Hawaiian magma-reservoir processes as inferred from the petrology of gabbro xenoliths in basalt, Kahoolawe Island

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Abstract. Gabbro xenoliths in a tholeiitic lava of Kahoolawe Island, Hawaii, a ~ 1.3-1.4 Ma shield volcano, are 1-3 cm in size and comprised of plagioclase, clinopyroxene, and orthopyroxene. Gabbro textures – while intergranular and in part subophitic – are “open” due to 28-48 vol.% of vesicular basalt occupying xenolith space. Vesicles in and around the xenoliths are lined or filled with rhyolitic glass (segregation vesicles). The host is evolved tholeiite (MgO 6.1 wt%) with phenocrysts, microphenocrysts, and glomerocrysts of olivine, clinopyroxene, orthopyroxene, and plagioclase, and megacrysts (~1 cm) of plagioclase. The Sr-isotope ratio of one xenolith is 0.70489; the host basalt ratio is 0.70460. Xenolith isotope composition, grain resorption, and clinopyroxene (Fs12.5-15Wo38-35.5), orthopyroxene (Fs19.5-24Wo4.1), and plagioclase (An65-68Or6.1-6.2) compositions suggest that these gabbros crystallized from Kahoolawe tholeiitic magma of essentially the same composition as the host basalt, but pre-dating the magma represented by the host. Based on the absence of intergranular Fe-Ti oxide phases from the pl+cpx+opx assemblages, and the open, vuggy textures, we envision crystallization on a reservoir roof at temperatures >1100°C. Entrainment of gabbro assemblages and plagioclase megacrysts from a roof mush/suspension zone occurred during convection associated with replenishment of the magma reservoir. These open-textured gabbro xenoliths are therefore not fragments of pre-existing coarse-grained bodies such as sills or segregation veins. Rhyolitic glass in vesicles represents a gas-effervescence filtration process that forced fractionated residual liquids from the groundmass into voids associated with the xenoliths.

Key words: Hawaiian tholeiite composition – gabbro xenoliths – magma convection – magma “mush” – basalt mineral compositions – rhyolitic glass – vesicles

Introduction

Among the xenoliths sampled from basaltic rocks, gabbroic xenoliths have received the least attention. Within the comparatively small coverage afforded gabbroic xenoliths, however, those in oceanic basalt (e.g. Dixon et al. 1986; Hekinian et al. 1985; Davis and Clague 1990) and in Hawaiian basalt (e.g. Fodor and Vandermyden 1988; Rudek et al. 1992) have provided insights into magma reservoir processes (e.g. convective mixing; cumulate layering). To further explore the significance of gabbro in basalt, we investigated a collection of gabbroic inclusions and plagioclase megacrysts from a rare occurrence on Kahoolawe Island, Hawaii. Our approach was to examine the xenoliths, megacrysts, and host basalt in terms of petrography, mineral compositions, host basalt composition, and Sr-isotope compositions in order to establish the origin of the gabbros and megacrysts with respect to the host basalt, and to determine what information such inclusions offer about basaltic magmatism in general.

Geologic setting

Kahoolawe Island is the smallest of the eight major Hawaiian Islands (Fig. 1), approximately 18 x 11 km. It is about 11 km southwest of Haleakala volcano on Maui. Details of Kahoolawe geochemistry and K-Ar ages show that the island is a tholeiitic shield at least 1.4 Ma with tholeiitic caldera-filling lavas and postshield tholeiitic and alkali basalts as young as 1.15 Ma (Fodor et al. 1992). We collected the gabbro xenoliths and plagioclase megacrysts from a tholeiitic lava located along the western shoreline (Fig. 1). We do not have a K-Ar age for this sample, but on the basis of field examination (an isolated shoreline outcrop) and composition, this lava could represent either the shield or postshield stages of volcano development.

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Petrography

**Basalt host**

The basalt host for the gabbro xenoliths and plagioclase megacrysts contains olivine, plagioclase, clinopyroxene, and orthopyroxene as euhedral and subhedral phenocrysts and microphenocrysts 0.5–2 mm in size (Fig. 2a, b). The mode for a representative thin-section is in Table 1. Olivine is subrounded and rimmed by or entirely converted to iddingsite. It generally occurs as individual grains but is sometimes clustered with other olivine grains. The plagioclase, clinopyroxene, and orthopyroxene, on the other hand, commonly occur as glomerocrysts of several grains (Fig. 2b). Whether separate or in clusters, some plagioclase grains have portions of their margins resorbed or rounded (Fig. 2a). The basalt groundmass is largely intergranular plagioclase laths, clinopyroxene, and Fe-Ti oxides, but with anhedral plagioclase occupying some of the spaces between the groundmass crystals. Ferropseudobrookite occurs in the groundmass associated with one of the gabbro xenoliths, but was not observed in other thin sections.

While only some portions of our basalt samples contain vesicles, thin-section examination shows that the host basalt surrounding the gabbro xenoliths is always vesicular (Fig. 2c). Also, thin sections reveal that substantial amounts of vesicular basalt, from 28 to 48 vol.% of basalt plus vesicles (Table 1), are included within the gabbro xenoliths (Fig. 2d). Some of the vesicles in the xenoliths reach 3.5 mm in size, and they can be circular or ameoboid in outline. This contrasts with the vesicles observed in thin sections of host basalt that do not contain xenoliths; those vesicles are typically < 1 mm and more elongate in form (Fig. 2b). Moreover, the vesicles within and in the vicinity of gabbro xenoliths can be filled, partially filled, or lined with glass (Fig. 2e, f). The glass in the vesicles can be opaque or translucent brown and may contain crystallites of plagioclase, clinopyroxene, titaniferous magnetite, ilmenite, ferropseudobrookite (Fig. 2g; needle-shaped and 0.5–2 mm long),apatite, and small SiO₂ grains (Fig. 2h; < 20 microns).

**Gabbro xenoliths and plagioclase megacrysts**

The five xenoliths studied (labeled A, B, C, D, and E) are only 1–2 cm in size in the thin sections examined, but gabbro xenoliths up to 3 cm occur at the sample locality. They have modal mineral proportions of 45–78 vol.% plagioclase and 22–55 vol.% pyroxene (Table 1). Microprobe analyses revealed qualitatively that orthopyroxene is subordinate to clinopyroxene, as low as ~1 vol.% in gabbro B. Altogether, the pl + px assemblages make up only about 52–72 vol.% of xenolith space because, as noted above, basalt (22–28 vol.% ) and vesicles (6–20 vol.% ) occupy the xenoliths (Table 1; Fig. 2d, 3). Hand-samples show the vuggy (vesicular) character of the gabbro fragments (Fig. 3d) and reveal that some vugs are lined with delicate quartz crystals.

We therefore describe these gabbro xenoliths as having “open” textures because the basalt (with vesicles)

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**Table 1. Modes (in vol.%) of five gabbroic xenoliths and their host tholeiitic basalt, Kahoolawe Island, Hawaii**

<table>
<thead>
<tr>
<th></th>
<th>Finer-grained (&lt;2 mm)</th>
<th>Coarser-grained (&gt;2 mm)</th>
<th>Basalt host</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>62.0</td>
<td>33.1</td>
<td>66.7</td>
</tr>
<tr>
<td>Pyroxene</td>
<td>38.0</td>
<td>20.3</td>
<td>33.3</td>
</tr>
<tr>
<td>Olivine</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Basalt groundmass</td>
<td>—</td>
<td>26.4</td>
<td>—</td>
</tr>
<tr>
<td>Vesicles</td>
<td>—</td>
<td>20.2</td>
<td>—</td>
</tr>
<tr>
<td>Total counts</td>
<td>1300</td>
<td>700</td>
<td>650</td>
</tr>
</tbody>
</table>

Columns 1 = proportions of pl, px (cpx + opx), and ol
Columns 2 = includes proportions of pl, px, and ol along with the basalt groundmass and vesicles present within the margins (as best interpreted visually) of the gabbro xenoliths.