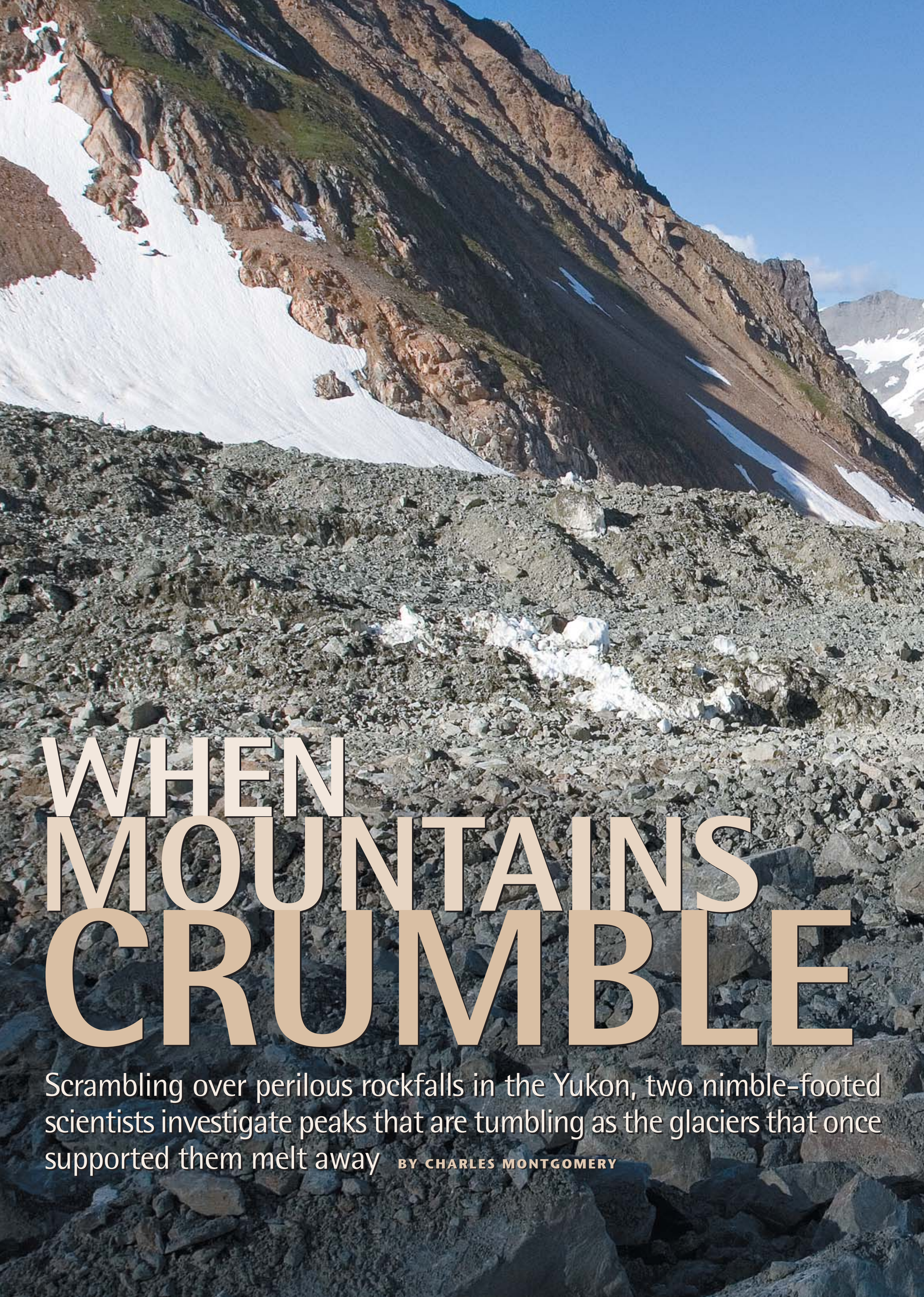

WHEN MOUNTAINS CRUMBLE

Scrambling over perilous rockfalls in the Yukon, two nimble-footed scientists investigate peaks that are tumbling as the glaciers that once supported them melt away BY CHARLES MONTGOMERY

THIS PAGE, BOTH: DAN SHUGAR; OPPOSITE AND PREVIOUS PAGES: CHARLES MONTGOMERY

The sandpiper is not much bigger than the palm of my hand. It lies on its back, wings splayed, neck twisted, thin beak jammed into the sun-softened snow near the middle of the valley of ice.

Denny Capps pulls off his sunglasses and gingerly nudges the carcass with the tip of his ice pick. He frowns, his gaze moving to the edge of the carpet of rock and debris that extends all the way up the glacier. Clambering somewhere amid that maze of smashed stone is his research partner, Dan Shugar, who would surely be as stunned by this discovery as we are.

Capps, a slow-talking 34-year-old Louisianan, is not a shouter. He emotes mostly with his eyes, and now his eyes are wide with excitement. "Looks like our little friend here got blasted right out of the sky," he murmurs.

The bird's feathers are splattered with fresh mud and specks of gravel. It died recently, and it died suddenly — apparently whacked from flight or some lofty perch by a chunk of the same landslide that buried much of this glacier. Judging by the snow still plastered to the boulders nearby, the slope above had ruptured perhaps weeks before our foray into the St. Elias Mountains, which straddle the Alaska, Yukon and British Columbia borders west of Whitehorse. In other words, Capps and Shugar have struck a geomorphologist's version of Yukon gold.

Denny Capps cautiously approaches a sinkhole (LEFT) and observes a 200-metre-wide track (PREVIOUS PAGES) left by landslides on the Jarvis Glacier. Capps and Dan Shugar (BOTTOM, at rear) sift through rubble from the same slide. Glacial lakes, such as this one atop Alaska's Brady Glacier (OPPOSITE BOTTOM), will drain as the ice dams that created them eventually melt.

Both Ph.D. students at the Quaternary Geoscience Research Centre at Simon Fraser University (SFU), in Burnaby, B.C., Capps and Shugar are trying to understand how mountains and glaciers respond to climate change. There is no better laboratory than here on the roof of North America.

The St. Elias Mountains are dominated by some of the continent's highest peaks and the biggest non-polar icefield on the planet. It is one of the most dynamic landscapes on Earth and is being made increasingly so by climate change. Capps, Shugar and others are finding growing evidence that rapid warming has kicked the age-old processes of mountain geomorphology into fast-forward.

For one thing, the mountains are crumbling.

We are at the Jarvis Glacier, southeast of Haines Junction, Y.T., to examine the remains of a landslide that tumbled onto this 11-kilometre-long valley glacier back in 1979. Shugar had been planning to chart the 26-year journey the slide's debris had taken down the Jarvis, but moments after setting up camp on the belly of the glacier, we spot a dark grey stain painted across a side valley. The blemish had not appeared in any of Shugar's aerial photos or on recent satellite images. It had to be fresh.

Shugar, a gregarious 27-year-old Vancouver native leading his first field expedition, vibrates with enthusiasm at the

MAP: STEVEN FICK/CANADIAN GEOGRAPHIC

In the pre-dawn hours of July 23, 2002, a surprise flood swept through the Taiya Valley. Dozens of people had to flee for their lives.

sight of it. Here is a chance to confront the rough edge of catastrophic change before time or the elements can tamper with the evidence. After the thump of helicopter blades fades into the mist, he pulls out his maps to plot the two-kilometre-wide maze of ice, crevasses and moraine.

The next morning, we rope up and head across the glacier's wrinkled surface. At first, the silence is broken only by the crunch of crampons on snow, but as we enter the side valley, the walls echo every few minutes with the thunder and pop of falling rocks.

We reach the terminus of the slide and climb onto a heap of chunked ice, sculpted snow and rubble caked in muck. The debris appears to have been torn from a wound in the crest of a 2,100-metre-high ridge. It had poured down a cliff and across an ice-covered bench, where it had hit a wall, banked like a bobsled, careened over an icefall and spilled down nearly two kilometres of gently sloping glacier into a tongue wider than two football fields.

"Right here is where climate change is manifesting itself," says Shugar, pointing to the steep valley walls on all sides. The receding glacier has left lines of scoured rock along its edges, like rings around a bathtub. "These glaciers have experienced significant downwasting since the Little Ice Age. As a glacier melts, it stops holding up the valley walls, making them liable to collapse. This has happened all over the St. Elias Mountains."

Much of the melting since the Little Ice Age — an approximately 350-year cold spell that bottomed out in the mid-1800s — is partly a reflection of the Earth's natural climate cycle. But the pace of warming has sped alarmingly in the past quarter-century, and there have been dozens of major landslides in the St. Elias range over the same period. Though some of the slides have been triggered by earthquakes, says Shugar, many scientists believe the root cause is rapid glacial retreat due to climate change itself.

With just three days before our helicopter ride out, Shugar has no time to waste. He straps on a GPS unit and sets off to chart the extent of the slide, while Capps and I explore the vast debris field, a place of alien beauty and strangeness. There are boulders as big as houses. One has plowed through the surface of the glacier like a meteorite, leaving a trench in its wake that could swallow me whole. Its uphill flank is still plastered with dirty snow and dripping mud.

There is our little sandpiper, which, despite the awesome mass of the slide, was not crushed or deformed. Had it been struck by a small stone? Had it been knocked to the ground by a blast of wind as the slide thundered down? There is no way of telling. Strangest of all, deep levees run for hundreds of metres along the flanks of the slide. Their walls are higher than we can reach and glassy, as though the debris had melted an ice track for itself.

Capps and I catch up to Shugar on the uphill edge of the rubble. He pulls down the scarf that protects his face from the snow's glare and smiles broadly.

"This is the place. This is it," says Shugar, kneeling on a boulder made of slatelike phyllite and peering at the grit-caked surface through a hand lens. "And we got here just in time. In a year or two, all this fine material will either have been blown away or sieved through the bigger rocks. The story will be lost."

As Shugar scribbles in his field book, Capps explains the other ways in which mountains are responding violently to climate change. When a glacier melts quickly, lakes form under and around it. The water is contained by walls of ice

LEFT AND TOP: CHARLES MONTGOMERY; OPPOSITE: DAN SHUGAR

or moraines, piles of sediment dumped at the glacier's terminus. These fragile dams can be breached by heavy rains, rapid melting or mini-tsunamis triggered by a landslide or falling ice. The result can be a catastrophic flood downstream.

It was one such flood that drew Capps to these mountains from his native Louisiana. In the pre-dawn hours of July 23, 2002, a surprise flood swept through the Taiya Valley north of Skagway, Alaska, which happens to house part of the famous Chilkoot Trail. Dozens of residents and campers had to flee for their lives.

"That flood came out of the blue," says Capps. "They had no idea it was coming." As an intern geoscientist for the U.S. National Park Program at the time, he was called in to figure out what had happened. He discovered that in the middle of the night, high up in the headwaters of a Taiya tributary, eight million cubic metres of water-saturated rubble and moraine — enough to fill Toronto's Rogers Centre more than twice — had liquefied and slid into a lake full of glacial meltwater. The lake burst its banks, and the flood came fast and furious into the valley.

When he searched for other risks in the area, Capps was shocked to find a handful of uncharted moraine-dammed lakes above the trail — and, later, above Skagway itself.

Car-sized boulders from a 1990 rock avalanche on the Frobisher Glacier lie behind a note-taking Capps (ABOVE). Scoured valley walls show where the Kaskawulsh Glacier (TOP) once was. Its thinning has created an ice-dammed lake at its terminus (OPPOSITE).

"The glaciers have pulled back, and those lakes are not even on the maps. No one seems to know they exist," he says. "A couple of them could threaten Skagway. They may be stable, but then again, who knows? They haven't been studied.

The Athapaskan and Tlingit warned that glaciers were sentient beings and responded to human foolishness or arrogance with devastating force.

So there are no warning devices, nothing to alert people if a flood goes off, say, during an earthquake."

Skagway is home to fewer than 900 people, but every summer, cruise ships disgorge thousands of tourists daily onto the town's boardwalks. Although Mayor Tim Bourcy says most people aren't worried about the risk of outburst floods, Hal Pranger, a former geologist with the U.S. National Park Service, says there are moraine-dammed lakes in the area worth worrying about, including one right above the town.

Capps has urged the town to learn more about outburst-flood risks and protect itself, but an in-depth study of these hazards has yet to be launched. His frustration at the apparent lack of concern was one of the reasons he sought the tutelage of glacial geologist John Clague, who specializes in linking earth science with catastrophic risk reduction. Clague, the Canada Research Chair in Natural Hazards Research at SFU, has guided Shugar, Capps and more than a dozen other graduate students through the thinning glaciers of the northwestern corner of North America.

"We are dealing with the effects of an unprecedented loss of snow and ice in the high mountains," said Clague when we met at the SFU campus a month earlier. "The St. Elias range is just a perfect region to study these things."

Temperatures in the region have climbed 0.4°C per decade since the 1960s. And, correspondingly, laser altimetry surveys show that glaciers along the Alaska, Yukon and B.C. borders thinned, on average, about half a metre a year between the 1950s and 1990s. In the past decade, the rate has jumped to 1.8 metres a year, a total loss almost double that of the Greenland ice sheet. A 2006 study compared digital elevation models with radar data from a space shuttle mission in 2000 and found even higher thinning rates — up to 14 metres a year in parts of the St. Elias Mountains. Glaciers are thinning at different rates. The area around our rock avalanche, for example, appears to be thinning by more than four metres a year. The ice in Glacier Bay, on the southwest edge of the St. Elias range, has melted so much in the past 150 years that it has contributed to a deformation of the Earth's crust, which is practically rebounding from its Little Ice Age burden like a trampoline.

Even without climate change, the St. Elias Mountains would be a fantastically dynamic place, fuelled by extremes in elevation and precipitation. The range forms an almost impenetrable barrier to the cyclonic systems that charge east across the North Pacific. The jet stream wows north

THIS PAGE: DAN SHUGAR; OPPOSITE, BOTH: CHARLES MONTGOMERY around the range, like a river thrown off course by a great boulder. Mount Logan, Canada's highest peak, soars to 5,959 metres, barely 60 kilometres from the ocean. The high icefields around it collect as much as four metres of snow every year, while the rain shadow to its east has produced a near-desert along Kluane Lake.

These conditions have made the range a mecca for scientists interested in the effects of climate change. Over the past 50 years, hundreds of researchers have conducted their fieldwork from a spartan collection of huts and labs on the shore of Kluane Lake run by the Arctic Institute of North America, an affiliate research organization based at the University of Calgary. By late July every year, the station is packed with dust-caked glaciologists, geomorphologists, limnologists and biologists comparing the evidence of environmental change they are now finding amid ice cores, tree rings and layers of lake mud.

Even the pilots who ferry researchers back and forth to the heart of the range have noticed alarming changes at their icefield landing strips.

"Our work is getting a hell of a lot harder," says Andy Williams, who manages the station and has been flying scientists to Mount Logan for more than 30 years. "I can't land on some of my old low-elevation sites anymore. There are more obvious crevasses, rougher surfaces and more avalanches. In the summer, we're getting more isothermal snow — freeze on top of a warm layer of mush. If you land on that stuff, *you* may not be done for, but your plane sure is."

Glaciers at lower elevations are receding, but climate change isn't necessarily erasing the St. Elias ice cap. In fact, it could be making it more dynamic.

In 2002, teams from Canada, the United States and Japan sunk their drills into high-elevation ice around Mount Logan. The Canadian team drilled all the way to bedrock and pulled out a 190-metre core, samples of which were shipped to labs around the world for analysis. Using indicators, such as comparing the core's sulphur content to that of prehistoric volcanic eruptions, scientists concluded that the ice represented 20,000 years or more of snow.

The molecular structure of ice crystals in the core provided evidence of striking shifts in large-scale atmospheric circulation long before the current warming trend. During the

Signs of summer paint the slopes above the Jarvis Glacier (ABOVE), but evidence of their fragility lies in the rubble of a fresh landslide in the valley. The Donjek River ran under the Donjek Glacier (OPPOSITE) until its ice dam burst, releasing a torrent of water. Capps (LEFT) peers into the Jarvis at what was likely a similar, smaller river.

'The slopes are being brought to a threshold of failure, and you could have a butterfly touch down, and that would do it.'

Little Ice Age, most of the storms dumping snow on the St. Elias range came from the North Pacific. That changed abruptly in the mid-19th century. Now they originate from as far south as the equator.

This effect may be fed by warmer oceans, says Geological Survey of Canada geoscientist Christian Zdanowicz. He believes that more cores are needed to determine any recent trend in snow accumulation. "But what we'd expect in the current warming scenario is more precipitation, which means higher snowfall at higher elevations and more rain down below."

In other words, as warming continues, the glacial conveyor belt would get shorter, but it would carry more ice crystals from mountaintop to valley bottom. The whole system, says Zdanowicz, would be spinning faster.

The power of ice to rapidly transform the landscape is evident just east of Kluane Lake, where the Kaskawulsh Glacier, wider and longer than the island of Manhattan, flows down from the ice cap into the Slims River Valley. Scoured valley walls reveal that the lower half of the Kaskawulsh has thinned by hundreds of metres since the Little Ice Age. Slide debris lies heaped in giant cones along the glacier's flanks.

The Kaskawulsh has advanced and shrunk with the rhythms of climatic change, radically altering the valleys around it. Clague and others have found evidence that Kluane Lake once drained west along the Slims River, past the Kaskawulsh, to the Pacific. The glacier pushed forward during the Little Ice Age, blocking the entire Slims Valley. Thus constrained, Kluane Lake rose four storeys and found an alternative outlet to the north. Its waters now flow all the way to the Bering Sea. The Kaskawulsh is receding again, leaving behind a wasteland of transported rubble, gravel pyramids and temporary lakes and streams in the Slims Valley.

The people who inhabited the flanks of the St. Elias Mountains for millennia have long attributed the movement of glaciers to human influence. According to retired University of British Columbia anthropologist Julie Cruikshank, who compiled histories from the region for her book *Do Glaciers Listen?* the Athapaskan and Tlingit warned the first European visitors to take care around glaciers. These were sentient beings, they said, and responded to human foolishness or arrogance with devastating force. When the vast Lowell Glacier surged forward in the 1850s, then fractured to create a calamitous flood along the Alsek and Tatshenshini rivers, one story suggested the event had been set in motion by a disrespectful word from an impetuous Tlingit child.

"The glaciers were as animate as any animals," says Cruikshank. "They were living. They responded to people. They took offence easily. You had to be very circumspect in the way you behaved around them, or you would be served catastrophic consequences."

European visitors never took such warnings seriously. When French explorer Jean-François de Galaup de La Pérouse, sailed into Latuya Bay on the western edge of the St. Elias Mountains in 1786, he thought himself on the very "verge of the world." The glacier-draped mountains seemed to Europeans an immaculate kingdom, untouched and unresponsive to human influence.

But, in a way, the First Nations storytellers, with their acknowledgement of the dynamic relationship between man and mountain, are proving more prescient. The internal combustion engine that emerged in the decade following La Pérouse's visit sparked a fire that seems to be touching every corner of the globe. As scientists grow increasingly certain about the atmospheric effects of burning fossil fuels, no mountain range is entirely pristine anymore — though in some ways many are becoming wilder.

While landslides and floods now threaten portions of the Alaska Highway and the proposed Alaska Natural Gas Pipeline that will run along it, on the eastern edge of the St. Elias Mountains, rapid change among glaciers in the Himalayas and Andes have long been devastating for the people who have settled the valleys beneath wasting glaciers.

In 1941, after two decades of pronounced warming in Peru's Cordillera Blanca, a chunk of weakened glacier ice fell into a moraine-dammed lake above the town of Huaraz. The resulting flood rushed into another lake, churning up and spilling a debris flow that destroyed one-third of the town and killed 6,000 people.

Twenty-one years later, after more glacial retreat, 13 million cubic metres of rock and ice detached from Huascarán, the highest peak in the range. The slide destroyed several villages and claimed up to 4,000 lives. Eight years later, an earthquake shook loose a slide many times bigger, burying the town of Yungay and killing some 18,000 people. The second slide couldn't be definitively blamed on climate change, but the peak had been extensively weakened by melting.

"Too many geologists are always searching for triggers," says Clague. "In these cases, the slopes are being brought to a threshold of failure, and you could have a butterfly touch down, and that would do it."

Meanwhile, the United Nations Environment Programme has warned that outburst floods have become increasingly common in the Himalayas since the 1950s. A 2002 United Nations study revealed that more than 45 glacier- or moraine-dammed lakes in Nepal and Bhutan are at the bursting point. When these lakes flood, people living as far as 100 kilometres downstream can be caught in the torrent, with little warning. When Dig Tsho, a moraine-dammed lake in Nepal, burst in 1985, a 15-metre wall of water destroyed 14 bridges and drowned dozens of people. Clague estimates that there have been about 30,000 deaths from glacier-related catastrophes in the past 150 years.

Dust rises from a landslide that Capps witnessed with awe and Shugar escaped.

"Catastrophes are a mix of factors, which increasingly include climate change," he says. "But they don't always offer the smoking gun."

Given the confluence of natural and man-made warming, many mountain glaciers will continue to melt for years to come. A better understanding of the mechanics of the resulting catastrophic events could help avoid tragedy.

This is one of the reasons Shugar and Capps move with such studious intensity over the St. Elias glaciers. The new slide offers an intriguing puzzle: how did all that rock manage to travel so far on such a gently sloping glacier?

Geomorphologists have been pondering the mechanics of landslides for decades. One old hypothesis of why debris flows farther on ice than elsewhere was that it moves like a hovercraft, on cushions of air. Shugar speculates the muddy rocks and polished walls of the snow levees on this slide might reinforce another emerging theory.

"Look at this stuff," says Shugar, scraping a handful of muck from the levee wall. "This could be evidence that the slide fluidized the snow as it travelled. The rocks seem to have pulverized and mixed with melted water on the way down. How else would this mud have gotten here?"

Although the mechanics of the Huascarán slides in Peru are still debated, such fluidization might help explain the devastating speed and reach of the events. In the Yungay disaster, the mountain of slurry sped at up to 75 metres per second across 16 kilometres before burying the village.

Scientists and engineers are taking action to mitigate further disasters. In 2000, engineers in Nepal partially drained one at-risk lake and installed sensors in the river course below it. The early-warning system will give villagers downstream a 15-minute head start on flood waters. In Peru, authorities have drained water from 40 high-altitude lakes through tunnels, open cuts and in some cases, security dams.

But the simplest way to avoid disaster is for people not to build in high-risk areas. Few Canadians live directly beneath the glaciated ranges of the Northwest, but research in the St. Elias Mountains may help scientists better understand the dynamics in regions where people have already settled among glaciers.

First, the risks must be identified. Remote-sensing techniques can help, says Capps. Satellite imaging has become so accurate that careful study of images and data can reveal the finger-thin creep in unstable terrain that often precedes a massive slide. Satellite radiometers can also measure differences in surface temperature and reflectivity, showing changes in snow cover and the growth of glacier-dammed lakes.

When he isn't helping Shugar on his landslides, Capps uses a combination of optical and radar remote-sensing techniques to identify an alarming collection of these lakes around and under the 50-kilometre-long Brady Glacier, above Alaska's cruise-ship-cluttered Glacier Bay. But to prove the usefulness of satellite data, researchers must measure changing landscapes at close range, which is why Capps planned to spend much of August poking around Glacier Bay, and why we now find ourselves halfway up the debris track in the searing glare of a late-July afternoon, clambering among snowy statuettes — measuring, pacing, note taking, recording — when the mountain suddenly speaks.

Capps and I are standing on the lip of the snow levee. Shugar is planted in the middle of the concave slide track, popping rock samples into Baggies.

A gut-punching groan resonates, then a rush and thud from above. Steeple-sized chunks of rock cleave from the cliff face. They fracture into shards as they strike the scree slope below, where tiny puffs of smoke explode as the bombs crack and whiz their way toward the glacier. I instinctively look to Shugar, who appears to be directly in the line of fire. He pauses for a moment, then bounds toward the high edge of the slide track, hopping frantically from boulder to boulder.

When a mountain is falling toward you, it is hard not to take it personally. Hard not to imagine that the mountain is responding to some slight, some lack of respect. The early explorers may have mocked the Tlingit who anthropomorphized these places, but they could not have known that one day, the clouds of our industry would draw a response from even the most remote icefields. You don't need to attribute supernatural power to glaciers to conclude that they are, indeed, listening and reacting to human behaviour.

After what seems like an eternity, the mountain is still again. The shattered rocks settle on the far edge of the glacier. Shugar gives up his sprint and falls back on a rock. Capps doesn't say a word. He simply looks at the mountain and nods gravely. A great cloud of dust and grit rises like a dirty shroud above the valley. The air grows bitter with the scent of ground phyllite. In those seconds, we feel the immensity of this message, the euphoria of witness and, finally, relief in the knowledge that we would not share the fate of our mud-caked sandpiper, at least not this afternoon.

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