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Just Sitting There, Growing Trees?

THE earth comes unglued for a variety of reasons, but there is usually a single triggering event. The largest, most catastrophic debris flows are caused by earthquakes and volcanic eruptions -- hence the prevalence of landslides throughout the Pacific Rim and the mountainous regions of China, the former Soviet Union, and Central Europe. But most often the culprit is simply water -- in the form of rainfall, snowmelt, or river flow. Thus there have also been spectacular slides in Iowa and in the placid river valleys of Quebec. Pittsburgh and Cincinnati, constructed on loose sediments cut by river systems, incur some of the highest landslide costs in the United States.

Aftermath of the 1995 La Conchita landslide, in southern California. (Photograph by Robert L. Schuster, USGS.)

Perhaps the most common medium for landslides is colluvium -- basically particles of weathered rock in the process of becoming soil. Mature soils settle out into homogenous layers, called horizons. If colluvium stays still long enough, it may form horizons too. But on unstable hillsides it remains young and restless, a poorly sorted conglomeration of silt, sand, pebbles, and rocks.

Colluvium covers most of the ground surface in humid temperate zones and semi-arid mountainous areas. It is ubiquitous in the western United States and the Appalachian Range, from Maine to Alabama. Along the California and Oregon coasts tectonic stress has shattered the sandstone-and-shale bedrock of the Coast Range, and frequent ocean storms have accelerated the weathering of the rock. The result is a mantle of loose, cruddy dirt --

pre-dirt, if you will -- that produces some of the best forests on earth. Colluvium appears to be just sitting there, growing trees, but over hundreds and thousands of years it is on the move, and the direction of its movement is always downhill. It trickles into narrow gulleys, or swales, which form distinctive tracks running straight down the steep foothills. These natural sluices also catch water draining off the hilltop ridges. Colluvium may accumulate for millennia in a swale, until it is washed out by a debris flow into the valley below and the cycle starts anew.

The angle of repose for colluvium slopes averages 35 degrees but varies widely. There are thickly forested 45-degree slopes in the Oregon Coast Range that appear stable, and 26-degree hillsides in the San Francisco Bay area that have failed catastrophically. The stability of the glacially compacted bluffs on Washington's Puget Sound is sorely threatened beyond 33 degrees, especially when conditions are unusually wet. The overall incline of the cliff at Rolling Bay is just under 40 degrees.

The first axiom of debris flows is that where one has occurred, others will inevitably follow. But nobody knows when. Water must enter the soil not only in sufficient but also in correctly timed amounts. Typically what is required is a long saturation period followed by intense bursts of rain concentrated in just a few hours or days. Water passes rapidly through surface material until it hits bedrock or clay, creating a saturated zone as it fills the pores between solid particles. Rising pore pressure creates a buoyancy that effectively reduces the stabilizing friction of the colluvium on the slope beneath it. At some point gravity overcomes the natural inertia, and the soil mass breaks loose, sliding down the less permeable surface below.

Or maybe not. The debris-flow scenario depends on numerous factors: soil depth and composition, the kind of vegetation and the size of tree roots, subtle variations in slope shape, road cuts, drainage pipes, incongruities in underlying bedrock, even the presence of small animal burrows. Water can collapse a slope after traveling beneath the surface from miles away. Vibrations from trains are suspected of triggering debris flows. And sometimes there seems to be no particular cause. The 1978 Bluebird Canyon landslide, near Los Angeles, which caused $15 million in property damage, had no obvious triggering event. In June of 1993, 75 acres of Ontario farmland suddenly liquefied and clogged the South Nation River, creating the great Lemieux landslide. In September of 1997 a man sitting at a bar in Port Angeles, Washington, was crushed to death when a mudslide destroyed the building. The area had had no appreciable rain for months.

There are basically two kinds of landslides: slow and fast. The latter are more likely in loose, coarse material like sand or colluvium; most clay soils stick together better and are less prone to rapid movement. Large, deep-seated slides, in which the dislocation originates far below the face of a slope, tend to occur more slowly than shallow debris flows, which are more deadly. Because a few growing seasons will cover the tracks of shallow slides, their telltale scars are harder to spot. Slide-prone slopes may remain hidden for generations until revealed by the perfect storm. For instance, it took geologists most of this century to grasp how vulnerable the San Francisco Bay area is to debris flows. "We had always considered it a southern-California problem," Ray Wilson, a landslide expert with the USGS, says. "Then we got this storm in 1982."

In January of that year a Pacific front stalled over the Bay area, dumping as much as twenty-four inches of rain. The steady downpour was punctuated by intense cloudbursts that reminded Wilson of his home town near Houston, where tropical deluges are commonplace. In San Francisco they precipitated the largest natural disaster in the region since the earthquake of 1906, causing thirty-three deaths and nearly $300 million in property damage. When the weather cleared, aerial photographs identified 18,000 debris flows in the ten counties around San Francisco Bay.

For most of California's history the periodic slides in the Coast Range took place far from populated areas. But when suburban development pushed out into the foothills, in the latter half of this century, it spread into the serpentine valleys beneath the swales. Seventy percent of the slides in 1982 took place in the swales.

The 1982 storm spawned volumes of research papers and forever altered geologists' understanding of the northern-California landscape. But it was also instructive for what it revealed about human nature. Jerry Weber, a consulting geologist in Santa Cruz, says that our "collective disaster memory" goes back only two years, even when lives have been lost. Even when those lives were next door. "People cannot focus any longer than that unless they're directly involved," Weber says. As time passed after the 1982 storm, the horror of the slides faded from memory -- and so did the idea that they might recur. When Santa Cruz County officials ordered two dozen houses removed from a dangerously unstable area where ten people had perished in a slide, homeowners fought the action and sued to reoccupy their dwellings. One turned away inspectors at gunpoint.

The Oddstad Tragedy

ONE of the most publicized debris flows of the 1982 storm occurred on Oddstad Boulevard, in Pacifica, a town of 37,000 people south of San Francisco. Mud with the consistency of wet concrete poured down a hillside in a 1970s subdivision, smashing two houses and trapping three small children inside one of them. Rescuers shoveled through the wreckage for thirty-six hours, hoping the children had survived in a pocket of air. They hadn't. Cal Hinton, a Pacifica city councilman who was the fire chief at the time, helped to dig out the bodies. "I remember taking the blanket off them. They'd been in bed asleep. They were still clean underneath, no blood or anything. I don't remember what the autopsy said, whether they were crushed or smothered. I imagine it was a combination."

The two lots where the houses had stood remained vacant for years. Ray Wilson often passed by on his way to a hiking trail at the end of Oddstad. One day he noticed a FOR SALE sign on one of the properties. By 1998 new houses had been built on both lots and sold to new owners. This did not seem to be a noteworthy event in Pacifica. The last newspaper story on the Oddstad tragedy was written years ago. The parents of the dead children divorced and moved away. Deflection walls have been built behind the new houses; dirt and vegetation have been scraped from the hillside, and subsurface pipes are in place that are supposed to collect water before it can cause more slides.

A legacy of the 1982 storm is Pacifica's policy requiring expert review of new construction on problem sites like these. These sites are common in Pacifica -- as might be expected in a town bounded by earthquake faults, a mountain range, and cliffs that are sloughing into the sea. But despite the precautions being taken, the San Francisco consulting geologist Robert Wright is uneasy. "I spent about five years of my life studying that slide," he says, "and I'm personally uncomfortable with rebuilding houses there. You just don't put homes in the mouths of swales if you can help it. It's just too risky."

There are "hard" solutions to landslide risk -- debris dams, retaining structures, graded slopes, elaborate drainage systems, even, in Japan, a $210 million highway overpass that coils improbably around a large slide area. Geoscientists argue that "soft" solutions like zoning and building codes, which rely on simple avoidance, are cheaper and safer in the long run. San Mateo County, which permits only one living unit per forty acres in geologically hazardous areas, probably has the strictest such ordinances in the country. But they don't apply inside Pacifica and other San Mateo towns, where local governments say "maybe" to developers far more often than "no." Saying no is especially difficult because slides occur so erratically, over such long intervals. New developments notwithstanding, the question persists: What should be done about dangerous places where people already live?

A landslide-warning system would at least alert residents when slide conditions were developing. "Even if you're in an area that in 1982 would have been a deathtrap, you're really only in danger for a few days a decade -- usually at night," Ray Wilson says. "You can broadcast a warning over the weather radio that advises people when they need to leave. If they choose to stay -- well, God bless 'em and keep 'em." In 1986 in the Bay area the USGS set up the nation's first warning system, employing a two-step rainfall threshold that correlated with high debris-flow activity. The first threshold was a seasonal accumulation of eleven inches, normally reached a few weeks after the winter solstice. The second threshold was any single storm that exceeded 30 percent of the local mean average precipitation. By monitoring a network of seventy-five rain gauges and several piezometers (which measure pore pressure in the water table), the USGS knew when rainfall was approaching dangerous levels, and issued warnings so that residents of risky areas could evacuate. There was talk of expanding the system to Los Angeles County. But when the agency downsized, in 1995, the program was abruptly canceled. "The whole thing cost peanuts -- maybe fifty thousand dollars a year," Wilson says. "We got all kinds of good publicity, and it really raised public consciousness. My worry is that people have forgotten all about it now."

Torrential rains brought by last winter's El Niño weather pattern produced what Wilson calls "a bumper crop" of debris flows along northern California's coastal hills, from Big Sur to Mendocino. As the geologists had hoped, slide activity appeared to correlate with their rainfall-threshold calculations. It also coincided with severe landsliding in southern California, raising concern that increasingly frequent heavy weather (there have been three strong El Niños and two weaker ones in the past sixteen years) will cause more debris flows than ever before. Even so, nothing yet compares to the scores of deaths and the tremendous damage wrought in the Coast Range by the storm of 1982. And after all this time a critical question remains unanswered. Why did the hillsides -- 18,000 of them -- suddenly fail in unison?

"I've always had this idea," Robert Wright says, "that when you have an Oddstad and it decides to go off, it's owing to something happening in the ground on a very small scale. I think the answer might be in microscopic changes brought about by weathering processes that change the nature of how the particles behave. On Oddstad there were several swales that did not fail in 1982. They had the same materials, the same rainfall, everything was the same -- except something was not. The swale that did fail had sat there for maybe eight thousand years. There's no way there haven't been rainstorms bigger than that in all that time. It went through maybe hundreds of them and didn't fail. Why then? We don't know."

Continued...

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Illustration by Bryant Wang

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