A petrological analysis of P-type (pipe vesicle bearing), blue glassy pahoehoe, Kilauea, Hawai'i

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INTRODUCTION

P-type (pipe vesicle bearing), blue glassy pahoehoe is a unique lava found in minor quantities (less than 5% of the total pahoehoe) on the active Kalapana flow field compared to the relatively abundant S-type (spongy) pahoehoe (Wilmoth and Walker, 1993). Blue glassy pahoehoe is characterized by its thick and sparsely vesiculated outer glassy rind, comparatively high density, distinct blue-silver surface color, and localized pipe vesicles. Outbreaks of blue glassy pahoehoe are found at many localities on the coastal terrace, either escaping as squeeze-ups from the base of tumuli, pressure ridges, and lava rises; or as sheet flows in areas of low topographic relief such as waning or collapsed lava tubes. Blue glassy pahoehoe is extremely susceptible to weathering and quickly loses its unique color on the flow field. The blue glassy pahoehoe for this project occurred on the coastal terrace of the Kalapana flow field whose lava was supplied by the Kupaianaha vent of Kilauea. Several flows were observed during their formation and sampled after cooling. Additional samples were collected by Laszlo Keszthelyi during their formation and flow temperatures were measured with a thermocouple. Although the physical characteristics of blue glassy pahoehoe are widely known, not much is known about its chemical composition, mineralogy, or petrogenesis. The goal of this project is to provide the first in-depth petrological analysis of blue glassy pahoehoe.

GEOLOGIC SETTING

The Pu'u O'o-Kupaianaha eruption (January 1983-present) of Kilauea is the longest recorded rift eruption in Hawai'i's history. The two dominant vents, Pu'u O'o and Kupaianaha, have supplied enough tholeiitic lava to cover a minumum area of 82 km^2 to depths as great as 25 m increasing the land surface area as much as 1.5 km^2 (Mangan, Heliker, Mattox, Kauahikaua, Helz 1995). The effusion rate of the rift eruption from the Kupaianaha vent has remained relatively low (3.5 m^3/s), creating an intricate system of tube-fed pahoehoe flows on the coastal terrace, collectively known as the Kalapana flow field (Mattox, Heliker, Kauahikaua, and Hon, 1993). The Kalapana flow field is in an area of low topographic relief (less than 2°) allowing for numerous breakouts from established lava tubes as well as dying lava tubes. The conditions on the Kalapana flow field are ideal for studying blue glassy pahoehoe due to the numerous outbreaks of lava from tubes on a relatively flat area.

FIELD WORK, METHODS, AND ANALYSIS

Field work was conducted from July 30, 1996, through August 13, 1996, over a majority of the Kalapana flow field. A 10×10 meter plot of blue glassy pahoehoe on the upper flow field was selected in order to study the field characteristics of blue glassy pahoehoe. The sight was located approximately 100 meters east of the coastal terrace pali (a steep embankment of entrail pahoehoe marking the beginning of the coastal terrace) and approximately 400 meters south of the most active lava tube during this eruptive phase. Other samples were collected randomly over the entire flow field to ensure a comprehensive analysis of blue glassy pahoehoe. Samples of S-type pahoehoe, transitional blue glassy pahoehoe, and blue glassy pahoehoe with known thermocouple and surface temperature data were provided by Keszthelyi. Blue glassy pahoehoe is a relatively cooler lava than the common S-type pahoehoe, but due to its high density is able to radiate more heat.

Thin sections and petrographic analysis of seven specimens (five blue glassy pahoehoe samples, one transitional blue glassy pahoehoe sample, and one S-type pahoehoe) were followed up by geochemical analysis and back-scattering electron imaging at the University of Oregon using the Cameca SX50 Electron Microprobe and the JEOL JSM-6300 XVScanning Electron Microscope under the guidance of Kathy Cashman and Michael Shaffer.

BLUE GLASSY PAHOEHOE

Blue glassy pahoehoe's blue-silver surface color and unique flow formations distinguishes it readily from the gold color of common S-type pahoehoe on the flow field (Figure 1.1). It has a thick dense outer glassy rind that forms a layer approximately 0.25-0.75 cm at the top of each sheet flow. The glassy rind is commonly thicker on the dorsal side of lobes and becomes progressively thinner around its circumference until reaching the base. Within the glassy rind, a transition area known as the "plastic mush zone" marks the point where the glassy rind is in contact with the more crystalline basalt. The plastic mush zone can be noted on samples by a thin white line on cross sections of broken sheet flows and lobes. Both the glassy rind and plastic mush zone exhibit little or no vesiculation. The inner crystalline layer is the area in which the pahoehoe is most porous.

Although blue glassy pahoehoe is believed to be the result of a bubble-poor melt (a result of bubble coalescence and loss due to increased storage time), pipe vesicles located in the crystalline layer form its inner selvage and project toward the flow center. Pipe vesicles are believed to be the result of the inward movement and coalescence of bubbles from the base toward the interior of the flow (Wilmoth and Walker, 1993). Enigmatic cylindrical tubes form the core of most blue glassy pahoehoe lobes. They extend through the length of lobes loading bulbous tips and unique beehive-shaped structures (Figure 1.2). In the storage area, bubble coalescence and loss is believed to increase the pressure and cause the forcible extrusion of lava through the brittle crust of the surrounding pahoehoe. Blocks of solid pahoehoe (some as large and as heavy as bowling balls) are sometimes thrust several feet from the outbreak point. Blue glassy pahoehoe also occurs as squeeze-ups in the axial and lesser clefts of tumuli (positive topographic features that form by the up-tilting of crustal plates due to lava injection, without any crustal shortening) and lava rises (flat-surfaced uplifts also caused by lava injection) where it progresses only a few meters from the outbreak point (Walker, 1991). Delicate glass bubbles forming in the upper glassy rind are believed to be caused by the rapid exsolution of volatiles forming in microcavities during the initial crystallization of the lava (Hon, 1994). Larger bubbles ranging from 5 cm to 2 m are also found in the glass/basalt transition area of blue glassy pahoehoe (Figure 1.3). The interior surface of the larger bubbles display brilliant colors of purple, green, and gold which may be the result of a thin film left by volatiles. The change in vesicle-size distribution is believed to be the result of blue glassy pahoehoe being an undercooled, supersaturated (with water and sulfur) melt released from a higher pressure equilibriating to 1 atmosphere (Hon 1994). Evidence of blue glassy pahoehoe being an undercooled melt is supported by Keszthelyi's thermocouple readings (Table 1.1); however, there is little scientific evidence to support the amount of degassing and supersaturation of the lava.

Figure 1.1: Blue glassy pahoehoe on S-Type pahoehoe (2 Feet Scale)

Figure 1.2: Bubble, beehive, and lobe formations.

Figure 1.3: Large bubble with salmon-gold colored interior.

GEOCHEMISTRY

Blue glassy pahoehoe is classified as a tholeiitic basalt. The constituents of this lava are glass, plagioclase, clinopyroxene, olivine, and chrome spinel with very minor chemical variations in all five blue glassy pahoehoe samples. The compositions for the minerals in blue glassy pahoehoe are plagioclase (An_{67-69}), clinopyroxene (En_{48-52} Fs_{11-13} Wo_{34-40}), and olivine (Fo_{80-81}). The chrome spinel was found only in the olivine crystals. Glass compositions with respect to depth were also taken for three samples; however, the chemical variation is minor. Glass compositions for S-type pahoehoe, transitional blue glassy pahoehoe, and blue glassy pahoehoe with known thermocouple readings taken by Keszthelyi are analyzed in Table 1.1. The glassy rinds of blue glassy pahoehoe contain less than 5% plagioclase, olivine, and pyroxene crystals. S-type pahoehoe, on the other hand, drastically lacks plagioclase and pyroxene, but the percent of olivine crystals is comparable. The increased abundance in minerals, especially plagioclase, in blue glassy pahoehoe indicates that it must crystallize from a cooler lava which correlates well with Keszthelyi's thermocouple data.

TABLE 1.1 Oxide Analysis for S-type Pahoehoe to Blue Glassy Pahoehoe with Extrusion Temperatures

Pahoehoe	T (°C)	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	CrO_2	MnO	Fe_2O_3
S-Type	1135.6	2.31	6.65	13.64	51.44	0.42	11.29	2.54	0.05	0.13	11.53
Intermed.1	1126.5	2.39	6.36	13.70	51.53	0.47	11.12	2.56	0.03	0.18	11.43
P-Type	1122.8	2.23	5.91	13.56	51.49	0.43	11.49	2.54	0.14	0.14	11.44

Note: The oxide values are averages.

CRYSTALLIZATION SEQUENCE

Although the mineral compositions of blue glassy pahoehoe remain constant, the relative abundance of the minerals varies with depth. The crystallization sequence of blue glassy pahoehoe is evident in each of its three layers: the glassy rind, the plastic mush zone, and the inner crystalline layer. The glassy rind is mainly glass with minor quantities of plagioclase, clinopyroxene, and olivine. The plastic mush zone is noted by delicate, pillowy blobs (Figure 2.2) and an increase in the abundance of plagioclase and pyroxene which display a dendritic texture. The inner crystalline layer consists mainly of plagioclase displaying dendritic patterns of nucleation and also contains pyroxene and olivine. The crystalline layer is a completely crystalline version of the platic mush zone. The olivine, present in all the layers, is coarser and was probably a phenocryst at the time of eruption. All of the following figures are back-scattered electron images.

Figure 2.1: Glassy Layer 100x

Figure 2.2: Pillowy blobs 250x

Glassy Layer (Figure 2.1): This layer is primarily composed of glass with very minor quantities of olivine, plagioclase, and clinopyroxene. The dark rectangular shapes are plagioclase. The clinopyroxene, the second darkest color, occurs in cumulophyric clusters with plagioclase. Olivine, not in this picture, is normally larger than the plagioclase and clinopyroxene and is often resorbed. The larger size of olivine indicates that it crystallized before plagioclase and clinopyroxene. The chrome spinels occur within the olivine minerals suggesting a possible sequence of crystallization (chromite→olivine→plagioclase+ clinopyroxene).

Figure 3.1: Mush Zone 100×

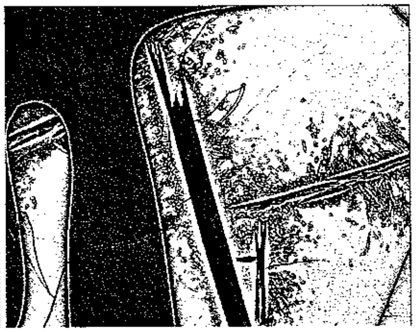

Figure 3.2: Mush Zone 800×

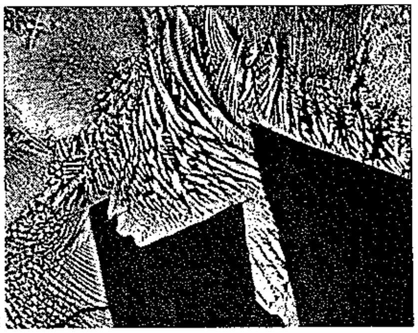

Figure 3.3: Plagioclase 2000×

Plastic Mush Zone (Figure 3.1, 3.2, & 3.3): Less than 1 cm below the previous image is the plastic mush zone marking the transition between the glass and crystalline layer (Figure 3.1). Higher magnification reveals the beginning of a unique quench crystallization phenomenon (Figure 3.2). Plagioclase crystals like those in Figure 2.1 begin rapid quench crystallization causing them to have uneven spiky ends (Figure 3.2). The nucleation of plagioclase (shown by a feathery/hairy texture) enriches the surrounding area in mafic components so that clinopyroxene nucleates on the plagioclase (Figure 3.3). The plagioclase and clinopyroxene form an expanding front of quench crystallization which become the pillowy blobs. These unique blobs increase in abundance with depth towards the center of the flow. Olivine shows signs of being resorbed, noted by the embayments and rounded holes in the crystal's interior.


Figure 4.1: Crystalline Layer 100×

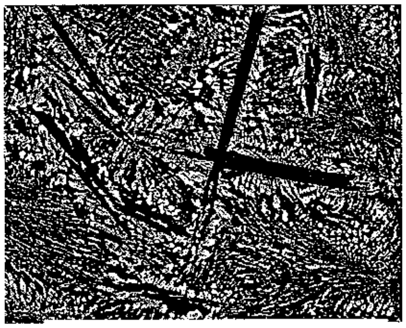
Figure 4.2: Crystalline Layer 500×


Figure 4.3: Crystalline Layer 1000×

Crystalline Layer (Figure 4.1, 4.2, & 4.3): Below the plastic mush zone, the plagioclase content increases steadily towards the inner vesicles. Unique dendritic patterns are created by the nucleating plagioclase.

CONCLUSION

This project provides the first detailed mineral and chemical description of blue glassy pahoehoe and the first account of a quench crystallization phenomena--the pillowy blobs. The layering of blue glassy pahoehoe is directly related to its crystallization rates. Plagioclase increases in abundance with increasing depth toward the inner selvage and displays unique dendritic textures. Crystallization melt geothermometry of Keszthelyi's samples is currently underway.

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