Microlite Size Distributions and P-T-t-x (H2O) constraints of Central Plateau tephras, New Zealand: implications for magma ascent processes of explosive eruptions

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November 23, 2022

Abstract

Crystals within erupted volcanic rocks record geochemical and textural signatures during magmatic evolution prior to the onset of eruptions. Growth times of microlites can be derived through Crystal Size Distribution (CSD) analysis combined with well-constrained microlite growth rates, yielding petrologically-determined magma ascent timescales. Our newly developed, machine learning image processing scheme allows for the rapid generation of CSD, saving many hours of processing time, which previously involved hand-drawing the outer margins of crystals. For the present study, we examined a range of andesitic tephras from the Tongariro Volcanic Centre, New Zealand. A total of 228 plagioclase and pyroxene microlites CSDs were generated from individual tephra shards. All combined pyroxene and plagioclase microlite CSDs exhibit concave-up shapes, and similar intercepts and slopes at the smallest sizes. This implies similar growth durations of the smallest microlites of 15±9 to 28±15 (2σ) hours, regardless of the eruptive style or source, using an orthopyroxene microlite growth rate constrained from one of the samples. The orthopyroxene thermometer and the plagioclase hygrometer reveal the magmas were erupted at ˜ 1079 to 1149 (±39 SEE), and H2O contents ranging from 0-0.4 to 0-1.7 wt.% (95% confidence maxima). In the absence of CO2, these results indicate shallow H2O exsolution pressures of < 240 bars, using a recent H2O-CO2 solubility model. Given the microlite residence times, shallow H2O exsolution driving microlite growth is inconsistent with the explosivity of the eruptions. Instead, our data suggest that the melts either carried large amounts of CO2, triggering earlier degassing of volatiles including H2O, or that microlite crystallisation began prior to degassing. Ongoing work investigates the H2O and CO2 contents hosted by melt inclusions in phenocrysts and microphenocrysts in these tephras to provide constraints on magma ascent rates, with implications for hazard characterization and mitigation.

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This research is funded by: Ministry of Business, Innovation & Employment

Introduction

- Taupo Volcanic Zone (TVZ): southern end of the Tonga-Kermadec arc-back-arc system affected by **oblique subduction**, clockwise **rotation** and **extension** e.g., [1] (*Fig. 1*)
- Tongariro Volcanic Centre (TgVC): andesitic compound structure at the southern end of the Taupo Volcanic Zone
- Multiple dispersed eruptive centres and vents producing events of various eruptive styles
- Microlite crystallisation due to **decompression-induced degassing** (e.g., [3] to [6]), change in eruptive style shortly before the eruption [7]
- CSD → tool to assess **ascent processes**, and **residence times** when growth rate can be constrained (e.g. [8] to [11])
- Aim: **use microlite textures to constrain magma ascent processes and timescales**

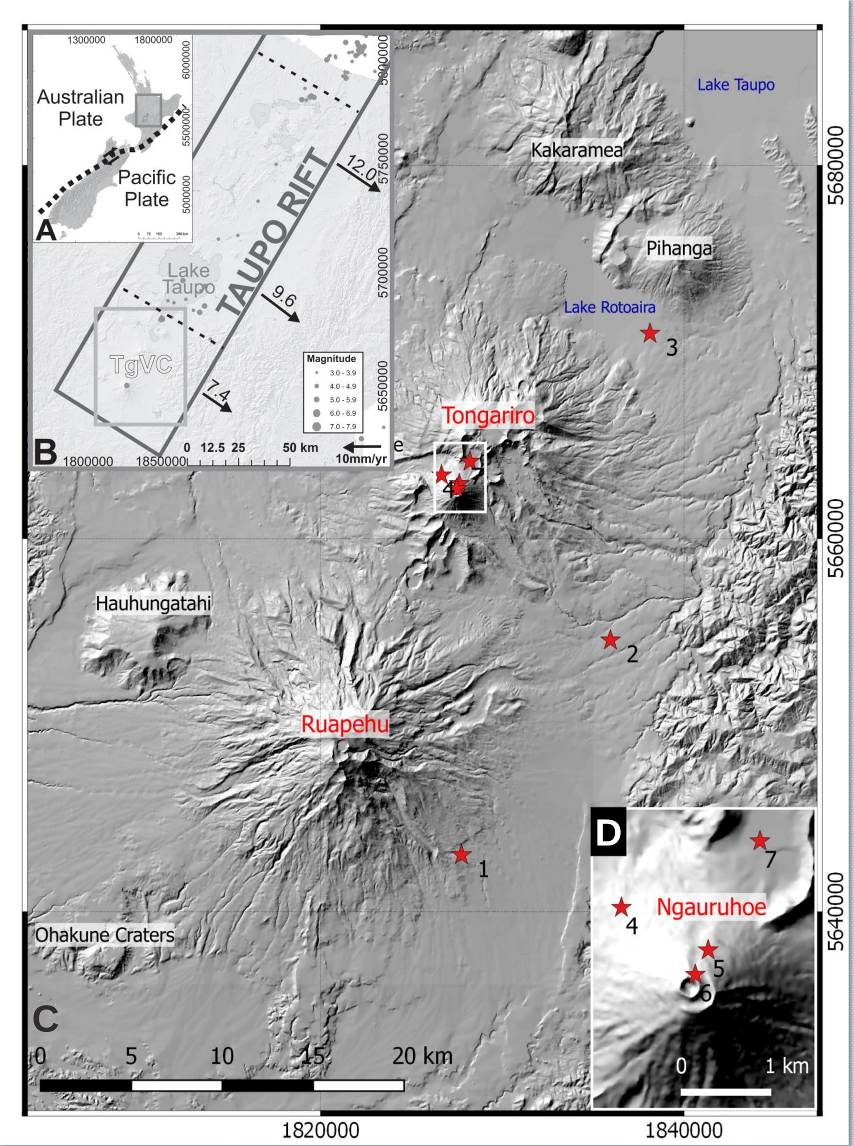

Figure 1: (A) Map of the subduction and location of the TVZ, and (B) location of the TgVC [2]. (C) (D) Map of the area with sample locations.

Methods and Materials

- BSE images of glass shards using FE-SEM
- Semi-automatic segmentation of plg and px microlites for CSD [12]
- Generation of CSDs using Csd_slice [13] and CSDCorrections [14]
- EPMA glass and microlite analyses
- Iteration of the plagioclase hygrometer [15], orthopyroxene thermo-barometer [16]

Table: description of tephra samples used for this research

ERUPTIVE SEQUENCE	AGE/DATE	MAIN ERUPTION STYLE	COMMENTS	REFERENCE
Ruapehu 1995 -1996	1995 -1996	Strombolian, phreatomagmatic and sub-Plinian	1995 sample:sub-Plinian 1996 sample : ash and bomb explosion	[17]
Ngauruhoe 1972 - 1975	1972 - 1975	Strombolian and Vulcanian	Steaming, block and ash ejections and flows, and eruptive columns	[18] & [19]
Tufa Trig	0 - 1.7 ka ago	Small volume Strombolian and phreatomagmatic	Focusing on Tf8, Tf13 & Tf14, Strombolian, rarely sub-Plinian	[20] to [23]
Mangatawai	1.7 - 3.5 ka ago	Small explosive up to sub-Plinian, mostly Vulcanian	Frequent, intermittent, very thin deposits containing beech leaves	[18], [22] & [24]
Mangamate	11 - 12 ka ago	Plinian	Large eruptions over a short period and from several vents along a fissure	[22] & [25]

Results

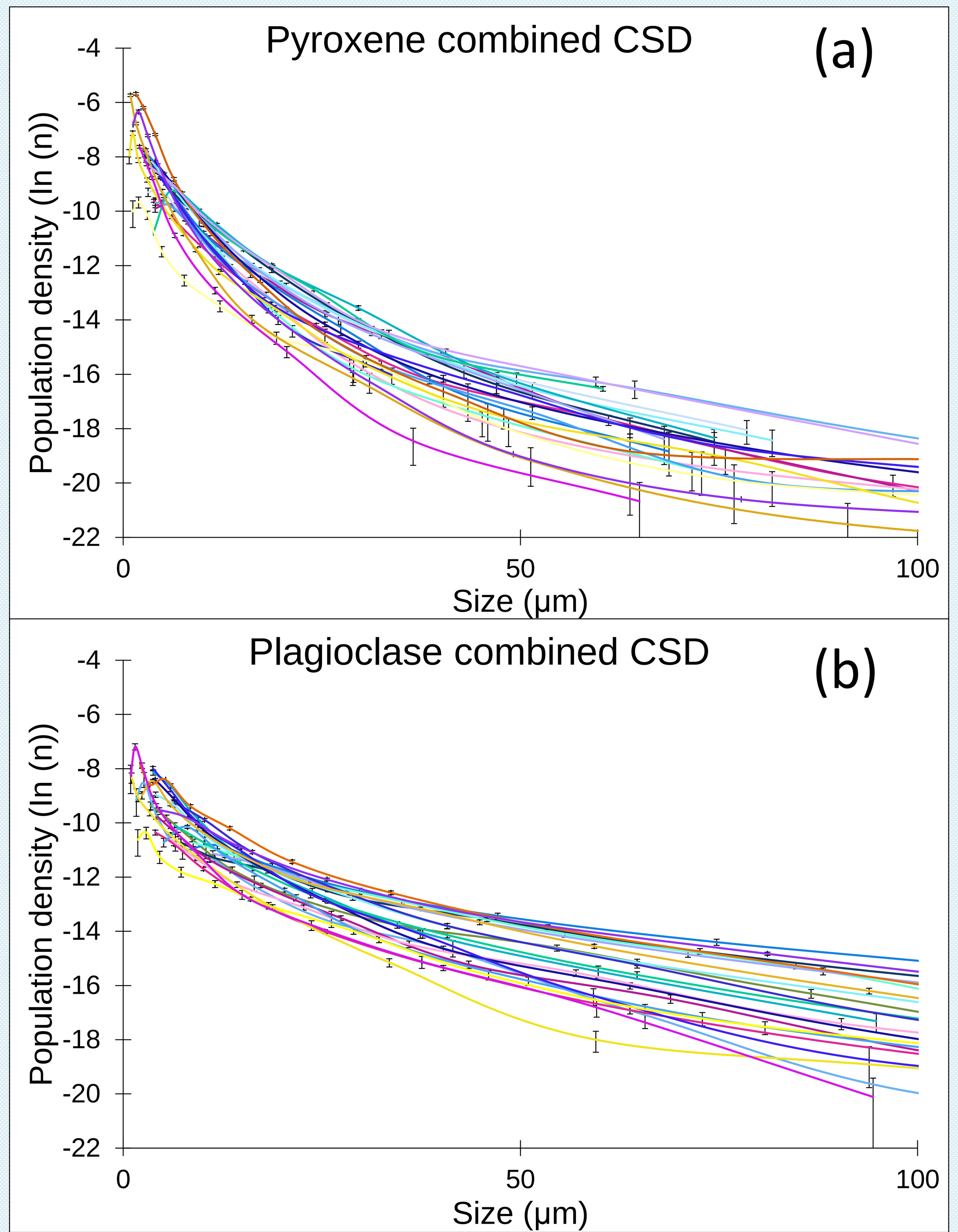

Figure 2: CSD plots of pyroxene (a) and plagioclase (b) microlites from andesitic glass shards of the TgVC tephras

A total of 228 CSDs were generated and combined when within error of each others.

A total of more than 65,000 pyroxene and plagioclase microlites are considered using the semi-automatic method for CSD generation from BSE images [13].

Concave-up CSDs → mixing of crystals populations (>50 µm micro-phenocrysts and microlites)

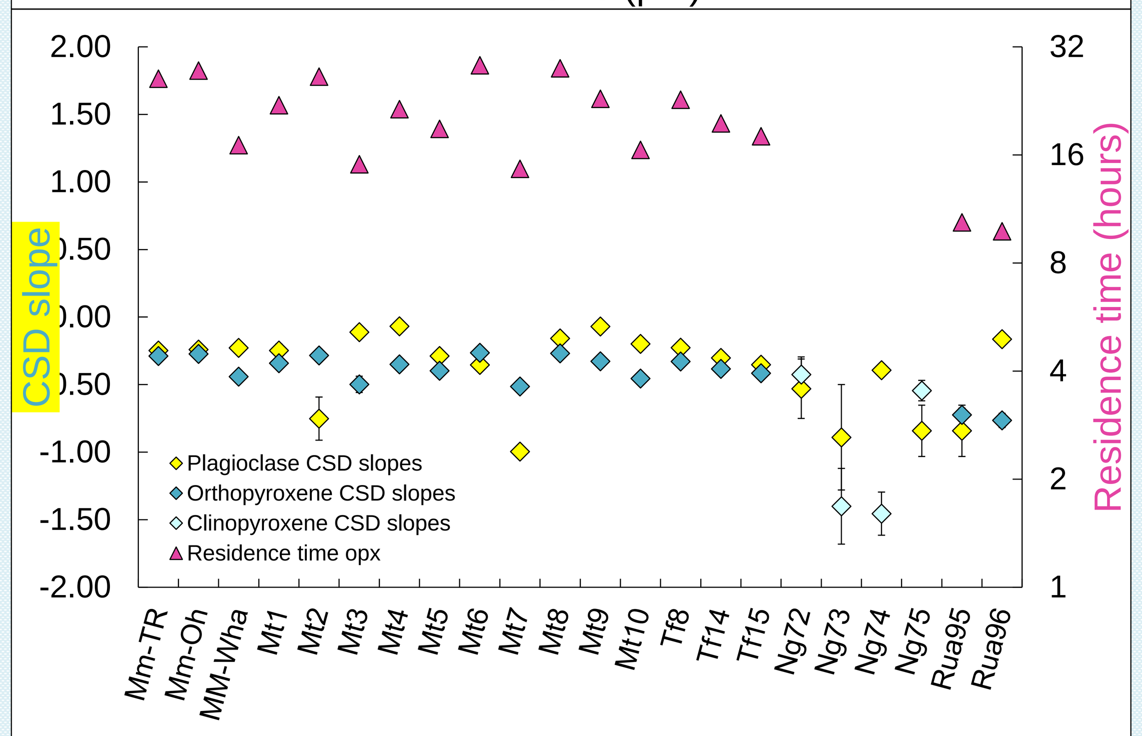

Figure 3: Pyroxene and plagioclase CSD steepest slopes, and opx residence time. The slope and the growth rate are combined to obtain the residence time

The orthopyroxene growth rate used was calculated for Mangatawai: 3 to 6×10^{-11} m.s^{-1} [26].

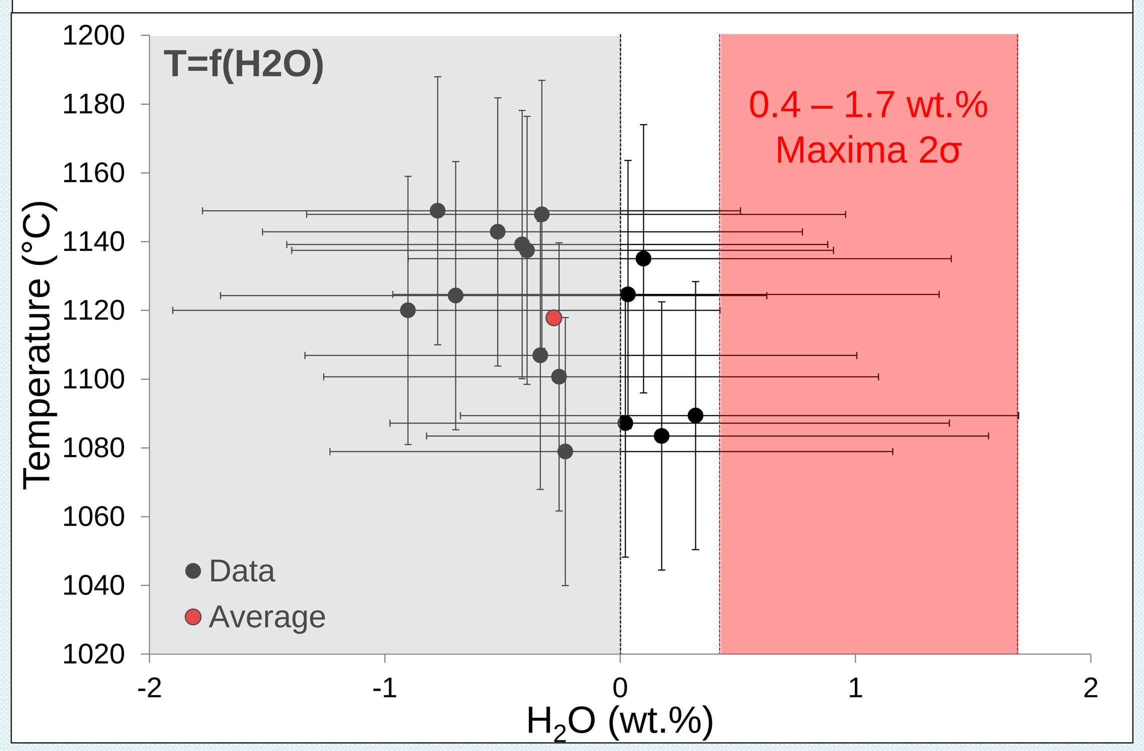

Figure 4: Temperature plotted against the water content for the TgVC andesitic tephras

Conclusion

- CSD slopes at smallest sizes (*Fig. 3*) are similar for different eruptive sequences and eruptive styles (*Table*)
- Similar slopes for opx and plg → crystallised **concomitantly**
- Opx residence times of 10±6 to 34±19 hours (*Fig. 3*) → long timescales for microlites!
- Plg growth rates of **1.4×10^{-11} to 1.9×10^{-10}** m.s^{-1} using opx residence times → in the range of experimental growth rates determined in previous works ([3] & [27])
- Our data point to ascent of **hot** ($T_{average}$=1117 °C), **low** H_2O (0.4 – 1.7 wt.% H_2O 2σ-maxima) magmas in line with data found in TgVC by previous workers ([28] & [29]) and very **shallow** degassing (i.e. <500m, [30])

Ascent rate of less than 1.4 cm/s if degassing-induced crystallisation…

TgVC microlites crystallised prior to H_2O degassing

Future work

- Analyses of **melt inclusions** in microlites and micro-phenocrysts using 1270 ion probe equipped with SCAPS (Isotope Imaging Laboratory, Hokkaido, Japan) → better constrain on H_2O and pressure

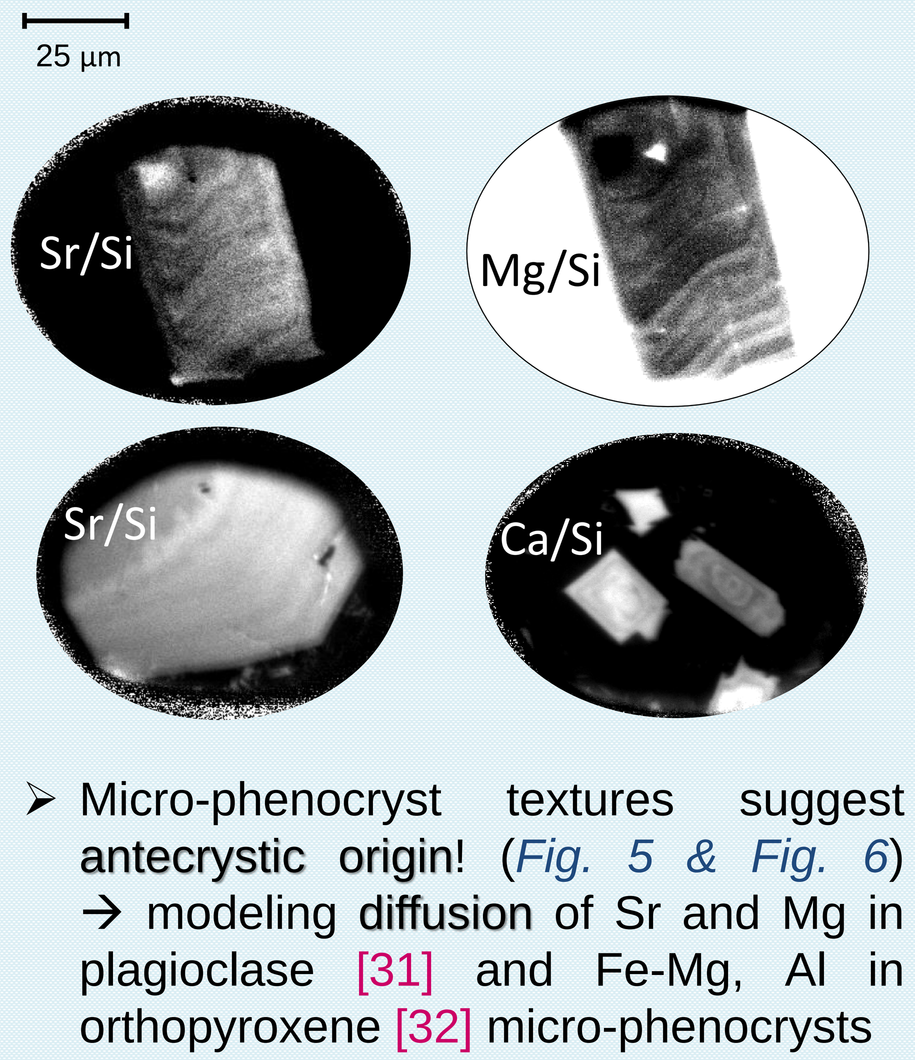

Figure 5: SCAPS images of plagioclases

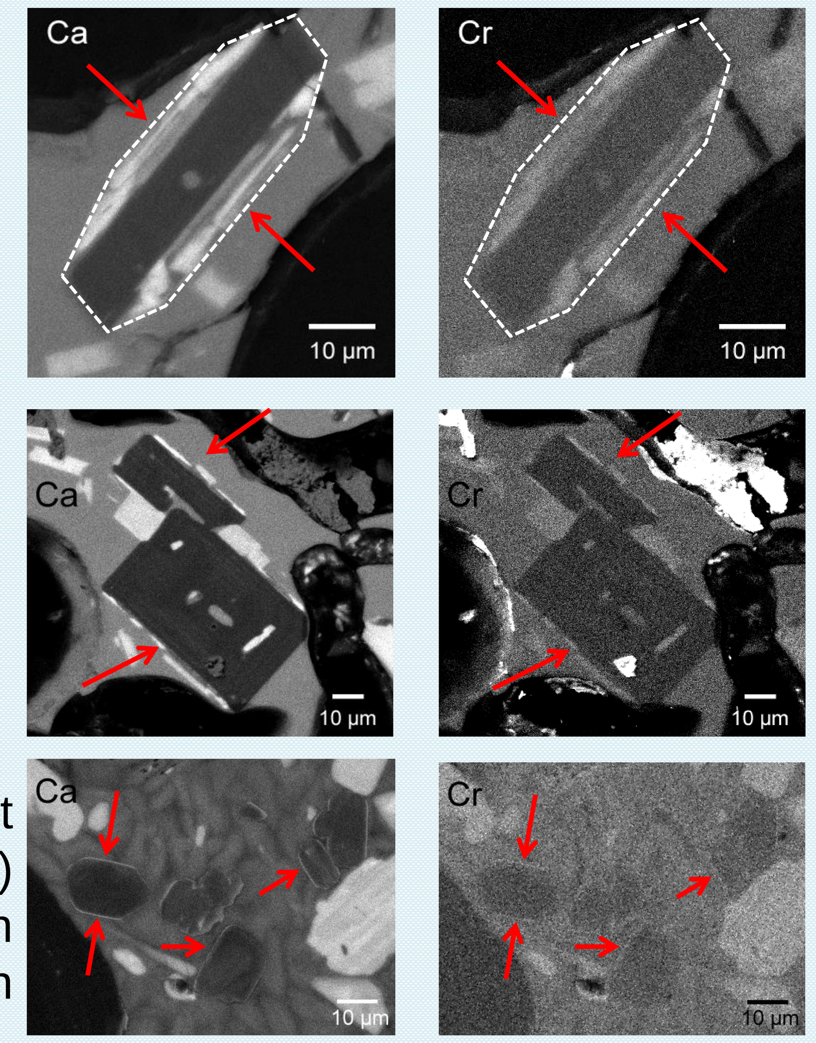

Figure 6: FE-SEM maps of orthopyroxenes

- Micro-phenocryst textures suggest **antecrystic origin**! (*Fig. 5 & Fig. 6*) → modeling **diffusion** of Sr and Mg in plagioclase [31] and Fe-Mg, Al in orthopyroxene [32] micro-phenocrysts
- Element maps of pyroxene microlites reveal **cryptic phase zoning** [33] in Ca and Cr layers along the long-axis of pyroxene microlites (*Fig. 6*)

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