The transition from plume-driven upwelling to lateral mantle flow: Geochemical evidence from Isla Santiago, Galápagos

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ABSTRACT

Widespread recent Galápagos volcanism reflects melting of anomalously hot mantle during upwelling and lateral transfer of plume material up to 200 km toward the adjacent Galápagos Spreading Centre (GSC). Isla Santiago is located in the centre of the archipelago, above the margin of active thermal upwelling, and provides an ideal setting in which to examine plume-ridge interactions. From SW to NE across Santiago (away from the hotspot axis), basalts range from mildly-alkaline to low-K MORB-like tholeiites (Fig. 1); a striking diversity of compositions that is rare from single eruptive episodes at ocean islands.

A greater rate of buoyancy-driven vertical mantle flow, combined with thicker lithosphere beneath southwest Santiago, causes accumulated fractional melts to be more alkaline and enriched in the central Galápagos plume component than those which formed beneath shallower lithosphere in the northeast of the island (Fig. 2). We further suggest that plume material is progressively depleted of its most volatile components during sub-ashrylic-peridotite-solidus lateral flow (Fig. 3 & 4), and adiabatic decompression to relatively shallow depths enables generation of MORB-like low-K tholeiites beneath northeast Santiago. At the adjacent GSC, an increased flux of warm plume mantle at the base of the melting region causes generation of MORB with more-enriched isotopic and incompatible trace-element signatures than those erupted on Santiago and islands in northeast Galápagos (Fig. 5). Our findings for Galápagos emphasize the importance of lithospheric thickness, geometries of melting regions, lateral flow paths and prior melting history of mantle material in controlling the nature and occurrence of oceanic basalts close to spreading centres.

SANTIAGO: LARGE SPATIAL VARIATION IN MAGMA TYPES & LITHOSPHERIC THICKNESS

Figure 1. Distribution of alkali, transitional & tholeiitic basalts on Isla Santiago. Note the general occurrence of alkali basalts with low [La/Nb], in the west of the island whereas tholeiites with high [La/Nb], are located in the east. Numbers enclosed by circles show the estimated depth to top of the melt column based on REE inversion modeling. As a first approximation, lithospheric thickness (a) and REE in Galápagos are defined by ca. 46-53 SMY (±) (Gibson & Geist, 2010).

Figure 2. Variation of [La/Nb], with (a) "Thold"Nd and (b) [Sm/Yb], ratios in basalts from the Galápagos archipelago & adjacent Galápagos Spreading Centre, including those with a high Fornasina "enriched" mantle component. In (a) the solid black curve illustrates binary mixing between melts derived from a depleted endmember that has the composition of a Galapagos tholeiite, & is a similar to average depleted MORB [GIRDER]. For the (b) curve, the "Thold"Nd endmember melt is in slight in collision with a transition to Fernandina basalts. The isotopically enriched melt used to generate the upper mixing curve has a much lower Nd concentration & slightly higher "Thold"Nd (C. M. P. Campbell in Genovesa, Marchena & Pinta Peninsula field areas). Note the strongly negative correlation between [La/Nb] and lower "Thold"Nd ratios. Santiago alkali basalts are similar to those erupted in western Galapagos.

Our findings for Galápagos indicate that there are at least 4 controls on the compositions of basalts in the area, in addition to the compositional domains of the mantle rocks themselves:

- Lithospheric thickness
- Geometries of melting regions
- Lateral flow paths
- Prior melting history of mantle material

These provide important constraints for future dynamical models of plume-ridge interactions.

DEPLETED SANTIAGO MANTLE MELTS HAVE LOW H2O CONTENTS

Figure 4. Variation of [Sm/Yb], with [La/Nb] in basalts from the Galápagos Spreading Centre together with available data for the Galápagos archipelago. Note the volatile-poor nature of tholeiitic basalts from eastern Isla Santiago relative to Fernandina data (data from Koleszar et al. (2003). Other data are from Schilling et al. (1982); Detrick et al. (2002); Cushman et al. (2004); Credo et al. (2005); Iggel et al. (2010). Normalisation factors are from McDonough & Sun (1995).

Figure 5. Schematic illustration of mantle flow northeast from the Galápagos plume to the adjacent Galápagos Spreading Centre (GSC). Note that T-MORB on the GSC is located above mantle that has previously undergone large amounts of melt generation beneath Santiago, Genovesa or Fína Peninsula. High levels of H2O in the source of Santiago tholeiitic basalts have been calculated. Data are from Graham et al. (1993); Kutz & Geist (1999); Detrick et al. (2002); Kutz et al. (2002).

SANTIAGO: MIXING OF PLUME & DEPLETED MANTLE MELTS

Figure 3. Regional variations in [Sm/Yb], of Galápagos basalts (shown in circles). Also shown are variations in mantle potential temperature (Tm) at 120 km depth, calculated from seismic data of Villagomez et al. (2007) using the parameterisation of Priestley & McKenzie (2006). Closed stars outline the locations of historic Galápagos volcanoes. Open stars outline the locations of vents. 1° represents the centre of symmetry of the isostatic axial depth profile. CPC and NPC are the Central and Northern Plume Components identified by Kokfelt et al. (2005). Representations [Sm/Yb], ratios are shown in circles and are from Gibson & Geist (2010); White et al. (1995); Saal et al. (2007); Harp & White (2001); Harp & Geist (2002); Harp et al. (2003); Iggel et al. (2010). Schilling et al. (2003). Cushman et al. (2004); Credo et al. (2005); Iggel et al. (2010). Schilling et al. (2003).

CONCLUSIONS

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