



# Assimilation of sediments embedded in the oceanic arc crust: myth or reality?



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## ABSTRACT

Arc magmas are commonly assumed to form by melting of sub-arc mantle that has been variably enriched by a component from the subducted slab. Although most magmas that reach the surface are not primitive, the impact of assimilation of the arc crust is often ignored with the consequence that trace element and isotopic compositions are commonly attributed only to varying contributions from different components present in the mantle. This jeopardises the integrity of mass balance recycling calculations. Here we use Sr and O isotope data in minerals from a suite of volcanic rocks from St Lucia, Lesser Antilles arc, to show that assimilation of oceanic arc basement can be significant. Analysis of  $^{87}\text{Sr}/^{86}\text{Sr}$  in single plagioclase phenocrysts from four Soufrière Volcanic Complex (SVC; St Lucia) hand samples with similar composition ( $^{87}\text{Sr}/^{86}\text{Sr} = 0.7089\text{--}0.7091$ ) reveals crystal isotopic heterogeneity among hand samples ranging from 0.7083 to 0.7094 with up to 0.0008 difference within a single hand sample.  $\delta^{18}\text{O}$  measurements in the SVC crystals show extreme variation beyond the mantle range with +7.5 to +11.1‰ for plagioclase ( $n = 19$ ), +10.6 to +11.8‰ for quartz ( $n = 10$ ), +9.4 to +9.8‰ for amphibole ( $n = 2$ ) and +9 to +9.5‰ for pyroxene ( $n = 3$ ) while older lavas (Pre-Soufrière Volcanic Complex), with less radiogenic whole rock Sr composition ( $^{87}\text{Sr}/^{86}\text{Sr} = 0.7041\text{--}0.7062$ ) display values closer to mantle range: +6.4 to +7.9‰ for plagioclase ( $n = 4$ ) and +6 to +6.8‰ for pyroxene ( $n = 5$ ). We argue that the  $^{87}\text{Sr}/^{86}\text{Sr}$  isotope disequilibrium and extreme  $\delta^{18}\text{O}$  values provide compelling evidence for assimilation of material located within the arc crust. Positive correlations between mineral  $\delta^{18}\text{O}$  and whole rock  $^{87}\text{Sr}/^{86}\text{Sr}$ ,  $^{143}\text{Nd}/^{144}\text{Nd}$  and  $^{206,207,208}\text{Pb}/^{204}\text{Pb}$  shows that assimilation seems to be responsible not only for the isotopic heterogeneity observed in St Lucia but also in the whole Lesser Antilles since St Lucia encompasses almost the whole-arc range of isotopic compositions. This highlights the need for detailed mineral-scale investigation of oceanic arc suites to quantify assimilation that could otherwise lead to misinterpretation of source composition and subduction processes.

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## 1. Introduction

A key question in oceanic arc geochemistry concerns the relative contributions of subducting slab and intra-crustal material in the chemical and isotopic characteristics of lavas. Oceanic arc magmas are generated by partial melting of the mantle wedge modified by  $\text{H}_2\text{O}$ -rich fluids and melts from the subducting slab

(Tatsumi and Eggins, 1995) and subsequently ascend through the arc crust before eruption. Lavas erupted at oceanic arcs rarely have major element compositions in equilibrium with mantle peridotite (Annen et al., 2006) which suggests that the magmas experienced differentiation during storage within or at the base of the arc crust. Depending on the nature of the arc basement, such magmas may interact with igneous or metasedimentary wall rocks during differentiation. Distinguishing between sediment addition to the mantle wedge and assimilation of metasediments located in the arc crust is not straightforward on the basis of whole rock compositions alone – the effects of mixing sediment into the mantle wedge or with basaltic melts in the crust are similar in most radiogenic isotope–isotope spaces.

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In order to investigate the role of crustal assimilation in oceanic arcs we selected a suite of rocks from the Lesser Antilles arc where, despite the absence of continental basement, whole rock isotope ratios of arc lavas can be very “continental”. As a result, the case has long been made both for crustal assimilation (e.g. Davidson, 1987; Davidson and Harmon, 1989; Smith et al., 1996; Thirlwall et al., 1996; Thirlwall and Graham, 1984; Van Soest et al., 2002), and incorporation of sediment or sediment melt into the mantle wedge (e.g. Carpentier et al., 2008, 2009; Labanieh et al., 2010, 2012, White and Dupré, 1986). Our suite of samples, from the island of St Lucia, encompasses almost the entire range of whole rock isotopic compositions observed in the Lesser Antilles, ranging from values close to typical intra-oceanic arc rocks to those resembling continental crust (e.g.  $^{87}\text{Sr}/^{86}\text{Sr}$ ,  $^{143}\text{Nd}/^{144}\text{Nd}$  and  $^{206}\text{Pb}/^{204}\text{Pb}$  ranging from 0.70411–0.70906, 0.51210–0.51298 and 19.291–19.797, respectively).  $^{87}\text{Sr}/^{86}\text{Sr}$  and  $\delta^{18}\text{O}$  analyses of individual minerals separated from lavas with extreme crust-like whole rock isotopic composition from the Soufriere Volcanic Complex (SVC), demonstrate the importance of open system behaviour on oceanic arc magmatism and challenge our understanding of magma differentiation in oceanic arcs.

## 2. Geological background

The Lesser Antilles arc (Fig. 1) formed as a result of subduction of the North American Plate under the Caribbean Plate. Its lavas have typical oceanic arc compositions in the northern section but unusually heterogeneous isotopic signatures in the central and southern part of the arc where both typical intra-oceanic arc and very continental crust-like signatures are observed (e.g. Macdonald et al., 2000; Fig. 2). Two main processes have been proposed to explain these extreme compositions: (1) incorporation of sediment into the mantle source or (2) significant assimilation of sediment-rich arc crust. While a high sediment input to the source could be explained by the presence of abundant sediment in the southern Antilles Trench, due to discharge from the Orinoco and Amazon rivers (e.g. Carpentier et al., 2008, 2009), assimilation of sediment in the arc crust is also possible because the central-southern Lesser Antilles arc is thought to have developed above the thick fore-arc basin of the (now extinct) Aves Ridge Arc, splitting it into the Grenada and the Tobago basins (Fig. 1; Aitken et al., 2011). Sediments entering the subduction zone are chemically and isotopically well constrained by analyses from DSDP Sites 144 and 543 (Fig. 1; Carpentier et al., 2008, 2009; White and Dupré, 1986). In contrast, the nature of the basement of the Southern Lesser Antilles arc is still poorly known. While the detrital sediments from the South American craton, which dominate the sequences on both the subducting and the overriding plates, were often targeted in the past to explain the high  $^{87}\text{Sr}/^{86}\text{Sr}$  and low  $^{143}\text{Nd}/^{144}\text{Nd}$  ratios of the lavas, they fail to explain their very radiogenic Pb signatures. Recently, analyses of Mesozoic black shales sampled at DSDP site 144 showed that these sediments have sufficiently radiogenic Pb to account for the compositions of the lavas from the southern arc (Carpentier et al., 2009). Because such radiogenic Pb has not yet been reported from the sediments of the Grenada and Tobago basins, sediment addition to the source alone has been suggested to explain the whole range of isotopic data in the southern arc lavas (Carpentier et al., 2008, 2009; Labanieh et al., 2010). However, it cannot be ruled out that such sediments exist within the basement of the southern arc since biogenic rich limestones have been reported in the overriding plate, in the Late Cretaceous to Oligocene sequences of the Carupano Basin (Ysaccis, 1997).

St Lucia is an island in the central-southern part of the arc (Fig. 1). The lavas from this single island encompass almost the whole range of isotopic variation observed in the arc making it the perfect location to study the influence of crustal components

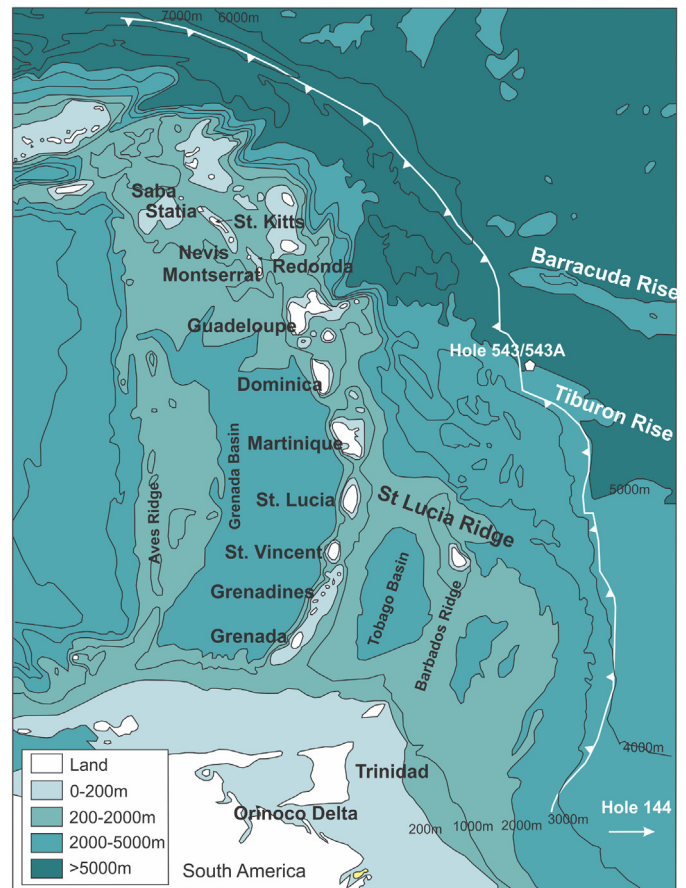


Fig. 1. Bathymetric map of the Lesser Antilles arc showing the islands, the trench-deformation front, the main ridges, the Grenada and Tobago basins and the locations of Deep Sea Drilling Project (DSDP) hole 543/543A and hole 144. Figure modified from Van Soest et al. (2002).

(Fig. 2). The more continental crust-like compositions are found in andesites (3 Ma to ca. 250 ka) and dacites (100 ka to present) of the Soufriere Volcanic Complex (SVC), while more mantle-like compositions are observed in the more mafic Pre-SVC lavas dominated by basalt, basaltic andesite and andesite (18 Ma to 1.1 Ma; Briden et al., 1979; De Kerneizon et al., 1983; Lindsay et al., 2013; Samper et al., 2008; Schmitt et al., 2010).

## 3. Methods

### 3.1. Whole rock Sr, Nd and Pb isotopes

Except for 7 samples in which Sr and Nd isotope ratios were measured at the Geochemical Analysis Unit at Macquarie University (Aus), whole rock powders were analysed at the Arthur Holmes Isotope Geology Laboratory (AHIGL) which is part of Durham Geochemistry Centre (DGC) at Durham University (UK). At both institutes, 0.1 g of sample powder was dissolved in Teflon distilled 29M HF and 16M HNO<sub>3</sub>.

At Durham, Pb and Sr were separated from the sample solution using Sr-spec resin columns. Nd was collected from the same Sr-spec column before being passed through a cation column where it was collected as part of a total REE cut after elution of Hf, Rb and Ba. Samples were analysed for their  $^{87}\text{Sr}/^{86}\text{Sr}$ ,  $^{143}\text{Nd}/^{144}\text{Nd}$  and  $^{206}\text{Pb}/^{204}\text{Pb}$ ,  $^{207}\text{Pb}/^{204}\text{Pb}$  and  $^{208}\text{Pb}/^{204}\text{Pb}$  compositions by plasma ionisation multicollector mass spectrometry (PIMMS) using a Thermo Scientific Neptune instrument. During the  $^{87}\text{Sr}/^{86}\text{Sr}$  and  $^{143}\text{Nd}/^{144}\text{Nd}$  analytical sessions, instrument performance was monitored by analysis of NBS987 Sr standard and an in

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