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New Zealand

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Mt. Ruapehu is Te Whare Toka o Paerangi (The House of Stone of Paerangi, Ngāti Rangi ancestor), Matua te Mana (The Powerful One; "Mana" means prestige and enduring, spiritual power) in Ngāti Rangi maori culture. The Waikato-iti stream, in the Rangipō Desert, is Te Onetapu (sacred place) where Ngāti Rangi people rise their "karakia" to the volcano, their ancestor.

Dedicated to the Ngāti Rangi Iwi on behalf of all the indigenous communities living around active volcanoes in the world, who constantly teach us about the unfolding of life, the dynamic interdependence between people and the environment, and how to integrate all sources of knowledge to consciously and truly build sustainable communities

## He Ruruku: Mai ara rā!

Mai ara rā! Mai ara rā! Mai ara rā te Tupua! Mai ara rā te Tawhito!

Tēnei au Tēnei au te rangahau ana, ki te ao, ki te pō Kia Ranginui e tū iho nei, Kia Papatuānuku e takoto ake nei.

Mai ara rā, mai whea ra tōku ahunga mai? Tāhuri whakataumaha, huri whakamāmā E te Kāhui Maunga ko wai ra koe?

Inā, Matua Te Mana te aunahi pīataata mātahi Pikimai Rawea te kai-kukume ake matua whenua rō wai

Te rongo nei ia hīhī, Te rongo nei ia hāhā me huka tātairango. Tina, tina toko te manawa ora, he manawa ora!

Ko te Roi-a-Rangi mo Rua-te-Tipua Ko te Roi-a-Rangi nō Nukuhau e Te pātukituki ka tū whakahirahira Kāhui Maunga mā.

Ko toka pokohiwi ka hora maru tapu, e Ngā Turi-o-Murimotu Te ahi kā o Paerangi i te Whare Toka Te puta mai te Kāhui-o-Rangi, te Kāhui-a-Rua Tōna hekenga mai i Te Wai-ā-Moe ki Paretetaitonga Ko te ara hekenga, ko te ara hokinga mo ngā uri kōtuku Ka tuku, ka tuku atu i ngā hau kaha ia Parakakariki, ia Mouwhakaarahia

> Hei tohu, hei whakaatu ki te ao! Whiti, whano, hara mai te toki! Haumia! Hui e! Taiki e!<sup>1</sup>

<sup>&</sup>lt;sup>1</sup> Karakia (i.e. prayer) offered by Ngati Rangi Iwi to Mt. Ruapehu, their ancestor. Provided by Che Wilson, Ohakune 2011, Aotearoa.

### ABSTRACT

A new detailed stratigraphy was developed for a sequence of pyroclastic deposits including the largest known eruptions associated with Mt. Ruapehu, deposited in the period ~27-10 ka BP cal. From the largest Plinian eruption deposits in this sequence, subtle lithofacies variations within componentry, pumice textures and sedimentary features were used to identify a systematic change in eruptive conditions over time. Early eruptions involved steady eruption columns, while younger eruptions involved unsteady, collapsing columns. Isopach and Isopleth (pumice and lithic) mapping of most widespread and distinctive units show that the largest explosive eruptions known from this volcano attained peak column heights between 22 and 37 km, with mass discharge rates reaching  $10^7$ - $10^8$  kg/s.

To characterise the conditions controlling the style of Plinian eruptions at this andesitic volcano, and to explain the systematic variation in column stability over time, five key units were sampled in detail, exemplifying the major contrasting lithofacies. The sampled tephras underwent grain-size analysis, along with quantification of componentry, porosimetry and density on particles of a range of size classes, as well as 2D and 3D microtextural analyses of juvenile pumice clasts to define vesicularity and crystallinity. In addition, physiochemical factors such as melt-evolution and volatile-contents were determined by analysing bulk pumice, glass-inclusions and residual glasses with electron microprobe and FTIR-spectroscopy.

Bulk compositions of these tephras vary from basaltic-andesite to andesite (56-62 wt.%,  $SiO_2$ ), and had minimum pre-eruptive H<sub>2</sub>O contents of 4-5 wt.%. The evolution of eruption behaviour over time was not correlated to any progressive change in bulk geochemical properties, but instead resulted from variations in physical processes within the conduit. Ascending magmas experienced heterogeneous bubble nucleation, and later-erupted units showed increasing degrees of rheological heterogeneities developed across the conduit. Differences between units were due to changes in the magma decompression rates, the degree of bubble-crystal-melt interactions and bubble shearing, as well as the composition of the residual melt. Conditions that led to the most variable physical states of the magma reaching the fragmentation level resulted in the highest variability in pumice textures, the greatest range in styles of fragmentation, and the most unstable eruption columns.

A new model describing the pre-eruptive magma storage region, conduit processes, magma fragmentation, and pyroclastic dispersal during Plinian eruptions at Mt. Ruapehu is proposed. This hypothesises that eruption column unsteadiness and collapse occurs when magma shear reaches extreme levels along the conduit under conditions of low isolated porosity (<3 vol.%). This situation also generates the worst-case hazard scenarios expected for Ruapehu, eruptions, where Plinian columns of over 30 km may produce widespread tephra fall, as well as partially collapse to generate pyroclastic density currents of over 15 km runout.

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Karakia	iii
Abstract	iv
Acknowledgements	vi
Table of contents	viii
List of abbreviations used in this study	xxv
CHAPTER 1. Introduction	1
1.1 Research questions and motivation	1
1.2 Literature review	
1.2.1 Subplinian and Plinian eruptions	
Magma Ascent and Fragmentation5Plinian and subplinian eruptive plumes and resulting deposits10On the resulting pyroclasts13Documented cases16Experiments and numerical models17	i
1.2.2 The Tongariro Volcanic Centre	
CHAPTER 2. Methodology	
2.1 Fieldwork and physical parameters	
2.2 Laboratory	
2.2.1 Grain-size analysis	
2.2.2 Componentry	27
2.2.3 Gas-Pycnometry: pumice density and porosity	
Bulk density29Skeletal and solid Density30Porosity31	<b>)</b>
2.2.4 Pyroclast 2D-microtextures and ash morphology	
2.2.5 Pyroclast 3D-Micro-textural analysis	
High resolution X-ray and computed micro-tomography34Image visualization and processing36	1 5
2.2.6 Dissolved volatiles	
Fourier Transform IR-spectroscopy (FTIR)	}

# Table of Contents

2.2.7 Geochemistry
Electron microprobe (EMPA)40X-ray fluorescence spectrometry (XRF)41
Laser Ablation Inductively Coupled Mass Spectrometry (LA-ICP-MS)
CHAPTER 3. Tephrostratigraphy of the Bullot Formation and characterisation of the largest explosive eruptions of Mt. Ruapehu
3.1 Introduction
3.2 Reconstructing the largest explosive eruptions of Mt. Ruapehu, New Zealand: lithostratigraphic tools to understand subplinian-Plinian eruptions at andesitic volcanoes 46
3.2.1 Abstract
3.2.2 Introduction
3.2.3 Geological Setting
3.2.4 The largest explosive eruptions recorded at Mt. Ruapehu
Hokey Pokey Eruptive Unit (HP)52Rangipo Eruptive Period54Tukino Eruptive Period62Karioi Eruptive Period64Ohinewairua Eruptive Period66Taurewa Eruptive Period69
3.2.5 Physical volcanology implications: towards a classification of subplinian- Plinian eruptions at Mt. Ruapehu
From lithofacies to eruptive dynamics
3.2.7 Conclusions
CHAPTER 4. Physical Volcanology
4.1 Introduction
4.2 Andesitic Plinian eruptions at Mt. Ruapehu: Quantifying the uppermost limits of eruptive parameters
4.2.1 Abstract
4.2.2 Introduction
4.2.3 Mt. Ruapehu Plinian eruption lithofacies associations
4.2.4 Ash morphology 10.
4.2.5 Eruptive parameters
Eruptive volumes

Isopleths and classification of the eruptions
4.2.6 Discussion
4.3.7 Conclusions 117
5. Steady Vs. Unsteady Plinian Eruptive Columns: magma composition, fragmentation, and pyroclastic deposition11
5.1 Introduction
5.2 Results: Contrasting Plinian behaviour at Mt. Ruapehu
5.2.1 Non-collapsing oscillatory columns of intermediate height (20-25km). The
Mangatoetoenui eruptive unit
Lithofacies (pumice textures, componentry, and ash morphology)
5.2.2 Steady and sustained, high (> 29km) columns: Shawcroft Eruptive Unit
Lithofacies (pumice textures, componentry, and ash morphology)
5.2.3 Unsteady and collapsing, high (> 30km) columns: Orumatua Eruptive Unit 14
Lithofacies (pumice textures, componentry, and ash morphology)
5.2.4 Unsteady, collapsing columns of intermediate height (<25 km): Okupata-Poruahu eruptive unit
Lithofacies (pumice textures, componentry, and ash morphology)
5.3 Conclusions
CHAPTER 6. Magma degassing and conduit dynamics
5.1 Introduction
5.2 Results 175
6. 2.1 The Mangatoetoenui unit pumice textures 175
Density and Porosity1753d-Textures176Volatile content obtained in melt inclusions183Interpretation185

6. 2.2 The Shawcroft unit pumice textures		5
Density and Porosity	186	
3d-Textures	194	
Volatile content obtained in melt inclusions Interpretation	191 192	
6. 2.3 The Oruamatua unit pumice textures	194	4
Density and Porosity	194	
3d-Textures	194	
Interpretation	198	
6. 2.4 The Okupata tephras pumice textures		0
Density and Porosity	200	
3d-Textures	202	
Volatile content obtained in melt inclusions	206	
Interpretation	. 207	
6.3 Glass composition and closure pressures		9
6.4 Discussion		)
6.4.1 Bubble nucleation mechanisms		0
6.4.2 Degassing processes in contrasting Plinian eruptions		2
6.4.3 Implications for column stability		3
6.5 Conclusions		5
CHAPTER 7. Discussion: An integrated model for the most violent explosive er expected at Mt. Ruapehu	uptions 	8
7.1 Introduction		8
7.2 Magma storage system		9
7.2.1 Whole-rock Geochemistry		¢
7.2.2 Groundmass glass and glass inclusions		)
7.2.3 Storage and magma supply model for Ruapehu Plinian eruptions		3
7.3 Conduit dynamics during Ruapehu Plinian eruptions		ŀ
7.3.1 Vesiculation and crystallisation processes		5
7.3.2 Magma fragmentation and eruptive mechanisms		7

Ash production and fragmentation
7.4 Implications on eruptive column height, stability, and pyroclast dispersal 241
7.5 Summary
7.6 Hazard Implications
CHAPTER 8. Conclusions: a new understanding of Mt. Ruapehu Plinian eruptions
8.1 Summary
8.2 Specific findings of this study 254
8.2.1 Identification of a systematic change in the dominant lithofacies association, Plinian style, vent location, and eruptive column behaviour over time of Deposition of the Bullot Formation
8.2.2 Clarification of the source of the Pahoka Tephra
8.2.3 (Re)Definition of the largest Plinian eruption of Mt. Ruapehu
8.2.4 Metrics of the largest Ruapehu Plinian eruptions
8.2.5 Tephra distribution patterns of Plinian eruptions at Mt. Ruapehu
8.2.6 Relationships between chemical and eruption variability of Mt. Ruapehu Plinian eruptions
8.2.7 Evolution of the eruptive/magmatic system at Mt. Ruapehu 256
8.2.8 Glass transition and fragmentation style changes
8.2.9 Controls on eruption column height and steadiness
8.3 Concluding statement and future research questions

# APPENDICES

APPE	NDICES
A.	Studied locations
	A.1 Locations maps and overview
	A.2 Coordinates
	A.3 Sratigraphic profiles
	A.4 Stratigraphic correlation
	A.5 Thickness data
B. Erup	otive parameters
_	B.1 Isopach data
	B.2 Isopleth data

B.3 Eruptive volumes and column heights (.xls files): comparative methods

#### C. Grain-size

C.1 Data

- C.2 Statistics (KWare SFT; K. Wohletz 2007 version) results (.pdf files)
- D. Optical microscopy
  - D.1 The Mangatoetoenui unit
  - D.2 The Shawcroft unit
  - D.3 The Oruamatua unit
  - D.4 The Okupata-Poruahu unit

#### E. Componentry

- E.1 The Mangatoetoenui unit
- E.2 The Shawcroft unit
- E.3 The Oruamatua unit
- E.4 The Okupata-Poruahu unit
- E.5 SEM images of ash particles  $\leq 3 \phi$

#### F. Geochemistry

- F.1 Whole-rock analyses
  - F.1.1 Legend
  - F.1.2 XRF data
  - F.1.3 LA-ICP-MS
    - F.1.4 Filtered data and variation diagrams
- F.2 Groundmass glass data
- F.3 Glass inclusions
- F.4 Mineral data
- F.5 Norm CIPW calculated with K. Hollocher norm 4 (free online software)

#### G. Porosity

- G.1 Porosity results for individual eruptive units
- G.2 Bulk and envelope volumes and solid density data

#### H. X-ray Microtomography

- H.1 High resolution X-Ray microtomography
  - H.1.1 Beamline 8.3.2 at Lawrence Berkeley National Laboratory
  - H.1.3 Sample preparation
  - H.1.4 Beam setup at Lawrence Berkeley National Laboratory (guide)
  - H.1.5 References
- H.2 Examples of individual steps during Image processing
- H.3 3D Textural quantification of pumice clasts (.xls files)
  - H.3.1 The Mangatoetoenui unit
  - H.3.2 The Shawcroft unit
  - H.3.3 The Oruamatua unit
  - H.3.4 The Okupata-Poruahu unit
  - H.3.5 Summary table
- H.4 Videos
  - H.4.1 The Mangatoetoenui unit
  - H.4.2 The Shawcroft unit
  - H.4.3 The Oruamatua unit
  - H.4.4 The Okupata-Poruahu unit

#### I. FTIR

I.1 Samples

I.2 Results

- I.2.1 Spectra (.SPA files readable with Thermo-Nicolet Omnic software)
- I.2.2 Results and calculations

I.3 Inclusions geochemical data I.4 Summary table

#### J. PUBLICATIONS (available at <u>www.springerlink.com</u>)

J.1 Pardo N, Cronin SJ, Palmer AS, Németh K (2012a) Reconstructing the largest explosive eruptions of Mt. Ruapehu, New Zealand: lithostratigraphic tools to understand subplinian–plinian eruptions at andesitic volcanoes. Bull Volcanol 74: 617-640. DOI 10.1007/s00445-011-0555-z

J.2 Pardo N, Cronin SJ, Palmer A, Procter J, Smith I (2012b) Andesitic Plinian eruptions at Mt. Ruapehu: quantifying the uppermost limits of eruptive parameters. Bull Volcanol (in press) DOI 10.1007/s00445-012-0588-y

#### List of figures

**Figure 3.8 a)** Fall deposits of units XIII to XIX as exposed at medial distances. Interbedded fluvial deposits lateral facies variation is evident, with thicker sequences filling paleochannels; **b)** Zoom of the lithic-rich unit XVII; **c)** Zoom of the lithic-poor Upper XVIII unit; **d-e)** Stratigraphic correlation from unit XVII to XIX ..... 59

**Figure 3.11** Deposits signalling the beginning of the Tukino Eruptive Period: a) Zoom in eruptive unit XIX. b and c show the overlying units XX and XXI, with the distinctive dark grey, dilute lahar depositional facies ... 63

Figure	5.7	Relative	proportions	of	the	different	glass	morphology	normalized	over	total	glass	content	as
vol.%													1	128

Figure 5.16 a) Main pumice textures identified within the Shawcroft eruptive unit, as seen under binocular microscope; b) Foamy, highly vesicular particles with subspherical vesicles; c) Expanded; d) Fluidal; e) Fluidal glass with ellipsoidal vesicles having thick walls and smooth surfaces; f) Pelée's tear; g) Poorly vesicular glass; h) Poorly vesicular clast with flattened altered, mossy-like surface; i) Blocky shaped, poorly to non vesicular

**Figure 5.23** Total alkalis vs. silica (TAS) diagram (Le Bas et al., 1986) showing the bulk and glass composition of juvenile pumice clasts within the Oru unit as well as the glass inclusions in pyroxene crystals. Note that the

**Figure 5.29** Total alkalis vs. silica (TAS) diagram (Le Bas et al., 1986) showing the bulk and glass composition of juvenile pumice clasts within the Okp unit. Note the large compositional span within the same unit, and the high glass groundmass silica content consistent with more crystal-rich textures relative to previous eruptive units. Data are consistent with previous published analyses (Donoghue 1991; Donoghue et al., 1995a)...... 166

**Figure 6.2** Reconstructed X-ray images as orthoslices and rendered subvolumes of three lapilli samples from the Mgt unit: **a-e**) Shows crystal-poor, foamy lapilli with subspherical vesicles having thin walls; **f-i**) Shows crystal-bearing, fluidal texture with elongated vesicles having thicker walls. White arrows in H point out glass shards included within a vesicle. Dashed arrows in (**i**) show a region of internal heterogeneity in the sample; **j**-

**Figure 6.9** Porosity and density frequency distributions within the Oruamatua eruptive unit. The individual parameters were obtained from measurements of: **a**) Bulk sample volume and envelop density; **b**) Connected + Isolated porosities relative to the bulk sample volume; **c**) Skeletal density; **d**) Solid density determined in crushed samples; **e**) Comparative plots of individual parameters against bulk porosity. Black histograms are for all analyses (n=99), while others show the individual analyses from the different stratigraphic positions...... 195

**Figure 6.14** Reconstructed X-ray images of: **a-d**) microvesicular-dense clasts within the L-Okp ( $\mu$ CT scan 1 pixel = 4.2  $\mu$ m); **e-h**) dense, coarsely porphyritic clasts within the U-Okp ( $\mu$ CT scan 1 pixel = 4.0  $\mu$ m). Note the typical micro-jig-saw structures in crystals (arrow in **g**) and irregular voids with sharp edges surrounding feldspars (**g**). **i-n**) Microfibrous (**d**): synchrotron: 1 pixel = 1.8 $\mu$ m; e:  $\mu$ CT scan: 1 pixel = 2.0  $\mu$ m), coarsely porphyritic textures within the U-Okp, where vesicles have thin walls, commonly wrinkled (w); note the thin

**Figure 7.7** Schematic diagram proposed by Price et al., (2005) showing Mt. Ruapehu magmatic system. This system includes: 1) underplating basaltic magmas heating the lower crust; 2) fractionation of lower-crust magmas and interaction between them and mantle-derived magmas; 3) The generation of smaller and dispersed storage systems throughout the crust, subject to fractionation and crustal assimilation, mixing and mingling

#### List of tables

 Table 2.1 Macrotextural classification of pumice rocks collected from Mt. Ruapehu, Late Pleistocene, Plinian

 eruptions.
 29

**Table 3.2** Synthesis of the general characteristics of the different lapilli and ash fall beds found in the studied stratigraphic record. Numbers correspond to the total of individual beds of that particular type found in the record

 78

**Table 5.1** Statistical results of grain-size analyses carried on for each eruptive unit at localities B50 and B14 (9-10 km from the vent; **Appendix A**). L/U-Mgt: Lower/Upper Mangatoetoenui; Sw: Shawcroft; Oru: Oruamatua;L/U-Okp: Lower/Upper Okupata Tephra; Ph: Pourahu121

 Table 6.5 Summary of microprobe and micro-FTIR analyses on glass inclusions for the Oruamatua eruptive unit. Chemical data are given in wt.%
 198

 Table 7.1 Whole-rock, major (XRF) and trace element (LA-ICP-MS) data for the Mangatoetoenui Eruptive Unit pumice clasts
 221

 Table 7.2 Whole-rock, major (XRF) and trace element (LA-ICP-MS) data for the Shawcroft Eruptive Unit pumice clasts
 222

 Table 7.4 Whole-rock, major (XRF) and trace element (LA-ICP-MS) data for the Lower and Upper Okupata pumice clasts
 224

## List of abbreviations

Graphic standard deviation

Inclusive standard deviation

Inclusive graphic asymmetry

Graphic asymmetry

Mass Spectrometry

Mean

Kurtosis

 $\sigma_{\!G}$ S<sub>Kg</sub> Mz

 $\sigma_{\!i}$ 

 $\mathbf{S}_{ki}$  $\mathbf{K}_{\mathrm{g}}$ 

Abbreviation	Meaning						
Locations and Stratigraphic Units							
Fm.	Formation						
TVZ	Taupo Volcanic Zone						
TgVC	Tongariro Volcanic Centre						
CL	Crater Lake	Density and p	orosity parameters				
Rhyolitic tephro	as (Okatania Caldera):	$\delta_{\text{bulk}}$	Bulk density [g·cm <sup>-3</sup> ]				
Ok	Okareka Tephra	$\delta_{\rm skel}$	Skeletal density [g·cm <sup>-3</sup> ]				
Rw	Rerewhakaaitu Tephra	$\delta_{\rm sol}$	Solid density [g·cm <sup>-3</sup> ]				
Wh	Waiohau tephra	$\phi_{\rm bulk}$	Bulk porosity [vol.%]				
Mt. Ruapehu ar	adesitic tephras:	$\phi_{\rm conn}$	Connected porosity [vol.%]				
HP	Hokey Pokey Eruptive Unit	$\phi_{iso}$	Isolated porosity [vol.%]				
Mgt	Mangatoetoenui Eruptive Unit	Textural para	meters				
Sw	Shawcroft Eruptive Unit	N <sub>v</sub>	Vesicle number density [cm <sup>-3</sup> ]				
Oru	Oruamatua Eruptive Unit	nv	vesicle number density per size class [cm <sup>-3</sup> ]				
Ak	Akurangi Eruptive Unit	N <sub>x</sub>	Mafic crystals number density [cm <sup>-3</sup> ]				
Okp-Ph	Okupata-Pourahu Eruptive Unit	vvD	Vesicle volume distribution				
L-	Lower	CVVD	Cumulative vesicle volume distribution				
M-	Middle	VSD	Vesicle size distribution				
U-	Upper	CVSD	Cumulative vesicle size distribution				
Mt. Tongariro a	indesitic tephras:	CVD	Mafic crystals volume distribution				
Pk	Pahoka Tephra	CCVD	Mafic crystals Cumulative volume distribution				
Rt	Rotoaira lapilli	CSD	Mafic crystals size distribution				
LA	Lithofacies Association	CCSD	Mafic crystals Cumulative size distribution				
		Mt	Magnetite				
PDC	Pyroclastic density current	Pl	Plagioclase				
cal yr BP	Calibrated years before present	Px	Pyroxene				
ka BP cal.	kilo-annum before present (calibrated)	Cpx	Clinopyroxene				
Eruption param	neters	Opx	Orthopyroxene				
V	Tephra volume [km <sup>3</sup> ]	Mt	Magnetite				
Vp	Proximal tephra volume [km <sup>3</sup> ]	Ox	Oxides				
Vt	Total tephra volume [km <sup>3</sup> ]	Gx	Glomerocryst				
Т	Deposit thickness [cm]	Others					
T <sub>0</sub>	Extrapolated thickness at the vent [cm]	ε	Molar absorptivity coefficient [Liters/(mol x cm <sup>-2</sup> )]				
А	Area [km <sup>2</sup> ]	LOI	Water from loss on ignition				
A <sub>ip</sub>	Break-in-slope distance [km]	$\Delta P$	Decompression rate				
k	slope	$\Delta P_{SS}$	Supersaturation pressure				
H <sub>b</sub>	Eruption column neutral buoyancy level [km]	Pc	Closure pressure				
H <sub>t</sub>	Eruption column total height [km]	GT	Growth rate in a given timescale				
b <sub>c</sub>	Clast half-distance	n <sub>o</sub>	Number of initial nuclei				
b <sub>t</sub>	Thickness half-distance	L	Dominant diameter				
D	Fragmentation Index of Walker (1973)	Ves	Vesicle				
0	Volume discharge rate $[m^3/s]$	Qz-Ab-Or	Ouartz-Albite-Orthoclase				
MDR	Mass discharge rate [kg/s]	-					
М	Eruption magnitude						
Sh	Shape factor						
Grain-size para	imeters						
М	Mode						
Md	Median						

Techniques and	l equipment	Institutions	
SEM	Scaning Electron Microscope	LBNL	Lawrence Berkeley National
BSE	Back-scatter electron image		Laboratory at Berkeley (CA, USA)
μ-CT	X-ray microtomography	ISTO	Institut des Sciences de la Terre d'Orléans
FTIR	Fourier Transform infra-red		l'Université d'Orléans (France)
EMPA	Electron Microprobe		
XRF	X-ray fluorescence spectrometry		
LA-ICP-MS	Laser Ablation Inductively Coupled		