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Understanding lahars: recent advances in monitoring, modelling and risk management

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The term lahar is an Indonesian word referring to a sediment-laden flow of (remobilised) pyroclastic or volcaniclastic material and water that travels down the slopes of a volcano and typically enters a river valley. Such events are amongst the most dangerous, far-reaching and persistent of volcanic hazards, being the 4^{th} most lethal volcanic phenomenon, having the potential to impact regions unaffected by and/or hundreds of kilometres from the original eruption source, and occurring for years to decades afterwards. Triggering mechanisms are diverse and complex, while flow behaviour spans a continuum, often varying spatially and temporally within a single lahar which can also grow or shrink in total volume and discharge as it entrains or deposits particulate material and water along its flowpath. Lahar studies are thus truly interdisciplinary, drawing on many elements of physical volcanology, fluid dynamics, classical clastic sedimentology, hydrology and geomorphology.

In the past 40 years our understanding of lahars and their triggering mechanisms and flow behaviour have grown exponentially for a number of inter-related reasons, including: (i) increased awareness of and interest in lahars owing to a number of high-profile and catastrophic volcanic eruptions such as Mount St. Helens in 1981, Nevado del Ruiz in 1985 and Pinatubo in 1991; (ii) the growth in the number of specialist lahar scientists inspired by these and other events; (iii) parallel advances in cognate disciplines including the mass-flow and fluid dynamics community; (iv) development of new constitutive models of multiphase flow behaviour and concomitant increases in the computational power needed to run model simulations; (v) improvements in the diversity, functionality and availability of in-situ, distributed and remote-sensing and monitoring equipment and techniques; (vi) the capture of more complete and detailed multi-parameter and multi-location datasets from actual case-studies including active flows; and (vii) advances in risk assessment, management and mitigation practices and protocols.

Ultimately, lahars and their consequences are the product of the interplay between the volcano (in terms of the style, magnitude and explosiveness of the eruption), the environment (as expressed by physiography, hydrology, energy, and accommodation space), and the human sphere (political, social, economic, infrastructural, demographic, and exposure and resilience).

Although our qualitative understanding of lahar initiation, behaviour, hazards and impacts is increasing there remain a number of major outstanding questions and challenges whose solution will draw on all these fields. While we broadly know the What? Where? and Why? of lahars in the aftermath of an explosive volcanic eruption, a great deal more work is required on the When? To Whom? and What will it cost? This shift from qualitative to quantitative assessments of lahar hazards, risk and consequences needs to operate over a range of timeframes, from the automated immediacy of event response at volcanoes where a blue-sky eruption can trigger potentially devastating lahars that can reach inhabited areas in a matter of minutes, to the decadal morpho-sedimentary aftermath of a major eruption where prodigious sediment yields impact downstream drainages for decades afterwards. It is truly an exciting time to be a lahar scientist.