Title of research (EQC grant reference number)

Physical controls and processes associated with the 1975 eruption of Ngauruhoe (Project No 17/U749) (Thesis title: Precursory Eruptions, Magma Priming and Eruption Dynamics associated with the Climactic 19th February 1975 Eruption of Ngauruhoe)

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Key words

Ngauruhoe, basaltic-andesite, eruption style, recharge, temperature, scoria, spatter, caprock

Summary

Ngauruhoe is an active, central North Island composite volcano, located at the south end of the Taupo Volcanic Zone. This basaltic andesite to andesite cone is one of the most active vents of the larger Tongariro Volcanic Complex; the active summit scoria cone (c. 150 m in diameter) was constructed within the older crater (c. 400 m in diameter) during the eruptions of 1954 to 1975. Approximately 9 m of volcanic material was added to the inner crater rim of Ngauruhoe during the 1975 eruption. This research investigated the physical parameters and eruption controls that led up to the 1975 eruption, including the activity observed from 1968. Specifically, this study examined the pre-eruptive conditions, triggers and eruption mechanisms that led to eruption and emplacement of the 1975 inner crater rim deposit. Fieldwork involved stratigraphic logging, high-resolution photography, and sample collection, in addition to sub-sample collection of the 1954-75 volcanic ash deposits stored on archive at GNS Science. Outcrop photos were subsequently point-counted to discriminate between the components, and collected samples described and characterised. Further laboratory analyses included optical microscopic petrography, component point counting, vesicularity studies, scanning electron microscopy, electron microprobe analysis, laser sizing, and quantitative software shape analysis.

Introduction

Composite cones are typically associated with intermediate to silicic magma (although mafic basaltic compositions are also possible) and can erupt both effusively (lava flows) and explosively (strombolian, vulcanian, subplinian and plinian eruptions) (de Silva & Lindsay, 2015). Eruptive behaviour has strong implications for the consequent volcanic hazard(s) most likely associated with a particular volcano; therefore, research aimed at better understanding the processes associated with the behaviour of frequently active cones has obvious significance (Hobden et al., 2002). Ngauruhoe is a frequently active composite cone in New Zealand which has displayed a variety of eruptive styles over its eruptive history, making it an ideal volcano to study the eruptive styles and dynamics of a young composite cone (in addition to the well-preserved and relatively accessible lava flows and inner crater deposits). The study of eruption deposits may assist with interpreting pre-eruptive magma conditions and processes which lead to certain eruptive behaviour and emplacement processes, and the knowledge obtained may subsequently be applied to other open-system composite volcanoes worldwide.

The past eruptions of Ngauruhoe have been well-documented (e.g. Nairn *et al.,* 1976, Nairn and Self, 1978, and Krippner, 2009); however, detailed observations and analyses of the 1975 eruption deposits are minimal. Some articles involve regional studies of Tongariro but do not focus specifically on the 1975

Ngauruhoe eruption, such as Greve et al. (2016), Hill et al. (2015), Miller and Williams-Jones (2016), Moebis et al. (2011) and earlier work by Hobden et al. (1996). Therefore, the pre-eruptive conditions and explosion dynamics of the 1975 climactic eruption are not well understood, and related deposits have not been described and quantified in significant detail.

Objectives

1) to reconstruct stratigraphy and facies characteristics (including the geometry, textural characteristics, spatial variations, and componentry) of the 1975 deposit, and characterise and correlate distal ring plain deposits from eruptions leading up to and including the 1975 eruption;
2) to characterise and quantify the morphologies, textures, and petrographic components of the different clasts that make up the 1975 eruption deposit, in addition to the components and morphologies of the distal 1954-1975 ash samples; and
3) to characterise the detailed mineral and glass chemistry from the 1975 deposit.

Conclusions and key findings

- This study has demonstrated the importance of crystal fractionation and magma mixing in the evolution of the magma that erupted during 1975. In particular, the transporting magma may have interacted with, and entrained, exotic crystals from a cooler, more evolved crystal mush zone formed by an antecedent magma.
- The 1975 eruption is geochemically different to earlier eruptions, particularly those which occurred in 1954, 1968, and 1972. Some very high silica contents in glass from earlier eruptions may be associated with hydrothermal alteration and/or halogen degassing.
- The high abundance of lithics in the 1972 ash suggests that this eruption involved conduit wall degassing, or simply strong degassing, that mined some of the plug/hydrothermally altered rock. The lithics may be derived from the brittle fragmentation of a degassed and hydrothermally altered plug from earlier 1954-55 eruptions, and at least some of the lithics may also be derived from older pre-1954 wall rock.
- Gas segregation and transport to the surface along preferential percolation pathways was a key process involved in priming the magma for the 1975 eruption, and the eruptible magma likely had a temperature of 1018-1114 (±56) °C.
- The presence of a coherent, degassed, and hydrothermally altered caprock contributed to the high explosivity of the climactic eruption which took place on the 19th February 1975. This cap rock may have been a solidified cap on the juvenile magma, and/or a plug consisting of solidified non-juvenile magma from the 1954-55 eruption as well as any recycled material and crater collapse debris from subsequent, less explosive activity in the late 1960's, 1972, and 1973. This cap rock led to the accumulation and coalescence of pressurised gas, resulting in overpressure in the conduit and subsequent mechanical failure of the plug. A violent vulcanian eruption was initiated upon plug disruption and was followed by a voluminous and continuous eruption plume lasting 1.5 hours due to the significant amount of gas that had built up beneath the cap rock.
- It is unlikely that the 1974-75 eruption was primarily triggered by a phreatomagmatic event, as suggested by Nairn & Self (1978), due to the lack of evidence displayed in the crater rim deposit. It is more feasible that the primary eruption mechanism was dominantly magmatic, with only minor magma-water interaction producing the steam observed in the eruption column.
- The 1975 inner crater rim is comprised of three different clast types which vary in terms of origin and cooling processes. The moderately vesicular scoria and fluidal spatter are both derived from the juvenile magma; scoria clasts erupted quickly and thus rapidly cooled and quenched prior to

emplacement, whereas spatter clasts have undergone limited cooling prior to deposition, leading to deformation and agglutination upon landing. The sub-angular to angular dense clasts are derived from a solidified and degassed cap rock and were thus solid upon emplacement.

- Two populations of melt inclusions are recorded in the 1975 deposit. The unusually evolved population are typically hosted in dense clasts, possibly related to post-entrapment crystallisation during slow cooling (these inclusions likely continued to crystallise along their interface with the host crystal).

- The 1975 inner crater rim deposit is now divided into four facies, A through D, based on textural characteristics and componentry (Figure 1). Facies A and B were most likely emplaced during discrete vulcanian activity associated with disruption of a caprock, leading up to the climactic eruption on the 19th of February 1975. This is consistent with the presence of loose clasts, and the higher proportion of dense clasts in facies A relative to the overlying facies. Facies C and D were most likely deposited during the continuous 1.5 hour 'subplinian' eruption on the 19th of February 1975 (from strombolian fire-fountaining activity at the base of large eruption plume). This is suggested by the mixture of scoria, agglutinated spatter, and dense clasts throughout these facies; which are indicative of a spatter-fed eruption. The densely welded domains within facies C suggest the involvement of a higher accumulation rate compared to that involved during the emplacement of facies D.

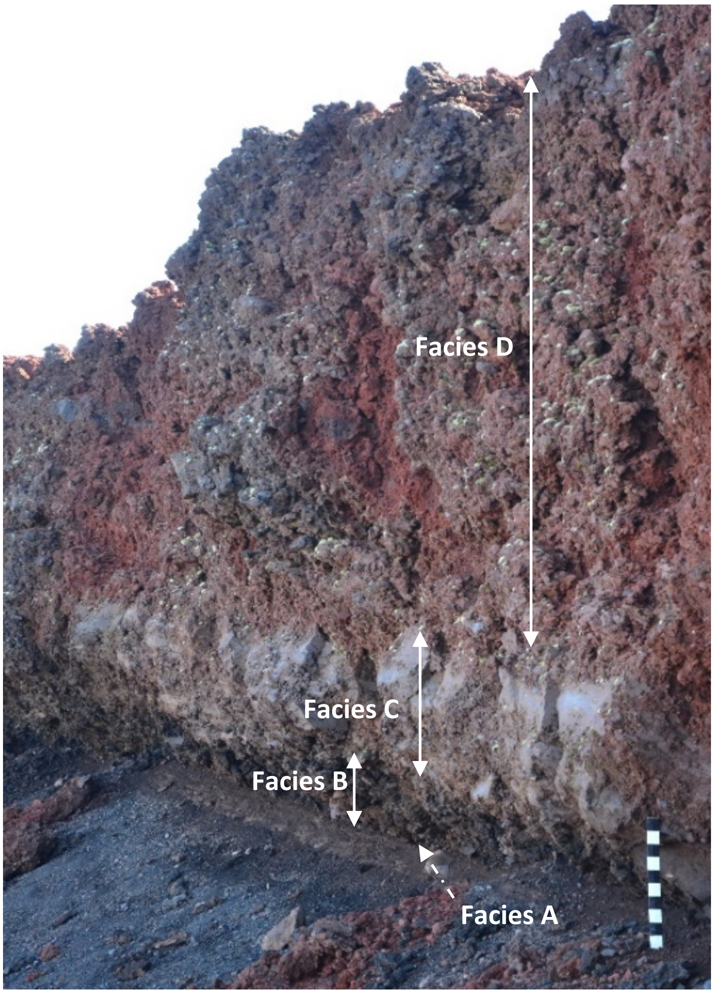

Figure 1. The crater rim deposit produced during the 1975 eruption of Ngauruhoe, including division of the deposit into four discernable facies (A, B, C, and D). Several ash-lapilli beds can also be seen underlying the 1975 deposit (photo by Geoff Kilgour, 2018).

Impact (i.e., how this research reduces the impact of natural disaster on people and property)

This research has significant implications to the safety of hundreds of people walking the Tongariro Alpine Crossing each day. In 2014 it was reported that daily visitor numbers to the crossing could reach up to 1500 during the busiest summer period (Jolly *et al.,* 2014), and this number has likely increased substantially over the past five years.

This study has provided improved knowledge regarding magmatic and volcanic processes (including magma evolution and ascent, priming conditions, triggers and eruption mechanisms) likely associated with the 1975 eruptions from Ngauruhoe. It is hoped that this improved understanding will assist with more reliable interpretation of monitoring data prior to and during such eruptions (not only associated with Ngauruhoe, but also to basaltic-andesite volcanoes worldwide).

Future work

Further work on Ngauruhoe could involve constraining the likely depth of melts and dykes associated with the 1975 eruption, based on volatile contents of phenocryst-hosted melt inclusions. There are a few ways in which probing transects across a crystal could also provide some useful information; 1) assuming that there is a well constrained experimental phase diagram, a transect could show how compositional changes reflect pressure or temperature dependence, and 2) a low pressure signature associated with decompression may be recorded in small zones near the rim, since the partition of trace elements between the melt and the crystal is partly pressure dependant.

By using the settling velocity of quartz-rich xenoliths, combined with knowledge of the viscosity and density of the magma, it may also be possible to work out a minimum ascent velocity required to keep the xenoliths from settling. This calculation could have several applications from a geological/petrological perspective, such as developing a conduit flow model and assisting with future monitoring of Ngauruhoe.

It may also be useful to obtain strontium (Sr) and/or oxygen (O) isotope data from mineral zones to help assess the extent of crustal contamination involved in the evolution of the 1975 magma.

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