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Origin of increased terrigenous supply to the NE South American continental margin during Heinrich Stadial 1 and the Younger Dryas

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ABSTRACT

We investigate the redistribution of terrigenous materials in the northeastern (NE) South American continental margin during slowdown events of the Atlantic Meridional Overturning Circulation (AMOC). The compilation of stratigraphic data from 108 marine sediment cores collected across the western tropical Atlantic shows an extreme rise in sedimentation rates off the Parnaíba River mouth (about 2°S) during Heinrich Stadial 1 (HS1, 18–15 ka). Sediment core GeoB16206-1, raised offshore the Parnaíba River mouth, documents relatively constant $^{143}Nd/^{144}Nd$ values (expressed as $\varepsilon_{Nd(0)}$) throughout the last 30 ka. Whereas the homogeneous $\varepsilon_{Nd(0)}$ data support the input of fluvial sediments by the Parnaíba River from the same source area directly onshore, the increases in Fe/Ca, Al/Si and Rb/Sr during HS1 indicate a marked intensification of fluvial erosion in the Parnaíba River drainage basin. In contrast, the $\varepsilon_{Nd(0)}$ values from sediment core GeoB16224-1 collected off French Guiana (about 7°N) suggest Amazon-sourced materials within the last 30 ka. We attribute the extremely high volume of terrigenous sediments deposited offshore the Parnaíba River mouth during HS1 to (i) an enhanced precipitation in the catchment region and (ii) a reduced North Brazil Current, which are both associated with a weakened AMOC.

1. Introduction

The North Brazil Current (NBC) constitutes an important conduit for the transfer of warm and salty surface waters into the high latitudes of the North Atlantic (Fig. 1), balancing the southward export of North Atlantic Deep Water (NADW) (Johns et al., 1998). The NBC is also responsible for the northwestward transport of an enormous amount of freshwater and terrigenous sediment delivered to the ocean by the Amazon River that amount to about 2×10^6 m^3/s and 40 t/s, respectively (Lentz, 1995; Allison et al., 2000). Instrumental data and model simulations showed that the NBC transport is positively correlated with the strength of the Atlantic Meridional Overturning Circulation (AMOC) on decadal timescales (Zhang et al., 2011). Based on stable isotope and Mg/Ca records, other studies (i.e. Arz et al., 1999; Wilson et al., 2011) also suggested a marked decrease in the NBC strength related to millennial-scale AMOC slowdown events of the last deglaciation, such as the Younger Dryas (YD, 13–11.5 ka) and Heinrich Stadial 1 (HS1, 18–15 ka). Modeling simulations of freshwater input into the high latitudes of the North Atlantic were even able to trigger a reversal of the NBC under both present-day (Chang et al., 2008) and Last Glacial Maximum (LGM, 23–19 ka) conditions (Schmidt et al., 2012).

Millennial-scale abrupt changes in AMOC strength during the last deglaciation greatly influenced the South American Monsoon System (SAMS) and the mean position of the Intertropical Convergence Zone (ITCZ). For example, northeastern (NE) Brazil, which is today characterized by a semi-arid climate, experienced wet conditions during HS1 and the YD in response to a southward displacement of the tropical rainbelt. Enhanced rainfall over NE Brazil asso-

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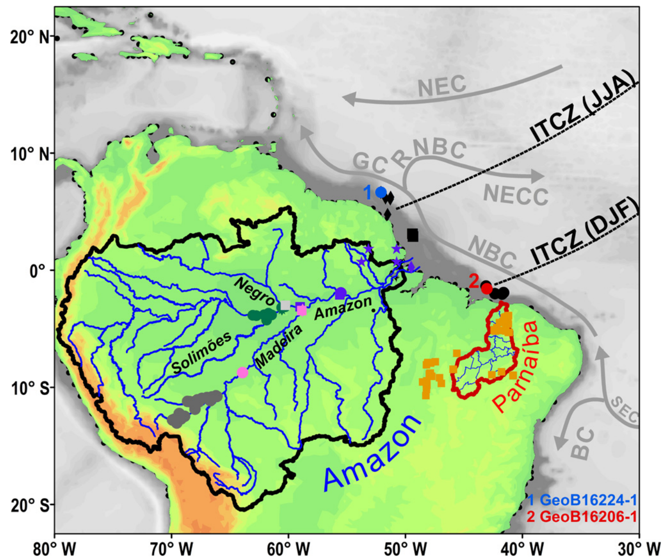

Fig. 1. Location of terrestrial samples in the Amazon and Parnaíba River drainage basins, as well as marine sediment cores used in this study (key to symbols are given in Fig. 4). The red and blue dots represent sediment cores GeoB16206-1 and GeoB16224-1, respectively. The schematic position of the Intertropical Convergence Zone (ITCZ) (black dashed line) during June–July–August (JJA) and December–January–February (DJF) and surface currents (grey arrows) in the western tropical Atlantic Ocean are also shown (Johns et al., 1998). BC: Brazil Current, GC: Guiana Current, NBC: North Brazil Current, NEC: North Equatorial Current, NECC: North Equatorial Counter Current, RNBC: Retroflection of the North Brazil Current, SEC: South Equatorial Current. The map was plotted using the Ocean Data View software (version 4.6.2) (Schlitzer, R., http://odv.awi.de, 2014). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

ciated with slowdown of the AMOC was documented by terrestrial archives like stalagmite isotopic records (i.e. Wang et al., 2004; Cruz et al., 2009) and also simulated by freshwater-hosing experiments with different coupled climate models (i.e. Zhang and Delworth, 2005; Jaeschke et al., 2007). The large increase in terrigenous sediments offshore NE Brazil during HS1 and the YD, observed in geochemical and palynological data of marine sediment cores, was interpreted as the product of massive fluvial input from the adjacent continent (Arz et al., 1998; Jennerjahn et al., 2004; Dupont et al., 2010). However, the role of the NBC (in particular its potential reversal) in the redistribution and deposition of terrigenous sediments on the NE South American continental margin remains unknown. If the NBC indeed reversed during slowdown events of the AMOC, the Amazon sediment discharge could be transported southeastwards rather than northwestwards and thus impedes robust interpretation of oceanic paleorecords offshore NE Brazil.

Here we reconstruct the provenance and distribution of terrigenous sediments off NE South America over the last 30 ka. We mainly focus on HS1, which was characterized by the longest perturbation in the AMOC of the last 30 ka (Böhm et al., 2015). First, we map the distribution of sedimentation rates off NE South America during the LGM and HS1 based on 108 marine sediment cores. Second, by using two marine sediment cores located under the influence of the NBC to the northwest and to the southeast of the Amazon River mouth, we analyze neodymium (Nd) isotopic compositions to determine changes in sediment provenance throughout the last 30 ka. We verify that (i) the terrigenous sediments deposited offshore NE Brazil during the last 30 ka are not compatible with an Amazon origin, and (ii) the NBC was very unlikely reversed during HS1. Furthermore, major element compositions from the two cores allow insight into the relationship between changes in continental climate and weathering patterns.

Table 1
Sediment cores and near-core-top samples from MSM20/3 used in this study.

Sediment core	Latitude	Longitude	Water depth (m)	Nd isotope analysis*
GeoB16203-1	2°02.11′S	41°43.11′W	1591	10 cm[a]
GeoB16204-2	1°59.75′S	42°20.31′W	1211	10 cm[a]
GeoB16205-4	1°21.11′S	43°05.80′W	1955	10 cm[a]
GeoB16206-1	1°34.75′S	43°01.42′W	1367	Downcore[a,b]
GeoB16211-3	2°52.69′N	49°20.98′W	56	10 cm[a]
GeoB16212-3	3°06.27′N	49°23.28′W	75	10 cm[a]
GeoB16216-3	6°14.43′N	51°15.34′W	2833	10 cm[a]
GeoB16217-2	6°04.17′N	51°17.41′W	2440	10 cm[a]
GeoB16218-4	4°46.17′N	51°31.33′W	41	10 cm[a]
GeoB16219-2	4°45.15′N	51°31.27′W	38	10 cm[a]
GeoB16220-1	4°43.41′N	51°30.82′W	31	10 cm[a]
GeoB16222-1	6°09.31′N	51°41.60′W	1749	10 cm[a]
GeoB16223-2	6°37.63′N	52°06.99′W	2253	10 cm[a]
GeoB16224-1	6°39.38′N	52°04.99′W	2510	Downcore[b]

* The Nd isotope analyses were performed at the (a) Laboratory of Geochronology, University of Brasília and the (b) Center of Geochronological Research (CPGeo), University of São Paulo.

2. Materials and methods

2.1. Calculation of sedimentation rates in compiled marine stratigraphies

Sedimentation rates for the western tropical Atlantic were calculated using stratigraphic data of 105 published marine sediment cores collected between 30°S and 20°N, 75°W and 25°W, and 472 and 5426 m water depth (Table S1 in Supplementary Material, hereafter 'SM'), and three marine sediment cores retrieved during RV Maria S. Merian cruise MSM20/3 (see Section 2.2 below) (Mulitza et al., 2013).

Among these selected cores, 70 chronologies were constrained by radiocarbon ages, 24 by stable isotope stratigraphy (based on planktonic or benthic foraminifera, Fig. S1) and 14 by stratigraphic alignment of various downcore properties (i.e. lithology, magnetic susceptibility, Fig. S2). For each core location, we estimated the sedimentation rates during the LGM and HS1 (expressed as centimeters per thousand years, cm/ka). We used Monte-Carlo resampling to estimate chronological uncertainties by calculating about 10 000 possible age models for each core. For all individual age models, ages were linearly interpolated to obtain the upper and lower depth corresponding to the LGM and HS1 time slices. This approach enabled us to derive mean sedimentation rates for the LGM and HS1, and 95% confidence intervals for the two time slices (see SM for further details). For all simulations, raw ^{14}C ages were recalibrated with the IntCal13 calibration curve (Reimer et al., 2013) and a reservoir age correction of 400 ± 100 (2σ error) years (Bard, 1988). Moreover, a constant dating uncertainty of 1500 years (2σ error) was assumed for age control points based on stable isotope stratigraphy or stratigraphic alignment of downcore properties.

2.2. New sediment cores from cruise MSM20/3

The two unpublished gravity cores used here were collected off NE South America under the influence of the NBC (Table 1) during RV MS Merian cruise MSM20/3 (Mulitza et al., 2013).

To the southeast and to the northwest of the Amazon River mouth, cores GeoB16206-1 and GeoB16224-1 were raised off the Parnaíba River mouth and off French Guiana, respectively (Fig. 1). In addition, near-core-top sediments (at a core depth of 10 cm) of other 12 gravity cores raised along the NE South American continental margin during MSM20/3 were also included in this study (see Section 2.2.3 below). We used near-core-top samples because