DETRITAL MAGNETIC AND ELEMENT PULSES OFF NE BRAZIL DURING THE LAST 85 KYR: SEDIMENT PROVENANCE CHANGES, CLIMATE RESPONSE OR BOTH?

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ABSTRACT

We present magnetic and geochemical data for four cores recovered from the continental margin off NE Brazil. Our cores are located along a W-E transect alongside the NE Brazilian coast under direct influence of the Intertropical Convergence Zone (ITCZ) and the North Brazilian Current (NBC). We investigated changes on sediment transport/source during abrupt climatic events. Changes in the composition of detrital magnetic minerals go along with variations in chemical element content. Magnetic characterization permitted us to investigate a possible relationship between river supply/longitudinal transport and precipitation enhancement caused by cold events over the North Atlantic.

Keywords: NE Brazil, Heinrich Events, Environmental magnetism

RESUMO

Esse trabalho apresenta dados magnéticos e geoquímicos para quatro testemunhos coletados na margem continental do NE do Brasil. Os testemunhos localizam-se em um transecto W-E ao longo da costa adjacente ao NE do Brasil sob influência direta da Zona de Convergência Intertropical (ITCZ) e da Corrente Norte do Brasil (NBC). Foram investigadas mudanças no transporte/fonte de sedimento durante eventos climáticos abruptos. Mudanças nos minerais magnéticos detritais são coevas àquelas registradas nos elementos. A caracterização magnética permitiu investigar a possível relação entre input dos rios/transporte longitudinal e aumento da precipitação causado pelos eventos frios do Atlântico Norte.

Palavras Chave: NE Brasil, Heirich Events, Magnetismo ambiental

1 Introduction

The southward displacement of the ITCZ is the main process that modulates the seasonal increase of precipitation over NE Brazil (*e.g*. Garreaud *et al.*, 2009). During the entire Holocene, this region has experienced increasingly dry conditions (Cruz *et al.*, 2009), but during the last glacial wet periods were identified by many studies (Arz *et al.*, 1998; H. W. Arz *et al.*, 1999; Behling *et al.*, 2000; Jennerjahn *et al.,* 2004). The enhanced precipitation over NE Brazil resulting from remote forcing of cold sea temperatures in the North Atlantic (Heinrich Stadials – HS) is widely accepted and fully understood (Arz *et al.*, 1998; H. W. Arz *et al.,* 1999; Behling *et al.,* 2000; Jennerjahn *et al.,* 2004). However, local oceanographic response to fresh water pulses and variable sediment sources in the North Atlantic are still a matter of discussion.

Compositional changes in detrital magnetic minerals go along with variations in chemical element content. Here we present new magnetic data for four cores recovered from the continental margin off NE Brazil (GeoB3913-3, GeoB3912-1, GeoB3911-3, GeoB3910-2). In previous studies performed on sediments from the NE Brazil margin, Fe/Ca and Ti/Ca have been published for cores GeoB3912-1 (Arz *et al.,* 1998;

Jennerjahn *et al.,* 2004), GeoB3911-3 (H. Arz *et al.*, 1999) and core GeoB3910-2 (Jaeschke *et al.,* 2007). Here, we show new geochemical data for core GeoB3913-3 and additional element ratios (Al/Si, Fe/K and Ti/Al) for cores GeoB3912-1, GeoB3911-3 and GeoB3910-2. Magnetic inventory and soil characterization over NE Brazil has shown that significant differences between Parnaíba Basin (west) and Bornorema Province do exist (east; Archanjo *et al.,* 2002; WRB, 2006; Journet *et al.*, 2013; Roud, 2014). Thus, identification of short-term climatic events along the NE coast using magnetic characterization permitted us to investigate a possible relationship between river supply/longitudinal transport and precipitation enhancement caused by cold events over the North Atlantic.

2 Study Area

Geological domains of NE Brazil change dramatically from West to East. The western domain comprises essentially the Paleozoic to Cenozoic sediments of the Parnaíba basin. The eastern sector corresponds to the Borborema Province, a crystalline basement constituted of Precambrian igneous and metamorphic rocks with granitic intrusions and patches of Cretaceous basaltic flows and dykes (Oliveira and Medeiros, 2012).

Among the rivers that debouch into NE Brazilian continental shelf, the Parnaíba River represents the second most important hydrographic region. To the East, Jaguaribe River is the main terrigenous supplier to the continental shelf adjacent to Ceará State (Fortaleza; Fig. 1). Further East, we find input of Piranhas-Açu and Apodi-Mossoró Rivers. Their drainage basins are smaller than that of Parnaiba River, but geomorphological studies performed at the adjacent continental margin revealed the presence of important submarine channels cutting into the continental shelf, suggesting an important influence of Piranhas-Açu and Apodi-Mossoró Rivers in the past (Vital *et al.*, 2010; Gomes *et al.*, 2014).

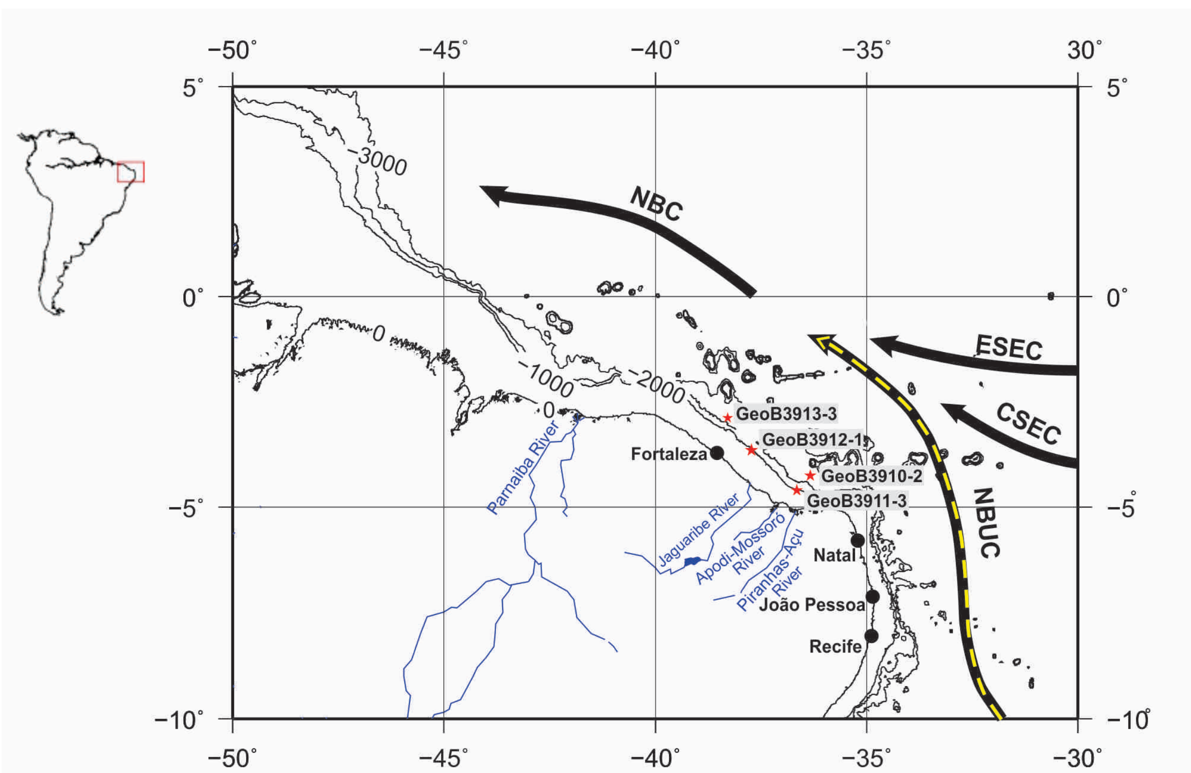

Figure 1. Studied cores from the margin off NE Brazil. The arrows are a schematic representation of the layers 0-100 m (central and equatorial branches of the SEC and NBC), 100-500 m (SEC, NBUC and NBC) and 500-1200 m (NBC) flowing at about 0°S.

3 Material and methods

Gravity-cores GeoB3913-3, GeoB3912-1, GeoB3911-3, GeoB3910-2 were recovered from the continental shelf off NE Brazil on cruise M34/4 of RV METEOR. Their lithologies consist mainly of alternating sections of nannofossil ooze and olive grey sediment, indicating fluctuations in marine and terrigenous components. Over the whole core lengths, signals of weak bioturbation were identified (Fischer *et al*., 1996).

Age models for cores GeoB3912-1, GeoB3911-3 and GeoB3910-2 were obtained from radiocarbon dating, and from correlation with cores previously recovered from same sites. Ages older than 40 ka were correlated to the SPECMAP curve (for detail see Arz *et al.*, 1998; H. Arz *et al*., 1999; Jaeschke *et al.*, 2007). We developed an age model for GeoB3913-3 by correlation of its Fe/Ca ratio to that of core GeoB3912-1. A global time-dependent ocean reservoir correction of about 400 years was applied.

Magnetic susceptibility was measured at 1 cm increments using a Bartington M.S.2 F-sensor. For measurements of magnetic remanence, we sampled the cores in 5 cm intervals using 6.2 cm^3 plastic cubes. Anhysteretic and Isothermal Remanent Magnetizations (ARM and IRM, respectively) and IRM acquisition curves (up to 700 mT) were obtained using an automated 2G 755R DC superconducting rock magnetometer at the Department of Geosciences (University of Bremen). For fields higher than 700 mT (up to 2700 mT) we used an "external' 2G 660 pulse magnetizer. Additionally, ARM/IRM, Hard-IRM (HIRM = IRM_{1500mT}- IRM_{300mT}) and S-Ratio (IRM_{300mT}/IRM_{1500mT})s were calculated. We scanned entire sections of cores GeoB3913-3, GeoB3911-3 and GeoB3910-2 at high resolution (1 cm) with a down-core slit size of 10 mm at the split surface of the archive halves with XRF Core Scanner III (AVAATECH Serial No. 12) at the Center for Marine Environmental Sciences (MARUM), University of Bremen. For core GeoB3912-1 we used the previously measured data with 2 cm resolution (Arz *et al.*, 1998).

4 Results

Rock magnetic parameters for our cores (Figs. 2 and 3) show remarkable changes in the ferromagnetic content related to Younger Dryas (YD) and the last eight HS Magnetic susceptibility (κ) is the main recorder for terrestrial input in our cores, changing substantially during all abrupt events (Figs. 2 and 3). Changes in grain size indicator (ARM_{100mT}/IRM_{100mT}) are not coeval among cores. Core GeoB3912-1 (Fig. 2b) shows MD-like behaviour during HS. In core GeoB3913-3 (Fig. 2a); this coarsening trend exits during HS6, HS7 and HS8, but for late HS and YD the increase is more gradually. SD-like magnetite was observed in core GeoB3911-3 between YD and HS1 (Fig. 2c) and in the upper half (after 35 ka) of core GeoB3910-2 (Fig. 3). In the lower half of core GeoB3910-2, MD behaviour was determined for HS4 and HS5. ARM_{100mT}/ IRM_{100mT} shows a variable behaviour, with an abrupt decrease at the beginning and an increase towards the end of YD and HS1 (Fig. 3). S-Ratio decreases, and HIRM increases during HS for cores GeoB3913-3, GeoB3912-1 and GeoB3910-2, suggesting the presence of high-coercive phases. Core GeoB3911-3 shows an anti-coeval behaviour during these abrupt events. Fe/ κ ratio (Fig. 2, black curve) increases in all cores during YD and HS, reflecting the presence of hematite and goethite. It could also reflect the presence of paramagnetic phases.

Similar to the rock magnetic parameters, element data show remarkable changes during YD and HS 1-8 (Figs. 2 and 3). Fe/Ca ratio is most outstanding and peaks distinctly during these abrupt events. Only in core GeoB3913-3 this ratio does not peak so remarkably during the YD.

5 Discussion

Humid periods over NE Brazil region during HE have been connected to southward migration of ITCZ using multiproxy data by many authors (*e.g*. Arz *et al.*, 1998; H. W. Arz *et al.*, 1999; Behling *et al.*, 2000; Jennerjahn *et al*., 2004; Dupont *et al.,* 2009). Our cores show some differences in geochemical and magnetic signals along the coast. We attributed these longitudinal dissimilarities to the weathering degree associated

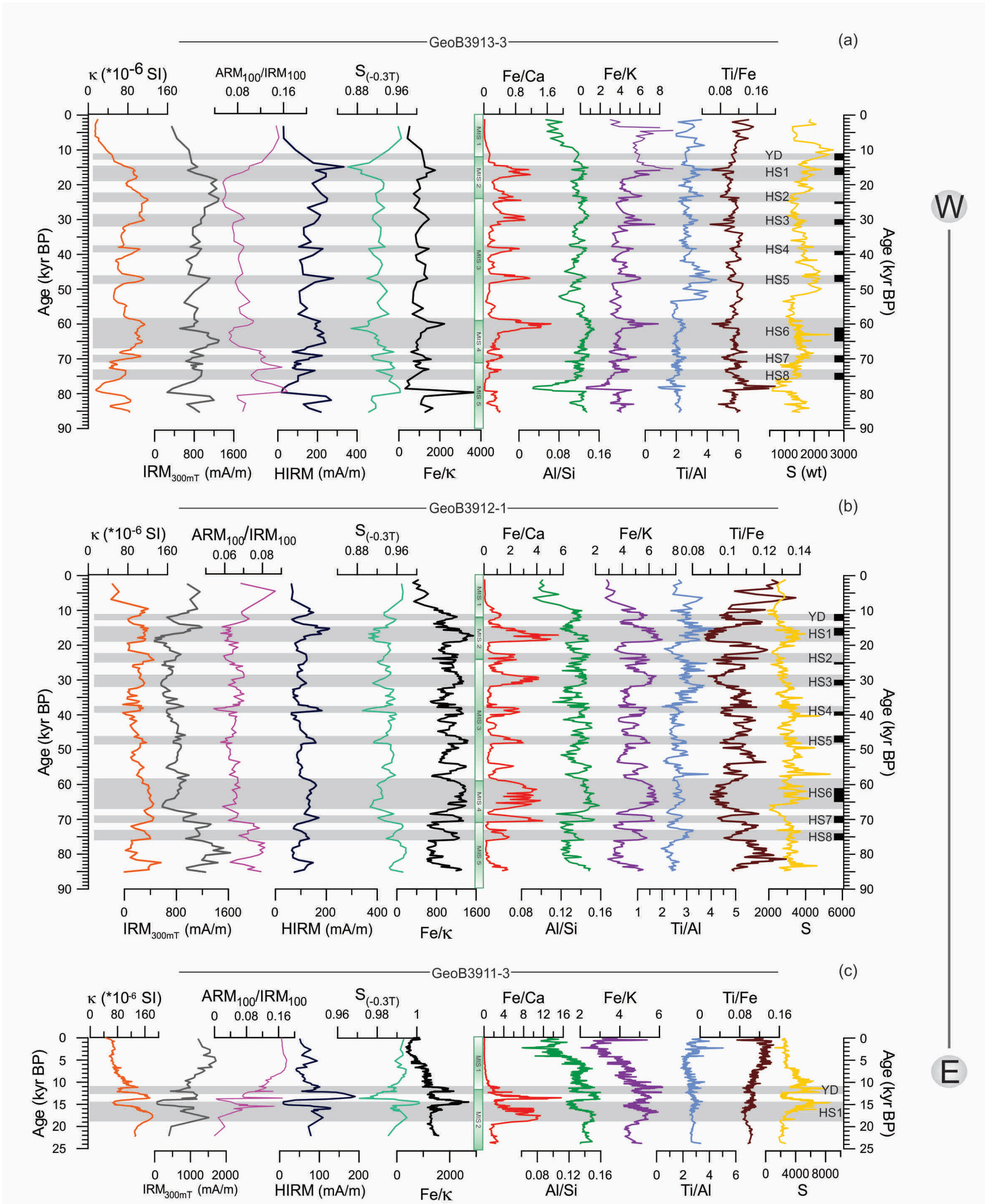

Figure 2. rock magnetic parameters and element ratios for cores GeoB3913-3 (upper), GeoB3912-1 (center) and GeoB3911-3 (lower). Greyish areas mark the Heinrich Stadials (HS) and Younger Dryas (YD, Fairbanks, 1989) Black squares represent Heinrich Events (H6 to H8, McManus et al., 1994; H1 to H5, Vidal et al., 1997). Greenish areas show Marine Isotope Stages (Sarnthein et al., 2001).

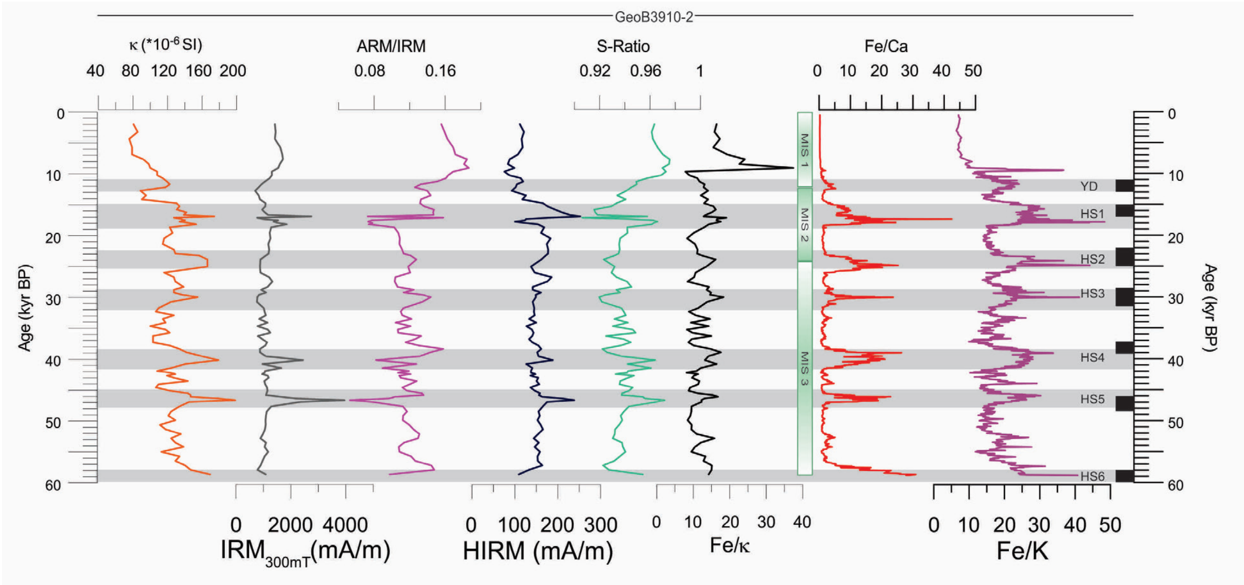

Figure 3. rock magnetic parameters and element ratios for core GeoB3910-2. Greyish areas mark the Heinrich Stadials (HS) that we matched with Younger Dryas (YD, Fairbanks, 1989) and Heinrich Events (H6 to H8, McManus et al., 1994; H1 to H5, Vidal et al., 1997), represented by the black squares. Greenish areas show the Marine Isotope Stages (Sarnthein et al., 2001).

to the W-E precipitation patterns, and to changes in sediment sources. Variations in concentrations of magnetic minerals from West to East are clearly expressed by crossplotting mean values of S-Ratio and susceptibility during Holocene, stadials and interstadials (Fig. 4). Separation between wet (stadials) / dry (interstadials) trends and amid Holocene and Pleistocene epochs are obvious. We observed higher availability of ferrimagnetic minerals (*i.e.* magnetite) in eastern cores compared to western cores, reflecting dominance of high magnetization minerals further East. S-Ratio shows that variations in relative concentrations of magnetite and high-coercive phases (hematite and goethite) are controlled rather by climate conditions over continental basins than by core location, suggesting that during humid periods (HS) the entire margin off NE Brazil was affected in the same way by increased precipitation over the continent with only slight spatial differences (Fig. 4a). Stadial samples exhibit more similar mean values than samples from interstadials or the Holocene. This shows that conditions of W-E sediment deposition along the coast were more uniform during HS than during interstadials and Holocene. ARM_{100mT} also reflects the dominance of fine-grained magnetite in the eastern cores (Fig. 4b). High values of ARM_{100mT} in core GeoB3910-2 suggest the dominance of titano(magnetite) in the source areas in Borborema Province, whilst in the western basin the dominance of high-coercive phases is expressed by lower values of susceptibility and ARM_{100mT}. Maybe this is caused by different oxidation of magnetite in soils in the distinct source areas. Besides studies of soils (Journet *et al.*, 2014) and rocks (Trindade *et al.*, 2006; Knesel *et al.*, 2011) from Parnaíba Basin and Borborema Province, confirming the presence of more high-coercive phases in the West compared to (titano)magnetite dominance in the eastern part of NE region, magnetic data from a marine record collected to the West of Parnaíba River's mouth confirm the W-E trend we propose here (Nace *et al.*, 2014). In this study, core CDH-86 shows high values of Ti/Ca associated to low values of susceptibility for the last 120 ka. The authors attributed this peculiarity to the prevalence of hematite and goethite in Parnaíba Basin. We observed peaks of susceptibility in our four cores during stadials (Figs. 2 and 3, orange curves), but it is remarkable that further east cores present higher values compared to cores in the West (Fig. 4a and 4b). Even though the comparison of our cores with core CDH-86 suggests a W-E trend reaching further to the western part of the continental shelf off NE Brazil, one must be careful simply assuming that low susceptibility values

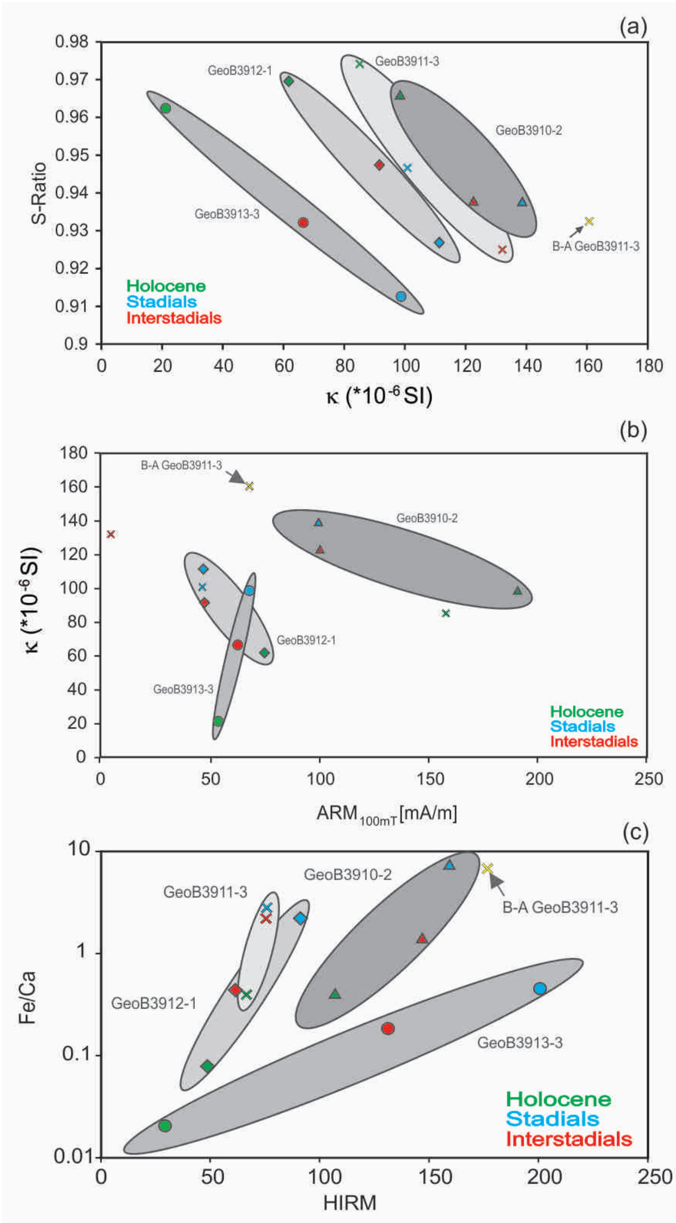

Figure 4. cross-plots using the mean value of magnetic and geochemical parameters for wet (stadials, blue) and dry (interstadials, red) conditions and during Holocene (green) in NE Brazil. Yellow dots represent Bølling-Allerød (B-A) variations.

suggest the presence of hematite and goethite. This is a very simplistic way to interpret complex relationship existing between ferrimagnetic (magnetite, maghemite, greigite) and antiferromagnetic (hematite and goethite) minerals. Ferrimagnetic minerals have magnetizations more than two orders of magnitude higher than those of antiferromagnetic minerals. In a way high-coercive antiferromagnetic minerals can be masked by highly magnetizable ferrimagnetic particles (Liu *et al.*, 2012). On the other hand, in general the presence of ferrimagnetic minerals in rocks is dominant in comparison to antiferromagnetic phases, and even considering regolith or oxidized soils, we cannot say that ferrimagnetic particles are absent. Further remanence-based measurements would clarify the magnetic mineralogy from Parnaíba River's mouth in more detail. In summary, considering the results of the environ-magnetic study that we performed on our four cores, we conclude that the main controller of magnetic changes from West to East is precipitation. The mean values of geochemical and magnetic parameters for different cores clearly separate in respective cross-plots demonstrating spatial trends. Figure 4c shows gradually high values of Fe/Ca ratio and HIRM from West to East, confirming an increase in river influx along the coast. So maybe, rivers from eastern part of NE Brazil region (Apodi-Mossoró and Piranhas-Açu rivers) experienced more significant increase in detrital influx than Jaguaribe River. For core GeoB3912-1, values of HIRM during stadials and interstadials do not follow this W-E trend (Fig. 4c). Based on our assumption that Jaguaribe River watercourse crosses terrains with dominance of high-coercive magnetic minerals than lands to the East, where Piranhas-Açu and Apodi-Mossoró rivers flow, smaller values of HIRM would be expected for this core.

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