OREGON GEOLOGY

published by the
Oregon Department of Geology and Mineral Industries

VOLUME 59, NUMBER 4 JULY/AUGUST 1997

A NEW VIEW OF MOUNT ST. HELENS: FROM THE JOHNSTON RIDGE OBSERVATORY

IN THIS ISSUE:

OREGON GEOLOGY

(ISSN 0164-3304)

VOLUME 59, NUMBER 4 JULY/AUGUST 1997

Published bimonthly in January, March, May, July, September, and 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.
Gary W. Lynch, Supervisor.
Internet: http://www.proaxis.com/~dogami/mlrweb.shtml

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, Donald J. Haines, Manager.
Internet: http://www.naturenw.org

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.

Oregon Geology is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Manuscript contributions are invited on both technical and general-interest subjects relating to Oregon geology. 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). Graphics should be camera ready; photographs should be black-and-white glossies. All figures should be clearly marked; figure 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.

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, letters, notices, and meeting announcements should be sent to Klaus Neuendorf, Editor, at the Portland office (address above).

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

Cover photo

Mount St. Helens, crater and dome from the north. View is from inside the theater of new observatory and visitor center on Johnston Ridge. See description of the new observatory on page 99. Photo courtesy Michael King, USDA Forest Service.

Oregon coastal communities install interpretive signs explaining tsunami hazards

As part of its program to mitigate tsunami risk on the Oregon coast, the Oregon Department of Geology and Mineral Industries (DOGAMI) has been working with Oregon coastal communities to find partners to help pay for installation of interpretive signs that explain why tsunamis occur and what people should do to save themselves when a tsunami occurs. The signs, which were developed as part of the Historical Marker Program, measure approximately 24 by 36 inches and will be mounted on permanent support structures in prominent locations along the coast.

The tsunami interpretive signs are jointly funded by the Federal Emergency Management Agency, DOGAMI, and local funding partners. The signs will be installed in the following communities, where the listed funding partners have been identified. Each sign will be formally dedicated after installation, and the dedications will be announced in local newspapers.

Location	Local funding partners
Astoria	City of Astoria
Bandon, Port of	City of Bandon, Coos. Co. Parks Dept., Port of Bandon
Brookings, Port of	City of Brookings, Port of Brookings
Depoe Bay	City of Depoe Bay
Florence	City of Florence, Florence Fire Dept., Port of Siuslaw
Heceta Head State Park	Oregon State Parks, Sea Lion Caves
Gold Beach	City of Gold Beach, Port of Gold Beach
Lincoln City Outlet Mall	Lincoln Factory Outlet Stores
Lincoln City, D-River Park	Oregon State Parks, Travel Information Council
Alsea Bay Interpr. Center	Oregon State Parks, Oregon Dept. of Transportation
Garibaldi waterfront	U.S. Coast Guard
Tillamook Bay	U.S. Coast Guard

Three larger site-specific tsunami interpretive signs have already been installed in Reedsport, Newport, and Seaside. Communities that want to install the 24- by 36-inch sign and can fund the cost of support structures and installation should contact Angie Karel, DOGAMI, (503) 731-4100, ext. 214. The signs are provided free of charge by DOGAMI. The maximum cost to funding partners is $500 to cover the cost of the selected support structure. Partners are also asked to help install and maintain the signs. □

The danger of collapsing lava domes: Lessons for Mount Hood, Oregon[1]

by Steven R. Brantley and William E. Scott, U.S. Geological Survey, Cascades Volcano Observatory, 5400 MacArthur Boulevard, Vancouver, Washington 98661[2]

INTRODUCTION

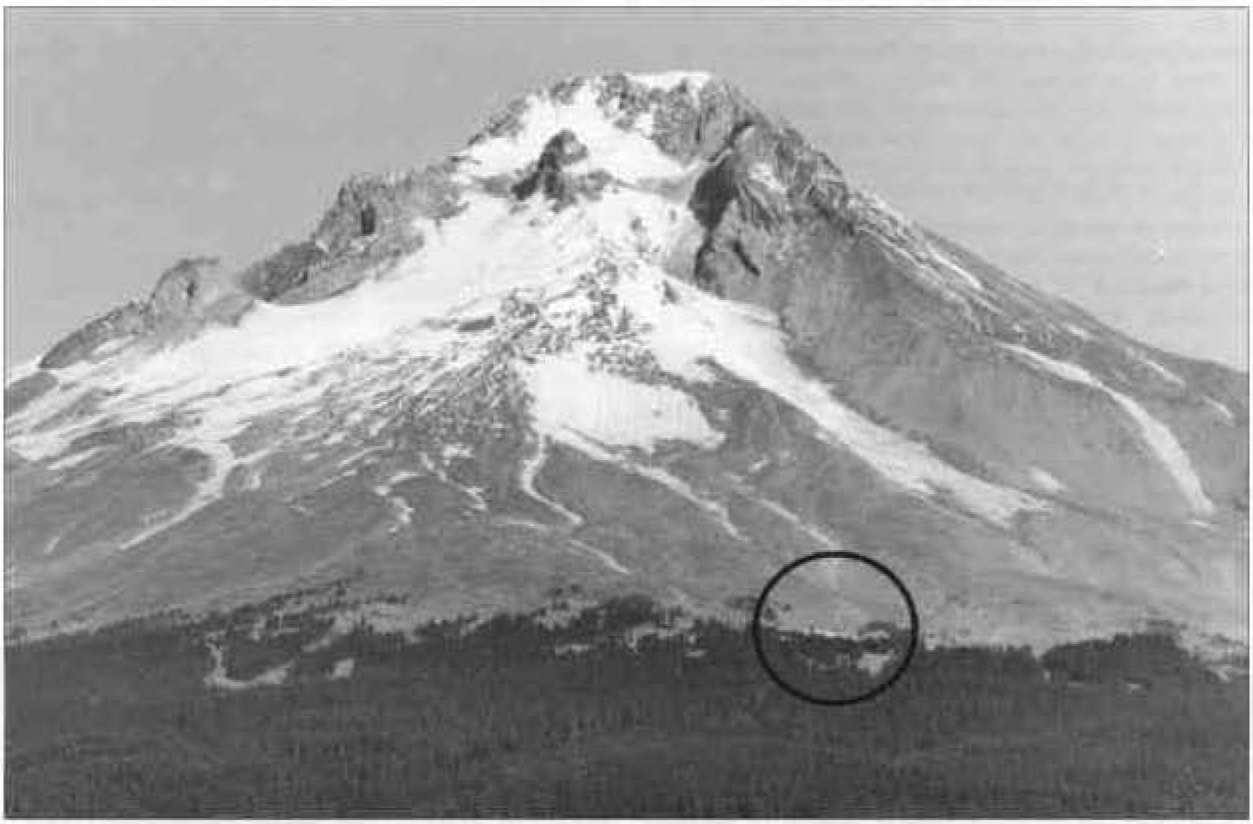
Nestled in the crater of Oregon's majestic Mount Hood volcano is Crater Rock, a prominent feature known to thousands of skiers, climbers, and tourists who journey each year to the famous Timberline Lodge located high on the volcano's south flank. Crater Rock stands about 100 m above the sloping crater floor, and warm volcanic vents along its base emit sulfur gases and a faint steam plume that is sometimes visible from the lodge. What most visitors do not know, however, is that Crater Rock is a volcanic lava dome only 200 years old.

[1] Reprinted in slightly modified form with permission from the U.S. Geological Survey publication *Earthquakes & Volcanoes*, v. 24, no. 6, 1993, p. 244–269.

[2] Contact: W.E. Scott, phone (360) 696-7909, e-mail wescott@usgs.gov

Lava domes are mounds that form when thick, pasty lava is erupted slowly and piles up over a volcanic vent. Crater Rock sits atop the vent and conduit through which molten rock traveled from deep below Mount Hood to the surface. During the past 2,000 years, growth and destruction of earlier lava domes at the site of Crater Rock produced hundreds of pyroclastic flows—avalanches of hot volcanic rock, gas, and air moving at hurricane speed—that swept down the volcano's steep southwest flank as far as 11 km. The strikingly smooth, sloping surface on which the lodge and ski area are built, as well as the nearby community of Government Camp and an important highway across the Cascades, was created by these pyroclastic flows.

During this century, scientists have documented py-



View to the north across Trillium Lake toward Mount Hood. About 1,500 and 200 years ago, debris from numerous lava dome collapses at the site of the Crater Rock dome (sharp peak just below the summit) created the broad smooth slope of the volcano's southwest flank. The famous Timberline Lodge (circle) attracts outdoor enthusiasts to the volcano year around. Photograph by D.E. Wieprecht.

roclastic flows generated by growing lava domes around the world. These studies have helped geologists recognize the products of similar volcanic activity hundreds to thousands of years old, including past eruptions at Mount Hood. Two recent dome eruptions are remarkable in their similarity to Mount Hood's past activity: Unzen volcano in Japan and Redoubt Volcano in Alaska. Both volcanoes extruded a series of lava domes that grew above steep slopes. The domes frequently collapsed downslope, triggering explosions and pyroclastic flows. Many destructive lahars (Indonesian term for volcanic mudflows and debris flows) occurred as a consequence of the frequent collapses. Lahars at Unzen were triggered by erosion of pyroclastic-flow deposits during intense rainfall. At Redoubt Volcano, lahars were caused by rapid melting of snow and ice by the pyroclastic flows.

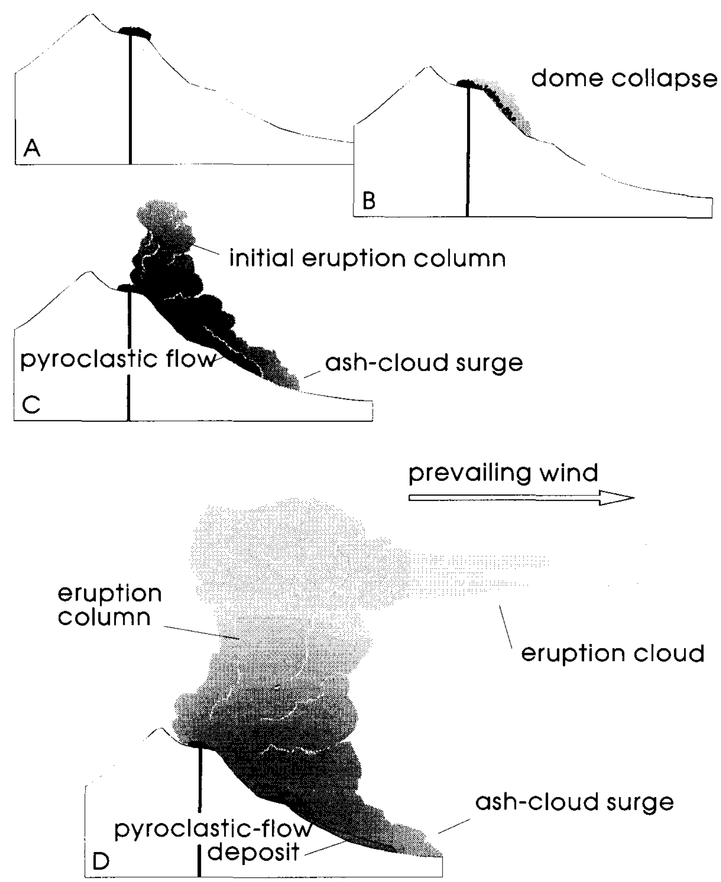
In this article, we describe the ways in which pyroclastic flows are generated from a lava dome and compare the effects of the Unzen and Redoubt dome eruptions to illustrate the type of activity that is almost certain to occur in the future at Mount Hood. Of course, the Unzen and Redoubt eruptions also illustrate potential volcanic activity at other volcanoes in the Cascade Range that have erupted domes, notably Mount St. Helens and Glacier Peak in Washington and Mount Shasta in northern California.

When compared to major eruptions, such as the eruption of Mount St. Helens in 1980, dome collapses are modest in size. Nonetheless, dome collapses can cause considerable destruction and interruption of human activity.

PYROCLASTIC FLOWS TRIGGERED BY DOME COLLAPSES OR EXPLOSIONS

A growing lava dome provides geologists with an exceptional occasion to study pyroclastic flows. One of the most lethal of volcanic phenomena, a pyroclastic flow is extremely dangerous to observe close up. When a dome grows high and steep sided or when it spreads onto a steep slope, the dome becomes unstable. Huge blocks or whole sections of the dome can suddenly break away to form an avalanche of mostly solidified, but still-hot lava fragments. With initial temperatures as high as 950°C, the fragments rapidly disintegrate, and the entire moving mass becomes a pyroclastic flow of shattered lava fragments and searing-hot gases. As a pyroclastic flow races across the ground at hurricane speed, a more dilute and highly turbulent cloud of hot gas and mostly ash-sized lava fragments, called an "ash-cloud surge" by scientists, forms above the flow. Ash-cloud surges are more mobile than the denser, coarser pyroclastic flows and can travel from hundreds of meters to a few kilometers farther.

The sudden gravitational collapse of a growing dome may also trigger a violent explosion by relieving pres-

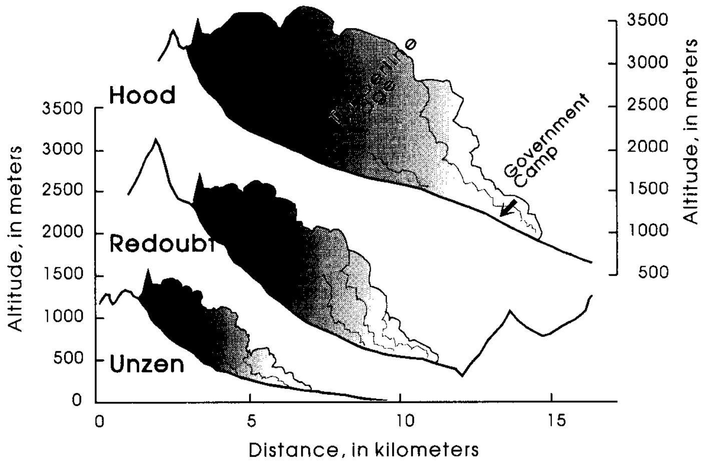


Sketches of a dome collapse showing the development of a pyroclastic flow, ash-cloud surge, eruption column, and eruption cloud. A. Pasty lava oozes onto the volcano's surface to form a lava dome perched precariously above a steep slope. B. Part of the dome collapses, forming a hot avalanche of lava blocks. C. The avalanche becomes a fast-moving mass of shattered lava fragments, volcanic gas, and air called a pyroclastic flow. A dilute cloud with smaller ash-sized fragments and greater mobility, called an "ash-cloud surge," forms above and in front of the pyroclastic flow. An eruption column composed of hot gas and ash begins to rise above the area covered by the main body of the pyroclastic flow. D. The ash-cloud surge travels beyond the pyroclastic flow, where it can rush up nearby hillslopes and overtop ridges. The eruption column continues to grow upward, sometimes reaching the stratosphere. Prevailing winds transport the ash away from the volcano; when detached from the volcano, the volcanic ash and gas are known as an eruption cloud.

sure on the dome's interior. When a mass of rock is removed from the outer solidified shell of the dome, gas dissolved in the pasty rock inside the dome can expand with tremendous force, hurling lava fragments as far as 10 km and contributing hot debris to the pyroclastic flow.

Pyroclastic flows can also be generated solely by the explosive release of volcanic gases that have accumulated inside a dome or the flashing to steam of super-hot groundwater within or beneath a dome. Such explosions can occur months or even years after a dome stops growing. For example, as magma within a dome cools and crystallizes, dissolved gas is expelled from the still-molten rock. Sufficient gas pressure may accumulate to cause an explosion. The sudden fragmentation of the dome by an explosion can generate a pyroclastic flow. A series of such explosions occurred at the dome on Mount St. Helens between 1989 and 1991, several years after lava was last extruded onto the dome.

A pyroclastic flow or an explosion triggered by a dome-collapse event generates an eruption column composed primarily of ash-sized rock fragments and gases that convect upward into the atmosphere. When material in the eruption column is transported downwind, it forms a "cloud" of ash and volcanic gas called an "eruption cloud." Low eruption columns typically form eruption clouds that travel only a few tens to hundreds of kilometers from the volcano. High eruption columns penetrate the stratosphere and can form eruption clouds that spread hundreds or thousands of kilometers downwind. Regardless of their size, eruption clouds interfere with and imperil air travel and lead to ash fall that can disrupt everyday life.



Topographic profiles and distance traveled by pyroclastic flows and ash-cloud surges. Arrowheads point to lava domes on each profile. The Redoubt and Unzen plots represent recent observations; the Mount Hood plot is inferred from prehistoric deposits. Ratios of height loss to distance traveled by flows and surges initiated by dome collapse can provide a rough guideline for estimating the range of distances that future events will travel.

CAN COLLAPSES BE PREDICTED?

Predicting exactly when a dome will collapse has proved elusive for scientists. Generally speaking, a dome will collapse when its strength is exceeded by the downward pull of gravity or by the force of an explosion from within the dome. The factors that affect the balance between dome strength and gravity include the steepness of slope and roughness of the ground surface on which the dome rests, development of fractures in the dome, rate of lava extrusion, volatile (gas) content, and thickness of the dome.

Volcano-monitoring techniques, however, help scientists assess a dome's instability and likelihood of collapse. For example, during growth of the Unzen and Redoubt domes, observations of the locations and character of earthquakes, the rate of volcanic gas release, and the rate of dome growth were useful in detecting changes in the rate of magma delivery to the dome or in pinpointing when a new episode of growth would begin. However, even with this information, the best that scientists could do at both volcanoes was to advise officials that dome collapses were more likely, perhaps even imminent. In general, predictions of specific collapse events can not yet be made.

IDENTIFICATION OF HAZARDOUS AREAS

Because the timing of a dome-collapse event cannot be reliably predicted, the best strategy for reducing risk to people from a growing dome is to limit access to areas that could be swept by a pyroclastic flow or its overriding ash-cloud surge. A long-term strategy for reducing risk to people and property is to minimize development within hazardous areas. The scientific basis for identifying these areas hinges on several factors: comparison of elevation loss to runout distance for observed pyroclastic flows and ash-cloud surges from domes, estimated volume of a potential collapse, local topography, geologic record of deposits from past dome collapses, and the state of restlessness of the volcano (for example, variations in seismic activity). The same general strategy applies in minimizing human exposure to lahars that may occur as a consequence of intense rainfall or the melting snow and ice by hot pyroclastic flows.

Whether public access to these potentially hazardous areas is restricted, especially for worst-case scenarios, depends on the level of risk that the public and officials are willing to accept. Agreement on an acceptable level of risk is difficult to achieve when such decisions may require people to abandon their land, homes, and businesses for extended periods of time. If an initial dome collapse fails to produce pyroclastic flows large

Unzen volcano, Japan. Buildings destroyed and vegetation burned by ash-cloud surges associated with pyroclastic flows in the Nakao River valley. Note absence of large lava fragments typical of pyroclastic-flow deposits near the buildings. Only the dilute ash-cloud surge reached this part of the valley floor (foreground). Large lava fragments typical of pyroclastic-flow deposits are visible near the mouth of the narrow canyon below Unzen. Photograph by K.M. Scott, 1993.

enough to reach the outer boundary of a designated hazard area, public pressure often develops to reduce the size of the exclusion zone, even though the true hazard has not changed. These issues severely tested Japanese scientists and officials in 1991 when, after 198 years of quiet, Unzen volcano erupted a lava dome.

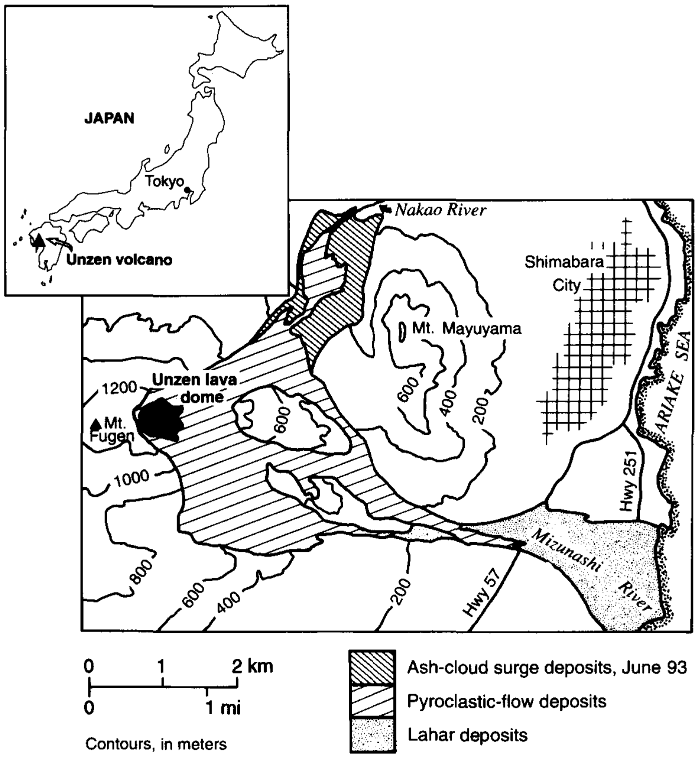
ERUPTION OF UNZEN VOLCANO, JAPAN, 1991–1993

When pasty lava first breached the forested summit crater of Unzen in May 1991 after several months of small explosions, nearby residents may have breathed a sigh of relief. The slow extrusion of gas-poor lava quietly built a small dome that made the volcano seem less threatening and less likely to erupt explosively. But, within three days, as the margin of the growing lava dome crept toward the crater's precipitous edge and then became perched above the volcano's east flank, the first of many small pyroclastic flows swept as far as 2 km down the volcano.

Suddenly on June 3, a much larger dome collapse and explosion produced a pyroclastic flow and ash-cloud surge that raced 4.5 km from the crater, burning about 180 houses and killing 43 people who had ventured into a previously designated hazard zone. Subsequently, lava continued to extrude from the summit crater toward the volcano's east flank. Another collapse event on June 8 swept 5.5 km down the same river valley, burning 210 additional houses. By the end of July, extruding lava had built an elongated dome—500 m long, 150 m wide, and 80 m thick—that generated an average of about 10 small pyroclastic flows every day.

Between June 1991 and December 1993, the pattern of eruption—extrusion of lava and frequent collapse of the dome's eastern margin—progressively increased the volcano's potential for wreaking havoc on local residents. By 1992, pyroclastic flows were rushing down a broader sector of the volcano, and lahars became commonplace as heavy rains remobilized the hot pyroclastic debris. Reaching beyond areas covered by pyroclastic flows, these lahars swept away bridges and buried roads, precious farmland, and houses with boulders, gravel, and sand.

The actively collapsing margin of Unzen's growing dome changed location many times in response to



Map of Unzen volcano and areas effected by pyroclastic flows, ash-cloud surges, and lahars. Figure based on a preliminary map prepared in July 1993 by S. Nakada, Kyushu University.

where magma was rising into the dome and leaking onto the surface. Depending on which margin was active, pyroclastic flows spilled into one of four stream valleys. Scientists devoted much of their attention to monitoring the dome's active margin to identify which valley was most at risk from pyroclastic flows. For example, two years after the eruption began, pyroclastic flows started cascading northeast into the Nakao River valley for the first time. The most extensive of these flows reached a point 4.5 km from the dome. Fortunately, officials had already ordered residents to evacuate this area in anticipation of these pyroclastic flows.

In addition to destroying previously inhabitated areas, pyroclastic flows created an enormous apron of loose fragmental deposits on the volcano's steep east side. The apron has filled the headwaters of streams with many tens of meters of debris. Combined with destabilization of old debris on Unzen's upper slopes owing to the death of vegetation, these deposits are a ready source of loose debris for generating lahars during rainstorms. Heavy rainfall, commonly exceeding 1 cm/hr in this area, readily erodes this material to form destructive lahars. For example, between August 1992 and July 1993, lahars triggered by heavy rains damaged about 1,300 houses. Each period of heavy rain required sudden evacuation of several thousand residents along the Mizunashi and Nakao Rivers.

Japanese officials worked hard to ensure public safety by developing an efficient warning system and evacuation plan. They also sought to minimize destruction from lahars by taking "countermeasures" designed to trap sediment and channelize the flows as much as possible. Countermeasures along the Mizunashi River included three sediment basins lined with interlocking concrete blocks and a series of discontinuous dikes along both sides of the main channel. The dikes funnel most of the flows down the main channel while allowing some material to spill around their margins. When the sediment basins and areas around the dikes fill with debris, workers excavate the debris with heavy equipment to make room for the next series of lahars.

A similar long-term eruption scenario is possible at Mount Hood in Oregon. Dome collapses and lahars at Mount Hood would require public officials and residents to wrestle with similar issues regarding evacuations, even though the area around the volcano is much less developed than at Unzen. Complicating the hazard scenario at Mount Hood is the presence of snow and ice, which ensure that lahars would be triggered directly by some dome-collapse events. The collapse of several domes at Redoubt Volcano in 1990 provided insight into the generation and effects of such lahars. This eruption also drew critical attention to hazards to aircraft posed by eruption clouds downwind from the volcano and to the danger from an ash-cloud surge that can move well beyond the edge of a pyroclastic flow.

ERUPTION OF REDOUBT VOLCANO, ALASKA, 1989—1990

Redoubt Volcano, 180 km southwest of Anchorage, erupted explosively on December 14, 1989, less than 24 hours after the beginning of an intense swarm of earthquakes beneath the volcano. From a new vent blasted through the ice-filled summit crater, a 10-km-high eruption column spread ash to the northeast. Ash from several subsequent explosive eruptions blanketed much of southern Alaska. By December 22, pasty lava began oozing from the vent, and a new lava dome rose.

On January 2, 1990, this initial dome was destroyed by two strong explosions and a collapse event. The dome collapsed down a deep canyon and across Drift glacier on the north flank of Redoubt. In the next four months, a succession of lava domes grew in the crater and then were subsequently destroyed, chiefly by gravitational collapse. The resulting pyroclastic flows swept over Drift glacier, cut huge channels in the glacial ice,

Redoubt Volcano, Alaska. A faint vapor plume rises from the 1990 lava dome in the breached summit crater. Numerous dome-collapse events melted snow and ice from Drift glacier to form lahars between January and April in 1990. Iliamna Volcano can be seen in distance on right. Photograph by D. Richardson, Bureau of Land Management.

and reached distances of 6–8 km from the crater. Many of the pyroclastic flows melted sufficient snow and ice to form lahars that reached Cook Inlet about 40 km to the east.

One pyroclastic flow triggered by a dome collapse spawned an unusually energetic overriding ash-cloud surge that ultimately reached a distance of 12 km from the crater. When the surge encountered a steep, 700-m-high ridge about 8 km north of the vent, it had sufficient momentum to climb the ridge and continue on for another 4 km. The hot mixture of gas and ash-sized and gravel-sized rock debris burned and abraded small willow trees on the ridge and drove the ends of broken branches at least 1 m into the snow.

We do not know why this ash-cloud surge traveled so much farther than the others. Clearly, some dome-collapse events can trigger pyroclastic flows with attendant ash-cloud surges that can travel several kilometers beyond the average distance. Such rare, but large, collapse-triggered surges at both Unzen and Redoubt volcanoes emphasize the need for scientists and public officials to be conservative when outlining hazardous areas.

Redoubt lahars close oil terminal

Lahars triggered by melting snow and ice from dome collapses at Redoubt Volcano caused a temporary shutdown of an oil-storage and tanker-loading facility at the mouth of Drift River. They also interrupted operations at 10 oil platforms in Cook Inlet. The platforms produced about 30,000 barrels of oil a day before the eruption. Parts of the oil-storage facility were inundated by water almost 1 m deep from a lahar during the eruption on January 2, 1990. Sedimentation by subsequent lahars caused the active channel of the river to shift many times as it flowed across the broad alluvial plain on which the terminal was built.

Redoubt eruption clouds disrupt air traffic

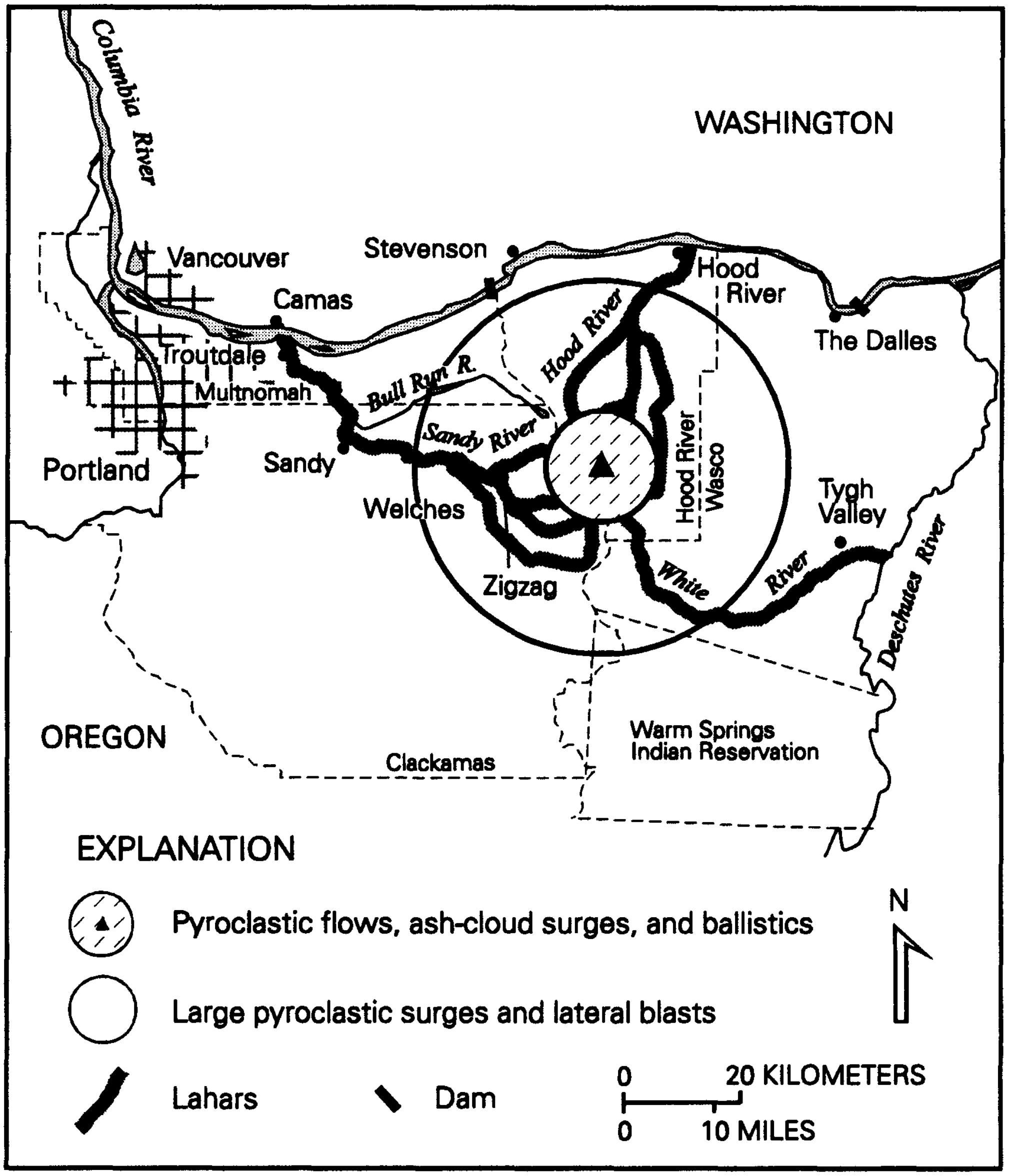
During the largest explosive eruption on December 15, 1989, a Boeing 747 en route from Amsterdam to Anchorage with 231 passengers unknowingly flew into Redoubt's eruption cloud about 240 km downwind from the volcano. As the pilot attempted to climb out of the cloud, tiny ash particles ingested by the engines melted to form a glassy deposit that impeded air flow and stalled all four engines. After gliding steeply for 8 min and losing 4,000 m of altitude—and with only 2,000 m of ground clearance remaining—the crew was able to restart the engines. The plane landed safely at Anchorage, but this near-tragic encounter galvanized action among commercial and military operators, aircraft manufacturers, and Federal agencies to prevent future volcanic-ash encounters. Aircraft successfully avoided direct contact with subsequent eruption clouds, but ash lingering in the atmosphere led to a higher than usual rate of window glazing and greater engine wear.

Between January and April 1990, each of the dome-collapse events at Redoubt Volcano formed eruption columns that rose at least 8,000 m above sea level. Downwind, the eruption clouds caused multiple ash falls in Kenai and Soldotna, resulting in darkness during daylight hours, local power outages, school closures, and cancellation of sports and cultural events.

DOME ERUPTIONS AT MOUNT HOOD

Visitors viewing Mount Hood from the south are impressed by the extensive, triangular-shaped apron of

Mount Hood, Oregon. These interbedded deposits of pyroclastic flows and lahars are exposed in Little Zigzag Canyon on the southwest side of Mount Hood. A series of dome collapses at the site of Crater Rock formed these deposits about 1,500 years ago. Note size of the lava blocks in the deposits; man standing on snow at bottom of photograph shows scale. Photograph by D.R. Crandell.

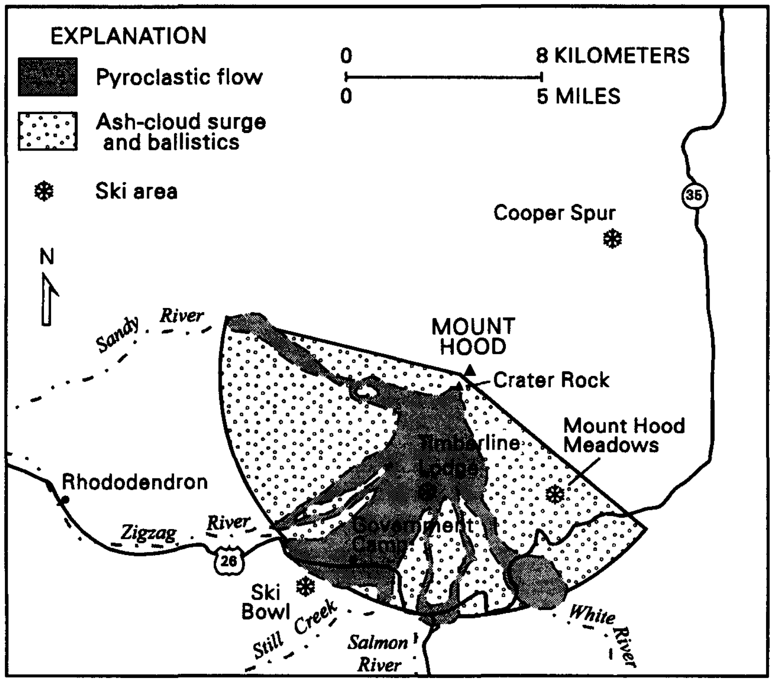


Volcanic hazards at Mount Hood, Oregon. This map shows river valleys that are subject to the effects of lahars originating at Mount Hood during growth and collapse of a new lava dome. A dome growing at the site of Crater Rock in the future would trigger lahars that travel east, south, and west. A dome growing high on a different side of the volcano would cause lahars to travel north. The most likely effects in the inner zone are shown in detail in the next figure. The outer zone is subject to the effects of large pyroclastic surges or lateral blasts like the one that occurred at Mount St. Helens on May 18, 1980.

rock debris tapering upward to Crater Rock. Individual lava rocks in the apron are more than 5 m in diameter. Hikers on the Timberline Trail, which cuts across the debris apron and descends into several deep canyons, find the secret of the debris apron and Crater Rock. The debris apron is composed of tens of layers of fragmented lava, some several meters thick. The layers are deposits of pyroclastic flows and lahars formed by dome collapses. Crater Rock is the most recent of a series of lava domes that grew and collapsed during two periods of activity, one about 1,500 years ago and the other only about 200 years ago.

At Mount Hood, the abundance of deposits related to dome collapse and the rarity of evidence for other types of volcanic activity indicate that the most likely type of eruption in the future will be the growth and collapse of another dome, probably at or near the site of Crater Rock. As indicated by the debris apron, future dome collapses will produce pyroclastic flows and overriding ash-cloud surges, the largest of which could travel 10 km or more down the volcano's south and west flanks. When pyroclastic flows melt snow and ice, or when an intense rainstorm erodes newly emplaced deposits, lahars will race down one or more drainageways, including Still Creek and the Sandy, Zigzag, Salmon, and White Rivers.

If we consider the events at Unzen and Redoubt Volcanoes as a guide, a future dome at Mount Hood could grow episodically over an extended period of time, perhaps months or several years. Numerous pyro-



Map showing areas most likely to be affected by volcanic activity during the growth and collapse of a lava dome near Crater Rock on Mount Hood. Dome growth elsewhere on the volcano would direct the activity east and north.

clastic flows, ash-cloud surges, eruption clouds, and lahars can be expected during such dome growth. Pyroclastic flows and lahars could affect major resorts, numerous businesses, bridges and highways, regional utility lines, and hundreds of private homes. Local, State, and Federal officials will need to make many decisions when the volcano begins to show signs of unrest. Will U.S. Highway 26, an important highway connecting Portland with central Oregon, be closed? Will residents of Government Camp be evacuated and for how long? Which areas of the Mount Hood National Forest, an important recreational area used by several hundred thousand people each year, will be closed to the public? How will commercial aviation cope with the threat of eruption clouds along several major air routes?

These questions will not be easy to answer in view of the inconvenience and economic losses that some of these decisions are likely to cause. Furthermore, decisions regarding public access and evacuations will have to be made in the face of scientific uncertainty as to exactly when pyroclastic flows or lahars will be triggered and how far they will travel. Making matters worse, a large quantity of sediment derived from pyroclastic flows and lahars is likely to cause river channels in the affected basins to aggrade, change course, and migrate across valley floors. The economically important shipping channel of the Columbia River will also be impacted.

Anticipating an eruption at Mount Hood

The scenario we describe for a future eruption at Mount Hood is based on the geologic record of its most recent eruptions and a comparison with observed dome eruptions at Unzen and Redoubt volcanoes. Experience with these recent eruptions suggests a range of warning time—from less than 24 hours to as long as one year—that we might expect between the onset of volcanic unrest and first eruption. Japanese scientists monitoring Unzen first detected anomalous earthquake activity beneath an area 13 km northwest of the volcano in November 1989. One year later, the locus of earthquake activity migrated directly beneath Unzen, and a series of small explosive eruptions began a few days later on November 17, 1990. The lava dome was extruded on May 20, 1991, and the first pyroclastic flows began four days later.

At Redoubt Volcano, scientists of the Alaska Volcano Observatory identified a rapid increase in the number of earthquakes beginning only 24 hours before the first explosive eruption on December 14, 1989. A lava dome appeared on December 22, and the first collapse event occurred 11 days later.

Similar sequences of precursory earthquakes at Mount Hood would be detected immediately. With support from the U.S. Geological Survey (USGS), scientists of the Geophysics Program at the University of Washington monitor seismic activity at Mount Hood. Three seismometers are presently located within 15 km of the summit and are supplemented by an extensive regional seismic network. At the first sign of signficant earthquake activity near Mount Hood, scientists will install additional seismometers and initiate other monitoring activities. For example, benchmarks placed high on the volcano in 1980 will be resurveyed; significant changes in these benchmark positions can mean that magma is rising toward the surface. Furthermore, scientists plan to measure sulfur dioxide and carbon dioxide gas emissions from the volcano.

When unusual activity is observed at Mount Hood in the future, scientists will immediately notify public officials and the public. According to the existing emergency-notification plan developed after the eruption of Mount St. Helens in 1980, the USDA Forest Service will serve as the primary dissemination agency for emergency information. As the volcano's activity changes, USGS scientists will provide updated advisories and meet with local, State, and Federal officials to

(Continued on page 92)

Recognizing miners who protect the environment

Mining awards grow to include one outstanding individual, voluntary reclamation, and salmon enhancement efforts

by Shannon Priem, Oregon Department of Geology and Mineral Industries

A Medford "catskinner" named Paul Ruff highlighted the presentation of the annual Mining Reclamation Awards given by the Mined Land Reclamation Program of the Oregon Department of Geology and Mineral Industries (DOGAMI). Ruff, a long-time equipment operator for Rogue Aggregates, Inc., was named Oregon's first Reclamationist of the Year. The awards ceremony was held during the Oregon Concrete and Aggregate Producers Association (OCAPA) annual meeting on May 17 in Bend and also included other awards given this year for the first time.

Reclamation awards recognize mine operators who go beyond the basic state requirements of planning, operation, and reclamation. They are chosen by a committee composed of an industry consultant, a mine operator, a county planner, a natural-resource expert, and a private citizen. Now in its sixth year, the award program has grown in popularity and competition, increasing awareness within the industry and helping to ensure that reclamation is successful and cost effective. Innovative management can reduce not only operating costs but also the impact on the surroundings.

Other new awards were for voluntary reclamation efforts, reclamation planning, and salmon habitat enhancement. "These awards recognize the growing commitment in the mining industry to 'do the right thing' in not only reclaiming the land back to a natural habitat, but in many cases, going well beyond what is required, through innovation and creativity in reclamation," said Gary Lynch, Supervisor of DOGAMI's Mining Reclamation Program. "This year, we also wanted to recognize the increased efforts to improve salmon habitat by creating more off-channel ponds and waterways to rivers for migration."

Reclamationist of the Year—*Paul Ruff, Rogue Aggregates, Inc., Medford*

This award honors Ruff for his attention to detail, often doing such work on his own time. An equipment operator for most of his life (the last 15 years with Rogue Aggregates, Inc.), Ruff prefers the older equipment over the new, "air conditioned" tractors.

"His work has caught the attention of more than one land owner," said Bill Leavens of Rogue Aggregates, Inc. "One time, he had gathered all of the large boulders that were scattered on the floor of the pit and pushed them into groupings—to provide better underwater habitat when the pit was allowed to fill. He's also created islands—and smaller ponds within those islands—as a refuge for frogs."

"Final reclamation at a mine site is the culmination of ideas and industry practices," Leavens added, "but in the final stages, it's often the instincts and experience of the lead equipment operator that makes it all work. Paul Ruff operates his blade like an artist uses a paintbrush." Rogue Aggregates, Inc., has several sites in various

(Continued on next page)

(Continued from page 91)

discuss the hazards and appropriate levels of emergency response.

ACKNOWLEDGMENTS

Information about Unzen volcano was provided by Japanese scientists and gathered by Steven R. Brantley and other USGS scientists during visits to the volcano that were supported by the Ministry of Construction of Japan for consultation with scientists of the Public Works and Research Institute. We thank Dr. Yoshiharu Ishikawa and his colleagues for arranging field trips to Unzen and for many engaging discussions.

ADDITIONAL READING

For a more complete description of the 1989–1990 eruption of Redoubt Volcano, of problems concerning volcanic ash and aviation safety, and of activity that could accompany future eruptions of Mount Hood, the reader may consult the following publications:

Brantley, S.R. (ed.), 1990, The eruption of Redoubt Volcano, Alaska, December 14, 1989–August 31, 1990: U.S. Geological Survey Circular 1061, 33 p.

Casadevall, T.J., 1994, Volcanic ash and aviation safety. Proceedings of the First International Symposium on Volcanic Ash and Aviation Safety: U.S. Geological Survey Bulletin 2047, 450 p.

Crandell, D.R., 1980, Recent eruptive history of Mount Hood, Oregon, and potential hazards from future eruptions: U.S. Geological Survey Bulletin 1492, 81 p.

Till, A.B., Yount, M.E., and Riehle, J.R., 1993, Redoubt Volcano, southern Alaska: A hazard assessment based on eruptive activity through 1968: U.S. Geological Survey Bulletin 1996, 19 p. □

(Continued from page 92)
stages of development north of Central Point along the Rogue River.

Coastal Salmon Enhancement—Dick Angstrom, Oregon Concrete and Aggregate Producers Association (OCAPA)

DOGAMI presented OCAPA's past Managing Director Dick Angstrom with the first Salmon Enhancement Award for his leadership in the organization's commitment to "innovative methods of mining and reclamation to protect existing salmon habitat as well as creating new, stable habitat." OCAPA members have also pledged to help financially support salmon restoration efforts through increased dues.

Outstanding Operator—*Dalton Rock, Inc., Dallas, Oregon*

The permit for aggregate mining was given in 1994 for 96 acres, located 3 mi west of Dallas, Polk County, above LaCreole Creek. The creek provides significant fish and wildlife habitat areas and is the sole source of drinking water for Dallas. The operators developed a quarry with minimal impact to adjacent landowners. DOGAMI noted outstanding storm-water and erosion control. At the start of mining, an intermittent stream was relocated to protect water quality. A storm-water control system was designed before mining began. Much of the topsoil material removed from the rock resource was trucked to other parts of the property to enhance reforestation of rocky soil. To ensure that the rock blasting would not harm the Dallas water system, the operator established a seismographic monitoring system at the pump station so that, if ground movement from blasting exceeds standards, blast sizes will be reduced or another means of extracting will be used. When mining is complete, this property will be returned to timber production.

Outstanding Small Operator—*Paul Gallagher, Nyssa, Oregon*

In 1994, this claim, located on Pine Creek in the southwestern corner of Baker County, included two old settling ponds and some bare gravel areas. Much of Pine Creek has been disturbed by mining since its beginning in 1898, when the area became famous for producing some very large gold nuggets.

"The reclamation of this mine was not legally required, but now you can't even tell it was mined," said Ben Mundie, DOGAMI mining reclamationist.

Paul Gallagher and partner Frank Lamb began developing a small-scale placer operation to mine for gold. Over 30,000 cubic yards of material was handled and regraded to get to the "pay zone." Gallagher stated that he "didn't get rich, but didn't go broke." They developed a pond to recycle process water used in gold mining operations. In 1995, they filled the process-water pond and regraded the entire four acres, preserving several "islands" of existing vegetation. They "tracked" slopes, creating a good seed bed. A seed mix of native species was applied in addition to natural seeding by adjacent native plants such as rabbit brush and sage brush.

Voluntary Reclamation—*George Groom Trucking, Inc., Shady Cove, Oregon*

The reclaimed area, located 1 mi northwest of Jacksonville, Jackson County, above Walker Creek, has been extensively mined for decades. Five acres of this site was mined prior to Oregon's reclamation act and was thus "grandfathered" (exempted) from the requirements; however, the owner voluntarily committed himself to reclaiming this area as well. Decomposed granite is mined by several operators, and erosion of "stockpiled" soil is a common problem. Groom began revegetating the site with grasses and installed several sediment-retention ponds. Material was no longer pushed over the edge and down the slope, so that the threat of sediment in Walker Creek was reduced. Erosion control measures were taken along haul roads on the site. Working with state agencies, the operator tried many plantings of different grasses and legumes such as lupine to determine what kind of vegetation worked best in this environment. In 1995, this site was used to demonstrate a new erosion control product developed by Weyerhauser Corporation—and the floods of 1996 proved to be a good test of the revegetation success.

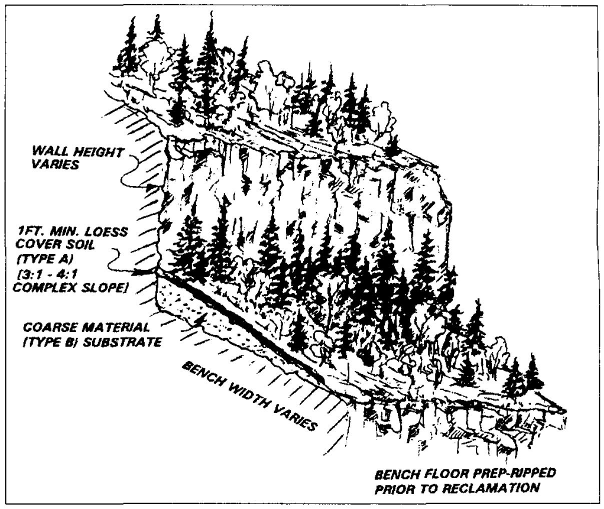
Outstanding Reclamation (tie award)—*Pendleton Ready Mix, Inc., Pendleton; and Beaver State Sand and Gravel, Inc., Roseburg*

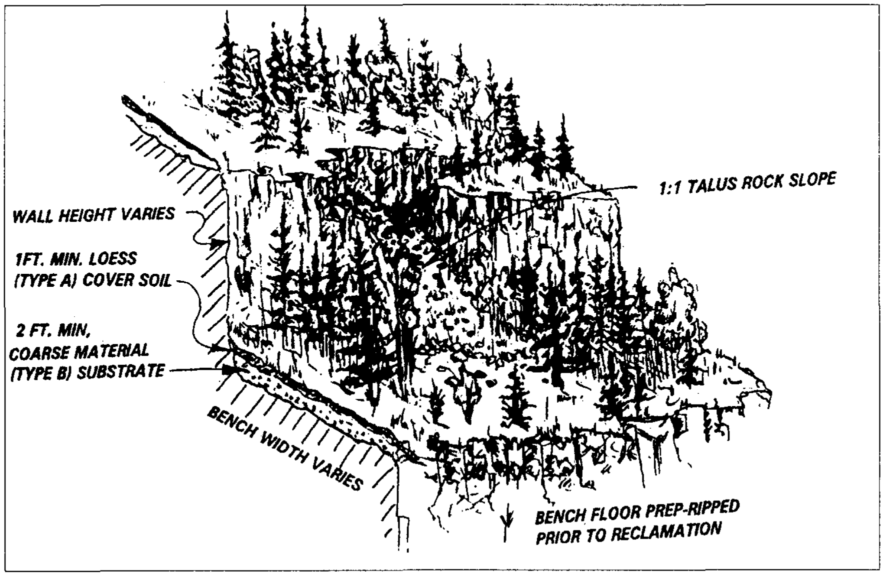
Pendleton Ready Mix mines sand and gravel in the Umatilla Indian Reservation. Excellent water management practices in the pits allowed dry mining and protected water quality. Proper sloping of the excavated pits, spreading of soil, and planting of riparian vegetation allowed mined areas to stabilize quickly and created wildlife habitat. Dozens of waterfowl were noted at the reclaimed ponds during a 1993 inspection. Today, a thriving wetland area has been created where wetlands did not exist before, including predator-free nesting areas and revegetation with native plants.

Beaver State had been mining sand and gravel since 1974 within the floodplain of the South Umpqua River, 6 mi south of Roseburg. Mining ended in 1993, and the land has been restored to agriculture and wetland use. Irregular shorelines and islands were created to provide a predator-free wildlife habitat; soil stripped from areas to be mined was placed on areas that had been graded and prepared for soil; and a stable overflow channel was established along the river. Two straight years of high-water events have not destabilized the vegetation on this floodplain.

Outstanding Reclamation Planning—Angell Brothers, Inc., Portland

Angell Brothers developed an extensive and exemplary Operating and Reclamation Plan [on file for inspection in DOGAMI's Portland library collection of site-specific reports—ed.] to address natural resource and public concerns regarding the expansion of a quarry located 10 mi northwest of Portland in Multnomah County. It is one of the few remaining active quarries in the Portland area and has been mined since 1967. The plan includes a storm-water control system to manage operations as mining increases. The company will practice "continuous revegetation" over the life of the project to promote plant diversity (age, size of regrowth, and species). Plantings, soils, and mulches will be tested, which will provide data to other quarries facing similar conditions in western Oregon. A geotechnical landslide evaluation was also completed to determine the stability of the quarry during operation as well as the long-term effects mining may have on the slopes. The company has also committed itself to maintaining test plots within reclaimed areas for three years after mining to ensure the success of revegetation, wildlife habitat, and erosion control. To minimize visual impact of mining operations, the plan calls for maintaining vegetated buffer strips to screen the area from view. Mining activities will also be conducted so that benches follow contour lines and that the final landforms will fit visually with the ridge lines of existing adjacent hills.





Examples from the award-winning operation and reclamation plan of Angell Brothers, Inc. The sketches show typical reclaimed bench detail for this rock quarry (Figures 15 and 16 in the permit application submitted to DOGAMI-MLR).

Agency Award—Baker County Road Department

Marble Creek quarry, a limestone mine located 8 mi west of Baker City on USDA Forest Service land, dates back to the 1960s. Mining ended in the early 1970s, with extensive stockpiles and waste rock left over. Impacts to Marble Creek from eroding lime spoils have been documented over the last 20 years. Baker County tested the rock and found it suitable for county roads. In 1995, the USDA Forest Service, Baker County, and the mine owner agreed to remove the waste rock, then bench and revegetate the land. Existing vegetation was preserved, and soil was salvaged from an old stockpile and spread along the creek. The original streambed was rebuilt with an erosion-control matting spread to hold the soil in place and help revegetation. Roads that had crossed the creek were removed. The county virtually rebuilt Marble Creek Road by resurfacing it, widening narrow areas, and installing new culverts and erosion-control systems. The agency graded and watered the road throughout the project. Scrap metal was collected and placed in a secure area, where a salvage contractor cut up the metal and hauled it away.

"Baker County reclaimed the Marble Creek quarry to a condition above and beyond what was required under the agreement and restored the creek to its natural condition," said DOGAMI Mining Reclamationist Ben Mundie in presenting the award. □

Topsoil and its role in successful reclamation[1]

by E. Frank Schnitzer, Oregon Department of Geology and Mineral Industries, Mined Land Reclamation Program (DOGAMI-MLR), Albany, Oregon

A typical soil is composed of approximately 45 percent minerals (sand, silt, and clay particles), 5 percent organic matter, and 50 percent pore space for air and water. The presence of organic matter, air, and water within a soil profile allows the soil to support a tremendous amount of animal and plant life, most of which is invisible to the naked eye.

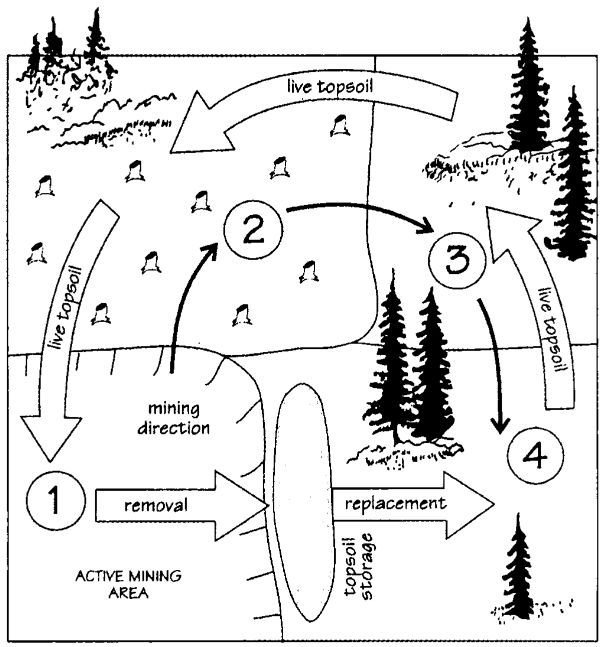
Soil systems continually produce and recycle organic matter. The presence of the organisms that live in a soil environment and their ability to decompose organic matter to a form usable by plants make soil a dynamic medium that is very much alive. Decomposition of organic matter also produces relatively strong acids that can react with minerals in the soil to extract base cations such as Ca^{++}, Mg^{++}, and K^{+}, which are essential for plant growth.

Soil fertility is created by recycling and decomposition of organic matter and by accelerated weathering of minerals. Unweathered geologic materials and subsoils are distinctly less valuable as a reclamation medium for mined lands because they lack fertility. Re-applying and conditioning the soil material can be critical to a successful reclamation project and may significantly reduce the time required for the determination of revegetation adequacy and bond release.

It is critical to remember that soils have about 50 percent pore space. These voids are essential for the proliferation of soil organisms, bacteria, fungi, algae, and micro- and macro-invertebrates. In 1 g of soil, the number of soil bacteria alone may range from several hundred million to 3 billion. Consequently, soils must be properly handled and stored to protect both the pore spaces and soil organisms. Soil porosity or the soil structure can be permanently damaged if soils are stripped when they are excessively wet or dry. This is particularly a problem with clays and loams.

Stockpiling of aggregate, equipment compaction, and burial by either overburden or creation of large soil stockpiles can destroy the dynamic, living qualities of a topsoil.

DOGAMI-MLR recommends "live topsoiling" wherever possible. Live topsoiling is the placement of salvaged soil material directly onto a reclaimed surface. If the topsoil is spread with a minimum of equipment traffic, the pore spaces in the soil can be protected. Since the soil organisms are relocated to their ecological niche and the soil contains viable seeds, revegetation occurs within a shorter time period. However, live topsoiling may not always be practical, particularly with quarry operations where long-term stockpiling cannot be avoided.



Example of topsoil handling from MLR "Best Management Practices" manual (DOGAMI Open-File Report O-96-2).

Soil storage piles should be constructed to minimize size and compaction, so that the soil and its organisms can breathe. Available plant material such as grasses and shrubs should be incorporated into the stockpiles. Limbs may be incorporated, but only after they have been processed through a chipper.

DOGAMI-MLR recommends that the surface horizons (soil layers) with their higher organic matter content be salvaged and replaced separately, away from subsoils or overburden. Organic-rich horizons can easily be lost through dilution by mixing if they are not properly handled. Soil horizons with elevated organic matter content can generally be recognized by their darker color.

Experienced operators in westem Oregon have learned that revegetation can be accomplished without the separate salvaging and replacing of the topsoil because of the abundance of moisture in this region. However, the quality of the revegetation may suffer. Plant species diversity will be limited until the system recovers. Additionally, plant vigor may quickly decline after the first planting, unless ample amounts of organic matter are provided or supplemental chemical fertilization is applied in order to initiate the cycle of plant growth, decomposition, and nutrient recycling. □

[1] (An earlier version of this article appeared in the October 1994 Newsletter of the National Association of State Land Reclamationists.)

Center for the Tsunami Inundation Mapping Effort (TIME) dedicated at Hatfield Marine Science Center in Newport

The Center for the Tsunami Inundation Mapping Effort (TIME) was dedicated at the Hatfield Marine Science Center in Newport at 10 a.m. on Saturday, May 17, 1997. The keynote address at the dedication was Oregon's Senator Mark O. Hatfield, who early recognized the threat posed by offshore earthquakes and led congressional efforts to address the issue.

Other speakers were Dr. Eddie Bernard, Director, Pacific Marine Environmental Laboratory, National Oceanic and Atmospheric Administration (NOAA); David de Courcy, Director, Region X, Federal Emergency Management Agency (FEMA); Sean Sinclair, speaking for Oregon Congresswoman Darlene Hooley; Dr. Donald A. Hull, Director and State Geologist, Oregon Department of Geology and Mineral Industries (DOGAMI); and Dr. Antonio Baptista, Oregon Graduate Institute of Science and Technology (OGI). Robert Kamphaus, the tsunami modeler for TIME, was also introduced. Approximately 75 people attended the event.

During the program, tsunami hazard zone and evacuation route signs were presented to Senator Hatfield and to Congresswoman Hooley. Hooley's signs were accepted by Sean Sinclair. Mugs with the tsunami logo in blue were presented to all the speakers.

The dedication was the first of three dedications held at the complex during the day. The second dedication—the dedication of the U.S. Fish and Wildlife Coastal Field Office—was held at noon. The last dedication was the opening of the remodeled Public Wing of the Hatfield Marine Science Center at 2:00 p.m. Speakers and invited guests joined in a luncheon at the U.S. Fish and Wildlife facility.

The TIME center is important to Oregonians because tsunamis caused by undersea earthquakes have caused tragic loss of life and extensive property damage in coastal communities in Alaska, Hawaii, California, Washington, and Oregon. Tsunamis in geologically similar areas in Japan, Nicaragua, and other Pacific Rim countries in recent years have been tragic reminders of the devastation that occurs in coastal areas that lack adequate preparation for these infrequent but powerful events.

In 1995 and 1996, Congress passed appropriation legislation that instructed NOAA to work with the Pacific states to design a comprehensive program to mitigate the risk posed by tsunamis. The first year of the five-year plan for a systematic risk reduction program was funded in the Federal budget in fiscal year 1997. The program includes the installation of new technology to detect offshore earthquakes and tsunamis, broad public education, and the creation of the Center for the Tsunami Inundation Mapping Effort (TIME).

Oregon Senator Mark O. Hatfield was the keynote speaker at the dedication of the TIME Center in Newport.

Federal funds were matched by State funds to create the Center for TIME. TIME will assist the Pacific states in tsunami mitigation by producing detailed maps of future flooding (inundation) that are needed for delineation of evacuation routes and long-term planning in vulnerable coastal communities. The Center for the Tsunami Inundation Mapping Effort will undertake mapping projects in the states of Oregon and Washington in 1997. Similar work is expected to be started in Alaska, California, and Hawaii in 1998 and later years. The Oregon mapping projects will be done in Gold Beach and the Astoria-Warrenton area in cooperation with OGI and DOGAMI. These maps will be prepared with the latest computer modeling techniques for both nearshore tsunamis generated by earthquakes in the Cascadia subduction zone and by tsunamis created by distant earthquakes around the Pacific Rim. Field studies of past tsunami impacts will be used to supplement the computer mapping.

The tsunami maps are an integral part of an overall strategy to reduce future loss of life and property from tsunamis. The Emergency Management Division of the Oregon State Police and local government will use these and similar maps being produced this year at Seaside and Newport to guide evacuation planning. Several Oregon communities have installed warning siren systems. The Oregon legislature in 1995 enacted new laws to provide coastal school children with education about tsunamis and periodic evacuation drills. Also in 1995 the legislature enacted a law which limits the construction of certain new facilities such as hospitals and fire stations in the zone of expected tsunami inundation. The information provided by the Center for TIME is a key element in the production of tsunami evacuation maps to prepare coastal residents and visitors to take the life-saving steps that are necessary to avoid the devastation that has resulted in other tsunami-prone areas.

For those ready to surf the internet, more information and graphics related to tsunamis may be found at http://www.pmel.noaa.gov/tsunami-hazard/. Tsunami inundation maps and other tsunami-related materials developed earlier by DOGAMI are available at the Nature of the Northwest Information Center, 800 NE Oregon St. #5, Portland, OR 97232, phone (503) 872-2750, web http://www.naturenw.org

Update on tsunami mapping progress in Oregon

by George R. Priest, Oregon Department of Geology and Mineral Industries

In 1995, the Oregon Department of Geology and Mineral Industries (DOGAMI), in cooperation with the Department of Land Conservation and Development, Oregon Graduate Institute of Science and Technology (OGI), and Portland State University (PSU), completed the first detailed tsunami inundation map in Oregon at Siletz Bay. In 1996, DOGAMI, in cooperation with OGI, produced reconnaissance-level (1″ = 2,000′) tsunami inundation maps for the entire Oregon coast in order to implement Senate Bill 379, which limits construction of certain critical and essential facilities in tsunami inundation zones. DOGAMI, again in cooperation with OGI and PSU, is currently conducting detailed mapping of potential tsunami inundation at Yaquina Bay, with funding from U.S. Geological Survey (USGS), U.S. Army Corps of Engineers (USACE), and City of Newport; and at Seaside, with funding from Oregon Department of Justice and City of Seaside. Similar projects will be starting this year at Gold Beach and Warrenton-Astoria. The two new projects were made possible by a special allotment of funds to the National Oceanic and Atmospheric Administration (NOAA). The new funds will allow :

1. Opening a national (NOAA) tsunami mapping center at the Hatfield Marine Science Center in Newport (Official opening, May 17, 1997).
2. Expanding tsunami education and outreach, including installation of more warning and evacuation signs.
3. Mapping inundation at Gold Beach, Warrenton-Astoria, and four sites in Washington (two in Grays Harbor and two in the Long Beach-Willapa Bay area).
4. Installing offshore tsunami sensors (newly developed by NOAA).
5. Upgrading of the USGS network of seismographs in the Pacific Northwest.

This special allotment of funds was obtained through close cooperation between NOAA, the Federal Emergency Management Agency (FEMA), USGS, and the States of Alaska, California, Hawaii, Oregon, and Washington. The NOAA funding is proposed as a five-year effort, although funds for the next four years are not assured without considerable work by supporters. Future years will focus on continued education, inundation mapping in other states, and continued upgrading of the offshore and onshore warning network (Table 1).

Table 1. ***Summary of detailed tsunami hazard mapping in Oregon***

Project area	Base map and digital elevation model (percent complete)	Inundation modeling (percent complete)	Education and outreach (percent complete)	Map publication date
Siletz Bay	100	100	80	1995
Yaquina Bay	90	75	50	Fall 1997
Seaside	100	75	50	Fall 1997
Gold Beach	5	10	10	Summer 1998
Warrenton-Astoria	50	20	10	Summer 1998

DOGAMI is working in cooperation with the OGI, PSU, the Canadian Geological Survey, Oregon State University, and others to design more accurate Cascadia subduction zone earthquake scenarios for inundation mapping. This work has occupied much of the last 10 months and has yielded 10 potential earthquake scenarios, which are being explored now for tsunami generation (Table 2).

Tsunami modeling is currently addressing (1) better physical simulations of inundation, (2) generation of refined numerical grids for the project areas, and (3) sensitivity analysis for tides coupled with tsunamis. The modeling should be complete for Yaquina Bay and Seaside by early June 1997. High, medium, and low

Table 2. *Summary of potential earthquake scenarios that are being explored for tsunami generation*

Scenario	Rupture length (km)	Locked width (km)	Locked width in partially locked zones (km)	Weighted mean locked width (km)	Slip (m)	M_w[1]
1A	1,050[2]	35–105	20–58	78	15–20	9.1
1B	1,050	14–43	33–88	64	15–20	9.0
1C	1,050	14–43	20–58	51	15–20	9.0
2A	1,050	60–105	38–58	107	15–20	9.2
2B	1,050	29–50	48–88	92	15–20	9.2
2C	1,050	29–50	38–58	79	15–20	9.1
1An	450[3]	45–105	53–58	103	7–10	8.7
1As	450[4]	39–45	22–25	60	7	8.5
2Cn	450	29–43	38–58	80	7–10	8.7
2Cs	450	43–50	38	77	7	8.6

cases will be mapped, based on modeling results and interpretations of available data on prehistoric tsunamis and coseismic subsidence. Where possible, tsunami inundation from the 1964 Alaskan tsunami will be mapped as a proxy for a maximum teletsunami[5] event.

Local cooperators have given invaluable help with both mapping and education efforts. The Cities of Seaside and Newport contributed substantial funding toward generation of base maps, bathymetry, and digital topography in their areas. Mike Brown and his students from Seaside High School mapped and catalogued buildings in the potential tsunami inundation zone at Seaside. Neal Maine of the Coastal Studies Technology Center at Seaside and Theresa Atwill of Newport assisted in education and outreach. Tom Horning catalogued historical observations of the runup from the 1964 Alaskan tsunami in Seaside.

Footnotes

[1] Moment magnitude assuming a rigidity of 4 x 10^{11} dyne/cm^2

[2] All 1,050-km ruptures extend from northern Vancouver Island at the Nootka Fault zone to northern California at the Mendocino Fracture Zone.

[3] 450-km ruptures labeled 1An and 2Cn extend from Depoe Bay, Oregon, north to southern Vancouver Island.

[4] 450-km ruptures labeled 1As and 2Cs extend from Depoe Bay , Oregon, south to Humboldt Bay, California.

[5] A teletsunami, also known as a distant tsunami, travels thousands of kilometers before arriving in Oregon. The Great Alaskan Earthquake of 1964 generated a teletsunami that caused extensive damage and loss of life along the California, Oregon, and Washington coasts. □

Yaquina Head Natural Area now has interpretive center

With a ceremony on May 10, the U.S. Bureau of Land Management (BLM) opened a new interpretive center at the Yaquina Head Outstanding Natural Area near Newport in Lincoln County. The area also includes the Yaquina Lighthouse, tidepools, and trails in the hills on the headland.

The BLM began reclaiming two former rock quarries at the headland after Congress decided in 1980 to acquire all of the headland for protection and public use. Reclamation of the lower quarry as a tidepool area under the name "Quarry Cove" was completed in 1994. This effort was honored by the Mined Land Reclamation Program of the Oregon Department of Geology and Mineral Industries as that year's Outstanding Reclamation by a Government Agency, described in the July 1995 issue of *Oregon Geology* (v. 57, no. 4, p. 91–92).

The $4 million interpretive center was built in the location of the former upper quarry on the Yaquina headland. Its central placement invites visitors to park at the interpretive center and walk to the lighthouse and the tidepools and also to use the other trails of the area.

The new interpretive center is divided into two areas: cultural history, devoted mainly to the history of the Yaquina lighthouse and its crew; and natural history, featuring especially marine birds and mammals.

The Yaquina Head Outstanding Natural Area is located 3 mi north of Newport on Highway 101. It is open from 10 a.m. to 6 p.m. daily through mid-October. From about mid-July on, visitors will be charged separate fees of about $2 to $4 (per adult) for entrance to the lighthouse and the interpretive center. As of this writing, the details of these fees have not yet been determined. The phone number to call for information is (541) 564-3100. □

Johnston Ridge Observatory opens at Mount St. Helens

On May 17, 1997, the USDA Forest Service, Gifford-Pinchot National Forest, opened the latest observatory at Mount St. Helens: The Johnston Ridge Observatory (JRO). It is located at the terminus of the Spirit Lake Memorial Highway (Washington State Highway 504), 52 mi east of Castle Rock, where Highway 504 joins Interstate Highway I-5 (Exit 49). The western approach to the mountain thus has a third visitor center, joining the two at Silver Lake and Coldwater Ridge, 5 and 43 mi east of Castle Rock, respectively.

Approaching the entrance to the Johnston Ridge Observatorium. Photo courtesy Michael King, USDA Forest Service.

Johnston Ridge was named in honor of U.S. Geological Survey volcanologist David A. Johnston, who was on duty at the Coldwater II observation post on this ridge during the eruption of May 18, 1980. David Johnston was one of 57 people who lost their lives in the eruption.

The new vantage point at JRO brings visitors within 5 mi of the north side of the volcano and offers spectacular views of the still-steaming lava dome, the crater, the pumice plain, and the landslide deposit. The one-story, concrete and glass structure is set back into the ridge to blend into the surrounding blast zone terain.

Completion of the JRO marks the end of a 12-year, $100 million capital investment program to create the Mount St. Helens National Volcanic Monument. The latest building was constructed and equipped for $10.5 million, about half of which was contributed by the State of Washington. In addition to the services to visitors, the JRO houses seismic, deformation, and other monitoring equipment (in some cases, also displayed for the visitors) that relays data to the USGS Cascades Volcano Observatory in Vancouver for analysis.

In the exhibit hall, state-of-the-art interpretive displays educate visitors about the sequence of geologic events on May 18, 1980, and how they transformed the surrounding landscape. Visitors can also learn about the art and science of volcano monitoring and eruption forecasting. Outside the observatory, a half-mile interpretive trail is still under construction but is expected to be completed late this summer.

The JRO is open daily, including holidays, from 9 a.m. to 6 p.m. through September 28, 1997. Winter hours are yet to be determined. The observatory is one of the Monument's designated fee areas, and visitors using the site must purchase and display a Monument Pass. Passes cost $8 for each person between 16 and 61 years of age, $4 for seniors from 62 years on. Children are free up to age 15. The Monument Pass is good for three days and for all designated fee areas around the Monument, which includes not only the visitor centers but also a number of interpretive sites, viewpoints, and picnic areas. Annual passes are available for $24 and $12 (seniors and Golden Access Passport discount). Monument Passes may be purchased at Monument visitor centers and information stations and at the Cascade Peaks Restaurant and Gift Shop on Forest Road 99. Information may also be obtained from the Mount St. Helens National Volcanic Monument, 42218 NE Yale Bridge Road, Amboy, WA 98601, phone (360) 247-3900. □

The view from the observation deck at the Johnston Ridge Observatory. Photo courtesy Michael King, USDA Forest Service.

DOGAMI PUBLICATIONS

Released April 3, 1997

Geology and Mineral Resources Map of the Grizzly Peak Quadrangle, Jackson County, Oregon, by Frank R. Hladky. Geological Map Series map GMS–106, 17 p. text , 1 map sheet (scale 1:24,000), $6.

The Grizzly Peak 7½-minute quadrangle covers part of the Western Cascades to the north and east of Grizzly Peak, a summit that lies east of Ashland. The quadrangle map is produced in two colors: the topographic base in brown is overlain by geologic information in black.

The map identifies rock units, faults, landslides, and mines and prospects. It substantially expands the stratigraphic detail provided in previous reports into what has been called a "high-resolution map." The accompanying text discusses the geologic history, structure, and landslide features of the quadrangle, as well as mineral and groundwater resources. Tables provide various data for 24 samples collected in the quadrangle and for 17 identified mines, quarries, and prospects. Some of the geochemical analyses found significant amounts of naturally occurring arsenic and mercury.

Released May 12, 1997

Tsunami Hazard Map of the Winchester Bay Quadrangle, Douglas County. Open-File Report O–97–31 (supersedes O–95–40), $3.

Tsunami Hazard Map of the Reedsport Quadrangle, Douglas County. Open-File Report O–97–32 (supersedes O–95–41), $3.

The Governing Board of the Oregon Department of Geology and Mineral Industries voted at its April meeting to change the tsunami inundation line in the Reedsport, Oregon, area. This change in the location of the tsunami inundation line affected four of the 58 maps that were published earlier as Open-File Reports O-95-9 through O-95-66. Consequently, because the new inundation line does no longer appear on them, maps O-95-39 (Fivemile Creek quadrangle) and O-95-42 (Deer Head Point quadrangle) were withdrawn. In addition, because of changes, maps O-95-40 (Winchester Bay quadrangle) and O-95-41 (Reedsport quadrangle) have now been replaced by newly released Open-File Reports O-97-31 and O-97-32, respectively. □

Robert L. Bates Scholarship Endowment Fund

—is seeking contributions to send a student to the Forum on the Geology of Industrial Minerals each year. Bates was founder of the Forum, the 25th of which was held in Portland, Oregon, in 1989.

For information or contributions, please contact the Fund at 901 W. Water St., Elmira, N.Y. 14905. □

THESIS ABSTRACTS

The Oregon Department of Geology and Mineral Industries maintains a collection of theses and dissertations on Oregon geology. From time to time, we print abstracts of new acquisitions that in our opinion are of general interest to our readers.

Petrogenesis of high-alumina tonalite and trondhjemites of the Cornucopia stock, Blue Mountains, northeastern Oregon, by Kenneth S. Johnson (Ph.D., Texas Tech University, 1995), 206 p.

The Cornucopia stock is a small composite intrusion comprising five distinct intrusive units: a hornblende biotite tonalite, a biotite trondhjemite, and three cordierite-bearing two-mica trondhjemites. Dikes of dacitic, granodioritic, and granitic compositions are common throughout the stock. The stock intruded greenschist-facies metasedimentary and metavolcanic rocks of the Wallowa terrane, remnants of a Permian-Triassic island arc. The age of the intrusion is 116.8±1.2 Ma determined by $^{40}Ar/^{39}Ar$ incremental heating measurements. Unaltered biotite from the first and last units emplaced yield concordant age plateaus at 116.8 and 116.7 Ma, respectively. The identical ages indicate cooling as a unit and imply coeval emplacement of the tonalitic and trondhjemitic magmas.

REE models suggest the tonalite and trondhjemites formed by 15–35 percent partial melting of a low-K tholeiitic source, in equilibrium with a garnet pyroxene hornblendite residue. Trace element models indicate the source had high Sr and Ba contents, similar to island arc tholeiite of the Wallowa terrane. The high Sr in the rocks, lack of residual plagioclase, abundant residual amphibole, and the H_2O-rich nature of the rocks suggest that H_2O in excess of that produced by amphibole dehydration was present at the site of melting. Residual garnet and hornblende implied by REE models indicate that melting occurred at a shallower depth than envisioned for slab melting (~10 kbars versus 23–26 kbars). In addition, the Cornucopia rocks do not possess characteristics (e.g., high MgO, Cr, Ni) of a typical slab-melt, precluding involvement of the overlying lithospheric mantle. Results of this study suggest that the tonalitic and trondhjemitic magmas were formed by hydrous partial melting of lower island arc crust, possibly as the result of underplating by mafic magmas. Furthermore, these results indicate that high-Al tonalitic and trondhjemitic magmas may be formed by processes other than slab melting.

The Cornucopia stock was one of several tonalitic/trondhjemitic plutons emplaced after peak metamorphism associated with the accretion of oceanic terranes to the continental margin during Early Cretaceous time (~128 Ma). Prior to this time, plutons were predominantly granodioritic and appear to have evolved by AFC

processes from mafic, mantle-derived magmas. In contrast, tonalitic/trondhjemitic magmas were apparently generated by partial melting of oceanic terrane rocks. This suggests that the style of magmatism changed, from mantle-derived to crust-derived, as a direct result of terrane accretion.

Geologic evolution of the Duck Creek Butte eruptive center, High Lava Plains, southeastern Oregon, by Jenda A. Johnson (M.S., Oregon State University, 1995), 151p.

Mixing during synextensional magmatism of a layered magma chamber, followed by prolonged fractionation during tectonic quiescence, is recorded in the stratigraphy, geochemistry, geochronology, and structural history of the Duck Creek Butte eruptive center (DBEC). The DBEC, located in the Basin and Range province of southeastern Oregon, is the easternmost center in a west-northwest-trending, northwest-younging sequence of silicic vents. DBEC was studied by a combination of detailed geologic mapping (400 km^2), 37 chemical analyses, mineral chemistry, three new $^{40}Ar/^{39}Ar$ ages, and Sr and Nd isotope data.

The DBEC sequence is dominated by rhyodacite and rhyolite but includes andesite, basaltic andesite, and basalt. Effusive volume decreases with time, and the compositional range becomes more restricted and more mafic. The earliest volcanic activity is recorded in more than 6 km^3 of pyroclastic and effusive lava flows of porphyritic rhyodacite (10.38±0.04 Ma; $^{40}Ar/^{39}Ar$, biotite) during movement along the faults related to uplift of the Steens Mountain fault block. The lava flowed over existing fault escarpments and was later truncated by these same faults. Late flows of rhyodacite contain quenched andesite inclusions that were entrained during evacuation of the magma chamber. Eruption of dacite with up to 30 percent quenched basaltic andesite inclusions ensued, possibly as the result of synmagmatic faulting. Andesite with mixing textures, associated with basaltic andesite and basalt, marks the end of DBEC activity along the fault system. Silicic magmatism migrated 2–4 km northwest to Indian Creek Buttes, where high-silica rhyolitic magma fractionated during tectonic quiescence and then was erupted (10.32±0.01 Ma; $^{40}Ar/^{39}Ar$, sanidine).

The oldest rock in the area is the 16.2-Ma Steens Basalt. It is conformably overlain by tuffaceous sedimentary strata and 12–11-Ma basalt, basaltic andesite, and andesite. The older strata are overlain conformably to slightly unconformably by the DBEC sequence.

Post-DBEC rocks were deposited chiefly in drainages and west-northwest-trending, fault-bounded valleys. The 9.7-Ma Devine Canyon Ash-Flow Tuff and underlying tuffaceous sedimentary strata are found throughout southeastern Oregon. Following a protracted hiatus, a primitive high-alumina olivine tholeiite was erupted adjacent to DBEC (1.38±0.01 Ma; $^{40}Ar/^{39}Ar$, whole rock). No further volcanic activity is recorded. Quaternary sediment covers much of the area.

Movement along north-northeast- and west-northwest-striking normal faults and synchronous volcanic activity at DBEC near the northern terminus of the Steens Mountain escarpment is constrained between 10.4 and 1.4 Ma. Contemporaneous lavas are affected by at least three periods of faulting. Regionally extensive east-west-directed extension was active prior to and during eruption of the 10.4-Ma rhyodacite, indicated by truncated plunging flow folds. West-northwest-striking faults, which are parallel to the Brothers fault zone, were active in the period between emplacement of the 10.32-Ma rhyolite and the 9.7-Ma Devine Canyon Ash-Flow Tuff. The 1.4-Ma olivine basalt filled a northwest-trending valley and subsequently was offset by north-striking normal faults. No further movement is recorded by Quaternary sedimentary units.

Compositional and textural evidence suggests that DBEC rocks result from several mechanisms including crustal melting, fractionation, magma mixing, and filter pressing. Rhyolite and rhyodacite apparently were derived by crustal melting and fractionation, respectively, during tectonic quiescence. Successive tapping during tectonism caused mixing with underlying, more mafic magma at a rate faster than silicic magma could be regenerated. Textural evidence and linear element-element arrays indicate that the dacite and andesite were derived mainly by magma mixing. Basalt and basaltic andesite of DBEC resulted from fractional crystallization of a primitive basalt.

Beach response to subsidence following a Cascadia subduction zone earthquake along the Washington-Oregon coast, by Debra L. Doyle (M.S., Portland State University, 1996), 113 p.

Beach shoreline retreat induced by coseismic subsidence in the Cascadia subduction zone is an important post-earthquake hazard. Sand on a beach acts as a buffer to wave attack, protecting dunes, bluffs and terraces. The loss of sand from a beach could promote critical erosion of the shoreline. This study was initiated in order to estimate the potential amount of post subsidence shoreline retreat on a regional scale in the central Cascadia margin. The study area is a 331-km stretch of coastline from Copalis, Washington, to Florence, Oregon.

Several erosion models were evaluated, and the Bruun model was selected as the most useful to model shoreline retreat on a regional scale in the central Cascadia margin. There are some factors that this model does not address, such as longshore transport of sediment and offshore bottom shape, but for this preliminary study it is useful for estimating regional retreat.

(Continued on page 102)

Beverly F. Vogt retires

With the end of June came also the end of a very fruitful relationship between the Oregon Department of Geology and Minerals (DOGAMI) and Beverly ("Bev") Frobenius Vogt—until then Publications Manager of the Department, now retired after more than twenty years of service.

Bev joined DOGAMI in early 1977 as geologist-editor and became Publications Manager in 1983. During her early years with the Department, she also managed to complete her graduate studies in geology, earning her master's degree at Portland State University in 1981.

Untiring enthusiasm for geology and for her work in the department was Bev's trademark. First among the visible effects she had on the history of DOGAMI are the name and look of this magazine, which used to be published in a different format under the name "Ore Bin" until 1979. Beverly's literary contributions began with the 1977 *Ore Bin*, when she was one of the authors of a geologic field trip guide. Since then, she has been author, coauthor, and editor of numerous *Oregon Geology* articles and DOGAMI book publications, particularly on the geology of the Cascade Range and the Columbia River Basalt Group.

In 1984, she spearheaded the Department's role as host of the annual conference of the Association of Earth Science Editors and later served as an officer in that organization. In the early 1990s, she started the Department's volunteer program, which she then also managed.

From the front cover of Bev's first issue of *Oregon Geology*—South Falls at Silver Falls State Park.

When in 1992 the Department offices were moved to the new location of the State Office Building, Bev organized the creation of the (then) Nature of Oregon Information Center and bookstore, in which many natural-resource agencies, both state and federal, cooperate to make their information more easily accessible to the public. The development won special praise and early support from the Oregon Governor's Office. In 1995, Vice President Al Gore's Hammer Award (for contributions in support of the National Performance Review principles) was presented to both the USDA Forest Service and DOGAMI as partners in operating what by then had become the Nature of the Northwest Information Center.

DOGAMI's increasing responsibilities in hazard mitigation, particularly earthquakes and tsunamis, again saw Bev in the vanguard of the Department's public outreach efforts, presenting issues, writing brochures, informing the media, and helping the citizens of Oregon participate in the decision-making.

We will miss her enthusiasm and her energy greatly—and her sharp eye for detail in editing and preparing publications. We wish her many more years to enjoy her love of nature and geology, perhaps with a little more leisure than before—although Bev never went especially easy on herself. And if you do not see a picture of her in this place, it is partly because Beverly usually was busy—as the one taking the pictures. □

(Continued from page 101)

The range of parameter input values for the Bruun model include: the depth of closure (h) range from 15-m to 20-m water depth; the cross-shore distance (L) range from 846 m to 5,975 m; and the estimated subsidence amount (S) range from 0 m to 1.5 m.

The minimum to maximum range of post-subsidence shoreline retreat is 142–531 m in the Columbia River cell, 56–128 m in the Cannon Beach cell, 38–149 m in the Tillamook cell, 25–91 m in the Pacific City cell, 11–126 m in the Lincoln City cell, 30–147 m in the Otter Rock cell, 0–165 m in the Newport cell, 0–76 m in the Waldport cell, and 0 m in the Winchester cell.

Results of the study suggest that many of the beaches in the study area are at risk of beach and personal property loss. Beach communities could limit the amount of potential damage in these areas through coastal zone planning. □

AVAILABLE PUBLICATIONS
OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

GEOLOGICAL MAP SERIES

	Price ☑
GMS-5 Powers 15' quadrangle, Coos and Curry Counties. 1971	4.00
GMS-6 Part of Snake River canyon. 1974	8.00
GMS-8 Compl. Bouguer gravity anomaly map, central Cascades. 1978	4.00
GMS-9 Total-field aeromagnetic anomaly map, central Cascades. 1978	4.00
GMS-10 Low- to intermediate-temp. thermal springs & wells. 1978	4.00
GMS-12 Oregon part, Mineral 15' quadrangle, Baker County. 1978	4.00
GMS-13 Huntington/Olds Ferry 15' quads., Baker/Malheur Co. 1979	4.00
GMS-14 Index to published geol. mapping, 1898-1979. 1981	8.00
GMS-15 Gravity anomaly maps, north Cascades. 1981	4.00
GMS-16 Gravity anomaly maps, south Cascades. 1981	4.00
GMS-17 Total-field aeromagnetic anomaly map, south Cascades. 1981	4.00
GMS-18 Rickreall, Salem West, Monmouth, Sidney 7½' quads., Marion and Polk Counties. 1981	6.00
GMS-19 Bourne 7½' quadrangle, Baker County. 1982	6.00
GMS-20 S½ Burns 15' quadrangle, Harney County. 1982	6.00
GMS-21 Vale East 7½' quadrangle, Malheur County. 1982	6.00
GMS-22 Mount Ireland 7½' quadrangle, Baker/Grant Counties. 1982	6.00
GMS-23 Sheridan 7½' quadrangle, Polk and Yamhill Counties. 1982	6.00
GMS-24 Grand Ronde 7½' quadrangle, Polk/Yamhill Counties. 1982	6.00
GMS-25 Granite 7½' quadrangle, Grant County. 1982	6.00
GMS-26 Residual gravity, north/central/south Cascades. 1982	6.00
GMS-27 The Dalles 1° × 2° quadrangle. 1982	7.00
GMS-28 Greenhorn 7½' quadrangle, Baker/Grant Counties. 1983	6.00
GMS-29 NE¼ Bates 15' quadrangle, Baker/Grant Counties. 1983	6.00
GMS-30 SE¼ Pearsoll Peak 15' quad., Curry/Josephine Counties. 1984	7.00
GMS-31 NW¼ Bates 15' quadrangle, Grant County. 1984	6.00
GMS-32 Wilhoit 7½' quadrangle, Clackamas/Marion Counties. 1984	5.00
GMS-33 Scotts Mills 7½' quad., Clackamas/Marion Counties. 1984	5.00
GMS-34 Stayton NE 7½' quadrangle, Marion County. 1984	5.00
GMS-35 SW¼ Bates 15' quadrangle, Grant County. 1984	6.00
GMS-36 Mineral resources of Oregon. 1984	9.00
GMS-37 Mineral resources, offshore Oregon. 1985	7.00
GMS-38 NW¼ Cave Junction 15' quadrangle, Josephine County. 1986	7.00
GMS-39 Bibliography and index: ocean floor, continental margin. 1986	6.00
GMS-40 Total-field aeromagnetic anomaly maps, north Cascades. 1985	5.00
GMS-41 Elkhorn Peak 7½' quadrangle, Baker County. 1987	7.00
GMS-42 Ocean floor off Oregon & adjacent continental margin. 1986	9.00
GMS-43 Eagle Butte/Gateway 7½' quads., Jefferson/Wasco Co. 1987	5.00
as set with GMS-44 and GMS-45	11.00
GMS-44 Seekseequa Junct./Metolius B. 7½' quads., Jefferson Co. 1987	5.00
as set with GMS-43 and GMS-45	11.00
GMS-45 Madras West/East 7½' quads., Jefferson County. 1987	5.00
as set with GMS-43 and GMS-44	11.00
GMS-46 Breitenbush River area, Linn and Marion Counties. 1987	7.00
GMS-47 Crescent Mountain area, Linn County. 1987	7.00
GMS-48 McKenzie Bridge 15' quadrangle, Lane County. 1988	9.00
GMS-49 Map of Oregon seismicity, 1841-1986. 1987	4.00
GMS-50 Drake Crossing 7½' quadrangle, Marion County. 1986	5.00
GMS-51 Elk Prairie 7½' quadrangle, Marion/Clackamas Counties 1986	5.00
GMS-52 Shady Cove 7½' quadrangle, Jackson County. 1992	6.00
GMS-53 Owyhee Ridge 7½' quadrangle, Malheur County. 1988	5.00
GMS-54 Graveyard Point 7½' quad., Malheur/Owyhee Counties. 1988	5.00
GMS-55 Owyhee Dam 7½' quadrangle, Malheur County. 1989	5.00
GMS-56 Adrian 7½' quadrangle, Malheur County. 1989	5.00
GMS-57 Grassy Mountain 7½' quadrangle, Malheur County. 1989	5.00
GMS-58 Double Mountain 7½' quadrangle, Malheur County. 1989	5.00
GMS-59 Lake Oswego 7½' quad., Clackam./Multn./Wash. Co. 1989	7.00
GMS-60* Damascus 7½' quad., Clackam./Multn. Counties. 1994	8.00
GMS-61 Mitchell Butte 7½' quadrangle, Malheur County. 1990	5.00
GMS-62* The Elbow 7½' quadrangle, Malheur County. 1993	8.00
GMS-63 Vines Hill 7½' quadrangle, Malheur County. 1991	5.00
GMS-64 Sheaville 7½' quadrangle, Malheur County. 1990	5.00
GMS-65 Mahogany Gap 7½' quadrangle, Malheur County. 1990	5.00
GMS-66 Jonesboro 7½' quadrangle, Malheur County. 1992	6.00
GMS-67 South Mountain 7½' quadrangle, Malheur County. 1990	6.00
GMS-68 Reston 7½' quadrangle, Douglas County. 1990	6.00
GMS-69 Harper 7½' quadrangle, Malheur County. 1992	5.00
GMS-70 Boswell Mountain 7½' quadrangle, Jackson County. 1992	7.00
GMS-71 Westfall 7½' quadrangle, Malheur County. 1992	5.00
GMS-72 Little Valley 7½' quadrangle, Malheur County. 1992	5.00
GMS-73* Cleveland Ridge 7½' quadrangle, Jackson County. 1993	5.00
GMS-74 Namorf 7½' quadrangle, Malheur County. 1992	5.00
GMS-75 Portland 7½' quadrangle, Multn., Wash., Clark Counties. 1991	7.00

	Price☑
GMS-76 Camas Valley 7½' quadrangle, Douglas/Coos Counties. 1993	6.00
GMS-77 Vale 30×60' quadrangle, Malheur County. 1993	10.00
GMS-78 Mahogany Mountain 30×60' quadrangle, Malheur Co. 1993	10.00
GMS-79* EQ hazards, Portland 7½' quad., Multn. Co. 1993	20.00
GMS-80* McLeod 7½' quadrangle, Jackson County. 1993	5.00
GMS-81* Tumalo Dam 7½' quadrangle, Deschutes County. 1994	6.00
GMS-82* Limber Jim Creek 7½' quadrangle, Union County. 1994	5.00
GMS-83* Kenyon Mountain 7½' quadrangle, Douglas/Coos Co. 1994	6.00
GMS-84* Remote 7½' quadrangle, Coos County. 1994	6.00
GMS-85* Mount Gurney 7½' quadrangle, Douglas/Coos Co. 1994	6.00
GMS-86* Tenmile 7½' quadrangle, Douglas County. 1994	6.00
GMS-87* Three Creek Butte 7½' quadrangle, Deschutes County. 1996	6.00
GMS-88* Lakecreek 7½' quadrangle, Jackson County. 1995	8.00
GMS-89* EQ hazards, Mt. Tabor 7½' quad., Multn. Co. 1995	10.00
GMS-90* EQ hazards, Beaverton 7½' quad., Wash. Co. 1995	10.00
GMS-91* EQ hazards, Lake Oswego 7½' quad., Tri-county. 1995	10.00
GMS-92* EQ hazards, Gladstone 7½' quad., Clack./Multn. Co. 1995	10.00
GMS-93* EQ hazards, Siletz Bay area, Lincoln County, 1995	20.00
GMS-94* Charleston 7½' quadrangle, Coos County. 1995	8.00
GMS-97* Coos Bay 7½' quadrangle, Coos County. 1995	6.00
GMS-98* Dora and Sitkum 7½' quadrangles, Coos County. 1995	6.00
GMS-99* Tsunami hazard map, Siletz Bay area, Lincoln County. 1996	6.00
GMS-100* EQ hazard maps for Oregon. 1996	8.00
GMS-101* Steelhead Falls 7½' quad., Deschutes/Jefferson Co. 1996	7.00
GMS-104* EQ hazards, Linnton 7½' quad., Multn./Wash. Co.1996	10.00
GMS-105* EQ hazards, Salem East/West 7½' quads. 1996	12.00
GMS-106* Grizzly Peak 7½' quadrangle, Jackson County. 1997	6.00

SPECIAL PAPERS

2 Field geology, SW Broken Top quadrangle. 1978	5.00
3 Rock material resources, Clackam./Columb./Multn./Wash. Co. 1978	8.00
4 Heat flow of Oregon. 1978	4.00
5 Analysis and forecasts of demand for rock materials. 1979	4.00
6 Geology of the La Grande area. 1980	6.00
7 Pluvial Fort Rock Lake, Lake County. 1979	5.00
8 Geology and geochemistry of the Mount Hood volcano. 1980	4.00
9 Geology of the Breitenbush Hot Springs quadrangle. 1980	5.00
10 Tectonic rotation of the Oregon Western Cascades. 1980	4.00
11 Bibliography/index of theses and dissertations, 1899-1982. 1982	7.00
12 Geologic linears, northern part of Cascade Range, Oregon. 1980	4.00
13 Faults and lineaments of southern Cascades, Oregon. 1981	5.00
14 Geology and geothermal resources, Mount Hood area. 1982	8.00
15 Geology and geothermal resources, central Cascades. 1983	13.00
16 Index to *Ore Bin* (1939-78) and *Oregon Geology* (1979-82). 1983	5.00
17 Bibliography of Oregon paleontology, 1792-1983. 1984	7.00
18 Investigations of talc in Oregon. 1988	8.00
19 Limestone deposits in Oregon. 1989	9.00
20 Bentonite in Oregon. 1989	7.00
21 Field geology, NW¼ Broken Top 15' quad., Deschutes Co. 1987	6.00
22 Silica in Oregon. 1990	8.00
23 Forum on Geol. of Industrial Minerals, 25th, 1989, Proceeds. 1990	10.00
24 Index to Forums on Geol. of Industrial Minerals, 1965-1989. 1990	7.00
25 Pumice in Oregon. 1992	9.00
26 On-/offshore cross section, N. Coast Range to cont. slope. 1992	11.00
27 Econ. analysis, construction aggregate markets and forecast. 1995	15.00

OIL AND GAS INVESTIGATIONS

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

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

Periodicals postage
paid at Portland, OR

AVAILABLE DEPARTMENT PUBLICATIONS (continued)

BULLETINS

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

MISCELLANEOUS PAPERS

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

SHORT PAPERS

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

MISCELLANEOUS PUBLICATIONS

	Price	☑
Hiking Oregon's geology, E.M. Bishop and J.E. Allen, 1996	16.95	
Assessing earthquake hazards in the Pac. NW (USGS Prof. Paper 1560)	25.00	
Geology of Oregon, 4th ed., E.L. and W.N. Orr and E.M. Baldwin, 1991, published by Kendall/Hunt (add $3.00 for mailing)	33.95	
Geologic map of Oregon, G.W. Walker and N.S. MacLeod, 1991, published by USGS (add $3.00 for mailing)	11.50	
Geology of the Pacific Northwest, E.L. and W.N. Orr, 1996, published by McGraw-Hill (add $3.00 for mailing)	43.00	
Geological highway map, Pacific Northwest region, Oregon, Washington, and part of Idaho (published by AAPG). 1973	8.00	
Oregon Landsat mosaic map (published by ERSAL, OSU). 1983	11.00	
Mist Gas Field map, rev. 1997, incl. 1993-96 production (OFR O-97-1)	8.00	
Digital form of map (CAD formats .DGN, .DWG, .DXF), 3½-in. disk	25.00	
Mist Gas Field production figures 1979 through 1992 (OFR O-94-6)	5.00	
Northwest Oregon, Correlation Sec. 24. Bruer & others, 1984 (AAPG)	6.00	
Oregon rocks and minerals, a description. 1988 (OFR O-88-6)	6.00	
Mineral information layer for Oregon by county (MILOC), 1993 update (OFR O-93-8), 2 diskettes (5¼-in., high-density, MS-DOS)	25.00	
Directory of mineral producers, 1993 update, 56 p. (OFR O-93-9)	8.00	
Geothermal resources of Oregon (published by NOAA). 1982	4.00	
Mining claims (State laws governing quartz and placer claims)	Free	
Back issues of *Oregon Geology*	3.00	

Separate price lists for open-file reports, tour guides, recreational gold mining information, and non-Departmental maps and reports will be mailed upon request.

GMS maps marked with an asterisk (*) are available in digital form on diskette (geological information only).

The Department also sells Oregon topographic maps published by the U.S. Geological Survey.

ORDER AND RENEWAL FORM

Check desired publications in list above or indicate how many copies and enter total amount below. Send order 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**. Payment must accompany orders of less than $50. Payment in U.S. dollars only. Publications are sent postpaid. All sales are final. Subscription price for *Oregon Geology*: $10 for 1 year, $22 for 3 years.

Renewal ___ / new subscription___ to *Oregon Geology*: 1 year ($10) or 3 years ($22) ____________________$

Total amount for publications marked above: $____________________
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: ____________________