Trace element zonation of phenocrysts from Ngauruhoe Volcano, New Zealand: constraints on magmatic processes

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Introduction

A proper understanding of the processes operating in a magmatic system requires a knowledge of the chemical changes that occur through time. Traditional whole-rock analysis of lavas from a stratigraphic section provides information on the composition at the time of each eruption, and the changes from one composition to another are interpreted in terms of processes. However, analysis of the chemical zonation in crystals that grew suspended in an evolving magma provides much greater and more direct information about the changes that occurred during the period between eruptions.

In this study, trace elements with well understood partition coefficients were analyzed to determine their zonation in phenocrysts. The samples used come from Ngauruhoe; a basaltic-andesite volcano situated at the southern end of the Taupo Volcanic Zone in the central North Island of New Zealand. These samples represent both prehistoric and all historic eruptions. The rocks are plagioclase-pyroxene phyric and commonly contain quartzofeldspathic xenoliths, and, rarely, xenocrysts of olivine. These features mean that Ngauruhoe is a good place to study a range of magmatic processes at the scale of single crystals.

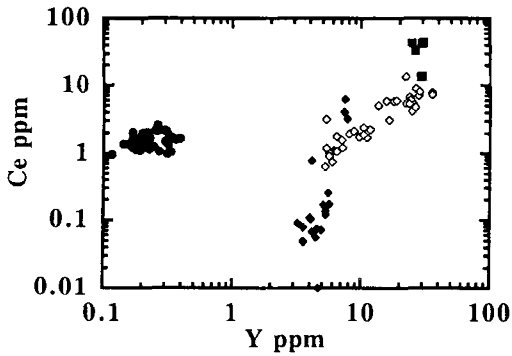

FIG. 1. Log-log plot of plagioclase (solid circles), orthopyroxene (solid diamonds), clinopyroxene (open diamonds), and groundmass (solid squares) compositions from 6 samples of basaltic andesite.

Analytical methods

Whole-rock analysis of major and trace elements (XRF) and major element mineral compositions (electron microprobe) were both done at the Open University. Trace element compositions of single points on crystals were determined using a Cameca ims 4f secondary ion mass spectrometer at the University of Edinburgh. A typical analysis includes Rb, Sr, Y, Zr, Nb, Ba, and the *REE*, and also Mg and Na in pyroxenes, Mg and K in plagioclase, and Ni in olivines. Electron microprobe analyses of Mg, Na, and K compare well with ion probe analyses.

Results

Crystals of different mineral phases growing during closed system fractional crystallisation will acquire trace element concentrations which define parallel trends on log-log plots. On Figure 1, plagioclase, orthopyroxene and clinopyroxene all plot at angles to one another, indicating they did not grow during closed system fractionation. Also, the degrees of trace element enrichment (almost an order of magnitude in cpx) are too extreme to have developed simply from fractionation of a magma, given the mass percent of crystals in these rocks (approximately 30%), and assuming closed system crystallisation. But given that crystal cores are not in equilibrium with the whole rock, and that the crystals have complex zonation, closed system crystallisation is unlikely.Evidence for processes other than fractionation is found in many crystals, and is illustrated by a plagioclase crystal from sample NG05 (Figure 2). This crystal can be divided into three parts on the basis of chemistry and optical microscopy; (I) the reversely zoned central portion (from 0 to approximately 0.3mm) with a constant K/*LREE* ratio, (II) an intermediate normally-zoned portion in which the K/*LREE* ratio increases, and (III) the

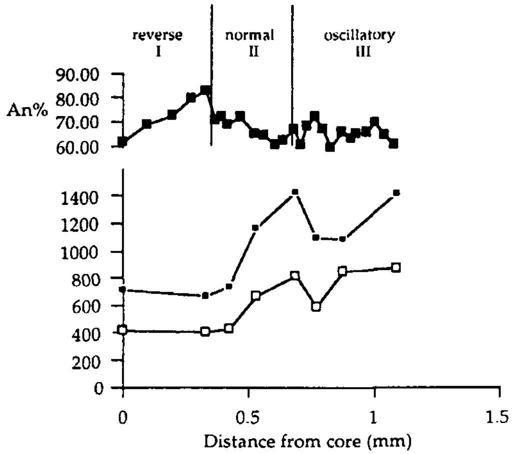

FIG. 2. K/Ce (open squares) and K/La (solid squares, lower graph), and anorthite content from the core to the rim of a plagioclase phenocryst in sample NG05.

outer oscillatory-zoned portion. Reverse zoning in this case was probably caused by the gradual introduction of a more primitive magma, while changes across the outer portions are most probably dominated by the assimilation of a high-K contaminant into the magma.

Conclusions

It is evident from the zonation of the crystals found in the lavas produced by Ngauruhoe that this volcano's magma supply system experienced sequences of mixing, contamination, and crystallisation. The crystals found in any one rock are complexly zoned, and are only broadly similar to one another, indicating that the magmas experienced fractionation of diverse phenocrysts such that the whole rock cannot be equivalent to a liquid composition. Phenocryst zonation provides a more complete picture of magmatic evolution because the whole rock compositions incorporate the integrated chemical histories of all the crystals and groundmass in a rock.