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Understanding the largest-scale explosive volcanism at Mt. Taranaki, New Zealand

A thesis presented in partial fulfilment of the requirements for the
degree of

Doctor of Philosophy

in

Earth Science

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New Zealand

2017





“In solitude we find ourselves, defeat our ego, discover our worst, our best, love, real life and real friends” Photo: Sharks Tooth from the summit of Mt. Taranaki, Jul/2016.

Dedicated to my mother - the strongest person I've ever met,
and to my beloved adopted sisters and brothers

Abstract

Over the last 5000 years B.P., at least 53 explosive eruption episodes occurred at Mt. Taranaki, (western North Island, New Zealand) from either the summit-crater (2500 m), or a satellite vent on Fanthams Peak (1966 m). These eruptions are represented in well-preserved pyroclastic successions on the upper volcano flanks. At least 16 episodes produced deposits with lithostratigraphic characteristics comparable to those of the last sub-Plinian eruption at AD 1655, suggesting an average recurrence of one Plinian/sub-Plinian eruption episode every 300 years. Several large-scale mafic-intermediate (~48-60 wt.% SiO₂) eruption episodes sourced from the two vents were studied in detail to determine the “maximum” intensity, magnitude and eruptive styles from this volcano. These episodes comprised climactic phases with sustained and steady, 14-29 km-high eruption columns, often starting and ending with unsteady pulsating, oscillating and collapsing plumes. The columns erupted 0.1-0.5 km³ DRE at mass and volume discharge rates of 10⁷-10⁸ kg/s and 10³-10⁴ m³/s, respectively, indicating magnitudes of 4.1-5.1. The unsteady initial, pre- and post-climactic eruptive phases were dominated by dome-collapse, column-collapse and lateral-blast pyroclastic density currents (PDCs), with run-out distances of 3-19 km and volumes of up to 0.02 km³ DRE. The steadiest phases were associated with eruption of rheologically homogeneous magmas producing homogenous pumice textures. Unsteady phases produced density and porosity pumice gradients by magma stalling in upper conduit levels. Three eruption onset scenarios were developed from this work: a) initial closed-conduit decompression by vent unroofing and dome-collapse, b) transient open and clogged conduits produced by repeated plugging-and-bursting of chilled or gas-depleted magma, and c) rapid conduit opening with more mafic eruptives. In all scenarios, the climactic phases are comparable, with pyroclastic fallouts

covering 1500-2500 km². The most violent phases of these events, however, are lateral-blast PDCs that could reach a broad arc between 14-19 km from source. This reappraisal of the hazardscape at Mt. Taranaki integrates many new details that enable a more realistic hazard management and provides a range of findings that can be applied to other similar andesitic volcanoes prior to reawakening.

Acknowledgements

The first time I heard about New Zealand was in 2009 during an outstanding poster presentation about Mt. Ruapehu at the Jorullo conference in Mexico, by PhD student Natalia Pardo. The next thing I discovered was an incredibly beautiful, almost perfect cone-shaped stratovolcano, confusingly named both Taranaki and Egmont. This I wished to climb if I ever had the chance to go for any reason to the other side of the world. A few years later I emailed Shane Cronin inquiring about PhD opportunities and he replied by asking if I would be interested in working on explosive volcanism at Mt. Taranaki - I felt that I had just won the lottery. Doing fieldwork in this volcano has been challenging, slow, and at times frustrating due to the multiple obstacles posed by topography and vegetation and the very intricate stratigraphy. Disentangling a little part of such complexity whilst walking on its slopes has been extremely rewarding, and I would never choose differently, even if I could.

For this once-in-a-life opportunity, and for his aid in my receiving a Massey University Doctoral scholarship, I am very thankful to my chief supervisor Dr. Shane J. Cronin. I was also greatly benefited from his extraordinary understanding of the “big and small picture” of volcanic processes, from his ability in quickly recognising the core relevance of data and in choosing the exact sentence and the right paper among limitless possibilities, from his enthusiasm and cheering during these years, and from his skills in writing, organizing, discussing and developing ideas.

I am also greatly thankful to my co-supervisor Dr. Natalia Pardo. Her advice was essential in coming to New Zealand. Her expertise and cheerful disposition in reviewing, discussing and providing work-related and personal support were vital in pursuing this

work. Natalia is a field and research geologist and volcanologist worth to be followed and emulated, but additionally her patience and friendship have been second to none.

Many thanks to my co-supervisor Dr. Alan S. Palmer for his great disposition, reviews and encouraging, especially valuable during fieldwork. And I also wish to thank my other co-supervisors Dr. Robert B. Stewart and Assoc. Prof. Ian E.M. Smith (The University of Auckland) for their support, advice, reviews, explanations and discussion at different moments during completion of this work. I also thank Drs. Vince Neall, Karoly Nemeth, Georg F. Zellmer, Gert Lube, John Procter, and Eric Breard for their collegial support, Dr. Kate Arentsen for her reviews and her assistance with logistics and procedures, and Dr. Anja Moebis, Bob Toes and Ian F. Furkert for their help during labwork. Drs. Darren Gravley, Ian Fuller, and Roberto Sulpizio are acknowledged for their deep and fruitful reviews of the final thesis.

My infinite thanks go to my friend and colleague Magret Damaschke. This work simply would not have been properly finished without her deep discussions and endless energy, care, support and encouraging, especially during the worst times. Working alongside such a determined, honest and clever person enriched every chapter of this thesis, and her work brought light into solving Mt. Taranaki's stratigraphic puzzle which otherwise would have remained unclear.

Very especial thanks to my friend, colleague volcanologist, and mountain-climbing partner in Mexico Juan Ramón de la Fuente. His selfless care, humbleness, disposition and honesty despite distance are admirable. I benefited from his ongoing support and his taking charge of personal issues and financial and legal procedures back home, including the bureaucratic and tedious processing of my CONACyT Doctoral scholarship.

Additional thanks go to my first mentor in Volcanology, Dr. Jose Luis Arce, who has never stopped providing advice, discussion, reviews, appreciation and concern. Many

thanks to my friend Dr. Gabor Kereszturi who provided outstanding personal and academic advice, cheering and support, interesting discussions (and rum-based drinks at any opportunity!). His enthusiasm and determination during fieldwork were greatly appreciated. I am also very thankful to my colleague and half-Mexican friend Szabolcs Kósik, who demonstrated an exceptional personality and interest, and did not vacillate in supporting me, my work and my future outcomes, at times by fuelling up with Palinka.

Endless thanks to friends and people I met at Palmerston North who provided their support in many different ways and at different moments during these years, including words of encouraging and comprehension, discussion, field-assistance, tramps and good memories: Angela Denes, István Hajdu, Eduardo A. Sandoval, Gaby Gómez, Kwan Maitrarat, Marcela Humphrey, Friederike von Schlippe, Soledad Navarrete, Javier Agustín Flores, Diana Cabrera, Manuela Tost, Omar Cristobal, Zsuzsa Szmolinka, Jimena Rodríguez and “Negrito” Adimar.

Last but not least, to my grandma and uncles, and to my non-blood family who have kept their unconditional support, encouraging and inspiration at any time during these years of PhD regardless of distance: David Alvarez, Juan Angel Torres-Rechy, Pasquinel de la Fraga, Heriberto Oliva, Francisca Vidal, Edgar Ocampo, Laura Scheffler, Mariela Díaz, and Emma Cesta.

This work was supported by a Massey University Doctoral scholarship, a CONACyT (Mexico) Doctoral scholarship, and the George Mason Trust of Taranaki.

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 Eruptive parameters and classification of the studied deposits. **a** Normal distribution of total column heights (HT) in kilometers, calculated by using different methods (Table 4.1, Appendix 4.9). Numbers indicate minimum, maximum and average HT corresponding to individual fall deposits. **b-c** Isopleth data plotted in the diagram of Carey and Sparks (1986) to determine HT and wind speeds, based on diameters of dense andesitic clasts and pumice clasts (or vesicular juvenile clasts of the Manganui-D bed-set), ranging from 0.8 to 2 cm and 1.6 to 4 cm, respectively, and on the corresponding clast's bulk-densities (kg/m^3). **d** Diagram of Pyle (1989) of classification of the eruptions based on parameters (bc, bt) calculated from isopach and average isopleth (pumice and dense andesitic clast) data, and on the dispersal index of Walker (1973, Appendix 4.9). **e** Diagram of Bonadonna and Costa (2013) of classification of eruptions based on HT, and on parameters (λ_{th} , λ_{ML}) calculated from isopach and isopleth data (Appendix 4.9). **f** Diagram modified from Sparks (1986) and Carey and Bursik (2000) to determine volume and mass eruption rates (Q and MER, respectively), considering the average HT calculated from each individual fall deposit. The curve of HT calculated by using the model of Sparks (1986) is indicated. Neutral buoyancy column heights (HB) were estimated by using the average HT of each fall deposit and "bc" of Pyle (1989, Appendix 4.9). Fields corresponding to Plinian and sub-Plinian eruptions were modified from Bonadonna and Costa (2013). **g** Plot of average HT vs. Minimum dense-rock-equivalent (DRE) eruptive volumes. The latter were calculated from average total volumes, and bulk and solid densities (Table 4.2). **h** Plot of average HT vs. Magnitude ($M = \text{Log}_{10}(\text{mT}) - 7$) calculated using the method of Pyle (2000). Total mass in kilograms ($\text{mT} = (\text{solid-density}) (\text{DRE volume})$) calculated using the method of Wilson (1976). **i** Plot of average HT vs.

minimum duration of the eruption, in hours ($T=mT/MER$, Table 4.2), estimated using the method of Wilson (1976).

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A Tectonic setting of the North Island (NI) of New Zealand (modified from King and Thrasher 1996; Henrys et al. 2003; Sherburn and White 2006). *CEFZ* Cape Egmont Fault Zone, *R* Mount Ruapehu, *SI* South Island, *TVL* Taranaki Volcanic Lineament (yellow line), *TVZ* Taupo Volcanic Zone. **B** Zoomed area of the TVL. The latter comprises four <1.75 Ma and NNW-SSE migrating andesitic volcanoes (Neall 1979) or their eroded volcanic edifice-remnants: Kaitake, Pouakai and Mt. Taranaki (and the satellite cone of Fanthams Peak – topped by Syme Hut). **C** Zoomed transect of the proximal eastern flanks of Mt. Taranaki and the type sections of this study (points A to Y, Appendix 5.1). Digital profile modified from Google Images (2017). **D** 10 cm-thick isopachs of fall deposits produced during <5 ka Plinian (white ellipses) and sub-Plinian (grey ellipses) eruptive episodes at Mt. Taranaki (modified from Torres-Orozco et al. 2017b, Table 5.2). Red circles indicate the position of the summit crater and the Fanthams Peak vent. Coordinate system of all insets: NZGD 2000 New Zealand Transverse Mercator.
- Figure 5.2**.....225
 Proximal lithofacies transitions of the 4700-4600 cal BP Kokowai (Kw1-Kw8). *KA* Kapuni-A, *KB* Kapuni-B, *Ko* Korito. Sections indicated on top of each profile (A-Y, Fig. 5.1). Yellow lines on photographs indicate lower and uppermost bed-set contacts. Lithofacies codes (Table 5.3) indicated to the right of each profile and inside white boxes on pictures. *FA* fine-ash, *CA* coarse-ash, *FL* fine-lapilli, *CL* coarse-lapilli, *B* block/bombs. Scale on pictures represented by a black bar or a scraper (32.5 cm-long).
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 Proximal lithofacies transitions of the 3800 to 3500 cal BP Kapuni-A (*KA*: KA1-KA2), Kapuni-B (*KB*: KB1-KB4) and Korito (*Ko*: Ko1-Ko8). *Kw* Kokowai, *Uig* Upper Inglewood. Sections indicated on top of each profile (A-Y, Fig. 5.1). Yellow lines on photographs indicate lower and uppermost bed-set contacts. See Fig. 5.2 for more details. The scale on pictures is represented by a black bar or a scraper (32.5 cm-long).
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 Proximal lithofacies transitions of the 3300 cal BP Upper Inglewood (*Uig1-Uig7*). Sections indicated on top of each profile (A-Y, Fig. 5.1). Yellow lines on photographs indicate lower and uppermost bed-set contacts. See Fig. 5.2 for more details. The scale on pictures is represented by a black bar, a long (32.5 cm-long) or a small scraper (20 cm-long), or a 10 cm-long scale.
- Figure 5.5**.....228
 Proximal lithofacies transitions of 3000-2600 cal BP members Manganui-A (*MA*: MA1-MA3), Manganui-B (*MB*), Manganui-C (*MC*), Manganui-D (*MD*: MD1-MD3) and Manganui-E (*ME*) of the Manganui Formation (Torres-Orozco et al. 2017a; b). *Uig* Upper Inglewood, *DF* debris flow. Sections are indicated on top of each profile (A-X, Fig. 5.1). Yellow lines on photographs indicate lower and uppermost bed-set contacts. See Fig. 5.2 for more details. The scale on pictures is represented by a black bar, and a long (32.5 cm-long) or a small scraper (20 cm-long).
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A Example of landscape elements that integrate the present-day micro-topography of the upper eastern flanks of Mt. Taranaki. The gradient of deposit confinement is indicated (modified from Schwarzkopf et al. 2005). **B** Profile of the general lateral transitions, relative to landscape, of deposits corresponding to each lithofacies association. Dotted white line indicates section not represented (not rep.) in the profile. Proximal (P-lateral) and proximal-medial (M-lateral) lateral lithofacies transitions relative to a reference incision-channel (i) are sketched. Digital image modified from Google Images (2017).

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- Figure 5.7**.....239
 Hazard maps indicating the possible distribution of different types of eruptive activity, throughout distinct eruptive phases, during a future Plinian eruption at Mt. Taranaki. Insets **A** to **D** correspond to opening, pre- or post-climactic eruptive phases. **A** dome-collapse block-and-ash flows, **B** blast type PDCs and lithic-rich surges, **C** column-collapse PDCs, **D** fallout, ballistics, and lava flow distributions. Insets **E** to **G** correspond to climactic eruptive phases. **E** blast type PDCs, **F** fallout, ballistics and lava flow distributions, **G** column-collapse PDCs. Inset **H** represents possible distributions of channel-confined lahars and small-scale landslides during any eruptive phase. Coordinate system of all insets: NZGD 2000 New Zealand Transverse Mercator.
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 Volcanic hazard scenarios for Plinian eruptions at Mt Taranaki’s summit-crater and Fanthams Peak vent. **A-F** Scenario I: initial eruptive phases of close-conduits and conduit-decompression by vent unroofing and dome collapse. **G-K** Scenario II: transient open and clogged conduits by repeated plugging-and-bursting of gas-depleted or chilled magma. **L-O** Scenario III: rapid progression into steady phases by open-conduits. The possible upper conduit dynamics for each scenario were sketched based on data and interpretations of Torres-Orozco et al. (2017a; b).
- Figure 5.9**.....247
 Event-tree sequence of the volcanic scenarios expected at Mt. Taranaki during a possible Plinian eruptive episode (magnitudes 4 to 5), produced at either the summit crater, or a satellite vent. For any vent, the eruptive sequence progresses from an opening and pre-climactic phase (1), throughout a climactic phase (2), to a post-climactic phase (3). Vent and/or conduit conditions (A to H) may direct into different processes and events (i.e., Scenarios I to III). Dotted lines indicate subsequent, alternative directions. Run-out distances simplified from Fig. 5.7.