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Testing provenance diagrams: Lessons from the well-constrained Cariaco Basin

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ABSTRACT

The fine-grained sediments of the Cariaco Basin, Venezuela, of the last 130 ky, whose deposition history is well characterized, were analyzed geochemically in order to test the validity of sediment bulk geochemistry as an indicator of detrital provenance. Several binary and ternary diagrams as well as the chemical index of alteration (CIA) were tested for their capacity to discriminate the poorly contrasted detrital sources to the Cariaco Basin, and to describe the temporal evolution of the contributions of these different sources. Most of the diagrams tested did not allow a good discrimination of sources or, when sources were well discriminated, did not allow an interpretation of the temporal variations consistent with the known history. A relatively good discrimination of sources and a consistent interpretation of temporal variations were however obtained using Hf vs. Th and La/Yb vs. Gd/Yb binary diagrams, as well as Ti–Zr–Th, Ti–Zr–La, and Lu–Hf–Th ternary diagrams. Compared to the previous studies of the detrital content of the Cariaco Basin sediments, the geochemical approach permitted the recognition of a sediment contribution eroded from the Unare platform and Gulf of Cariaco during rapid sea level oscillations, and the contribution of Saharan eolian particles during the Younger Dryas–Preboreal and MIS6-5 transition. The choice of plotted elements was determined after considering carrier minerals, so that different elements may be informative in different sedimentary contexts. Overall, mineral sorting during transport appears as a major limit to quantitative estimation of the different contributions. In particular mineral sorting leads to the selective enrichment of elements associated with clays (Al, Rb, Th and LREE) in sediments deposited in the basin. Unless the geochemical effect of mineral sorting can be measured, it appears that quantitative provenance analysis should be performed on fractions of similar grain size instead of bulk sediment.

1. Introduction

Provenance analysis has historically been based on mineralogical studies of sandstones (see Weltje and von Eynatten, 2004 for a review), however the analysis of whole-rock element composition has known an increasing interest during the last decades, as it is a convenient method that can be applied on any type of sediment and (meta-)sedimentary rock (e.g., Bhatia and Crook, 1986; McLennan, 1989; McLennan et al., 1993; Mongelli et al., 1996; Young, 1999; Cullers, 2002; Mahlen et al., 2005; Pe-Piper et al., 2008; Spalletti et al., 2008). The range of information obtained by this geochemical approach is wide, but in particular, provenance analysis is largely applied on sedimentary rocks in order to determine their paleotectonic and/or paleogeographic settings (Eriksson et al., 1992; Garver et al., 1996; Savoy et al., 2000; Joo et al., 2005; Meinhold et al., 2007; Spalletti et al., 2008). Another application of geochemical provenance analysis for both ancient and recent deposits is the determination of paleoclimatic conditions and their variability, through the use of weathering indices such as the chemical index of alteration (CIA; Nesbitt and Young, 1982, 1984) or by the identification of the geographic origin of the detrital flux, allowing to determine changes in rainfall patterns or marine currents (Young, 1999; Young and Nesbitt, 1999; Yarincik et al., 2000; Passchier, 2004; Latimer et al., 2006; Martinez et al., 2010; Monien et al., 2012).

In order to identify the tectonic setting of sediments, different discrimination diagrams have been proposed (Nesbitt and Young, 1984; Bhatia and Crook, 1986; Roser and Korsch, 1986; McLennan et al., 1993). These diagrams have been developed for sandstones and several studies demonstrated that discrimination diagrams were sometimes inefficient for the accurate identification of paleotectonic settings (Totten et al., 2000; Armstrong-Altrin and Verma, 2005; Ryan and Williams, 2007; Pe-Piper et al., 2008). Mineralogical sorting during sand deposition is one of the reasons for this failure (Garcia et al., 2004; Ohta, 2004). Despite this, discrimination diagrams are still often used, and in particular those based on trace metals have been extended to fine-grained and/or carbonate sediments (e.g., Mongelli et al., 1996; Cullers, 2002; Pe-Piper et al., 2008). In the case of fine-grained

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sediments, multi-element diagrams may be used in order to compare the chemical characteristics of a sediment and its possible sources of known composition, an approach particularly useful in Quaternary paleoclimatology (Yang et al., 2003; Latimer et al., 2006; Montero-Serrano et al., 2010; Monien et al., 2012). Difficulties however may arise if the considered sources present similar geochemical characteristics (Pe-Piper et al., 2008).

In the present study, we assessed the effectiveness of the geochemical approach in discriminating and identifying detrital sources showing poorly contrasting geochemical characteristics. For this purpose, we used the recent sediments from the Cariaco Basin, Venezuela. The Cariaco Basin is the second largest euxinic basin in the world and its annually laminated organic-rich sediments represent one of the best low-latitude paleoclimatic records (Peterson et al., 1991, 2000; Hughen et al., 1996, 2004b; Black et al., 2009; Goni et al., 2009; among others). For these reasons, the water column and sediments of the Cariaco Basin have been the object of numerous oceanographic, geochemical, biological and paleoclimatic studies (e.g., Tuttle and Jannasch, 1979; Scranton, 1988; Wakeham and Ertel, 1988; Peterson et al., 1991; Haug et al., 2001; Muller-Karger et al., 2004; among others). The present-day pattern of detrital sedimentation in the Cariaco Basin has recently been the object of provenance studies based on the geochemistry and clay mineralogy of surface sediment (Martinez et al., 2007, 2010; Elmore et al., 2009; Bout-Roumazeilles et al., 2013). The geochemical study of Martinez et al. (2010) however revealed that the different detrital sources to the Cariaco Basin presented relatively similar geochemical features. Past variations of the detrital input to the Cariaco Basin also have been explored on several timescales, in particular by the use of the clay mineral content (Clayton et al., 1999; Black et al., 2009; Bout-Roumazeilles et al., 2013; Riboulleau et al., 2014), so that the detrital history of the Cariaco Basin during the last glacial cycle is relatively well known. Temporal variations of the sediment geochemistry compared to the clay mineralogical proxies therefore offer the opportunity to test geochemical provenance tools in this restricted and well-constrained context.

2. Material and methods

2.1. Studied material

The present study is based on sediment from the IMAGES Program core MD03-2625 (10°40.65′ N, 64°58.24′ W, water depth 847 m) recovered during the PICASSO cruise (R/V Marion Dufresne; Laj and Shipboard Scientific Party, 2004) and Ocean Drilling Program (ODP) Site 1002 (10°42.36′ N, 65°10.16′ W; water depth, 893 m; Shipboard Scientific Party, 1997). Sediments from Holes 1002D and E were used in order to get the most complete record (Hughen et al., 2004a). Both coring sites are located on the central saddle of the Cariaco Basin, however core MD03-2625 is located on its eastern side while ODP site 1002 is located on its western side (Fig. 1).

Geochemical data from the platform surrounding the Cariaco Basin (Martinez et al., 2010), from sediment cores PL07-39PC (Piper and Dean, 2002) and ODP 1002 (Yarincik et al., 2000) and from sediment traps (Martinez et al., 2007; Martinez, 2009) are added to the discussion. Location of these different samplings is presented in Fig. 1.

2.2. Age model

For Site ODP 1002, as previously observed by Hughen et al. (2004a), the ODP depth scale does not allow a perfect correlation of the different ODP 1002 holes. A new composite depth scale was therefore established by correlating the parameter L* and the magnetic susceptibility of cores 1002C, 1002D and 1002E (Riboulleau et al., 2014; Table S1, Fig. S1). The age model was then derived from the age models established by Hughen et al. (2006) and Drenzek (2007) using the new composite depth scale. In brief, for sediment younger than 75 ka (Hughen et al., 2006), the age model is based on the correlation of core 1002D sediment reflectance with ^{230}Th-dated stalagmite δ^{18}O records from Hulu Cave, China (Wang et al., 2001). For sediment older than 75 ka, the age model is based on a correlation of the oxygen isotopic composition of planktonic foraminifer *Globigerinoides ruber* shells collected from core

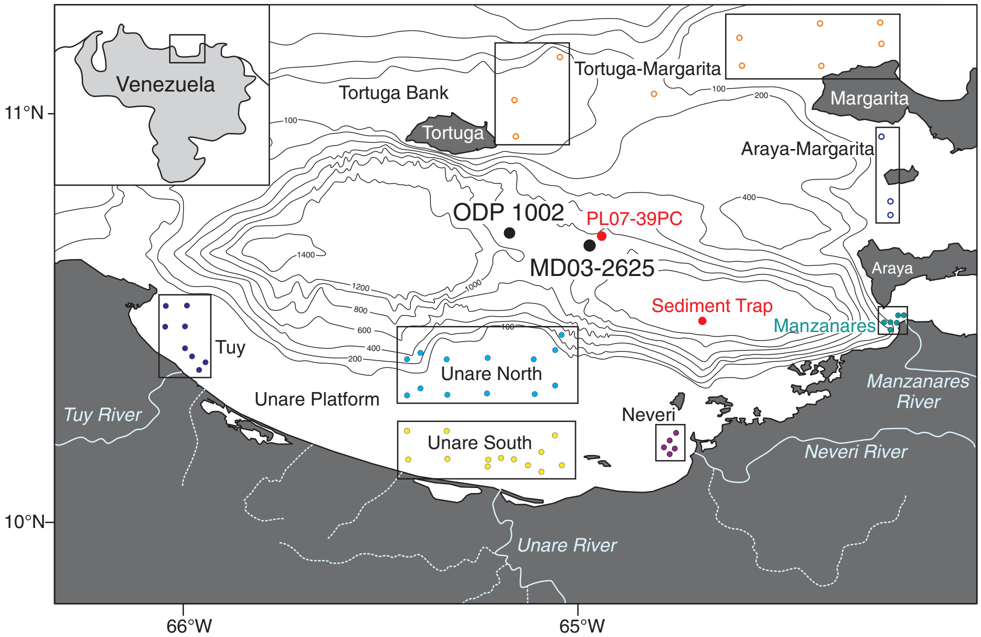

Fig. 1. Location map of the Cariaco Basin, of the studied core sections, as well as of the different samplings mentioned in the text: sediment trap (Thunell et al., 2007; Martinez, 2009), core PL07-39PC (Piper and Dean, 2002), and the different areas of the platform surrounding the basin (Martinez et al., 2010). MIS: marine isotopic stage.