# When Mountains Fall

## What makes huge avalanches run so far?

By RICHARD MONASTERSKY

The town of Elm, Switzerland, didn't stand much of a chance when a nearby mountainside suddenly collapsed, transforming a solid cliff into a river of rock. Roaring down the valley faster than a runaway train, the landslide entombed 116 souls beneath a blanket of broken slate before it ground to a dusty halt.

The Swiss disaster, which struck on Sept. 11, 1881, gave geologists their first look at the phenomenon of giant landslides. But despite a century studying the Elm slide and scores of other modern and prehistoric examples, scientists still do not know how these avalanches move so quickly and cross such vast distances, seemingly in violation of the laws governing friction.

"It's really a fascinating area where — unlike a lot of things in geology — we do not understand the principles of this bizarre phenomenon," says H. Jay Melosh, a geologist at the University of Arizona in Tucson.

Although such large slides occur infrequently, they have the potential to cause great destruction because they can travel so far, obliterating towns that seemed a safe distance from precarious mountain slopes.

Over the decades, earth scientists have put forward more than a dozen ideas to explain such enigmatic rockslides. While no consensus yet exists, new opportunities for research are raising hopes that geologists can now advance the long-stalled effort to understand this phenomenon.

The landslide problem plaguing today's researchers is the same one faced by Albert Heim, the Swiss geologist who traveled to Elm right after the disaster there. Heim realized that large slides, unlike smaller avalanches, are exceptionally mobile, distinguished by their ability to travel with little apparent friction to slow them down. Modern researchers have dubbed these avalanches "long-runout landslides."

The friction factor is really what separates long-runout slides from ones that yield to explanation. Most smaller avalanches slide horizontally less than twice the distance they fall. In the case of the Elm slide, though, the collapsing cliffside plummeted 610 meters and sped through the valley for a horizontal distance of 2.1 kilometers, more than three times as far as it dropped. Many landslides show even more mobility, traveling roughly 10 times as far as they fall.

The largest slides manifest the least friction of all. Oceanographers mapping the seafloor around the Hawaiian Islands five years ago discovered evidence of huge prehistoric slides, one of which spread more than 200 km from its origin — a distance more than 30 times the length of its fall. On land, geologists have recently discovered a similarly mobile slide that came off Mexico's Nevado de Colima volcano more than 18,000 years ago. The longest avalanche ever reported on land, the Colima slide sped 120 km to the Pacific coast and then some unknown distance into the ocean, a horizontal flight roughly 25 times longer than the distance it dropped, according to a report in the April GEOLOGY.

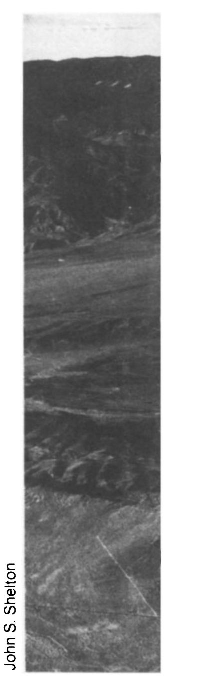
At the southern edge of the Mojave Desert, about 135 km east of Los Angeles, one of the more spectacular examples of a long-runout landslide lies draped across the sun-baked plain. Called the Blackhawk slide, this avalanche occurred roughly 17,000 years ago, when a large chunk of Blackhawk Mountain collapsed. The mass of marble rock fell about 1.5 km and spread 9 km horizontally over essentially flat land at estimated speeds of 120 km per hour. From the air, it looks almost as if the mountain had suddenly turned into chocolate milk, spilling across the desert in a dark sheet and then freezing instantly in place.

While studying the Blackhawk slide in the late 1950s, geologist Ronald L. Shreve hit upon an intriguing idea: Perhaps the avalanche spread so far because it took a ride on a layer of compressed air. Shreve, now at the University of California, Los Angeles, hypothesized that the falling rocks gained enough momentum to become airborne when they passed over a projecting ledge. This launch ramp caused the avalanche to trap a layer of air that supported the slide, allowing it to move with little friction over the desert plain, much like a hovercraft.

Shreve developed the air-layer theory to explain some of the puzzling geology apparent in the Blackhawk slide. Previous investigators, such as Heim, had suggested that large landslides flow like fluids, with individual rocks and boulders jostling together like water molecules in a stream. But the Blackhawk slide could not have moved in this way, Shreve thought, because it has distinct layers that match the strata of rock on Blackhawk Mountain. Had the rock come down like a fluid, the original layers would have mixed together. Furthermore, the rock fragments in the slide have sharp edges. These would have worn smooth had the fragments tumbled against each other.

Shreve theorized instead that a thin, lubricating layer must have allowed the bulk of the rock to take a relatively smooth ride downslope.

He later extended the air-layer lubrication theory to explain the Elm slide and several other famous ones with features similar to those of Blackhawk. One of these, the Sherman landslide, occurred in 1964 when a great quake in Alaska loosened the top of a Matterhorn-like peak, sending a flood of dark sandstone spreading across the Sherman glacier. Among the debris from this slide, geologists found a boulder still bearing a coat of lichens, moss, and even grass clumps, a testament to the tame trip the boulder took across the glacier.


John S. Shelton

Because the air-layer theory could explain so many disparate qualities of large landslides, it gained wide recognition among geologists. Today, it remains one of the best-known explanations for the long-runout phenomenon. But familiarity does not equal acceptance. Most researchers who actively study landslides do not favor the air-layer concept.

"I don't think the idea holds air anymore," quips George Plafker, a field geologist with the U.S. Geological Survey (USGS) in Menlo Park, Calif.

Physicists, engineers, and geologists investigating landslides have put forward a cascade of arguments against the air-layer theory. Some contend that a landslide could not trap enough air underneath to support its weight. Others argue that the air would quickly escape up through the rock and would not remain trapped. Further questions arose after researchers discovered immense, Blackhawk-type slides on Mars. How could the extremely diffuse atmosphere of this planet support the weight of a huge landslide? Some investigators have also identified putative landslide deposits on Earth's moon, which has no atmosphere at all.

The air-layer theory is only one of the myriad proposals raised to explain long-runout slides, notes geologist Philip J. Shaller, who investigated the phenomenon last year for his doctoral thesis at the California Institute of Technology in Pasadena. A similar theory holds that large slides ride on a layer of molten rock produced by frictional heat at the base of the slide. To date, however, researchers have little evidence to support this idea, says Shaller.

According to another theory, air becomes mixed inside the slide, whipping the rock into a mobile fluid. This mechanism, however, would not explain why rock layers remain well ordered in many long-runout slides.

One of the more novel ideas focuses on the issue of noise in the slide. Melosh has proposed that the tremendous acoustic energy generated by a landslide vibrates some rock fragments enough to lower the friction between them and other fragments, allowing them to move more freely. Melosh is currently trying to measure the amount of acoustic energy generated in laboratory experiments to see whether the vibrations are strong enough to lubricate the slide. He also believes this mechanism could explain how faults move in earthquakes.

Charles S. Campbell, an engineer at the University of Southern California in Los Angeles, thinks the long-runout phenomenon may not require fancy explanations. Campbell has sought to capture landslides in a computer, using a two-dimensional model of particles sliding down a slope. In this simple representation, he finds that the normal collisions among particles agitate the lowest portion of the slide most of all. The bottom particles bounce so energetically that they support the bulk of the avalanche, holding it off the ground. This lubricating layer of particles allows the rest of the slide to travel downslope relatively undisturbed.

In the past, Campbell has performed small simulations, monitoring up to 200,000 particles as they fall downslope. Now he has moved up into the big leagues. For the last eight months, a mini-supercomputer has been running a 1,000,000-particle simulation that should finish up this fall. Campbell finds it encouraging that the slides have been getting more mobile with each jump in size – an observation that matches what happens in nature.

Even as Campbell explores landslides in a computer-generated landscape, geologists are finding broad new opportunities for studying the real thing. Once thought to be extremely rare, examples of giant landslides have been turning up almost everywhere researchers look.

Geologists were particularly surprised two years ago when they learned that the Soviet Union had for decades triggered large landslides with explosive blasts. The greatest of these slides measured about eight times the volume of the Elm slide. American scientists may soon get a chance to watch some artificial landslides in action (see next page).

Geologists working around the world have also recognized a vast number of natural landslides in different environments. Most recently, a USGS program to map the ocean floor around U.S. territory has located 40 giant submarine landslides, a group of USGS researchers reports this month in the international newsletter LANDSLIDE NEWS. The slides were found along a chain of submerged volcanoes running from the westernmost Hawaiian island of Kauai to the island of Kure, near Midway, says James G. Moore of the USGS in Menlo Park. Prior to that, sonar mapping had identified 17 giant slides around the Hawaiian volcanoes.

The submerged deposits near Hawaii rank among the largest landslides on the planet, says Moore. One, called the Nuuanu slide, occurred when part of the island of Oahu collapsed, sending debris 235 kilometers out across the deep-ocean floor.

Such massive cataclysms must have created truly gargantuan waves. Geologists have found pieces of coral and other material deposited by a tsunami that reached 365 meters (almost 1,200 feet) above sea level on the Hawaiian island of Lanai. It appears the monster wave was generated when part of the Mauna Loa volcano collapsed and dropped into the sea.

Such slides will recur sometime in the future, most likely coming off the big island of Hawaii, the youngest member of the chain, says Moore. The resulting tsunami would prove catastrophic for Hawaii and would even cause damage along the California coast. The only question is whether any of these slides will occur soon. Current evidence suggests that Mauna Loa has collapsed three times in the last 300,000 to 500,000 years, with the most recent slide occurring about 105,000 years ago. Smaller slides, which recur much more often and can cause considerable damage, are probably a much greater threat to the islands, says Moore.

Like their cousins on land, the undersea slides have stumped scientists trying to understand the long-runout problem. Water may have helped lubricate the moving rock, but it also would have provided considerably more resistance. Though they differ from slides on land, undersea slides could help researchers understand how above-water landslides travel so far, Moore says. Later this year, he and his colleagues plan to make the first visit to a deeply submerged landslide, using the Navy's *Seacliff* submersible.

The recent ocean discoveries come just as researchers are recognizing the importance of collapsing volcanoes on land. For most of this century, geologists thought large landslides occurred only rarely at volcanoes, but that view crumbled with the 1980 eruption of Mount St. Helens in

*The Blackhawk slide: A textbook example of long-runout. Dark debris from the landslide forms a fan-like shape, draped across the smooth desert floor. Falling from one of the low ridges in the background, the avalanche of marble spread 8 kilometers out across ground that has a slope of only 2.5°. The slide overtopped low hills in the left part of the photo, indicating it had a speed of at least 120 kilometers per hour.*

Washington state. That blast started when an entire flank of the volcano suddenly broke off, generating a massive avalanche of debris that removed the upper kilometer of the volcano, says Lee Siebert, a volcanologist with the Smithsonian Institution in Washington, D.C.

Recent studies have shown that some volcanoes have a habit of falling apart. In April, two researchers reported evidence that Alaska's Mount St. Augustine volcano has undergone 11 major collapses in the last 1,800 to 2,000 years (SN: 4/25/92, p.260). At this volcano and others like it, "there is potential for an extremely catastrophic event," says Siebert. Because such avalanches can spread so far, they can inflict tremendous damage on nearby communities.

Along with the artificially triggered avalanches in the former Soviet Union, the numerous recent discoveries of volcanic landslides could give scientists the push they need to make headway on understanding this phenomenon. Shreve, who has taken part in the debate for almost four decades, believes that one simple answer probably will not suffice. When the dust finally settles, geologists may learn that several different mechanisms work together to make large landslides so mobile. □

# Dams on Demand

In a project that makes Western engineers cringe, explosives experts in Moscow are planning to trigger a huge landslide in the mountainous country of Kyrgyzstan with the aim of building the world's second largest dam.

While this plan, called the Kambarata dam project, raises a long list of troubling issues, investigators interested in giant landslides see it as a rare opportunity. Geologists normally happen upon landslide scenes long after the action has ended. Scrutinizing a mass of lifeless rubble, they try to recreate what happened hours or thousands of years ago. The Kambarata project would present U.S. investigators with their first chance to witness a giant slide in motion.

While the potential research bonanza does not in itself justify the Kambarata plan, landslide investigators would love to be there if it is going to occur, says Bruce Murray of the California Institute of Technology in Pasadena.

American scientists first learned of the Kambarata dam plans two years ago at a pair of workshops, in Pasadena and in Moscow, on giant landslides. Discussing their research, Soviet scientists revealed that for decades they have triggered landslides with explosions, including underground nuclear blasts, says H. Jay Melosh of the University of Arizona in Tucson. While some of these landslides occurred as unintended by-products of explosions, a few were experimental slides used to build small dams in central Asia.

The Kambarata project calls for the creation of two separate dams: one about 70 meters high, the other roughly 270 meters high with a volume of about 112 million cubic meters. Located in a narrow granite gorge of the Naryn River, the dams will deliver hydroelectric power for the central Asian nation of Kyrgyzstan, a former republic in the Soviet Union. Plans for the project require a whopping 275 kilotons of conventional explosives to trigger the series of landslides that will create the larger of the dams, according to project leader Vitaly Adushkin, director of the Institute for the Dynamics of the Geospheres in Moscow.

Conceived before the Soviet Union collapsed, the Kambarata project has since been postponed as Kyrgyzstan tries to find the necessary funds. Last spring, Adushkin's group announced that construction of the main dam will occur in the year 2000 instead of 1997, as earlier planned.

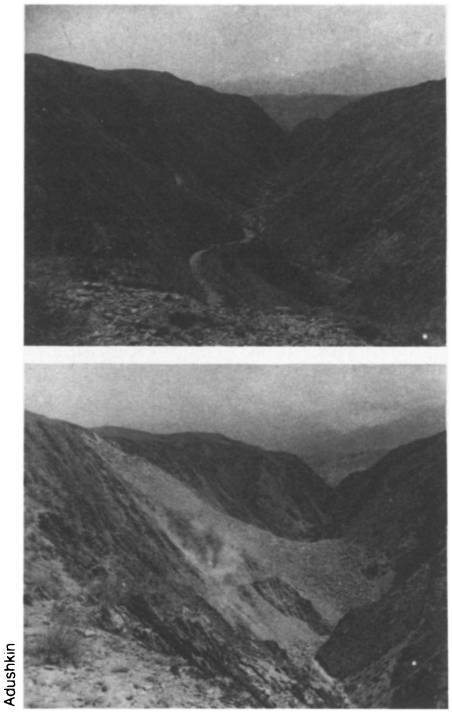
In the United States, investigators are seeking funds to perform experiments during the Kambarata landslide. These avalanches can't serve as true representations of long-runout landslides because they will come down one side of the canyon and quickly run into the opposite side. But geologists can't afford to be choosy. This is the closest to a giant landslide they will ever get.

U.S. researchers have dreamed up a number of possible experiments, ranging from the simple to the sophisticated (and expensive). On the cheaper side, some suggest painting sections of the canyon with different colors and then tracking the colors as they fall. More complicated experiments would involve embedding transmitters within artificial rocks that would accompany the rest of the slide. By tracking the transmitters, researchers could discover how rocks within the slide moved.

While the project has captured the interest of U.S. landslide researchers, several engineers who have learned about the Kambarata plan express reservations. "It's not a good way to build a dam," says Ronald F. Scott, a Caltech engineer who studies dams and their safety during earthquakes.

Normal earthfill dams have a number of features that make them impermeable and strong. But landslide dams are more like a pile of rocks than a well-constructed dam. What's more, this region of Kyrgyzstan is prone to large earthquakes, as demonstrated by a magnitude 7.5 shock that caused considerable damage there last week. "I would not feel at all comfortable about the seismic resistance of such a dam," says Scott.

Adushkin told SCIENCE NEWS that the landslide method is an inexpensive way to construct dams. But Scott believes the impetus to build dams through landslides may come not from economics but from a community of explosives researchers facing unemployment with the demise of the Soviet weapons-testing program. Scott adds that the landslide method may not end up any cheaper than other methods, because workers will have to spend considerable time shaping the Kambarata dam after the landslide.



Adushkin

*Two photographs show the Uch-Terek valley in Kyrgyzstan before and after an explosively triggered landslide in 1989. The 45-meter-high dam was made to simulate the Kambarata project.*

Alexander Potapov, a former researcher at Adushkin's institute, says, "As far as a stable job, the [Kambarata project] is probably the only real work that will be 100 percent sure in the future" for physicists who had previously studied nuclear explosions. The government of Kyrgyzstan is very interested in building a hydroelectric dam and will be willing to pay, says Potapov, now a postdoctoral researcher at the University of Southern California.

At present, though, many researchers in the United States and Russia are wondering whether the Kambarata project is likely to move forward anytime soon, if ever. The official plan calls for building the smaller of the dams in 1994, but some Russian researchers do not take that date very seriously.

*– R. Monastersky*