

CASCADIA, NATIONAL GEOGRAPHIC, MAY, 1998

DANGER LURKS IN THE CASCADES,

THE VOLCANIC RANGE THAT BRISTLES BETWEEN NORTHERN CALIFORNIA AND BRITISH COLUMBIA. MANY PEAKS ARE STEAMING AND COULD ERUPT LIKE WASHINGTON'S MOUNT ST. HELENS, WHERE VISITORS COMPARE THE CONE WITH A PHOTOGRAPH TAKEN BEFORE ITS 1980 BLOWOUT. NEARBY MOUNT RAINIER (PRECEDING PAGES) AND OTHER PEAKS COULD SEND TORRENTS OF MUDDY DEBRIS DOWN THEIR SLOPES. IN ADDITION, MASSIVE EARTHQUAKES MAY CAUSE TSUNAMIS TO CRASH INTO TOWNS SUCH AS CANNON BEACH, OREGON (BELOW). EACH OF THESE EVENTS HAS TRANSFORMED THE REGION MANY TIMES BEFORE—AND COULD HAPPEN AGAIN IN AN INSTANT.





FIRE AND ICE

Snowy spires that stretch northward from Oregon's Three Sisters to Mount Rainier belie the red-hot magma that built them and still simmers below. Part of the Pacific Ring of Fire, these volcanoes are the heart of an 800-mile-long arc that marks the slow, grinding descent of an oceanic fragment of Earth's outer shell beneath North America—a process called subduction. Beacons for early explorers and settlers, the stunning peaks are attracting ever more residents to Cascadia.



“NEED TO TELL YOU about the etiquette of fire walking,” says Ariel Frager, a serene, raven-haired woman in her 20s. She is speaking to a group of rain-soaked spiritual adventurers who have gathered at Breitenbush Hot Springs, a retreat in the foothills of Oregon’s Cascade Range. It’s almost midnight, and as Ariel speaks, the glow from the hundreds of red-hot coals we have raked into a 12-foot-long path radiates across her face.

“Walk with purpose,” she tells us. “Be mindful of the others ahead of you on the coals. Breathe deeply. And always respect the fire. Otherwise, you’re going to get burned.”

Fire walking has become a popular ritual along the West Coast. “It teaches you to overcome your fears and do what you thought was impossible,” Ariel’s appropriately named co-leader, Heather Ash, says. “In the past this opportunity was given only to medicine men, priests, and shamans.”

My fellow fire walkers have gathered here for various reasons. A skeptical firefighter from the Willamette Valley wants to learn what the trick is. Others seek inner renewal. Some are here on a whim: “I want to get rid of a wart on my foot,” quips a young man from Breitenbush.

I am here as part of a geologic quest. Intense fires burn beneath this stretch of the Pacific Northwest that geologists call Cascadia, after the chain of Cascade volcanoes that includes Mounts Shasta, St. Helens, and Rainier. Cascadia begins about 200 miles north of San Francisco and ends along the north coast of Vancouver Island (maps, pages 20-22).

The geologic turmoil beneath this 200-mile-wide sliver is created mostly by a slab of ocean crust known as the Juan de Fuca plate, which is subducting, or diving beneath the continent, along a zone of faults off the coast. As that plate subducts, it triggers the melting of deep-seated rocks into magma, which rises to the surface to form the range of Cascade volcanoes.

The plate can also subduct in a sudden lurch, producing a powerful earthquake. Geologists have recently realized that such earthquakes can exceed magnitude 9 and send 40-foot-high waves known as tsunamis crashing onto the coastline. As Oregon’s state geologist, Don Hull, told me in Portland: “We’ve got Godzilla sleeping under us.”

Since the residents of Cascadia are walking

on fire geologically, I can’t resist joining a group of them to actually do it. When my turn comes, I take a deep breath. Twelve steps later I am off the coals, heaving with relief and unburned.

The next morning we wonder how we could have walked those 1200°F coals unscathed, but we simply don’t know enough about the science involved. In that way we are like the geologists who are grappling to understand the many unknowns that keep the fires beneath Cascadia burning.

My interest in Cascadia began four years ago, while I was working on an article about California’s San Andreas Fault.* I had driven with Gary Carver, a geologist at Humboldt State University, through windswept ranchland along California’s north coast to see where the San Andreas ended. We crossed a grand and lonely landscape. Mountains seemed to surge out of the blue sea, tumbling inland from aprons of isolated beaches. Finally we caught sight of a 326-foot-high coastal rock called Sugarloaf Island, the westernmost point in California and the first landmark of Cascadia.

“We’ve left San Andreasland,” said Carver. “From here north it’s timbered forests, spotted owls, salmon, and rain—everything the Pacific Northwest is known for.”

One thing the Pacific Northwest has not been well known for is earthquakes. Ask the many Californians who moved to Oregon thinking they had left earthquake country behind.

Native Americans knew better. A spirit called Earthquake survives in stories passed on by indigenous peoples throughout Cascadia. When I return to the region in 1997, Carver takes me to Big Lagoon, about 50 miles north of Cape Mendocino. We walk to the remnants of a Yurok village called Oketo.

“There was a sweat lodge here,” says Carver, who has been researching native legends with his wife, Deborah. “One story tells how people came here in terror when they saw the ocean standing high like hills. They brought their woodpecker headbands, which they wore only when doing a jumping dance to ward off

*See “Living With California’s Faults,” by the author, in the April 1995 issue.

This is photographer JIM RICHARDSON’S 11th story for NATIONAL GEOGRAPHIC. He lives in the seismically stable state of Kansas.

impending disaster. Soon waves were hitting the walls of the sweat lodge.”

Since the sweat lodge was at least 30 feet above sea level, Carver is convinced that the Yurok were describing a tsunami that struck following an earthquake along the Cascadia subduction fault. Tsunamis are sometimes erroneously called tidal waves but have nothing to do with tides. The word “tsunami” means “harbor wave” in Japanese, and they are natural responses to earthquakes.

Such earthquakes occur when all or part of the subducting plate gets locked against the

Then a geologist named Brian Atwater began publishing disquieting evidence he had found in the coastal marshes of Washington State.

MEEET ATWATER at his campsite on the central Washington coast on a gray, lightly raining morning in June. He straps a canoe onto his pickup, and we drive with a team of students toward the estuary at Copalis Beach. Atwater, a self-effacing, bearded geologist with the United States Geological Survey (USGS) in Seattle, wants to show me his ghost forest.



overlying plate, and strain builds. The sea-floor plate subsides, while the land on the overlying crust slowly buckles upward. When the lock eventually breaks, the subsided sea-floor rebounds, displacing many cubic miles of ocean in a series of tsunami waves. At the same time, the elevated land along the coast drops.

Until the mid-1980s there was no evidence that a subduction quake had ever hit Cascadia. Most scientists figured the Juan de Fuca plate was diving smoothly beneath the continent.

CREATIVE POWER

You're looking at the growth of North America, says Ray Wells of the U.S. Geological Survey (USGS), describing rocks at Copalis Beach, Washington. These contorted layers were once mud and sand swept to shore by waves. Offshore the sediments settled as a dust blanket on the ocean floor. But the dust was moving eastward and downward, subducting under the continent. Like a conveyor belt, the continent's edge scraped up the sediments to form this new land.

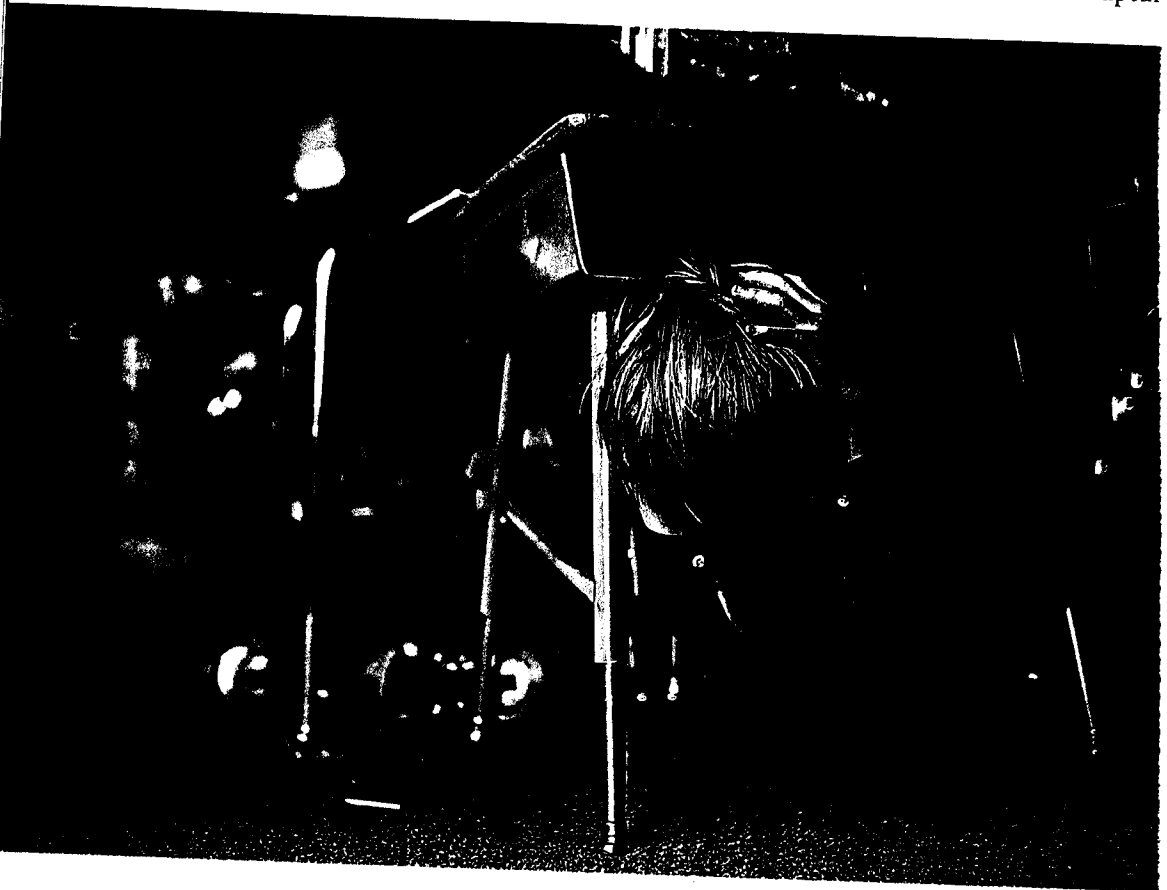
At Copalis we put on hip waders and paddle deep into the estuary, stopping at a bank covered with grasses. We climb out of our canoe and trudge through sucking mud up the steep bank. Once on top we see an army of dead cedar trees, bleached and leafless, rising out of the marsh.

"They are quite out of place here," says Atwater. "Cedars don't like salt water, and here they have their feet in it. Until 300 years ago this would have been an upland. We would be looking at an old-growth forest. Then the land dropped at least a meter, and

similar evidence for this 300-year-old even along the Cascadian coast, as well as evidence for many earlier subduction earthquakes.

Geologists have debated the size of these earthquakes. If the entire subduction-zone fault ruptured from northern California in Canada, it could create an earthquake of magnitude 9 or higher. If just a small part of the fault broke, the earthquake might be only a

But thanks to the detective work of Ken Satake, a tsunami specialist with the Geological Survey of Japan, many geologists now agree that the entire subduction zone ruptur



the upland became a tidal flat, killing the trees."

Atwater has also found evidence here for the tsunamis that followed the earthquake. He digs into the five-foot-high mudbank to show me an inch-thick band of oceanic sands sitting on top of dark soils typical of forest floors. Radiocarbon dating of tree roots in the soil shows that the trees died and the sand was laid down around 1700.

Since the discovery of the tsunamis in 1986 Atwater and other researchers have found

nearly 300 years ago. Satake found in local Japanese records that tsunamis struck the coast of Honshu, directly across the Pacific from Cascadia, on January 27 and 28 of 1700. Through a painstaking process of elimination, he ruled out all possible sources for the tsunamis other than an earthquake in Cascadia of magnitude 9. Then, calculating the time required for a tsunami to cross the Pacific, he determined that Cascadia's last great earthquake struck at about 9 p.m. on January 26, 1700.

Tree-ring scientists have since figured out when ghost-forest trees died along the Washington coast. The most exactly dated of these trees laid down their last ring in the year 1699.

HOW OFTEN do the big quakes recur? Seven centuries had elapsed between the one in 1700 and the one before it. But the two before those were only three centuries apart. Using satellite positioning systems that let them measure the distances between a number of ground-based antennas to within millimeters, geophysicists can actually watch the strain build beneath Cascadia. At the University of Washington scientists have determined that the tip of the Olympic Peninsula in the northwest corner of the state is moving northwest at about half an inch a year. As Tony Qamar, Washington's state seismologist, puts it: "The earth here is being compressed like a big spring."

To the north along the subduction zone at the town of Ucluelet on the west coast of Vancouver Island, Canadian scientists see a similar squeeze. Their ground-based satellite station is moving west at about the same rate. The coast there is also buckling upward at about a fifth of an inch a year. "Strain has been building for 300 years," says Garry Rogers of the Geological Survey of Canada as we gaze out over the Pacific from the peaceful shores of Ucluelet. "If the earthquake happened right now, we would quickly drop several feet and jolt ten feet seaward."

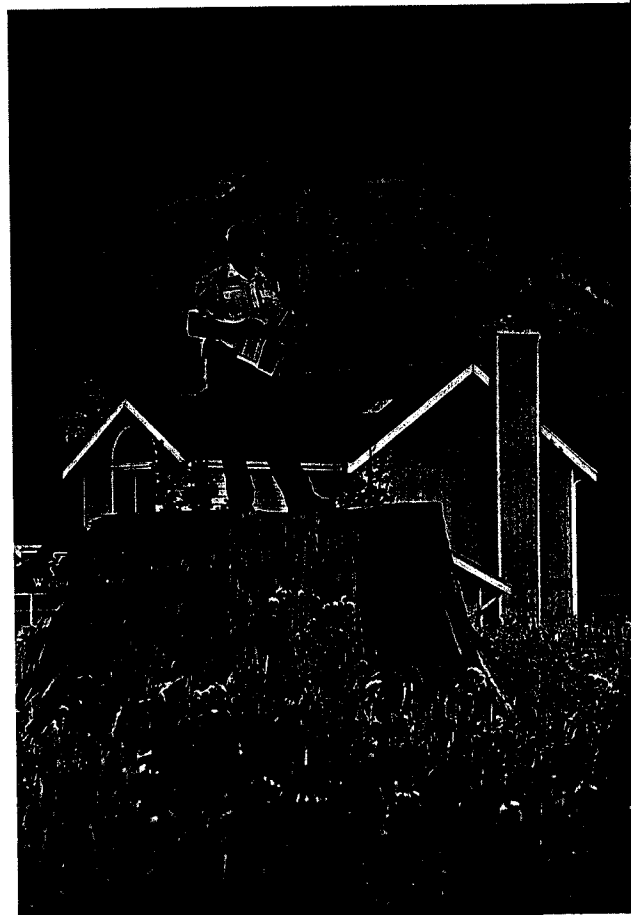
Along the coast, tsunamis would intensify the dangers of such an earthquake. To appreciate what those tsunamis would do, I drive Oregon's scenic coastal highway with Don Hull, the state geologist.

"After the great earthquake, there'll be a series of large waves," says Hull. "The first will arrive within 5 to 30 minutes, and we'd expect heights of 15 to 25 feet, but they could be much higher in places. Several more waves may strike over the next few hours."

Hull is taking me to a town meeting in Waldport, about midway along the coast. Bonnie Conrad Dunn, a port commissioner there, had called his office after learning of past tsunamis in nearby wetlands. Alarmed, she had mustered community leaders to discuss the need for tsunami emergency plans.

"It comes from my old Girl Scout training," she tells me when I meet her in Waldport. "Be prepared."

At the meeting Hull explains steps that can be taken by this town, which has an average elevation of 12 feet above sea level and two schools that sit on a floodplain. Critical facilities can be built high enough to stay dry. Tsunami warning signs can be posted along the beaches. Evacuation drills should be conducted, especially in low-lying schools.



IN HARM'S WAY

in low-lying areas in Oregon: All schools on the coast must conduct periodic safety drills.

In Cannon Beach students duck for cover in earthquake practice; next they hurry to a nearby hill beyond the range of tsunamis.

Waldport, Washington, faces risk from Mount Rainier. There's more to it than an eruption,"

the town's emergency planner Scott Fielding. The town's first school building belonged to a tree felled

by a landslide 600 years ago and dug out to make room for new houses.

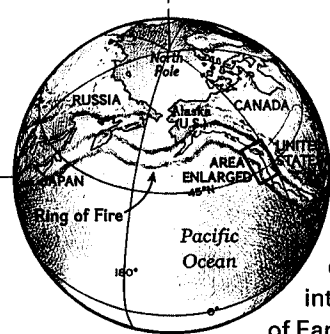
-  Earthquake
-  Volcano
-  Tsunami

quake, magnitude 9
The entire subduction zone, from Vancouver Island to Cape Mendocino, probably ruptured, creating tsunamis that hit Japan.

earthquake, M 7.5
The largest onshore earthquake in Canadian history was felt as far south as Portland, Oregon.

NATIONAL GEOGRAPHIC MAPS
DIGITAL MAP SOURCE:
RALPH A. HAUGERUD, USGS

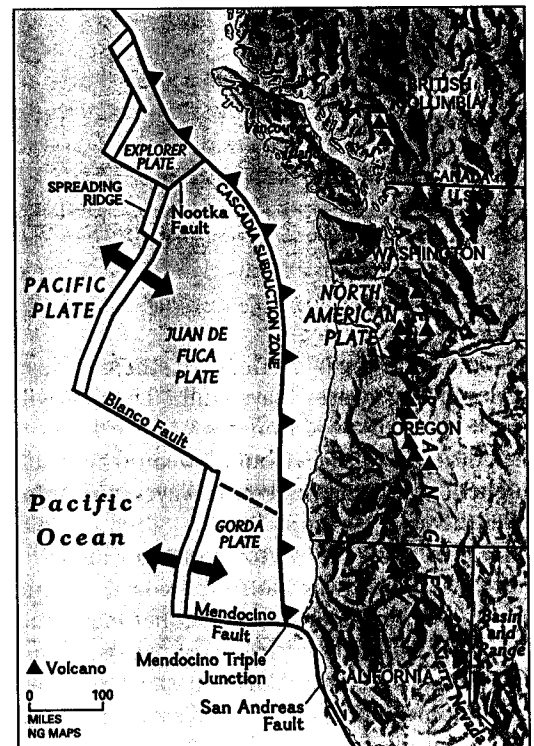
Scale varies in this perspective.



ETERNAL UNREST

A sobering array of hazards results from the movement of tectonic plates, the interconnected pieces of Earth's crust. In Cascadia the subduction of the Juan de Fuca, Gorda, and Explorer plates causes devastating earthquakes and tsunamis every few centuries and creates the range of volcanoes that gives the region its name.

Though the same process stokes geologic fires around the Pacific Ocean, this subduction zone has unique complications. Edging toward Vancouver Island, the Juan de Fuca plate drags at North America, causing earthquake-prone fractures. Another source of stress: The Pacific plate's shift northwestward along the San Andreas Fault forces Oregon into Washington. Adding to the pinch, the Basin and Range area is pushing from the east. The calamities cited here (top) are but a fraction of what these forces have wrought over many millions of years.

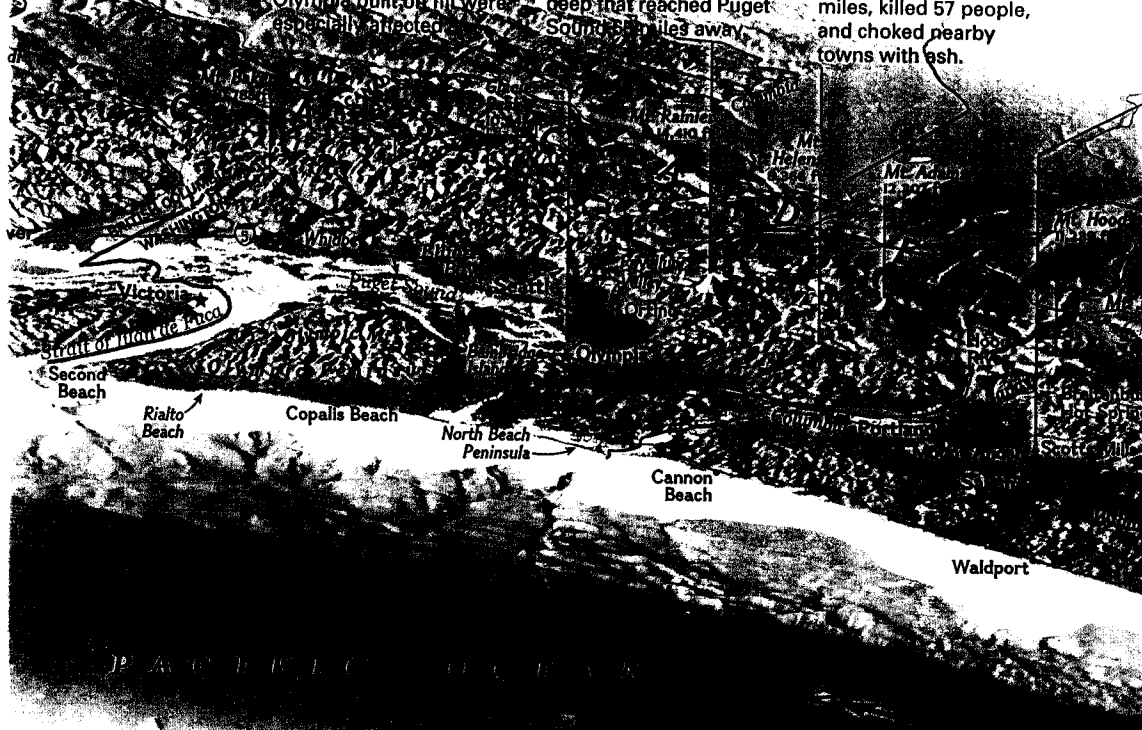


1872, North Cascades earthquake, M 7.4
 This is the largest crustal earthquake ever recorded in Washington or Oregon.

1949, Puget Lowlands earthquake, M 7.1
 Shaking was felt across 150,000 square miles. The parts of Seattle and Olympia built on fill were especially affected.

3600 B.C., Osceola Mudflow
 Mount Rainier's summit collapsed, creating mudflows in places 700 feet deep that reached Puget Sound 80 miles away.

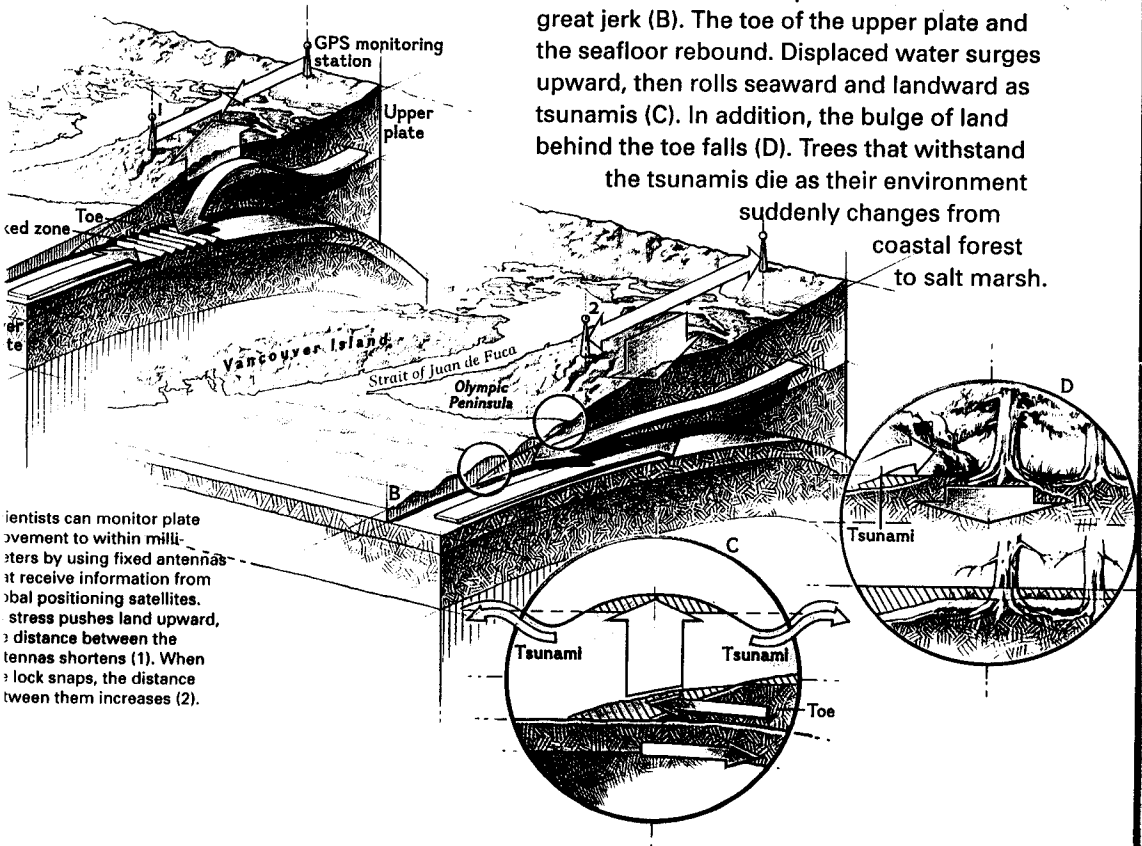
1980, Mount St. Helens eruption
 The largest Cascadia blast in two centuries scoured 200 square miles, killed 57 people, and choked nearby towns with ash.



When a Subduction Zone Rips

Straining against the locked zone on the subduction surface, the lower plate presses forward (A). It drags the toe of the upper plate

with it, causing the coast to bulge up. Finally, sufficient pressure builds to overcome the lock, and the lower plate moves in one great jerk (B). The toe of the upper plate and the seafloor rebound. Displaced water surges upward, then rolls seaward and landward as tsunamis (C). In addition, the bulge of land behind the toe falls (D). Trees that withstand the tsunamis die as their environment suddenly changes from coastal forest to salt marsh.



Scientists can monitor plate movement to within millimeters by using fixed antennas that receive information from global positioning satellites. As stress pushes land upward, the distance between the antennas shortens (1). When the lock snaps, the distance between them increases (2).

This earth in W...

Earthquakes

A zigzag cutaway across Cascadia—from the Olympic Peninsula to Seattle, turning south and then east through Mount Rainier—reveals the origins of three types of seismic events.



Subduction Earthquakes
Along the length of the subduction surface the lower plate can lock against the upper plate for centuries. When it finally moves, a huge quake results.

Deep-slab Earthquakes
Deep-slab earthquakes occur as the subducting plate bends and starts to sink. They have caused the most severe shaking in the region this century.

Crustal Earthquakes
Movement along faults in the upper plate causes crustal earthquakes. One such upheaval 1,100 years ago lies along the Seattle Fault.

SOURCE: RICHARD J. BLAKELY, USGS
ART BY DOUG STERN

When the subducting plate war...

UNSETTLING DETAILS

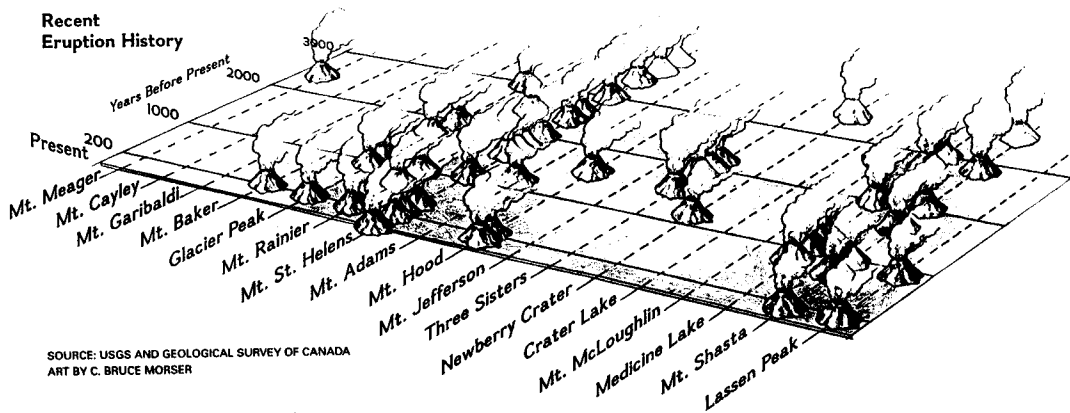
Volcanoes

Cascadia's soaring landmarks seem ageless, but all have arisen in only the past several hundred thousand years. "These are young volcanoes built on the remnants of older ones that are, themselves, built on volcanoes that are even older," says Ray Wells of USGS. "We can trace that history in the Cascades to about 40 million years, and it probably goes back

further." Though eruptions occur erratically, they are inevitable in an active subduction zone. As the oceanic plate descends, increased temperature and pressure force its fluids upward, causing rocks in overlying layers to melt. Less dense than the continental crust, the melted rock, or magma, rises to the surface—often explosively.

Locked zone A Lower plate

Scientists move meter that re global As str the di anten the lo betwe



SOURCE: USGS AND GEOLOGICAL SURVEY OF CANADA
ART BY C. BRUCE MORSER



Citizens should know to head uphill as soon as they feel a strong quake. Such guidelines may seem simple enough to implement, but even after the meeting ends, Waldport's leaders continue to debate the best ways to do so.

Farther north along the Oregon coast, the town of Cannon Beach has already developed a tsunami awareness program. At noon on a July day tourists fill downtown streets, eating ice-cream cones and meandering in and out of gift shops. Suddenly the air is filled by the sound of an angry cow mooing from six loudspeakers set up throughout the town. A voice explains that the bovine ruckus is simply a test of the town's tsunami warning system.

"Some people don't like the noise," says Al Aya, president of the Cannon Beach Fire District, which initiated the system in 1988. "But we've got nine miles of recreational beaches and thousands of visitors. Little kids play in the water. We can't have them swept away."

Residents might have less than half an hour to reach high ground, so powerful sirens will

sound immediately after any earthquake is felt. But in many locations along Cascadia's coastline people could have trouble reaching safety in time. About 1,500 people, for instance, live on a low-lying sand spit across Humboldt Bay from Eureka, California. Only one bridge connects this spit with the mainland. That bridge almost certainly will fail during a subduction earthquake. Likewise, the residents of Washington's North Beach Peninsula, essentially a 25-mile-long sandbar, have only one way off. In the summer thousands of panicked tourists could be trapped.

THE POTENTIAL for Cascadia's earthquakes doesn't end with the subduction zone. "There are actually three forces duking it out in the Pacific Northwest," says Ray Wells, a tall, lanky plate-tectonics specialist at USGS. Wells, who heads a project to assess the hazards underlying the urban corridor of the Northwest coast, takes me on a field trip directly through harm's way.

"Subduction is certainly one important force," he says as we drive east out of Medford, a booming city in southern Oregon, toward the chain of volcanoes that forms the backbone of Cascadia. "But the entire region is also being butted from the south by a large chunk of northern California, including the Sierra Nevada."

That block of California, he explains, is being dragged northwest by the massive Pacific plate and is causing western Oregon to rotate out to sea around a pivot point near Portland. The push from the south is also jamming Oregon into Washington, causing crustal earthquakes and helping to lift the Olympic Mountains.

The third force putting pressure on Cascadia, says Wells, is the Basin and Range—the vast expanse of mountains and valleys that extends between the Cascade and Sierra ranges on the west side and the Rocky Mountains on the east. Geologic heating beneath the Basin and Range has forced that region to swell up

and push westward, eating into the Cascades from the east. To see the impact of the Basin and Range on Cascadia, we head for the town of Klamath Falls, which in September 1993 was surprised by a 5.9 magnitude earthquake, the largest to be felt in Oregon since 1872.

We drive through old volcanic rocks, created, as are all lavas in subduction zones, deep beneath the land's surface at a point where the rocks in the subducting plate grow warm enough to release the abundant water that had been bound up in their minerals. That water migrates upward, lowering the melting point of overlying rocks and turning them into magma. That magma, laden with gases under high pressure, works upward through zones of weaker rock. Eventually the magma breaks through to the surface, creating volcanoes.

As we climb into the western foothills of the Cascades we drive through a canyon that exposes the base of one of the earliest Cascade volcanoes. It is part of a now vanished range of giants that formed when subduction first began beneath Cascadia about 40 million years ago. Today the zone of melting beneath Cascadia has shifted east, so these basement rocks are all that's left of once lofty volcanoes. But one of the subduction zone's most recent offspring gleams in the distance like a snow-streaked pyramid sitting astride the current axis of volcanism.

"That's Mount McLoughlin," says Wells. "More than 9,000 feet high and almost a perfect cone."

Soon Mount Shasta comes into view, some 75 miles to the south. It last erupted in 1786.

To the north lie Crater Lake and hundreds of other volcanoes, large and small, aligned along a north-south arc. We descend into a valley largely filled by 20-mile-long Upper Klamath Lake. High cliffs on both sides of the lake mark faults along which the valley floor is dropping, creating a big hole.

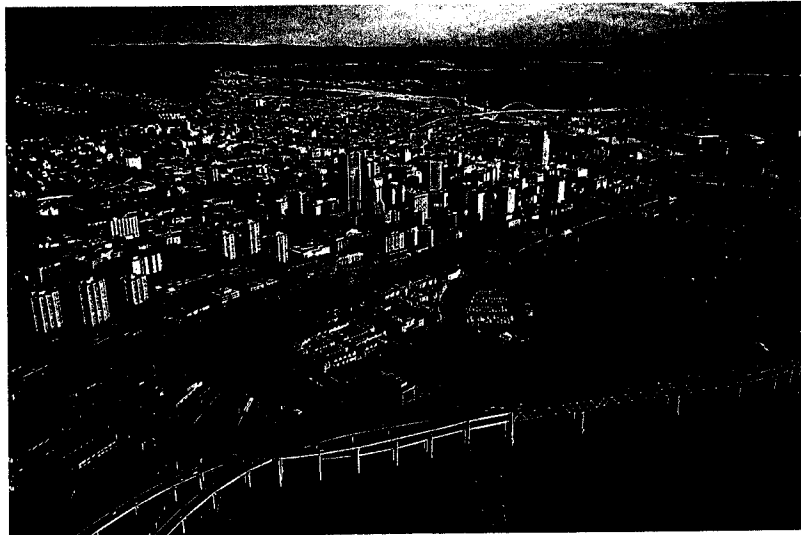
"We have just entered the Basin and Range," says Wells. "Earth's crust here is stretching, cracking, and extending into Cascadia."

Downtown Klamath Falls remains scarred

by that last crack, which pummeled the town with what Wells calls "a wake-up call for all Oregon." A chain-link fence surrounds the two-story county courthouse, its fractured walls now condemned. Vacant lots mark where buildings were torn down after being damaged too severely to repair. On the road north of town, flowers along a fence commemorate the spot where a driver was killed when the quake flung a boulder off a cliff onto his truck.

We drive north toward the city of Bend, then cut back west into the heart of the Cascades. We pass the jagged peaks of the Three Sisters, Mount Bachelor, and Three Fingered Jack. At McKenzie Pass we stand on a sea of black lava that erupted across 40 square miles about 1,500 years ago.

We descend into the flat agricultural Willamette Valley, famous for its fruits and vegetables. Like Klamath Falls, towns here were shaken in 1993 when a 5.6 temblor, known as the Scotts Mills earthquake, woke them on the morning of March 25.



ON SHAKY GROUND

Wedding faults, Portland, Oregon, has strengthened some buildings as well as the interstate highway bridge in the foreground to stand up to the force of future quakes. Thirty miles south in Mount Angel, engineer Edmund Smith inspects steel beams that brace the Church of St. Mary, damaged by the 1993 Scotts Mills temblor. "We have two choices," says state geologist [unclear]. "Reduce the risk before the earthquake or pick up the pieces later."

"I thought it was a herd of elk going across my deck," recalls Larry Owings of the Molalla River School District, whose historic high school was condemned after the quake.

The Scotts Mills earthquake occurred along a shallow fault created as the upper crust of Cascadia was crunched from the south by California, a process that continues today. But no one had known exactly where the fault was—a situation that's disturbingly common in Cascadia.

BUT ON THE DESERT you can find faults easily," explains Silvi Pezzopane of USGS. "In Cascadia the surface is covered over by trees, glacial debris, or sediments. The faults are difficult to find, they erode, and only the largest events break the surface."

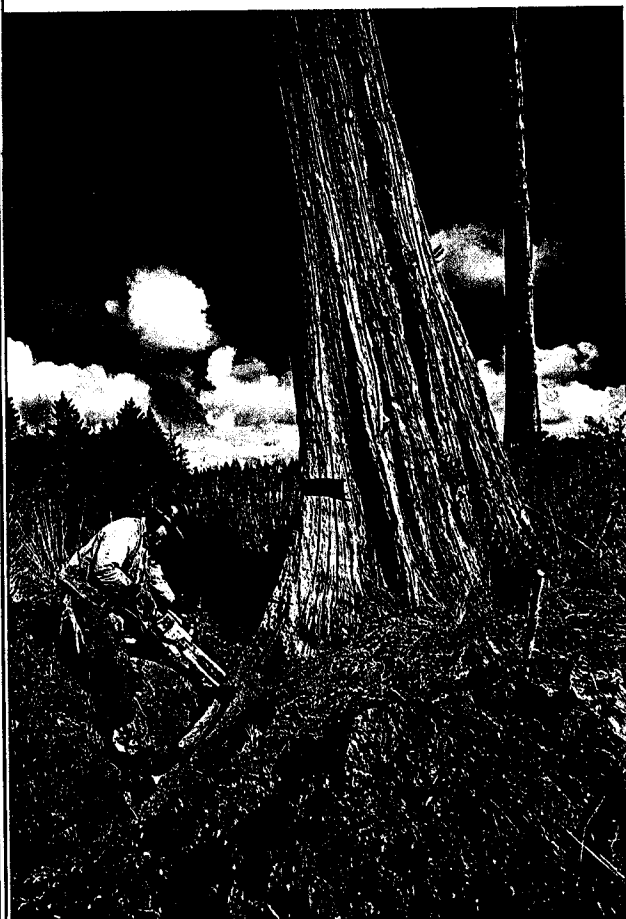
But faults can create small local variations in the magnetism of the crust, and by analyzing aerial magnetic surveys, USGS geologist Rick Blakely has been finding evidence of many subsurface faults in Oregon. Along with Pezzopane and Ray Wells, Blakely suspects that the same fault that created the Scotts Mills earthquake may connect with other faults closer to Portland. The longer the fault, the more powerful an earthquake it can produce. And a quake doesn't have to be that strong to devastate an urban area. The earthquake that rocked Kobe, Japan, in 1995 measured only 6.9. The Northridge quake in Los Angeles in 1994, which took a 20-billion-dollar toll, was a 6.7.

"We now think we've grossly underestimated the number of large crustal earthquakes that could hit the Puget Sound area," says Craig Weaver, a USGS seismologist working at the University of Washington.

Weaver and several colleagues meet me on Bainbridge Island, about seven miles across the sound from downtown Seattle, to show what a quake on one of those hidden faults can do. We walk onto the fairway of a country club along the shore. Seattle's skyline sparkles in the distance as we climb about 12 feet down a cliff onto a rocky beach. One of Weaver's colleagues, Brian Sherrod, points out holes halfway up the cliff that were drilled more than a thousand years ago by a marine mollusk called rough piddock. He reaches up and plucks a clam shell out of the cliff.

"All these mollusks were living underwater," he says. "The ground here was uplifted 21 feet by an earthquake that probably measured about magnitude 7.5."

That uplift probably also generated a tsunami that swept across the sound, depositing a layer of sand in marshes north of Seattle. Radiocarbon dates of marsh plants caught in the deposits indicate that the earthquake hit about 1,100 years ago. It struck along a seismic zone known as the Seattle Fault, which geologists hadn't even documented as active until about five years ago.



MOVING EVIDENCE

"If the tide were high, water would be up to my waist," says USGS geologist Brian Atwater, who cuts a section from a large western red cedar in a Washington salt marsh. Growth rings show that the tree died around the time of the great quake of 1700, when land fell and the ocean inundated coastal forests. A slip on the Seattle Fault 1,100 years ago lifted Bainbridge Island to its former shoreline about the height of the cliff held by Brian Sherrod, also from USGS.

"We now know this entire Puget Sound region is riddled with hidden faults," says Sam Johnson, a USGS geologist.

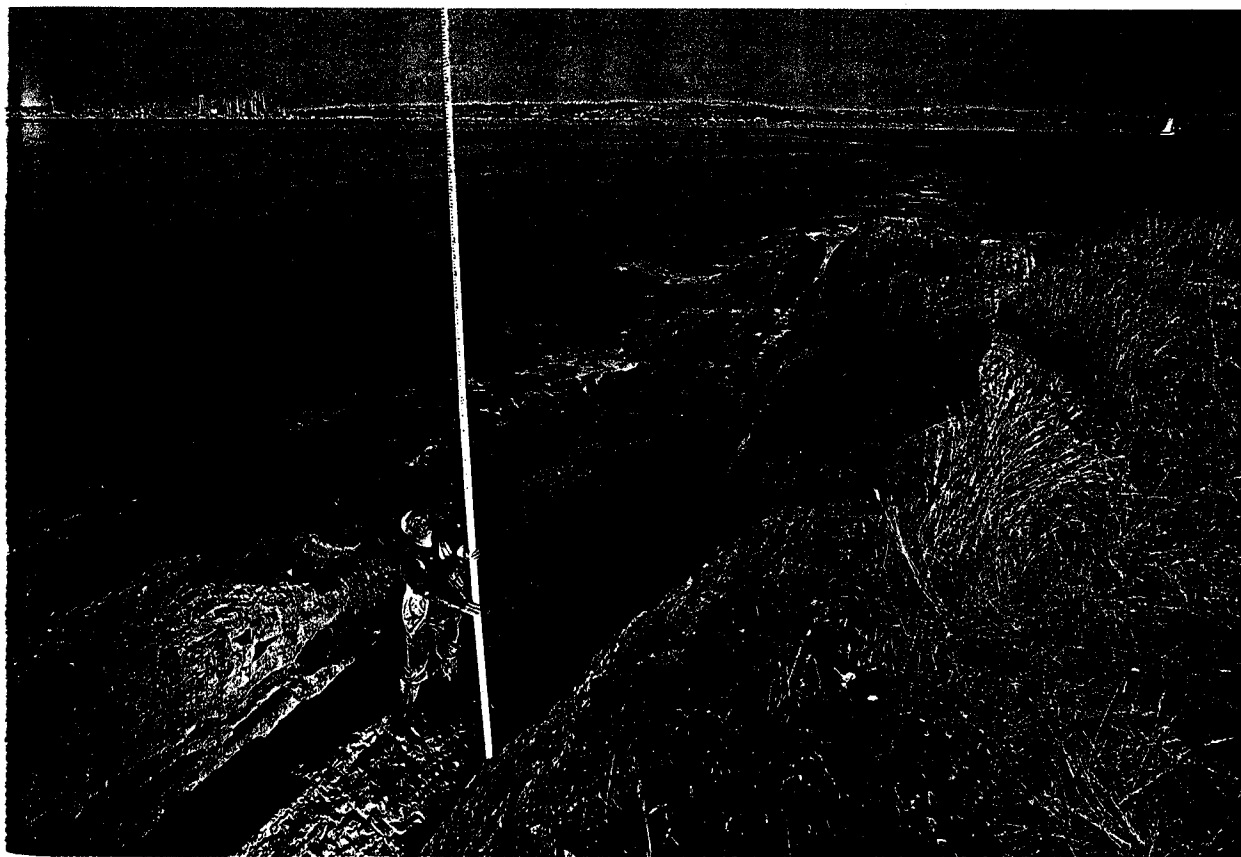
I join Johnson on a refurbished tugboat, the *Robert Gray*, which is towing seismic surveying equipment over the sound, trying to locate some of those faults. The faults are particularly difficult to find here; a layer of glacial debris 3,000 feet deep in places mantles the bottom of the sound.

To penetrate that layer, the boat is towing an air gun and another noise-making device to fire sound waves into the muddy bottom. Every

identify the buried faults and evidence of their recent activity.

Today the crew is studying a 50-mile-long fault that runs offshore from Whidbey Island. Geologists recently realized that a massive earthquake occurred along that fault about 100,000 years ago. Johnson's team hopes to get more information on how often earthquakes recur there.

They have already mapped three strands of the Seattle Fault zone. They determined that those strands are cut by another previously unknown north-south fault zone in the center



ten seconds the air gun pulses a sonic shot downward, inaudible to us but creating a burp of white water behind the boat. Microphones arrayed along a separate line pick up the echo of the shot as it bounces back off rocks and sediments below.

Different geologic structures reflect sound waves in different ways. Computers onboard the *Robert Gray* compile the data and turn out cross-sectional images. Known as seismic profiles, the images let Johnson and his colleagues

of the sound. They have also determined that strain builds up along that fault at the rate of about four-hundredths of an inch a year. In Seattle the impact of a major break on one of those faults would be profound.

"Downtown would be challenged," says John Hooper, a structural engineer in Seattle. The city's newer high-rises would probably not collapse, he says. But Seattle, like Portland, has many older structures built of brick walls without bracing or support, and many of them

Seattle's entire waterfront lies atop fill. In earthquakes such loose soils often liquefy, behaving like quicksand. If that happens along the waterfront, the harborside could splay out into the sound. A major freeway known as the Viaduct would probably collapse. And a repeat of the tsunami that struck the area 1,100 years ago would take many casualties on the waterfront, including ferryboat passengers.

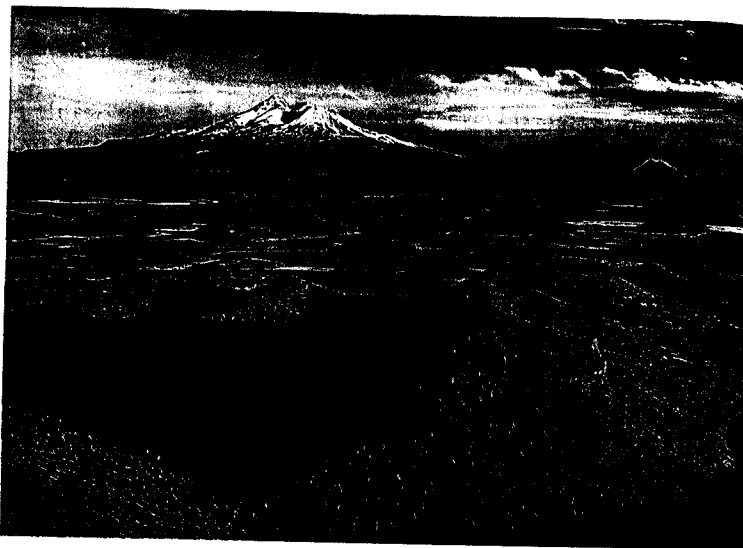
Though such earthquake hazards have been widely publicized in the Seattle area, many residents view the problem with detached bemusement. A series of small quakes rocked the region during the summer of 1997, swaying skyscrapers and getting everyone's attention.

"We all just kind of looked at each other," reports a local friend, John Treat. "People still think earthquakes are California's problem."

Across the Canadian border Vancouver and other cities in British Columbia are also facing the unfamiliar. The possibility of subduction quakes has sent earthquake insurance rates soaring in some locations. Emergency planners are struggling to alert residents to the hazard.

"We've had our heads in the sand," says Allan Galambos, an engineer involved with the seismic upgrading of bridges along British Columbia's south coast. Galambos has helped pioneer a disaster-response program, which includes designating a network of routes for emergency vehicles only. Bridges are particularly vital lifelines for Vancouver, whose central business district sits on a peninsula. Yet Galambos says that only two of the ten major bridges he oversees would be secure in a big quake. Liquefaction would threaten most. But the cost of adequately strengthening those bridges is prohibitive. "We'd have to spend 25 million dollars a year for the next ten years," he says. "Our budget this year is only \$150,000."

Bso much and affect so many people, they pose by far the greatest hazard to Cascadia. But the big volcanoes of the region are also of concern. On May 18, 1980, the eruption of Mount St.



DÉJÀ VU

Hummocks pop up like prairie dog mounds across 175 square miles near Mount Shasta (above). Geologists puzzled over their origin until the Mount St. Helens eruption, whose huge landslide created similar terrain (above right).

Shasta's hummocks are mostly composed of volcanic ash and tephra.

Helens killed 57 people and humbled volcanologists by exceeding their worst-case scenarios for what the mountain could do.* To help explain what he and his colleagues learned the day St. Helens erupted, Ed Wolfe of USGS's Cascades Volcano Observatory takes me by helicopter into the mountain's steaming crater.

"Where we are landing was inside the mountain the day before it exploded," says Wolfe, as we prepare to set down on gray rubble. "Nearly 4,000 feet of rock would have risen above our heads."

Although it's officially in repose, the mountain still seems alive. Rockfalls continually crash down the 2,000-foot-high crater walls, sending huge boulders embedded in billowing dust clouds racing toward us.

*See "Eruption of Mount St. Helens," by Rowe Findley, in the January 1981 issue.

"This is only a moderately hazardous place to be now," says Wolfe. "Since 1480 there have been four major eruptions here. The one in 1480 was about five times bigger than the one on May 18, 1980."

On a timescale of centuries St. Helens is now

making it too steep to be stable. When a magnitude 5 earthquake struck the mountain that day in May, the bulging north flank and old summit collapsed in a massive landslide traveling at the rate of about 80 miles an hour and spreading a blanket of debris as

thick as 600 feet for more than 17 miles. If that weren't enough, the collapse exposed and depressurized the magma that had been steadily rising within the volcano.

"It was like popping a champagne cork," explains Wolfe. "Within seconds a cloud of hot gas, rock debris, and magma blasted out of the opening that had been created by the landslide at more than 200 miles an hour. It overtook the landslide. Then for nine hours the volcano blew ash into a column 65,000 feet high, spreading it as far as Montana."

a landslide 20 times the size of the one at St. Helens destroyed an ancestral version of Shasta. "It was one of those 'Ah ha!' kinds of things," says USGS volcanologist Robert Christiansen, who helped figure it out. "Once you know the right answer, it's obvious. But no one had

THE LANDSLIDE ON Mount St. Helens and resulting mudflow have forced volcanologists to reexamine other Cascade volcanoes. They haven't had to look far.

the most active of all Cascade volcanoes. Whereas Mount Adams, a huge Cascade volcano to the east, was born about half a million years ago, St. Helens is only 40,000 years old. But it has blown itself apart so often that few rocks in the mountain today are more than 4,000 years old. St. Helens may be so active because it lies in a seismic zone between two faults where the earth is stretching apart. That stretching might be creating passageways for the magma below.

One of the most important lessons of the 1980 eruption, says Wolfe, is that volcanoes can collapse. They can be weakened structurally by injection of magma or actually rotted from the inside by corrosive hydrothermal fluids that convert hard rocks to clay. In the case of St. Helens, two months of magmatic intrusion had forced the north flank outward hundreds of feet, fracturing its rock and

About 50 miles north of St. Helens rises 14,410-foot-high Mount Rainier, the tallest of the Cascade volcanoes. Tom Sisson, a young geologist at USGS, has spent much of the past five summers climbing Rainier, collecting rock samples from often precipitous slopes in order to determine the history of the 500,000-year-old mountain.

Unlike St. Helens, Rainier does not usually erupt explosively, Sisson explains. Its style is to pump out lava flows that gradually build the mountain. He takes me on a steep climb to a meadow on the western flank of the mountain. The debris-covered Puyallup Glacier cuts through the valley below us, while ice-mantled cliffs known as the Sunset Amphitheater tower above. Built from layers of old lava flows, those cliffs appear discolored even from this distance.

"They've been corroded by acidic fluids

circulating through this part of the volcano's plumbing system," Sisson says. He climbs several hundred feet down a scree-covered slope to fetch a rotted, orange-size rock. He smacks it against a boulder, breaking it open.

"This used to be hard rock," he says, giving me half. It crumbles in my hand.

About 500 years ago a huge chunk of rotted lava crumbled from the cliffs of the Sunset Amphitheater. The debris avalanche, known as the Electron Mudflow, melted immense amounts of Rainier's ice, mixed with it, and then roared down the Puyallup Valley, ripping

miles an hour, it slowed to the pace of a galloping horse by the time it reached Puget Sound.

"A repeat would go through the big industrial corridor south of Seattle into Elliott Bay, where the Port of Seattle is located," says Scott.

Far smaller mudflows would devastate the fast-growing communities closer to the mountain. The town of Orting, for instance, is built on top of the 500-year-old Electron Mudflow.

"It would have come through as a crashing, ripping wave," says Pat Pringle, a geologist with the state's Department of Natural Resources. "You couldn't have outrun it."

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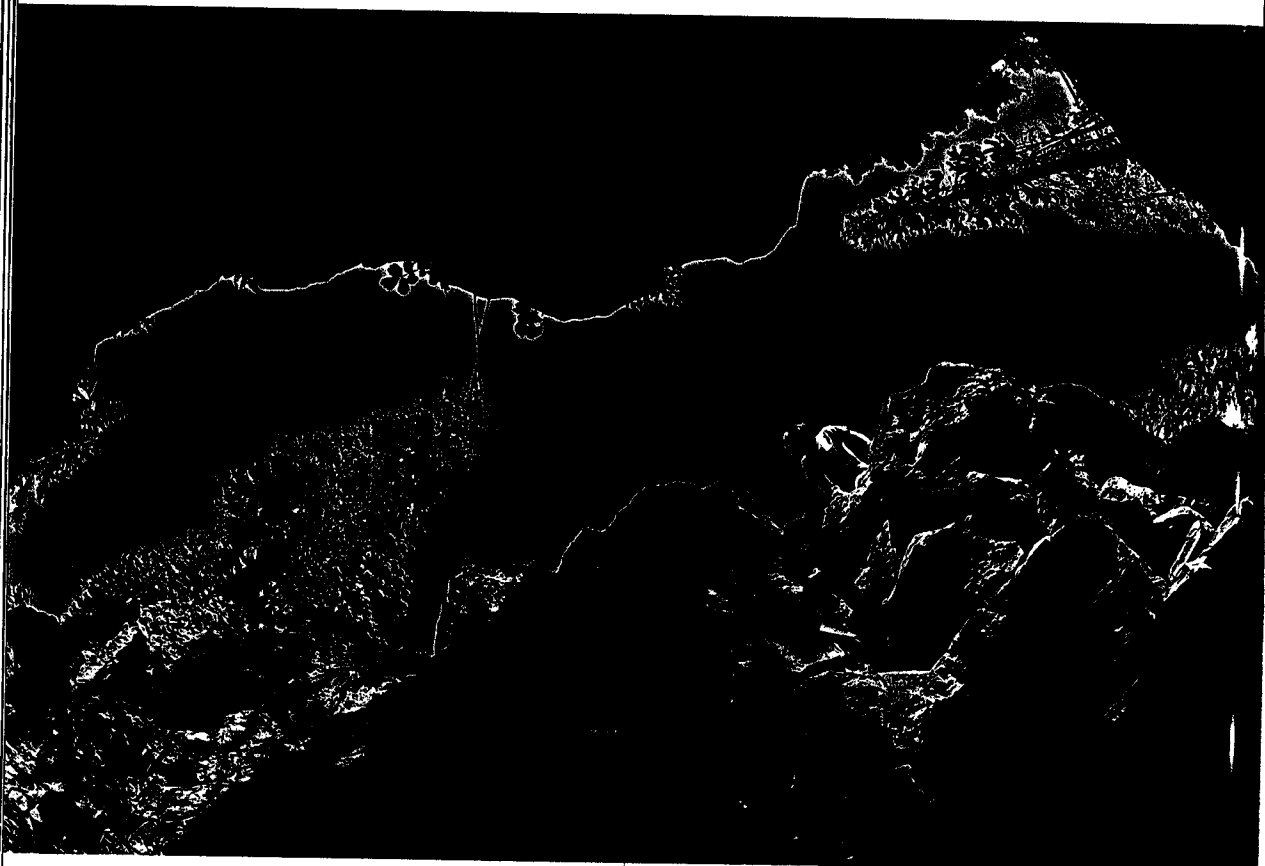
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through forests and burying the valley floor in a blanket of mud 20 feet deep.

Geologists now know that mudflows—or lahars—like the Electron are not rare. "There've been at least 7 and perhaps 12 in the past 5,600 years," says Kevin Scott, a USGS geologist who has been documenting past flows.

The 5,600-year date he cites is an apocalyptic marker. That's when the entire northeast side of the mountain slid off in what's known as the Osceola Mudflow. Traveling a hundred

The town has installed evacuation sirens, but since Rainier's mudflows can occur without warning, one could be almost on top of the town before an alarm was sounded. This uncertainty creates anxiety. When I pass through the entrance of Mount Rainier National Park with a USGS team, the ranger on duty, Lindsay Carlson, notices the Survey emblem on our van. "Is something happening?" she asks nervously.

But most residents regard their odds of

being covered by a mudslide as remote. Kevin Scott, however, calculates the odds in any one year to be about one in 500, more likely than having your house catch fire.

AFTER RAINIER, the volcanic fires most hazardous to Cascadia residents probably burn beneath Mount Shasta, far to the south in northern California. "It's a very scary volcano," says Charles Bacon, a USGS volcanologist.

But people living within eyesight of Shasta regard this 14,162-foot-high volcano mostly with reverence. Visible from as far away as a hundred miles, its white flanks seem to anchor northern California to the Earth.

"It's one of the power centers of the planet," says a friend, Jim Berenholtz. Berenholtz, an artist and musician in San Francisco, is among the many pilgrims who come to Shasta. Some believe fervently that the mountain is inhabited by refugees from a lost continent, aliens from space, angels, and other spirits.

Native Americans pray to the mountain but do so from afar. "It's beyond sacred," says Mary Carpelan of the Shasta Nation. "It's the home of Waka, the Creator, when he comes to visit. Our people never go on the mountain."

"It's the source of our power," agrees another Native American, Jack Thom. Thom tells me that he has seen the mountain open up and bright light stream out of it. Scientists believe that Shasta has indeed opened in the past. And the light that streamed out would have been incandescently hot, accompanying a collapse of the entire mountain about 300,000 years ago.

"That collapse was 20 times bigger than at Mount St. Helens," says Bob Christiansen, the volcanologist who was in charge of the USGS monitoring team the morning St. Helens blew. After seeing the chunks of debris that spread across the landscape in lumpy hummocks, he realized that similarly shaped hills on the north side of Mount Shasta had been created by the same phenomenon.

"They are actually pieces of an earlier Mount Shasta that must have rotted and collapsed," he says. The sweeping scale of the landslide was too big for geologists to have comprehended before Mount St. Helens.

Since that collapse Shasta has rebuilt itself, creating four distinct cones. The youngest and

highest of them, called Hotlum, is as young and as large in itself as Mount St. Helens.

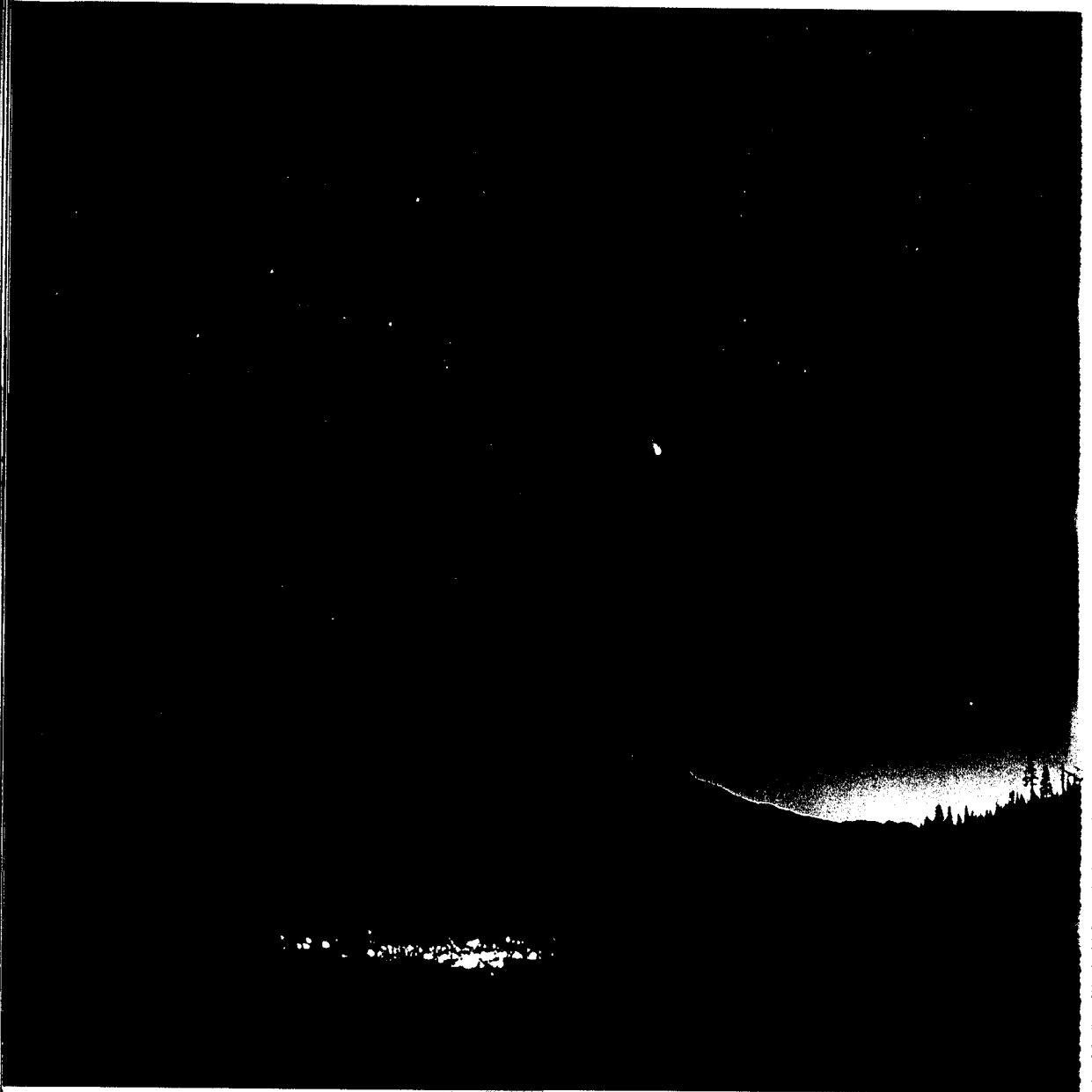
"Shasta has been the most active volcano in the Cascades after St. Helens," Christiansen says. "Over the past 6,000 years it has erupted about every 200 to 300 years, the last time in the 1700s. A big eruption here could threaten the I-5, the major transportation route on the West Coast, along with major utility corridors."

The other Cascade volcanoes, from Lassen



WORLDS OF INSIGHT

Walking the caldera rim of Medicine Lake volcano, USGS geologist Julie Donnelly-Nolan surveys a crack that opened 1,100 years ago. Scientists have only begun to study such cracks, but the native Yurok believe the Creator taught them about Earth's movements at the beginning of time. Every two years Walt and other elders don regalia to perform a ceremony to balance the world. "We are not doing this just for our own people," he says. "It's for everyone."

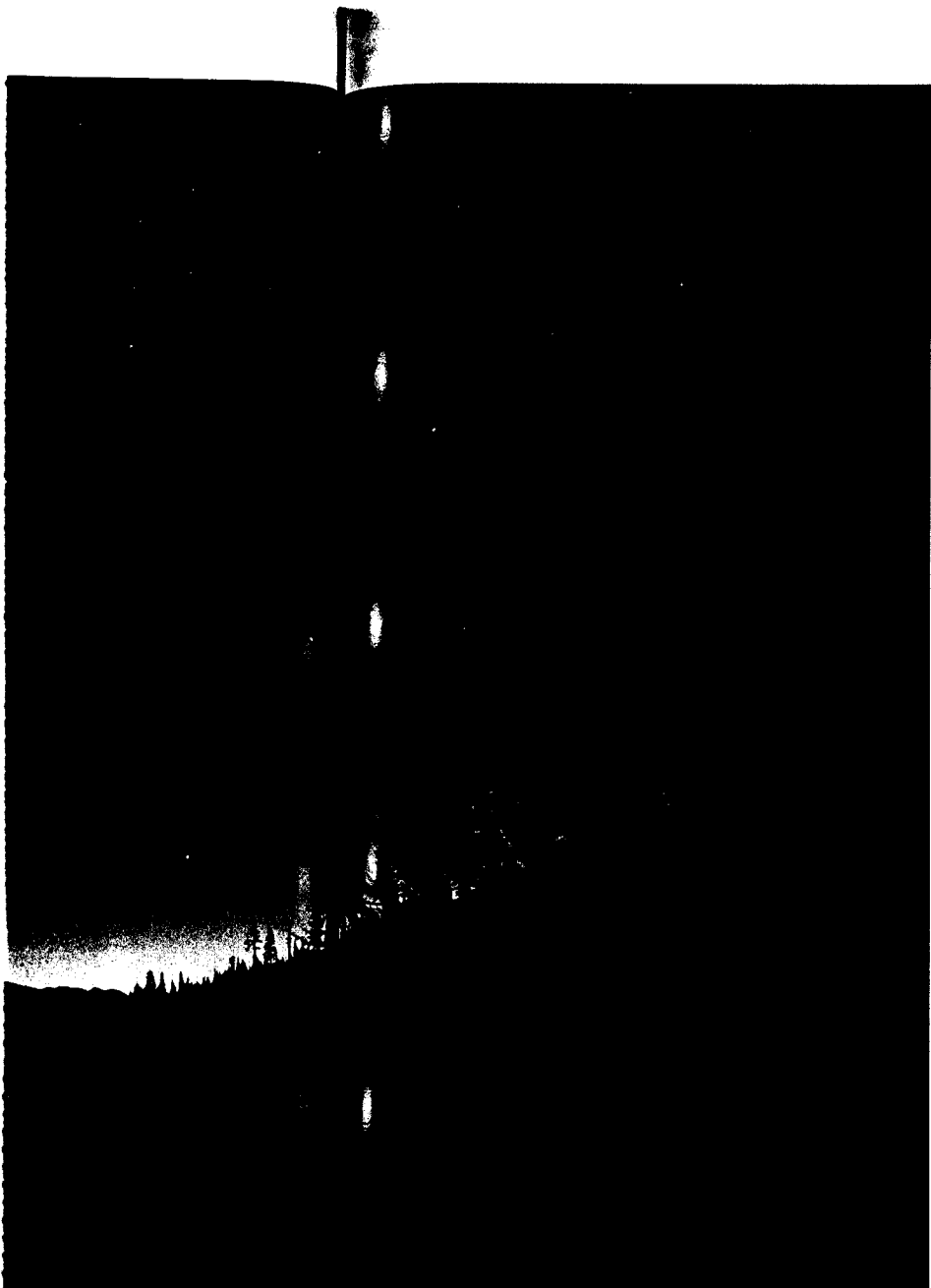


RECURRING WONDERS

Blazing briefly over Mount Shasta last year, comet Hale-Bopp should return to our skies in about 2,400 years. By then eruptions will likely have reshaped the volcano's silhouette several times, judging from the geologic record, while humans scramble to safety and then return. "This is a very pleasant place to live, but to enjoy the benefits you have to put up with some of the occasional burps and outbursts," says Bob Tilling. "The challenge for scientists is to provide warnings in enough time so that no one gets hurt."

Peak in northern California to Mount Meager in British Columbia, pose lesser hazards. Most are too remote to affect many people. But Mount Hood, which is Portland's playground, could send avalanches of hot gases and volcanic debris down its world-famous ski runs. Parts of its upper flanks have rotted, and a partial collapse could trigger mudslides down the Sandy River, taking out the pipelines that supply much of the city's water.

And most of the major volcanoes could go into the rare kind of spasm that created Crater Lake in Oregon about 7,700 years ago. At that



“An explosion in shallow water within the caldera could send a surge of volcanic debris hot and fiery enough to toast you alive and cover you with mud if you were within a couple of miles of the crater rim,” says Bacon.

ON MY LAST DAY in Cascadia I seek relief from the endless stream of potential catastrophes I have been hearing about. I ask the Canadian geophysicist Garry Rogers and his colleague Mike Schmidt to take me to the end of Cascadia, on northern Vancouver Island along a remote fault zone near Nootka Island. We fly low in a seaplane over rocky beaches where impenetrable forests come right to the water’s edge. We pass isolated tribal villages and clusters of brightly dressed sea kayakers. We land on the island in Friendly Cove, at a tiny settlement that includes a couple of houses, a lighthouse, and an old church.

We meet Ray Williams, a Mowachaht and the only permanent resident on Nootka. Most of his people have moved to a nearby town, but Williams decided to stay on this misty cove. “Living here,” he says, “tells the white people this is our land.”

Williams introduces me to the Mowachaht chief, Ambrose Maquinna, and other friends who are visiting for a few days. The talk turns to legends, and Rogers asks if they have stories that might indicate the occurrence of ancient earthquakes. The chief, a large man with a full face, glasses, and grizzled whiskers, nods. His friend, Thomas Dick, answers: “My grandmother spoke of a great flood. The water came up and suddenly there was no land, nothing to tie the canoes to. People had to leave. They scattered everywhere. Some went to California, others to Russia.”

The fires beneath Cascadia, it seems, have been affecting the people of this land throughout history. And as unlikely as all those worst-case scenarios may be in my lifetime, they are eventually going to happen. Again and again. At least until the embers beneath Cascadia burn out. And anyone who has to walk those hot coals should remember the rules of etiquette my instructor Ariel taught me: Take a deep breath, and always respect the fire. □

To read more from author Rick Gore about fire walking, go to www.nationalgeographic.com and click on the 2000 icon.

time a volcano called Mount Mazama, about 50 miles north of Klamath Falls, stood about 12,000 feet high. Then, in the largest explosive eruption known to have occurred in the Cascades, it beheaded itself, creating the lake-filled caldera that is one of Oregon’s most popular scenic attractions.

“It threw its guts out on the landscape all at once,” says Charles Bacon, the USGS expert who spent four field seasons climbing the harrowing slopes of the caldera. Although an eruption of that scale probably will not occur in the near future, the area remains hazardous.

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