

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

**ERUPTION CYCLES AND MAGMATIC PROCESSES AT
A REAWAKENING VOLCANO,
MT. TARANAKI, NEW ZEALAND**

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

Doctor of Philosophy

in

Earth Science

at Massey University, Palmerston North, New Zealand.



Massey University

Michael Bruce Turner

2008



Mt. Taranaki viewed from the north, March 2006.

Abstract

Realistic probabilistic hazard forecasts for re-awakening volcanoes rely on making an accurate estimation of their past eruption frequency and magnitude for a period long enough to view systematic changes or evolution. Adding an in-depth knowledge of the local underlying magmatic or tectonic driving processes allows development of even more robust eruption forecasting models. Holocene tephra records preserved within lacustrine sediments and soils on and surrounding the andesitic stratovolcano of Mt. Taranaki (Egmont Volcano), New Zealand, were used to 1) compile an eruption catalogue that minimises bias to carry out frequency analysis, and 2) identify magmatic processes responsible for variations in activity of this intermittently awakening volcano.

A new, highly detailed eruption history for Mt. Taranaki was compiled from sediment sequences containing Holocene tephra layers preserved beneath Lakes Umutekai and Rotokare, NE and SE of the volcano's summit, respectively, with age control provided by radiocarbon dating. To combine the two partly concurrent tephra records both geochemistry (on titanomagnetite) and statistical measures of event concurrence were applied. Similarly, correlation was made to proximal pyroclastic sequences in all sectors around the 2518 m-high edifice. This record was used to examine geochemical variations (through titanomagnetite and bulk chemistry) at Mt. Taranaki in unprecedented sampling detail.

To develop an unbiased sampling of eruption event frequency, a technique was developed to distinguish explosive, pumice-forming eruptions from dome-forming events recorded in medial ash as fine-grade ash layers. Recognising that exsolution lamellae in titanomagnetite result from oxidation processes within lava domes or plugs, their presence within ash deposits was used to distinguish falls elutriated from block-and-ash flows. These deposits are focused in particular catchments and are hence difficult to sample comprehensively. Excluding these events from temporal eruption records, the remaining, widespread pumice layers of sub-plinian eruptions at a single site of Lake Umutekai presented the lowest-bias sampling of the overall event frequency. The annual eruption frequency of Mt. Taranaki was found to be strongly cyclic with a 1500-2000 year periodicity.

Titanomagnetite, glass and whole-rock chemistry of eruptives from Mt. Taranaki's Holocene history all display distinctive compositional cycles that correspond precisely with the event frequency curve for this volcano. Furthermore, the largest known eruptions from the volcano involve the most strongly evolved magmas of their cycle and occur during the eruptive-frequency minimum, preceding the longest repose intervals known.

Petrological evidence reveals a two-stage system of magma differentiation and assembly operating at Mt. Taranaki. Each of the identified 1500-2000 year cycles represent isolated magma batches that evolved at depth at the base of the crust before periodically feeding a mid-upper crustal magma storage system.

Acknowledgements

This research would not have been possible without guidance and assistance of my chief-supervisor Assoc. Prof. Shane Cronin. He taught me much about how to present my ideas and thoughts, and how to interpret volcanic deposits. I appreciate his assistance in receiving a Massey University Doctoral Scholarship and support to attend national and international conferences and field courses. The lake coring ‘expedition’ that he and I took in 2005 provided the eruption stratigraphy that underpins much of this thesis.

I also would like to thank my co-supervisors, Assoc. Prof. Ian E.M. Smith (The University of Auckland) and Dr Robert B. Stewart (Massey University) for their guidance and encouragement over the years. Their many fruitful discussions and criticisms greatly assisted in the development of my geochemical understanding. Assoc. Prof. Smith also arranged the use of the geochemical equipment at both Auckland and the Australian National University. In addition, my co-supervisor, Prof. Vince E. Neall first introduced me to Mt. Taranaki and suggested the re-coring of Lake Umutekai, on which this research is greatly reliant.

The statistical expertise of Assoc. Prof. Mark S. Bebbington (Institute of Information Sciences and Technology, Massey University) greatly strengthened many aspects of this research. Through his collaboration with the volcanology community, increasingly robust statistically based eruption predictions are now becoming available. I would also like to thank Prof. Richard Price (The University of Waikato) for his discussions that assisted the geochemical aspects of this thesis.

I am grateful to Mr and Mrs Rumball for access to Lake Umutekai, Mr Sulzberger and the Rotokare Scenic Reserve Trust for access to Lake Rotokare, and the Department of Conservation for unlimited access to Egmont National Park.

I wish to thank every person who has assisted and supported me throughout this study:

Massey University – Palmerston North

I wish to thank fellow post-graduate students; Dr Katherine Holt, Dr. Thomas Platz, Mr Jonathan Proctor and Ms Anke Zernack, for the many shared experiences of post-graduate life. I also thank my office companion, Ms Susan Cole, for always being there with tea and biscuits. Of special significance is my friend, flatmate and colleague, Ms Anja Möbis. We have spent much time discussing and discovering New Zealand and volcanology together.

I am also grateful to Mr Bob Toes and Mr Mike Bretherton of the Soil and Earth Sciences Group for assisting with many technical needs. Special thanks are needed for Mrs Moira Hubbard; her expertise in presentation and formatting were invaluable for this thesis and the many posters and presentations made throughout this study.

The friendships of Dr Gert Lube, Dr Emma Doyle, Dr Karoly Németh, Ms Deborah Crowley and Mr Douglas Charley have also been invaluable during the last year of this research.

Auckland University

Dr Ritchie Sims provided outstanding assistance during use of electron microprobe, for which I am very grateful. His enthusiasm for music and comedy made the many hours of microprobe data collecting pass by with fun. I also thank Mr Jon Wilmshurst for his assistance in XRF-analysis. I am grateful to the post-graduate students and staff of Auckland University, especially Dr Vicki Smith, Ms Lou Fowler and Dr Darren Gravley for making Auckland feel like my second home.

Additional acknowledgements

Throughout this research there have been a group of people who I have had the pleasure of sharing my home and life with. These people include: Bryant Cook, Heather Purdie, Marti Sik, Richard Pederson, Renee Gearry and Rachel Paterson.

Furthermore I give my sincere thanks to the following people for their support: Ms Rachel Crimp, Ms Tanya O'Neill, Ms Kataizyna (Emilia) Bogdan and Ms Claire Spiller.

Lastly, I give my greatest thanks to my parents; Mrs Beverly and Mr Bruce Turner. They have consistently supported me through every part of this research and life.

This work was funded and supported by a Massey Doctoral Scholarship, the George Mason Trust of Taranaki, Claude McCarthy Scholarship, the FRST-PGST contract MAUX0401, and an Institute of Natural Resources transitional scholarship.

Table of Contents

	Page
Abstract	i
Acknowledgements.....	iii
Table of Contents.....	vi
List of Figures	xi
List of Tables.....	xvi
 Chapter One:	
Introduction	1
1.1. Introduction	1
1.2 Problem statement and hypotheses.....	7
1.3 Aims and Objectives.....	7
1.4 Regional geological setting	8
1.5 Mt. Taranaki	11
1.5.1 Introduction and brief eruption history	11
1.5.2 Geophysical observations.....	12
1.5.3 Petrology of Taranaki rocks	12
1.6 Outline of the thesis.....	14
1.7 References	15
 Chapter Two:	
Pyroclastic Eruption Records of Mt. Taranaki.....	19
2.1 Introduction	19
2.2 Previous tephrochronology at Mt. Taranaki.....	20
2.3 Edifice stratigraphic sections.....	21
2.3.1 Edifice stratigraphic descriptions.....	21
2.3.2 Chronology.....	23
2.4 Lacustrine sediments	23
2.4.1 Lake-sediment coring.....	27
2.4.2 Recognition and sampling of tephra in lake sediments.....	28

2.4.3	Chronology	29
2.4.5	Additional implications of the lake-records	33
2.5	References	34

Chapter Three:

Andesitic Tephrochronology and its Importance for Probabilistic Eruption Forecasting 37

3.1	Introduction	37
3.2	Merging eruption datasets: building an integrated Holocene eruptive record for Mt. Taranaki, New Zealand	40
3.2.1	Abstract	40
3.3	Introduction	41
3.3.1	Mt. Taranaki: the eruption records	42
3.3.2	The age/depth curves of Lake Umutekai and Lake Rotokare	48
3.4	Combining datasets using the event ages	49
3.5	Geochemical fingerprinting	52
3.5.1	Titanomagnetite geochemistry	53
3.6	Titanomagnetite geochemical correlations	56
3.7	Eruption Hazard Model	60
3.8	Implications for probabilistic eruption forecasts	66
3.9	Conclusions	69
3.10	Acknowledgements:	70
3.11	An integrated temporal record of edifice deposits.....	70
3.11.1	Introduction	70
3.11.2	Discriminant function analysis.....	71
3.11.3	Titanomagnetite tephrochronology	72
3.11.4	DFA on the titanomagnetite dataset	72
3.12	Conclusions	75
3.13	References	75

Chapter Four:

Eruption Classification and Identification of Cyclic Volcanic Processes at Mt. Taranaki. 79

4.1	Introduction	79
4.2	Using titanomagnetite textures to elucidate volcanic eruption histories	82
4.2.1	Abstract	82

4.3	Introduction	83
4.4	Titanomagnetite in fast- and slow-ascent eruptions	84
4.5	Application to volcanic eruption history	86
4.5.1	Grain lithology	88
4.5.2	Titanomagnetites	88
4.5.3	Identification of eruption styles.....	89
4.5.4	Elucidation of magma-system processes in eruption histories.....	90
4.6	Conclusions	93
4.7	Acknowledgements	93
4.8	Cyclic magma evolution and associated eruption frequency at andesitic volcanoes and its implications to eruption forecasting: a case study from Mt. Taranaki, New Zealand.....	94
4.8.1	Abstract	94
4.9	Introduction	95
4.10	The Holocene eruption rate of Mt. Taranaki	95
4.10.1	Mt. Taranaki	95
4.10.2	Eruption frequency analysis	97
4.10.3	Large eruption dataset	99
4.11	The magmatic evolution of the volcano during the Holocene period	102
4.11.1	Titanomagnetite compositions	103
4.12	Identification of distinct magma batches and geochemical cycles.....	106
4.12.1	Titanomagnetite-defined magma batches.....	106
4.12.2	Magma batches defined by whole-rock geochemistry	107
4.13	Geochemical magma cycles	112
4.14	Implications for probabilistic eruption forecasting	114
4.15	Conclusion.....	115
4.16	Acknowledgements	115
4.17	Combined References.....	115

Chapter Five:

Identification of Magmatic Replenishment 119

5.1	Introduction	119
5.2	Eruption episodes and magma recharge events in andesitic systems: Mt. Taranaki, New Zealand.....	121
5.2.1	Abstract	121
5.3	Introduction	122

5.3.1	Mt. Taranaki	122
5.4	The Curtis Ridge eruption episode	123
5.4.1	Stratigraphy of the Curtis Ridge events	124
5.5	Whole-rock geochemistry	127
5.6	Petrology	130
5.6.1	Plagioclase	131
5.6.2	Amphibole	134
5.6.3	Clinopyroxene	137
5.6.4	Titanomagnetite	138
5.7	Discussion	140
5.7.1	Plagioclase zoning	141
5.7.2	Amphibole	144
5.7.3	Clinopyroxene compositional profiles	146
5.7.4	Titanomagnetite	147
5.8	Magma recharging and the generation of an eruption episode	148
5.8.1	Recharge of andesite magma	149
5.8.2	Timescales of recharge and/or heating before eruption: Eruption triggering?	152
5.9	Conclusions	153
5.10	Acknowledgements	154
5.11	References	154

Chapter Six:

Understanding Magma Batch Production at Andesitic Volcanoes:

A case study from Mt. Taranaki, New Zealand 159

6.1	Introduction	159
6.2	Evidence of two-stage magmatic storage, crystallisation and fractionation and Magma batch development	160
6.2.1	Phenocryst evidence of two-stage magma differentiation	160
6.2.2	Mechanisms for magma generation at andesite volcanoes	161
6.2.3	Temporal evolution of the lower crustal hot zone: Generation of high K-andesite at Mt. Taranaki	162
6.2.4	Magma recharge models	164
6.2.5	Magma segregation	167
6.2.6	Structural consequences of magma assembly	168
6.3	Speculation on eruption frequency and magmatic processes	169
6.4	Conclusions	170

6.5	References	171
-----	------------------	-----

Chapter Seven:

Conclusions and Avenues for Future Research.....175

7.1	Conclusions	175
-----	-------------------	-----

7.2	Avenues for future research.....	178
-----	----------------------------------	-----

7.3	References	180
-----	------------------	-----

List of Appendices:181

List of Figures

	Page
Figure 1.1: <i>The North Island of New Zealand showing the major volcanic provinces. Insert shows the plate tectonic setting of New Zealand. The area between the Hikurangi Trough and the axial ranges is the forearc. Volcanic provinces marked include the Tongariro Volcanic Centre (TgVC), Mt. Ruapehu (R), White Island (W) and the Alexandra Volcanic lineament defined by the white line.</i>	4
Figure 1.2: <i>Regional tectonic setting of western Taranaki. The Taranaki Volcanic Lineament comprises the Sugar Loaf Islands (SLI), Kaitake (K), Pouakai (P) and Mt. Taranaki (T) with Fanthams Peak (F). Contours begin at 300 m, rising at 300 m intervals for the volcanic edifices only. Modified after Sherburn and White (2005). There are three active oblique normal slip NE-SW-trending faults of the Taranaki region: the Oaonui Fault (OF), Inglewood Fault (IF), and Norfolk Fault (NF). The Oaonui fault shows a vertical displacement of 5 m over the last 6500 years (Hull and Dellow 1993).</i>	6
Figure 2.1: <i>Summary of key, edifice stratigraphic profiles: Locations numbered on the orthophoto. See Appendix 3 for full descriptions.</i>	25
Figure 2.2: <i>Location map of the lakes used in this study. 300 m contours in thin grey lines. S = summit vent. F = Fanthams Peak vent. The grey squares T-1 and T-3 are the sample sites used by Alloway et al. (1994) to date the rhyolitic marker bed: the Stent Ash.</i>	27
Figure 2.3: <i>Stratigraphy of Lakes Umutekai and Rotokare. (a) Photograph of Lake Umutekai, looking SW towards Mt. Taranaki; (b) part of the D-section core from Lake Umutekai; (c) X-Ray radiograph of approximately the same stratigraphic depth; (d) stratigraphic profile of Lake Umutekai; and (e) tephrostratigraphic profile of Lake Rotokare (excluding mud-layers).</i>	28
Figure 2.4 <i>The southern hemisphere, calibrated radiocarbon curve (McCormic et al. 2004). The width of each curve is equal to errors of one standard deviation.</i>	31
Figure 2.5 <i>Calibration of radiocarbon date NZ23066 (years B.P.) to Calendar years (A.D.) years using OxCal v.3.10 (Brook-Ramsey 2005).....</i>	32
Figure 3.1: <i>Map of the Taranaki region showing the locations of the sample sites; Lake Umutekai and Lake Rotokare in relation to Mt. Taranaki's edifice. 300 m contours shown in grey with the >1500 m highlighted. (S) Summit vent, (F) Fanthams Peak vent, (P) Pouakai Volcano (extinct), (K) Kaitake Volcano (extinct). The grey squares T-1 and T-3 are the sample sites used by Alloway et al. (1994) to date the rhyolitic marker bed: the Stent Ash. The black square gives the location of Eltham Township and main river</i>	

	<i>channels which direct flows towards the lakes are shown in dark grey (see text). Insert: North Island, New Zealand.</i>	<i>43</i>
Figure 3.2:	<i>Depth-age curves. Dated events indicated by circles, imputed events by their estimated age ± 2 standard deviations.</i>	<i>48</i>
Figure 3.3:	<i>A magnified section of the depth-age curves from Umutekai (left) and Rotokare (right).</i>	<i>49</i>
Figure 3.4:	<i>Photomicrograph of titanomagnetite grains from distal fall deposits at Lake Umutekai, Mt. Taranaki. A: Homogeneous grain in reflective light. B and C: Exsolved grains in reflective light. D: Titanomagnetite microlite in transparent light. TM = titanomagnetite. The white scale bar is 25 μm in length.</i>	<i>54</i>
Figure 3.5:	<i>Geochemistry of the matches initially identified in Table 3.2. Data from Umutekai is labelled by the tephra number positioned above and to the right, Rotokare below and to the left. Titanomagnetites from the tephras preserved within the lake sediments were extracted and EMP analyses were carried out with a JEOL JXA-840 equipped with an energy dispersive spectrometer at the University of Auckland. Analytical conditions included an accelerating voltage of 15kV, a beam current of 600 pA and 100 seconds live time. A focused beam of 2 μm was used for each analysis.</i>	<i>58</i>
Figure 3.6:	<i>Geochemistry of the U7-R10 and U8-R11 matches. Data points are squares (U7), circles (U8), upward pointing triangles (R9), diamonds (R10) and downward pointing triangles (R11). Ellipses are labelled at their centre.</i>	<i>59</i>
Figure 3.7:	<i>Geochemistry of the U63-R42 match. Data points are squares (U60), circles (U61), stars (U63), upward pointing triangles (U64), diamonds (R40), downward pointing triangles (R41) and crosses (R42). Ellipses are labelled at their centre.</i>	<i>60</i>
Figure 3.8:	<i>Geochemistry of the U24-25 matches. Data points are squares (U24), circles (U25), stars (R22), upward-pointing triangles (R23), diamonds (R24), downward-pointing triangles (R25) and crosses (R26). Ellipses are labelled at their centre; the U24 ellipse includes the entire diagram.</i>	<i>60</i>
Figure 3.9:	<i>Dates of eruptions. Error bar is \pm twice the estimated standard deviation. The dashed lines indicate the potential data sources for the given age range.</i>	<i>61</i>
Figure 3.10:	<i>Histogram of 96,000 sampled inter-event times based on 1000 Monte Carlo runs. Curves show the fitted densities for this data set: Dotted line = exponential distribution, dashed line = Weibull, solid line = mixture of Weibulls, dot-dashed line = mixture of Weibulls from Turner et al. (2008a; Appendix 1).</i>	<i>63</i>

Figure 3.11:	<i>Annual eruption probabilities. Dotted line = exponential distribution, dashed = Weibull, solid = mixture of Weibulls, dot-dashed = mixture of Weibulls (Turner et al, 2008a; Appendix 1). Vertical line indicate present (AD 2008) hazard depending on the date of the last eruption.</i>	65
Figure 3.12:	<i>Correlation diagram of edifice stratigraphic sites identified in Chapter 2. Each site is correlated to the better-dated eruption records of Lakes Umutekai and Rotokare by canonical DFA on titanomagnetite compositions. The correlations are simplified and grouped into the temporally defined eruption of the magma batches as identified in Chapter 4.</i>	74
Figure 4.1:	<i>Photomicrographs in reflected light of sectioned and polished titanomagnetite grains from distal fall deposits at Lake Umutekai, Taranaki. (A and B) Exolved grains from a slow-ascent eruption; (C) Homogenous grain from a fast-ascent eruptive. The white scale-bar is 25 μm in length.</i>	85
Figure 4.2:	<i>X-ray photograph of the 1910–2210 mm section of the Lake Umutekai core (measured depth). Tephra (white layers) have contrasting density. Each unit is classified as being either slow(s)- or fast(f)-ascent eruption deposits by its proportions of glass (black bar) and non-exsolved titanomagnetite grains (grey bar). The grey star indicates the location of radiocarbon date NZ23085: 4354 \pm 40 yrs B.P..</i>	86
Figure 4.3:	<i>Plot of the radiocarbon age versus sediment depth (mm – less tephra) model for the Lake Umutekai core. Radiocarbon dated layers are indicated by stars and dotted lines. The highlighted area corresponds to Figure 4.2.</i>	87
Figure 4.4:	<i>Electron microprobe line-scan across an exsolved titanomagnetite grain (Jeol JXA840 electron microprobe of the Auckland University using a Princeton GammaTech Prism 2000 Si (Li) EDS X-ray detector and an accelerating voltage of 12.5 kV at 600 pA. A 2 μm focused beam and 10 second live-time count was used, with one analysis every 1 μm along the line). The grey horizontal line indicates the TiO_2 content of an unexsolved grain from the same deposit.</i>	89
Figure 4.5:	<i>Kernel smoother estimates for the overall annual eruption rate from Mt. Taranaki, split into the component rates for fast-ascent and slow-ascent eruptions. The bandwidth of the smoother was optimized at 485 yr using the Kullback-Leiber score (Marron 1985), and edge effects were dealt with by inverse weighting of the kernel density (Diggle 1985). The highlighted area corresponds to Figure 4.2.</i>	91
Figure 4.6:	<i>Location map of tephra deposition sites around Mount Taranaki used in this study. 300 m contours are in grey. S = Summit vent. F = Fanthams Peak vent.</i>	97

- Figure 4.7: *Kernel smoother estimates for a sample of the annual eruption rate from Mt. Taranaki, concentrating on fast ascent, sub-plinian eruptions from the combined datasets of Lake Umutekai and Maketawa eruption records. Modified after Turner et al. (2008b; Appendix 1). Open stars (summit-sourced) and circles (Fanthams Peak sourced) represent the best-estimated positions of the larger tephras (>0.6 km³ bulk rock) identified by Alloway et al. (1995). Filled stars and circles represent positions of largest tephras as identified from dated lake records and geochemically correlated to major units on the edifice. 99*
- Figure 4.8: *Plot of electron-microprobe derived Al₂O₃ vs. TiO₂ wt.% in titanomagnetite grains for the entire Holocene record of sub-plinian tephra eruptions from Mt. Taranaki. Each numbered and coloured set of points indicates individual batches of related compositions erupted from the summit vent, which are also temporally constrained (hence the apparent overlaps of some groups). The black dots indicate titanomagnetite derived from more primitive Fanthams Peak eruptions that overlap temporally with summit batches 0 and 1. 105*
- Figure 4.9: *SiO₂ and MgO variation diagrams for Taranaki eruptives. These data also cluster into defined “batches” labelled identically to those defined on the basis of titanomagnetite chemistry. 108*
- Figure 4.10: *Lower curve shows the rate of sub-plinian (pumice) eruptions (left Y-axis), including star (summit-sourced) and circle (Fanthams Peak sourced) symbols showing the timing of the largest-known eruptions (>0.6 km³ in bulk volume). Upper orange symbols represent the ranges of MgO concentrations in titanomagnetite crystals within erupted products. These are used to define the upper curve showing variations in the geochemistry (confident=solid line, tentative=dotted line). Individual magma batches, indicated from geochemistry are vertically shaded alternately white and grey. Periods of intense soil development (indicating quiescence) from on-volcano sites are indicated by vertical green shaded zones. 113*
- Figure 5.1: *Orthophotograph showing Mt. Taranaki and the distribution of the Curtis Ridge unit-1 eruptive. 50, 100 and 150 mm isopachs are shown. Spot thicknesses in mm. Localities mentioned in the text are labelled. 123*
- Figure 5.2: *Partial composite stratigraphic record of Holocene eruptions, eastern Mt. Taranaki. Modified from Neall and Alloway (1986). 125*
- Figure 5.3: *Optical micrographs of selected phenocrysts under cross-polarised light from CR units. The white scale bar is 0.5mm in a, b and c, and 100 µm in d, e, f, g, h and i. (a) Overview of CR unit-1 pumice clast (b) Overview of CR unit-1 dense-juvenile clast (c). Overview of CR unit-2 scoria clast. (d) Plagioclase with patchy textured core in CR unit-1 pumice. (e) Plagioclase with patchy textured core and rim in CR unit-1 pumice. (f) Plagioclase texture variability in CR unit-1 pumice. (g) Plagioclase phenocryst with patchy/sieve textured core*

	<i>in CR unit-2 basaltic scoria (h) Amphibole of CR unit-1 pumice. (i) Replaced amphibole in CR unit-1 dense-juvenile clast.</i>	126
Figure 5.4:	<i>Major oxide variations as a function of SiO₂ abundances for Taranaki eruptives. Samples are grouped by age.</i>	130
Figure 5.5:	<i>Compositional transects of selected plagioclase phenocrysts from the CR unit-1 pumice. Rim to core compositional profiles of two phenocrysts (a) and (b) were determined by EMP analyses. Black-diamonds represent 20 sec live-time EMP analyses every 2.5 μm along the white line. Grey squares represent 100 sec live-time EMP spot analyses of the locations shown as white spots. For (a) the compositions within the shaded area represent glass contamination.</i>	133
Figure 5.6:	<i>Compositional transect of an amphibole phenocryst from CR unit-1 pumice. EMP analyses with 20 second live-count times were collected every 4 μm along the white line. Grey squares indicate SiO₂ contents; black crosses are Al₂O₃ and Mg# are black diamonds. The grey dashed line on the photomicrograph highlights gradual diffuse zoning. The rim is apparent by a thick black zone in the photomicrograph.</i>	136
Figure 5.7:	<i>Compositional transects through selected clinopyroxene phenocrysts. (a) 20 sec live-count time EMP analyses every 2 μm from CR unit-1 pumice and (b) CR unit-2 scoria with analyses every 4 μm. Mg# are represented as black diamonds and Al₂O₃ contents as black crosses. Note scales are different between each graph. Grey bar in (b) refers to accidental analyses of glass/melt inclusion.</i>	138
Figure 5.8:	<i>Al and Ti contents of titanomagnetite microphenocrysts from CR units. Filled circles: analyses from CR unit-2 scoria. Crosses: analyses from CR unit-1 pumice. Compositions and Scanning Electron Microscope (SEM) backscatter micrographs of euhedral and resorbed grains are highlighted (discussed in text). Al and Ti pfu: normalised Al and Ti contents of titanomagnetites per unit formula (atoms per 24 cations, 36 oxygen formula unit). Inclusions of resorbed grain are apatite.</i>	140
Figure 5.9:	<i>Summary of phenocryst textures, their chemical characteristics and interpreted origins.</i>	144
Figure 5.10:	<i>Schematic diagram of andesite magma recharge. The recharging magma contains phenocrysts of amphibole, plagioclase, clinopyroxene and titanomagnetite that are resorbed due to decompression upon ascent (a). Rims of phenocrysts are crystallised under the magmatic environment of the upper storage area (b). Areas of the residing magma which are not affected by the recharging event are shown in (c).</i>	150
Figure 6.1:	<i>Plots of Dy/Yb vs. SiO₂ wt% for Mt. Taranaki Holocene tephtras showing trends relating to amphibole fractionation (c.f., Davidson et al. 2007). Raw data can be found in Appendix 6.</i>	164

Figure 6.2:	<i>Eruption rate curve (black line), with large eruptions from Mt. Taranaki summit (stars) and Fanthams Peak (circles) [see Chapter 4]. The orange/broken line above is the geochemical trend indicated by MgO content of titanomagnetite. The shaded, numbered stripes indicate time-frames of geochemically constrained magma batches [see Chapter 4]. Red vertical lines represent eruptions where late-stage magma recharge is indicated by bi-modal titanomagnetite compositions.....</i>	166
-------------	--	-----

List of Tables

	Page	
Table 3.1:	<i>Radiocarbon dates from lake sites used in this study.....</i>	44
Table 3.2:	<i>Radiocarbon dates of ‘near source events’ used in this study</i>	46
Table 3.3:	<i>Temporal distances between Umutekai (U) and Rotokare (R) tephtras. Tephtras in bold have geochemistry results available, and the Stent Ash (R27-U27) is highlighted. A distance that is the minimum in both row and column is in bold italics. Underlining indicates matches inconsistent with the geochemistry, and italics preferred alternatives. Parentheses indicate other potential alternative matches. See text for further details.....</i>	50
Table 3.4:	<i>Temporal distances between near-source (N) and lake (U + R) derived tephtras. A distance that is the minimum in both row and column is in bold. See text for further details.....</i>	52
Table 3.5:	<i>Representative titanomagnetite analyses. Sample numbers refers to the dataset used in this study (i.e. U05 = Umutekai lake samples). FeO^T = total Fe.....</i>	56
Table 3.6:	<i>Eruption coverage of each site (number of events). Numbers in parentheses indicate an alternative matching scenario of U22-U26 to R21-R25.....</i>	62
Table 3.7:	<i>Fitted mixture of Weibull distributions.</i>	64
Table 3.8:	<i>An example of D^2 statistics from canonical DFA: Rk samples from Lake Rotokare are compared to selected M05 samples of edifice location 2 (see Figure 2.1 and Appendix 4).</i>	72
Table 4.1:	<i>Largest known explosive pyroclastic eruptions ($>0.6 \text{ km}^3$) from Mt. Taranaki. The named tephtras and associated dates are described by Neall (1972). In addition, Mt. Taranaki tephtras identified within lakes of the Waikato district (Lowe 1988) are listed.....</i>	101
Table 4.2:	<i>Largest tephtras identified within the lacustrine record ($>1 \text{ cm}$ and mean grain size $>250 \mu\text{m}$) that are also correlated to major on-edifice units. See Turner (Chapter 3) for details of interpolated ages.....</i>	102

Table 4.3:	<i>Titanomagnetite analyses from each of the identified magma batches. Sample numbers refer to dataset used in this study. M=Maketawa. U=Umutekai. FeO and Fe₂O₃ recalculated (36 oxygens per 24 cations).</i>	107
Table 4.4	<i>Representative whole rock geochemical samples. Major and trace element concentrations were measured by X-ray fluorescence (Siemens SRS303AS spectrometer) using standard techniques on glass fusion discs prepared with SPECTRACHEM 12-22 (lithium tetraborate/lithium metaborate) flux following the method of Norrish and Hutton (1969). Major elements have one-sigma relative errors <1%, whereas trace elements have one-sigma relative errors of <1% for Sr and Zr, 1-3% for V, Cr, Cu, Zn, Ga and Y, 3-5% for Sc and Ni and 5-10% for Rb and Nb. In addition Cs, Ba, Pb, Th, U, Hf, Ta, and Rare Earth Elements (REE) were analysed by LA-ICP-MS at the Research School of Earth Sciences, Australian National University, using an Excimer LPX120 laser and Agilent 7500 series mass spectrometer. For this work the same fused glass discs as for XRF were used. Detection limits are <1 ppb and analytical errors <1% relative.</i>	109
Table 5.1:	<i>Selection of whole-rock major and trace element data for Taranaki eruptives.</i>	128
Table 5.2:	<i>Representative patchy/sieve textured plagioclase phenocryst analyses.</i>	132
Table 5.3:	<i>Representative compositions and structural formulae of amphibole phenocrysts.</i>	135
Table 5.4:	<i>Representative clinopyroxene phenocryst analyses.</i>	137
Table 5.5:	<i>Representative titanomagnetite analyses.</i>	139