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Deep sea corals off Brazil verify a poorly ventilated Southern Pacific Ocean during H2, H1 and the Younger Dryas

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ABSTRACT

Simultaneous ^{14}C and Th/U dating of deep sea corals are useful for reconstructing the intensity of deep ocean circulation in the past, as they deliver the time between the gas exchange of the water with the atmosphere and the incorporation of the ^{14}C in the carbonates (Adkins and Boyle, 1997; Adkins et al., 1998; Mangini et al., 1998). Th/U ages of deep sea corals sampled in sediment cores from locations off the coast of Brazil bathed by Antarctic Intermediate Water at depths between 600 and 800 m group close to Heinrich events H2, H1 and the Younger Dryas. The $\Delta^{14}C$ of the water bathing the corals starts to decrease approximately 2 kyr before the Heinrich events and decreases to values 400‰ lower than the corresponding back tracked atmospheric values. The timing and the magnitude of the decrease is similar to that observed in intermediate water in the N. Pacific off Baja California (Marchitto et al., 2007) and in the Eastern Pacific (Stott et al., 2009). High ventilation ages, partly exceeding 4000 years, are an unambiguous indication for a reduction of North Atlantic deep water formation during H2, H1 and the YD, as deduced from higher $^{231}Pa/^{230}Th$ activity ratios and from εNd in N. Atlantic Ocean sediments (McManus et al., 2004; Pahnke et al., 2008; Yu et al., 1996). They also could indicate a poorly oxygenated Southern Pacific Ocean at the end of the Heinrich events.

1. Introduction

The strength of the Atlantic Meridional Overturning Circulation is believed to have crucial influence on global climate. Several different proxies, such as $^{231}Pa/^{230}Th$ activity ratios in sediments and εNd in the post depositional Fe–Mn coatings of sediments have been applied for reconstruction of the deep water structure and strength (McManus et al., 2004; Pahnke et al., 2008; Yu et al., 1996). Deep sea corals provide another high resolution archive of ocean circulation as they record calendar age (U/Th ages) and ^{14}C concentration of the surrounding water masses (Mangini et al. 1998; Adkins et al. 1998). Accordingly, they are a direct archive for atmospheric ^{14}C variations, ageing of water masses and hence circulation changes. Robinson et al. (2005) detected pronounced switches between radiocarbon-enriched and depleted waters during the deglaciation in the Western North Atlantic. The available data support the concept of reduced NADW export during H1 and probably earlier Heinrich Events as well. However, this concept urgently needs validation.

2. Sample locations

We analyzed deep sea corals sampled in sediments taken from off the shore of Brazil, from two locations that are about 400 km apart (Fig. 1). These localities are bathed today by Antarctic Intermediate Water (AAIW). It irrigates the middle slope between 550 m and 1200 m (Viana et al., 1998).

The two sediment cores taken: Piston core ENG-111, hereafter referred to as core C1, Campos Basin continental slope, water depth 621 m; Piston core 21210009, hereafter referred to as core C2, Santos Basin continental slope, water depth 781 m. C1 was sampled on an elongated mud mound with abundant coral bushes and recovered specimens of *Lophelia pertusa*. Core C2 was taken in a pockmark field and recovered both *L. pertusa* and *Solenosmilia variabilis*. In both cores, the sediment consists of hemipelagic mud (marl, carbonate-rich and carbonate-poor mud) with biogenic components consisting mainly of coral fragments and planktonic foraminifera. The carbonate coral mounds in the Campos Basin where C1 was taken were first reported by Viana et al. (Viana et al., 1998). C2 was collected in a pockmark field in

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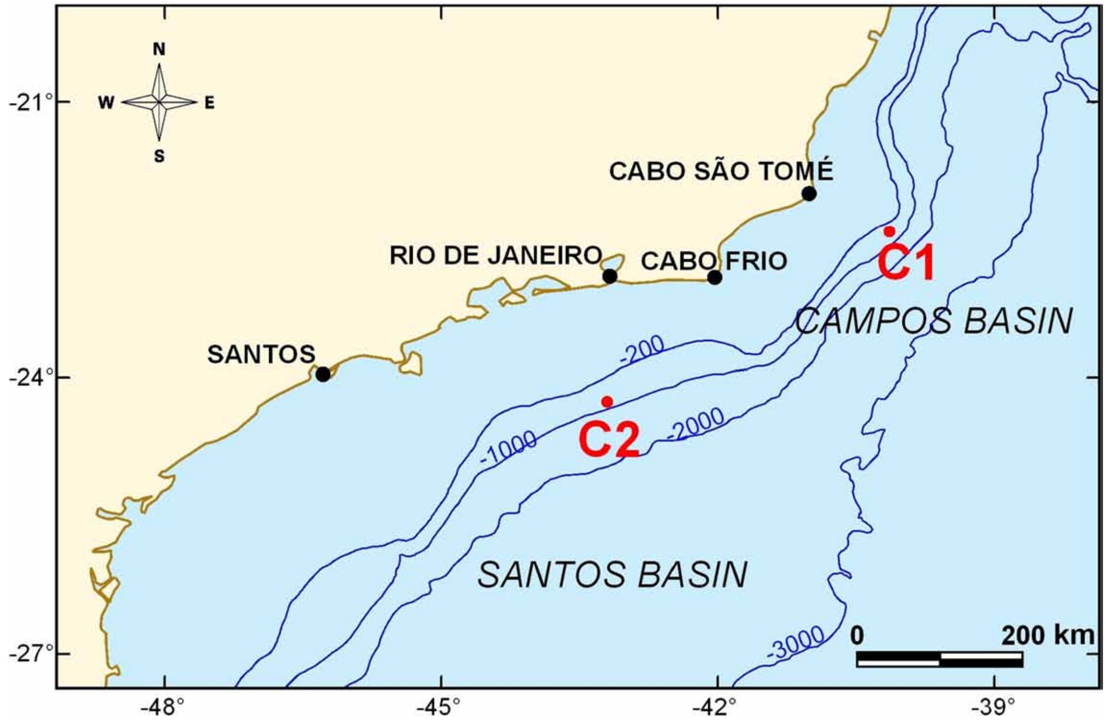

Fig. 1. Location of the sediment cores C1 and C2.

the opposite end of the Santos Basin. The morphology there is similar to the one described by Sumida et al. (2004).

The corals occur throughout about half of the sediment columns for C1 and C2 cores, as shown on Fig. 2. A darker sediment section from 300 cm to the basis of C1 at 380 cm does not display corals. Similarly, core C2 displays no corals in the section between 70 and 220 cm depth.

3. Methods

3.1. Th/U dating of the corals in cores C1 and C2

Coral samples for Th/U dating were taken from approximately 300 cm thick top sections of cores C1 and C2. A first series of samples from core C1 consisted of few mg of materials, as they were the remains of the corals used for ^{14}C dating. These samples have only been cleaned with water and were therefore partly contaminated with ^{230}Th and ^{232}Th adsorbed on their surface. Consequently, they also have larger uncertainties of the ages. They are marked on Table 1 as "old series". Instead, all the samples from core C2 and a second series from core C1 consisted of larger pieces that had been precleaned with ultrasonic and mechanical procedures, followed by gentle dilution in 0.1 N HNO_3 steps, as described elsewhere (Schröder-Ritzrau et al., 2003).

The sample weights ranged from 0.1 to 0.6 g. The solutions were spiked with a ^{233}U/^{236}U double spike and a ^{229}Th spike. Uranium and thorium were isolated by iron co-precipitation and anion exchange columns (Dowex 1X8). The samples were loaded on a preheated rhenium filament and thorium and uranium were measured with a multicollector mass spectrometer (Finnigan MAT 262 RPQ) following instrumental analysis described by Scholz et al. (2004). The Th/U ages of deep sea corals were corrected for initial ^{230}Th, which does not accrue from decay of ^{234}U in the sample, as described by Cheng et al. (2000). The calibration of our spikes is based on the same HU-1 reference material used by N. Frank (Frank et al., 2009). This calibration is in very good agreement with that applied in Bristol (Hoffmann, pers. comm.).

The results derived for the coral samples in sediment cores C1 and C2 are listed in Table 1. Uncorrected and corrected ages are listed in two columns together with their 2 sigma uncertainties, respectively. This correction is performed using the ^{232}Th content of the samples under the assumption of an activity ratio of ^{230}Th/^{232}Th in the water column of 8 ± 4 (Frank et al., 2009; Schröder-Ritzrau et al., 2003). The uncertainty of this correction was propagated into the age uncertainty. After the correction five samples of the old series with ^{232}Th contents exceeding a 10 ng/g plot on the depth/age relationship (Fig. 3) close to samples with negligible corrections suggesting that the applied correction factor is approximately right. Nevertheless, these five samples with ^{232}Th contents exceeding 10 ng/g were rejected for the determination of Δ^{14}C.

All the initial δ^{234}U values of corals from C1 and C2 in the section between 8000 and 15,000 years (Fig. 4) are within the expected range for the present day sea water of 146.6–149.6‰ (Delanghe et al., 2002 ; Robinson et al., 2004). The average of these samples, 145.5 ± 3.4‰, comes close to the average initial δ^{234}U of 148 ± 3.5‰ observed in cogenetic corals in the N. Atlantic (Frank et al., 2009). In contrast, the corals in the section between 15,000 years and 20,000 years display a slightly lower initial δ^{234}U of 139.9 ± 2.9‰ than the samples in the younger section. These lower values could be interpreted either as due to diagenetic alteration of the samples or to a lower δ^{234}U of glacial sea water. We exclude diagenetic processes as the cause of the lower glacial values in corals off Brazil because glacial reef corals off Barbados and Papua also display lower δ^{234}U values than younger ones, as compiled by Esat (Esat and Yokoyama, 2006). The lower glacial values in the corals off Brazil support their conclusion of variable uranium isotope composition in the ocean over glacial-interglacial scales. In summary, except for two samples from core C2 at depths below 220 cm, corresponding to the last Interglacial period, the initial δ^{234}U shows no increase with age, as one would expect for older samples being exposed for longer time to exchange with sea water uranium (Neff et al., 1999).

3.2. ^{14}C dating and derivation of Δ^{14}C in cores C1 and C2

The ^{14}C dating of coral samples was performed at the Keck-CCAMS facility, USA, and at the ^{14}C AMS Lab of the ETH-Zurich. Both labs require graphite samples to perform ^{14}C measurements on their Accelerator