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Volcano amphitheater formation by massive hydrothermally driven collapse

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Enormous volcano collapses, such as at Mount St. Helens in 1980, can begin as large flank landslides that retrogress rapidly into the core of an edifice via a series of subsequent failures. These massive excavations create steep-walled, curved amphitheaters with gently sloping floors. Such catastrophic collapses have dramatically sculpted over 200 steep stratovolcanoes around the world; some have occurred with eruption of juvenile magma (e.g. Mount St. Helens volcano), whereas others have not (e.g. Bandai volcano). The volume of rock removed by a collapse is fundamental to both hazard assessment and long-term volcano evolution; larger failures commonly travel farther and they tremendously modify the edifice. Using a 3-D slope stability model coupled with groundwater and heat flow models, I examine the potential for amphitheater formation by landslide retrogression in two scenarios - with and without hydrothermal fluid pressurization within an edifice. The 3-D method searches a digital topography and determines the locations of minimum stability and the volumes of potential failures. Nearly instantaneous removal of rock by a large landslide may produce transiently elevated pore-fluid pressures within the remaining edifice, because insufficient time elapses to allow fluids to drain and equilibrate with the new topography. Such temporarily elevated pore pressures further destabilize the oversteepened scar of the initial landslide. Thus, rapid undrained unloading can instigate failure retrogression.

3-D modeling results demonstrate that rapid removal of an initial large landslide volume (about 0.5 km^3) from an edifice containing cold, topography-driven groundwater flow can induce modest transiently elevated pore pressures. In this scenario, failure retrogression is limited to relatively small slices in the steep headscarp of the initial failure, with each subsequent retrogression removing about 20-30% of the initial landslide volume. In contrast, given a volcano flank containing pressurized pore flu-

ids, unloading from an initial failure can provoke extensive retrogression. Pressurized fluids within an edifice can result from the heating of hydrothermal fluids by magma intrusion. In addition, transiently elevated fluid pressures generated at depth can propagate outward and upward into the edifice. With pressurized fluids in the edifice, 3-D simulations show that initial failure is more likely. Moreover, extensive retrogression following initial failure can remove more than 10 times the volume of rock as in the cold groundwater scenario. With pressurized fluids in the edifice, failure retrogression can remove the summit and create a large, steep-walled amphitheater with a gently sloping floor.