. The cores are further divided into five regions by latitudes (20°N and 20°S) and longitude (150°W): Northwest Pacific (NWP), Western Equatorial Pacific (WEP), Eastern Equatorial Pacific (EEP), Southwest Pacific (SWP) and Southeast Pacific (SEP). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

ness of Nd isotopes for studying water mass provenances. Besides riverine and aeolian inputs, seawater–sediment interactions near the continental margin or volcanic islands (Abbott et al., 2015; Amakawa et al., 2009; Jeandel and Oelkers, 2015; Lacan and Jeandel, 2001) have been proposed to play an important and perhaps dominant role for the Nd budget. Thus the use of Nd isotope as a water mass tracer reflects the balance between the rate of water mass advection and the rate of local Nd addition via seawater–particle interaction. Reliable interpretation of Nd isotopic records as a paleoceanographic proxy for intermediate and deep water circulation therefore depends on knowledge of the variability of these boundary sources in the ocean basins.

Various fractions of marine sediments have been used to extract the past seawater Nd signatures. Among them, the use of planktonic foraminifera allows a continuous high-resolution record to be measured and directly compared to other geochemical proxies to reconstruct paleoenvironment and paleoclimate conditions. A growing body of evidence suggests that Nd isotopic signatures of sedimentary uncleaned planktonic foraminifera correspond to bottom water values (Roberts et al., 2012; Tachikawa et al., 2014). However, to date most of the foraminifera Nd data have been collected in the Atlantic, to a lesser extent in the Indian Ocean and South Pacific, while the Pacific Ocean as a whole has been poorly investigated, especially during the glacial times when the deep Pacific may have been a larger carbon pool (Jaccard and Galbraith, 2012).

A study of the conservative behavior of Nd isotopes in the North Pacific using fish teeth (Horikawa et al., 2011) has suggested that high rates of Nd inputs from volcanic islands/arcs in the subarctic North Pacific and western equatorial Pacific are important sources of radiogenic Nd isotopes to the Pacific, and also implied that the EEP is a region with conservative mixing in terms of Nd isotopes. This contrasts with a recent seawater study indicating Nd isotope compositions of the EEP are strongly influenced by local inputs (Grasse et al., 2012). A better understanding of the control of Nd isotope distribution in the modern Pacific is therefore needed. Interestingly, pore fluid Nd isotope measurements from the Oregon margin (Abbott et al., 2015) revealed that the overlying water mass Nd isotopes were modified by the benthic Nd flux, and proposed that the deep Pacific ε_{Nd} is controlled by sedimentary “bottom up” flux. One major uncertainty, however, is that the reactivity of sediments may vary in different locations with different types of materials (Dupré et al., 2003) and the extrapolation of such findings to the whole Pacific Nd isotope distribution thus warrants more investigation.

In this study, we look into these issues based on a spatially comprehensive analysis of Nd isotopes on planktonic foraminiferal coatings from 55 new cores distributed throughout the Pacific Ocean. By comparing the Holocene foraminiferal ε_{Nd} with previously reported seawater data, the reliability of uncleaned planktonic foraminifera for recording Pacific bottom water ε_{Nd} is discussed as well as the major control of the spatial ε_{Nd} distribution in the deep Pacific. We also performed Nd isotope analyses on samples from the LGM, and inferred changes in glacial Pacific Nd isotope inputs as well as in the deep ocean circulation.

2. Modern oceanography

As there is no deep water formation in the North Pacific today, the modern deep Pacific is exclusively ventilated by Southern Component Water (SCW) originating from the Antarctic Circumpolar Current (ACC) as either Lower/Upper Circumpolar Deep Water (LCDW/UCDW) below 2 km, or Antarctic Intermediate Water (AAIW) at 0.5–1.5 km depths (Fig. 1). LCDW itself is a mixture of Antarctic Bottom Water (AABW) and North Atlantic Deep Water (NADW). The advection of residual NADW to the west-