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Neodymium isotopic composition of intermediate and deep waters in the glacial southwest Pacific

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ABSTRACT

Neodymium (Nd) isotopes, tracers of deep water mass source and mixing, were measured on sedimentary planktic foraminifera with authigenic coatings from a depth-transect of cores (1400–4800 m) from Chatham Rise in the southwest Pacific, over the past 30 ka. We observe deglacial variations in the Nd isotopic composition, which showed an average glacial composition of $\varepsilon_{Nd} = -5.0$ (1σ; ± 0.3 $n = 4$) for cores sites below 3200 mbsl. No significant deglacial variation was observed in the Nd isotopic composition of intermediate depth waters (1400 mbsl), in contrast with benthic foraminifera δ^{13}C data. The deglacial ε_{Nd} shift of CDW in the southwest Pacific is consistent with changes observed in the deep South Atlantic and Equatorial Indian Ocean, but ε_{Nd} values are offset by $\sim 1\varepsilon_{Nd}$-unit to more radiogenic values throughout the deglacial records, likely due to admixture of a Nd isotope signal which was modified in the Southern Ocean or Pacific, perhaps by boundary exchange. However, this modification did not overprint the deglacial Nd isotope change. The consistent deglacial evolution of ε_{Nd} in the South Atlantic, Equatorial Indian and southwest Pacific CDW, is evidence for the connection of CDW during the glacial, and propagation of diminished North Atlantic Deep Water export to the glacial Southern Ocean. In contrast, spatial heterogeneities in the benthic foraminifera δ^{13}C of CDW have been observed in the Atlantic, Indian and Pacific basins of the deep glacial Southern Ocean. The Nd isotope data implies a well-connected deep Southern Ocean, which transported waters from the Atlantic to the Indian and Pacific oceans, during the glacial. This suggests that basin-scale variability in the glacial δ^{13}C composition of CDW was unrelated to circulation changes.

1. Introduction

The carbon isotope composition (δ^{13}C) of seawater in the deep ocean today shows a continuous decrease from the Atlantic to Pacific Ocean, due to an increase in dissolved CO_2 fixed by primary producers along the global thermohaline circulation. Today Circumpolar Deep Water (CDW) has a homogeneous δ^{13}C value of 0.5‰ in the Atlantic, Indian and Pacific sectors of the Southern Ocean (Kroopnick, 1985). However, during the last glacial, distinct heterogeneities have been observed in the δ^{13}C of CDW between the Southern Ocean basins. For example, the δ^{13}C values of benthic foraminifera (*Cibicidoides* spp.) living in glacial CDW were higher in the Pacific (−0.5 to −0.2‰; Ninnemann and Charles, 2002; Moy et al., 2006; McCave et al., 2008) compared to the Atlantic sector (−0.7 to −0.9‰; Hodell et al., 2003). Different hypotheses have been invoked to explain the regional heterogeneities in the benthic δ^{13}C distribution of the glacial Southern Ocean, including changes in the mode of Southern Ocean deep water formation (Ninnemann and Charles, 2002), and the separation of glacial deep waters by topographic highs (∼3500 m) (McCave et al., 2008). This study builds upon the work of McCave et al. (2008), which inferred no changes in the water mass structure of the southwest Pacific between the glacial and Holocene. We test these hypotheses using neodymium (Nd) isotopes to trace changes in the source and advection of CDW in the glacial Southern Ocean.

1.1. Nd isotopes

We used unclean sedimentary planktic foraminifera to reconstruct the Nd isotopic composition of water masses in the southwest Pacific and constrain changes in water mass mixing during the past 30 ka. The Nd isotopic composition (^{143}Nd/^{144}Nd) is expressed as ε_{Nd}, where $\varepsilon_{Nd} = [(^{143}\text{Nd}/^{144}\text{Nd}_{(\text{measured})}/^{143}\text{Nd}/^{144}\text{Nd}_{(\text{CHUR})}) - 1] \times 10^4$, and the Chondritic Uniform Reservoir, $^{143}\text{Nd}/^{144}\text{Nd}_{(\text{CHUR})} = 0.512638$ (Jacobsen and Wasserburg, 1980). The ε_{Nd} of surface seawater is determined by the composition of fluvial and aeolian inputs from the continents surrounding ocean basins (Frank, 2002) and the release of dissolved Nd from ocean margins (termed "boundary exchange" Lacan and Jeandel, 2001).

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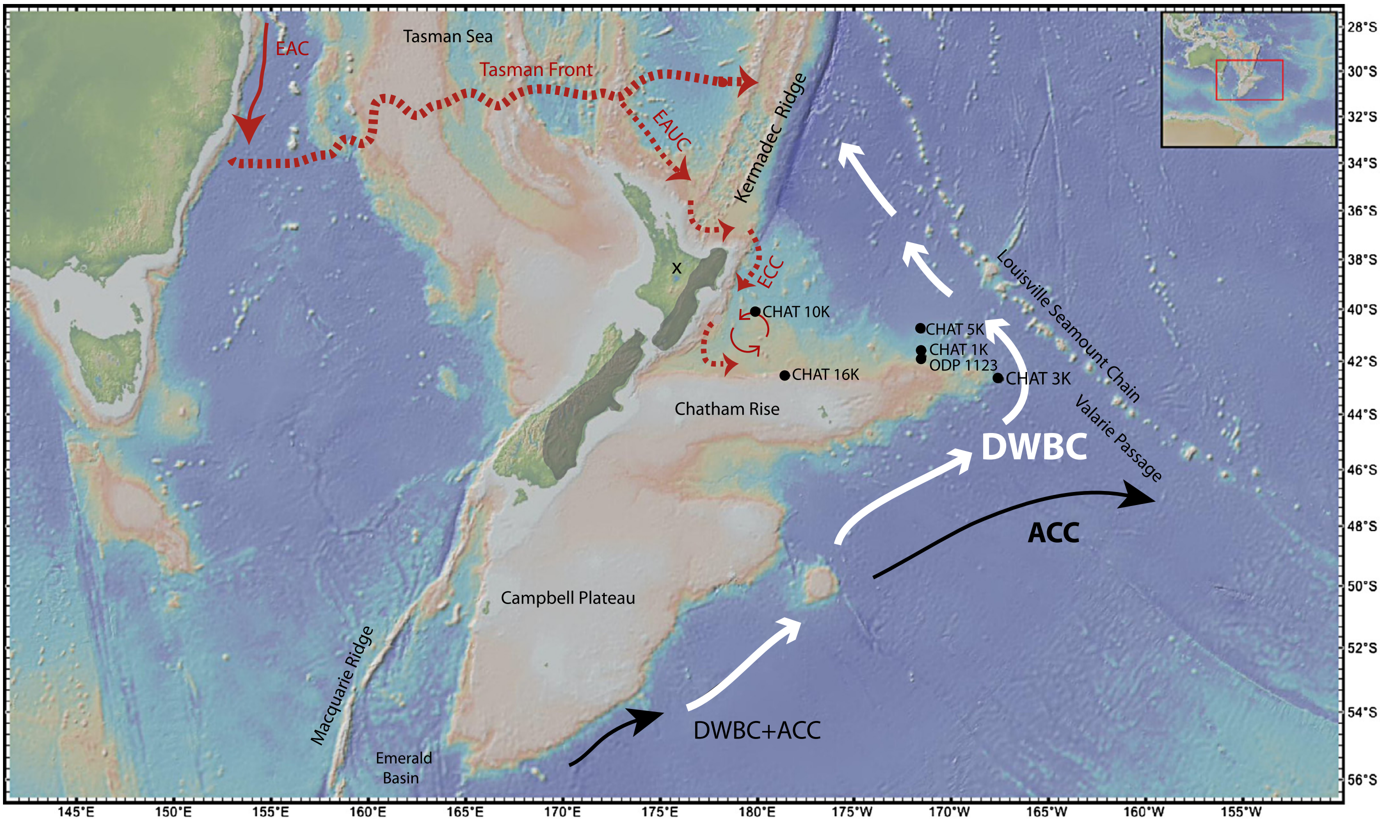

Fig. 1. Regional map showing the location of the study region and modern circulation in the southwest Pacific. DWBC: deep western boundary current, ACC: Antarctic Circumpolar Current, EAC: East Australian Current, EAUC: East Auckland Current, ECC: East Cape Current. The four core sites studied (CHAT 16K, 10K, 5K and 3K) are shown in relation to CHAT 1K and ODP1123 (Elderfield et al., 2012). The grey shaded region of New Zealand denotes the presence of Torlesse terrane geology. The cross on the North Island is the location of the Taupo Volcanic Zone (GeoMapApp).

The surface water signal is transferred to the deep ocean at locations of convection and deep water mass formation, such as the Nordic and Labrador Seas sites of NADW formation and the Weddell Sea where AABW forms. The shorter residence time of Nd in the ocean (300–1000 yr; Tachikawa et al., 2003) compared to deep ocean mixing, plus the absence of biological fractionation processes, results in deep water masses preserving distinct Nd isotopic compositions. Today, North Pacific Deep Water (NPDW) has radiogenic values ($\varepsilon_{Nd} = -3.9 \pm 0.7$; Piepgras and Jacobsen, 1988) due to weathering inputs from the surrounding young mantle-derived rocks. In contrast North Atlantic Deep Water (NADW) has a less radiogenic composition ($\varepsilon_{Nd} = -13.5 \pm 0.4$; Piepgras and Wasserburg, 1987) due to inputs from old continental crust. The Nd isotopic composition of CDW ($\varepsilon_{Nd} = -8$ to -9) reflects mixing between these two water masses in the open ocean where Nd behaves conservatively (Piepgras and Wasserburg, 1982; Stichel et al., 2012; Carter et al., 2012). Ocean water masses can therefore be traced along the thermohaline circulation using Nd isotopes in the present and past ocean (Piepgras and Wasserburg, 1980; Rutberg et al., 2000).

Sedimentary planktic foraminifera were physically processed to remove foreign particles (e.g. clays) in order to limit contamination from volcanogenic minerals present in the sediment. An increasing number of studies have validated the use of unclean sedimentary planktic foraminifera as a reliable method to reconstruct bottom water Nd isotopic signals in a range of different oceanographic settings and sedimentary environments (cf. Roberts et al., 2010; Elmore et al., 2011; Piotrowski et al., 2012; Tachikawa et al., 2013). We also present Nd isotopic data of reductive sediment leaches and detrital dissolutions in discussion of the processes controlling the Nd isotopic composition recorded in the sedimentary planktic foraminifera.

The majority of seawater studies in the Pacific Ocean have been carried out in the North Pacific (cf. Lacan et al., 2012), Equatorial region (Amakawa et al., 2000; Lacan and Jeandel, 2001; Tazoe et al., 2011; Grasse et al., 2012; Grenier et al., 2013), and the southeast Pacific sector of the Southern Ocean (Carter et al., 2012). Although few modern seawater Nd isotopic data have been reported for the South Pacific, a compilation of existing seawater data shows that the South Pacific basin has an ε_{Nd} of around -5.6 (Lacan et al., 2012). The central South Pacific shows a gradient in ε_{Nd} with depth, displaying more radiogenic ε_{Nd} values (-4.7 ± 0.7) at 2500 m and less radiogenic values ($\varepsilon_{Nd} = -8.1 \pm 0.6$) at 4500 m (Piepgras and Wasserburg, 1982). A similar gradient in ε_{Nd} with depth is observed in the southeastern Pacific basin, but with more radiogenic deep and intermediate waters (Jeandel et al., 2013). These vertical characteristics in the Nd isotope compositions in the South Pacific result from northward-flowing deep water with less radiogenic ε_{Nd}, which originate in the Southern Ocean, and southward-flowing mid-depth water with more radiogenic ε_{Nd} that originate in the North Pacific. The deep waters become increasingly more radiogenic (values of up to $\varepsilon_{Nd} = -2$) as they flow northward due to input of radiogenic Nd signatures to the water column (Lacan and Jeandel, 2001, 2005; Horikawa et al., 2011; Grasse et al., 2012; Jeandel et al., 2013).

1.2. Water masses in the southwest Pacific

This study is located on the southeastern continental margin of New Zealand, at the main entry point for CDW into the Pacific Basin, transported by the deep western boundary current (DWBC) (Fig. 1). The DWBC inflow to the Pacific Ocean is one of