Eruption initiation timescales at a very high threat Washington volcano: Clues from crystal cargo in lavas from Koma Kulshan (Mt. Baker)

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Meet the presenter:

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Introduction

Understanding the timescales of pre-eruptive processes is key for improving future eruption forecasts. Although Mt. Baker is classified as a very high threat volcano (Fig. 1), we lack eruption initiation timescales. This study examines three andesitic lava flows from Mt. Baker: Dobbs Creek (~119 ka), Dobbs Cleaver (~105 ka), and Swift Creek (~48 ka). In these preliminary results, we focus on plagioclase from Dobbs Cleaver and Swift Creek with the following goals:

(1) Assign eruption initiation timescales for Dobbs Cleaver and Swift Creek

(2) Compare timescales across lavas and between mineral populations within Dobbs Cleaver and Swift Creek

(3) Using crystal chemistry and textures, determine initiation mechanisms associated with Dobbs Cleaver and Swift Creek timescales

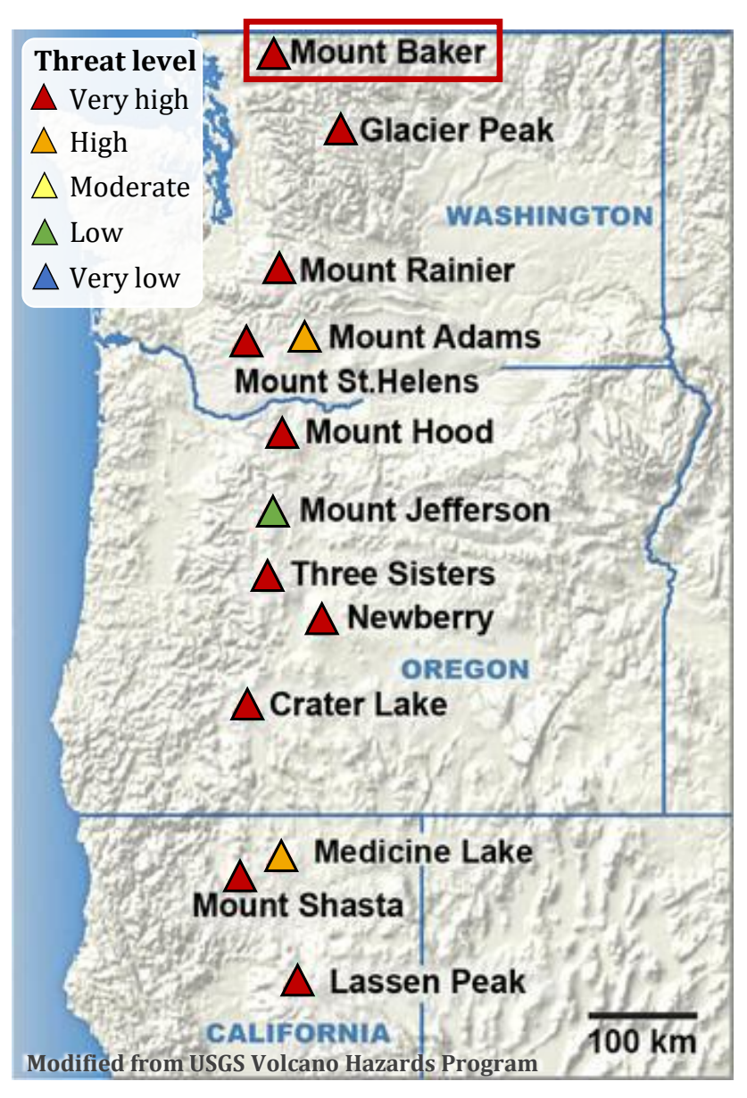
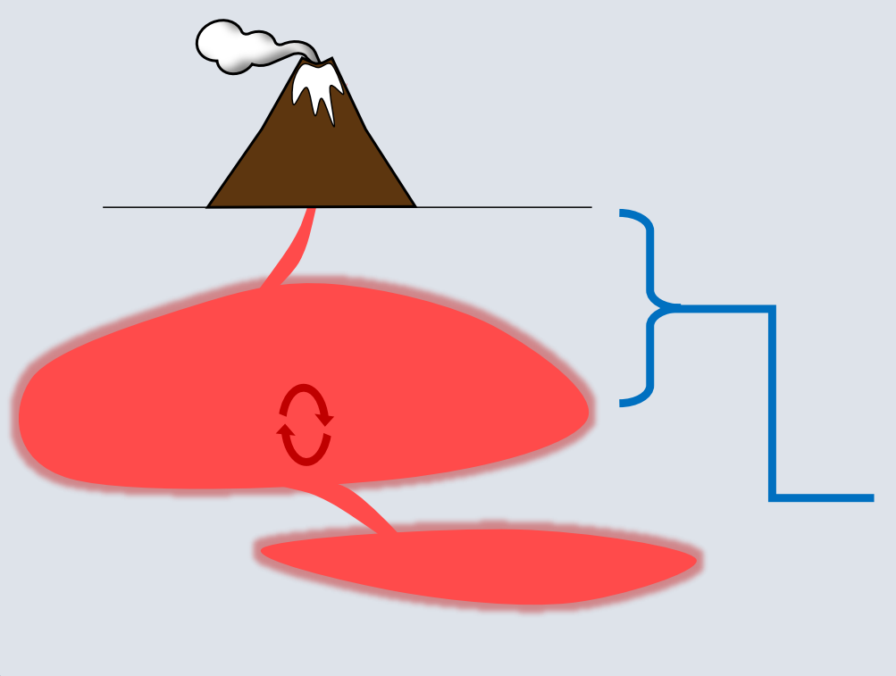


Fig. 1 – Map of Cascade volcanoes by threat level (Ewert, 2018; USGS).

Key Terms



Eruption Initiation

The processes or processes that result in a previously stable accumulation of magmatic material within the crust to ascend and erupt (Kent et al., 2023)

Eruption Initiation Timescale

The duration of time from the initiation mechanism (e.g., mixing) to eruption

Background

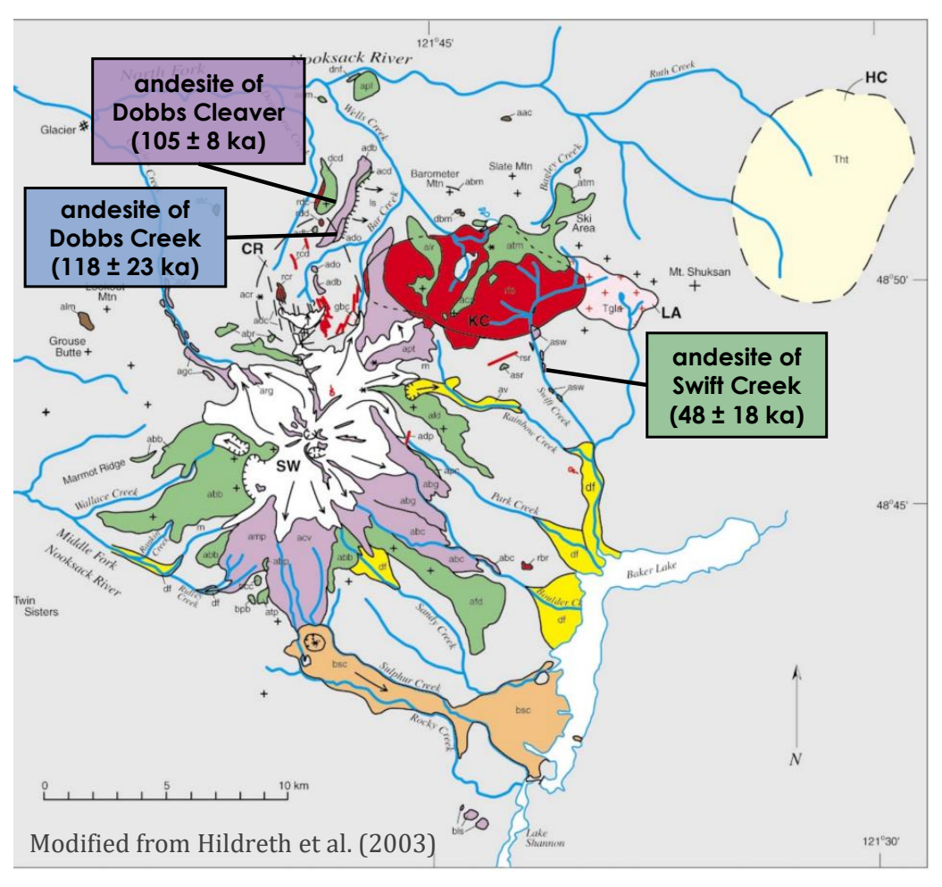


Fig. 2 - Geologic map of Mt. Baker; modified from Hildreth et al. (2003)

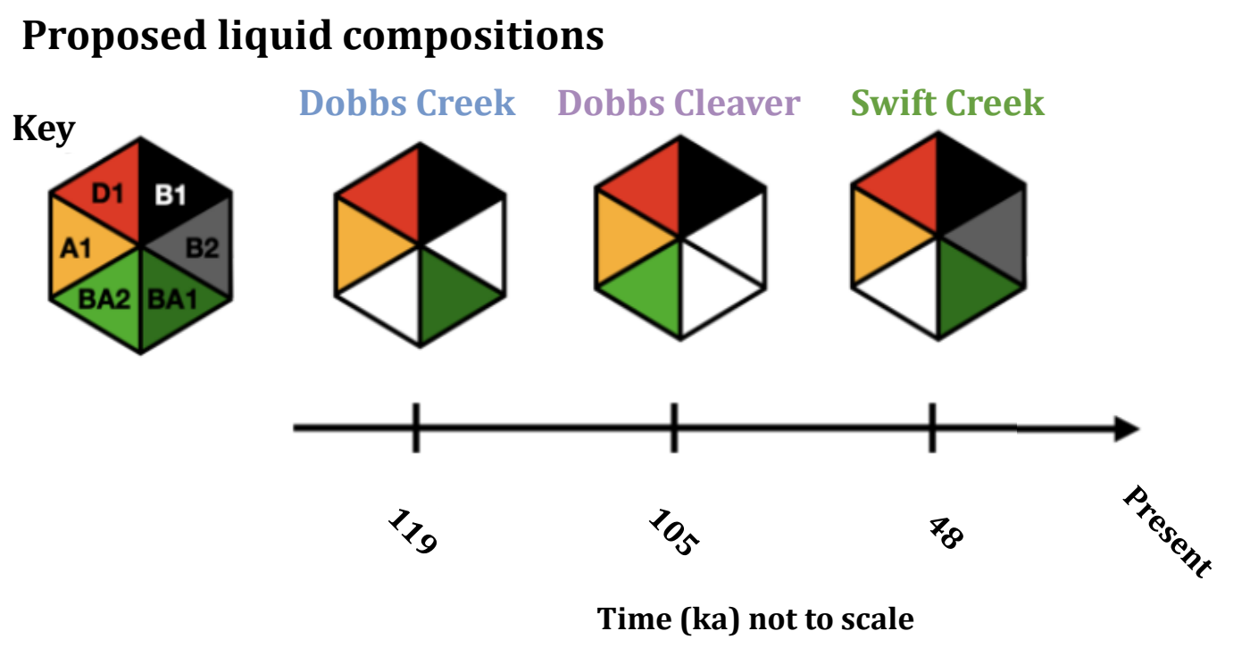


Fig. 3 - Magma compositions previously identified in Dobbs Creek, Dobbs Cleaver, and Swift Creek lavas: D1 (dacite), A1 (andesite), BA1 and BA2 (basaltic andesites), B1 and B2 (basalts); modified from Escobar-Burciaga (2016)

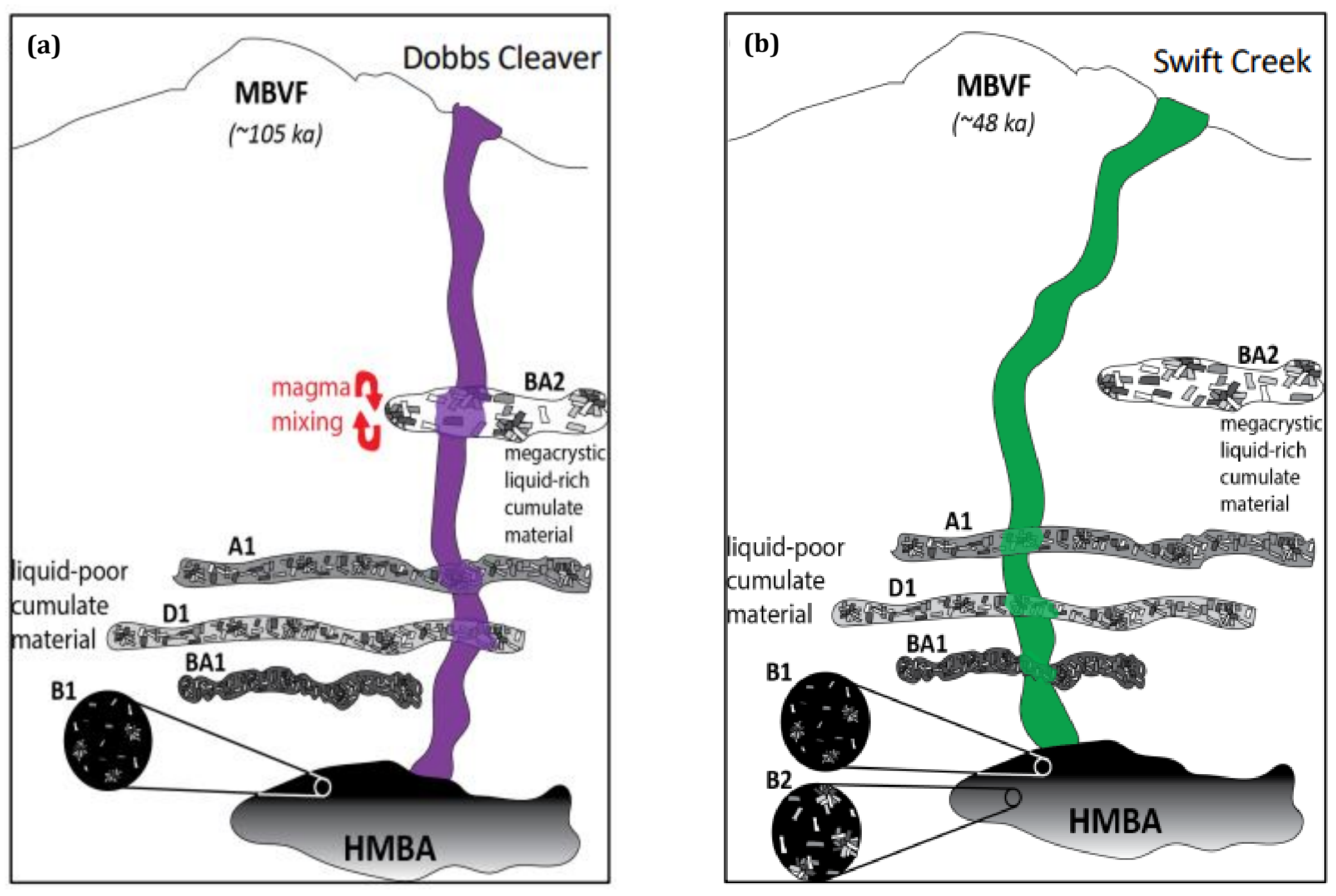


Fig. 4 – Mt. Baker Volcanic Field (MBVF) mush models for the **(a)** Dobbs Cleaver and **(b)** Swift Creek eruptions based on mineral textures, chemistry, and thermobarometry (Escobar-Burciaga, 2016)

Methods

(1) Petrographic analysis

- Identification of mineral abundances and textures

(2) SEM-BSE: Scanning Electron Microscopy: Back-Scatter Electron Imaging

- Identification of zoning patterns in crystals and crystal

(3) EPMA: Electron Probe Microanalysis

- Major element chemistry along transects from crystal rim to interior (5 µm spot size)

(4) LA-ICP-MS: Laser Ablation Inductively Coupled Plasma Mass Spectrometry

- Trace element chemistry along same transects (6 µm spot size)

(5) Plagioclase-liquid thermometry

Feldspar-Liquid Thermobarometry using Thermobar (v.1.0.19, Weiser et al., 2022) with Eq. 24a (Putirka, 2008)

- Estimate temperature of crystal growth and diffusion

(6) Sr and Mg plagioclase diffusion chronometry modeling

Python code (Lubbers, 2022) using solution to diffusion equation from Costa et al. (2003)

- Sr: Bindeman (1998) equilibrium model (Arrhenius parameters from Giletti & Casserly (1994)
- Mg: Mutch (2022) equilibrium model (Arrhenius parameters from Van Orman et al. (2014)

Future Work

- Model eruption initiation timescales from clinopyroxene of Dobbs Cleaver and Swift Creek to (1) compare with plagioclase timescales and (2) better constrain crystal populations and associated equilibrium liquids
- Model eruption initiation timescales from clinopyroxene of Dobbs Creek
- Model residence timescales to better understand mush storage conditions

Acknowledgements

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References

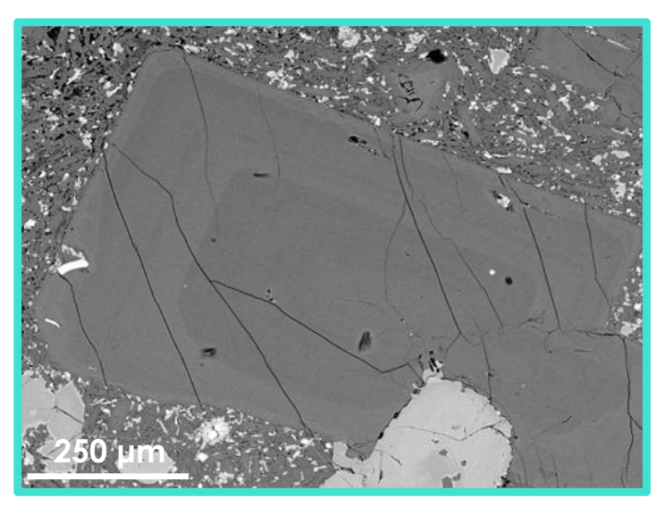
Name and Land Acknowledgement

We recognize that we work in the ancestral homelands of the Coast Salish Peoples, who have lived in the Salish Sea basin, throughout the San Juan Islands, and the North Cascades watershed from time immemorial. We express our deepest respect and gratitude for our Indigenous neighbors, the Lummi Nation and Nooksack Tribe, for their enduring care and protection of our shared lands and waterways. There are many different names with unique meanings used for Mt. Baker volcano by the Coast Salish Peoples, such as *Kweq' Smánit* (Nooksack) and *Kwelshán* (Lummi). *Koma Kulshan* has been the most common derivation of a native name used by local historians over the past hundred years, although this name is also controversial (Richardson and Lloyd, 2014). In this work, I use the name Mt. Baker out of geographic convention in reference to the Cascade Range stratovolcano located in northwestern Washington, not out of disrespect for the many names and cultural significance of the volcano to the Coast Salish Peoples.

Results

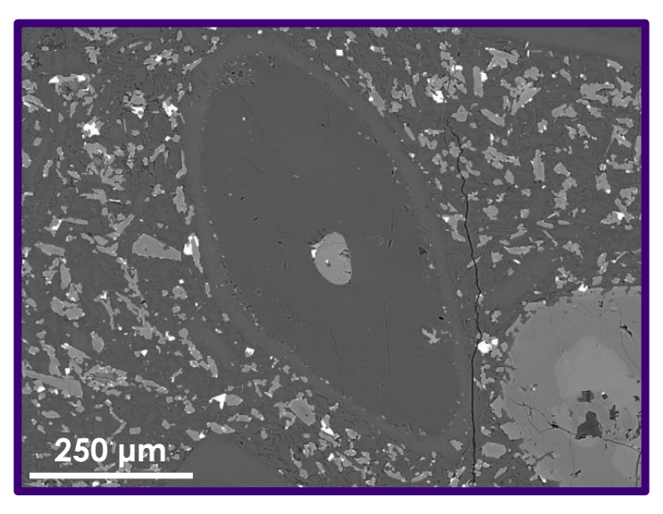
Mineral Populations

adb pop 3 (n=12 crystals; 10 modeled transects)



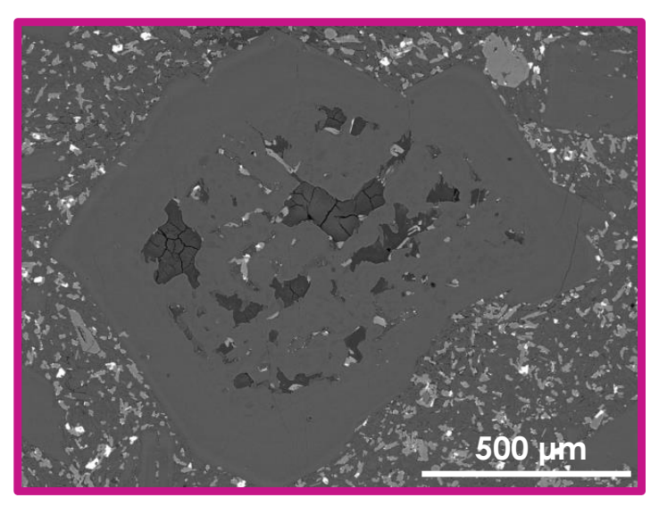
- Commonly sub-euhedral with oscillatory zoning
- May have more rounded edges
- Occasionally finely sieved with inclusions
- Mostly reversely zoned rims

asw pop 1 (n=1 crystal; 1 modeled transect)



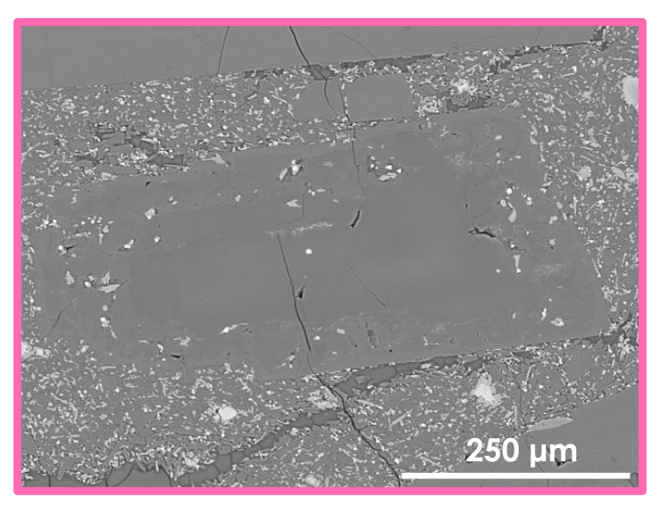
- Subhedral with a fine-sieved outer zone and rounded rims
- Simple reverse zoning
- Lowest An ($An_{43\text{-}46}$)
- Note textures are similar to the previously established asw pop. 2, but chemistry is distinct

asw pop 2 (n=11 crystals; 5 modeled transects)



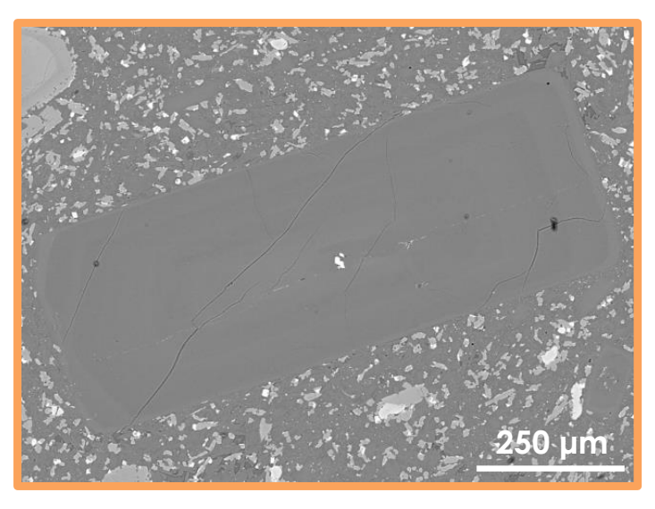
- Notably coarse-sieved, reacted cores with inclusions
- Commonly have oscillatory zoning; may have patchy zoning
- Reversely zoned rims

asw pop 3 (n=5 crystals; 2 modeled transects)



- Notably coarse-sieved mid-zones also with inclusions
- Commonly have patchy zoning; may have oscillatory zoning
- Reversely zoned rims

asw pop 6 (n=9 crystals; 7 modeled transects)



- Sub-euhedral with few, if any, inclusions
- Commonly have oscillatory zoning
- Mostly reversely zoned rims
- Note texturally these resemble the previously established asw pop. 6, but chemistry is distinct (not well constrained in prior work)

Populations previously identified by Escobar-Burciaga (2016) and Valgardson & DeBari (2022)

Mineral Populations & Inferred Liquids

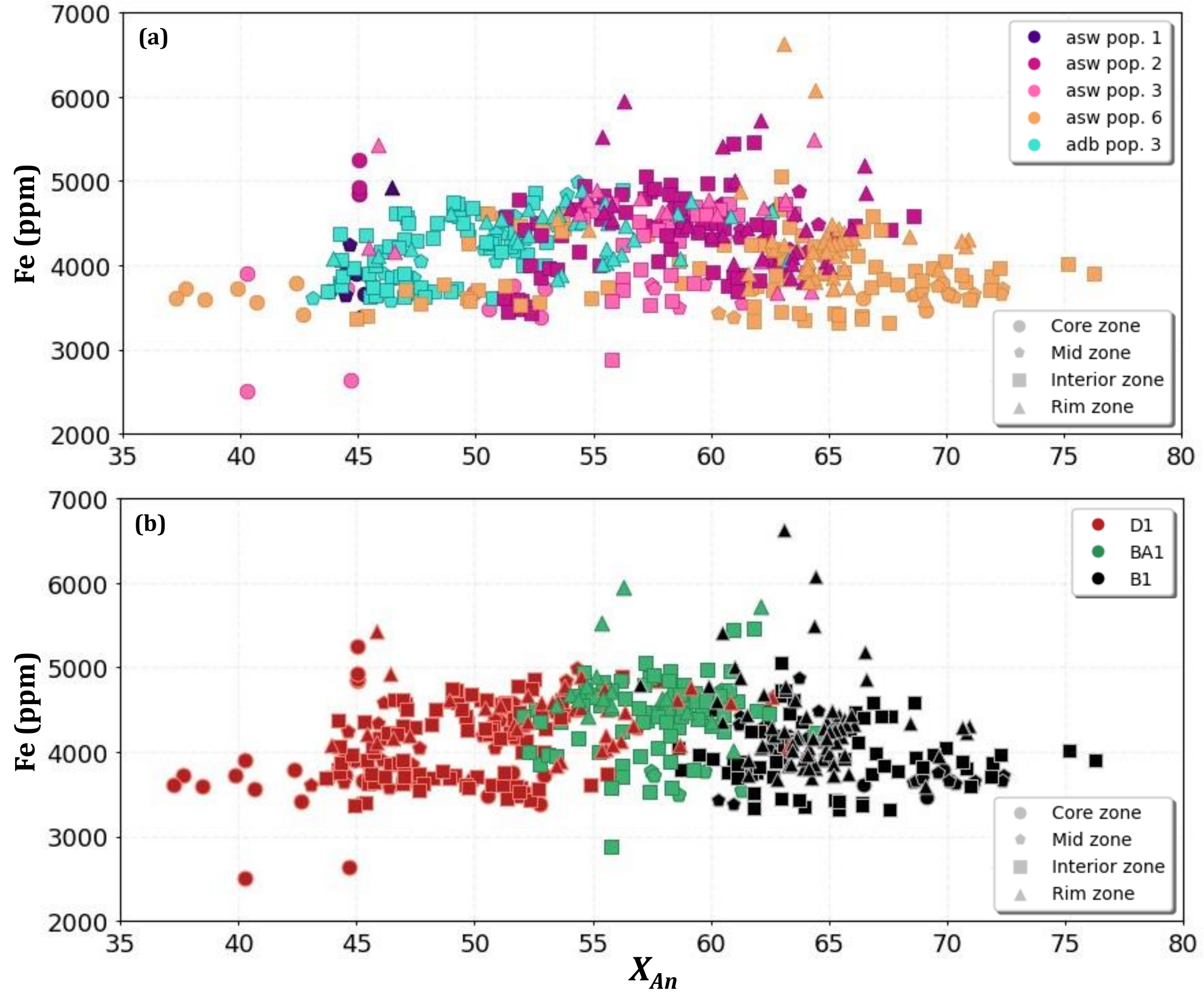


Fig. 5 (a) Anorthite content (An mol.%) vs Fe content colored by population and (b) by inferred equilibrium liquid. A single crystal may interact with multiple liquids during its formation, creating zones of different chemistry. Symbols for both (a) and **(b)** are based on what crystal zone the point came from (core, mid, interior – *this is the zone directly adjacent to the rim zone*, and rim zone).

Thermometry

Plagioclase-liquid thermometry was run with previously constrained D1 and B2 liquid compositions*. The liquid in equilibrium with the rim of each crystal constrained the temperature of diffusion in the rim.

Population	*n*	Plagioclase Rim Equilibrium Liquid	Average Rim Temperature (°C) (± 23°C error from Eq. 24a of Putirka, 2008)
asw pop. 6	*7*	B1*	1137.5 ± 23
asw pop. 3	*2*	B1*	1126.5 ± 23
asw pop. 2	*5*	D1 or B1*	D1: 960.5 ± 23 B1: 1136.2 ± 23
asw pop. 1	*1*	D1	949.1 ± 23
adb pop. 3	*10*	D1	954.4 ± 23

*B2 liquid composition serves as a proxy for B1

Diffusion Chronometry: Eruption Initiation Timescales

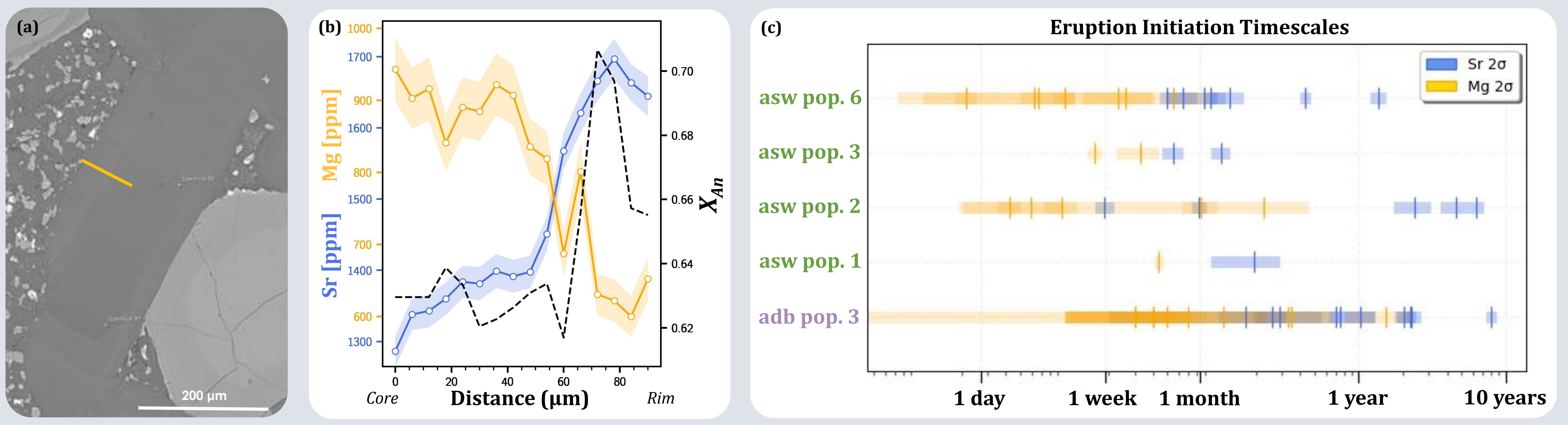
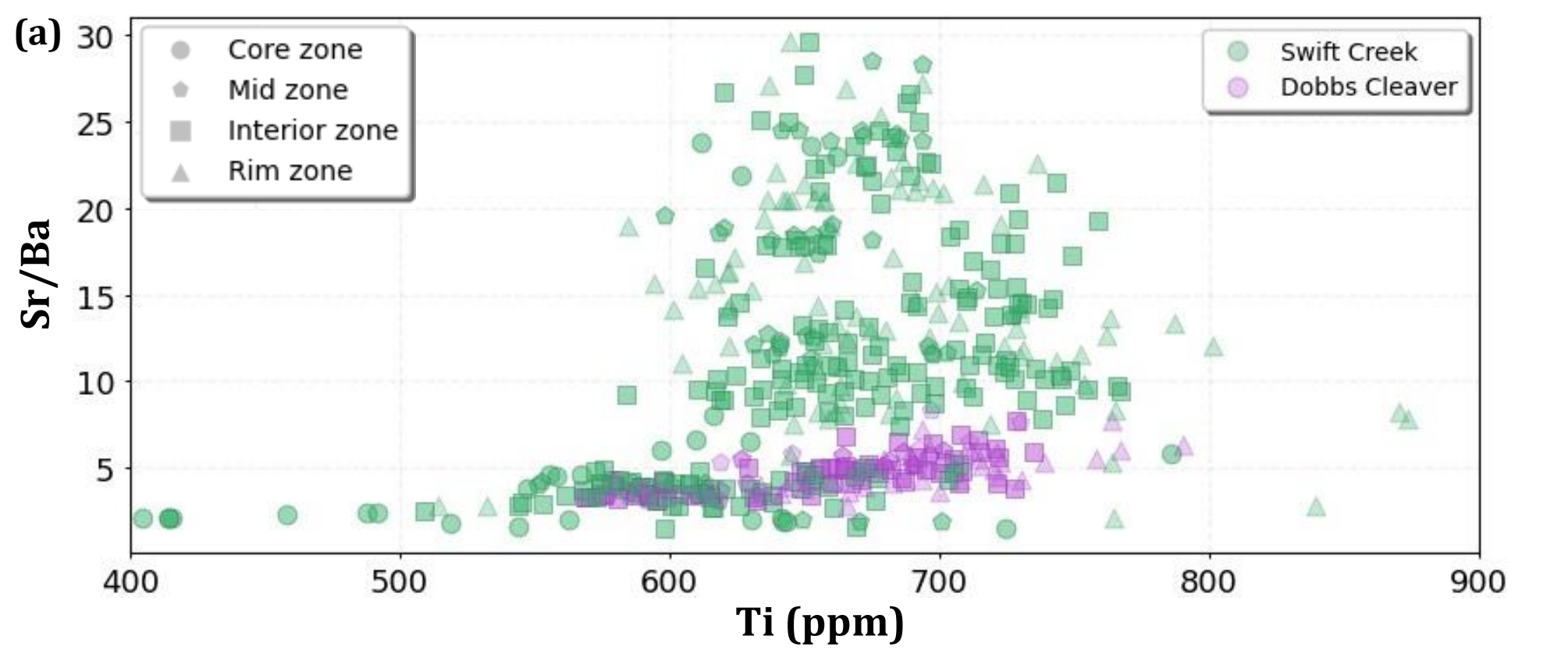


Fig. 6 (a) Example crystal with transect perpendicular to the crystal rim **(b)** Example chemical profile (Mg, Sr, and An content) from interior to rim. **(c)** Comparison of eruption initiation timescales by population. The mean best-fit time for each transect is represented by a single vertical line, with bars showing error around the mean for each transect. Mg diffuses faster than Sr. Ideally, timescales should be the same from modeling diffusion of both elements, but crystal growth may influence the modeled timescales.

Population	*n*	Mg mean best-fit time	Sr mean best-fit time
asw pop. 6	*7*	0.018 years (1 week)	0.32 years (3.8 months)
asw pop. 3	*2*	0.025 years (1.3 weeks)	0.085 years (1 month)
asw pop. 2	*5*	0.067 years (3.5 weeks)	2.68 years
asw pop. 1	*1*	0.044 years (2.3 weeks)	0.19 years (2.3 months)
adb pop. 3	*10*	0.26 years (3.1 months)	1.78 years

Interpretations

All eruption initiation timescales across lavas and populations are on the order of weeks to a few years. In the case of a future Mt. Baker eruption, these timescales can be combined with other physical monitoring methods (e.g., seismic, gas) to provide important estimates of the time until eruption from the first signs of unrest. These eruption initiation timescales are similar to those constrained for other Cascade Range volcanoes ([1]Mt. St. Helens, [2]Mt. Shasta, and [3]Lassen cinder cones; [1]Saunders et al. 2012; [2]Phillips & Till, 2021; [3]Hollyday et al., 2020; [3]Walowski et al., 2019), indicating a need to be prepared for short response times across the Cascades.



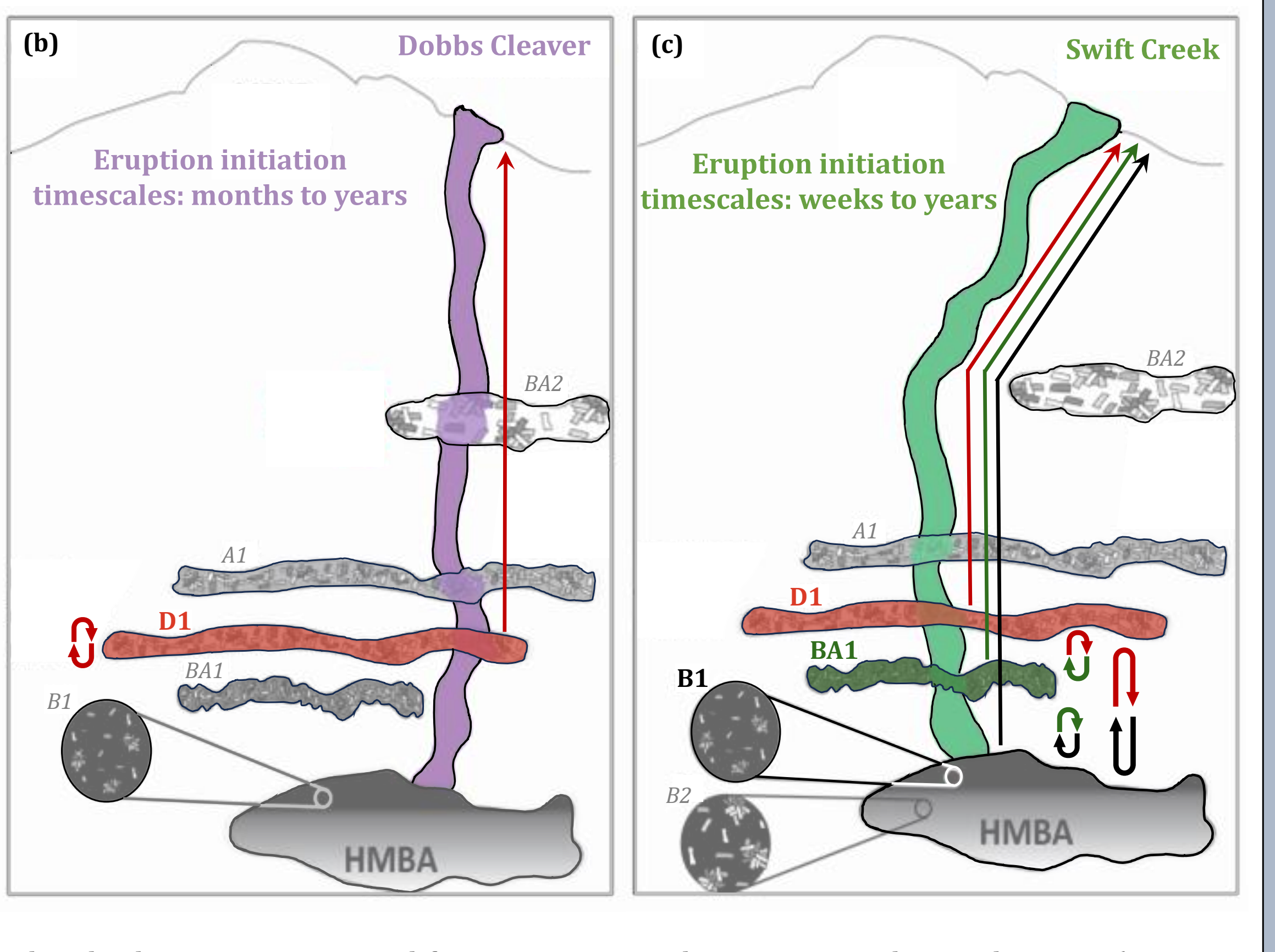


Fig. 7 - (a) Ti content vs Sr/Ba ratio colored by lava flow. Dobbs Cleaver and Swift Creek data both intersect expected fractionation trends, suggesting chemical mixing (Kent et al., 2010). Fig. 5 (An vs Fe content) also supports evidence of thermal mixing (Ruprecht & Wörner, 2007) **(b)** Updated Dobbs Cleaver mush model: adb pop. 3 only provides insight to the D1 mush **(c)** Updated Swift Creek mush model: B1 recharge and rapid B1, BA1, and D1 mixing to ascent.