Towards Improving Volcanic Mass Flow Hazard Assessment at New Zealand Stratovolcanoes

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

Doctor of Philosophy

In

Earth Science

Massey University, Palmerston North, New Zealand.

Massey University

Jonathan N. Procter

2009

Abstract

The most common hazards for communities surrounding mountain-forming stratovolcanoes are mass flows of a range of types. Determining their frequency, characteristics and distribution is a major focus of hazard mapping efforts. Recent improvements in computer power and numerical models have meant that simulation of mass flow scenarios is a new tool available for hazard analysis. Its application to hazard mapping, land use planning and emergency management awaits robust evaluation of the conditions under which simulation tools are effective. This study focuses on this question in attempting to improve mass-flow hazard assessments at the typical stratovolcanoes of Mts. Taranaki and Ruapehu in New Zealand. On Mt. Ruapehu, Titan2D modelling was applied to forecast behaviour of non-cohesive lahars in the Whangaehu River, primarily produced by Crater Lake break-outs, such as on 18 March 2007. The simulations were accurate in predicting inundation area, bifurcation, super-elevation, hydraulic ponding, velocity and travel times of the lahar to 9-10 km. A 6×10^6 m^3 simulated granular flow had a minimum discharge of 1800-2100 m^3/s at the apex of the Whangaehu Fan, 9-10 km from source, comparable to all historic information. The modelling implied that it was highly unlikely for a flow of this nature to overtop a lahar training dyke (bund) at the fan-apex location and avulse northward into a more vulnerable catchment. Beyond this point, the model could not cope with the rapid and complex changes in rheology of these non-cohesive lahars. At Mt. Taranaki chronostratigraphic grouping of mapped past lahar deposits often clouds the actual series of landscape forming processes and hence variations in hazard that occurred over time. Here, patterns of mass flows following emplacement of a 7 km^3 debris avalanche deposit were examined from field geology and Titan2D modelling to define a three-stage recovery process, where lahars of different types and sources were focused initially beside and later on top of the debris avalanche deposit for up to 10 000 years. Results from Titan2D were used to identify source areas of mass flows at different stages and their probable rheologies. Debris avalanche emplacement at Mt. Taranaki was investigated on the c. 7 ka B.P. Opua Formation with the help of Titan2D simulations to identify initial collapse parameters and major flow paths. Once again, the simulations were reliable in proximal reaches, but could not reproduce the rheological transformations from an initial collapsing/sliding pile through to a cohesive clay-rich flow with long runout. In a further example, past block-and-ash flows (BAFs) and dense pyroclastic flow deposits northwest of the current crater were analysed to define the range of realistic model parameters for Titan2D simulations. These could be incorporated inside a Geographic Information System to produce a gradational map of relative probabilities of inundation by future BAF events that took both modelling and geological variability into account. This study highlights that computational models are now reaching the stage where a holistic approach can be taken to hazard analysis that combines both geological mapping and simulation of mass flow scenarios in a probabilistic framework to provide better tools for decision makers and land-use planners.

Acknowledgements

I would like to thank my supervisors for guiding me through this research: Prof. Vince Neall for his wisdom and depth of knowledge of geology; Mr Mike Tuohy for his unique methods and approaches to GIS as well as his related anecdotes; and Prof. Mike Sheridan for providing a new dimension to understanding and studying geology from a computational and modelling basis.

This research would not have been possible without the encouragement, close collaboration and meticulous direction of my supervisor, A/Prof. Shane Cronin who also provided the March 2007 Ruapehu lahar on cue, as well as an unpredictable and mind-boggling journey over the past years.

The Geophysical Mass Flow Group at the State University of New York at Buffalo (Profs. Mike Sheridan and Abani Patra) provided valuable knowledge and the Titan2D toolkit, as well as access to their geology laboratories and Scanning Electron Microscope. I would particularly like to thank Dr. Keith Dalbey for providing assistance and introducing me to linux, programming, uncertainty and super-computing in trailers.

At Massey University I would like to thank Dr. Kat Holt for speedy laboratory work, Dr. Thomas Platz for assistance in the field (and always having his cellphone ready in case of an emergency) and Matt Irwin for a surly and direct approach to answering my many GIS questions. Dr. Gert Lube also provided invaluable theoretical background and advice as well as many ponderous questions. Comments and proof-reading from Dr. Kate Arentsen were very helpful and much appreciated. I also thank all the post graduate students in the Earth Science department for providing an interesting experience and many distractions.

I would not have been able to undertake this research without the financial support of the Foundation for Research Science and Technology (FRST) Tuapapa Putaiao Maori Fellowship. I also greatly appreciate the financial support from the Freemasons Scholarship, the Puke Ariki/George Mason Trust Scholarship, Massey University and the FRST Living with Volcanic Risk programme. I would particularly like to acknowledge the financial and cultural support of Tanenuiarangi Manawatu Inc. who also provided an invaluable retreat.

I am very grateful to my parents who have kept me focussed and supported me throughout this process and been ready and willing to help whenever required.

Finally, I would like to thank my fiancée Dr. Anke Zernack whose immeasurable support kept me encouraged to persevere. While providing priceless field work assistance, proof-reading and organisation, Anke also provided thoughtful and understanding discussions about everything. Thanks for also introducing me to German culture and for saying yes.

TABLE OF CONTENTS

List of Tables

List of Figures