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Cryptic eruption of Mount Ruapehu revealed by deposits of sediment laden streamflow in a steep mountain valley: The 4 ka Kiwikiwi Formation, Whangaehu Valley, NZ

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ABSTRACT

A distinctive deposit of unaltered reworked volcaniclastic sediment, here designated the Kiwikiwi Formation, is described from the upper Whangaehu Valley at Mount Ruapehu, New Zealand. The grain-size distribution and sedimentary features of the unit suggest deposition from a sheetflow-dominated alluvial system, but simple sediment entrainment calculations show that the unit's granulometry is inconsistent with normal streamflow deposition at the observed steep depositional slope. Streams have produced deposits at Mount St. Helens and Mount Pinatubo under similarly anomalous conditions following debris avalanche and/or volcanic eruptions, when highly charged with sediment and subject to common lahars (debris flows and hyperconcentrated flows). Reported sediment transport rates from Mount St. Helens' Toutle River, and Pinatubo's Pasig–Potrero River, show that a virtually unlimited supply of relatively fine-grained (sand-range) tephra renders some established sediment transport formulae inapplicable because the volume of available material effectively exceeds the transport capacity of the system. We use simple equilibrium flow calculations to demonstrate that this sedimentary unit, which has open porosity, framework grain support and bedding characteristics compatible with alluvial sheet flows, would not have been deposited under normal streamflow conditions. This approach provides a means to confirm the role of capacity limitations on stream behaviour during the post-eruptive sedimentary response phase in catchments overwhelmed by pyroclastic material, and is particularly useful given the lack of clear depositional fingerprints for hyperconcentrated flow. We further infer that because the material in the Kiwikiwi Formation is uniform, unaltered and minimally abraded, differs from older sediment in the valley, overlies a 4.6 ka debris-avalanche deposit, and was emplaced from an over-capacity stream by hyperconcentrated flows or extremely thinned ones, and without evidence of interruption, it represents the previously unidentified proximal products of an unstudied Holocene eruption of Ruapehu.

1. Introduction

Mount Ruapehu (2797 m) is an active andesitic stratovolcano in the central North Island of New Zealand (Fig. 1), with a history extending back to c. 250 ka (Hackett and Houghton, 1989). During historic times frequent phreatic, phreatomagmatic, and magmatic eruptions have occurred through the active vent beneath a summit crater lake, producing cock's-tail plumes, base surges, lahars and sub-Plinian tephra falls (Healy et al., 1978; Nairn et al., 1979; Johnston et al., 2000; Kilgour et al., 2010). The lahars, and also volcanogenic floods, have accompanied most of the significant historic eruptions because Crater Lake water has been displaced and overflowed the normal lake outlet, or was explosively ejected along with pyroclastic material onto the summit slopes (Paterson et al., 1976; Nairn et al., 1979; Cronin et al., 1997). Post-eruptive lahars have been triggered by heavy rainfall on fresh pyroclastic deposits (Hodgson and Manville, 1999) or breaching of natural tephra dams by the refilling lake (O'Shea, 1954; Manville and Cronin, 2007; Carrivick et al., 2009). Debris avalanches have occurred on at least 3 occasions: an ancient major event at around 110 ka with deposits preserved in a boulder-capped terrace downstream (Te Punga, 1952); the Murimotu Formation avalanche that moved northeastward, triggered by intrusion of a cryptodome at c. 10 ka (Palmer and Neall, 1989; McClelland and Erwin, 2003); and most recently emplacement of the Mangaio Formation towards the east at c. 4.6 ka, associated with syn-eruptive collapse of a hydrothermally altered part of the summit (Donoghue, 1991; Kastl and Manville, in review). The risk of a future debris avalanche has been assessed for the less than

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Fig. 1. Oblique airphoto of the Whangaehu Valley. Arrows indicate prominent accumulations of the Kiwikiwi Formation.

2000 year old accumulation of pyroclastic material of Pyramid Peak (Fig. 1) (Hales, 2000). An evaluation of related hazards, as well as numerical modelling, indicates that such an event is not unlikely and probably would be an order of magnitude larger than the 2007 failure of the tephra dam (Manville et al., 2003; Phillips, 2011). In this paper we investigate the evolution of the post-Mangaio sedimentary system in the Whangaehu Valley, focusing primarily on the distinctive fluvial deposits of the directly overlying Kiwikiwi Formation (Fig. 1).

2. Geological setting — the Whangaehu Valley

Ruapehu's Crater Lake (2530 m elevation) sits within the historically active south crater, one of three present on the summit plateau of Mount Ruapehu (Fig. 2). Under normal conditions it overflows into the steep gorge at the head of the Whangaehu Valley, which descends the eastern flank of the volcano and is cut into >60 ka andesite lava flows and pyroclastic units of the Wahianoa and Mangawhero Formations (Hackett and Houghton, 1989; Gamble et al., 2003). Fig. 2 shows a profile along the valley axis. Gradients are steepest (ca 0.2 m/m) between the lake outlet (2530) and point A (1920), with abundant cascading waterfalls. A second stream branch unites with the main branch at about 6 km downstream from the lake outlet. Valley gradients for the reaches between point A and B (Fig. 2) are about 0.1 m/m (ca 5°). The exit of the gorge is at the apex of a large fan of young volcaniclastic material (Palmer et al., 1993b). The gorge has been modified by glaciation (McArthur and Shepherd, 1990), and partly infilled by Holocene lava flows, the 4.6 ka Mangaio Formation, and younger lahar and landslide deposits that are preserved as discontinuous terraces and barforms (Graettinger et al., 2010). The Mangaio Formation comprises three depositional units that crop out mainly in the northern branch of the gorge, and which are dominated by colourful mud-rich material inferred to be derived from a highly altered hydrothermal vent region (Kastl and Manville, in review). In the upper part of the valley the Mangaio Formation is preserved as mostly buried flat-topped erosional remnants on valley sides, in sites downstream from mid-gorge obstacles, and as veneer deposits at higher elevations. Further down the Whangaehu Valley, at the apex of the Whangaehu fan, avalanche deposits locally show a hummocky surface morphology (Fig. 4 with location in Fig. 2).

3. Kiwikiwi Formation

Deposits of the Kiwikiwi Formation are up to 30 m thick and directly overlie the Mangaio Formation, often with a thin (c. 2 cm) layer of phreatomagmatic vesicular ash preserved at the contact. It is inferred that little time elapsed between emplacement of the Mangaio Formation at 4.6 ka and the onset of Kiwikiwi deposition because no pre-Kiwikiwi channels were cut into the Mangaio, there are no surficial lag deposits such as would result from fluvial or aeolian winnowing, and no paleosol was developed. Also, both units are young and unlike other, typical, deposits of the valley, it would be a surprising coincidence if there was no relationship between them.

Prior to extensive erosion, Kiwikiwi deposits are inferred to have formed a planar-surfaced, gently wedge-shaped downstream-thinning body of sediment extending wall to wall across the Whangaehu Gorge; now they form large elongate ridges up to several hundred metres long and flat-topped terrace surfaces that dip downstream (Fig. 3) at 2 to 5°. The sub-planar upper depositional surface conforms with layering in the deposit, and has approximately the same gradient as the present-day valley floor (Fig. 3).

At the mouth of the Whangaehu Valley a 6 km long and 4.5 km wide accumulation of volcaniclastic sediment extends well into the Rangipo Desert on the eastern and southeastern ring-plain of Ruapehu (Fig. 4) (Palmer et al., 1993a), and the Kiwikiwi sediment has been successively reworked into deposits of younger Onetapu lahars (Fig. 4). This sediment interfingers with older fan deposits and is overlain by younger lahar units that surface the fan (Palmer et al., 1993a; Donoghue and Neall, 2001).

Distinctive characteristics of the Kiwikiwi Formation are its uniform grey colour and the landscape-modifying accumulation of valley-confined, decimetre-bedded, poorly sorted but fines-poor coarse sand to fine pebbles of variably vesicular andesite volcaniclastic sediment (Fig. 5a,b). The unit has been informally named in previous works the "grey unit" (Graettinger et al., 2010; Kastl and Manville, in review); it is here formally named the Kiwikiwi Formation, 'kiwikiwi' being the word for 'grey' in the indigenous Māori language. The unit contrasts strongly with the normal laharic deposits of coarse bouldery gravels deposited in thick terraces and barforms that constitute the typical cover of volcaniclastic sediment in the partially bedrock floored Whangaehu