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High-precision tephrostratigraphy: Tracking the time-varying eruption pulse of Mt. Taranaki, North Island, New Zealand

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

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Magret Damaschke

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Mt. Taranaki and the Ahukawakawa Swamp viewed from the Pouakai Tarns, North Island, New Zealand. (December 2014)
Abstract

In this research it was proposed that a more robust record of volcanic activity for Mt. Taranaki (New Zealand) could be derived from tephras (pyroclastic fall deposits) within cores from several lakes and peatlands across a 120° arc, NE-SE of the volcano, covering a range of prevailing down-wind directions. These data were integrated with previous tephrochronology studies to construct one of the longest and most complete volcanic eruption history records ever developed for an andesitic stratovolcano. Using 44 new radiocarbon dates, electron microprobe analysis of glass shard and titanomagnetite chemical composition, along with whole-rock chemistry, a chrono- and chemostratigraphy was established. The new record identifies at least 272 tephra-producing eruptions over the last 30 cal ka BP. Six chemo-stratigraphic groups were identified: A (0.5 – 3 cal ka BP), B (3 – 4 cal ka BP), C (4 – 9.5 cal ka BP), D (9.5 – 14 cal ka BP), E (14 – 17.5 cal ka BP), and F (23.5 – 30 cal ka BP). These were used to resolve previous stratigraphic uncertainties at upper-flank (proximal) and ring-plain (medial) sites. Several well-known “marker tephras” are now recognized as being ~2000 years older than previously determined (e.g., Waipuku, Tariki, and Mangatoki Tephra units) with the prominent Korito Tephra stratigraphically positioned above the Taupo-derived Stent Tephra. Further, new markers were identified, including the Kokowai Tephra unit (~4.7 cal ka BP), at a beach-cliff exposure, 40-km north-east of the volcano. Once age-models were established for each tephra, units were matched between sites using statistical methods. Initial statistical integration showed that the immediate past high-resolution tephrochronological record suffered from a distinctive “old-carbon” effect on its ages (Lake Rotokare). This had biased the most recent probabilistic forecasting and generated artificially high probability estimates (52-59% eruption chance over the next 50 years). Once the Rotokare record was excluded and chemostratigraphy constraints were applied, a reliable multi-site tephra record could be built only for the last ~14 ka BP. The new data confirms a highly skewed distribution of mainly (98% of cases) short intervals between eruptions (mode of ~9 years and average interval ~65 years). Long intervals (up to 580 years) as seen in earlier records were reduced to 2% of the record, but can now be considered real, rather than missing data.
The new data confirm a cyclic pattern of varying eruption frequency (with a five-fold range in annual frequency) on a period of ~1000-1500 years. The new time-varying frequency estimates suggest a lower probability for a new eruption at Mt. Taranaki over the next 50 years of 33-42%. The newly established chemostratigraphy was further used to investigate time-related compositional changes. Whole-lapilli analyses highlighted that a specific very evolved Ca-rich and Fe-poor composition was only found within the easterly and south-easterly depositional sites. This was explained by eruption of a stratified magma reservoir, which holds greater modal proportions of plagioclase and lower proportions of pyroxene within low-density, gas-rich upper conduit regions. During the most explosive phases of eruptions, when plumes reach the stratospheric jet-stream, the lowest-density pumice is thus dispersed by high-level stable westerly winds. Further, two distinct evolutional trends were seen in the long and new tephrochronological record; from 17.5 to 3 cal ka BP and <3 cal ka BP; with whole-lapilli, glass, and titanomagnetite compositions overall evolving over time. The former compositional trend indicates a crystallising and cooling magma source in the deep crust, with multiple, spatially separated magma source regions forming, each generating magmas (i.e., magma batches) with unique titanomagnetite compositions. This trend is interrupted by a distinct shift towards less-evolved compositions and the initiation of a second parasitic vent (Fanthams Peak at the southern flank of Mt. Taranaki).
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Figure 4.2 Compositions of titanomagnetite phenocrysts from flank and ring-plain tephra deposits analysed in the current study. Each point is the average ±1 standard deviation for each tephra unit. Each dotted field (numbered from 1-12) and colour represent an individual titanomagnetite group defined by Damaschke et al. (2017) and summarised in Table 4.3. Bi- and multi-modal titanomagnetite compositions are indicated by additional letters “-b” and “-c” after the sample name. *E1-Konini and Mahoe (Franks et al., 1991) = Kaponga and Konini (Alloway et al., 1995) (refer to text. Analyses in weight percent (wt%) and cation proportion (cat. prop.) calculated on the basis of four oxygen atoms as in Carmichael (1966). All data summarized in Appendix 5.

Figure 4.3 Glass chemistry of the flank and ring-plain tephra deposits analysed in the current study. Normalised analyses are plotted as total alkalis, FeO$_{total}$, and CaO vs. silica. The compositional fields (after Le Bas et al., 1986) of basalt-andesite (bA), basalt-trachyandesite (bTA), trachyandesite (TA), trachydacite (TD) and rhyolite (R) are also shown. Each point is the average ±1 standard deviation for each tephra unit. Colours represent the titanomagnetite composition of each sample (refer to Fig. 4.3, Table 4.3). *E1-Konini and Mahoe (Franks et al., 1991) = Kaponga and Konini (Alloway et al., 1995) (refer to text). All data summarized in Appendix 6.

Figure 4.4 Electron microprobe-determined titanomagnetite composition of the Manganui tephra units (MA-MF) and single Manganui tephra unit (M) from the Mangatoki Stream section shown as compositional fields and correlative lake and peat tephra layers shown as average points with ±1 standard deviation. Note the large compositional variability of Manganui D.
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Figure 4.6 Representation of the links between lake and peat tephra sequences, and proximal and medial tephra successions on Mt. Taranaki. Each coloured line in the lake and peat column and coloured names in the medial and proximal column indicate the titanomagnetite composition (i.e., group) of the respective tephra deposit (refer to Fig. 4.3, Table 4.3). Asterisks indicate bi- or multimodal titanomagnetite compositions. The coloured bands that link the columns indicate Tephra Sequences (TS A-F) characterised by their dominant titanomagnetite group. Dotted lines highlight specific correlations (refer to text). Age references are according to Table 4.1 and ages for the lake-and-peat composite record after Damaschke et al. (2017). Note the previous stratigraphy of Alloway et al. (1995) at the Onaero Beach section (grey-coloured names), which has been revised in the current study. ........................................................................................................ 157

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**Figure 5.4** Annual tephra deposition rates of each single record in comparison with the statistically-combined record. Rates are generated using a Gaussian kernel smoother (Silverman 1984, 1986; Wand and Jones 1994) with a 100-year bandwidth. Note the offset of the Lake Rotokare events.

**Figure 5.5** Histogram of 19,900 sampled inter-event times based on Monte Carlo simulations of the new statistically-merged Mt. Taranaki eruption record. Curves show the different densities fitted for this data set with AD1785 (red) and AD1820 (blue) as last volcanic activity events.

**Figure 5.6** (A) Probabilities of no eruption of Mt. Taranaki occurring over future time periods, based on three models of inter-event distributions with AD1785 (red) and AD1820 (blue) as last volcanic activity events. (B) Annual eruption probabilities estimated for Mt. Taranaki, assuming the last volcanic activity event was at AD1785 (red) and AD1820 (blue). Note: The Weibull renewal distribution is similar to a simple Poisson process.
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**Figure 6.1** Total Alkalis vs. Silica (TAS) diagram (Le Bas et al., 1986) for the Mt. Taranaki whole-lapilli samples analysed from lake and peatland tephras recovered in this study (Appendix 7). Compositional fields are basalt (B), basalt-andesite (bA), andesite (A), trachybasalt (TB), basalt-trachyandesite (bTA), and trachyandesite (TA). All analyses are on a water-free basis. Colours represent the titanomagnetite group of each tephra sample (refer also to Fig. 6.8 and Chapter 3). Dotted line represents the alkaline/subalkaline compositional boundary. .................................................................................................................. 216

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Figure 6.6 Minor and trace element titanomagnetite variation as function of Mg abundances (latter is based on microprobe data) for Mt. Taranaki lake and peatland tephra layers. All analyses are in parts per million (ppm) with Mg as cation proportion (cat. prop.) calculated on the basis of four oxygen atoms as in Carmichael (1966). Colours represent different tephra sequences and their respective dominant titanomagnetite group (see Chapter 3).

Figure 6.7 Time-series glass (gl) and whole-lapilli (wl) compositional trends observed within distal and proximal tephra deposits of Mt. Taranaki. Bulk-analyses of young lava flows, including the Summit and Fanthams Peak lavas (Stewart et al., 1996; Price et al., 1999), are also shown so as to complete the youngest time-frame of emplacement. All analyses are on a water-free basis with total iron as Fe$_2$O$_3$ in bk, and FeO in gl. Each point is the average ±1 standard deviation for each tephra layer within the gl. Note:
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Figure 6.8 Time-series titanomagnetite compositional trends observed within distal and proximal tephra deposits of Mt. Taranaki. All analyses are weight percent and cation proportion (cat. prop.) is calculated on the basis of four oxygen atoms as in Carmichael (1966). Each tephra (each point = average +1 standard deviation) is indicated by its respective tm-group (see colour). Only tephras from the composite record are shown (Chapter 3 and 4). Triangles represent tephras with bimodal compositions. (sub-population is indicated by ellipsoid; referred to in text). Note: Tephra Sequence F is stratigraphically separated from the rest of the tephra sequences by a ~6000 cal yr BP depositional hiatus (for more information see Chapter 3).

Figure 6.9 Major element glass (gl) vs. titanomagnetite (tm) abundances, and MgO whole-lapilli (wl) vs. MgO titanomagnetite (tm) abundances for Mt. Taranaki tephras. Diamonds represent lake and peat tephras (Damaschke et al., 2017a) and circles represent proximal tephra deposits (Damaschke et al., 2017b).