Summary & rationale

Diffusion methods allow us to investigate the timescales of short-lived processes occurring in magmatic systems before, and in some cases during, eruption. Three case studies from the 25.4ka Oruanui super-eruption reveal a series of timescales across different mineral species.

Li in feldspars and quartz

Due to the small size and low charge of the Li\(^+\) ion, it diffuses quickly.\(^2\)\(^,\)\(^5\) At magmatic conditions, Li can record events minutes prior to quenching.

Fe-Ti oxides

Fe-Ti oxides equilibrate quickly, making a useful thermometer but can preserve information on events in the hours to days prior to eruption.\(^3\)\(^,\)\(^4\)\(^,\)\(^5\)

Fe-Mg interdiffusion in Orthopyroxene

This process is slow, but can resolve processes occurring decadal timescales in silicic magma systems. The diffusion likely depends on oxygen fugacity.\(^6\)\(^,\)\(^7\) and crystal composition,\(^8\) making modelling non-trivial.

Simple models: Li in feldspar and quartz

Li diffusion is rapid

- 100 microns of diffusion in minutes\(^1\)\(^,\)\(^2\)
- D: no known dependencies
- T: requires correction for adiabatic cooling
Composition: expressed as Li per tetrahedral site in feldspar, relative to Al in quartz
Modelling: simple

Profile in feldspar

Profile in quartz

Diffusion triggered by fluid-melt disequilibria as critical pressure is passed\(^9\)
Adiabatic cooling and quench rate are important, considered in model
3-10 minutes, ascent rate up to 21 ms\(^{-1}\)

More complexity: interdiffusion in Fe-Ti oxides

Grains zoned in Fe-Ti.
Visible by BSE imaging

- T: eruption temperature
- D: depends on \(\text{O}_2\)
Modelling: simple

False-colour BSE images of phase 7 magnetite.
Timescales between 9 and 15 hours pre-eruption

Syn-eruption intrusions?

Published in EPSL, 2012\(^\text{(11)(1)}\) (Take one)!

More complex diffusion: Fe-Mg interdiffusion in orthopyroxene\(^12\)

Zonation inconsistent on different axes; possible recrystallisation?

Grains complexly zoned under BSE imaging.
Dominantly Fe-Mg signal

X-ray maps show disruption to Al zoning along c-axis, consistent with recrystallisation hypothesis

Modelling done across the c-axis as a result. Main junctions near core.

T: eruption temperature
D: depends on both \(\text{O}_2\),\(^7\)\(^,\)\(^6\) and crystal composition\(^8\)
Modelling: 1D finite difference model coupled to Excel (paper in prep)
Results give a range of ages as shown to the right. Uncertainties are significant. There is much more to say for this unit, but the results can be seen elsewhere:

Conclusions

These case studies show that:

- Recovery of diffusion timescales from multiple mineral phases within a single deposit is possible.

The timescales represent various processes of assembly, mobilisation, accumulation and eruption:
- Lithium diffusion in plagioclase and quartz can give syn-eruptive information of late-stage conduct processes (minutes)
- Fe-Ti oxides can address magmatic events occurring hours to days before eruption
- Fe-Mg interdiffusion in orthopyroxene can address diffusion occurring over the century scale in cooler, rheolithic systems. Uncertainties are, however, large, as the interdiffusion coefficient is likely dependent on many variables. Zoning is complex but can be interpreted with sufficient care.

The Oruanui deposits

The Oruanui eruption of 25.4ka B.P. is the youngest known supereruption (erupted mass >10\(^{19}\) kg) on Earth.\(^9\) The eruption produced over 500 km\(^3\) of rhyolitic products in an eruption that is inferred to have lasted several months.

Earlier work on U-Th age spectra of zircon populations\(^10\) shows that the Oruanui magma is distinct from that of the preceding Okata eruption (28.4ka\(^11\)). As the eruptive vents were coincident, the eruptible Oruanui magma body was assembled in 5000 years, or less, from earlier, accumulated materials.\(^10\)

The Oruanui eruption products are here analysed with a variety of different diffusion-based techniques to recover timescale information related to mobilisation and eruption of the final magma body.

References

- Morgan, D.J. et al., 2007. Alkali diffusion in plagioclase feldspar. Econ. Geol. 102, 321-334.