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Recycling and transport of continental material through the mantle wedge above subduction zones: A Caribbean example

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ABSTRACT

Estimates of global growth rates of continental crust critically depend upon knowledge of the rate at which crustal material is delivered back into the mantle at subduction zones and is then returned to the crust as a component of mantle-derived magma. Quantification of crustal recycling by subduction-related magmatism relies on indirect chemical and isotopic tracers and is hindered by the large range of potential melt sources (e.g., subducted oceanic crust and overlying chemical and clastic sediment, sub-arc lithospheric mantle, arc crust), whose composition may not be accurately known. There is also uncertainty about how crustal material is transferred from subducted lithosphere and mixed into the mantle source of arc magmas. We use the resilient mineral zircon to track crustal recycling in mantle-derived rocks of the Caribbean (Greater Antilles) intra-oceanic arc of Cuba, whose inception was triggered after the break-up of Pangea. Despite juvenile Sr and Nd isotope compositions, the supra-subduction zone ophiolitic and volcanic arc rocks of this Cretaceous (∼135–70 Ma) arc contain old zircons (∼200–2525 Ma) attesting to diverse crustal inputs. The Hf–O isotope systematics of these zircons suggest derivation from exposed crustal terranes in northern Central America (e.g. Mexico) and South America. Modeling of the sedimentary component in the most mafic lavas suggests a contribution of no more than 2% for the case of source contamination or less than 4% for sediment assimilation by the magma. We discuss several possibilities for the presence of inherited zircons and conclude that they were transported as detrital grains into the mantle beneath the Caribbean Plate via subduction of oceanic crust. The detrital zircons were subsequently entrained by mafic melts that were rapidly emplaced into the Caribbean volcanic arc crust and supra-subduction mantle. These findings suggest transport of continental detritus, through the mantle wedge above subduction zones, in magmas that otherwise do not show strong evidence for crustal input and imply that crustal recycling rates in some arcs may be higher than hitherto realized.

1. Introduction

In the present plate tectonic regime, crustal recycling occurs along subduction zones where oceanic crust and sediments are dragged into the mantle (Stern, 2002a) or where the fore-arc region of a continental arc is tectonically eroded (Scholl and von Huene, 2009). Delamination of dense, thickened lower crust is another mechanism for returning crustal material to the mantle (Gao et al., 2004; Zandt et al., 2004). The transfer mechanisms from the slab to the mantle are strongly debated and include: (1) direct transfer of slab-derived fluids/melts via fractures or diapirs (Spandler and Pirard, 2013), (2) diapirs of slab + peridotite partially melted mélanges (Castro et al., 2010; Marschall and Schumacher, 2012) or (3) diapirs of subducted sediment, tectonically eroded forearc, and subducted arc and/or

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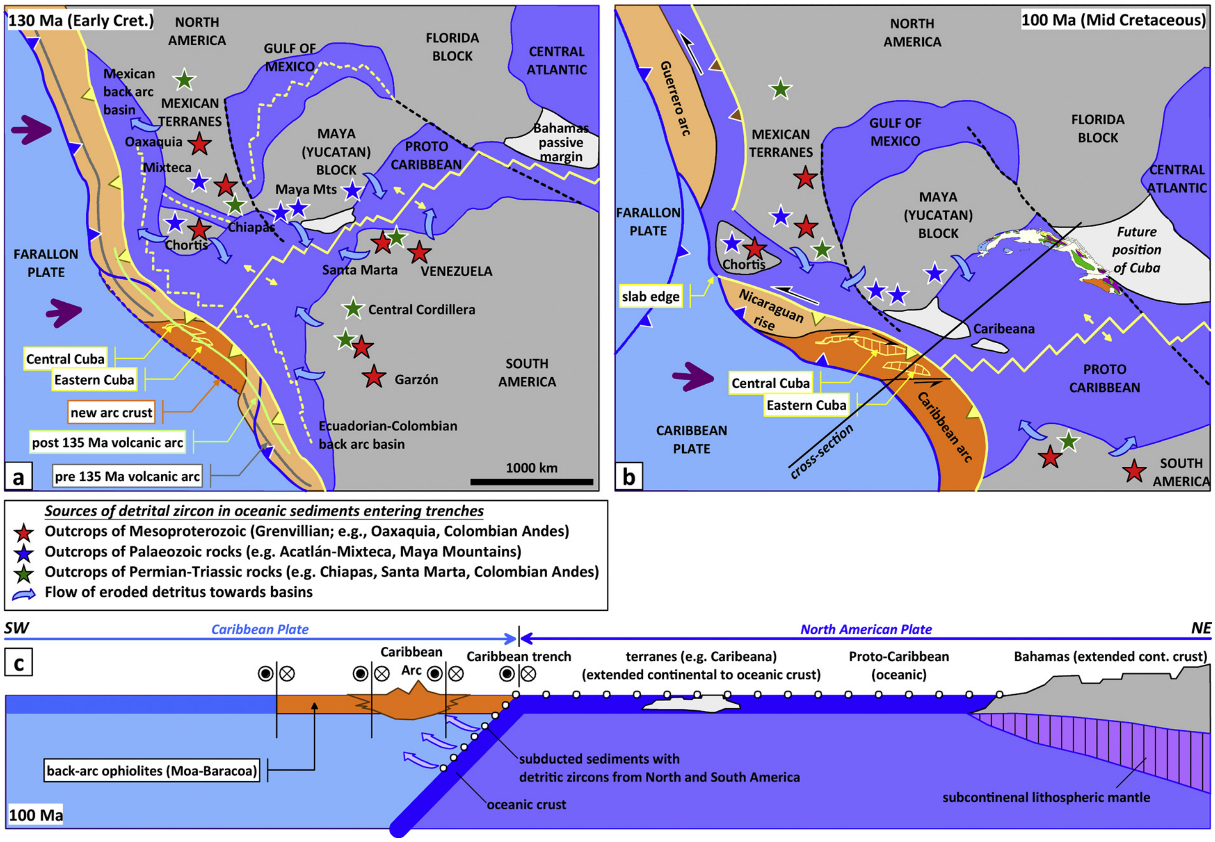

Fig. 1. Cretaceous palaeogeographic and tectonic reconstruction of the Caribbean region (after Pindell and Kennan, 2009; Pindell et al., 2012 and references therein). a) Early Cretaceous onset of subduction of the Proto-Caribbean lithosphere. The three different stars show potential source areas for Triassic and older zircons in the Cuban arc. b) Mid (to Late) Cretaceous enlargement of the Caribbean arc (due to widening of the Proto-Caribbean basin) and trench migration due to slab-roll back (Pindell and Kennan, 2009; Pindell et al., 2012). Location of cross-section (black line) and the present day position of Cuba are indicated. The blue arrows indicate direction of sediment flow towards the Proto-Caribbean basin. c) Cross-section showing mid-Cretaceous evolution of the Caribbean and subducted sediment (zircon) incorporation into the upper-plate mantle. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

continent that refine into delaminant dense eclogite that sinks into the mantle and relaminates less dense silica-rich material that rises buoyantly and accretes to the base of an arc (Hacker et al., 2011). All these processes allow the introduction of exotic material into the mantle which may thus become the source of arc magmas and of arc magma contamination. A range of whole-rock geochemical and isotopic evidence suggests that continental material is assimilated into the convecting mantle as sampled by arc basalts (Hawkesworth et al., 1997) and MORB (Jeffcoate et al., 2007). Moreover, olivine phenocryst compositions in oceanic and continental basalts also imply the involvement of up to 28% of recycled crust in the mantle source (Sobolev et al., 2007). Another, more direct, piece of evidence is the presence of old, continent-derived zircon grains in oceanic mantle-derived magmatic rocks (Pilot et al., 1998; Hargrove et al., 2006; Kröner et al., 2007; Tapster et al., 2014; Ali et al., 2009; Buys et al., 2014) and in chromitites hosted in the mantle of supra-subduction zone (SSZ) ophiolites (Yamamoto et al., 2013; Robinson et al., 2015).

Zircon is a robust accessory mineral, common in continental rocks that can retain primary geochemical information through weathering, sedimentary transport, and high-grade metamorphism. It has a closure temperature for the diffusion of radiogenic Pb greater than typical magmatic temperatures (1000 °C; Cherniak and Watson, 2001), and may survive as 'inherited' grains in igneous rocks. Furthermore, zircon hosts isotope systems including O and Hf that constrain the composition and crustal residence age of the source to the magma from which the zircon crystallized (Kemp et al., 2007). The U–Pb, O and Hf isotope systematics of zircons in oceanic rocks thus offer a means to trace the origin and recycling of old lithospheric components through the mantle. In this contribution we report rare inherited zircon grains found in igneous rocks of the oceanic volcanic arc of the Antilles (Cuba). We discuss the origin of the inherited zircon population and the implication of these for the processes of crustal recycling at subduction zones.

2. Geological setting

The present-day Caribbean region formed in the eastern Palaeo-Pacific Ocean (Farallon Plate) during the early Cretaceous (Fig. 1; Pindell et al., 2012). The region developed after the North and South American portions of Pangea drifted apart in the mid-Jurassic. The onset of sea-floor spreading formed an intervening oceanic basin, the Proto-Caribbean (connected to the central Atlantic), where sediments from the diverging North and South American continents accumulated (Fig. 1a; Pindell et al., 2012 and references therein). Supercontinent break-up also triggered the inception of a W-dipping oceanic subduction system in a complex sinistral transform scenario (i.e., the "inter-American transform"; Pindell et al., 2012). The resulting intra-oceanic volcanic arc was active from ∼135 to 47 Ma (Fig. 2a; Rojas-Agramonte et al., 2004, 2011a; Pindell and Kennan, 2009). Subduction consumed Proto-Caribbean oceanic lithosphere as the Proto-Caribbean seaway widened (Fig. 1a, b). Final collision of the Caribbean (Greater Antilles) arc with rifted North American terranes (e.g., Caribeana, a Pangea-derived crustal block(s) overlain by thick Jurassic–Cretaceous sediment; Garcia-Casco et al., 2008) and the passive margin of the Maya Block and the Bahamas platform