OREGON GEOLOGY

Oregon Department of Geology and Mineral Industries Volume 61, Number 6, November/December 1999

IN THIS ISSUE:

THROUGH THE EYES OF THE STATE GEOLOGIST

John D. Beaulieu
Oregon State Geologist

Oregon has the "privilege" of being home to many geologic processes that become hazards when they interfere with human activity. We have the "privilege" of experiencing landslide slumps, debris flows, floods, shrink-swell soil, coastal erosion, local tsunamis, distant tsunamis, volcanism, crustal earthquakes, subduction earthquakes, land subsidence, and others. These hazards give us our mountainous scenery, valleys, picturesque coastline, fertile fields, and, to some extent, our economy and livelihood. Things are said to "Look different here".

Although it is a privilege that "Things look different here," there are responsibilities, too. It is our responsibility to manage the hazards to assure the health, safety, and well-being of the public.

Worldwide, nationwide, and statewide, losses from geologic hazards are increasing rapidly each year. The losses from geologic hazards in Oregon can easily amount to many lives and many tens of millions of dollars annually. Yet we learn from experiences in other states that proper management can greatly reduce losses. Well-managed development of hillsides, for example, has been shown to reduce losses by more than 95 percent in test areas in California.

Good management depends on the ready availability of good, reliable, and well-designed information. Good management also requires effective partnerships. In such partnerships, each member agency must know its unique role clearly, must perform it well, and must perform it in concert with others.

The Oregon Department of Geology and Mineral Industries is the leading source for much of the general information about geologic hazards in Oregon. To reduce risk, we are partnering with many entities, including the Office of Emergency Management, the Department of Land Conservation and Development, and the Progress Board, as well as other state agencies, the private sector, local government, and others.

We are seeking an information-based, disaster-resilient state from border to border. The broad diversity of hazards poses challenges but does not necessarily lead to disasters. We at DOGAMI would like to do our part. We would like to cultivate understanding of the finely tuned balances that have produced and are producing the landscapes and the resources we all enjoy. We would like to further the use of this information to reduce risks from geologic hazards in Oregon.

OREGON GEOLOGY

(ISSN 0164-3304)

VOLUME 61, NUMBER 6 NOV./DEC. 1999

Published bimonthly in January, March, May, July, September, November by the Oregon Department of Geology and Mineral Industries. (Volumes 1 through 40 were entitled The Ore Bin.)

Main Office: Suite 965, 800 NE Oregon Street # 28, Portland 97232, phone (503) 731-4100, FAX (503) 731-4066.
Internet: http://sarvis.dogami.state.or.us

Baker City Field Office: 1831 First Street, Baker City 97814, phone (541) 523-3133, FAX (541) 523-5992.
Mark L. Ferns, Regional Geologist.

Grants Pass Field Office: 5375 Monument Drive, Grants Pass 97526, phone (541) 476-2496, FAX (541) 474-3158.
Thomas J. Wiley, Regional Geologist.

Mined Land Reclamation Program: 1536 Queen Ave. SE, Albany 97321, phone (541) 967-2039, FAX (541) 967-2075.
Internet: http://www.proaxis.com/~dogami/mlrweb.shtml
Gary W. Lynch, Supervisor.

The Nature of the Northwest Information Center: Suite 177, 800 NE Oregon St. # 5, Portland, OR 97232-2162, phone (503) 872-2750, FAX (503) 731-4066
Internet: http://www.naturenw.org
Donald J. Haines, Manager.

Periodicals postage paid at Portland, Oregon. Subscription rates: 1 year, $10; 3 years, $22. Single issues, $3.

Address subscription orders, renewals, and changes of address to Oregon Geology, Suite 965, 800 NE Oregon Street # 28, Portland 97232.

POSTMASTER: Send address changes to Oregon Geology, Suite 965, 800 NE Oregon St. # 28, Portland, OR 97232-2162.

Cover photo

The massive Bonneville slide into the Columbia Gorge has been recently dated at 300 years in the past. This places the slide at the same time as the last big subduction earthquake, suggesting that this seismic event may have triggered the landslide.

The article beginning on the next page discusses this and other hazards that have shaped "The other face of Oregon."

The other face of Oregon: Geologic processes that shape our state

By Elizabeth L. Orr and William N. Orr, Department of Geological Sciences, University of Oregon, Eugene

Note: As we end the century and the millenium, it is an appropriate time to review the geologic processes that formed and continue to re-form Oregon. We enjoy, and even take for granted, Oregon's great outdoors. But the flip side of our scenic wonders are natural disasters—the geologic processes that wreak havoc when they intersect with people's lives. *–ed.*

INTRODUCTION

The Pacific Northwest is known for its wonderful diversity of natural landscapes including deserts, deep river canyons, high snow-covered mountains, flat well-watered fertile valleys, and a coastline with quiet coves and dramatic headlands. Unavoidably, however, the breathtaking scenery goes hand in hand with geologic processes that can be responsible for recurring and destructive hazards.

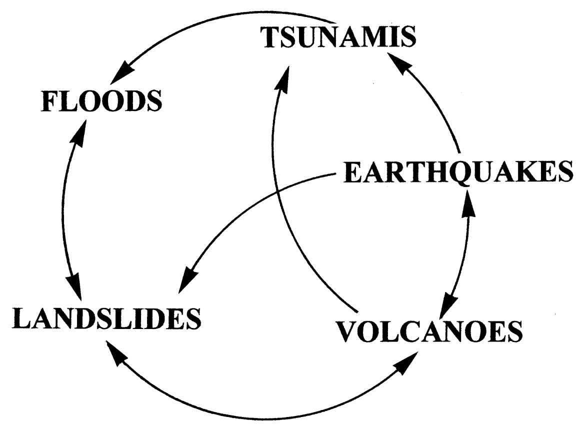
The long view of geology, or uniformitarianism, recognizes that most geologic processes shaping the topography are remarkably slow and that all of these features can be explained by ongoing natural events. Oregon's landscape is being continuously shaped by crustal plate movement, heavy winter rainfall, and ocean storms.

Are hazardous geologic occurrences increasing in frequency? There is a tendency to suggest that this is the case. In a headlong rush for news items, the media will often pump up any event to catastrophic levels—even when no deaths and only minimal property damage have occurred. Additionally, the wonder of modern communication is such that news stories are pulled in from remote corners of the globe, while 50 years ago they would have been missed or rated only a line in a newspaper.

On the other hand, it is true that the increase in population and the dispersal of populations into some areas previously considered marginal or unsafe dictate that more of these natural disasters will be witnessed than before.

Humans themselves often aggravate disastrous situations by placing themselves in harm's way, and activities such as redirecting rivers, oversteepening slopes, or clear-cutting may create problems. Moreover, development of dwellings and highways is so widespread and growing that natural disasters are much more likely to impact mankind and cause loss of life and property than at any time in the past.

The 1964 flood at the confluence of the Pudding and Molalla rivers in the northern Willamette Valley near Canby.



The interrelationship of hazards

In the Pacific Northwest, natural geologic catastrophes may be placed into five categories: floods, landslides, earthquakes, volcanic eruptions, and tsunamis. All five of these catastrophes have occurred in Oregon within the past century. Quite often the effect of two or more events occurring simultaneously greatly accentuates the destructiveness of the episode. Floods are nearly always accompanied by landslides, mudflows are often a significant part of volcanic activity, and a major quake following a flood results in a multitude of large and small landslides. Earthquakes in coastal areas frequently precede tsunamis.

SURFICIAL HAZARDS

Flooding and accompanying landslides should surprise no one living in the rainy Northwest. Of all the destructive natural phenomena that have taken place in Oregon, floods

At the height of the 1894 flood, the entire business district at The Dalles was under 10 ft of water.

and landslides have been the most costly to life and property. Receding slowly, flood waters can take days to disappear; cleanup of slides that block highways can take months; and buildings on slides can be completely destroyed.

FLOODS

Floods occur when rising waters spill over the established streambed. In western Oregon, the underlying causes are heavy rainfall, unseasonably warm spells, and ensuing snow melt. Rainfall is greatly accentuated by moisture-laden marine air encountering the Coast Range and Cascade Mountains. In eastern Oregon, flooding is directly related to rainfall amounts.

Flood waters rise quickly but retreat slowly. While the flow in stream channels is rapid, runoff on a flat landscape is gradual. Such wide avenues, flood plains, are natural safety valves for periodic flooding. As the looping meanders of a stream move progressively back and forth, water is dissipated across the flood plain. Unfortunately, the level surfaces of floodplains often appeal to those who build roads, highways, and housing tracts; however, this planar topography is deceptive because moving waters can gradually purge the surface of any structure.

Channels within the floodplain are remarkably ephemeral, and course-altering streams can pose problems for houses nearby. Evidence of ancient streambed patterns can be seen, for instance, where glacial debris, borne by Western Cascade fluvial systems, pushed the channel of the Willamette River well off to the west side of the valley. Ancient abandoned channels of the river along Mill Creek as it enters Salem, as well as at Lake Labish where it leaves Salem, show how profound channel displacement can be.

Human efforts to control stream flow often cause more difficulties than are solved. Straightening and deepening meander channels tends to focus stream energy into a narrow line, where previously it was dispersed along miles of meanders. Artificially smoothed channels also greatly speed up the flow, greatly enhancing erosion capacity. Although the placement of riprap along the outside of meander bends may work as a medium-term remedy, it often only delays the inevitable erosion and channel migration.

Prehistoric and historic floods

One of the most far-reaching prehistoric series of floods in the Northwest affected the entire Columbia River drainage from Montana through Idaho, Washington, and Oregon to the Pacific Ocean. A succession of Ice Age dams, between 15,000 to 12,000 years ago, blocked the Clark Fork River in Montana, creating glacial Lake Missoula. As the dams broke periodically, up to 400 cubic miles of water were suddenly released. With an estimated flow of 9 cubic miles per hour, two days would have been needed to empty the basin. From Montana, flood waters raced across the Idaho panhandle and into the Spokane River Valley before spreading into multiple channels throughout eastern Washington. Pouring into the Columbia River, the waters backed up into the Willamette Valley, turning the valley into glacial Lake Allison, before reaching the ocean. Over 40 similar floods took place, permanently molding the topography here. In the Willamette Valley only the tops of the buttes—Mount Tabor, Rocky Butte, Mount Scott, and others—would have been visible. Over 200 feet of water covered present-day Lake Oswego, while Beaverton, Hillsboro, and Forest Grove would have been under a mere 100 feet.

Even though no floods of this dimension have taken place in historic times, the state has been subjected to annual flooding problems since European settlement. Some of these were the Willamette River floods of 1861, 1890, 1964, and 1996, the Heppner flood of 1903, and the Vanport flood on the Columbia River in 1948. In each case, the floods were said to be one of a kind, never to recur. Governor John Whiteaker termed the December 1861 flood on the Willamette "a scourge . . . which has resulted in the loss of immense quantities of property . . . and seriously crippling . . . the agricultural interests of the state."

November 1861 was cold and wet, with snow on the hills of both ranges paralleling the Willamette valley. When this weather pattern occurs, subsequent flooding is frequent. On December 14, a combination of warm winds and temperatures along with copious rains brought up the level of the river, which drains over 11,000 square miles of the eastern Coast Range and Cascades. Since it flows through what has always been the most populous region of the state, the impact on human development was inevitable. Roads were closed and bridges washed out as the water rose steadily with continuing rain and snow melt. Towns situated near the river for the advantages to business suffered extensive damage, although Eugene and cities toward the southern end of the valley experienced less flooding. An estimated 500,000 acres was covered with water with $1/3$ billion dollars in damages, in current dollars.

By contrast, the tragedy that struck Heppner in Morrow County on Sunday, June 14, 1903, was caused by a sudden flash flood that resulted from a heavy storm. Dark clouds in late afternoon brought rain to Willow Creek, a mile or two above the town. The roaring wall of water, funneled down the narrow creek bed, was 200 yards wide. Property loss was placed at $400,000, and 247 lives were lost. Many were saved because a barrier of trees piled up against downtown buildings, catching debris and slowing the water enough to push it back into the Willow Creek bed.

Torrential rains and a rapidly melting deep snow pack on Sunday, May 30, 1948, combined to raise levels of the Columbia River at Portland more than 13 feet above flood stage, threatening people, homes, and businesses along its bank. The community of Vanport was most seriously affected. Built during World War II to house newly arriving workers at the Kaiser Company shipyards in Portland, it had quickly grown to be Oregon's second largest city.

In this view to the west at the business district, up to six feet of water from the Willamette River covered Oregon City during the 1964 flood.

Even though situated on low ground between old meanders of the Columbia, Vanport was thought to be protected by dikes. But a 10-foot-high wall of water broke through an earthen barrier that was 75 feet across at the top and 125 feet wide at the base. The low-lying slough was saturated, and residents had 30 to 40 minutes of warning to escape with whatever they could carry. Fifteen people were killed. Some of the housing was later reoccupied and used for a time. Today the Portland International Raceway and the Multnomah County Expo Center are on the site.

Tualatin shows water still standing five days after the rains of the 1996 flood. Photo courtesy of Scott Burns.

It is possible that these historic floods may never recur, but statements made in 1861 about "the greatest flood known" have been repeated more recently in reference to contemporary events. Memories of previous floods fade quickly, even though the combination of abundant rains, warm temperatures, and melting snow occur almost annually. In 1996, news media and state officials underestimated the flood potential, expressing surprise at how fast the water rose.

February 1996 was called "the winter from Hell" by many who experienced the flooding. Once again, dangerous weather conditions brought rivers up over their banks. The Cascades snow cover of 200 inches was reduced to 50 inches in two weeks by warm temperatures. After a succession of storm-weather systems, the Columbia and Willamette Rivers began to rise. As rain fell without letup, water from tributary streams overwhelmed main channels. At the height of the event, 29 rivers were above flood level in the Willamette Valley and coastal region. The Columbia crested at 27.6 feet and the Willamette at 35 feet.

The entire state was involved in the 1996 floods. In Portland, the Burnside and Steel bridges were closed. A number of sections of Interstate 5 as well as highways near Vancouver, Lake Oswego, and Canby were blocked by mud. In low-lying Tillamook County, there was a large loss of livestock. Six

Bent railroad tracks and blocked coastal road at Mapleton, Oregon, reflect the power of a mudflow there in 1964.

blocks of downtown Corvallis were under water, and 1,000 families were evacuated. The Mapleton highway was blocked by sliding debris. Homes and businesses at Oregon City were evacuated. Interstate 84 west of Cascade Locks was closed by two major landslides, one 300 yards wide. Even as cleanup was taking place, a third slide tumbled down the unstable slope. In eastern Oregon, rain-swollen streams washed out roads and isolated families and even entire communities as highways in Wallowa County were covered by mudslides.

A recurring hazard of the flooding was from sewage treatment plants located near waterways. As lines were broken or water rose over the tanks, vast amounts of raw sewage were discharged into streams. Disabled plants in Milwaukie and Oregon City sent over 30 million gallons of sewage daily into the Willamette. Similar situations took place at Salem, McMinnville, and The Dalles.

In all, 22,000 people were evacuated and six were killed. In Oregon, 18 counties were declared disaster areas, along with 13 in Washington, making them eligible for federal aid.

The question to be asked is with the placement of multiple dams altering stream-flow, why do destructive floods still occur? Historically, dams have been considered to be one of the "solutions" to flooding. In spite of a network of dams throughout the Northwest, flooding continues. It is informative to compare the flood levels of February, 1996, after dam construction, with those of the previous century, when there were fewer dams. Willamette River waters reached 35 feet above flood stage at Salem during the 1996 floods, 37.8 feet during the 1964 floods, and 37 feet in 1861. If the extensive dam construction projects of the past 135 years do not halt flood waters, perhaps it is time to reexamine the whole program for controlling streamflow.

LANDSLIDES

Landslides are the downslope movement of rock, soil, or related debris. Geologists use the term "mass movement" to describe a great variety of processes such as rock fall, creep, slump, mudflow, earth flow, debris flow, and debris avalanche. In most mass movement, water plays a pivotal role by assisting in the decomposition and loosening of rock, lubricating rock and soil surfaces to enhance the beginning of movement, adding weight to an incipient landslide, and imparting a buoyancy to the individual particles, which helps overcome the inertia to move. The composition of slides is also very important, and the proportions of rock, sand, clay, and water will dictate the initiation, speed, and areal extent of each slide.

Although landslides are propelled by gravity, they can be triggered by other natural geologic disasters or human activity. Volcanic eruptions and earthquakes can initiate earth movement on a grand scale. A variety of mudflows called a "lahar"—a mixture of volcanic ash and water—is specific to volcanic activity. Indeed, lahars are often the major hazard experienced in a volcanic episode. Although earthquakes can initiate mudflows, the major causes of landslides in the northwest are continuous rains that saturate soils.

There can be no doubt that mud and debris flows are frequently the direct consequence of human activity. Seemingly insignificant modifications of surface flow and drainage may induce landslides, and once the slide is established, it will continue to move over remarkable distances.

The placement of buildings, to capture a spectacular view, on slide-

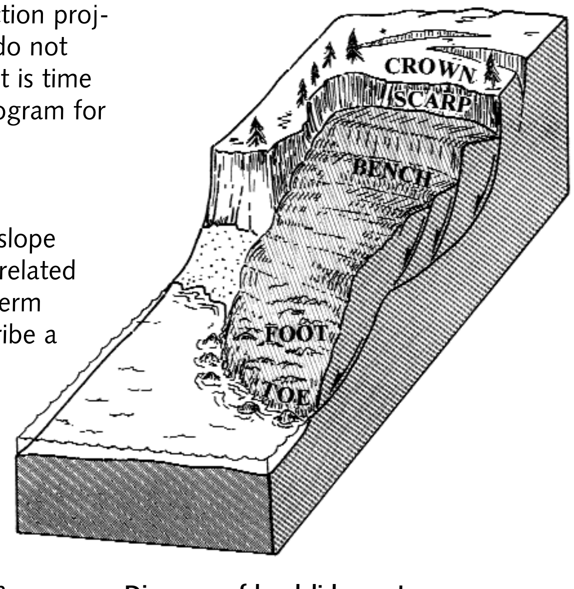


Diagram of landslide anatomy.

Both scenes in the southern Willamette Valley near Sweet Home show how clear-cutting initiates landslides. The rumpled appearance of the slope behind the house is a shallow earth-flow above bedrock that began to slide shortly after the trees were removed.

prone coastal dunes, eroding headlands and sand spits, or at the edge of a receding shoreline, may lead to the loss of the structure. It has been noted that in Portland, population pressure has pushed construction into many areas and sites previously rejected as landslide-prone. In an urban setting, improper drainage most often induces disastrous sliding.

Agricultural irrigation and forestry practices such as clear-cutting and stripping vegetation from naturally oversteepened slopes have been shown to be responsible for a spate of landslides. Highway construction on similar slope conditions awaits only the first good rain to provoke earth movement.

During the floods of 1996, most of the 250 landslides in the Clackamas River watershed and 75 percent of the slides in the Mount Hood National Forest were in logged-over lands or those criss-crossed by dirt logging roads.

Research on slides in relation to clear-cutting in the Pacific Northwest over the past 30 years documents a direct causal relationship. A 1996 Forest Service study of 244 slides found 91 instances of mass movement on logged-over lands, 93 in association with roads, but only 59 in undisturbed forests. The combination of both logging and road-building increases slide frequency five times over a twenty-year period when compared to undisturbed forested lands.

Forestry regulations, modified in 1997, address only those logging or road-construction operations where there might be a risk to human life from landslides or debris flows, as opposed to considering the overall environmental picture.

One characteristic of landslides is that virtually all unstable and movement-prone slopes can be recognized, so mass movement should not be totally unexpected. Tip-offs to incipient hazard-prone slopes include scarps, tilted and bent ("gunstocked") trees, wetlands and standing water, irregular and hummocky ground topography, and oversteepened slopes with a thick soil cover. The technology of spotting landslides by use of aerial photography has become so refined that NASA routinely recognizes and maps mass-movement features on several of the planets in our solar system as well as on our own moon.

Prehistoric and historic landslides

Even though landslides are not restricted to any one part of Oregon, most are triggered by erosion or water-saturated soil in the Coast Range, the Willamette Valley, and, to a lesser degree, along the Columbia River.

The geologic history of the Columbia Gorge is closely linked to the Missoula floods between 15,000 to 12,500 years ago. The raging torrents purged the lower canyon wall of soils and rock, leaving over-steepened slopes and erosion, conditions that contribute to landslides.

Historically, the Columbia River Gorge was the scene of massive slides that took place around 300 years ago—the same time as the last great subduction earthquake. Remnants of this immense earth flow can be seen today between Bonneville Dam and Cascade Locks. Before waters of the dam covered the debris flow, the rapids created by water flowing over the rock and soil of the landslide, were a noted feature to the Indians and a hindrance to early pioneers.

The Bonneville slide, which covers 14 square miles, flowed into the Co-

The Royce home still sits on its foundation, surrounded by a rock garden of flow debris. Looking out of a back window, Ms. Royce saw a line of huge rocks rolling toward the house at about five miles per hour. She and her husband barely escaped before mud from the flow poured into the house and filled most of the lower floor. Photo courtesy of Scott Burns.

lumbia channel from the north, pushing the river southward and creating a 200-foot-high obstruction that temporarily blocked the flow. That land bridge from present-day Oregon to Washington may have been the origin of the Indian legend of the Bridge of the Gods.

Today the distinctive hummocky surface of low, rounded mounds and shallow depressions is a hallmark of slides in the Gorge between Vancouver and Bonneville Dam. In this area, older ash and mudflow layers lying beneath the Columbia River basalts erode easily. Landslides are not uncommon, most flowing from north to south into the river.

Upriver at The Dalles, the clay-rich Dalles Formation atop the Columbia River basalt is responsible for most of the slides. Water accumulates between the two formations, and acts as a lubricant to send a thick soup of rock debris into valleys and streams. In addition, The Dalles has been disrupted by slides that are slow but ongoing. The wide meander of the Columbia River, where the town is presently situated, was eroded during the Missoula floods, predisposing the terrain to landsliding. Hazardous conditions were then accelerated by human activity such as housing, roads, increase in water runoff from paved areas, and irrigation of lawns and orchards.

Because it was moving so slowly, the ongoing landslide was not noticed until 1977, when a study by the Oregon Department of Geology and Mineral Industries (DOGAMI) reported bent water mains and sewer lines, distorted sidewalks and roads, as well as structural damage to houses. Several buildings were retrofitted for support, while others, as The Dalles Junior High School, had to be abandoned.

The Oregon coast is the scene of ongoing landslides, which can be directly correlated with erosion by high winter waves and increased rainfall during the major storms of January and February. Storm surges have caused considerable coastal damage by eroding sand and cutting away at headlands, which leads to sliding.

Once again, human intervention has been responsible for altering beach processes and changing patterns of deposition and erosion. Considerable money and effort have been expended to halt coastal erosion, which in places carries away as much as two feet per year. Much of the problem can be attributed to a poor understanding of coastal processes. Sea walls and riprap, as well as housing on sand spits and headlands, quite often result in effects opposite those desired.

Examples in the historic record are numerous. A jetty constructed on the northside of Tillamook Bay restricted the flow of sand down the coast to Tillamook Spit, where the community of Bay Ocean had been built in 1910. A post office, indoor pool, hotel, bowling alley, and 59 homes had been placed on the unconsolidated sand, which began to disappear in less than a decade. Retreating at around 50 feet per year, the spit was breached in 1939, and the community destroyed by 1940.

A large landslide in Tillamook County blocked 600 feet of Highway 6 on April 4, 1991, with 500,000 cubic yards of rock and soil partly damming the Wilson River. This highway has been closed annually by mudslides or rock-falls, and the 1991 episode took nearly two months for debris removal at a cost exceeding $2 million. The slide occurred when soils on the steep slope became saturated from nine inches of winter rain in two days. Cracks appeared along the upper planar slide and permitted infiltration of runoff to satu-

The community of Bay Ocean, constructed on a spit in Tillamook County, was completely destroyed by erosion.

rate soils. The soil liquefied immediately before movement. When the event took place, the slide was being monitored, and an attempt was being made to drain the slide block.

A similar long-standing problem exists in Curry County, where a section of coastal Highway 101 is periodically closed by landslides. Sliding began in 1938, when the roadway was newly constructed, and is still ongoing. In response to heavy rainfall, a debris flow took place on March 23, 1993, and blocked the highway for two weeks until a bypass was constructed. A number of measures had been tried over the years to control the slide, including drains and re-grading the surface, but none were effective. More recently, increased knowledge of landslide behavior prompted the installation of a horizontal drainage system, which was able to decrease dramatically the amount of movement during the stormy winter of 1996.

A currently active landslide at The Capes, in Tillamook County near Netarts, was first noticed in 1997 by local home owners. A small slope failure on the seaward side of a steep hill indicated that minor but steady movement was accelerating. The slide began with small problems when a stairway to the beach was damaged and had to be removed. Ground cracks opened, and lawns dropped vertically some 18 inches in January 1998. Five more feet of drop were added a few weeks later, and fresh slumping was visible downslope.

The main area of movement is presently 900 feet long and 500 feet wide, endangering 10 houses, with 10 more at risk. Because the slide is now moving so rapidly, assessment of hazards is ongoing.

The situation at The Capes could have been easily prevented if an existing geologic assessment had been used by planners and developers. The landslide is an old structure that cuts through a 100-foot-thick body of Holocene (less than 10,000 years old) dune sand lying over muddy debris and, together with it, filling an ancient valley. Groundwater saturated the valley lined by the impermeable muds, but a contributing factor to reactivation was the erosion of a high modern dune which had supported the toe of the landslide.

On the Wilson River in Tillamook County, a 1991 landslide completely covered Highway 6 and dammed the stream. Clean-up took two months. Photo courtesy of Oregon Dept. of Transportation.

South of Tillamook Bay, steep cliffs at Cape Meares, Ecola State Park, and Newport have been subject to continuous wave erosion and landsliding. Cape Meares in Tillamook County was cut back 350 feet between 1930 and 1960, and in 1961 a mass of 125 acres at Ecola State Park in Clatsop County was carried downslope at a rate of three feet per day. Over a two-week period, much of the debris entered the ocean. At Newport in Lincoln County, coastal sliding that began in the 1920s accelerated during the middle 1940s. Roadways, drain pipes, and 15 houses were moved seaward. At present, storm waves are carrying off the mass of debris, which will eventually disappear.

In the Willamette Valley, landslides resulting from a combination of heavy rain, steep slopes, and thick soils are especially costly in this most populous region of Oregon. Portland in the northern valley, Salem in the central area, and Eugene to the south furnish good examples of ongoing sliding as well as the potential for hazardous future earth flows.

Erosion of dune sand at The Capes development led to landsliding which endangered homes.

During the intense rains of February 1996, Portland officials estimated there were 168 slides, 90 percent of which were in the West Hills. Almost 40 homes were rendered uninhabitable, and total damage to public facilities alone was $33 million. Supersaturated soils, steep slopes, and natural water drainage diverted by streets and gutters, sent the soil downslope during the February storms. Most slides in the West Hills take place in the Portland Hills Silt, a wind-blown loess deposit dating from dry intervals of the Ice Ages.

Southwest of the Salem downtown area, large tracts of the Salem Hills, zoned for future development, are of concern because of slope instability. Hummocky topography, an indicator of slumping ground, as well as recent slides during heavy rains, are clear warning signs of conditions unfavorable to construction. A 1999 study of soil movement in the Salem Hills, carried out by DOGAMI, identified many areas of high risk. Both rainfall and earthquakes were considered as factors that could induce sliding. Slope topography—whether gentle, moderate, or steep—was indexed and compared to the rock/soil composition in order to identify and map localities where hazardous conditions might be present. In addition to assessing potential hazards, the study also developed mitigation plans.

Beginning in 1922, the Jump-off Joe landslide at Newport in Lincoln County moved dramatically in 1942. Despite its known instability, attempts to build houses here have been made as late as the 1960s and 1970s.

During 1997, work in the Eugene-Springfield area by DOGAMI and the U.S. Geological Survey showed that despite warnings, housing construction on unstable hillsides was increasing dramatically. After the 1996 rainfall, large earth and rock masses in the South Hills slumped off below dwellings placed on steep slopes. To avoid such hazardous situations, a map by the two agencies identifies soil and slope properties and possible earthquake scenarios for the area.

Remedies for landslides in urban areas are rarely easy or inexpensive. Most of the slides are shown to be

(Continued on page 143)

Both houses in Portland were damaged by the 1996 floods and subsequent landslides. The white house on Fairview Street is threatened by sliding on the adjacent vacant lot. The land movement here is due to runoff from the road above. A sheer wall of Portland Hills Silt can be seen at the top of the slide, while the toe has moved onto the road. The three-story house with the failing foundation has rotated as a result of sliding. Situated on the toe of an ancient landslide on Bull Mountain in Tigard, mass movement was reactivated by the 1996 floods. Incredibly, today new houses are being placed on the same slide surface. Photos courtesy of Scott Burns.

PLEASE SEND US YOUR PHOTOS

Since we have started printing color pictures on the front cover of *Oregon Geology*, we are finding ourselves woefully short of good color photographs showing geologic motifs in Oregon.

We also want to make recommendations for scenery well worth looking at in a new series of black-and-white photos on the back cover of *Oregon Geology*. For that, too, your contributions are invited.

Good glossy prints or transparencies will be the best "hard copy," while digital versions are best in TIFF or EPS format, on the PC or Mac platform.

If you have any photos that you would like to share with other readers of this magazine, please send them to us (you know, "Editor, etc."). If they are used, the printing and credit to you and a one-year free subscription to *Oregon Geology* is all the compensation we can offer. If you wish to have us return your materials, please include a self-addressed envelope.

Information for Contributors

Oregon Geology is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Color photos for publication on the front cover are highly welcome, as are letters or notes in response to materials published in the magazine and notices of meetings that may be of interest to our readers.

Two copies of the manuscript should be submitted. If manuscript was prepared on common word-processing equipment, a file copy on diskette should be submitted in place of one paper copy (from Macintosh systems, high-density diskette only). Hard-copy graphics should be camera ready; photographs should be glossies. All illustrations should be clearly marked; captions should be together at the end of the text.

Style is generally that of U.S. Geological Survey publications. (See USGS *Suggestions to Authors*, 7th ed., 1991, or recent issues of *Oregon Geology*.) Bibliography should be limited to references cited. Authors are responsible for the accuracy of the bibliographic references. Include names of reviewers in the acknowledgments.

Conclusions and opinions presented in articles are those of the authors and are not necessarily endorsed by the Oregon Department of Geology and Mineral Industries.

Authors will receive 20 complimentary copies of the issue containing their contribution.

Manuscripts, letters, notices, and photographs should be sent to Klaus Neuendorf, Editor, at the Portland office (address in masthead on first inside page).

PUBLICATION ORDER AND *OREGON GEOLOGY* RENEWAL FORM

Use the publication lists on the following pages. Mark desired titles and enter total amount below. Separate price lists for open-file reports, tour guides, recreational gold mining information, and non-Departmental maps and reports will be mailed upon request.
Send order form to **The Nature of the Northwest Information Center, Suite 177, 800 NE Oregon Street, Portland, OR 97232-2162,** or to **FAX (503) 731-4066**. If you wish to order by phone, have your credit card ready and **call (503) 872-2750** or access the Center's homepage: **http://www.naturenw.org**. Payment must accompany orders of less than $50. Payment in U.S. dollars only. Publications are sent postpaid, except where noted. All sales are final. Subscription price for Oregon Geology: $10 for 1 year, $22 for 3 years.

Renewal __ / new subscription__ to Oregon Geology: 1 yr ($10) or 3 yrs ($22) $ ____________________

Total amount for publications marked in list of available publications: $ ____________________

Total payment enclosed—or to be charged to credit card as indicated below: $ ____________________

Name/Address/City/State/Zip ____

____

Please charge to Visa__ / Mastercard__, account number: ______________________

Expiration date: ___________ Cardholder's signature ______________________

AVAILABLE PUBLICATIONS
OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

BULLETINS

	Price*
103 Bibliography (8th supplement, 1980-84). 1987	8.00
102 Bibliography (7th supplement, 1976-79). 1981	5.00
101 Geologic field trips, W. Oregon/SW Washington. 1980	10.00
99 Geologic hazards, NW Clackamas County. 1979	11.00
98 Geologic hazards, E. Benton County. 1979	10.00
97 Bibliography (6th supplement, 1971-75). 1978	4.00
96 Magma genesis. Chapman Conf. on Partial Melting. 1977	15.00
95 North American ophiolites (IGCPproject). 1977	8.00
94 Land use geology, central Jackson County. 1977	10.00
93 Geology, min. res., and rock material, Curry County. 1977	8.00
92 Fossils in Oregon. Reprints from the Ore Bin. 1977	5.00
91 Geol. hazards, Hood River, Wasco, Sherman Co. 1977	9.00
90 Land use geology of western Curry County. 1976	10.00
89 Geology and mineral resources, Deschutes County. 1976	8.00
88 Geology and min. res., upper Chetco R. drainage. 1975	5.00
87 Environmental geology, W. Coos/Douglas Counties. 1975	10.00
82 Geologic hazards, Bull Run watershed. 1974	8.00
78 Bibliography (5th supplement, 1961-70). 1973	4.00
71 Geology of lava tubes, Bend area, Deschutes County. 1971	6.00
67 Bibliography (4th supplement, 1956-60). 1970	4.00
65 Proceedings of the Andesite Conference. 1969	11.00
53 Bibliography (3rd supplement, 1951-55). 1962	4.00
46 Ferruginous bauxite, Salem Hills, Marion County. 1956	4.00
44 Bibliography (2nd supplement, 1946-50). 1953	4.00
36 Papers on Tertiary Foraminifera (v. 2 [parts VII-VIII]). 1949	4.00
33 Bibliography (1st supplement, 1936-45). 1947	4.00

MISCELLANEOUS PAPERS

20 Investigations of nickel in Oregon. 1978	6.00
19 Geothermal exploration studies in Oregon, 1976. 1977	4.00
15 Quicksilver deposits in Oregon. 1971	4.00
11 Articles on meteorites (reprints from the Ore Bin). 1968	4.00
5 Oregon's gold placers. 1954	2.00

SHORT PAPERS

27 Rock material resources of Benton County. 1978	5.00
25 Petrography of Rattlesnake Formation at type area. 1976	4.00

OIL AND GAS INVESTIGATIONS

	Price*
19 Oil and gas potential, S. Tyee Basin. 1996	20.00
18 Schematic fence diagram, S. Tyee Basin. 1993	9.00
17 Cross section, Mist Gas Field to continental shelf. 1990	10.00
16 Avail. well records and samples, onshore/offshore. 1987	6.00
15 Hydrocarbon exploration/occurrences in Oregon. 1989	8.00
14 Oil and gas investigation of the Astoria Basin. 1985	8.00
13 Biostratigraphy–explor. wells, S. Willamette Basin. 1985	7.00
12 Biostratigraphy–explor. wells, N. Willamette Basin. 1984	7.00
11 Biostratigraphy, explor. wells, Coos, Douglas, Lane Co. 1984	7.00
10 Mist Gas Field: Explor./development, 1979-1984. 1985	5.00
9 Subsurface biostratigraphy, E. Nehalem Basin. 1983	7.00
8 Subsurface stratigraphy, Ochoco Basin. 1984	8.00
7 Cenozoic stratigraphy, W. Oregon/Washington. 1983	9.00
6 Prospects f. oil and gas, Coos Basin. 1980	10.00
5 Prospects f. natural gas, upper Nehalem Basin. 1976	6.00
4 Foraminifera, E.M. Warren Coos County 1-7 well. 1973	4.00
3 Foraminifera, General Petroleum Long Bell #1 well. 1973	4.00

SPECIAL PAPERS

29 Earthquake damage and loss estimates for Oregon. 1999	10.00
28 Earthquakes Symposium Proceedings, AEG Meeting. 1997	12.00
27 Construction aggregate markets and forecast. 1995	15.00
26 Cross section, N. Coast Range to continental slope. 1992	11.00
25 Pumice in Oregon. 1992	9.00
24 Index to Forums on Industrial Minerals, 1965-1989. 1990	7.00
23 Forum on Industrial Minerals, 1989, Proceedings. 1990	10.00
22 Silica in Oregon. 1990	8.00
21 Geology, NW¼ Broken Top 15' quad., Deschutes Co. 1987	6.00
20 Bentonite in Oregon. 1989	7.00
19 Limestone deposits in Oregon. 1989	9.00
18 Investigations of talc in Oregon. 1988	8.00
17 Bibliography of Oregon paleontology, 1792-1983. 1984	7.00
16 Index to Ore Bin and Oregon Geology (1939-82). 1983	5.00
15 Geology/geothermal resources, central Cascades. 1983	13.00
14 Geology/geothermal resources, Mount Hood area. 1982	8.00
13 Faults and lineaments of southern Cascades, Oregon. 1981	5.00
12 Geologic linears, N. part of Cascade Range, Oregon. 1980	4.00
11 Bibliography/index, theses/dissertations, 1899-1982. 1982	7.00
10 Tectonic rotation of the Oregon Western Cascades. 1980	4.00
9 Geology of the Breitenbush Hot Springs quadrangle. 1980	5.00
8 Geology and geochemistry, Mount Hood volcano. 1980	4.00
7 Pluvial Fort Rock Lake, Lake County. 1979	5.00
6 Geology of the La Grande area. 1980	6.00
5 Analysis and forecasts of demand for rock materials. 1979	4.00
4 Heat flow of Oregon. 1978	4.00
3 Rock material, Clackam./Columb./Multn./Wash. Co. 1978	8.00
2 Field geology, SW Broken Top quadrangle. 1978	5.00

MISCELLANEOUS PUBLICATIONS

Oregon earthquake and tsunami curriculum. 1998. 3 vols., ea.	25.00
*Oregon fossils.1999	40.95
*Living with earthquakes in the Pacific Northwest. 1998	21.95
*Islands & Rapids. Geologic story of Hells Canyon. 1998	25.00
*The Pacific Northwest coast: Living with shores. 1998	18.50
*Hiking Oregon's geology, E.M. Bishop and J.E. Allen, 1996	16.95
*Assessing EQ hazards in the PNW (USGS Prof. Paper 1560)	25.00
***Geology of Oregon, 5th ed. 1999**	**41.95** NEW!
*Geologic map of Oregon. 1991	11.50
*Geology of the Pacific Northwest. 1996	45.00
*Geologic highway map (AAPG), PNW region. 1973	8.00
*Landsat mosaic map (published by ERSAL, OSU). 1983	11.00
Mist Gas Field map. 1999 (OFR O-99-1)	8.00
Digital disk (CAD formats .DGN, .DWG, .DXF)	25.00
Mist Gas Field production 1979-1992 (OFR O-94-6)	5.00
Oregon rocks and minerals, a description. 1988 (OFR O-88-6)	6.00
Mineral information by county (OFR O-93-8), 2 diskettes	25.00
Directory of mineral producers. 1993 (OFR O-93-9)	8.00
Geothermal resources of Oregon (DOGAMI/NOAA map). 1982	4.00
Mining claims (State laws on quartz and placer claims)	Free
Back issues of Oregon Geology	3.00

* Non-Departmental publications require additional $3 for mailing.

Separate price lists for open-file reports, tour guides, recreational gold mining information, and non-Departmental maps and reports will be mailed upon request. The Department also sells Oregon topographic maps published by the U.S. Geological Survey.

AVAILABLE PUBLICATIONS
OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES (continued)

GEOLOGICAL MAP SERIES

		Price*
GMS-113	Fly Valley 7½' quad., Union County. 1998	10.00
GMS-110	Tucker Flat 7½' quad., Union/Baker C. 1997	6.00
GMS-109	**Brownsboro 7½' quad., Jackson County 1998**	**10.00**
GMS-108	Rio Canyon 7½' quad., Jackson County 1998	6.00
GMS-106	Grizzly Peak 7½' quad., Jackson County. 1997	6.00
GMS-105	EQ hazards, Salem East/West 7½' quads. 1996	12.00
GMS-104	EQ hazards, Linnton 7½' quad. 1996	10.00
GMS-101	Steelhead Falls 7½' quad. 1996	7.00
GMS-100	EQ hazard maps for Oregon. 1996	8.00
GMS-99	Tsunami hazard map, Siletz Bay, Lincoln C. 1996	6.00
GMS-98	Dora and Sitkum 7½' quad.s, Coos County. 1995	6.00
GMS-97	Coos Bay 7½' quad., Coos County. 1995	6.00
GMS-95	Henkle Butte 7½' quad., Deschutes County. 1998	10.00
GMS-94	Charleston 7½' quad., Coos County. 1995	8.00
GMS-93	EQ hazards, Siletz Bay area, Lincoln County. 1995	20.00
GMS-92	EQ hazards, Gladstone 7½' quad. 1995	10.00
GMS-91	EQ hazards, Lake Oswego 7½' quad. 1995	10.00
GMS-90	EQ hazards, Beaverton 7½' quad. 1995	10.00
GMS-89	EQ hazards, Mt. Tabor 7½' quad. 1995	10.00
GMS-88	Lakecreek 7½' quad., Jackson County. 1995	8.00
GMS-87	Three Creek Butte 7½' quad., Deschutes C. 1996	6.00
GMS-86	Tenmile 7½' quad., Douglas County. 1994	6.00
GMS-85	Mount Gurney 7½' quad., Douglas/Coos C. 1994	6.00
GMS-84	Remote 7½' quad., Coos County. 1994	6.00
GMS-83	Kenyon Mountain 7½' quad., Douglas/Coos C. 1994	6.00
GMS-82	Limber Jim Creek 7½' quad., Union County. 1994	5.00
GMS-81	Tumalo Dam 7½' quad., Deschutes County. 1994	6.00
GMS-80	McLeod 7½' quad., Jackson County. 1993	5.00
GMS-79	EQ hazards, Portland 7½' quad. 1993	20.00
GMS-78	Mahogany Mountain 30´60' quad., Malheur C. 1993	10.00
GMS-77	Vale 30´60' quad., Malheur County. 1993	10.00
GMS-76	Camas Valley 7½' quad., Douglas/Coos C. 1993	6.00
GMS-75	Portland 7½' quad. 1991	7.00
GMS-74	Namorf 7½' quad., Malheur County. 1992	5.00
GMS-73	Cleveland Ridge 7½' quad., Jackson County. 1993	5.00
GMS-72	Little Valley 7½' quad., Malheur County. 1992	5.00
GMS-71	Westfall 7½' quad., Malheur County. 1992	5.00
GMS-70	Boswell Mountain 7½' quad., Jackson County. 1992	7.00
GMS-69	Harper 7½' quad., Malheur County. 1992	5.00
GMS-68	Reston 7½' quad., Douglas County. 1990	6.00
GMS-67	South Mountain 7½' quad., Malheur County. 1990	6.00
GMS-66	Jonesboro 7½' quad., Malheur County. 1992	6.00
GMS-65	Mahogany Gap 7½' quad., Malheur County. 1990	5.00
GMS-64	Sheaville 7½' quad., Malheur County. 1990	5.00
GMS-63	Vines Hill 7½' quad., Malheur County. 1991	5.00
GMS-62	The Elbow 7½' quad., Malheur County. 1993	8.00
GMS-61	Mitchell Butte 7½' quad., Malheur County. 1990	5.00
GMS-60	Damascus 7½' quad., Clackamas/Multnomah C. 1994	8.00
GMS-59	Lake Oswego 7½' quad. 1989	7.00
GMS-58	Double Mountain 7½' quad., Malheur County. 1989	5.00
GMS-57	Grassy Mountain 7½' quad., Malheur County. 1989	5.00
GMS-56	Adrian 7½' quad., Malheur County. 1989	5.00
GMS-55	Owyhee Dam 7½' quad., Malheur County. 1989	5.00
GMS-54	Graveyard Point 7½' quad., Malheur/Owyhee C. 1988	5.00
GMS-53	Owyhee Ridge 7½' quad., Malheur County. 1988	5.00

		Price*
GMS-52	Shady Cove 7½' quad., Jackson County. 1992	6.00
GMS-51	Elk Prairie 7½' quad., Marion/Clackamas C. 1986	5.00
GMS-50	Drake Crossing 7½' quad., Marion County. 1986	5.00
GMS-49	Map of Oregon seismicity, 1841-1986. 1987	4.00
GMS-48	McKenzie Bridge 15' quad., Lane County. 1988	9.00
GMS-47	Crescent Mountain area, Linn County. 1987	7.00
GMS-46	Breitenbush River area, Linn/Marion Counties. 1987	7.00
GMS-45	Madras West/East 7½' quads., Jefferson County. 1987	5.00
	as set with GMS-43 and GMS-44	11.00
GMS-44	Seekseequa Junction/Metolius Bench 7½' quads. 1987	5.00
	as set with GMS-43 and GMS-45	11.00
GMS-43	Eagle Butte/Gateway 7½' quads. 1987	5.00
	as set with GMS-44 and GMS-45	11.00
GMS-42	Ocean floor off Oregon & adj. cont. margin. 1986	9.00
GMS-41	Elkhorn Peak 7½' quad., Baker County. 1987	7.00
GMS-40	Aeromagnetic anomaly maps, north Cascades. 1985	5.00
GMS-39	Bibliogr. & index: Ocean floor, cont. margin. 1986	6.00
GMS-38	NW¼ Cave Junction 15' quad., Josephine County. 1986	7.00
GMS-37	Mineral resources, offshore Oregon. 1985	7.00
GMS-36	Mineral resources of Oregon. 1984	9.00
GMS-35	SW¼ Bates 15' quad., Grant County. 1984	6.00
GMS-34	Stayton NE 7½' quad., Marion County. 1984	5.00
GMS-33	Scotts Mills 7½' quad., Clackamas/Marion C. 1984	5.00
GMS-32	Wilhoit 7½' quad., Clackamas/Marion Counties. 1984	5.00
GMS-31	NW¼ Bates 15' quad., Grant County. 1984	6.00
GMS-30	SE¼ Pearsoll Peak 15' qu., Curry/Josephine C. 1984	7.00
GMS-29	NE¼ Bates 15' quad., Baker/Grant Counties. 1983	6.00
GMS-28	Greenhorn 7½' quad., Baker/Grant Counties. 1983	6.00
GMS-27	The Dalles 1° ´ 2° quadrangle. 1982	7.00
GMS-26	Residual gravity, north/ctr./south Cascades. 1982	6.00
GMS-25	Granite 7½' quad., Grant County. 1982	6.00
GMS-24	Grand Ronde 7½' quad., Polk/Yamhill Counties. 1982	6.00
GMS-23	Sheridan 7½' quad., Polk and Yamhill Counties. 1982	6.00
GMS-22	Mount Ireland 7½' quad., Baker/Grant C. 1982	6.00
GMS-21	Vale East 7½' quad., Malheur County. 1982	6.00
GMS-20	S½ Burns 15' quad., Harney County. 1982	6.00
GMS-19	Bourne 7½' quad., Baker County. 1982	6.00
GMS-18	Rickreall, Salem W., Monmouth, Sidney 7½' quads. 1981	6.00
GMS-17	Aeromagnetic anomaly map, south Cascades. 1981	4.00
GMS-16	Gravity anomaly maps, south Cascades. 1981	4.00
GMS-15	Gravity anomaly maps, north Cascades. 1981	4.00
GMS-14	Index to published geol. mapping, 1898–1979. 1981	8.00
GMS-13	Huntington/Olds Ferry 15' quads., Baker/Malheur C. 1979	4.00
GMS-12	Oregon part, Mineral 15' quad., Baker County. 1978	4.00
GMS-10	Low- to intermediate-temp. thermal springs/wells. 1978	4.00
GMS-9	Aeromagnetic anomaly map, central Cascades. 1978	4.00
GMS-8	Bouguer gravity anom. map, central Cascades. 1978	4.00
GMS-6	Part of Snake River canyon. 1974	8.00
GMS-5	Powers 15' quadrangle, Coos and Curry C. 1971	4.00

INTERPRETIVE MAP SERIES

IMS-12	**Tsunami hazard map, Warrenton area. 1999**	**10.00**	NEW!
IMS-11	**Tsunami hazard map, Astoria area. 1999**	**10.00**	NEW!
IMS-10	**Rel. EQ hazard maps, coastal urban areas. 1999**	**20.00**	NEW!
IMS-6	Water-induced landslide hazards, Salem Hills. 1998	10.00	
IMS-4	Geology/faults/sedim. thickness, Oregon City quad. 1997	10.00	

(Continued on next page)

AVAILABLE PUBLICATIONS
OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES (continued)

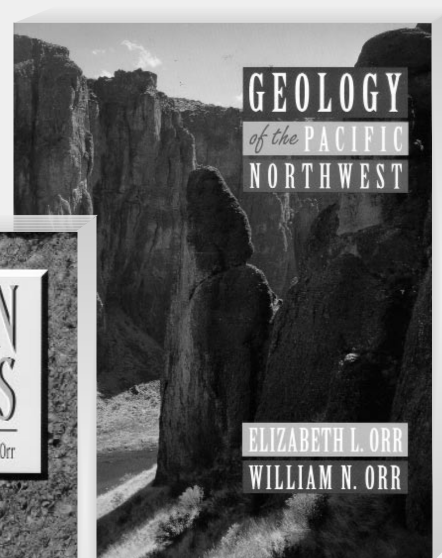
	Price*
IMS-3 Tsunami hazard map, Seaside area. 1998	6.00
IMS-2 Tsunami hazard map, Yaquina Bay area. 1997	6.00
IMS-1 Relative EQ hazards, Portland metro area. 1997	12.00
MINED LAND RECLAMATION PROGRAM STATUS MAPS	
MLR-03 Clackamas County. 1998	10.00
MLR-10 Douglas County. 1998	10.00
MLR-17 Josephine County. 1998	10.00
MLR-24 Marion County. 1998	10.00
U.S. GEOLOGICAL SURVEY MAPS PLOTTED ON DEMAND	
OFR 97-513 Volcano hazards at Newberry volcano	10.00
OFR 97-089 Volcano hazards in the Mount Hood region	10.00
OFR 94-021 Geologic map, Tillamook highlands (2 sheets)	20.00

Allow 2 weeks for delivery on all maps plotted on demand.

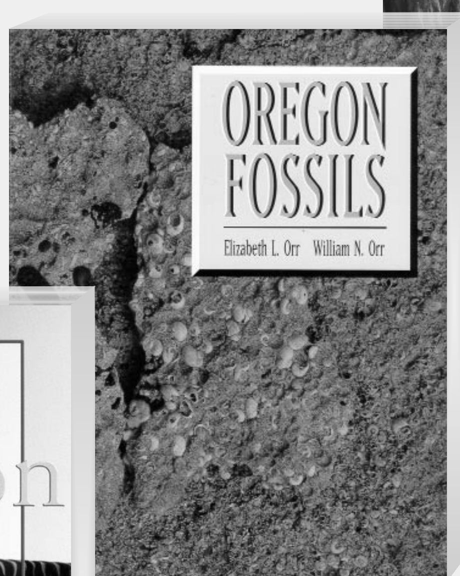
Highlighting Recent Publications

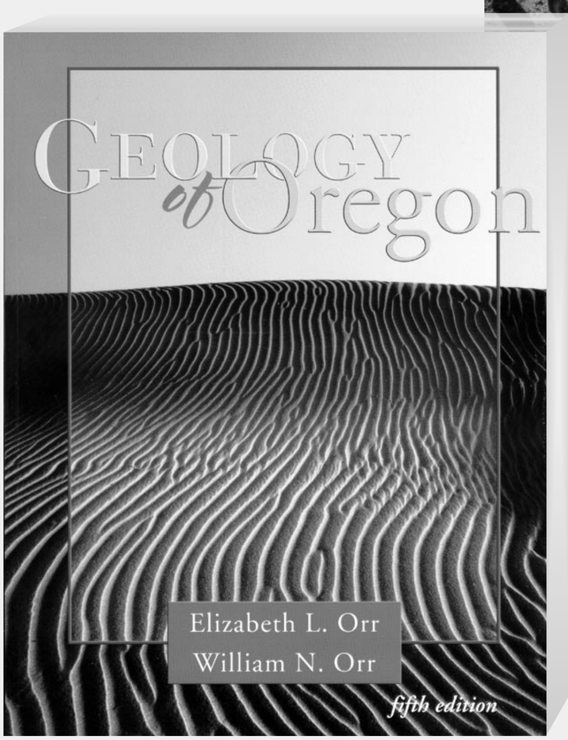
now available from The Nature of the Northwest Information Center

Elizabeth and William Orr, the authors of the article in this issue, have contributed much to our knowledge of the geology of Oregon and the Pacific Northwest. Their most current books are featured here.



Geology of the Pacific Northwest, published 1996 by McGraw-Hill, represents the first major update of Pacific Northwest geology since the 1972 book *Cascadia* by Bates McKee. It reflects the growing understanding of tectonic plate movements and particularly accretionary events and how they shaped our region. Expanding our view beyond the Geology of Oregon, it includes British Columbia, Washington, and Idaho.





Oregon Fossils, published 1999 by Kendall/Hunt, grew out of the Orrs' 1981 *Handbook of Oregon Plant and Animal Fossils* and a 1984 *Bibliography of Oregon Paleontology*. A comprehensive overview, which also tells of the major events and people involved.

Geology of Oregon, 5th edition, published 1999 by Kendall/Hunt, revises and updates the out-of-print 4th edition. The latter had been coauthored with Ewart Baldwin, sole author of the first three editions published between 1959 and 1976. The new edition adds color photos (13, on 8 pages), fills four previously blank pages or spaces with more black-and-white photos, and updates illustrations modeling the possible plate-tectonic history of the Cascade and Coast Ranges.

All three books are intended for both amateur and professional readers and are richly illustrated. You will find them listed on the previous pages under "Miscellaneous Publications."

(Continued from page 138)
ancient structures that have been reactivated by careless land use practices, and once a serious landslide has been activated, ten or more years of effort can go into arresting the flow.

TECTONIC HAZARDS

Earthquakes, volcanic eruptions, and tsunamis in the Pacific Northwest have recently had ample press coverage. Yet, they are relatively rare in modern times and therefore have not caused as much damage here as floods and landslides. In the public mind, however, the destructive power these tectonic hazards have occupies a position of major importance—and with good reason.

Earthquakes

Earthquakes are seismic shock waves generated by breaks in the earth's crust. Striking without warning, quakes are among the potentially most catastrophic of geologic processes, destroying property and killing on a vast scale. Deaths are primarily due to falling structures or landslides, while fires, started by the quake and fed by rubble, contribute to the devastation.

Most large quakes in the Pacific Northwest can be classified as either crustal shear, tensional, or subduction earthquakes. Crustal shear quakes are induced by stresses set up near the edges of large juxtaposed blocks moving in different directions. The magnitude (M) of crustal shear earthquakes may be up to M 7, and the duration is usually less than a minute. Tensional quakes relate to extreme stretching of the crust, and they can reach M 6.5.

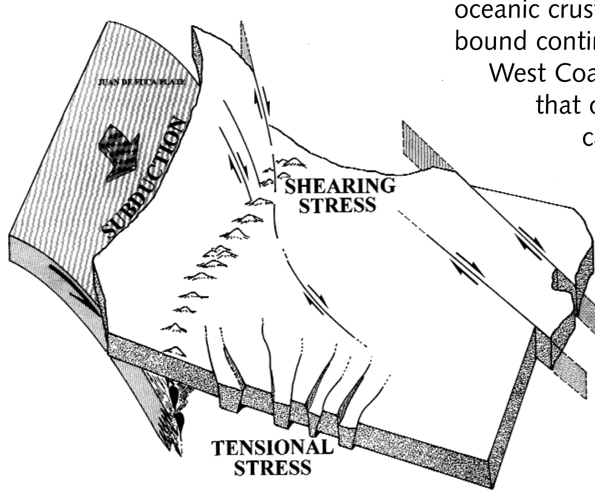


Diagram showing different types of stresses that characterize the main types of earthquakes in the Pacific Northwest.

Subduction quakes, where crustal slabs are overriding each other at collision boundaries between plates, are far more destructive with magnitudes reaching 8.0 or even 9.0 and a duration of three or more minutes. Major quakes of this nature fortunately take place centuries apart, and Oregon's geologic history suggests an irregular 300-year to 500-year cycle.

The recognition that the Pacific Northwest is subject to massive subduction quakes came only recently as the result of excellent scientific work. During the early 1980s, emerging evidence suggested that the subduction process along the Pacific Northwest margin—far from being gradual and benign—might be catastrophic in nature. Data from coastal soil and sediment profiles, liquefaction, large-scale landslides, and even deep-ocean drill cores showed a clear record of intermittent but devastating quakes.

When the Cascadia subduction system—young, warm, buoyant oceanic crust sliding beneath a westbound continental mass along the West Coast— was compared to that of Chile in South America, startling similarities emerged. In Chile, the configuration of a sediment-filled trench, an uplifted coast range, an interior valley, and a volcanic chain further to the east mirror that of Oregon's Coast Range, Willamette Valley, and Cascade Range. Most disturbing is, of course, the seismic history of Chile whose M 9.5 quake in 1960 was the largest of the 20th Century.

Prehistoric and historic earthquakes

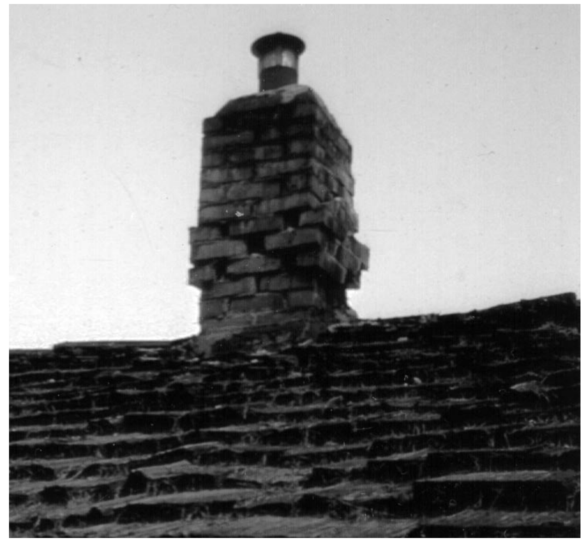
Compared to California and Washington, earthquakes in Oregon are infrequent. Of the approximately 33,000 historic quakes recorded in the Pacific Northwest, 26,000 took place in Washington and 7,000 in Oregon. Most were less than M 3.0.

The lack of historic records for quakes is misleading, due, in part, to the fact that Oregon's recorded seismic past goes back only about 175 years. No subduction earthquake has occurred since the European settlement of the Pacific Northwest.

Off the West Coast, the Juan de Fuca slab is subducting beneath the overriding North American plate. It is thought that the subduction process here is characterized by periodic binding of the two plates, causing the overlying slab to arch upward. When the plates release, the event is accompanied by a massive seismic shock and very rapid depression of large tracts of the coast.

By looking at the record of subsidence as seen in buried coastal marshes, earthquake events can be chronicled. Depth, stratigraphy, and radiocarbon dates of buried forests and peat layers at seven estuaries covering over 100 miles of the Oregon coast were compared, from Necanicum River in Clatsop County to South Slough in Coos County. The comparisons were then used to calculate the degree of subsidence produced by the quakes, the magnitude of the quakes, and the interval of time between events. Estimates are that Cascadia subduction margin quakes of at least M 8.0 took place over a time span from 2,400 to 300 years in the past, recurring at an average of 400-year intervals. Additional studies of late Pleistocene coastal terraces from Seaside to Gold Beach substantiate this record.

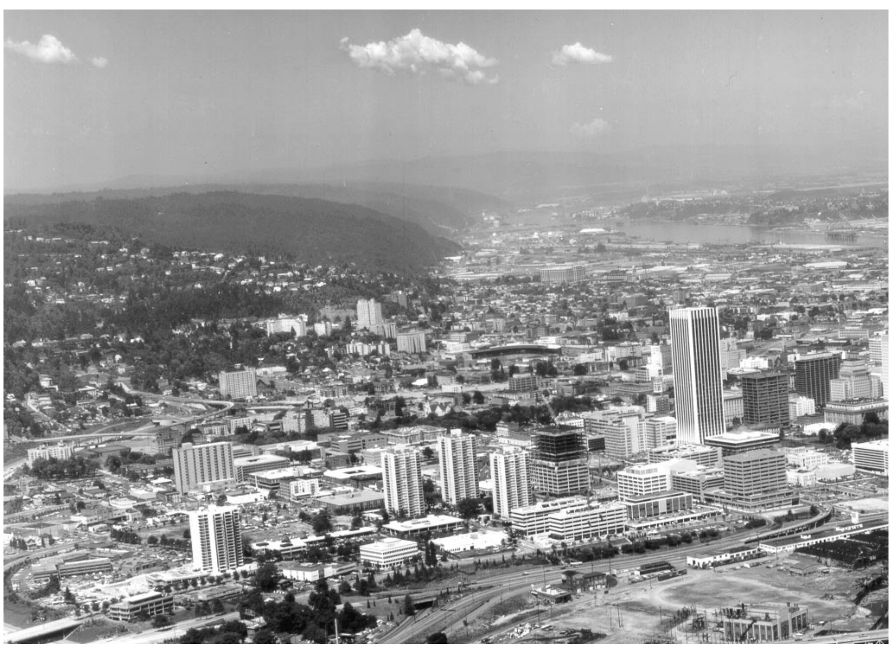
A similar record has been exposed at sites in the Columbia Gorge showing soil liquefaction from a 300-year-



Chimneys, usually built of unreinforced masonry, show the most common type of damage caused by the 1993 Scotts Mills earthquake. Photos show house near Molalla on left and roof of authors' home near Scotts Mills (right). Photos courtesy of Doug Eaton.

old earthquake. In contrast to other studies, these localities were plentiful but indicated a fairly low intensity for the event.

In historic times, the Port Orford-Crescent City earthquake of November 23, 1873, was the strongest to shake Oregon. The shaking from the M 8.0 event was felt from San Francisco to Portland. There were no aftershocks, which leads to the conclusion that the quake originated offshore either from a crustal fault or from the Cascadia subduction zone.



Two major north northwest-trending faults slice across Portland. The Portland Hills fault to the left is marked by the straight northeast margin of the foothills, while across the Willamette River, the parallel East Valley fault is buried beneath alluvium and fill. Photo courtesy of Delano Photographics.

The historic record on earthquakes in Portland and the Willamette Valley is far too brief for a complete seismic picture. However, from 1846 to 1993 there have been clusters of earth tremors roughly every five to 10 years. Most of these were moderate to slight and centered over a region from Woodburn northward to Vancouver.

Portland could be struck by either a shallow crustal shear earthquake along the north-northwest trending Portland Hills-Clackamas River fault zone or by a shock wave from the deeper Cascadia subduction system. In the case of either type of earthquake, the Portland metropolitan center will experience considerable ground shaking. Research aimed at specific sites here postulates that soils and unconsolidated sediments downtown would be more severely affected than deeper soil profiles at the Marquam Bridge and Portland Airport.

Coming as a complete surprise to most people, including geologists, the M 5.6 Scotts Mills quake of 1993 was one of the strongest events in Oregon's recorded history. Because it was so unexpected, it should be seen as a warning that fu-

The huge boulder above was dislodged and fell on Highway 140 west of Howard Bay at Upper Klamath Lake during the 1993 Klamath Falls earthquake, which also produced a rotational slump and its associated crescent-shaped cracks in the roadbed nearby (right).

ture seismic events could be equally unforeseen. It is probably fortunate, in this case, that the epicenter was in a remote area, approximately three miles east of the small community of Scotts Mills in Clackamas County.

The Scotts Mills quake originated at a depth of 12 miles, whereas the February 24, 1999, earthquake at Molalla in Clackamas County was almost twice that deep, at 22 miles. Although it only measured M 2.7, the Molalla quake was felt over an extremely wide area from Vancouver to southern Linn County.

Although no ground cracking, landsliding, or soil liquefaction was visible on the surface following these earthquakes, nearby population centers of Woodburn, Mount Angel, and Molalla, as well as Newberg and the State Capitol Building in Salem suffered considerable damage during the Scotts Mills event, while only minor loss resulted from the Molalla quake.

The Scotts Mills quake was caused by crustal movement along the Mount Angel fault which runs from west of Woodburn toward Scotts Mills. On the west side of the Willamette River, the Gales Creek fault is part of the same north-northwest trending structural zone near Newberg. An earlier series of small earthquakes in 1990 close to Woodburn as well as the Thanksgiving Day quake of 1999 indicate that the activity along the Mount Angel fault is ongoing. This zone, as in the case of the Portland Hills fault zone, consists of faults caused by right-lateral movement (i.e., looking across the break, a viewer would see the block on the far side move to the right).

By contrast, the earthquake that struck Klamath Falls on September 20, 1993, was the strongest so far measured in the state and the strongest since the 1873 Port Orford-Crescent City event. Two main shocks at Klamath Falls, centered near the Mountain Lake Wilderness southwest of Upper Klamath Lake, were followed by 16 smaller tremors and then the largest tremor at M 6.0. Surface evidence of the event included ground cracks, and landslides. Two people died, one whose car was struck by a boulder and another of a heart attack. Over 1,000 buildings were damaged, but because it was even further from a population center than the quake at Scotts Mills, overall property damage was less.

Dramatic north-northwest scarps mark a zone of tensional quakes in south-central Oregon where normal faults (i.e., the viewer would see one block move downward relative to the other)—are part of the Basin and Range system. In this province, the earth's crust was stretched as much as twice its original width, before failure produced faulting.

A similar tensional fault and quake in the Warner Valley in Lake County on June 4, 1968, registered M 4.7, but little damage was evident other than fallen chimneys and foundation cracks.

Seismic processes have been studied even east of the Cascades, away from the population density of the Willamette Valley. Numerous quakes in the range of M 2.0 to M 3.0 have shaken open cracks in plaster and chimneys in the Deschutes valley, near Baker City, and at Hermiston. Stronger shocks causing more damage measured M 4.8 northeast of Maupin in Wasco County on April 12, 1976, and M 7.0 near Milton-Freewater on July 15, 1936.

At Milton-Freewater, large ground cracks, some 300 feet long and six feet wide, along with marked changes in the flow of local well water were noted. In some cemeteries a number of the head stones moved, and many houses were badly damaged.

The Oregon Legislature passed a law in 1993, requiring that sites for public-use buildings such as hospitals and schools be evaluated for soil and slope stability, and building codes were subsequently revised. In 1999, DOGAMI released earthquake hazard maps for several coastal communities. These maps analyze potentially hazardous conditions that might increase damage and risks from earthquakes. In 2000, the department will release maps for many of the urban areas in western Oregon.

VOLCANOES

Volcanoes, like most earthquakes, are related to tectonic plate motion. Since the eruption of Mount Lassen in 1919 and Mount St. Helens in 1980, most Northwesterners have accepted intermittent volcanic events as part of life here.

Volcanoes bring about a diversity of hazards to human culture, including clouds of hot gasses carrying rock and sand, blast effects, ash falls, and mud flows. On the positive side, it can be said that, unlike earthquakes, volcanoes generally give plenty of warning that they are awakening, although the actual moment of eruption may come as an unpleasant surprise.

More than any other single event in this century, the May 18, 1980, eruption of Mount St. Helens brought the reality of geologic hazards to the public's awareness. Photo courtesy of U.S. Geological Survey.

Following an eruption, ash may take weeks to settle from the air. This fine powder is quite harmful to lungs and incredibly abrasive to moving parts of any machinery or engine. The weight of wet ash can collapse a building.

A most sensational aspect of a volcanic eruption is the *nuée ardente* or fiery ash flow. In this event, superhot, burning gas is suddenly pumped into the air to fall back to earth as a heavy cloud and move across the landscape at hundreds of miles per hour, immolating everything in its path. Even though these ash flows were known to geologists, they were only rarely witnessed and not filmed until the 1980s, when they were captured on videotape in Japan. In 1902 over 30,000 people in the village of St. Pierre on Martinique were incinerated by a *nuée ardente*, and more recently the island of Monserrat experienced the same phenomenon, fortunately without loss of life. In Oregon, deposits from ash flows are a frequent part of the geologic record east of the Cascades.

Before the 1980 Mount St. Helens episode, the incidence and impact of lateral eruptions was poorly understood. During this event, the northeastward blast knocked down trees and increased the damage significantly. Since then, it has been found that lateral blasts are not uncommon in Cascade volcanoes. An urban center in the path of such a force would be totally devastated.

Mount St. Helens displays the debris avalanche and mudflow deposits that supplemented the blast effect of the eruption. Photo courtesy of U.S. Geological Survey.

Prehistoric and historic volcanic eruptions

In the Cascade volcanic chain, that extends from Lassen Peak in northern California to Meager Mountain in British Columbia, over 3,000 large and small volcanoes have erupted during the past five million years. Within the vicinity of Portland alone, close to 50 volcanoes erupted more than half a million years ago. Between 1843 and 1860, a series of 21 eruptions took place in the Cascades, and there is speculation that the Northwest may be entering another period of volcanic activity.

The Cascade peaks in Washington and California have erupted more recently than those in our state. Mount Hood has erupted three times over the past 2,000 years. Flows of hot ash, rock, and mud poured down the southwest side of the mountain near Crater Rock about 1,400–800 years ago, 600–400 years ago, and between 1760 CE and 1800 CE. In each event, lava reached the surface through vents, accumulated, then collapsed, sending streams of the hot debris downslope. Melting snow combined with lahars of ash, lava, rock, and mud to travel along the Sandy, Zig-Zag, and White Rivers, burying forests upright.

Predictions about future eruptions of Mount Hood have been based on observations of volcanism elsewhere. Warning times from as little as a few hours to as long as one year have been suggested as needed; but a system of seismometers, located on the mountain and recording present-day tremors, should give adequate advance notification for civil evacuation. As during earlier eruptions, molten material and an ash cloud could be expected to affect the same river valleys, and the projected hazard zone could extend to the communities of Hood River, Sandy, and Zig-Zag.

Across the Columbia River in Washington, the eruption of Mount St. Helens on May 18, 1980, devastated a wide area of the Northwest. The destruction shocked people living here and made them realize that such a violent event could easily recur.

Mount St. Helens gave substantial warning that it was to erupt. About two months prior, small earthquakes were detected by a network of seismographs, and a minor eruption on March 27 opened a summit crater. These were followed by a M 5.1 earthquake that triggered massive landslides on the north slope and brought about the rapid release of pressure on the superheated interior of the cone. The ensuing eruption took off the upper 1,300 feet of the peak. Lahars of melted snow, ice, and hot rock combined to descend the side of the volcano, and a visible plume of airborne ash was carried as far east as Denver, Colorado. Powdery gray ash fell eastward to Spokane and later south to the Willamette Valley.

About 7,000 years earlier, the eruption of Mount Mazama—now Crater Lake—in southern Oregon was more violent and would have been spectacular to any one viewing it. During the Pleistocene Epoch, over 400,000 years ago, numerous early eruptions spread individual flows of lava up to 30 feet thick. After an extended period of cone building, the stratovolcano exploded with clouds of ash and fiery debris that would have covered the present-day city of Bend six inches deep. Ash layers would also have accumulated on what is now Portland and the Willamette Valley. After about six cubic miles of magma had drained from the subterranean chamber, the roof collapsed into the caldera, removing approximately 2,000 feet from the mountain top. Today the beautiful blue waters of Crater Lake occupy the collapsed volcano.

This idyllic scene in the Hood River valley would be destroyed by a northward lateral blast from an erupting Mount Hood. Photo courtesy of Oregon Department of Transportation.

Warning signs of a possible volcanic eruption such as earthquakes, swelling, heat flow, tilting, and gas plumes need to be monitored. If a volcano shows signs of increased activity, people should be alerted and plans announced for evacuations, whenever necessary. Available maps of volcanic hazardous zones should be rated for potential danger so that local, state, and federal authorities can guide development in these regions.

TSUNAMIS

Tsunamis, the first cousins to earthquakes, can arrive with only slight warning. A tsunami, also called a seismic sea wave, or incorrectly called a tidal wave, travels across the deep ocean at speeds up to 500 miles per hour. A tsunami generated offshore from Japan or Alaska might not hit the Oregon coast for several hours. A tsunami following a Cascadia earthquake may hit in less than 30 minutes.

On the open ocean, a fast moving tsunami might be a wave only three to four feet high, with 100 miles separating wave crests. Approaching the coast, however, the tsunami begins to slow in shallow water, and successive waves bunch up, increasing in height. As the ocean bottom shallows even more, the wave rapidly rises and may break several tens of feet high with incredible destructive power. It has been conjectured that the configuration of the Oregon and Washington continental shelf could produce tsunami waves that would appear to rise slowly out of the ocean but build up to 30 feet or more in height as water is cast shoreward.

If you throw a pebble into standing water, a succession of ripples or waves moves across the water. Similarly, tsunamis almost never come as single waves but arrive as multiple crests that are sometimes hours apart. Often the first tsunami is not even the largest or most destructive, and wave four or five may be the largest of all.

Tsunamis are caused by undersea volcanic eruptions, landslides, or faulting as slabs of the sea floor are displaced vertically. Most commonly, rapid uplift or subsidence of the sea floor along faults is transmitted to the surface of the ocean, forming unusually large waves. Coastal slides from land under the water, also triggered by earth movement, can intensify the effects of tsunamis.

The undersea subduction zone, paralleling the Oregon coast at a distance of about 75 miles, is the junction between the Juan de Fuca and the North American tectonic plates. The two plates lock together, but periodically the stress is released suddenly with a snapping motion, and the resulting shock may trigger a tsunami. Distinctive, thin deposits of shallow marine sands along the coast are physical evidence of these ancient waves.

Prehistoric and historic tsunamis

Most inhabitants of the Pacific Northwest have never experienced a tsunami—in contrast to experiences of flooding, landslides, earthquakes, and even volcanic eruptions.

The past occurrence of seismic sea waves in the Pacific Northwest has come to light with recent research that matches records from Japan with carbon-isotope-14 data from wood buried in tsunami sands on the West Coast. Because the Japanese data are so accurate, exact dates can be given for sea wave occurrences. The date of the last large tsunami, recorded in the sands and correlated with Japanese records, was January 26, 1700. The earthquake that generated the wave registered M 9, and the ensuing tsunami destroyed coastal villages in Japan.

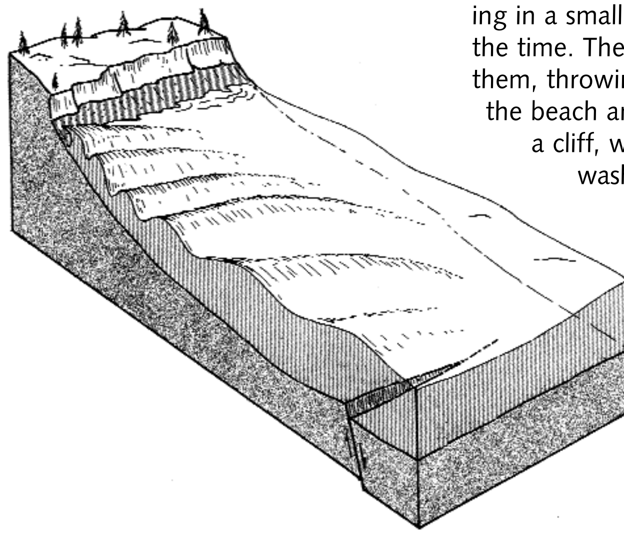
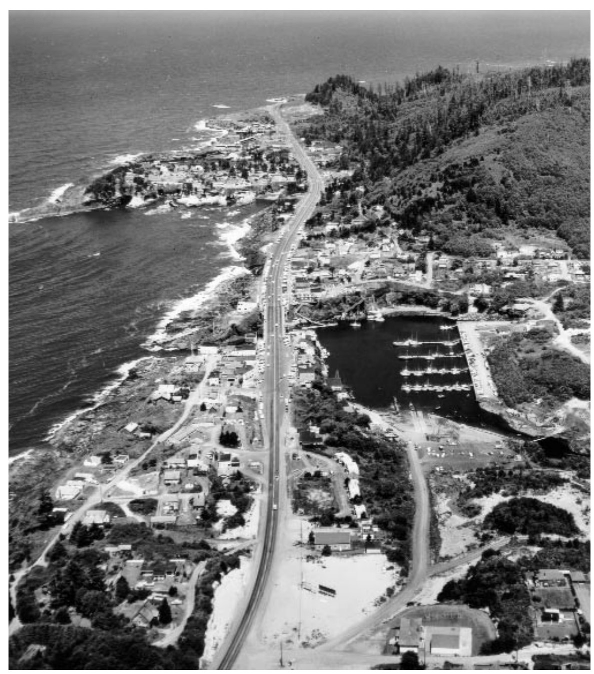


Diagram showing generation of tsunamis.

In Oregon, prehistoric runups (i.e., how high a tsunami wave reaches above mean sea level) can be deduced with numerical methods. From such models, it was concluded that a tsunami that struck Salishan Spit in Lincoln County between 300 and 800 years ago had a runup of up to 40 feet above sea level. It is likely that the same wave probably overtopped a 16-foot-high barrier ridge at Cannon Beach and breached a 20-foot ridge at Seaside.

One of the largest subduction zone earthquakes ever recorded was the M 9.2 quake on March 27, 1964, centered in Prince William Sound, Alaska. This generated a tsunami that struck the Oregon coast at 11:30 p.m. with waves as high as 10 feet, swamping houses, destroying bridges and sea walls, and tragically killing four children. A family was camping at Beverly Beach and sleeping in a small driftwood shelter at the time. The second wave reached them, throwing the mother out onto the beach and the father up against a cliff, while the children were washed out to sea. In March 1999, a plaque remembering the children and providing information about tsunamis was dedicated at Beverly Beach State Park.

A predicted tsunami on the Oregon coast in 1995 turned out to be a barely recognizable small wave, but the effect on local residents was revealing. Hysterical television and radio warnings led to panic as food and bottled water were emptied from grocery shelves and families were hastily thrown into automobiles that sped to higher ground. Other people, driving to the coast to view the event, caused traffic jams that were worse than the natural disaster which never materialized.



Clinging to the coastline, communities such as Depoe Bay, Oregon, would be devastated by a large-scale tsunami, which might give as little as 20 minutes of warning before reaching land. Photo courtesy of Oregon. Dept. of Transportation.

The recently hightened awareness of the potential for a seismic sea wave to inundate the western coastline has caused the National Oceanic and Atmospheric Administration, the U.S. Geological Survey, and the Federal Emergency Management Administration to initiate a program to upgrade their seismic system in order to predict tsunamis more accurately. As a tsunami traverses the ocean, a network of sensitive recorders on the sea floor measures pressure changes in the overhead water, sending the information to sensors on buoys, which, in turn, relay the data to satellites for immediate transmission to warning centers.

Tsunami maps of the Oregon coast were produced by DOGAMI in response to a bill passed by the 1995 Legislature, limiting construction of new hospitals, schools, and other similar public-service buildings in tsunami flood zones. Additional mapping was begun in 1997 with the establishment of the Center for the Tsunami Inundation Mapping Effort at the Hatfield Marine Science Center in Newport. The maps, as well as offshore detection systems, public education, and evacuation planning, are part of a strategy to save lives and reduce loss from tsunamis. In order to educate and alert coastal residents and visitors to potential risks, interpretive signs have been installed to explain hazards. Blue-and-white reflective signs depicting high waves and a person running uphill are being placed at a variety of locations in coastal communities.

SUMMARY

It is ironic that building is still taking place on floodplains, ocean cliffs, landslide-prone slopes, and at other high-risk sites, in spite of increased knowledge of geologic hazards and a tightening of government regulations. The Oregon Department of Agriculture has even recommended placing a 200-foot-high earth-fill dam on Butte Creek in Clackamas County—on the epicenter of the 1993 Scotts Mills earthquake. On many of the known hazardous slopes in Portland, houses that were destroyed by landslides are being reconstructed or replaced. Most of the decisions pertaining to these practices seem to be made by individuals without any understanding of the hazards and certainly without benefit of trained geologists. The answer to avoiding potentially hazardous situations is research, public education, sensible planning, and rigid restrictions in problem areas.

Ongoing geologic processes that shape Oregon's scenic landscape can also set up hazardous conditions. Regardless of human efforts to the contrary, natural phenomena will have the final word.

ACKNOWLEDGMENTS

We would like to thank Scott Burns for suggestions, references, and photographs, as well as for a spectacular field trip to Kelso, Washington.

Corvallis as seen from the east. During even minor floods the entire flatland between meanders is usually under water.

BIBLIOGRAPHY

Allen, J.E., 1988, Volcanic hazards from High Cascade peaks: Oregon Geology, v. 50, no. 5/6, p. 56–63.

Bates, D., Hallman, T., and O'Keefe, M., 1996, Return of the river: The Oregonian, February 11, p. A1/A12.

Beaulieu, John, 1976, Geologic hazards in Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 38, no. 5, p. 67–83.

——1985, Geologic landslides in and near the community of The Dalles, Oregon: Oregon Geology, v. 47, no. 9, p. 103–106/108.

Bernton, H., 1996, Survey ties some slides to roads, clear-cuts: The Oregonian, February 24, p. A1/A9.

Black, G.L., 1999, Intensities for the February 1999 Molalla earthquake: Oregon Geology, v. 61, no. 4, p.97–98.

Bott, J.D.J., and Wong, I.G., 1993, Historical earthquakes in and around Portland, Oregon: Oregon Geology, v. 55, no. 5, p. 116–122.

Brantley, S.R., and Scott, W.E., 1997, The danger of collapsing lava domes: Lessons for Mount Hood, Oregon: Oregon Geology, v. 59, no. 4, p. 83–92.

Burns, S.F., 1996, Landslides in the West Hills of Portland: A preliminary look: Oregon Geology, v. 58, no. 2, p. 42–43.

——ed., 1998. Environmental, groundwater, and engineering geology: Applications from Oregon: Belmont, Calif., Star Publishing Co., 689 p.

Byerly, P., 1952, Pacific coast earthquakes: Eugene, Oregon State System of Higher Education, Condon Lectures, 38 p.

Cameron, K.A., and Pringle, P.T., 1991, Prehistoric buried forests of Mount Hood: Oregon Geology, v. 53, no. 2, p. 34–43.

Darienzo, M.E., and Peterson, C.D., 1995, Magnitude and frequency of subduction-zone earthquakes along the northern Oregon coast in the past 3,000 years: Oregon Geology, v. 57, no. 1, p. 3–12.

Donner, H., 1953, The Heppner flood, June 14, 1903: The East Oregonian Newspaper, June 12, 1953.

Hart, R., and Peterson, C.D., 1997, Episodically buried forests in the Oregon surf zone: Oregon Geology, v. 59, no. 6, p. 131–144.

Hill, R., 1998, Threat propels drive to improve tsunami alerts: The Oregonian, September 9, p. A1/A12.

Hofmeister, R.J., 1999, Earthquake-induced slope instability: A relative hazard map for the vicinity of the Salem Hills, Oregon: Oregon Geology, v. 61, no. 3, p. 55–63.

Hogan, D., 1996, High water, slides keep many Northwest roads closed: The Oregonian, February 11, p. A15.

Mabey, M.A., Black, G.L., Madin, I.P., Meier, D.B., Youd, T.L., Jones, C.F., and Rice, J.B., 1997, Relative earthquake hazard map of the Portland metro region, Clackamas, Multnomah, and Washington Counties, Oregon: Oregon Department of Geology and Mineral Industries Interpretive map IMS–1, scale 1:62,500.

Madin, I.P., Priest, G.R., Mabey, M.A., Malone, S., Yelin, T.S., Meier, D., 1993, March 23, 1993, Scotts Mills earthquake-western Oregon's wake-up call: Oregon Geology, v. 55, no. 3, p. 51–57.

McElderry, S., 1998, Vanport conspiracy rumors and social relations in Portland, 1940–1950: Oregon Historical Quarterly, v. 99, no. 2, p. 134–163.

Miller, G., 1999, The great Willamette River flood of 1861: Oregon Historical Quarterly, v. 100, no. 2, p. 183–207.

North, W.B., and Byrne, J.V., 1965, Coastal landslides of northern Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 27, no. 11, p. 217–241.

The Oregonian [Portland newspaper], 1996, Along with the high water comes mud: February 9, p. A19.

Orr, E.L., and Orr, W.N., 1996, Geology of the Pacific Northwest: New York, McGraw-Hill, 409 p.

——1999, Geology of Oregon, 5th ed., Dubuque, Iowa, Kendall-Hunt, 254 p.

——1999, Oregon Fossils: Dubuque, Iowa, Kendall-Hunt, 381 p.

Peterson, C.D., and Madin, I.P., 1997, Coseismic paleoliquefaction evidence in the central Cascadia margin, USA: Oregon Geology, v. 59, no. 3, p. 51–74.

Peterson, G.L., Scofield, D.H., Squier, L.R., and Toor, F., 1998. Engineering geology and drainage of the Arizona Inn landslide, U.S. Highway 101, southern Oregon coast, *in* Burns, S., ed., Environmental, groundwater, and engineering geology: Applications from Oregon: Belmont, Calif., Star Publishing Co., p. 231–246.

Pfeiffer, T., D'Agnese, S., and Pfeiffer, A., 1998, Wilson River rockslide, Mile Post 31, Highway #6, Wilson River Highway, Tillamook County, *in* Burns, S., ed., Environmental, groundwater, and engineering geology: Applications from Oregon: Belmont, Calif., Star Publishing Co., p. 249–266.

Priest, G.R., 1995, Explanation of mapping methods and use of the tsunami hazard maps of the Oregon coast: Oregon Department of Geology and Mineral Industries Open-File Report O–95–67, 95 p.

——1998, The Capes landslide, Tillamook County, Oregon: Oregon, Department of Geology and Mineral Industries Open-File Report O–98–02, 10 p.

Rosenfeld, C.L., 1992, Natural hazards of the Pacific Northwest, past, present, and future—a field trip guide for western Oregon and Mount St. Helens: Oregon Geology, v. 54, no. 4, p. 75–86.

Shedlock, K.M., and Weaver, C.S., 1991, Program for earthquake hazards assessment in the Pacific Northwest: U.S. Geological Survey Circular 1067, 28 p.

Stover, C.W., and Coffman, J.L., 1993, Seismicity of the United States, 1568–1989 (Revised): U.S. Geological Survey Professional Paper 1527, 418 p.

Wang, Y., and Neuendorf, K.K.E., eds., 1997, Earthquakes—Converging at Cascadia. Symposium proceedings, Association of Engineering Geologists, 40th Annual Meeting, September 30–October 4, 1997, Portland, Oregon: Oregon Department of Geology and Mineral Industries Special Paper 28 and Association of Engineering Geologists Special Publication 10, 90 p.

Wiley, T.J., Sherrod, D.R., Keefer, D.K., Qamar, A., Schuster, R.L., Dewey, J.W., Mabey, M.A., Black, G.L., and Wells, R.E., 1993. Klamath Falls earthquakes, September 20, 1993—including the strongest quake ever measured in Oregon: Oregon Geology, v. 55, no. 6, p. 127–143.

Wold, R.L., and Jochim, C.L., 1995, Landslide loss reduction: A guide for state and local government planning: Oregon Department of Geology and Mineral Industries Open-File Report O–95–8, 50 p.

Wong, I.G., Silva, W.J., and Madin, I.P., 1993, Strong ground shaking in the Portland, Oregon, metropolitan area: Evaluating the effects of local crustal and Cascadia subduction zone earthquakes and near-surface geology: Oregon Geology, v. 55, no. 6, p. 137–143.

Yeats, R.S., 1989, Current assessment of earthquake hazard in Oregon: Oregon Geology, v. 51, no. 4, p. 90–91.

Take a geothermal world trip

A new 588-page volume, *Stories from a Heated Earth, Our Geothermal Heritage*, edited by Raffaele Cataldi, Susan F. Hodgson, and John W. Lund, is available through the Geothermal Resources Council for $70 (plus shipping).

This book presents a fresh look at mankind living on a geothermal planet, focusing on people and how geothermal phenomena have affected cultures around the world. True and imaginary accounts covering more than 25 countries are interspersed with 215 photos and illustrations in an easy, nontechnical style. All contribute to fascinating reading of a journey through time, focusing on the cultural influences of geothermal phenomena on the world's peoples.

Order from the Geothermal Resources Council, PO Box 1350, Davis CA 91617, e-mail: <grc@geothermal.org <mailto:grc@geothermal.org>>.

U.S. POSTAL SERVICE STATEMENT OF OWNERSHIP, MANAGEMENT, AND CIRCULATION

Publication title: OREGON GEOLOGY, no. 600040; filing date 9-24-99. Published bimonthly, 6 issues per year, annual subscription price $10. Address of publication office, publisher's business office, editor, and owner: State Office Building, 800 NE Oregon St., #28, Portland, OR 97232-2162. Publisher and owner: Oregon Department of Geology and Mineral Industries; editor: Klaus K.E. Neuendorf. No bondholders. Circulation during last 12 months/of single issue, respectively: Net press run 2,500/2,500; paid circulation est. 50/50; mail subscriptions 1,180/1,158; total paid circulation 1,230/1,208; free distribution 168/168; free distribution outside the mail 306/333; total free distribution 474/501; total distribution 1,704/1,709; not distributed 796/791; return 0/0; total 2,500/2,500; percent paid and/or requested circulation 72/71. I certify that the statements made by me above are correct and complete.

Klaus K. Neuendorf, Editor

Index to OREGON GEOLOGY, volume 61, 1999

Numbers refer to issue and first page of entry. Subject entries cross-referenced to author entries (in parentheses).

OREGON GEOLOGY
Suite 965, 800 NE Oregon Street # 28,
Portland, OR 97232-2162

Periodicals postage paid
at Portland, OR

Places to see—Recommended by the Oregon Department of Geology and Mineral Industries:

Shore Acres State Park near Cape Arago in Coos County

A marine terrace borders the Coos County shore for much of the distance between the entrance to Coos Bay and the Curry County line. Rocks on which the terrace was formed differ along the shore, and erosion along this terrace has produced a shore with varied and magnificent scenery. Different degrees of resistance to erosion have allowed the waves to sculpture the terrace into sharp points of land, reefs, islands, secluded coves, and a myriad of smaller forms. Here, near Cape Arago, the terrace is on a sequence of Tertiary sedimentary rocks that are inclined steeply toward the east and cut by numerous fractures. Erosion has shaped a shore that is distinctly different from that of any other part of the Oregon coast. (From E.H. Lund, "Landforms along the coast of southern Coos County, Oregon," a 1973 article in the *Ore Bin*, v. 35, no 12)

The predominant rock unit, the Coaledo Formation, contains an abundance of marine fossils. The park is also home to a famous formal garden and has, on the site of the former owner's mansion, an observation building that is popular for spectacular views and whale watching.

Access: On the Cape Arago Highway, 13 miles southwest of Coos Bay/North Bend and U.S. Highway 101.