How long have we got to act? Magma ascent rates in the Auckland volcanic field
(EQC Biennial Grant 16/725)

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Key words
Auckland Volcanic Field, monogenetic basalt, olivine xenocryst elemental diffusion, water diffusion, magma ascent rates, alkaline basalt

Summary
Monogenetic basalts are spatially and temporally unpredictable and are commonly interpreted to rise extremely rapidly and directly from their mantle source, increasing their potential hazard. The assumption of rapid ascent is commonly based upon the presence of xenocrysts and xenoliths as well as generally short OH and elemental diffusion profiles at the margins of xenocrystic material. We have shown that small-volume monogenetic basalts may also have complex multi-stage deep mantle magma storage prior to rapid ascent, using coupled diffusion modelling of major and trace elements and OH within olivine xenocrysts. The xenocrysts and crystal clusters were extracted from a tuff ring in Auckland City (New Zealand), within the Late Pleistocene-Holocene 100 km2 Auckland Volcanic Field (AVF). Forsterite-rich olivine xenocrysts (Fo#89.5-91.7) have undergone Fe-Mg (Fo#), Ca, Ni and Mn element diffusion that extends up to ~200 microns from their rims. Major and minor element diffusion at frozen melt-xenocryst interfaces was modelled using crystallographically oriented grains. These profiles show that the host basalt collected most of the olivine xenocrysts and xenoliths over approximately 1 month. The narrow OH diffusion profiles in the olivine suggests late-stage degassing over <1 day (i.e., not extremely rapid ascent rates). Some olivine crystals have diffusion profiles requiring step function initial conditions; these indicate that magma resided in the mantle for up to one year and accumulated from multiple batches of mixed magmas. Our results show that primitive magmas in small volume monogenetic volcanoes may have complex lithospheric magmatic histories, but they may suddenly rise to eruption, with seismic detection providing less than a week of warning.

Introduction
Monogenetic volcanoes often erupt chemically and petrographically simple small-volume basaltic magmas apparently directly ascending as near-primary mantle-derived melts. In these magmas, the absence of shallow crystallizing phases (e.g. plagioclase), or large and complexly-zoned crystals, coupled with the presence of mantle xenoliths, are interpreted as evidence for lack of crustal stalling. This has led to a model of monogenetic basaltic magmas rising to eruption rapidly from a source area in the mantle shortly after their generation through partial melting. The uncertain nature of eruptive events in both time and space within a typical volcanic field, coupled with the likely short unrest times of even a small volcanic eruption give rise to great public uncertainty and potentially vast hazard implications. Cities such as Auckland with populations of >1 million people lie on an intraplate monogenetic basaltic fields. Lack of magma storage within the crust in these settings limits ongoing monitoring possibilities, leading to a key question: if magma is geophysically detected as it rises through the crust beneath a monogenetic volcanic field, how quickly could an eruption ensue?

Objectives

Our goal was to construct a comprehensive model of the expected timescale for eruptive events in the AVF from onset of magma ascent to eruption. We accomplished this by achieving the following objectives:

1) We characterized olivine crystals in relation to their mantle (xenocrysts) or magmatic (phenocrysts) origin from AVF volcanoes
2) We determine by a variety of independent analytical methods diffusion profiles in identified olivine xenocrysts.
3) We calibrated and integrated all the results to determine the rates of ascent of magmas in the AVF from mantle and crustal depths to the surface.

Conclusions and key findings

Olivine crystals and olivine-pyroxene clusters collected from tuff ring scoria deposits at Pupuke volcano in the Auckland Volcanic Field (AVF) represent xenocrysts and xenoliths entrained in ascending basaltic magma at depths between ~ 80 to ~27 km in the lithospheric mantle. Elemental diffusion gradients indicate xenocryst residence times of within the host magma of ~1 month, which gives ascent rates of 0.01-0.03 ms^{-1}. However, some xenocrysts show evidence of longer residence times, which implies that magma stalled in the mantle over a period of several years before final ascent was triggered. Further, some crystals show sudden step-changes and hooked diffusion profiles, evidencing magma mixing and specifically the arrival of a new more mafic magma to the accumulation zone. This short outer diffusion zone indicates magma moved rapidly after contact with the new melt and thus the newly arrived magma was a trigger to eruption.

OH-diffusion results are incongruous in showing extremely rapid diffusion of water in the xenocrystic olivine over <12 hours. Rather than interpreting this as extremely rapid magma rise as in past studies, we consider it records only shallow degassing of the rising magma as it reached the last stage of its rise within 1-2 km of the surface.

The implications of this study refute the common view that monogenetic basalts with simple crystal cargos are primary magmas directly derived from a mantle source. Homogenizing magma storage areas may occur in the shallow mantle, giving rise to the broad spectrum of continuous magma compositions between alkalic and subalkalic end members seen in monogenetic fields. In this way, these deep-seated magmatic systems share similar styles of accumulation and mixing, albeit on a smaller scale, as those observed in crustal systems at typical strato-volcanoes.

Our new evidence helps to clarify questions of eruption warning time beneath monogenetic fields. Past estimates of warning periods concluded generally much longer times for the AVF. Here we confirm that the lowest extremes of such estimates are likely, i.e., weeks to <1 month rise from lithospheric mantle depths. Thus, seismic detection (within the brittle crust) may only be possible for a week or two. Once magma reaches 1-2 km depth, eruption is likely in less than 12 hours.

Impact *(ie, how this research reduces the impact of natural disaster on people and property)*

The results from this research will inform monitoring scientists (GeoNet) as well as emergency management authorities as to the expected timeframes between the detection of seismic unrest beneath Auckland and the ensuing eruption.

Future work

Further research will investigate further centres to improve the xenocryst dataset density and better characterize the 3D spatial extent of deep storage areas and interacting magma batches.

Acknowledgements

This research was supported by Earthquake Commission Biennial Grant 16/725, Australian Synchrotron beamtime project 10916 and a University of Auckland School of Environment Research Fund.

Outputs and Dissemination -

Brenna, M., Cronin, S., Smith, I. E. M., Tollan, P. M. E., Scott, J. M., Prior, D. J., Bambery, K. and Ukstins, I. A. 2018. Olivine xenocryst diffusion reveals rapid monogenetic basaltic magma ascent following complex storage at Pupuke Maar, Auckland Volcanic Field, New Zealand. Earth and Planetary Science Letters 499, 13-22. DOI https://doi.org/10.1016/j.epsl.2018.07.015.

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Link to publication:

https://www.sciencedirect.com/science/article/pii/S0012821X18304217

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