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PETROLOGIC EVIDENCE FOR MAFIC RECHARGE AT VOLCÁN BARÚ, PANAMA
SHANNON BRADY, Union College
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VOLUME CONSTRAINT AND POTENTIAL SECONDARY VOLUME INPUTS OF LATE PLEISTOCENE AGE SECTOR COLLAPSE, VOLCÁN BARÚ, PANAMA
LOGAN SCHUMACHER, Pomona College
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VOLCÁN BARÚ DEBRIS AVALANCHE FACIES AND AGES
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INTRODUCTION
The purpose of this study is to understand a large sector collapse at Volcán Barú that occurred during the Late Pleistocene and destabilized the southwestern flank of the edifice. The most profound physical evidence of this sector collapse is the vast deposit of hummocks and lahars. The initial purpose of this project was to determine the distribution of different lithologies at the cores of hummocks and correlate them to a pre-collapse edifice. However, the geographic distribution of lithologies, defined by geochemistry and mineralogy, does not provide significant insight to understand the mechanism of emplacement by debris avalanches. Yet, an interesting petrologic story has emerged from disequilibrium mineral textures observed in samples taken from these hummocks. Reaction rims on hornblende phenocrysts in conjunction with crystal aggregates and dusty sieve-textured plagioclase suggest disequilibrium, possibly due to the injection of a hotter mafic batch of magma into the andesitic storage chamber of Volcán Barú (Rutherford and Devine, 2003, Plechov et al., 2008, Seaman, 2000). Opacitization of hornblende phenocrysts further suggests that hornblende was raised out of its stability field by decompression during ascent. The combination of an increase in temperature and a decrease in pressure of the pre-existing andesite magma may have possibly triggered eruptive activity at Barú (Plechov et al. 2008, Eichelberger and Izbekov 2000).

GEOLOGIC SETTING
Volcán Barú is an active, calc-alkaline, stratovolcano located in the Chiriquí Province of western Panama (Gardner, Fig 2, this volume), 35 km from the Costa Rican border at the southern end of the Central American Volcanic Arc (CAVA) (Fig. 1). The summit of Volcano Barú reaches 3,374 m in elevation and the edifice covers an area of 280 km² (Sherrod et al. 2007). Volcán Barú lies inboard of the Panama Triple Junction (PTJ), where there is convergence of the Cocos, Nazca, and Caribbean plates (Gardner, Fig. 1, this volume). The tectonic setting of Volcán Barú is complex due to oblique, aseismic, shallow slab subduction of the Nazca plate beneath Panama, where a clear Benioff zone does not exist below the volcanic arc in western Panama (Sherrod et al. 2007, Defant et al. 1992). The edifice of Volcán Barú, which was built up by numerous lava flows, pyroclastic flows, and lahar deposits, may have reached up to 4,000 m in elevation and 250-350 km³ in volume prior to the collapse of its western flank (Sherrod et al. 2007). Volcanism is thought to have commenced ca. 0.5 Ma and Quaternary products at Volcán Barú are andesite-dacite in composition (Sherrod et al. 2007, Hidalgo and Rooney 2010). There have been four major episodes of dome growth, explosive eruptions, and block-and-ash flows over the past 1,600 years, and recent seismicity since 2006 suggests that it is still active (Sherrod et al., 2007).

FIELD METHODS
Rock samples were collected from the cores of hummocks and from the modern volcanic edifice of Volcán Barú. Large hummocks proximal to the modern volcanic edifice consist of closely spaced brecciated megaclasts of andesite composition that are shattered throughout (Fig. 1C). The combination of an increase in temperature and a decrease in pressure of the pre-existing andesite magma may have possibly triggered eruptive activity at Barú (Plechov et al. 2008, Eichelberger and Izbekov 2000).
point-counter. Samples were also crushed using RockLabs® Laboratory Hydraulic Crusher/Breaker and powdered using RockLabs® Laboratory ring and puck mill. Major element geochemistry was performed at ACME Analytical Laboratory LTD in Vancouver, British Columbia, Canada. Trace element geochemistry was performed at Union College using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) following high-pressure HF digestion. Photomicrographs were taken using PAXcam digital microscope camera. Backscattered Electron images were acquired using the Zeiss EVO50XVP Scanning Electron Microscope.

RESULTS & OBSERVATIONS

Samples from the hummocks and edifice range in composition from 51.8 to 61.7 wt. % SiO₂. Samples from a newly discovered basaltic cinder cone and lava flow have 43.7 and 45.9 wt. % SiO₂ respectively (Fig. 2). Based on field relations, the cinder cones appear to post-date the sector collapse, but their relationship to Volcán Barú and the sector collapse remains under investigation. Mineral phases present within the andesite debris avalanche blocks include plagioclase, clinopyroxene, orthopyroxene, ± hornblende, Fe-Ti oxides, and trace amounts of olivine, apatite, quartz, and biotite in decreasing abundance. Based on point-counts, the average phenocryst total is 56.8%. Hornblende bearing samples have concentrations that vary from 0.4-18.7 %. Three lithofacies are defined in this study based on the mineralogy and textures observed in the Barú samples: 1) samples without hornblende, 2) samples with fine-grained pyroxene dominant rims around hornblende grains, and 3) samples with fine-grained crystal aggregates at the interior of hornblende grains (Fig. 1, 2).

Plagioclase
Plagioclase phenocrysts are calcic in composition based on SEM EDS (energy dispersive spectrometry) analyses. Plagioclase crystals display a dusty sieve-texture, common throughout most samples from Barú. This sieve texture appears as a corroded interior with a clean outer rim. The core may consist of tiny glass particulates (Fig 3A).

Mafic Glomerocrysts
Mafic glomerocrysts occur as fine-grained cumulates

LAB METHODS
Samples were prepared for geochemical and petrographic analyses at Union College in Schenectady, New York. Rocks were cut into thin sections for observation under a petrographic microscope and to determine mineral phase percentages using a
of microcrystalline clinopyroxene, orthopyroxene, plagioclase, and Fe-Ti oxides in the groundmass. Clinopyroxene appears to be the dominant mineral phase. Crystals within the clots do not appear to form along euhedral faces, rather they are subhedral to anhedral.

Hornblende
The first type of reaction rim on hornblende in the andesite samples from Volcán Barú is defined by crystal aggregates: it is a fine-grained rim of clinopyroxene, orthopyroxene, plagioclase, and Fe-Ti oxides, with clinopyroxene as the dominant mineral phase (Fig. 3E-F). These rims appear to shield hornblende phenocrysts where the crystal is in contact with the melt (Fig. 3C). Where fine-grained rims are absent, hornblende-bearing samples display fine-grained microlite cores also consisting of pyroxene, plagioclase and oxide crystals (Fig. 3B, 3H). Overall, crystal aggregates occur as fine-grained reaction rims around hornblende grains, within the interior of hornblende grains, and also as individual glomerocrysts (Fig. 3D).

The second type of reaction rim around hornblende grains is characterized by varying degrees of oxidation (Fig. 3A-C). Rutherford and Devine (2003) refer to this reaction as opacitization. Opacitization is not limited to crystal rims where the hornblende is in contact with the melt because this reaction occurs along crystal margins, fractures, and cleavage planes of individual hornblende phenocrysts. Some hornblende grains also display an oxide core (Fig. 3C).

All hornblende-bearing samples from Barú demonstrate opacitization to some degree and the opacitized hornblende grains can be organized into three stages. [1] The first degree of opacitization is a distinct and easily identifiable oxide rim around a hornblende grain, which is also clearly recognizable with its 56° and 124° cleavage planes. This oxide rim can be easily measured. [2] The second degree is characterized

Figure 2. Total alkalies v. silica discriminant diagram for Volcán Barú samples. Classification grid from Lebas et al. (1986).

Figure 3. (A-D) Photomicrographs of disequilibrium mineral textures from Volcán Barú hornblende-bearing samples in transmitted light. (A) Hornblende phenocrysts displaying opacitization and fine-grained core, dusty sieve-textured plagioclase. (B) Opactized hornblende phenocryst with fine-grained core. (C) Opacitized hornblende phenocrysts with high-Ca fine-grained rims. (D) Clinopyroxene crystal aggregate. (E-H) Backscattered electron images from the SEM. (E) Hornblende phenocryst with opacitization along crystal cleavage planes (white). (F) Magnified fine-grained rim of cpx, plag, and Fe-Ti oxides from (E). (G) Fine-grained rim around hornblende. (H) Hornblende displaying good cleavage, thin reaction rim, and fine-grained core.
by hornblende phenocrysts that have been almost entirely consumed by oxides and there is no distinct rim around the crystal. Hornblende appears “moth-eaten” due to oxidation along fractures and cleavage planes; however, the brown-greenish hue of the amphibole grain is still visible in the core of the crystal. [3] The third and final stage of opacitization is characterized by psuedomorphism. Hornblende phenocrysts have become entirely oxidized to the core, displaying an opaque appearance. Psuedomorphs are distinguishable from Fe-Ti oxides because they have a fuzzy appearance and maintain the diamond or lath shape of the original hornblende crystal.

All three stages of opacitization have been observed to coexist in a single sample. Smaller hornblende crystals become completely opacitized first, as opposed to coexisting larger crystals that demonstrate thin oxide rims. The distribution of varying degrees of opacitization appears to occur randomly within each thin section.

INTERPRETATIONS

Hidalgo and Rooney (2010) have previously addressed the presence of amphibole-cumulates as evidence for deep crystal fractionation processes beneath Volcán Barú. They have proposed a crystal mush model for an amphibole sponge deep within the Panamanian arc. The geochemical values and mineral contents of samples in this study compare well with the findings of Hidalgo and Rooney (2010). However, Hidalgo and Rooney’s sample/chondrite versus REE values for the summit domes unit are slightly more enriched in HREE than Barú samples (Fig. 4). Fine-grained and coarse-grained amphibole cumulates are present in Barú samples from this study; however, they are in trace amounts. Hidalgo and Rooney (2010) do not have any record of reaction rims on amphiboles from Quaternary volcanism at Barú. Therefore, new evidence for hornblende disequilibria in this study can provide more information about the petrologic conditions operating beneath Volcán Barú.

Empirical studies reveal that the crystallization conditions of hornblende require pressures greater than 1 kbar and an upper temperature limit of 950oC (Plechov et al. 2008). Therefore, the disequilibrium textures observed in Barú samples may imply that hornblende was raised outside of its stability field by

an increase in temperature due to a mafic injection and/or a decrease in pressure that causes dehydration of the melt during ascent (Rutherford and Hill, 1993) (Fig. 5).

Figure 4. Chondrite-normalized versus rare earth element diagram for each lithofacies defined in this study, including the mafic samples, plotted in comparison to the summit domes unit (fine-grained cumulates + debris avalanche block) addressed by Hidalgo and Rooney (2010).

Figure 5. Pressure-temperature phase diagram for Volcán Barú andesite illustrating the stability field of hornblende in red at pressures S>1000 bars based on the partial pressure of water and temperatures <950oC. The arrow represents the adiabatic ascent path of magma leaving the stability field of hornblende. Modified from Moore and Carmichael (1998).
Crystal aggregates, especially in the form of fine-grained rims on hornblende phenocrysts, and the dusty sieve-texture of plagioclase suggest disequilibria by reheating (Rutherford and Devine, 2003, Plechov et al., 2008). The presence of crystal aggregates and fine-grained rims are products of amphibole breakdown and replacement (Garcia and Jacobson, 1979). As the host magma is heated to temperatures above the stability limit of hornblende, there is a decrease in water in the melt and that promotes the growth of anhydrous minerals by the exchange of components from hornblende phenocrystals (Murphy et al., 2000).

According to Seaman (2000), dusty plagioclase phenocrysts form by resorption of more albitic plagioclase due to an influx of calcic magma into the storage chamber. The “dusty” interior of the plagioclase may have formed by an initial injection of hotter magma that disrupted the equilibrium of the crystal. After the injection of a hotter, more calcic, mafic magma into the cooler andesite magma, an overgrowth rim may have formed due to the crystallization of An-rich plagioclase during cooling (Murphy, 2000).

Opacite rims are attributed to the partial breakdown of hornblende as the magma was raised outside the hornblende stability field by means of a decrease in pressure during ascent. Opacitization of hornblende phenocrysts is a function of decompression and the longer the magma spends near the surface and outside the stability field of hornblende, the more oxidized the hornblende phenocrysts appear (Rutherford and Devine, 2003). Opacite rims can also form due to magma degassing as it ascends and becomes subject to less pressure during eruption or dome extrusion (Plechov et al. 2008, Garcia and Jacobson, 1979).

Overall, the injection of a hot mafic magma into the crystal-rich andesite storage chamber is a possible mechanism that raises hornblende outside of its stability field by increasing temperature, which further causes dehydration of the melt and decreases pressure (Fig. 5).

Mafic recharge is a possible eruption trigger because it causes high temperature, density, and viscosity contrasts between the host magma and the recharge magma that promote convection. The intrusion of mafic magma causes the exsolution of volatiles, which leads to pressurization and can further remobilize the host magma causing it to ascend (Murphy et al. 2000). Mafic recharge into a silicic chamber can occur via dykes and is likely to result in an effusive style eruption. The two end member magmas can either become well-blended within the storage chamber or the denser mafic batch of magma can pond at the bottom and simply heat the more silicic magma (Eichelberger and Izbekov, 2000).

CONCLUSION

Mafic recharge is a commonly accepted mechanism for eruption trigger in arc volcanoes. Replenishment of a silicic magma chamber with more mafic magma has been used to explain the eruptive episodes at Bezymyannyi, Karymsky, and Soufriere Hills Volcanoes to name a few (Plechov et al. 2008, Eichelberger and Izbekov 2000, Murphy et al. 2000, Rutherford and Devine 1993). Based on the disequilibrium mineral textures observed in andesite samples from Volcán Barú, it is possible that Barú has also experienced episodes of mafic recharge that remobilized host magmas and possibly triggered an eruption.

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