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Frequency and magnitude of debris flows on Cheekye River, British Columbia

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ABSTRACT

Natural hazard and risk assessments are predicated on a detailed understanding of the relationship between frequency and magnitude of the hazardous process under investigation. When information is sought from the deep past (i.e., several thousand years), continuous event records do not exist and the researcher has to rely on proxy data to develop the frequency–magnitude (*F–M*) model. Such work is often prohibitively expensive and few well-researched examples for mass movement are available worldwide. The Cheekye fan is a desirable location for land development and has a depth and breadth of previous research unprecedented on any debris-flow fan in Canada. We pursued two principal strains of research to formulate a reliable *F–M* relationship. The first focuses on stratigraphic analyses combined with radiometric dating and dendrochronology to reconstruct a comprehensive picture of Holocene debris-flow activity. The second approach examines hydrological limitations of rock avalanche evolution into debris flows through either entrainment of saturated sediments or by failure of a landslide-generated dam and upstream impoundment. We thus hypothesize that debris flows from Cheekye River can be separated into two quasi-homogenous populations: those that are typically triggered by relatively small debris avalanches, slumps, or rock falls or simply by progressive bulking of in-stream erodible sediments; and those that are thought to result from transformation of rock avalanches. Our work suggests that debris flows exceeding some 3 million m^3 in volume are unlikely to reach the Cheekye fan as a result of limited water available to fully fluidize a rock avalanche. This analysis has also demonstrated that in order to arrive at reasonable estimates for the frequency and magnitude of debris flows on a complex alluvial fan significant multidisciplinary efforts are required. Without the significant precursor investigations and the additional efforts of this study, life and property may be jeopardized or the design of debris-flow mitigation may be subject to considerable and unquantifiable error.

1. Introduction

In the last 5 years southern British Columbia has seen an unprecedented development boom that continues today. Given the topographic constraint of the mountainous region at the head of the Howe Sound fjord, land suitable for residential development is scarce (Fig. 1).

The head of Howe Sound is a broad valley occupied by the Squamish River floodplain and low hills underlain by glacially rounded bedrock or thick Quaternary drift deposits (Friele and Clague, 2002a,b). Within the District of Squamish, in the lower reaches of the Squamish River, lies the 10-km^2 expanse of the gently sloping, treed, and largely undeveloped Cheekye fan (Fig. 1). This landform is undeveloped because previous engineering studies found unacceptable levels of landslide risk. The landform and associated hazards has been the subject of some 10 scientific studies (Mathews, 1952, 1958; Friele et al., 1999; Ekes and Hickin, 2001; Ekes and Friele, 2003; Friele and Clague, 2002a,b, 2005, 2009; Clague et al., 2003) as well as six comprehensive consulting reports (Jones, 1959; Crippen Engineering, 1974, 1975, 1981; Baumann, 1981, 1991; Thurber and Golder, 1993; Kerr Wood Leidal, 2003). The studies have covered aspects of the fan stratigraphy, Quaternary history of fan development, debris-flow hazard, and risk, and debris-flow mitigation. The long-term geomorphic evolution of the fan as well as the stability of potential source areas in the upper Cheekye River watershed provides input to the development of an *F–M* relationship, which in turn is the backbone for a quantitative debris-flow risk assessment. Ultimately, the risk assessment provides a rational basis to conceptualize debris-flow mitigation that would reduce existing risk to acceptable levels. With regard to characterizing fan stratigraphy and debris-flow history, the work completed prior to the present study included test trenching and radiocarbon dating, ground penetrating radar (GPR), and compilation of historical data. The studies dating back to the early 1950s conducted on Cheekye River relevant to its hazard and risk aspects are summarized herein as they build the foundation on which this paper is based. This most recent study has closed some important gaps in the understanding

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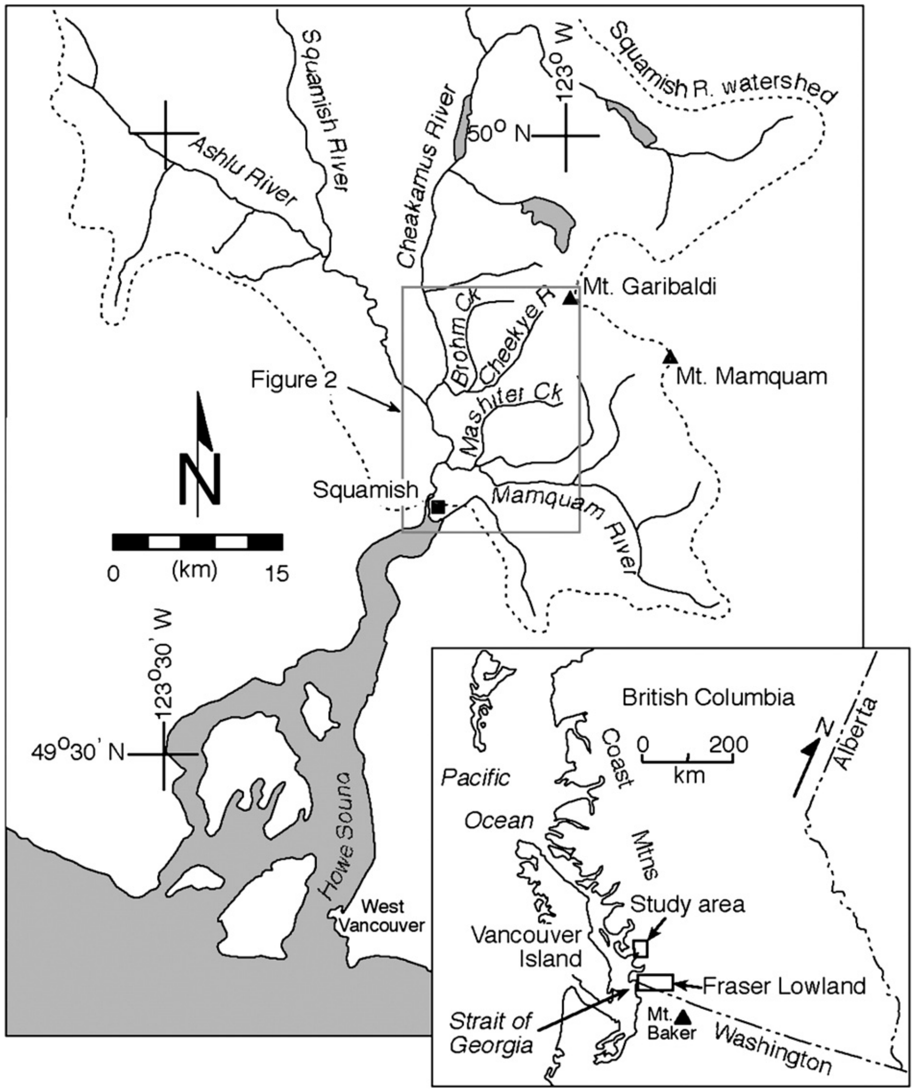

Fig. 1. Study area map.

of *F–M* relationships on the Cheekye fan and provides a basis for debris-flow modelling and risk analysis that are the subject of companion papers.

2. Chronology of Cheekye River studies

Understanding of the frequency and magnitude of debris flows on the Cheekye River has evolved in an impressive body of research over the past 60 years, which has been integrated in the present work.

The first scientific study of the Cheekye fan dates back to the late 1940s and 1950s. William H. Mathews studied the volcanic rocks and glaciers in Garibaldi Provincial Park and showed that Mount Garibaldi erupted repeatedly during the waning stages of the Fraser Glaciation which peaked between approximately 29 kyr and 10 kyr (Mathews, 1952, 1958). He demonstrated that part of the volcano had formed on and against the late Pleistocene glacier in the adjacent Squamish valley. During glacier retreat, the west flank of the volcano collapsed to form ice-contact terraces and kettled terrain underlying the area now encompassed by Alice Lake Park and the Garibaldi Highlands neighbourhood (Fig. 1). The collapsed debris was subsequently incised, reworked and redeposited, with additional material eroded from the Cheekye basin, to form the "lower Cheekye fan" that is the subject of this study.

A debris flow that swept down the Cheekye River to the Squamish River in August 1958 was described by Jones (1959) as a single surge of debris up to 3 m deep travelling at 8 m/s (estimated) at the confluence with the Cheakamus River. It was a confined debris flow and did not overtop the channel at the main northerly bend, or "dogleg." It crossed the Cheakamus River and formed a 5-m-thick dam of logs and boulders. Eisbacher (1983) estimated a volume of 100,000 m^3 for this event, although estimating the volume that was lost as a result of fluvial erosion during the early stages of deposition is very difficult. Anecdotal evidence of a similar debris-flow occurrence in the early 1920s was also mentioned in Eisbacher's guidebook.

A hazard analysis of the fan was conducted in the early 1970s in response to the proposed development of the "Tantalus Project." This was completed by Crippen Engineering who produced three reports in 1974, 1975, and 1981. The 1974 report formed the background study and hazard evaluation; the 1975 report focused on the design for the proposed protective works; and finally, the 1981 report reviewed their previous findings to address concerns raised in a letter by local geologist Baumann (Baumann, 1981), who suggested that the potential for a 30-million-m^3 landslide from the Cheekye linears would present an unacceptable hazard by the hazard tolerance standards of the day. Crippen Engineering (1974) concluded on the basis of an analysis of the Cheekye basin, inspection of available exposures, soil development on the fan, and in consideration of the paraglacial model of Church and Ryder (1972) that the probability of a catastrophic debris flow affecting