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Complex Differentiation Histories Revealed by Short-Term Geochemical and Isotopic Variations Between and Within Lavas of Ngauruhoe Volcano, New Zealand

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Ngauruhoe is the youngest composite cone in the Tongariro volcanic complex, situated in the southern Taupo Volcanic Zone. Cone growth has been rapid but intermittent, with a rate of 0.9 km^3/ka averaged over Ngauruhoe's 2500 year lifetime. Detailed sampling of more than 70 historical and prehistoric lava flows and pyroclastic deposits has made it possible to identify abrupt and non-systematic changes in magma composition over short time scales.

The Ngauruhoe lavas are basaltic andesites to andesites spanning a relatively narrow range in SiO_2 (54.2 - 58.6 wt%). They typically display a strongly porphyritic texture (25-37% phenocrysts) dominated by plagioclase (An_{54-90}), with both orthopyroxene (En_{61-76}) and clinopyroxene ($Ca_{41}Mg_{47}Fe_{12}$ - $Ca_{35}Mg_{41}Fe_{24}$), and minor Fe-Ti oxides. Olivine (Fo_{67-91}) is a minor constituent of 40% of Ngauruhoe lavas. Petrographic evidence for disequilibrium includes plagioclase sieve texture and internal resorption surfaces, reversely-zoned crystals, resorbed orthopyroxene rimmed by augite, and resorbed olivine rimmed by orthopyroxene. Mineral compositions commonly extend beyond the ranges expected from whole-rock compositions.

Mapping has identified five major groups of temporally and spatially related flows and each group is compositionally distinct, related to progressive growth on different sectors of the cone. These groups do not fall on a simple evolutionary 'trend' that would link all Ngauruhoe lavas to a single fractionating magma chamber. Instead we see considerable data scatter, multiple and often linear trends of varying slopes, and inconsistent age-composition relationships between and within groups (Figure 1). The oldest Group 1 lavas are the most SiO_2-poor, with notably high Sr (316-359 ppm) relative to other Ngauruhoe groups, and the lowest $^{87}Sr/^{86}Sr$ ratios. Fo_{67} olivine is not in equilibrium with host rock Mg# of 54.5 and is surrounded by Mg-rich orthopyroxene. The Group 4 andesites are among the most silicic from Ngauruhoe, but they are also among the most MgO-rich with the highest Cr (108-193 ppm) and Ni (34-57 ppm). They exhibit strong evidence for disequilibrium, including Cr spinel-bearing Fo_{91} olivines rimmed by Fe-rich orthopyroxene and hosted by a rock with Mg# 57. The olivine-bearing (Fo_{80}) Group 5 lavas are the youngest, and encompass the widest SiO_2, MgO and $^{87}Sr/^{86}Sr$ ranges of all the Ngauruhoe groups. Sieve-textured, reversely-zoned plagioclase phenocrysts are particularly common. Significant chemical and isotopic variations among consecutive historical eruptions indicate frequent mafic recharge and mixing.

Overall data trends of the five Ngauruhoe groups also point to evidence for open system processes. K/Rb and Sr/Rb decrease, and K/P, K/Ti and Rb/Zr increase with increasing SiO_2, and the ratios also correlate with $^{87}Sr/^{86}Sr$, suggesting an important role for contamination by the Mesozoic Torlesse metasedimentary basement. Although they span a similar SiO_2 range, the historical eruptive products form a distinctly higher $^{87}Sr/^{86}Sr$ trend (0.70531-0.70613) than the more scattered data for the prehistoric lavas (0.70419-0.70540). Particularly common occurrences in the historical eruptive products are xenoliths interpreted as refractory quartz veins from the basement metasediments. $^{143}Nd/^{144}Nd$ ranges from 0.51264 to 0.51279 and decreases with increasing $^{87}Sr/^{86}Sr$, although there is considerable scatter in the data. The chondrite-normalised REE patterns of all Ngauruhoe groups are very similar, with negative Eu anomalies and light REE enrichment.

Analysis of the Sr isotopic compositions of single crystals from historical lavas indicates disequilibrium between crystals (lower $^{87}Sr/^{86}Sr$) and groundmass (higher $^{87}Sr/^{86}Sr$). For any one lava, $^{87}Sr/^{86}Sr$ varies between phenocryst phases (e.g. plag = 0.70553 augite = 0.70513), as well as between different size populations of the same phase. For most lavas analysed to date, larger crystals of plagioclase had lower $^{87}Sr/^{86}Sr$ than smaller ones, but for one lava the reverse is the case (small plag = 0.70502, large plag = 0.70573). The evidence strongly suggests that many of the 'phenocrysts' in Ngauruhoe lavas should be regarded as entrained *xenocrystic* remnants of earlier magma batches or the crust, which mingled with variably contaminated magmas to produce the lava sampled at the surface. At Ngauruhoe the complex interaction of crustal assimilation, fractional crystallization and magma mingling processes has been responsible for modifying magma compositions on time scales as short as a year. We envisage the frequent injection of small (<0.1 km^3) and short-lived (years to decades) magma batches into a complex plumbing system of narrow conduits and small holding chambers, where ascent rates and residence times could often vary for different batches.

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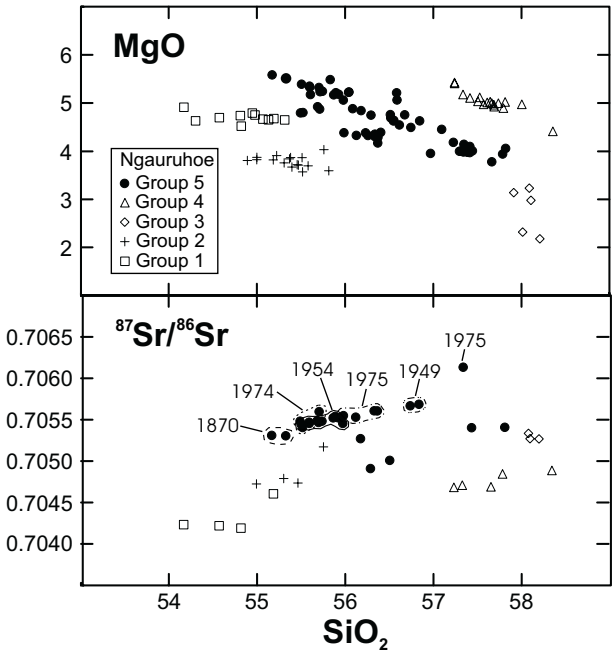

Figure 1: Variation of MgOwt% and $^{87}Sr/^{86}Sr$ with SiO_2 wt% for the five Ngauruhoe lava groups. Data for historical eruptive products are labelled with year of eruption. Errors are less than symbol size.