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HIGH SPATIAL RESOLUTION ANALYSIS OF CHEMICAL ZONING IN VOLCANIC CRYSTALS

J. Blundy[1], O. Melnik[2] and R. Dohmen[3]

1 University of Bristol, School of Earth Sciences
Wills Memorial Building, Queens Road, Bristol BS8 1RJ, Great Britain
2 Moscow State University, Institute of Mechanics
Moscow, Russia
3 Bochum-Ruhr University, Institute of Mineralogy and Petrology
Bochum, Germany
e-mail: jon.blundy@bristol.ac.uk

ABSTRACT

Zoned plagioclase phenocrysts are ubiquitous in volcanic rocks. Their zoning patterns hold clues to the pre-eruptive magmatic processes that shaped their host rocks. An enduring question is whether this information pertains to kinetic processes, changes in intensive variables, open system behaviour, or combinations thereof. The challenge is to unpick the testimony of zoned plagioclase as an archive of processes occurring in the sub-volcanic magma reservoir. A perennial issue in such studies is achieving sufficiently high spatial resolution (~1 µm) and analytical precision (±10 % relative) for both major and trace elements at concentrations of 1,000 ppm or less. For volcanic plagioclases from Mount St. Helens (MSH) dacites from the 1980-1986 eruption, we have approached the problem using a combination of electron microprobe (EPMA) and ion microprobe (SIMS) analysis, thermodynamic models for plagioclase-melt equilibrium and element partitioning, and numerical models of intracrystalline diffusion. The conventional SIMS technique was modified to provide spatial resolution on the order of 1 - 2 µm by running at very low beam currents (0.2 nA) and collecting secondary ions without offset to enhance count rates. This approach requires carefully matrix-matched standards of known major and trace element composition.

Major elements were measured by EPMA and trace elements (Sr, Ba, Mg, Li, Ti) were measured by SIMS for five zoned plagioclase phenocrysts (e.g., Fig. 1). Typical profiles from a crystal from the May 18th, 1980, eruption are shown in Fig. 2. Using published phase equilibrium experiments on MSH dacites [1] to parameterise plagioclase composition as a function of pressure (*P*), temperature (*T*) and melt fraction (*F*), we have developed a numerical method to invert zoned MSH plagioclase phenocrysts for their core-rim evolution in *P*-*T* space prior to eruption. We remove ambiguity in the family of plausible *P*-*T* paths by solving simultaneously for *F* using the Sr and Ba contents of the plagioclase as measured by SIMS combined with their plagioclase-melt partition coefficients [2]. This approach is valid at MSH because of the relative monotony of magma composition and the absence of significant magma magma inputs to perturb the bulk composition. Data from a representative sample of crystals from the 1980-1986 eruption record the same evolution – an abrupt change from plagioclase core crystallisation at 12 km depth to rim growth at 4 km.

Simultaneous with crystal growth, trace element diffusion occurs in an attempt to restore chemical potential equilibrium. Using correlations between anorthite and Sr we show that the cores are >10,000 yrs old, whereas the rims pre-date eruption by ≤ 3 yrs. The core-rim interface, that is related to the time of magma ascent from 12 to 4 km, can be precisely dated our high spatial resolution SIMS Sr profiles (2 µm spacing; Fig. 2). At Mount St. Helens a picture emerges of a long-lived, vertically extensive, mushy, magmatic system that became abruptly destabilised, probably gravitationally, in the months to years before eruption, a timescale commensurate with volcano monitoring. Mush destabilisation appears to be a key process in volcano rejuvenation and eruption triggering.

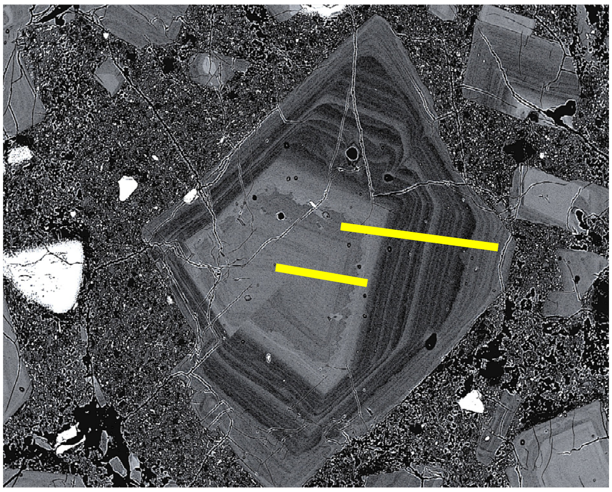

Figure 1. Zoned plagioclase phenocryst from May 18th 1980 eruption of Mount St. Helens. BSE image. Crystal is approximately 1 mm across. Analysed profiles shown as yellow lines.

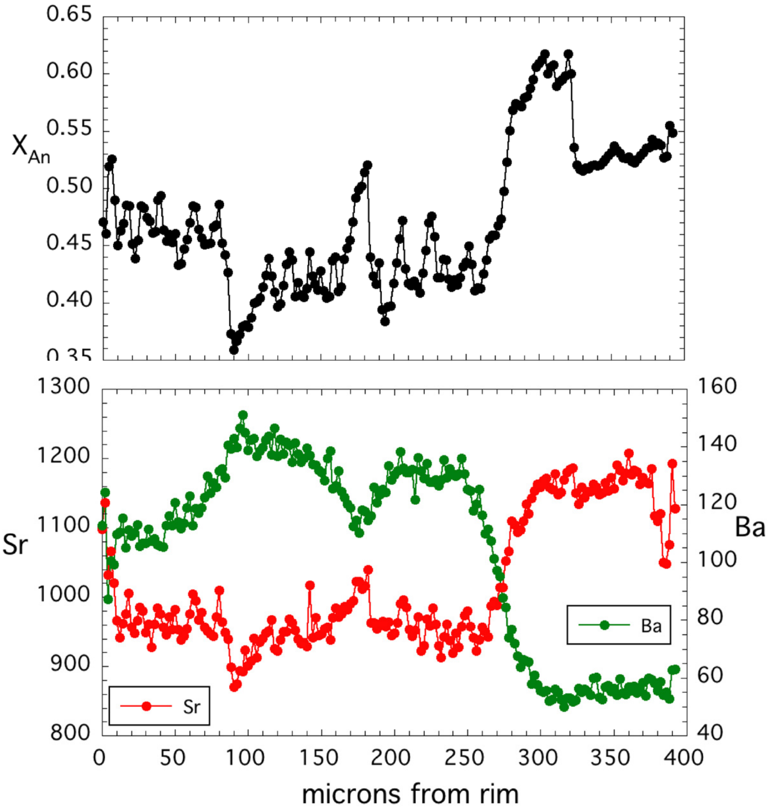

Figure 2. Chemical profiles across zoned crystal in Fig. 1. Top: Anorthite contents measured by EPMA. Bottom: Sr (red) and Ba (green) measured by high-resolution SIMS.

REFERENCES

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