INTERPRETING MAGMATIC PROCESSES FROM CLINOPYROXENE IN TERRESTRIAL ANKARAMITE LAVAS: A PROCEDURAL BLUEPRINT FOR STUDYING THE NAKHLITES? S. R. Jacob[1*], J. E. Hammer[1], and B. Welsch[1], [1]University of Hawaii at Manoa, 1680 East-West Rd, Honolulu, HI 96822; *srjacob@hawaii.edu

Introduction. We are conducting a morphological, petrographic, and microanalytical study of Ca-clinopyroxene (cpx) in terrestrial ankaramite lava flows from the post-shield eruptive stage of East Maui Volcano, Hawaii. These rocks provide a potentially fruitful comparison to the martian Nakhlites, for which comparatively little magmatic context is available. Both magma suites present opportunities to address the thermal structure of magma reservoirs and pre-eruption magmatic processes including *in situ* crystallization [1], crystal accumulation, and eruption initiation. The Maui ankaramites we studied contain up to 50 vol % olivine and pyroxene crystals, and thus are considered magmatic cumulates [2]. The Nakhlites range in crystallinity from 78 vol % in MIL03346 to 92 % in Nakhla, and are suggested to represent igneous cumulate rocks [3].

Methods. The ankaramite lava (194-230 k.a.) representing postshield volcanism [4] was collected near the summit of East Maui (Haleakala) volcano. Petrographic thin sections of oriented cpx crystals were prepared in the Experimental Petrology lab at the University of Hawaii at Manoa. SHAPE software [5] was used to determine the crystallographic orientation of the mounted crystals. The major and minor element compositions of the rims and cores of seven cpx crystals were determined by spot, profile, and mapping analysis using the JEOL Hyperprobe JXA-8500F electron microprobe at the University of Hawaii at Manoa. Bulk compositions were determined by X-ray fluorescence spectrometry for replicate samples of crushed material. A hand magnet was used to separate oxide-rich groundmass from phenocryst fragments, creating a "groundmass fraction".

Sample Description. The ankaramite contains 29 vol % pyroxene, 22 vol % olivine, and 49 vol % matrix material. The matrix contains 43.4 wt% SiO_2 and 3.49 wt% total alkalis, characterizing the interstitial liquid as a basanite [6]. The alkalinity of this magma is attributed to small degrees of mantle melting and magma differentiation in the volcanic plumbing system [7].

Cpx texture and composition. Crystal forms and three-dimensional surface features of cpx phenocrysts are exceptionally well-preserved in single crystals up to 30 mm in diameter that weather out from the lava. The dominant forms of these euhedral 2/m crystals are the (010) pinacoid, (100) pinacoid, (110) prism, and (111) prism, in order of increasing prominence. In addition, crystals are characterized by crystallographically-aligned contact crystals (Fig. 1), or "buds".

Optical microscopy and backscatter electron (BSE) imaging reveal consistent domains among cpx crystals: (a) 25 μm thick outer rims (b) a spongy, mottled section, approximately 400 μm thick, mantling (c) unzoned to gently zoned, unperforated center. The voids in the spongy margin are notably not glass inclusions. Those not attributable to plucking during thin section preparation contain glass, microlites, and empty space into which crystals protrude (Fig. 1B). Evidently, clinopyroxene acquired this spongy texture within the magma, and not after cooling.

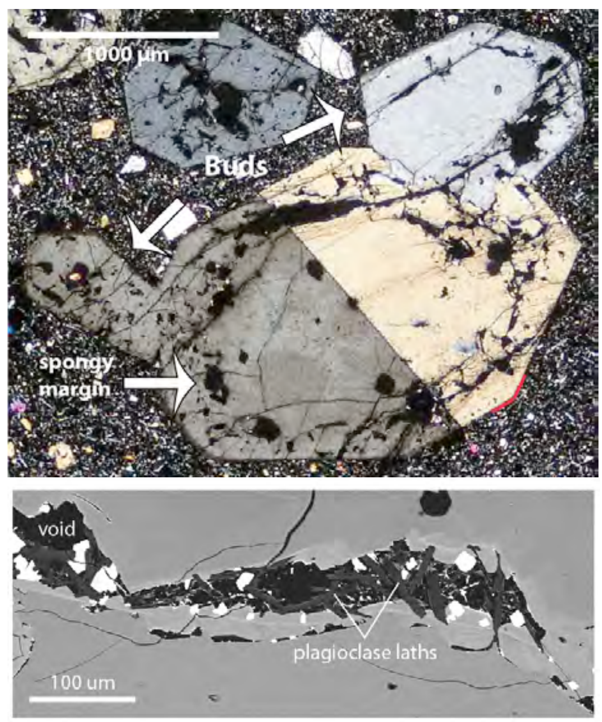

Figure 1. A. XP optical image of an augite crystal in the Maui ankaramite lava flow, showing the spongy margin along the outer edge and buds. B. BSE image detail showing matrix and magmatic void within cpx.

Results. 1. *Maui ankaramite.* The major element compositions of the pyroxenes correlate with quadrilateral compositions $En_{44-47}Fs_{11-15}Wo_{40-44}$ (cores) and $En_{44-50}Fs_{10-12}Wo_{38-44}$ (spongy regions). Spot analyses reveal consistent variations among Ti, Al, Mg, and Si that correspond to the substitution mechanism [9]: ${}^{VI}Ti^{4+} + 2{}^{IV}Al^{3+} = {}^{VI}Mg^{2+} + 2{}^{IV}Si^{4+}$. Element mapping reveals compositional domains that correspond with the domains identified petrographically, including an Al-poor rim, margin consistently enriched in Cr toward the outer edge, and an Na-rich core that is either Cr- or Al-rich (Fig. 2).

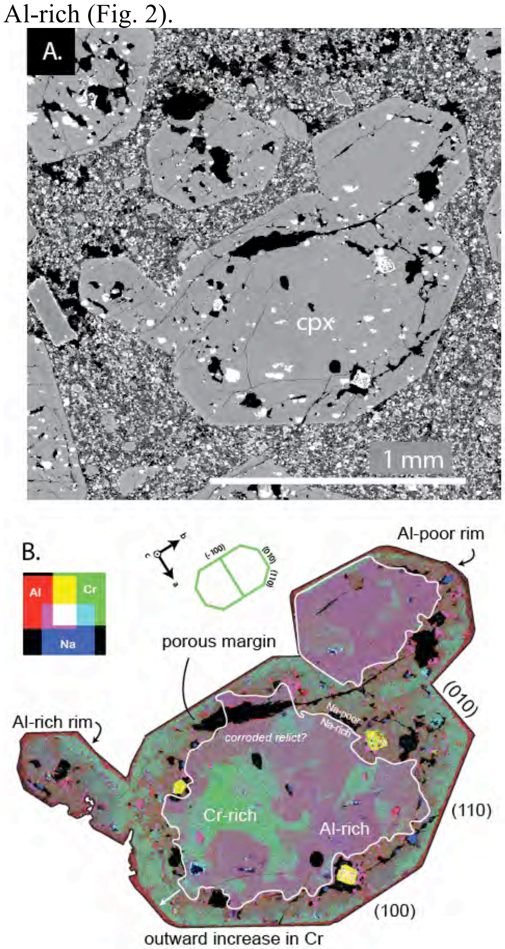

Figure 2: A) BSE image showing spongy margin and gray-scale variations. B) Na-Al-Cr composite image with outlines delineating compositional domains.

2. Nakhlites. Nakhlite meteorites are augite-rich basaltic cumulates that contain up to 90% crystals of olivine and pyroxene, and are slightly altered by aqueous processes [3, 8]. Ca-cpx crystals are euhedral to subhedral and are up to 1 cm long, normall-zoned, and surrounded by a fine-grained groundmass [3] Compared with Maui augite crystals, nakhlite crystals are Fe-rich and Al-poor, e.g., the cores of Miller Range 03346 are $En_{35\text{-}40}Fs_{22\text{-}28}Wo_{38\text{-}42}$. The Fe-rich, Al-poor character of Nakhlite crystals is inherited from the parent magma from which the nakhlites formed [3]. Spot analyses from the literature do not permit spatial contextualization or investigation of sector influences on cpx composition.

Although the abundances of Al and Ti in Nakhlite cpx are generally much lower than in the ankaramite, the element covariations in Nakhlite cpx are similar to those in the Maui cpx (Fig. 3).

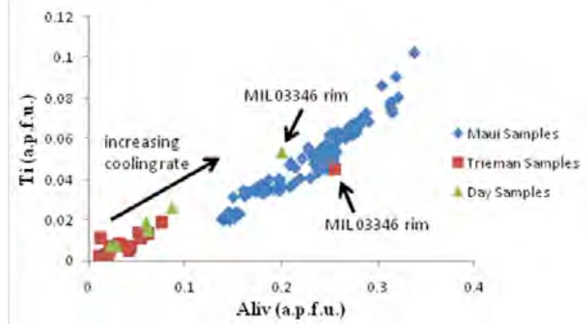

Figure 3: Ti vs. Al plot of Maui and Nakhlite cpx.

Discussion: According to MacDonald et al. (1983), ankaramite lava represents the lower portion of a magma body that crystallizes upward from the floor and accumulates clinopyroxene and olivine crystals from above. In this model, the sinking of crystals produces a chemical gradient in the reservoir, yielding a crystal poor upper portion and a crystal rich lower portion. However, voluminous eruptions of ankaramite at Maui without complementary crystal poor magma, and the ubiquity of void-rich spongy regions are both consistent with crystal growth occurring primarily at the top of a reservoir, where vapor bubbles accumulate.

The patterns observed in the Maui crystals suggest a degree of shared physico-chemical history, a simplified form of which is largely consistent with prevailing models of postshield magmatic activity and genesis of ankaramite: (1) rapid crystal growth at high pressure, [1], forming hoppered cpx crystals relatively rich in Al and Na, with variable Cr; (2) partial dissolution; (3) renewed overgrowth of a porous margin at lower pressure, characterized by fluctuating ambient liquid composition and crystal growth rate; (4) low-pressure, syneruptive, crystallization of Na-poor, Al-rich rims.

Conclusions. The spatial context for quantitative spot analyses afforded by our BSE images, profile analyses, and X-ray element maps are proving essential in understanding the growth history of the Maui cpx crystals. Similarly contextualized analysis of Nakhlite cpx may improve understanding of subvolcanic and surface magmatic processes of the Nakhlite magmas [3].

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