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ScienceDirect
Lithos 95 (2007) 346–362
LITHOS
www.elsevier.com/locate/lithos

Arc dacite genesis pathways: Evidence from mafic enclaves and their hosts in Aegean lavas

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Received 4 January 2006; accepted 17 August 2006
Available online 25 September 2006

Abstract

Mafic enclaves are commonly found in intermediate arc magmas, and their occurrence has been linked to eruption triggering by pre-eruptive magma mixing processes. New major, trace, Sr–Nd and U–Th isotope data of rocks from Nisyros in the Aegean volcanic arc are presented here. Pre-caldera samples display major and trace element trends that are consistent with fractionation of magnetite and apatite within intermediate compositions, and zircon within felsic compositions, and preclude extensive hybridization between mafic and felsic magmas. In contrast, post-caldera dacites form a mixing trend towards their mafic enclaves. In terms of U-series isotopes, most samples show small ^{238}U excesses of up to ~10%. Mafic enclaves have significantly higher U/Th ratios than their dacitic host lavas, precluding simple models that relate the mafic and felsic magmas by fractionation or aging alone. A more complicated petrogenetic scenario is required. The post-caldera dacites are interpreted to represent material remobilized from a young igneous protolith following influx of fresh mafic magma, consistent with the U–Th data and with Sr–Nd isotope constraints that point to very limited (<10%) assimilation of old crust at Nisyros. When these results are compared to data from Santorini in the same arc, there are many geochemical similarities between the two volcanic centers during the petrogenesis of the pre-caldera samples. However, striking differences are apparent for the post-caldera lavas: in Nisyros, dacites show geochemical and textural evidence for magma mixing and remobilization by influx of mafic melts, and they erupt as viscous lava *domes*; in Santorini, evidence for geochemical hybridization of dacites and mafic enclaves is weak, dacite petrogenesis does not involve protolith remobilization, and lavas erupt as less viscous *flows*. Despite these differences, it appears that mafic enclaves in intermediate Aegean arc magmas consistently yield timescales of at least 100 kyrs between U enrichment of the mantle wedge and eruption, on the upper end of those estimated for the eruptive products of mafic arc volcanoes. Finally, the data presented here provide constraints on the rates of differentiation from primitive arc basalts to dacites (less than ~140 kyrs), and on the crustal residence time of evolved igneous protoliths prior to their remobilization by mafic arc magmas (greater than ~350 kyrs).

Keywords: Mafic enclaves; Remobilization; U-series isotopes; Timescales; Petrogenesis

1. Introduction

A variety of processes have been identified as potential triggering mechanisms for volcanic eruptions, including volatile build-up, fractional crystallization and

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doi:10.1016/j.lithos.2006.08.002

magma recharge (e.g. Francis et al., 2000). In particular, it has been shown that the injection of mafic magma into a magma reservoir of intermediate composition may trigger eruption due to the combined effects of increased mass, heat and volatile input (Sparks et al., 1977). The abundance of mafic enclaves in andesites and dacites from a number of arc volcanoes, and disequilibrium textures in the host lavas, provide support for this model (e.g., Bacon, 1986; Clynne, 1999; Murphy et al., 2000; Harford and Sparks, 2001; Zellmer et al., 2003b; Mortazavi and Sparks, 2004). However, the petrogenetic relationship between mafic enclaves and their host lavas remains elusive, and the origin of arc lavas of intermediate composition is still controversial (e.g., Reagan et al., 2003; Zellmer et al., 2003a, 2005).

U–Th isotopes provide information on time scales of <350 kyrs and can, in principle, be used to determine the age relationships between different magmas (e.g., Condomines et al., 2003; Turner et al., 2003). In the simplest model, island arc dacites evolve largely by fractional crystallization from basaltic parents, which typically have ^{238}U excesses. Since ^{238}U excesses return to secular equilibrium via ^{230}Th in-growth, mafic enclaves injected prior to eruption into a dacite produced by fractionation of similar but older basalts should plot vertically below the dacite at lower (^{230}Th/^{232}Th) on a U–Th equiline diagram (Fig. 1a). However, it has been suggested that some arc dacites are produced by a more complex process involving a combination of partial re-melting of older arc basalts and partial crystallization of new mafic inputs in a lower crustal hot-zone (Annen and Sparks, 2002). So long as the process only involves re-melting of previous arc inputs, a similar relationship should result in U–Th isotope space because old lavas will have simply evolved vertically up to the equiline (Fig. 1b). In contrast, assimilation of old continental crust with low U/Th ratios will result in a trajectory to low (^{230}Th/^{232}Th) and U/Th (Fig. 1c). Thus, in combination with other geochemical and petrological data, U–Th isotopes may provide valuable constraints on different models for the origin of, and the relationships between, mafic and evolved arc magmas.

In this contribution, data from lavas erupted on Nisyros in the Aegean volcanic arc, including a number of dacites and associated mafic enclaves, are presented. Together with data from Santorini (Zellmer et al., 2000), which also include a number of dacites and mafic enclaves, the results are then used to explore likely relationships between the mafic and evolved compositions, and to provide constraints on the processes and rates of petrogenetic evolution of intermediate arc magmas.

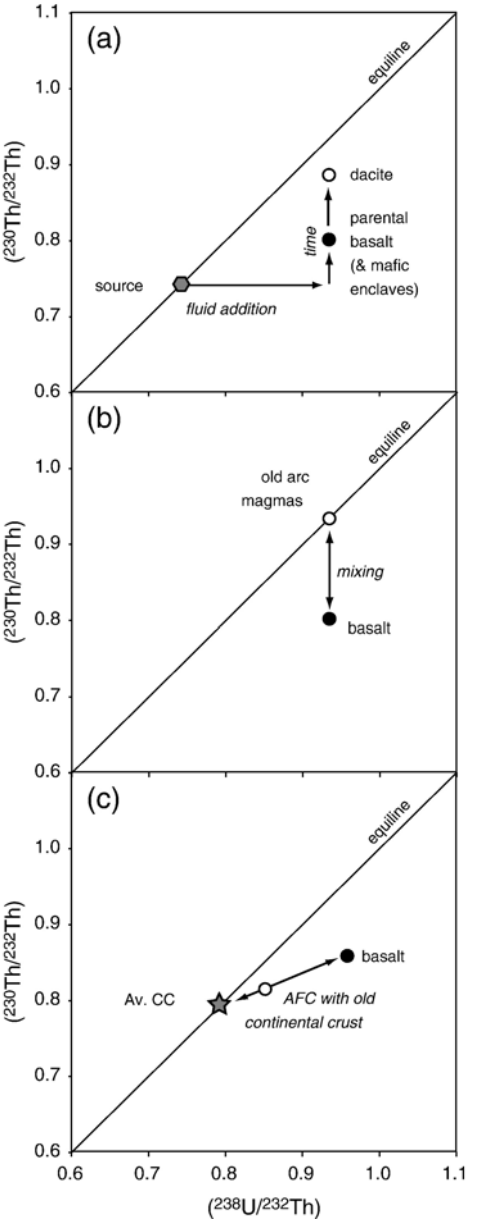

Fig. 1. The U–Th equiline diagram can be used to test simple models for the petrogenesis of intermediate arc magmas and their mafic enclaves. (a) In arcs, the U–Th mantle wedge composition is dominated by subducted sediments, e.g. GLOSS (Plank and Langmuir, 1998). Fluid addition to the mantle wedge produces ^{238}U excesses in the parental basalts. Dacites are generated through fractional crystallization from these basalts over time, resulting in a vertical array. (b) A similar array is produced by mixing of basalts with more evolved arc magmas that formed as in (a), but aged to secular equilibrium. (c) Mixing of basalts with old continental crust, e.g. average CC (Taylor and McLennan, 1995), will also produce dacites, but will introduce a range in U/Th ratios.