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Volcanic debris flows

James W. Vallance

10.1 INTRODUCTION

Volcanic debris flows, more commonly known as lahars, behave similarly to debris flows in other settings, but can most strikingly differ in origin and size. Whereas debris flows in other settings commonly range in size from about $10^2$ m$^3$ to $10^7$ m$^3$, volcanic debris flows range in size from $10^4$ m$^3$ to more than $10^9$ m$^3$. This size difference can be explained by the abundance of loose debris on the steep slopes and aprons of volcanoes; the presence of weakened hydrothermally altered rock within some volcanic edifices; the abundance of water stored in glaciers, crater lakes, and hydrothermal systems; rainfall that washes over denuded slopes after eruptions; and the potential for releasing both water and sediment during and immediately after eruptions.

Origins of debris flows at volcanoes include the direct and indirect effects of eruptions, as well those typical of other environments. Volcanic eruptions can generate avalanches of hot rock and ash (pyroclastic flows) that move across glacial ice or snow, melt it, and generate debris flows. Volcanic eruptions through crater lakes sometimes generate floods of water that subsequently entrain sediment and generate lahars. Eruptions or earthquakes associated with eruptions can cause volcanic edifices to collapse. If the resulting debris avalanches contain sufficient volumes of weakened, altered rock and water, they can evolve to form debris flows. Explosive eruptions coat volcano slopes with voluminous easily erodible deposits of volcanic debris that form lahars during periods of heavy rain.

Because of their large sizes and propensity for long-distance transport, volcanic debris flows show downstream evolutions less commonly observed in debris flows from other environments. Many volcanic debris flows evolve from water floods. Those that move down rivers tend to incorporate river water with distance downstream and evolve over river reaches of tens of kilometres to more dilute flow types (see Chapter 8). Volcanic edifice collapses generate debris avalanches that sometimes
evolve partially or completely to debris flows. There is a complete spectrum of behavior between unsaturated debris avalanche and water-saturated debris flow in volcanic settings (see Chapter 27).

Because the precise timing of lahar events is unpredictable and working with active flows can be hazardous, much of our present knowledge of flow behavior is inferred from study of lahar deposits. Nonetheless, a few key observational studies have improved understanding of debris-flow processes. The chief purpose of this chapter is to summarize what is known about the causes and behavior of volcanic debris flows on the basis of observations and careful examination of deposits, and to further describe carefully the nature of hazards that derive from such events.

10.2 DEFINITIONS

Lahar is an Indonesian (Javanese) word used in that country to describe highly concentrated flowing mixtures of rock debris, mud, and water coming from volcanoes, and was introduced into the volcanological literature through the work of Schmidt (1934) and van Bemmelen (1949). The term has wide usage in the volcanological and geological literature as a synonym for “volcanic mudflow or debris flow” (e.g., Crandell, 1971; Fisher and Schmincke, 1984; Pierson and Scott, 1985; Smith, 1986). A rheologically specific definition causes confusion, however, because some sediment-water flows from volcanoes transform from water flood, to hyperconcentrated flow, to debris flow, and back again to more dilute phases during a single event sequence (Pierson and Scott, 1985; see also Chapters 8 and 27) and other sediment-water flows evolve wholly or partly from debris avalanches (e.g., Crandell, 1971; Vallance and Scott, 1997).

A rheologically non-specific definition adopted by the 1988 Geological Society of America Penrose Conference on Volcanic Influences on Terrestrial Sedimentation (Smith and Fritz, 1989) is: lahar, a general term for a rapidly flowing, gravity-driven mixture of rock debris and water (other than normal streamflow) from a volcano. A lahar event can vary in character with time and distance downstream. It may comprise one or more flow phases, which include a debris-flow phase, transitional or hyperconcentrated-flow phase, and streamflow phase (Vallance, 2000). A debris-flow phase is one in which the solid and liquid fractions are approximately equal volumetrically and in which the two fractions in a vertical section move downstream approximately in unison. A streamflow phase is one in which fine-grained sediment moves in suspension with the fluid (suspended load) and coarse-grained sediment moves along the bed at discrete intervals (bedload). It is useful to define a transitional flow phase, commonly known as hyperconcentrated flow, intermediate between that of debris flow and streamflow. Unlike streamflow, this transitional phase carries very high sediment loads, and unlike the debris-flow phase coarse-grained solids tend to separate vertically from the liquid-and-fine-solids mixture. Although the literature distinguishes the hyperconcentrated-flow phase from more dilute and more concentrated phases in terms of solids fraction, transitions are gradational and dependent