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The "zircon effect" as recorded by the chemical and Hf isotopic compositions of Lesser Antilles forearc sediments

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ABSTRACT

Oceanic sediments contain the products of erosion of continental crust, biologic activity and chemical precipitation. These processes create a large diversity of their chemical and isotopic compositions. Here we focus on the influence of the distance from a continental platform on the trace element and isotopic compositions of sediments deposited on the ocean floor and highlight the role of zircons in decoupling high-field strength elements and Hf isotopic compositions from other trace elements and Nd isotopic compositions.

We report major and trace element concentrations as well as Sr and Hf isotopic data for 80 sediments from the Lesser Antilles forearc region. The trace-element characteristics and the Sr and Hf isotopic compositions are generally dominated by detrital material from the continental crust but are also variably influenced by chemical or biogenic carbonate and pure biogenic silica. Next to the South American continent, at DSDP Site 144 and on Barbados Island, sediments, coarse quartz arenites, exhibit marked Zr and Hf excesses that we attribute to the presence of zircon. In contrast, the sediments from DSDP Site 543, which were deposited farther away from the continental platform, consist of fine clay and they show strong deficiencies in Zr and Hf. The enrichment or depletion of Zr–Hf is coupled to large changes in Hf isotopic compositions ($-30<\varepsilon_{Hf}<+4$) that vary independently from the Nd isotopes. We interpret this feature as a clear expression of the "zircon effect" suggested by Patchett and coauthors in 1984. Zircon-rich sediments deposited next to the South American continent have very low ε_{Hf} values inherited from old zircons. In contrast, in detrital clay-rich sediments deposited a few hundred kilometers farther north, the mineral fraction is devoid of zircon and they have drastically higher ε_{Hf} values inherited from finer, clay-rich continental material.

In the two DSDP sites, average Hf isotopes are very unradiogenic relative to other oceanic sediments worldwide ($\varepsilon_{Hf}=-14.4$ and -7.4) and they define the low Hf end member of the sedimentary field in Hf–Nd space. Their compositions correspond to end members that, when mixed with mantle, are able to reproduce the pattern of volcanic rocks from the Lesser Antilles. More generally, we find a relationship between Nb/Zr ratios and the vertical deviation of Hf isotope ratios from the Nd–Hf terrestrial array and we suggest that this relationship can be used as a tool to distinguish sediment input from fractionation during melting during the formation of arc lavas.

1. Introduction

Worldwide oceanic sedimentation results from the combined effects of three main processes: the deposition of detrital grains of continental origin, the accumulation of biogenic materials derived from marine organisms and chemical precipitation of components dissolved in seawater. These processes are influenced by the location and mechanism of deposition, and the composition of the final sediment depends strongly on factors such as the distance to continental sources, the carbonate compensation depth, the level of biological activity and the sedimentation rate, which all vary within individual ocean basins.

In the Lesser Antilles forearc on the Atlantic oceanic plate, the sedimentation rate is high and the authigenic component is low (Wright, 1984). In this region, two sediment-forming processes compete, the accumulation of biogenic material and input of detrital material from the nearby continental platforms. This area is thus a good target to study the composition of the detrital fraction and compare it to average upper continental crust. By selecting sites located at various distances from the continental shelf, we can investigate the geographical changes and relate them to sedimentary sorting – preferential deposition of coarser-grained material near the continent and dispersion of the finer clay-rich

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fraction – during transport of the crustal material away from the continent. The Pb–Nd–Sr isotopic compositions of surface sediments in the Lesser Antilles forearc domain display a north–south geochemical gradient that White et al. (1985) attribute to a southward increase of detrital input supplied by the Orinoco River which drains the Guyana Precambrian shield. Our investigation extends this approach to a large set of trace element and Sr–Hf isotopic data obtained on sediments deposited over a period of about 115 Ma.

We analyzed sediments from three sites located in front of the Lesser Antilles island arc at distances of 340 km (Site DSDP 144), 480 km (Barbados Island) and 860 km (Site DSDP 543) from the South American continent. In a previous paper (Carpentier et al., 2008), we showed that changes of the Pb–Nd isotopic compositions of these sediments mimic the north–south isotopic variation along the Lesser Antilles island arc (White and Dupré, 1986). The northern sediments have relatively unradiogenic Pb compositions while the southern sediments have elevated values due to the proximity of the South American continent and to the presence of black shale layers with extreme Pb isotopic compositions.

Here, we report major and trace element concentrations as well as Hf and Sr isotopic compositions of about 80 sediments and examine these data together with the previously published Nd isotopic compositions. The main goal of the present paper is to use the geochemical data to help understand the processes that control the compositions of oceanic sediments. We show that detrital input from the Southern American continent dominates the sedimentary budget for most elements in the entire area. In addition, we establish that fractionation of Zr and Hf relative to other trace elements is correlated with the distance to the continent and is related to the proportion of zircon-rich sands in the detrital fraction. Finally, we calculate the average sediment compositions for the three sites, compare them to GLOSS (GLObal Subducting Sediment; Plank and Langmuir, 1998), and evaluate the potential impact of these detrital sediments on the sources of magmas of the Lesser Antilles island arc, as they are introduced by the subduction into the mantle.

2. Geological background and sampling

The Atlantic oceanic plate approaches the Lesser Antilles trench from the east (Fig. 1) at a rate of about 2 cm/year (Minster and Jordan, 1978). Cretaceous crust is currently subducting beneath the volcanic arc and, because of the geometry of the arc-ridge system, its age increases from ca. 80 Ma in the north to more than 105 Ma in the south (Westbrook et al., 1984; Carpentier et al., 2008). The forearc region is dominated by a large accretionary complex, the Barbados Ridge, which is also characterized by a north–south gradient in lithology and thickness of the

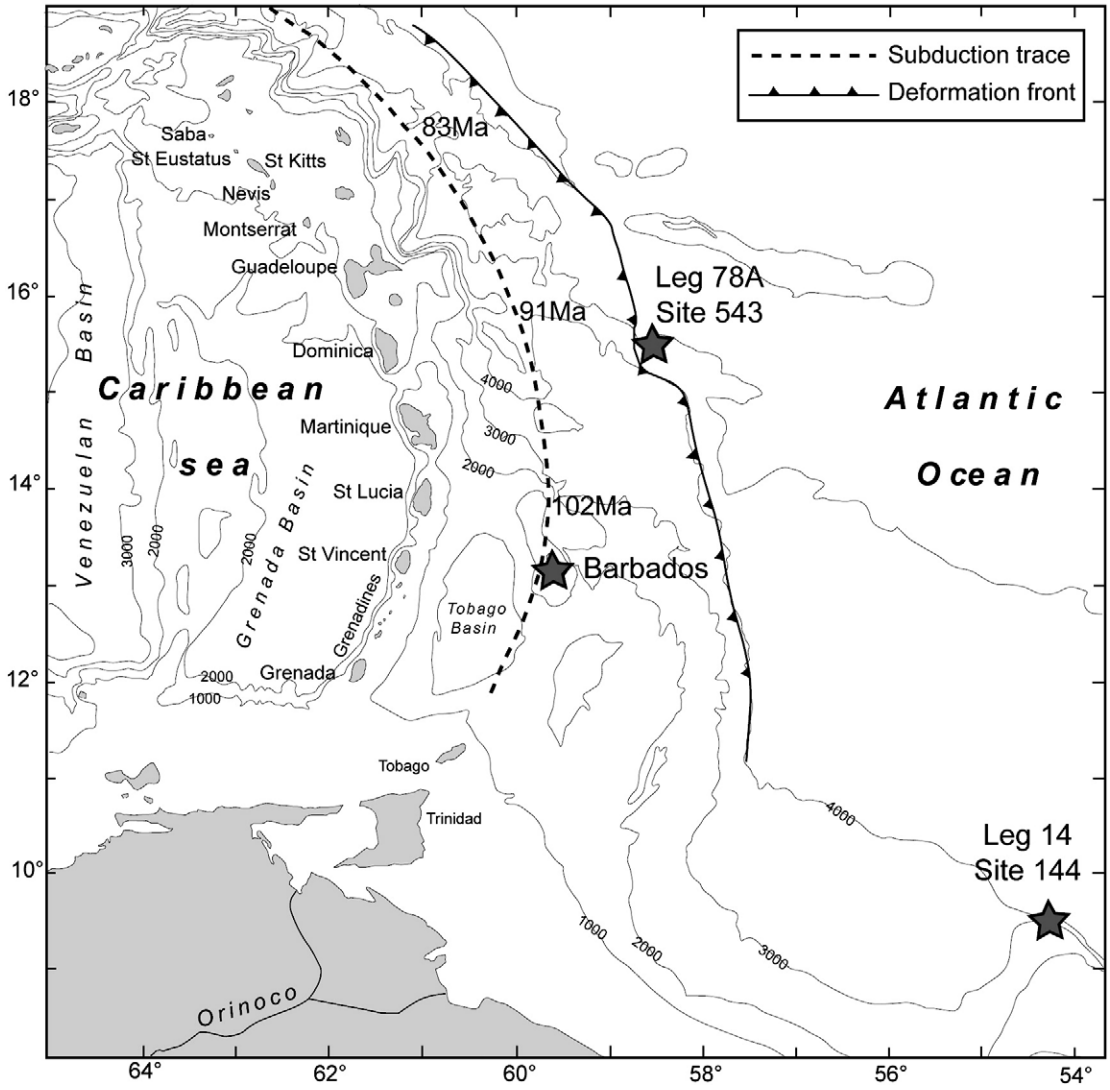

Fig. 1. Bathymetric map of the studied area showing the location of the three sampled sites (DSDP 78A Site 543, DSDP 14 Site 144 and Barbados Island), modified from Speed et al. (1984) and Carpentier et al. (2008). The age of the subducting slab is indicated next to the trench.