Trace-element distribution coefficients for pyroxenes, plagioclase, and olivine in evolved tholeiites from the 1955 eruption of Kilauea Volcano, Hawai‘i, and petrogenesis of differentiated rift-zone lavas

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Abstract

Reliable values for mineral-melt trace-element distribution coefficients (D) are essential for constructing realistic models of magma evolution based on trace elements. We have determined D-values for an extensive set of compatible and incompatible trace elements in clinopyroxene, orthopyroxene, plagioclase, and olivine phenocrysts in two moderately evolved (5.4 and 6.6 wt% MgO), tholeiitic lavas from the 1955 eruption of Kilauea volcano, Hawai‘i, using laser ablation-ICPMS. Coexisting melt compositions were obtained by analyses of quenched mesostasis. These D-values are consistent with experimental results when major element variations in the host phase are considered. Lattice strain models reproduce many of the partitioning characteristics. The distribution coefficients determined here can be applied to understanding the petrogenesis of evolved tholeiitic magmas from two recent Kilauea eruptions. Trace-element compositions of the 1955 lavas are consistent with 30–40% fractional crystallization of a gabbroic assemblage from an olivine tholeiite parental magma. The reduced influx of melt to Kilauea during the late 19th and early 20th centuries may have allowed the formation of evolved magmas in the rift zone.

Introduction

Accurate values for mineral-melt trace-element distribution coefficients (D = concentration of an element in the mineral/concentration in the melt) are essential for understanding the partitioning of trace elements in magmatic systems and for constructing realistic models of igneous processes. Microbeam analytical techniques are especially well-suited for the in situ measurement of trace-element distribution coefficients in both natural and experimental systems due to their high spatial resolution and their ability to avoid inclusions that can compromise the trace-element compositions of mineral separates (Foley et al. 1996). For this study, we used laser ablation ICPMS to measure D-values for an extensive suite of trace elements in clinopyroxene, orthopyroxene, plagioclase, and olivine phenocrysts in fractionated tholeiitic lavas from the 1955 eruption of Kilauea volcano, Hawai‘i. This phenocryst assemblage is unusual among Hawaiian tholeiites (e.g., Garcia et al. 2003). It provides the opportunity to establish a self-consistent set of D-values for general use in the study of silica-saturated basalts, and to assess in greater detail the petrogenesis of ocean-island magmas. The measured D-values are evaluated against lattice strain models that predict trace-element partitioning behavior (Beattie 1994; Blundy and Wood 1994, 2003), and used to evaluate fractional-crystallization models that have been proposed for the 1955 lavas based on their major-element compositions (Wright and Fiske 1971; Ho and Garcia 1988). We also present a brief discussion of the petrogenesis of evolved lavas from two recent Kilauea rift zone eruptions using the new trace-element data.

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Geologic setting

Most lavas erupted from Kilauea volcano are olivine tholeiites with ≥7 wt% MgO. These lavas typically contain only olivine (chromite) phenocrysts, and have major-element compositions consistent with olivine fractionation (e.g., Wright 1971). Although some Kilauea tholeiites contain sparse (<1 vol%) phenocrysts of augite and plagioclase (Garcia et al. 2003), only rare examples such as those from the early part of the 1955 east rift eruption differentiated sufficiently to also crystallize orthopyroxene (Wright and Fiske 1971). The 1955 eruption occurred after a 115 year hiatus in subaerial rift-zone activity, the longest gap in Kilauea’s historical rift-zone activity (Macdonald and Eaton 1964). Strongly differentiated lavas (5.0–5.7 wt% MgO) were produced during the early part of the 1955 eruption, whereas later lavas are less differentiated (6.2–6.7 wt% MgO) and contain olivine, augite, and plagioclase phenocrysts and microphenocrysts, but no orthopyroxene (Wright and Fiske 1971; Ho and Garcia 1988). There is a debate regarding the petrogenesis of the later lavas, i.e., whether they formed by mixing of differentiated magma similar to the early 1955 lavas with more primitive melts (Wright and Fiske 1971; Helz and Wright 1992), or simply by less differentiation of the same magma that produced the early lavas (Ho and Garcia 1988). The samples used in this study were described in detail by Ho and Garcia (1988). They have bulk compositions representing liquids, and they lack petrographic evidence of mixing such as reversely zoned, resorbed phenocrysts. Some of the lavas from this eruption contain rare xenocrysts (Helz and Wright 1992), which are common in east rift-zone lavas (Clague et al. 1995); such xenocrysts were not observed petrographically in the samples analysed for this study.