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Katrin Sattler

Periglacial Preconditioning of Debris Flows in the Southern Alps, New Zealand

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Doctoral Thesis accepted by
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Supervisor's Foreword

Debris flows share an intimate relationship with mountain permafrost; climate warming is leading to greater melting of permafrost, activation of previously stable mountain slopes, and an increase in associated hazards. The New Zealand Southern Alps contain both mountain permafrost and debris flow activity; however, the relationship between these two phenomena has not been studied.

In this thesis, Katrin Sattler investigates both. First, she develops a spatial and temporal inventory of debris flow activity for the last few decades. Second, she develops a comprehensive rock glacier inventory for New Zealand and uses it to create a first regional estimate of the spatial distribution of mountain permafrost. Finally, Katrin uses statistics to assess the impact of permafrost, intensive frost weathering as well as other non-periglacial environmental factors on debris flow activity in the Southern Alps.

What does she discover? Unlike in the European Alps, permafrost within debris slopes or its degradation do not appear to be playing a key role in debris flow activation, as most debris flows originate below the permafrost zone. In the New Zealand Southern Alps, the availability of readily mobilised sediment, promoted in high-alpine areas by intense frost-weathering activity, and the spatial distribution of heavy rainfall events are more important preconditions and triggers of debris flow activity. This negative result is informative—pointing to subjects (such as understanding bedrock-weathering rates and mountain rainfall patterns) that need more attention. However, arguably the largest contribution of Katrin's work is her estimate of the mountain permafrost distribution in the Southern Alps, a valuable benchmark in today's rapidly changing environment.

Wellington, New Zealand
February 2016

AProf. Andrew Mackintosh

Abstract

The lower boundary of alpine permafrost extent is considered to be especially sensitive to climate change. Ice loss within permanently frozen debris and bedrock as a consequence of rising temperature is expected to increase the magnitude and frequency of potentially hazardous mass wasting processes such as debris flows. Previous research in this field has been generally limited by an insufficient understanding of the controls on debris flow formation. A particular area of uncertainty is the role of environmental preconditioning factors in the spatial and temporal distribution of debris flow initiation in high-alpine areas. This thesis aims to contribute by investigating the influence of permafrost and intensive frost weathering on debris flow activity in the New Zealand Southern Alps. By analysing a range of potential factors, this study explores whether debris flow systems subjected to periglacial influence are more active than systems outside of the periglacial domain.

A comprehensive debris flow inventory was established for thirteen study areas in the Southern Alps. The inventory comprises 1534 debris flow systems and 404 regolith-supplying contribution areas. Analysis of historical aerial photographs, spanning six decades, identified 240 debris flow events. Frequency ratios and logistic regression models were used to explore the influence of preconditioning factors on the distribution of debris flows as well as their effect on sediment reaccumulation in supply-limited systems. The preconditioning factors considered included slope, aspect, altitude, lithology, Quaternary sediment presence, neo-tectonic uplift rates (as a proxy for bedrock fracturing), permafrost occurrence, and frost-weathering intensity. Topographic and geologic information was available in the form of published data sets or was derived from digital elevation models. The potential extent of contemporary permafrost in the Southern Alps was estimated based on the statistical evaluation of 280 rock glaciers in the Canterbury region. Statistical relationships between permafrost presence, mean annual air temperature, and potential incoming solar radiation were used to calculate the spatially distributed probability of permafrost occurrence. Spatially distributed frost-weathering intensities were estimated by calculating the number of annual freeze–thaw cycles as well as frost-cracking intensities, considering the competing frost-weathering hypotheses of volumetric ice expansion and segregation ice growth.

Results suggest that the periglacial influence on debris flow activity is present at high altitudes where intense frost weathering enhances regolith production. Frost-induced debris production appears to be more efficient in sun-avert than sun-facing locations, supporting segregation ice growth as the dominant bedrock-weathering mechanism in alpine environments. No indication was found that permafrost within sediment reservoirs increases slope instability. Similarly, the presence of permanently frozen bedrock within the debris flow contribution areas does not appear to increase regolith production rates and hence debris flow activity. Catchment topography and the availability of unconsolidated Quaternary deposits appeared to be the cardinal non-periglacial controls on debris flow distribution.

This thesis contributes towards a better understanding of the controls on debris flow formation by providing empirical evidence in support of the promoting effect of intense frost weathering on debris flow development. It further demonstrates the potential and limitations of debris flow inventories for identifying preconditioning debris flow controls. The informative value of regional-scale data sets was identified as a limitation in this research. Improvement in the spatial parameterisation of potential controls is needed in order to advance understanding of debris flow preconditioning factors.

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Contents

Abbreviations

Study Regions

AP	Arthur's Pass region
KR	Kaikoura ranges
MA	Mount Aspiring region
MC	Mount Cook region
TT	Two Thumb Range

Study Areas

BBS	Black Birch Stream valley
CC	Camp Creek
CHFS	Castle Hill and Foggy Stream valley
DC	Denas Creek
ES	Enys Stream valley
FC	Forest Creek
GB	Glacier Burn valley
KCET	Kay Creek eastern tributary
LDS	Lower Dart Stream valley
MSV	Middlehead Stream valley
SSV	Stony Stream valley
TSV	Trolove Stream valley
USCT	Upper Stony Creek tributary

Debris Flow Types

COMB	Combined-type debris flow (slide-related)
RIT	Run-off-generated debris flow
SIT	Slide-initiated debris flow