Earth and Planetary Science Letters 442 (2016) 162–172

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Geochemical investigation of Gabbroic Xenoliths from Hualalai Volcano: Implications for lower oceanic crust accretion and Hualalai Volcano magma storage system

Ruohan Gao [a,*], John C. Lassiter [a], Jaime D. Barnes [a], David A. Clague [b], Wendy A. Bohrson [c]

[a] *Department of Geological Sciences, Jackson School of Geosciences, University of Texas at Austin, TX 78721, USA*
[b] *Monterey Bay Aquarium Research Institute, Moss Landing, CA 95039, USA*
[c] *Department of Geological Sciences, Central Washington University, Ellensburg, WA 98926, USA*

ARTICLE INFO

Article history:
Received 25 July 2015
Received in revised form 22 February 2016
Accepted 23 February 2016
Available online 17 March 2016
Editor: T.A. Mather

Keywords:
geochemistry
lower oceanic crust
Hawaii volcanoes
oxygen
gabbroic xenoliths

ABSTRACT

The patterns of axial hydrothermal circulation at mid-ocean ridges both affect and are influenced by the styles of magma plumbing. Therefore, the intensity and distribution of hydrothermal alteration in the lower oceanic crust (LOC) can provide constraints on LOC accretion models (e.g., "gabbro glacier" vs. "multiple sills"). Gabbroic xenoliths from Hualalai Volcano, Hawaii include rare fragments of *in situ* Pacific lower oceanic crust. Oxygen and strontium isotope compositions of 16 LOC-derived Hualalai gabbros are primarily within the range of fresh MORB, indicating minimal hydrothermal alteration of the *in situ* Pacific LOC, in contrast to pervasive alteration recorded in LOC xenoliths from the Canary Islands. This difference may reflect less hydrothermal alteration of LOC formed at fast ridges than at slow ridges. Mid-ocean ridge magmas from slow ridges also pond on average at greater and more variable depths and undergo less homogenization than those from fast ridges. These features are consistent with LOC accretion resembling the "multiple sills" model at slow ridges. In contrast, shallow magma ponding and limited hydrothermal alteration in LOC at fast ridges are consistent with the presence of a long-lived shallow magma lens, which limits the penetration of hydrothermal circulation into the LOC.

Most Hualalai gabbros have geochemical and petrologic characteristics indicating derivation from Hualalai shield-stage and post-shield-stage cumulates. These xenoliths provide information on the evolution of Hawaiian magmas and magma storage systems. MELTS modeling and equilibration temperatures constrain the crystallization pressures of 7 Hualalai shield-stage-related gabbros to be ∼2.5–5 kbar, generally consistent with inferred local LOC depth. Therefore a deep magma reservoir existed within or at the base of the LOC during the shield stage of Hualalai Volcano. Melt–crust interaction between Hawaiian melts and *in situ* Pacific crust during magma storage partially overprinted clinopyroxene Sr and Nd isotope compositions of LOC-derived gabbros. Although minor assimilation of Pacific crust by Hawaiian melts cannot be excluded, the range of oxygen isotope compositions recorded in Hawaiian lavas and cumulates cannot be generated by assimilation of the *in situ* LOC gabbros, which have relatively uniform and MORB-like $\delta^{18}O$ values. To first order, the isotopic heterogeneity observed in Hawaiian melts appears to derive from the heterogeneous plume source(s), rather than assimilation of local oceanic crust.

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1. Introduction

Hydrothermal circulation at mid-ocean ridges is intimately linked to the processes of oceanic crust accretion. Axial hydrothermal circulation drives cooling and crystallization of axial magmas. In addition, the distribution of magmas in the crust, in particular the presence or absence of a long-lived shallow axial magma chamber, influences the depth and degree of axial hydrothermal circulation. Hydrothermal alteration of newly formed oceanic crust dominates the heat and mass exchange between the Earth's lithosphere and hydrosphere. However, the intensity and distribution of hydrothermal circulation in gabbro cumulates, the thickest layer of oceanic crust, is still poorly constrained.

The ca. 1800 Kaupulehu flow of Hualalai Volcano, Hawaii contains abundant dunite, wehrlite and gabbro, and rare websterite and anorthosite xenoliths (Jackson et al., 1981; Clague, 1987; Kauahikaua et al., 2002). A small subset of the gabbros appears to be Pacific lower oceanic crust (LOC) layer-3 gabbros (Clague, 1987;

* Corresponding author.
E-mail address: ruohangao@utexas.edu (R. Gao).

http://dx.doi.org/10.1016/j.epsl.2016.02.043
0012-821X/Published by Elsevier B.V.

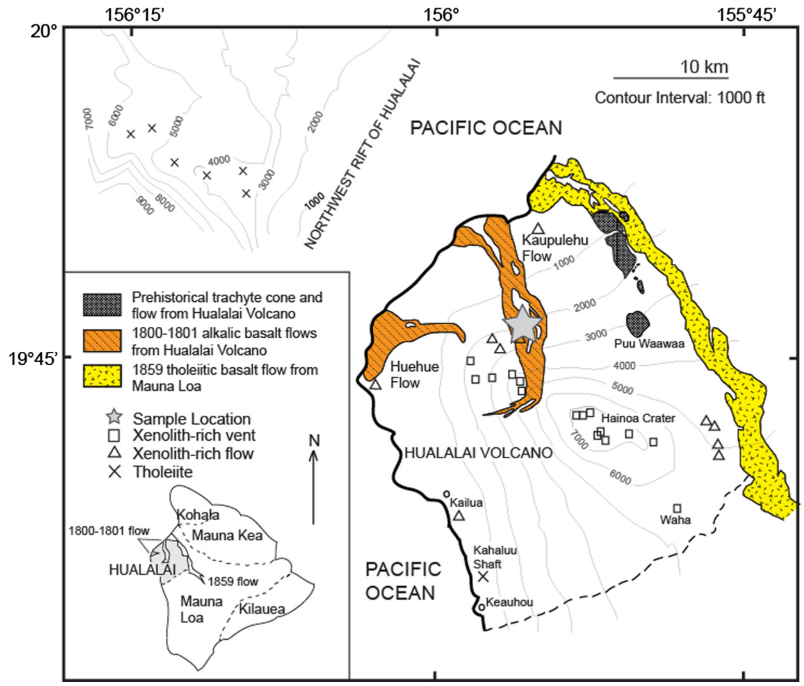

Fig. 1. Simplified map of Hualalai Volcano. Star marks location where gabbroic xenoliths were collected (modified from Clague, 1987). Inset shows the location of Hualalai Volcano on the Big Island of Hawaii.

Lassiter and Hauri, 1998). These gabbros can be used to examine the hydrothermal alteration history of LOC, and provide constraints on the mechanism of LOC accretion. The majority of Hualalai gabbros are cumulates derived from Hualalai shield- and post-shield-stage melts (Clague, 1987). These gabbros can be used to investigate the Hualalai magma plumbing system and the role of crustal assimilation in the evolution of Hawaiian magmas.

In this study, we report mineral major and trace element and Sr–Nd–O isotope variations in a suite of 28 Hualalai gabbros, including 16 samples with chemical characteristics indicative of derivation from *in situ* Pacific LOC and 12 samples related to the shield and post-shield stages of Hualalai magmatism. Strontium and oxygen isotope data of LOC-derived gabbros are used to evaluate the extent of hydrothermal alteration of the *in situ* LOC, providing constraints on different models of LOC formation. We examine mineralogical and compositional constraints on the fractionation pressures of Hualalai-related gabbros to constrain the depth(s) of magma storage, and examine compositional variations in LOC- and Hualalai-derived gabbros to evaluate the effects of melt–crust interaction in the evolution of the *in situ* LOC and Hawaiian magmas.

2. Background

Hawaiian volcanoes commonly evolve through four stages that are characterized by different lava types, magma supply rates and inferred degrees of mantle melting (Clague, 1987). Magma supply rates and degree of melting increase as the volcano moves towards the center of the plume, and then decrease as the Pacific plate moves away from the plume (e.g., Frey et al., 1990). Small volumes of alkalic basalt are primarily erupted during the pre-shield stage. Large volumes of tholeiitic basalt dominate the following shield stage. The post-shield stage is characterized by a return to mostly alkalic basalt and associated differentiated lavas. Finally, some Hawaiian volcanoes erupt small volumes of alkalic basalt, basanite and nephelinite during a rejuvenated stage, usually following a hiatus in activity at the end of the post-shield stage (Clague, 1987).

Hawaiian lavas also display significant temporal and spatial variability in isotopic composition. Post-shield and rejuvenated-stage lavas typically have more depleted isotopic compositions than shield-stage lavas (e.g. Chen and Frey, 1985). In addition, recent Hawaiian volcanoes display systematic spatial-compositional variations that define two parallel linear trends. "Loa trend" volcanoes typically have more "enriched" Sr–Nd isotopic compositions compared to "Kea trend" volcanoes, and are also characterized by higher $^{208}Pb/^{204}Pb$ at a given $^{206}Pb/^{204}Pb$ (Abouchami et al., 2005). In addition, olivine in "Loa trend" lavas have $\delta^{18}O$ values that extend as high as $+6.1‰$, beyond the range of fresh MORB or most mantle peridotites. Olivine in "Kea trend" lavas have $\delta^{18}O$ values as low as $+4.3‰$ (Eiler et al., 1996).

The chemical characteristics of "Loa trend" lavas likely reflect ancient recycled oceanic crust and sediments entrained in the Hawaiian plume source (e.g. Eiler et al., 1996; Lassiter and Hauri, 1998). In contrast, several different origins have been proposed for the "Kea trend" lavas, including incorporation of depleted upper mantle asthenosphere (e.g. Chen and Frey, 1985), lower Pacific crust or lithospheric mantle (e.g. Eiler et al., 1996), and recycled lithosphere within the Hawaiian plume itself (e.g. Lassiter and Hauri, 1998). Evaluation of the role of local crust/lithospheric mantle is difficult because the composition of the *in situ* Pacific crust and lithospheric mantle is not well characterized. Furthermore, the extent to which Hawaiian magmas pond and crystallize within the oceanic crust/lithospheric mantle during different stages of Hawaiian volcanism is unclear.

Hualalai Volcano is located on the west coast of the Big Island of Hawaii (Fig. 1). Post-shield alkali basalts cover most of the subaerial portion of Hualalai Volcano. Shield-stage tholeiitic basalts are exposed along the submarine northwest rift zone. The 1800–1801 Huehue and the slightly older Kaupulehu alkali basalt lava flows contain abundant mafic and ultramafic xenoliths that are interpreted as Hualalai cumulates and *in situ* Pacific LOC (Clague, 1987). These xenoliths provide new constraints on the composition and evolution of the local LOC, and on the evolution of Hawaiian volcano magma storage systems.