Landslides from Volcanoes Seen as Common

Given the example of Mount St. Helens' catastrophic collapse, geologists are recognizing volcanic debris avalanches elsewhere

For 50 years geologists have been walking the valley of northern California's Shasta River, climbing its curious mounds, hillocks, and ridges that number in the hundreds, and chipping at the rock where streams or quarrying have revealed what lies beneath. And they wondered what it all meant.

Some said the hummocks are individual little volcanoes that popped up during ancient eruptions in the Cascades, nearby Mount Shasta representing more productive though younger activity. Another geologist suggested that any feature rising above the flat floor of the valley had been left there by glaciers or carved out of volcanic rock by streams. Another included volcanic eruptions, glaciers, and stream deposits in his explanation. Others continued to wonder.

Then Mount St. Helens gave a graphic lesson in how a volcano can fall apart catastrophically, leaving a gaping hole in its side and transforming the surrounding landscape into a hummocky plain. With that unforgettable example in mind, a brief inspection of the Shasta Valley was enough to convince most geologists of its true nature—it is the largest known landslide of the past 2 million years. Knowing what to look for is helping geologists define a volcanic hazard that is far more common than once thought. When combined with lateral blasts like Mount St. Helens', which may be associated with landslides from volcanoes, the hazards seem even greater.

Part of the problem in recognizing the Shasta landslide, which is more specifically called a debris avalanche deposit, was its sheer immensity. When a moderate earthquake shook the bulging north slope of St. Helens on 18 May 1980, first one block of the mountain began slipping downward, then a second, and finally a third, each one gouging farther into the heart of the volcano until 2.8 billion cubic meters of debris was barreling down the mountainside at 350 kilometers per hour. It did not stop until it had covered 60 square kilometers.

According to a recent study (*1*) by Lee Siebert of the Smithsonian Institution in Washington, D.C., even after the increased interest following the St. Helens eruption, only a half dozen of the world's more than 75 identified debris avalanche deposits are known to exceed the 2.8-cubic-kilometer volume of the St. Helens event. But the Shasta deposit's volume is a mammoth 26 cubic kilometers and covers at least 450 square kilometers (*2*) according to its "discoverers," Dwight Crandell and C. Dan Miller of the U.S. Geological Survey (USGS) in Denver, Harry Glicken and Christopher Newhall of the USGS Cascades Volcano Observatory, and Robert Christiansen of the USGS in Menlo Park.

They had all seen or knew of the Shasta Valley before the St. Helens eruption. While studying deposits much younger than those of the Shasta debris avalanche, Miller produced the USGS evaluation of volcanic hazards for the Shasta area, noting that the more distant hummocks in the valley might provide refuge from mud and ash flowing down from Shasta. Glicken had repeatedly driven over the avalanche deposit on Route 5 as he passed Weed, Edgewood, and Yreka on his way to study the St. Helens deposit for his dissertation. Crandell and Christiansen had done field studies in the area. Then came the St. Helens eruption. After they individually became suspicious of the resemblance between the two deposits, they needed only the first hour or two of a joint field trip to convince themselves that an avalanche could be the only explanation.

The horseshoe-shaped scar that the avalanche presumably left on the mountain had filled and healed in the approximately 300,000 years since the slide, but the deposit itself closely resembled those at St. Helens and other volcanoes. In particular, at the heart of each hummock or ridge was one or more volcanic blocks as large as hundreds of meters across. They had slid as much as 40 kilometers immersed in the pulverized debris that formed the flat valley floor. Many blocks are obviously still right side up.

The St. Helens and Shasta debris avalanches were not the first of their kind to be recognized, but the St. Helens deposit has prompted this and other studies leading to the realization that the collapse of a volcanic edifice is not the rare event it was once thought to be. The Shasta deposit was only one of many that was misidentified, often as volcanic mudflows. Some scars remaining on mountainsides were taken as explosion craters or the depression left by the sinking of one block of the volcanic cone.

D. R. Crandell *et al.* (*2*).

Three hundred thousand years after a great debris avalanche

Looking southward 40 kilometers toward Mount Shasta, the Shasta Valley is dimpled by hills underlain by volcanic blocks that slid off the volcano.

Japanese workers did begin to recognize, in the years before the eruption of St. Helens, that some debris deposits had formed while relatively dry rather than saturated with water, as a mudflow is. Since St. Helens, uncertain identifications have been clarified and new deposits have been recognized, including a 1-cubic-kilometer avalanche deposit formed about 20,000 years ago to the south of St. Helens itself. Siebert's compilation suggests that such major debris avalanches occur about four times per century, or several times more often than the infamous, self-consuming eruptions of the sort that largely destroyed the island of Krakatau in 1883.

Anticipating where and when the next debris avalanche will strike would greatly reduce the danger. The when of the

After 26 years

In 1956 the volcano Bezymianny in Soviet Kamchatka blew its side out in a blast, debris avalanche, and eruption much like Mount St. Helens' of 1980. By the time of this photograph in 1982, much of the amphitheater-like cavity had been filled by later eruptions. [Photograph by G. E. Bogoyavlenskaya, Institute of Volcanology, Petropavlovsk Kamchatsky.]

next debris avalanche is impossible to predict now, but the prospects of predicting where look better. From his compilation, Siebert has found that the existence of volcano heights above 500 to 1000 meters and slope angles larger than 20 degrees greatly increase the likelihood of slope failure. But many volcanoes maintain such heights and steepness without failing, he notes. That suggests the need for a trigger, such as an earthquake, an explosive eruption, or an intrusion of magma into the upper part of the cone. At Mount St. Helens, a moderate earthquake triggered the failure of its north slope where a bulging magma intrusion had weakened it.

In addition to their being too high with too small a base for support, volcanoes may shed avalanches from their slopes simply because they are shoddily constructed and tend to weaken with age. Relatively sturdy lava flows may be laid down over weak layers of loose ash. Swarms of lava fingers can work up through the cone and push opposite sides of it apart. Hot water can weaken rock by saturating it as well as by turning part of it into clay. As Siebert notes, "Volcanoes can be thought of as ephemeral aggregations of unstable material. . . ." Catastrophic collapse may not be an unavoidable stage of volcano growth, researchers now agree, but it makes sense that it is a common one.

Less clear is the relation between debris avalanches and the kind of lateral blast that followed the St. Helens avalanche. Once the slope failure had removed the rock that had bottled up the pressures within the mountain, a total of 24 megatons of energy drove 60 tons of rock, gas, and ice through each square meter of the blast front per second, according to calculations by Susan Kieffer of the USGS in Flagstaff. Trees snapped off at the ground as far away as 25 kilometers. Do most avalanches have such stunning side effects? Glicken notes that the three other oft-cited debris avalanches of historic times—Bandai-san of 1888, Bezymianny of 1956, and Sheveluch of 1964—are widely reported to have been accompanied by blasts.

"Circumstantially," says Glicken, "the evidence is good that debris avalanches are generally associated with lateral blasts." Siebert is more cautious in making the connection. Blast deposits, unlike debris avalanche deposits, are thin and easily lost to erosion (*Science*, 12 June 1981, p. 1259), he notes, which places reliance on as yet unverified field reports, historical accounts, and indicators other than deposits, such as downed trees. Some of these observations are now being questioned. From a hazard point of view, he adds, the greatest loss of life in historic times has not been from accompanying blasts but from a debris avalanche entering the sea and creating a tsunami. The potential hazard from directed blasts triggered by debris avalanches is high, though, and requires further searches for blast deposits, he says.

The difficulty of proving the existence of ancient blasts pales beside the current efforts to determine what really happened during the most recent—and most thoroughly documented—example. The Mount St. Helens debris avalanche and blast were photographed from a small plane overhead and from the ground from several different angles, imaged in the infrared by two military satellites, and even recorded on distant seismographs. Then geologists dissected the resulting deposits, all to show how a beautifully symmetric mountain could be gouged out and strewn violently over 600 square kilometers.

Despite the unprecedented records made at St. Helens, there is no agreement on what made it all happen once the debris avalanche began removing rock from the north slope of the mountain. The first controversy was whether the energy of intruded magma or superheated water permeating the rock drove the lateral blast. The most common assumption now is that both made significant contributions to starting the blast on its way.

More controversial is what happened next. Near one extreme is the suggestion by Michael Sheridan of Arizona State University and others that the megaton energies of the blast carried the suspended rock, ice, and water only 1 or 2 kilometers before it all decelerated and gravity took over. The debris-laden gas of the "blast" would then swiftly flow downhill under its own weight. On the other hand, Kieffer emphasizes the ability of the blast gases to expand like steam from a ruptured steam boiler and thus to carry material at least 11 kilometers before gravity became important. James Moore of the USGS in Menlo Park and Carl Rice of The Aerospace Corporation have suggested something of a hybrid event (*3*) in which the debris avalanche carries with it the sources of later explosions, including a major one more than 5 kilometers from the origin of the blast. Sheridan is organizing a workshop to be held this summer to sort out exactly what might have happened.

Like the Mount St. Helens blast and debris avalanche, which were unprecedented in the known geologic record there, the recognition of the huge Mt. Shasta debris avalanche deposit once again reminds geologists that extreme size and infrequency cannot eliminate a potential hazard from consideration. The past practice of evaluating volcanic hazards on the basis of the past 10,000 years of activity at the single site under consideration would seem to yield too narrow a view. As an example of an extreme event that would not fall within the usual hazard evaluation, Robin Holcomb of the USGS Cascades Volcano Observatory has added new evidence in support of Moore's suggestion that a landslide carried away half of the eastern end of the 60-kilometer-long Hawaiian island of Molokai.—**Richard A. Kerr**

References

1. L. Siebert, *J. Vol. Geotherm. Res.*, in press.
2. D. R. Crandell, C. D. Miller, H. X. Glicken, R. L. Christiansen, C. G. Newhall, *Geology* **12**, 143 (1984).
3. J. G. Moore and C. J. Rice, in *Explosive Volcanism: Inception, Evolution, and Hazards*, National Research Council Geophysics Study Committee (National Academy Press, Washington, D.C., 1984), pp. 133–142.