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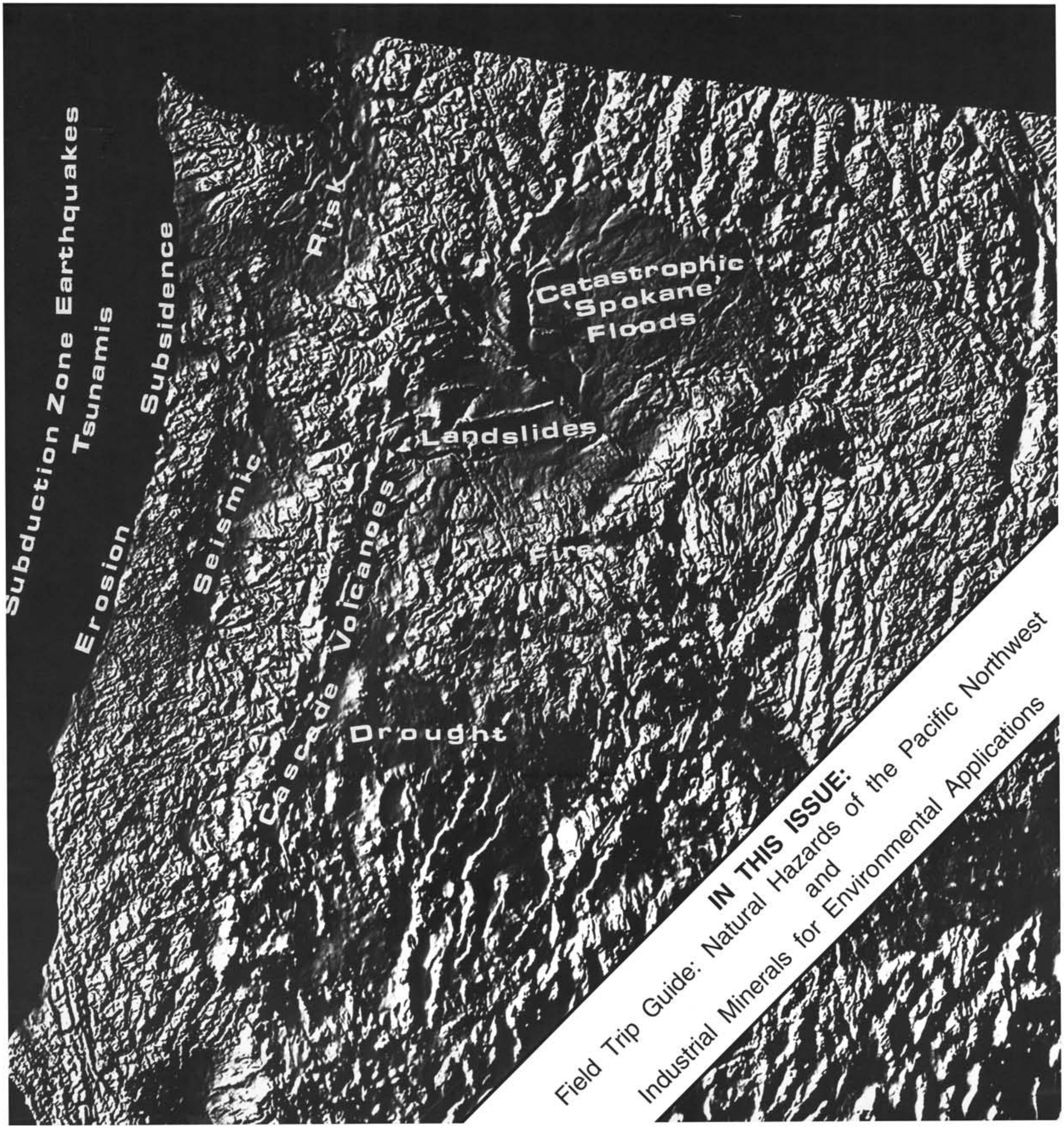

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Field Trip Guide: Natural Hazards of the Pacific Northwest
and
Industrial Minerals for Environmental Applications

OREGON GEOLOGY

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Information for contributors

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, typed double-spaced throughout (including references) and on one side of the paper only. If manuscript was prepared on common word-processing equipment, an ASCII file copy on 5-in. diskette may be submitted in addition to the paper copies. Graphic illustrations should be camera-ready; photographs should be black-and-white glossies. All figures should be clearly marked, and all figure captions should be typed together on a separate sheet of paper.

The style to be followed is generally that of U.S. Geological Survey publications. (See the USGS manual *Suggestions to Authors*, 7th ed., 1991 or recent issues of *Oregon Geology*.) The bibliography should be limited to references cited. Authors are responsible for the accuracy of the bibliographic references. Names of reviewers should be included in the acknowledgments.

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of the Oregon Department of Geology and Mineral Industries.

Cover photo

Digital elevation model (DEM) of the Pacific Northwest, showing areas and types of natural hazards related to the geology of the region. Field trip guide beginning on next page leads to points in Oregon and southwestern Washington where the effects of such hazards can be observed. Illustration courtesy of the U.S. Geological Survey.

OIL AND GAS NEWS

Drilling underway at Mist Gas Field

During May, Nahama and Weagant Energy Company of Bakersfield, California, began a multi-well drilling program at the Mist Gas Field, Columbia County, Oregon. The first well drilled, Columbia County 23-31-65, located in SW¼ sec. 31, T. 6 N., R. 5 W., reached a total depth of 2,272 ft and is currently suspended. Drilling operations have also been completed at the second well, Columbia County 43-33-75, located in SE¼ sec. 33, T. 7 N., R. 5 W., and the well is also suspended. Taylor Drilling Company, Chehalis, Washington, is the drilling contractor.

NWPA elects Board

The Northwest Petroleum Association (NWPA) announced the results of the elections to the Board for 1992-1993. The officers now are Jack Meyer, President; Nancy Ketrenos, Vice President; Dick Bowen, Secretary; Todd Thomas, Treasurer; and Lanny Fisk, Past President. Directors are Peter Hales, Western Washington; Thomas Deacon, Land; Williams Holmes, Legal; and John Newhouse and Dan Wermiel, At-large.

The NWPA is an organization of persons interested in oil, gas, and geothermal energy resources in the Pacific Northwest. Meetings with a speaker are held each month, and an annual field symposium is held each fall. This year, the field symposium is entitled "New Exploration Concepts and Opportunities for the Pacific Northwest." It will be held on October 11-13, 1992, in Lincoln City, Oregon. Contact the NWPA, P.O. Box 6679, Portland, Oregon 97228-6679, for further information.

Oregon DOE revising rules

The Energy Facilities Siting Council (EFSC) of the Oregon Department of Energy (ODOE) is revising its rules pertaining to the siting of energy facilities in Oregon. These rules affect a variety of energy facilities in Oregon, including underground natural-gas storage projects and pipelines. For more information on the proposed EFSC rules, contact David Stewart-Smith, ODOE, 625 Marion Street NE, Salem, OR 97310, phone (503) 378-4040.

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
469	Nahama and Weagant CC 31-15-65 36-009-00294	NE¼ sec. 15 T. 6 N., R. 5 W. Columbia County	Permit; 2,800.
470	Nahama and Weagant CC 43-33-75 36-009-00295	SE¼ sec. 33 T. 7 N., R. 5 W. Columbia County	Permit; 2,550.
471	Nahama and Weagant Wilson 11 A-5-65 36-009-00296	NW¼ sec. 5 T. 6 N., R. 5 W. Columbia County	Permit; 3,500.
472	Nahama and Weagant CC 41-33-75 36-009-00297	NE¼ sec. 33 T. 7 N., R. 5 W. Columbia County	Application; 2,850.

□

Correction

In the last (May) issue, on page 68 of the summary of activities of the Oregon Department of Geology and Mineral Industries, geologic mapping for southeastern Oregon should, of course, have referred to the mapping of the **west** half of the Boise 1° by 2° sheet. Thanks to Allen Agnew for catching the error!

Natural hazards of the Pacific Northwest, past, present, and future—a field trip guide for western Oregon and Mount St. Helens

by Charles L. Rosenfeld, Associate Professor, Department of Geosciences, Oregon State University, Corvallis, Oregon 97331

INTRODUCTION

The United States is the host nation for the 27th International Geographical Congress, an event that occurs at four-year intervals. Oregon State University is the host institution for the Study Group on Geomorphological Hazards, whose members will participate in an excursion and symposium focused on hazard analysis, response, and planning in the Pacific Northwest during August 1-7, 1992.

The following article traces, in a summary fashion, the route of this excursion (Figure 1). (Readers may wish to break it into several day-long trips at their own discretion.—*ed.*) The excursion highlights many of the natural hazards that have been recognized and studied in northwestern Oregon and southwestern Washington.

It is generally recognized that the setting of this region, with its tectonically active plates and volcanoes, its dynamic rivers, and its high-energy coastline, naturally concentrates numerous geomorphic processes posing hazards to human occupancy. Scientists, engineers, and planners, who recognize the significance of past events, have been successful at limiting the impacts of recent catastrophic events and helping to prepare the region for the future. In this light, we welcome Chairman Professor Clifford Embleton of King's College, London, U.K., and the distinguished international membership of this study group to share our observations, insights and concerns about the nature of hazards in our environment. We laud their efforts on behalf of the United Nation's International Decade for Natural Hazards Reduction (IDNHR).

THE REGION

The physiography and geology of the region are dominated by an active plate margin. Spreading from the Juan de Fuca and Gorda Ridges, the Juan de Fuca Plate converges on the North American Plate along the Cascadia Subduction Zone, which extends from the Queen Charlotte Islands of southern British Columbia southward for over 1,000 km (600 mi) to Cape Mendocino in northern California

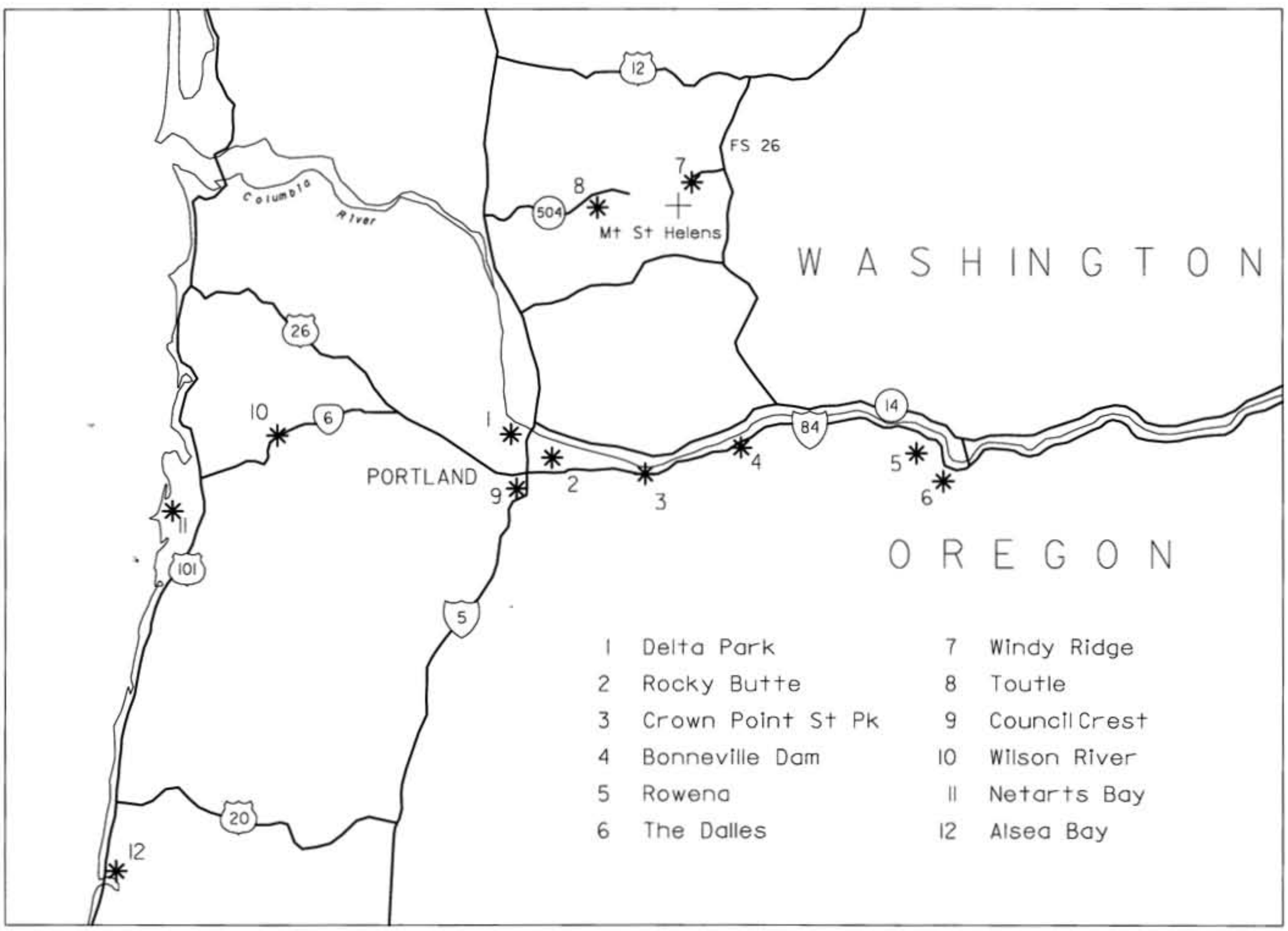


Figure 1. Location map showing stops of field trip.

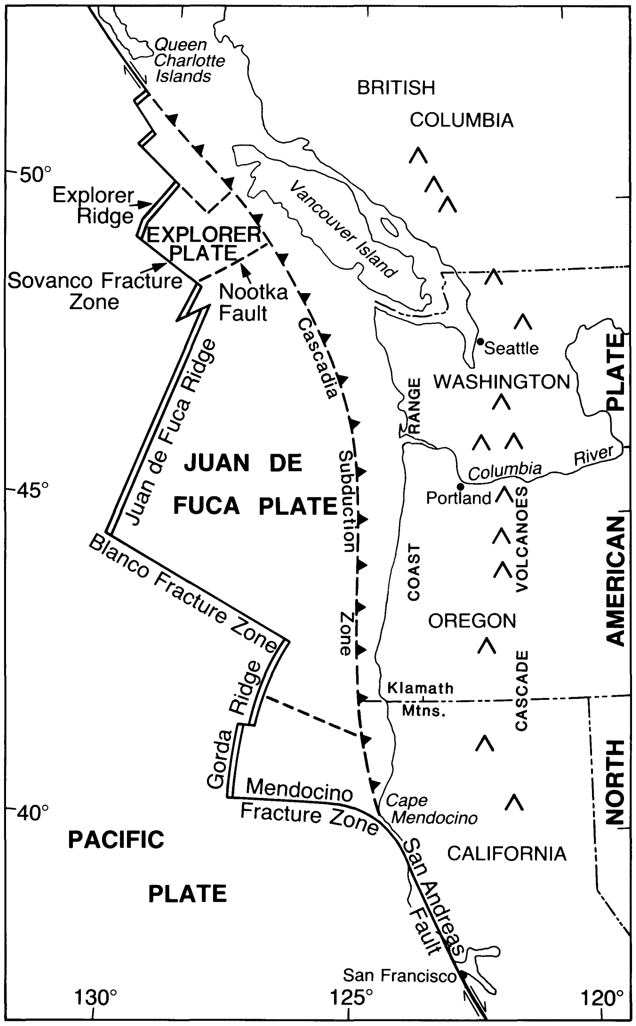


Figure 2. Plate-tectonic map of the Pacific Northwest. The active subduction of the Juan de Fuca Plate, estimated at 40 mm/yr, dominates the tectonic activity of the region and affects both its seismicity and volcanic activity. From Madin (1989).

(Figure 2). Seismic activity defines the geometry of the subducting Juan de Fuca Plate beneath western Washington and British Columbia. In the past, the nature of the subduction—seismic or aseismic—was in dispute. Recently discovered geologic evidence strongly suggests that the subduction convergence is accomplished seismically, i.e., accompanied by earthquakes (Peterson and others, 1988; Madin, 1989).

The deformed sedimentary rocks and the igneous intrusions of the Coast Range stand as testimony to the dynamics of this continental margin, as do the Cascade volcanoes—highlighted by the 1980 eruption of Mount St. Helens: Both ranges are evidence of the continuous production of magma from the remelted sea floor.

The mountain ranges that block the abundant moisture from the Pacific Ocean produce orographic precipitation resulting in the lush coniferous rain forests of the coast and the deep snow packs common to the Cascades. Thus, the tectonic and climatic settings of the Pacific Northwest reflect a dynamic environment, subjected to strong endogenetic and exogenetic energy and producing an awesome array of physical processes.

When active processes occur in a developing landscape, the consequences can be catastrophic. It is with this certain knowledge that we explore the cataclysms of the recent past, in order to contain the effects of future natural disasters. Since the "written" historical record of the Pacific Northwest is less than 200 years old, scientists must explore the nature of those high-magnitude/low-frequency events that have affected much of the region in its "pre-historic" past. The security of the population and economy of the region depend on cautious assessments and careful planning.

FIELD TRIP STOP 1. THE VANPORT FLOOD

We begin our exploration of the natural hazards of the Pacific Northwest at Portland's Delta Park near the Interstate Bridge to Vancouver, Washington (Stop 1, Figure 1). This is the site of one of the most catastrophic flood events in this region's recent history, the Vanport flood of 1948. Floods are a nearly universal problem. In the Pacific Northwest, the annual spring snowmelt accelerated by warm rainfall is the primary cause of overbank flows on most of this region's rivers.

On Sunday morning, May 30, 1948, Memorial Day, the gauge on the Columbia River at Vancouver, Washington, read 8.65 m (28.3 ft), more than 4 m (13 ft) above flood stage. By sunset, across the river, the 18,700 residents of Vanport, Oregon, were homeless as the Columbia inundated its flood plain in the second largest flood on record.

The Columbia River basin encompasses 666,000 km^2 (259,000 mi^2), draining parts of Oregon, Washington, Idaho, Montana, Wyoming, Utah, Nevada, and British Columbia. Approximately 75 percent of the region's precipitation falls in the winter months, from November to April, with a significant portion occurring as snow at the higher elevations. The Columbia River's annual hydrograph peaks in May or June, reflecting the culmination of the period of maximum snowmelt runoff. Most major historical floods on the Columbia were the result of spring snowmelt (Pacific Northwest River Basins Commission, 1971).

On April 1, 1948, the water content of the snowpack was estimated to be 97 percent of normal (Pacific Northwest River Basins Commission, 1971). Spring was late that year, with cyclonic storms bringing sizable amounts of precipitation. On May 1, the water content of the snowpack exceeded that measured in April. By mid-May, spring had finally arrived with such force that the subnormal temperatures of April were replaced by above-normal ones. A two-week period of warm weather was capped by rain, occurring in extremely heavy downpours locally on May 28 and 29.

Vanport was the largest federal housing project in the United States (Maben, 1987). Located on the flood plain of the Columbia River in north Portland, the city was within Peninsula Drainage District Number One, a low-lying area between the Columbia and Willamette Rivers. While it was considered protected, in reality the dikes surrounding the area were merely highway and railroad fills. None had been constructed to serve as levees for flood protection. But on May 30, 1948, authorities advised the residents not to panic—"the dikes are holding."

At 4:17 p.m. on May 30, a 6-ft break opened on the west dike, which consisted of railroad fill (Figure 3, point A). Within minutes it widened to 150 m, allowing a wall of water 3 m high to surge through the area (Maben, 1987). Buildings collapsed, and cars were overturned as the Columbia River flooded the district. The sloughs temporarily slowed the onrush by absorbing the water, but as they filled, the waves again surged eastward, inundating the city of Vanport.

Within two hours, Vanport was completely destroyed. At midnight, the water level within the district stood at 5 m (15 ft). Many apartment buildings floated on the waves, torn intact from their foundations. The losses were magnified by the fact that the waters had only one exit from the City's street network.

On May 31, the Denver Avenue levee on the eastern margin of the district failed (Figure 3, point B), flooding the western portion of neighboring Peninsula Drainage District Number Two. Four hours later, District Two was completely flooded when the

Union Avenue fill also gave way (Figure 3, point C). Highways, railroads, and navigation facilities that provided access to Portland from the north, east, and west were disrupted. Miraculously, only 15 lives were lost during the Vanport flood.

Peak discharge of the Columbia River reached 28.3 million liters/sec (1.0 million ft^3 per second) at the maximum flood stage when it crested at 9.2 m (30.2 ft) on June 1. The river remained above flood stage for 26 days and at bankfull stage for 51 days.

Today, Peninsula Drainage Districts Numbers One and Two are owned by the City of Portland and have been subject to a reversal in zoning. District One, the former site of Vanport, is now zoned for parks and recreational use with a race track, radio towers, a golf course, and a wildlife refuge. With improved levees, District Two now contains recreational parks as well as a commercial area consisting of a business park, shopping facilities, restaurants, and a horse race track. However, the flood risk rating for District Two is predominantly 1-0.2 percent return frequency, with low-lying areas rated at the 1-percent return frequency, as is District One.

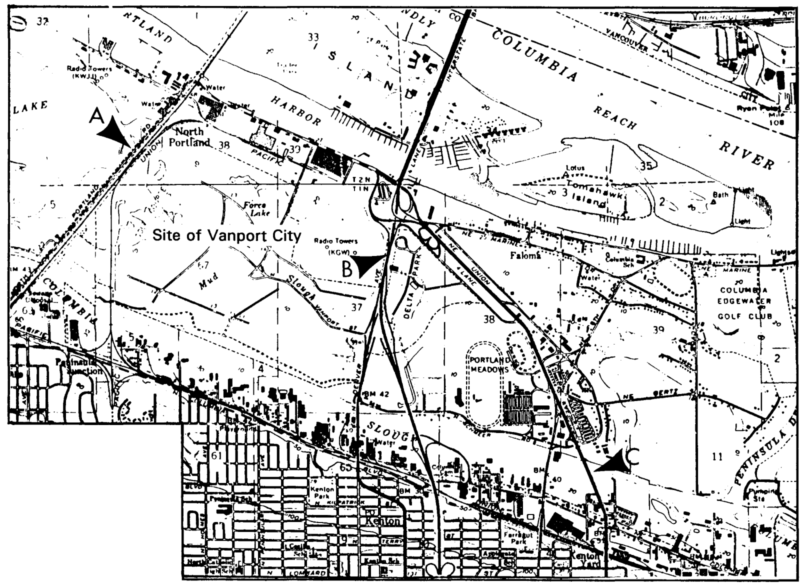


Figure 3. Location of former Vanport City and of the sites of progressive failure of (A) railroad fill on May 30, 1948; (B) Denver Avenue fill on May 31; and (C) Union Avenue fill later that same day.

This "nonstructural" approach to flood mitigation is consistent with the Flood Insurance Program administered by the Federal Emergency Management Administration (FEMA). This program encourages the nonresidential use of flood-prone areas by providing low-cost flood insurance to property owners but also imposing restrictions on the reoccupancy of flood-prone areas, including "flood proofing" of buildings and minimum elevation for residential structures. Since 1948, additional flood-control capacity has been added by dams on the upper Columbia River, so that the flooding threat to the Portland area is significantly reduced.

Exit Delta Park and drive east along Marine Drive, follow signs onto Interstate 205 (south), then exit at NE Halsey (westbound). Turn north on 92nd Avenue to Rocky Butte Road and Stop 2 at Joseph Wood Hill Park atop Rocky Butte.

FIELD TRIP STOP 2. SPOKANE FLOODS

Floods of much greater magnitude than even the largest Columbia River seasonal floods played a major role in shaping the Portland landscape. During the Pleistocene epoch, the Spokane Floods (also referred to as the Missoula Floods) surged westward out of glacial Lake Missoula through northern Idaho and eastern Washington and down the Columbia Gorge, producing a heavily scoured region in eastern Washington that is called the "Channeled Scabland" and temporarily filling the Willamette Valley as far south as Eugene (Figure 4).

Lake Missoula formed when a lobe of the Cordilleran ice sheet dammed the Clark Fork River in northwestern Montana. As the ice lobe waned, the ice dam collapsed, releasing 2,000 km^3 (500 mi^3) of water (Price, 1987). Estimates indicate that the flood flow velocities reached 30 m/sec (100 ft/sec) along constrictions in the Gorge, with a discharge of nearly 7 km^3/h (1.66 mi^3/h) (Baker and Nummedal, 1978). As the debris- and ice-laden water surged into the lower Columbia River, it scoured out a channel 100 m (330 ft) deep beneath the present river bed and flooded almost 800 km^2 (300 mi^2) of the Willamette Valley. The water level in the Portland region rose to 120 m (400 ft), and as the flood subsided, sediments accumulated to a depth of 75 m (250 ft).

That several floods occurred as the Cordilleran ice sheet waxed and waned throughout the Pleistocene is evidenced by the terraces found throughout Portland. Five distinct terrace levels are located at 45 m, 60 m, 250 m, 88 m, and 100 m (150 ft, 200 ft, 250 ft, 290 ft, and 330 ft, respectively) above sea level and are composed of unconsolidated sand and gravel with an occasional granitic erratic (Price, 1987). The University of Portland is situated on the lowest terrace located in north Portland, with the higher terraces found in east Portland. As the floods exited the Columbia Gorge, they surrounded Rocky Butte, forming a depositional delta with two lag bars to the west, and scoured a dry channel, Sullivan Gulch, into the gravels in the area now occupied by Interstate 84 and the rapid-transit system (Price, 1987). Figure 5 shows the location of this delta, the bars, and the scour channel, along with several of the terraces.

Return to I-205 (north), then exit eastbound on I-84. Continue eastward for 21 km (13 mi) to Corbett, then follow the Columbia River Scenic Highway east to Crown Point State Park.

FIELD TRIP STOP 3. COLUMBIA GORGE

The scour effect of the Spokane Floods greatly altered the stream valley that traversed the Cascade Range before the deluge. The flood waters entered this canyon at The Dalles, cresting at over 300 m (1,000 ft) while scouring the local basalts to 70 m (225 ft) below sea level. The powerful torrents stripped soils and plucked bedrock along the canyon, leaving oversteepened walls, prone to mass wasting. The floods rose to overtop 300-m (1,000-ft) bluffs at the east end, dropping to 275 m (900 ft) by Hood River and about 180 m (600 ft) at the Crown Point overlook. The numerous water falls that descend from the 150-m (450-ft) elevation attest to the widening of the Gorge by the Spokane Floods. The steep walls are especially unstable along the north side of the river between Washougal and Dog Mountain, where the old volcanic ash and mudflow deposits of the Eagle Creek and Ohanapecosh Formations comprise the bedrock—in contrast to the resistant Columbia River basalt that forms the south rim and Crown Point. Several of the major slides that may be seen from the Crown Point overlook include a basalt slide block at Rooster Rock (immediately west of the overlook) and the large headwalls of the Skamania slide, which exposes the Eagle Creek Formation across the Gorge to the north. The large Cascade slide may be seen further upstream on the north end of Bonneville Dam (Figure 6).

Exit Crown Point and continue eastwards on the Scenic Highway, rejoining I-84 east of Dodson. Turn off at Bonneville Dam.

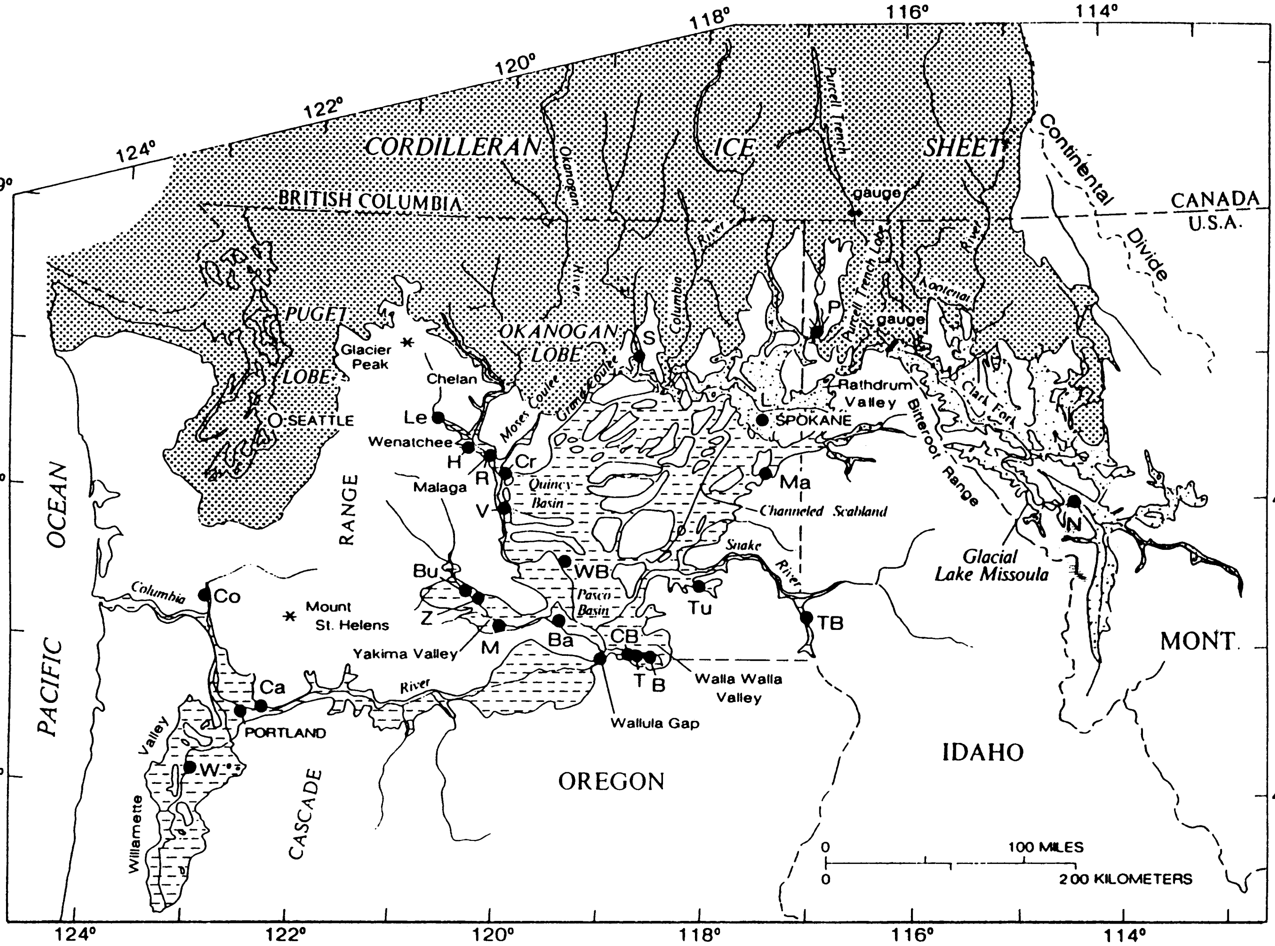
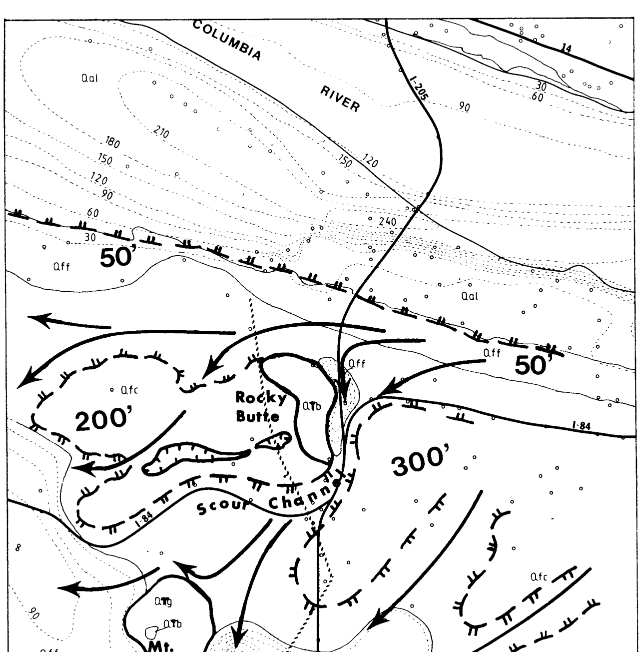


Figure 4. Regional extent of the Spokane floods during the Pleistocene, showing extent of glacial ice (densely dotted), glacial lakes Missoula and Columbia (light dots), and flooded areas (dashed pattern). Reproduced with permission from Allen and others (1986).



←Figure 5. Deflection of Spokane flood currents by the resistant basalts of Rocky Butte and Mount Tabor with lag bars to the west of Rocky Butte and a deep scour channel to the south. This channel is used by Interstate 84 and Portland's light-rail transit system. Terrace edges and approximate elevations are shown by hachured lines and large elevation figures. Surficial geology supports the geomorphic interpretation: Qal=Recent alluvial sand and silt; Qff=outburst-flood silt of late Pleistocene age; Qfc=outburst-flood gravel of late Pleistocene age; QTg=Pliocene-Pleistocene gravels; QTb=Pliocene-Pleistocene basaltic lava flows; Tt=Pliocene gravels; diagonal dashed lines indicate inferred buried faults. Modified from Allen (1979) and Madin (1989).

FIELD TRIP STOP 4. BONNEVILLE DAM

Finding an acceptable site for Bonneville Dam was exceedingly difficult. The geology of the Columbia Gorge at Bonneville is extremely complex, largely due to the results of volcanic activity, catastrophic ice age floods, and over 130 km^2 (50 mi^2) of landslides. The largest of the landslide debris flows, the Cascade slide, occurred approximately 700 years ago and covered an area of 50 km^2 (14 mi^2). Bonneville Dam is located on the toe of that landslide (Figure 7). Carbon (^{14}C) analyses of buried trees (Lawrence and Lawrence, 1958) indicate that the slide occurred around A.D. 1260. The temporary damming of the river that resulted was known in Native American legend as the "bridge of the gods." The remnants of the landslide toe formed the "cascades of the Columbia" until drowned by the water impounded behind the dam.

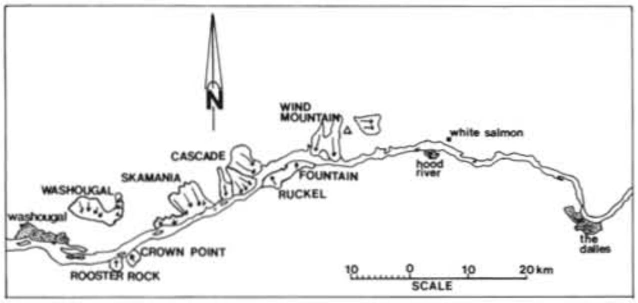


Figure 6. Major landslide areas between Washougal, Washington, and The Dalles, Oregon. Names of landslide areas are written in capital letters, names of cities in lower-case letters. Modified from Allen (1979).

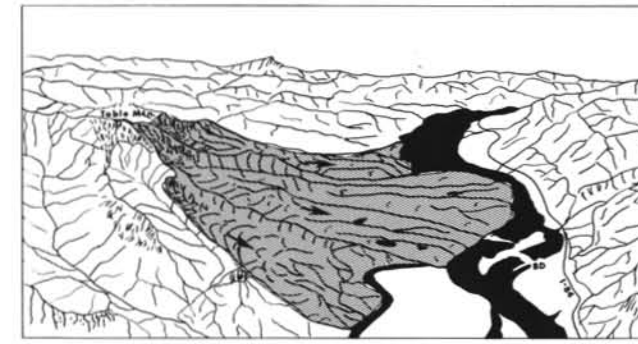


Figure 7. Oblique view of Cascade landslide zone, looking east. Arrows indicate three major slides within the zone. BD=location of Bonneville Dam. Sketch by Bret Hazell.

The Columbia River and its tributaries account for 40 percent of the hydropower potential of the United States. Bonneville Dam was the first dam built as part of the massive Columbia-Snake River development project. It is located 64 km (40 mi) east of Portland in one of the most scenic spots in the Pacific Northwest, the Columbia River Gorge. Its location places it at the tidal limit of the Columbia River, about 235 km (145 mi) from the Pacific Ocean. The dam impounds 77-km (48-mi)-long Lake Bonneville and incorporates a spillway, two powerhouses, three fish ladders, and a fish hatchery.

In 1930, engineers and geologists in search of a stable dam foundation were unable to find suitable bedrock through the Cascade slide). Additional core samples identified an acceptable site near Bonneville in November of 1933, and construction began immediately. However, after more drilling, geologists located a better site 2,000 ft downstream for the original site. Construction was moved to the dam's present location, where engineers found a good bedrock foundation for the dam in two basalt intrusions or uplifts.

Bonneville Dam is a key part of the government's multipurpose development of the Columbia-Snake River region. Its two powerhouses have a generating capacity of 1,084.3 Megawatts and are part of a vast hydropower system supplying 85 percent of the electricity for the Pacific Northwest. Bonneville Dam was constructed to provide hydropower and navigation but does not provide any flood control. Besides hydropower, dams on the Columbia-Snake system provide navigation, irrigation, recreation, fish and wildlife habitat, and crucial flood control.

Bonneville Fish Hatchery is operated by the Oregon Department of Fish and Wildlife and is the oldest hatchery in Oregon. The Bonneville Hatchery is just one of many in the Columbia system that together produce 150 million salmon and 9 million steelhead fingerlings each year. The hatchery is part of the most extensive fish preservation project in the world. In the past decade, over $1 billion was spent on improvement of fish runs or in revenue losses through reduced hydropower production.

The new Bonneville Navigation Lock is scheduled for completion in 1993 and will replace the original lock built in the mid-1930s. During an average year, 10 to 12 million tons of cargo, primarily grains and petroleum products, pass through the facility. The new lock, built at a cost of $329 million, will improve the average time in system for a barge from 12.7 hours to 1.9 hours.

Continue east on I-84 to Mosier, exit and turn east toward Rowena and Mayer State Park. Continue 14.5 km (9 mi) to the Tom McCall Memorial Grassland and overlook.

FIELD TRIP STOP 5. ROWENA OVERLOOK

The overlook is located at the entrance to the Columbia Gorge, where the waters of the Spokane floods washed over the valley walls to an elevation of 300 m (1,000 ft). The rocks have been stripped of soil, and the floodwater elevation can easily be seen on the opposite shore, where Columbia River basalt is exposed just east of Lyle, Washington. The Ortney anticline (east) and Mosier syncline (west) deform the basalts along this section.

Descend the Rowena loop eastbound and return to I-84 East. Continue to The Dalles. Exit I-84 at the Second Street exit, turn right on Liberty Street, climbing to the top of the hill, then turn left on The Dalles Scenic Drive. Stop at the Sorosis Park overlook.

FIELD TRIP STOP 6. THE DALLES

The city of The Dalles has had a long history of progressive landslide damage to structures and utilities due to slow-moving creep of a deep-seated slide (Beaulieu, 1985) (Figure 8). The upper surface at the overlook consists of the clay-rich Chenoweth Formation, which has been progressively sliding on top of the Columbia River basalt, which dips locally toward the river. The Spokane floods ponded here to depths of 300 m (1,000 ft) and almost certainly caused oversteepening and erosion of the lower slopes by removal of lateral support to the slope. As the city grew, local springs were blocked, buildings loaded the slope, and drainage was allowed to infiltrate into the slide mass. As a result, ground movement of 1.2-5.3 cm/yr have been recorded throughout much of the area.

Figure 8. Landslide area in The Dalles. Outlined arrows indicate damage to structures, streets, and utilities due to ground movement; solid arrows indicate recent slide activity. Stippled area shows most active "inner zone" of this nested slide block. Modified from Sholin (1982).

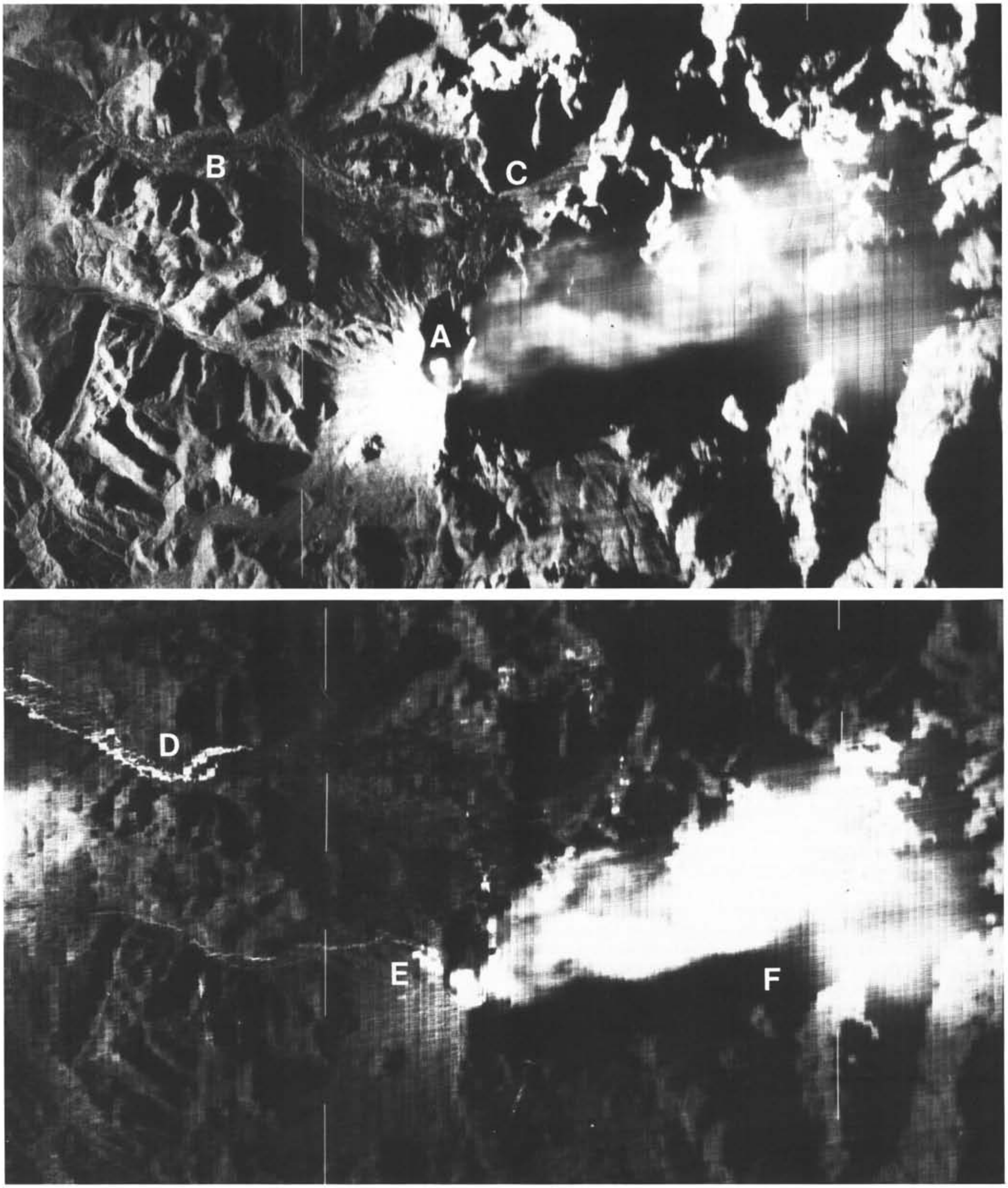


Figure 9. Side-looking airborne radar (SLAR) images of the May 18, 1980, eruption of Mount St. Helens. This technique was used to penetrate the heavy ash in the lower atmosphere. The image is divided into two channels: The top image illustrates stationary objects, such as the newly formed explosion crater (A), the hummocky surface of the debris avalanche (B), and the debris covering the surface of Spirit Lake (C).In the bottom picture, objects in motion are emphasized, such as the mudflows emanating from the terminus of the debris avalanche (D), a nuée ardente descending the west flank of the volcanic cone (E) and the debris-laden Plinian ash plume moving to the east of the volcano (F). The vertical dashed lines are 20 km (12.5 mi) apart. Imagery courtesy of Oregon Army National Guard.

Cross the Columbia River and return (west) to Carson, Washington, along Highway 14. Continue north to Swift Creek Reservoir and on to Mount St. Helens National Volcanic Monument and the Windy Ridge Viewpoint via Forest Service Roads 26 and 99.

VOLCANIC HAZARDS: THE MOUNT ST. HELENS EXAMPLE

The devastating eruption of Mount St. Helens on May 18, 1980, had a profound impact on the region. This formerly popular recreational area suffered complete destruction—with over 430 km^2 (166 mi^2) of forest destroyed and over 50 lives lost. But beyond the immediate destruction, the downwind ash fall, and the disruption of rivers by mudflows, the people of the Northwest were shocked into the realization that the volcanoes of the Cascade Range were much more than benign objects of beauty on the horizon. A heightened sensitivity to natural hazards has resulted from this dramatic event.

For scientists, Mount St. Helens, the youngest and most studied Cascade volcano, is an excellent natural laboratory. Many pioneering studies already underway at the time of the May 18, 1980, eruption have given us new insight to complex processes involved in an eruption, such as volcanic landslides, debris avalanches, lateral phreatic blasts, Plinian ash plumes, pyroclastic flows, lahars, and subsequent erosion and dissection of the landscape. The devastated landscape provides a rare opportunity for long-range geomorphic, hydrologic, and biological studies as it recovers from this catastrophic event.

During the last 4,500 years, Mount St. Helens has been more explosive than any other volcano in the conterminous United States (Crandell and Mullineaux, 1978). At the time when Mount Baker was showing increased thermal activity (Rosenfeld and Schlicker, 1976), Crandell and others (1975) warned that, based on past history, Mount St. Helens could erupt soon—possibly before the end of the century.

On March 15, 1980, the western Washington seismic network detected a series of small earthquakes beneath the volcano. Seismicity markedly increased on March 20, followed by a small phreatic eruption on March 27 that opened a small summit crater (Rosenfeld, 1980). The summit crater continued to enlarge for two months as phreatic (steam-blast) activity continued, eventually reaching 700 m (2,300 ft) in length and 200 m (656 ft) in depth. During this phase, viscous magma was intruding high into the older volcanic cone, inflating the northeast flank of the mountain and creating an ominous "bulge" beneath Forsyth Glacier. The inflation continued at a constant rate of 2.5 m (8 ft) per day with no acceleration until the cataclysmic eruption.

At 0832 local time on May 18, a Richter magnitude 5.1 earthquake triggered the failure of the unstable north slope in a landslide that was enhanced by the rapid unloading and depressurizing of the buried magmatic injecta and associated superheated ground water. The landslide and the debris subsequently produced by phreatic explosions formed a complex debris avalanche that descended the volcano's north flank and traveled 25 km (15 mi) west down the valley of the North Toutle River in about 10 minutes. Unloading by the landslide and rapid release of confining pressure on the superheated interior of the cone together produced a north-facing lateral explosion that carried pyroclastic debris outward, toppling trees over a 500-km^2 (193-mi^2) area and killing most living things with an air temperature of about 600°C (Rosenfeld, 1980).

The eruption eliminated the upper 400 m (1,300 ft) of the volcanic cone and excavated a 625-m (2,000-ft)-deep crater, 2.7 km (1.7 mi) long and 2.0 km (1.2 mi) wide, in the remaining mountain. About 30 minutes after the blast, lithic fragments were explosively ejected in an eruption column that reached 14-16 km (8.5-10 mi) in altitude throughout the morning. Around noon, a lighter colored and more energetic eruption plume (possibly as fresh supply of gas-rich magma reached the surface) attained an altitude of over 19 km (12 mi) and was carried as far east as Denver, Colorado. Also around noon, melting ice, and ground water began to coalesce in the 2.5-km^3 (0.6-mi^3) debris avalanche. As a result, saturated debris formed a lahar (volcanic mudflow) that descended down the North Fork Toutle River valley in to the Cowlitz and eventually the Columbia Rivers. This mudflow destroyed over 200 homes and deposited over 72 million m^3 (94 million yd^3 or 2.5 billion ft^3) of sediment along its course (Lipman and Mullineaux, 1981).

In addition to ground observations, remote sensing captured many of these events. Rosenfeld (1980) used side-looking airborne radar (SLAR) to penetrate the heavy ash concentrations in the lower atmosphere that obstructed most direct observations. Figure 9 shows many of the features described in the preceding text as they actually occurred.

FIELD TRIP STOP 7. WINDY RIDGE VIEWPOINT

The viewpoint is located 7 km (4.3 mi) northeast of the crater, along the divide between the Toutle River basin and the Lewis River basin. Windy Ridge is capped by about 1 m (3 ft) of blast deposits from the lateral blast. These deposits include gravel- to coarse-sand-sized rock fragments from the volcanic cone, including light-gray vesicular dacite from the "bulge" intrusions, and fragments of shredded wood.

From the crest of the ridge, north of the parking lot, the top of the 235-m (770-ft)-high dacite dome (extruded between 1980 and 1986) can be seen, as can the hummocky debris-avalanche deposits, the lighter toned pyroclastic flows, and Spirit Lake. Figure 10 shows a sketch of the panorama from this site. One can visualize the eruptive sequence: First the lateral blast surged over the landscape, shredding the forest and scouring up to 1 m (3 ft) of soil. The hot blast deposit then coated the landscape. The landslide/debris avalanche, moving at 250 km/h (155 mi/h), entered Spirit Lake and caused a catastrophic wave that washed northwards nearly 400 m (1,300 ft) up the flanks of Mount Margaret. Losing momentum, this wave sloshed back into the lake basin, washing many broken trees with it. Large blocks of the debris avalanche, some more than 20 m (65 ft) in diameter, came to rest in Bear Cove on the northwest shore of the lake, 10 km (6 mi) from the mountain. Another high-speed portion of the avalanche overtopped Johnston Ridge on the north side of the Toutle valley, as the remainder of this broken mass headed down the valley for an additional 20 km (12 mi).

The Spirit Lake basin collects runoff and snowmelt from the north flank of the volcano and its basin. Pumping was used to keep the lake from overtopping and possibly causing liquefaction or catastrophic erosion of the unstable debris-avalanche blockage. The pumps were replaced by a 2,500-m (8,200 ft)-long, gravity-fed

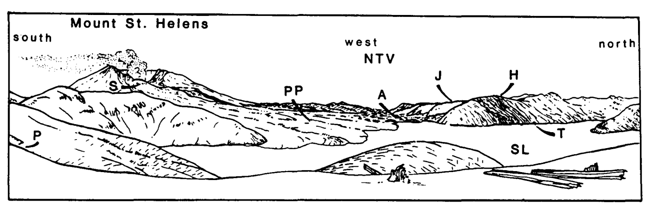


Figure 10. Panoramic sketch of the view to the west from the hill above the Windy Ridge parking lot. Volcanic gas and water vapor always rise from the dome. During humid weather, water vapor condenses to form visible plumes from dome and fumaroles in the pyroclastic flows of the Pumice Plain. P=Windy Ridge parking lot, J=Johnston Ridge, S=Sugar Bowl dome, H=Harry's Ridge, PP=Pumice Plain, SL=Spirit Lake, NTV=North Fork Toutle River valley, T=Spirit Lake outlet tunnel, A=debris-avalanche deposit (Spirit Lake blockage). Drawing by Bobbie Myers.

tunnel cut through Harry's Ridge to Coldwater Creek, thus fixing the water level in Spirit Lake.

A small instrument shed on Harry's Ridge houses measurement and telemetry equipment used by the U.S. Geological Survey to monitor volcanic activity. When significant changes occur, the Survey notifies the USDA Forest Service, the agency that is responsible for all access decisions within the Mount St. Helens Volcanic National Monument.

Return from Windy Ridge parking lot back to the Meta Lake turnoff (Road 26). Meta Lake is an excellent example of the blowdown area, and a point about 8 km (5 mi) north of Meta Lake shows the terminus of the lateral blast 18.7 km (11.6 mi) north of the crater. Continue north to Randle, Washington. Proceed west on Highway 12, then south on Route 505 towards Toutle, Washington. Turn east on Route 504 and proceed to the Toutle River Sediment Retention Structure.

FIELD TRIP STOP 8. TOUTLE RIVER SEDIMENT RETENTION STRUCTURE

This location demonstrates the geomorphic disruption of the landscape caused by the eruption. The immediate concern following the eruption was to assess the natural-hazard potential posed by outburst flooding from avalanche-dammed lakes, flooding, and renewed mudflow activity. Such outburst flooding could be caused by increased runoff and sediment constriction of the main channel. Initial assessment techniques included (1) interpretation of aerial photos of the impacted basins to determine the location and volume of deposits, detention ponds, and blockages to drainage, and (2) aerial surveillance by aerial photo radar and during periods of renewed volcanic activity to provide downstream warning in the event of resultant outburst-flooding or mudflow events (Rosenfeld and Cooke, 1982).

Following the rescue and recovery operation, scientists started numerous erosion monitoring activities within the devastated area, including placement of erosion stakes, measurements of sedimentation and discharge, and aerial photography after each storm.

The U.S. Army Corps of Engineers constructed the Sediment Retention Structure to inhibit the release of sediment from the upper Toutle River basin and reduce sediment constriction of the lower reaches of the Toutle, Cowlitz, and Columbia Rivers. A hasty retaining structure, N-1, was constructed on the North Fork Toutle River and completed by fall of 1980. Monitoring of sediment storage and periodic dredging of accumulated materials was planned for this structure.

Figure 11 summarizes the major components of the 1980-81 sediment budget as determined by the aerial inventory, field measurement of erosional processes, and periodic sampling of the stream. Various components of the landscape responded differently to episodes of volcanic activity, climatic events, and man-made erosion control and stabilization projects, and this has thwarted efforts to accurately model a long-term sediment budget for the area. However, several important process-response relationships have been accurately observed, and their trends can be identified.

The rockslide-debris avalanche deposits occupied a 35-km (22-mi)-long path from the breached northern face of Mount St. Helen, down the north flank of the cone, and filled more than 60 km^2 (23 mi^2) of the North Fork Toutle valley to depths ranging from 10 to 195 m (33-640 ft). The composition of this material averaged 45 percent gravel to boulders, 40 percent sand, and 15 percent silt, with coarse pumice resulting from successive pyroclastic flows overlying parts of the upper 5 km (3 mi) of the deposit. Erosion of the debris avalanche proceeded chiefly by the development of new channels and the extension, deepening, and widening of channels initiated by the floods and mudflows of May 18-19, 1980, and subsequent breaches and outburst floods from impounded tributary lakes and detention ponds. Channels and gullies range 3-50 m (9-164 ft) in depth and 3-200 m (9-650 ft) in width, with banks sloping from 30° to 70°. Bank undercutting during high flow periods causes slumping and bank recession, especially where the channel is braiding. Initial channel development was rapid, excavating over 43 million m^3 (1.5 billion ft^3 or 56 million yd^3) during the first year of post-eruption activity, an amount roughly equivalent to 2 percent of the total volume of the debris avalanche and more than half the total sediment yield for the basin. Continued mapping and measurements through October 1983 suggest that while wet-season channel network extension continues, it does so in response to specific volcanic or climatic events; furthermore, due to the hummocky nature of the debris surface, it does not develop a predictable pattern. A ten-year storm event is predicted to yield 8.78 million m^3 (35.3 million ft^3 or 100 million yd^3.

As several of the marginal lakes dammed by the debris avalanche have threatened to breach and cause outburst flooding, artificial spillways were constructed at Coldwater Lake and Castle Creek Lake. Continued volcanic activity through 1986 built a lava dome over 230 m (755 ft) above the crater floor. Character-

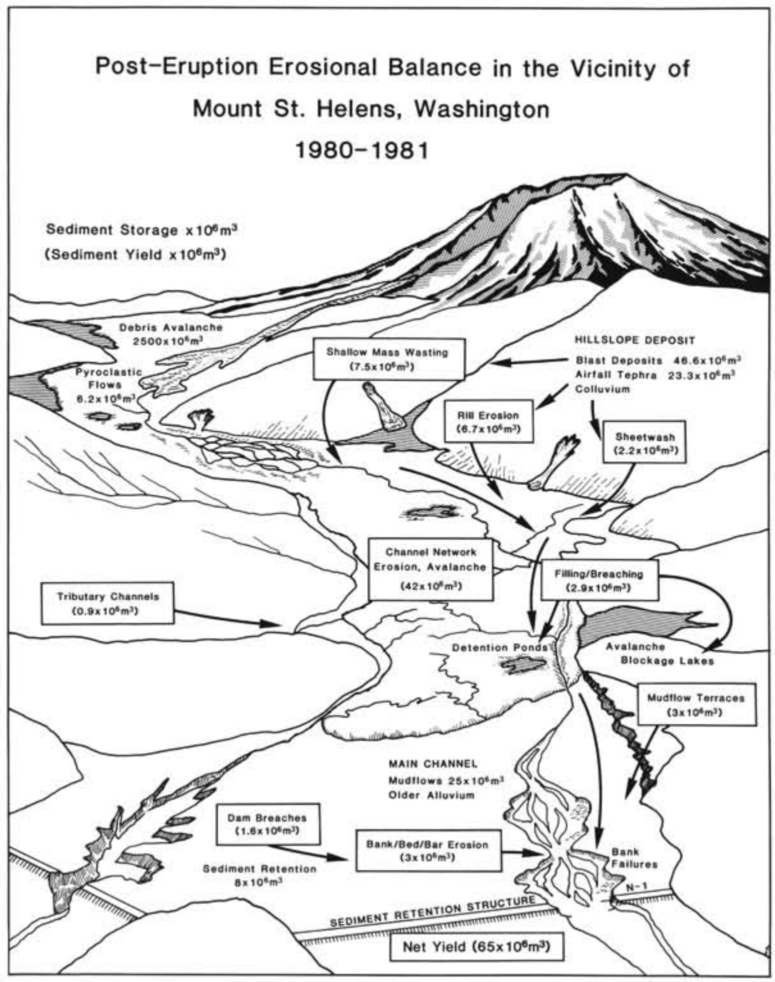


Figure 11. Schematic illustration of Mount St. Helens sediment budget. See discussion in text.

ized by pumice flows, lava extrusion and small, ash-laden explosions, several episodes have had substantial impact. For example, on March 19, 1982, a blast of hot pumice, dome rocks, and gas dislodged snow from the crater wall, triggering an avalanche of rock and ice that descended 8 km (5 mi) down the north flank of the mountain. A combination of frictional heat and warmth from the juvenile pumice caused rapid melting of the avalanche deposit, forming a transient lake within the crater with an estimated volume of 4 million m^3 (141 million ft^3 or 5.2 million yd^3. A flood of water and pumice simultaneously discharged both east and west of the lava dome, coalescing into a fluid lahar that cut a 30-m (98-ft)-deep channel while reaching an estimated discharge of 14,000 m^3 (494,000 ft^3 or 18,000 yd^3) per second. After descending the north flank of the volcano, the lahar divided into anastomosing channels across the surface of the 1980 debris flow, causing the integration of previously isolated basins into the channel network and incising certain channel segments more than 10 m (33 ft). Two lithologically distinct surges reached the N-1 retention dam 35 km (22 mi) from the crater, filling the basin with 1.9 million m^3 (67 million ft^3 or 2.5 million yd^3) of sediment, then breaching and severely eroding the structure. Below the spillway, the sediment aggraded into the main channel of the Toutle River, previously choked by deposition from the winter storms of 1981 and 1982. Although peak discharge was an order of magnitude less than the deluge of May 18, 1980, the mudlines of this event came within a few meters of the initial lahar. As long as Mount St. Helens remains volcanically active, a potential exists for additional destruction from floods and muddy lahars far from the vent.

Construction of the Toutle River Sediment Retention Structure (SRS), just upstream from the confluence of the Toutle and Green Rivers, was completed in 1989 at the cost of $73.2 million. Its design was based upon a worst-case scenario of an explosive volcanic eruption during a large winter snowpack. If such an event were to occur, models have predicted, a flow of 75 million yd^3 (57 m^3) of mud and debris would come down the North Fork Toutle River.

The SRS is designed to retain sediment and debris, not water. Its unique design consists of a 550-m (1,800-ft) embankment, a concrete outlet structure, and a 600-m (2,000-ft)-long spillway along the north side. The SRS embankment is primarily built of rock fill over a compacted alluvial foundation. Its design allows water to pass through filter zones both underneath and through the edifice. The huge concrete outlet structure has six rows of five outlet pipes allowing water and fish to plunge vertically into the downstream outlet basin. These pipes will be systematically closed as sediment accumulates on the upstream side of the structure.

It is estimated that the 1,300-ha (3,200-acre) lake behind the SRS will fill completely with 250 million m^3 (8.8 billion ft^3 or 327 million yd^3) of sediment and debris by the year 2010. SRS functions unmanned and is monitored by instruments for seepage, settlement, lateral deflection, internal pressure, and seismic movement.

When Hwy 504 is completed in summer of 1993, the debris avalanche will be open for visitors, who will be able to drive to Coldwater Lake within the National Monument.

Return along Highway 504 to Castle Rock. Be sure to stop at the Mount St. Helens visitors center to see the displays. Return to Portland via I-5 south.

FIELD TRIP STOP 9. COUNCIL CREST PARK, PORTLAND

Council Crest Park in the Portland Hills provides a good view of the metropolitan area, its terraced floodplain portions as well as the reminders of past volcanic activity, and, weather permitting, of the chain of the High Cascades. Among the geologic hazards of the area (Figure 12), one type is now receiving particular attention: the earthquake hazards.

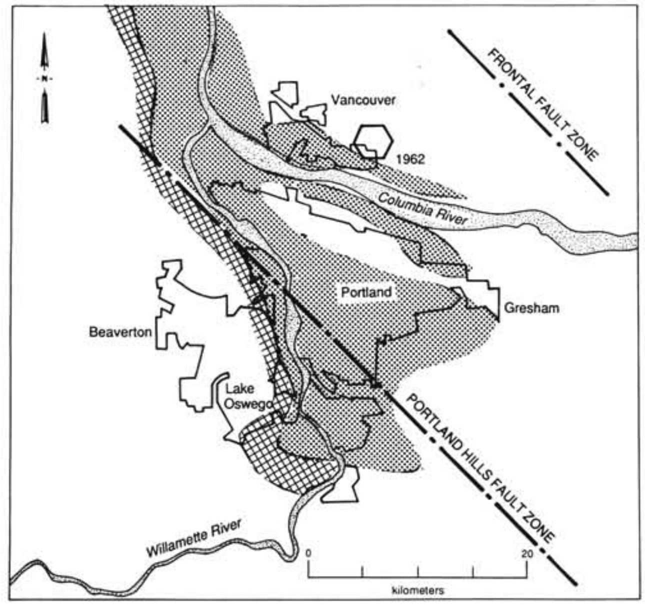


Figure 12. Portland area sketch map showing fault zones, areas of steep slopes (crosshatched), areas of unconsolidated sediments (dotted), and epicenter of 1962 earthquake (hexagon). Modified from Wong and others (1990).

Seismic risks in the Portland metropolitan area

The active subduction process along the Cascadia Subduction Zone implies several possible types of earthquakes in the Portland area: (a) Shallow crustal (upper plate) earthquakes, occurring along local faults and with potential magnitudes (M) up to M 7.0; (b) large, deep (intraplate) earthquakes, occurring within the subducted Juan de Fuca Plate, 40-60 km (25-37 mi) beneath the surface and with potential magnitudes up to M 7.5; or (c) very large (interplate or interface) earthquakes, occurring where the surfaces of the plates meet and periodically slip, with the potential of causing earthquakes of magnitudes M 8, 9, or greater (Figure 13).

All of the historical earthquakes have been the shallow crustal variety, the largest being a M-5.1 event centered on Vancouver. The current state of fault mapping and the short record of historical earthquakes make estimation of earthquake potential and magnitude difficult. Large, deep earthquakes, originating at depths of 40-60 km (25-37 mi) within the subducted Juan de Fuca Plate, have occurred in the Puget Sound region. The occurrence of a small number of well-located, similar earthquakes suggests that those seismogenic plate conditions also exist under northwestern and southwestern Oregon. Although it is easy to dismiss the seismic risk on historic

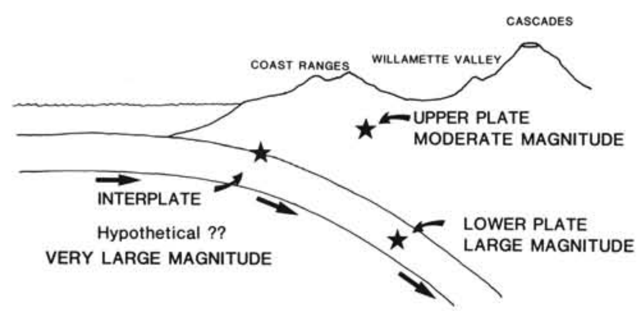


Figure 13. Schematic cross section through the Portland metropolitan area showing the location of potential earthquake zones. Courtesy of Ian P. Madin.

grounds, a growing body of geologic and seismic evidence suggests that a previously unrecognized level of earthquake hazard may exist in the Portland area.

In view of the lack of data for determining potential earthquake sources, efforts in Portland are focusing currently on characterizing the area's potential for disastrous responses to earthquakes, particularly amplified ground shaking and liquefaction. Soft or low-cohesion soils up to 50 m (164 ft) deep are widespread in the metropolitan area (Madin, 1989), and drilling is underway to map their location, character, and proximity to adjacent faults. The current mapping efforts will eventually lead to maps that can be used by government agencies, engineers, and planners for hazard mitigation.

Drive west on Highway 26 to Highway 6, continue toward Tillamook. Stop at Milepost 31.

FIELD TRIP STOP 10. WILSON RIVER LANDSLIDE

On April 4, 1991, a large planar slide occurred at this site, closing Highway 6 with an estimated 400,000 m^3 (14 billion ft^3 or 523,000 yd^3) of landslide debris (Figure 14). This type of mass wasting event is quite typical of large-scale landslides in the Coast Range. Precursors to this event were heavy saturation of the slope by a series of winter storms, tension cracking along the upper failure plane, which allowed rapid infiltration of surface runoff, and small mudslides of liquefied soils at the site immediately preceding the rapid failure of the slope.

The failure plane occurred along the contact of two deeply weathered basaltic breccia units at an average depth of 17 m (55 ft) at a 33° angle. The apparent "trigger" for this catastrophic failure was the increased loading and elevated pore-water pressure that resulted from abnormally high antecedent rainfall. The crest of the Coast Range received more than 150 mm (6 in) of precipitation in the preceding 24 hours and a total of 275 mm (8.8 in) over the preceding 30 hours. The slide blocked 200 m (650 ft) of the highway and partially obstructed the Wilson River. Removal and repair costs exceeded $2 million.

Figure 14. Wilson River canyon landslide of 1991. Photo courtesy of Susanne L. D'Agnese, Oregon State Highway Division.

Continue west, pass through Tillamook, turn south on Highway 101, and follow the Three Capes Scenic Loop to Netarts Bay Drive. Continue south on Netarts Bay Drive to Wee Willie's Restaurant.

FIELD TRIP STOP 11. SHORELINE SUBMERGENCE AT NETARTS BAY

Although western Oregon comprises about a third of the Cascadia Subduction Zone, it has not experienced a subduction earthquake in historic times (<200 years). This apparent lack of large-scale subduction may be attributed to aseismic slip of the subducting plate, terminated subduction, or intervals of periodic seismicity that are longer than the historic record. Recent large-scale subduction-zone seismicity (Chile, 1960; Alaska, 1964) have produced rapid coastal subsidence. From wetland burial sequences of Holocene age along the coast of Washington, Atwater (1987) has reported multiple events of abrupt coastal subsidence found by coring in protected bays. Peterson and others (1988) have located similar buried organic horizons in the protected environment of Netarts Bay. Using ^{14}C dating of the Holocene organic material to establish a chronology of multiple marsh burial events, they reasoned that rapid submergence is marked by burial of a peat layer that represents the drowned marsh vegetation. The peat horizons are covered, often in extremely abrupt transition, by a capping layer of sandy and silty sediments and then finer silts and bay sediments. Evidence in the capping sediment layer indicates turbulent sand deposition from a large-scale sheetflood that was possibly caused by a tsunami event. Many of the peat horizons contain freshwater diatoms indicating a high marsh setting, while the bay silts contain marine-brackish diatoms of subtidal origin.

Radiocarbon ages of the youngest buried peats come from borings in the mud flats at the south end of the bay and indicate an event 400 years B.P., clearly before the historical record. A total of seven marsh burial events are recorded in the upper 5 m (16 ft) below the present marsh, with ages ranging up to 3,300 years B.P.

The shortest duration in radiocarbon age between burial events was possibly less than 100 years, while the greatest interval is on the order of 1,000 years.

Longer records of Holocene marsh burials are needed to understand the tectonic cycles inferred from these data; however, some additional evidence indicates that subsidence of marshes in Netarts Bay can be traced back into late Pleistocene time in adjacent bay terrace deposits. At least two wetland forest horizons rooted in Pleistocene terrace material are similarly buried by bay muds. The magnitudes of coastal subsidence associated with the forest burials must certainly be greater than those that buried wetland marshes. The best exposure of these remnant forests may be seen at the tidal flats and terrace exposures just north of Wee Willie's Restaurant, near point T3 in Figure 15.

At low tide, numerous tree stumps are exposed in the modern tidal flat. Several of these stumps are close to the base of the terrace exposure. Trenching through the thin cover of modern muds reveals that these trunks are rooted in the Pleistocene terrace deposits. Additional tree roots can be seen protruding from an additional organic-rich layer about 1 m (3 ft) above the base of the terrace bluff. The probable age of the terrace deposits exceeds 83,000 years B.P. and hence precludes the use of ^{14}C dating to estimate the recurrence intervals. Figure 15 details the terrace exposures at three points in the vicinity of this stop.

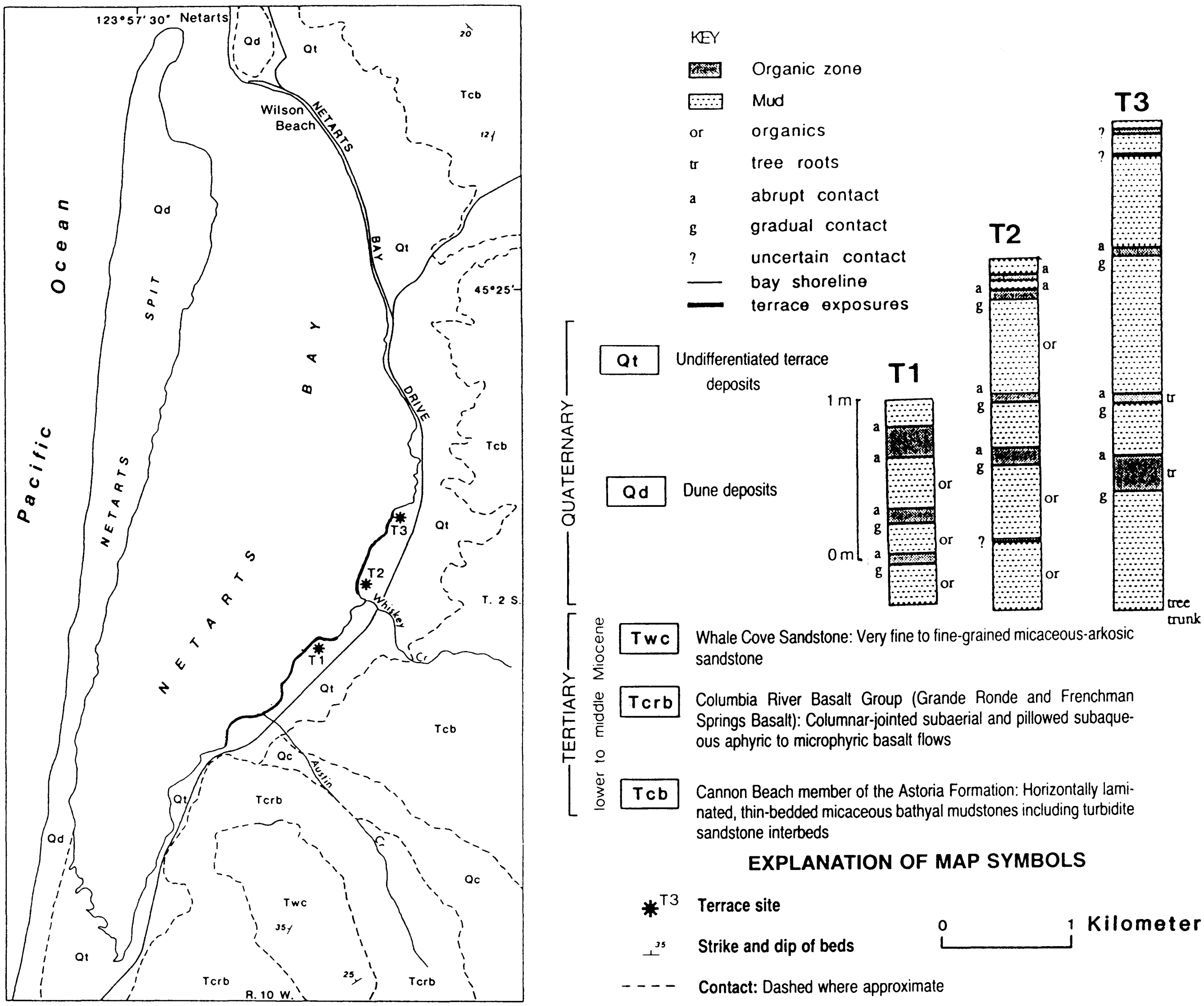


Figure 15. Netarts Bay area, late Pleistocene terraces, and stratigraphic sections of buried wetland horizons from the areas identified as T1, T2, and T3 on the map. Modified from Peterson and others (1988).

Return to Highway 101 and continue south to Waldport and Alsea Bay. Be sure to visit Alsea Bay Bridge Visitors Center for informative displays. Stop at Governor Patterson Memorial State Park south of the bay.

FIELD TRIP STOP 12. COASTAL EROSION AT ALSEA BAY

The threat of gradual sea-level rise over the next few decades poses an erosion hazard to much of the earth's inhabited coastline. A preview of such problems resulted from a brief rise of sea level related to the El Niño that lasted from April 1982 through July 1983, when a sea-level "bulge" was pushed northward along the west coast of the United States and, arriving at the Oregon coast during winter and spring, combined with an increased frequency of high-energy storm wave conditions.

The winter storms of 1982-83, accentuated by the El Niño, were a nightmare for the residents of Alsea Spit. The powerful northward longshore drift, accompanied by sediment from freshly eroded beaches and terrace deposits to the south, produced a massive sandbar along the south shore of the bay mouth. As a result, the discharge from the bay was effectively deflected northward and cut a channel close to shore along the distal tip of the spit. This allowed the big storm waves to attack the spit unimpeded by shallow-water shoaling (Jackson and Rosenfeld, 1987). The results were catastrophic: erosion was intense, rip-current creeps caused severe shoreline recession, and the spit was narrowed by 65 m (200 ft).

The northwest sea swells of summer gradually eliminated the bay mouth bar, but in doing so they exposed the tip of the spit to the southwest storms of winter. Between September and November 1985, over 120 m (400 ft) was lost to early winter storms. Figure 16 shows the position of the spit during December of 1978, 1983, 1985, and 1991. During the peak erosion winter of 1985-86, many of the homes on the tip of the spit were saved only by repeated placement of large basalt blocks or "rip-rap" along the shoreline. Vacant lots were permitted to erode. Since then, artificial backfills and natural reclamation have been used to rehabilitate the spit, and many previously eroded lots now contain new homes. Although the 1982-83 El Niño was arguably the strongest such event in this century— the actual change in sea level was an increase of about 50 cm (20 in.) over a five-week period. If predictions of future sea-level rise are accurate, significant shoreline change will certainly reach catastrophic proportions along the beach areas of the world.

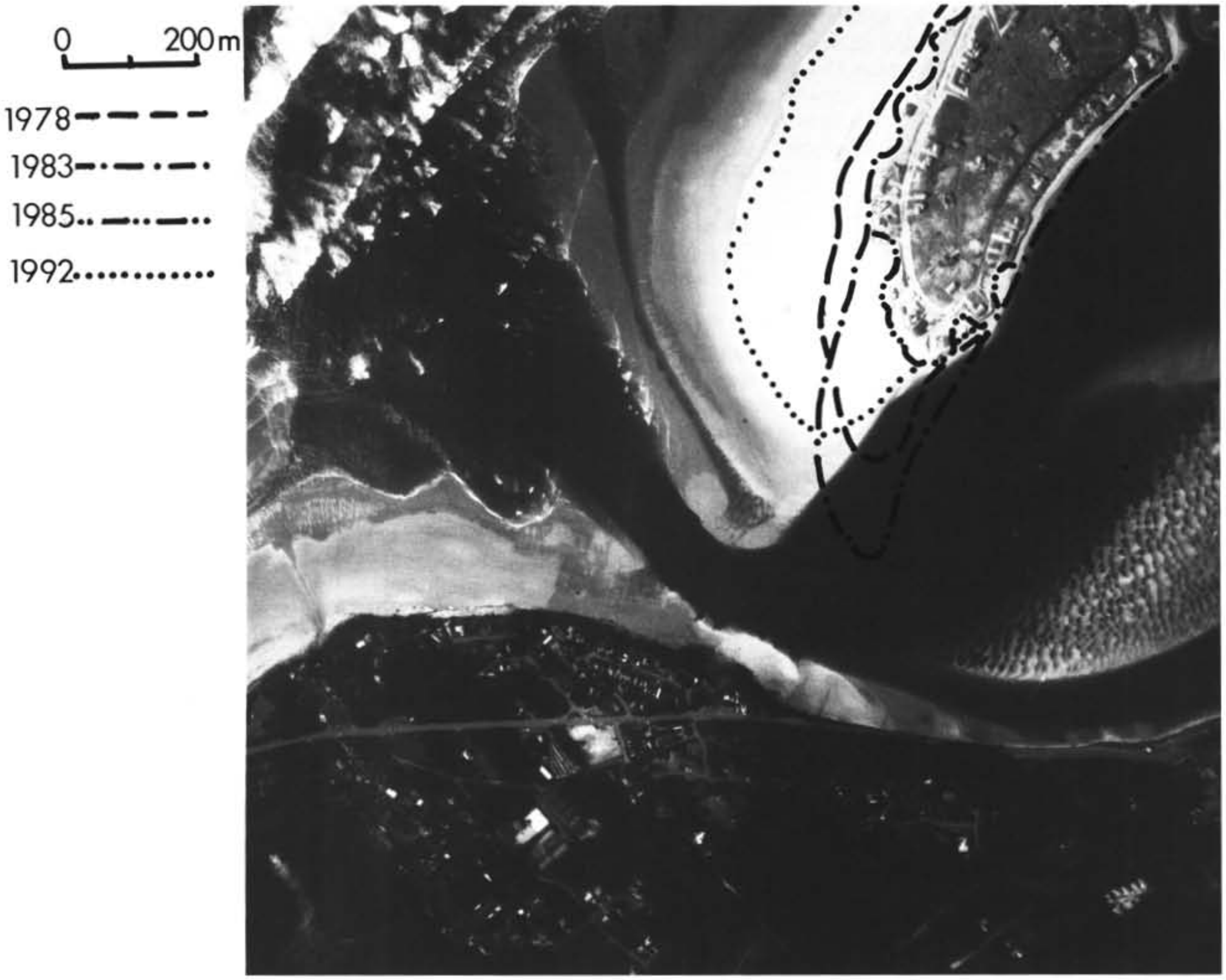


Figure 16. Shoreline changes at Alsea Bay, 1977-1991.

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Industrial minerals for environmental applications

by Ronald P. Geitgey, Oregon Department of Geology and Mineral Industries, Portland, Oregon 97232

INTRODUCTION

Industrial minerals, the nonmetallic minerals, are the foundation of modern economies. They are the raw materials for the manufacturing, chemical, construction, and agricultural industries. Industrial minerals and their derived products are encountered daily in highways, glass, paper, fertilizers, toothpaste, plastics, cosmetics, table salt, and stonewashed jeans.

A perhaps lesser known field of industrial mineral use is the area of environmental protection and of mitigating environmental hazards. Mined materials remove, neutralize, or isolate various pollutants and reduce burdens on the environment by aiding energy and water conservation. The cleanup of massive oil spills and the bombing of forest fires with retardants are spectacular ways industrial minerals protect our environment, but most uses are far less conspicuous, such as insulation in homes and buildings, maintaining proper acid/base (pH) conditions in paper manufacturing and food processing, waste-water treatment, and drinking-water purification. Industrial minerals are used for environmental applications ranging from sealing waste disposal sites and removing sulfur dioxide from coal-fired power plants to smaller scale, more personal, protective uses such as sunscreen lotions and condoms. Some of the environmental applications are decades and even centuries old, others have been developed recently, and still others have been proven effective by laboratory testing but have not yet been developed into commercial products or processes.

This paper reviews a range of industrial minerals and their uses in environmental protection and in the conservation of various resources, which are ultimately means of minimizing environmental insult. A specific industrial mineral may have numerous applications, and a given use may employ various industrial minerals; thus, any discussion approach, from either the minerals or the uses, must involve some repetition. Figure 1 shows their major occurrences and producers in Oregon. Figure 2 shows the major connections between these minerals and their applications. The text lists the commodities in alphabetical order; no attempt has been made to rank the by volume used, market price, or any other means.

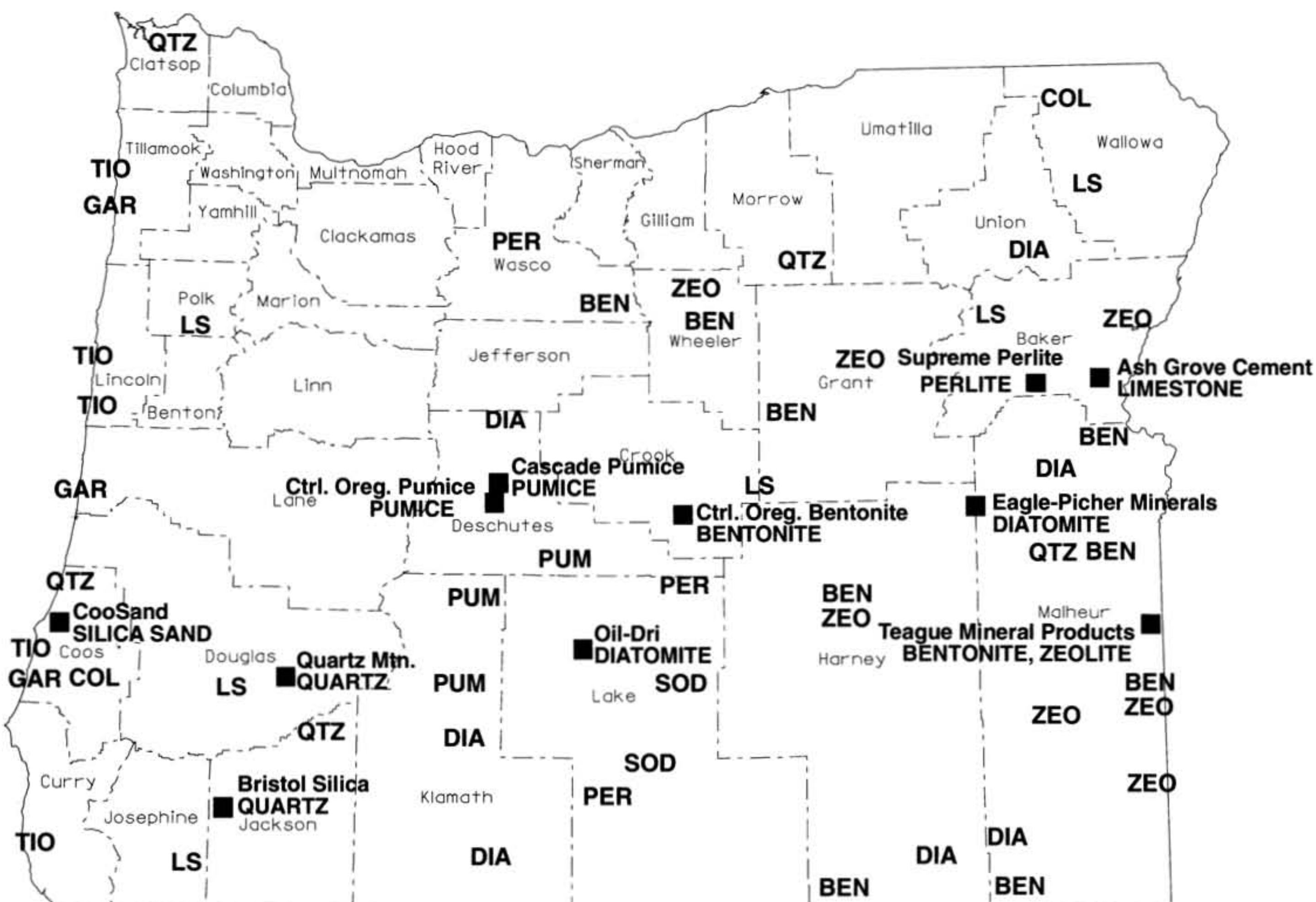

Figure 1. Producers and major occurrences in Oregon of industrial minerals with environmental applications. Producers and their products are approximately located by symbol and written out in full; other occurrences are identified by abbreviations: BEN=bentonite clay; COL=coal; DIA=diatomite; GAR=garnet in mineral sands; LS=limestone; PER=perlite; PUM=pumice; QTZ=quartz; SOD=sodium minerals from alkaline lakes and brines; TIO=titanium dioxide minerals; ZEO=zeolite, several different types.

BENTONITE CLAY

Bentonite is a type of sodium- and calcium-bearing clay that can absorb a large amount of water and swell to as much as 20 times its dry volume, forming a range of plastic solids, gels, or viscous fluids, depending on the amount of water present. It is formed by the natural alteration of beds of volcanic ash. The specific characteristics of bentonite can be modified by changing the proportions of sodium and calcium and by adding various organic polymers.

Historically, the largest use of bentonite has been in oil-, gas-, and water-well drilling, where it is circulated down the hole as a viscous mud to remove rock cuttings, cool the drill bit, prevent the hole wall from collapsing, and contain and control any fluids encountered. Increasing amounts of bentonite are being used in civil engineering—as a sealant and liner in ditches, ponds, reservoirs, building foundations, and waste disposal pits, often in conjunction with plastic liners. A small amount of bentonite mixed with soil in the pond or pit floor before it is filled swells when wet, forming a flexible, self-sealing barrier that can be tailored to specific requirements by adjustments in the amount and type of bentonite used. This barrier protects ground water against leachates from disposal sites and fluids from process pits and reduces losses from water reservoirs and irrigation ditches. Because of its high absorbency, bentonite is also used to clean up oil and gasoline spills and is a major component in many cat-litter products.

COAL

Nearly all coal is burned to produce heat, but a small amount is used as an industrial mineral in water filtration. As water flows through a bed of granular material, contaminant particles are trapped and filtered out. Smaller contaminant particles must be filtered out with smaller granules. Ideally, larger particles should be removed first to minimize clogging of the finer filter granules. A multilayered filter bed with coarser sand granules on top and finer sand granules on the bottom is a workable system—but difficult to clean without disturbing the layering. A layered and easily cleaned filter bed can be prepared with a bottom layer of fine garnet sand, a middle layer of medium-size quartz sand, and a top layer of coarse coal granules. Garnet is a heavy mineral, about four times as dense as water, quartz is about 2½ times as dense as water, and coal is only slightly heavier than water. These differences are the key to cleaning a used filter bed. Clean water pumped into the bottom of the bed stirs and mixes all the grains and flushes out the contaminant particles. When pumping is stopped, the heavy garnet sand settles to the bottom first, followed by the quartz sand, and finally the coal grains, reforming the layered filter bed.

DIATOMITE

Diatomite, or diatomaceous earth, is a powdery rock composed of the minute silica skeletons of aquatic plants that live in both marine and freshwater environments. Each skeleton is about the size of a dust particle and often resembles a finely filigreed or lacelike cage with elaborate holes and projections. This structure is a tiny sturdy sieve and a particle with very high absorbency. The filtration characteristics of each diatomite deposit vary with the species present and can be modified by heat treating. Numerous liquids are cleaned with diatomite filters for clarification, purification, and recycling. Drinking water, juices, beer, wine, vegetable oils, used motor oil, used dry-cleaning fluids, and sewage are a few examples.

Diatomite is highly absorbent and is used to clean up various liquid spills. Used by itself, diatomite can be an effective nonchemical insecticide, killing by laceration and desiccation. Insects secrete a waxy coating that prevents the loss of body fluids, but diatomite can absorb the wax faster than the insect can replace it. The sharp diatomite skeletons also work between the joints of the insect's exoskeleton, lacerating soft tissues and accelerating desiccation. Because of its absorbency, diatomite is also used as a slow-release carrier for chemical and biological insecticides such as the pyrethrins that would otherwise dissipate rapidly. The insecticides then last longer and can be applied at lower dosages.

GARNET

Garnets are a group of heavy, hard, and tough minerals that occur in various metamorphic rocks, as well as in mineral sands. The use of garnet in water-filtration systems was described above. However, the major use of garnet is as an abrasive, both on paper- and cloth-backed sheets and as air-blast abrasives (for "sand blasting"). It is in this latter application that garnet offers environmental advantages over quartz sand. Inhalation of quartz dust can cause a fatal disease, silicosis. Garnet does not present this hazard, and since it is harder and more durable than quartz, it can be reclaimed and reused repeatedly.

LIMESTONE

Limestone, calcium carbonate, typically occurs as a bedded deposit associated with other marine sediments. Roasting limestone at high temperatures produces lime (calcium oxide) and carbon dioxide. Limestone slowly dissolves in water, producing a weakly alkaline solution, while lime dissolves quickly producing a strongly alkaline solution. Both limestone and lime have long been used to neutralize acidic solutions and environments to maintain specific pH conditions for various processes. Examples include paper production, water treatment, waste-stream treatment, and neutralization of acid soil conditions to increase crop yields.

In recent years, processes have been developed to use limestone and lime in flue gas desulfurization, the removal of sulfur dioxide from the flue gases of coal-burning electric generating plants. Sulfur dioxide is a major component of acid rain. Much of the sulfur in coal, such as the iron sulfide minerals pyrite and marcasite, can be removed by various processing methods, but enough remains to form large amounts of sulfur dioxide when the coal is burned. Limestone or lime injected into the burners combines with the sulfur dioxide to form calcium sulfate, or gypsum, which is used to a limited extent in traditional gypsum markets. The United States has very large reserves of sulfur-bearing coal, and clean-air standards require increasingly lower sulfur dioxide emissions.

PERLITE

Perlite is glassy volcanic rock similar to obsidian but with about 2 to 5 percent water in its structure. Under proper heating conditions the glass softens, and the water turns to steam, causing the perlite to expand or pop, much like popcorn. The end result is a particle that is composed of tiny glass-walled bubbles, very light in weight, noncombustible, and with excellent insulating properties. Expanded perlite is used as loose fill insulation and as an insulating aggregate in concrete and in plaster products such as wallboard and ceiling tile. Milling, by grinding or crushing expanded perlite, produces material used for filter applications similar to diatomite. The most readily recognizable use of perlite is made in the form of the white beads added as an amendment in potting soil mixes to improve soil texture and aeration.

PUMICE

Pumice is a frothy volcanic rock that is often light enough to float on water. Its cellular structure, light weight, and relatively high crushing strength contribute to its use as a lightweight aggregate in cast concrete and concrete blocks. Using lightweight concrete can considerably reduce the total amount of structural material required in a building, and its insulating qualities reduce energy requirements for heating and cooling. Pumice is also used as a decorative ground cover in landscaping—to reduce or eliminate areas with plants that would require irrigation.

QUARTZ

Quartz, or silica, is one of the most common minerals in and on the Earth's crust. It occurs as veins and massive quartzite bodies as

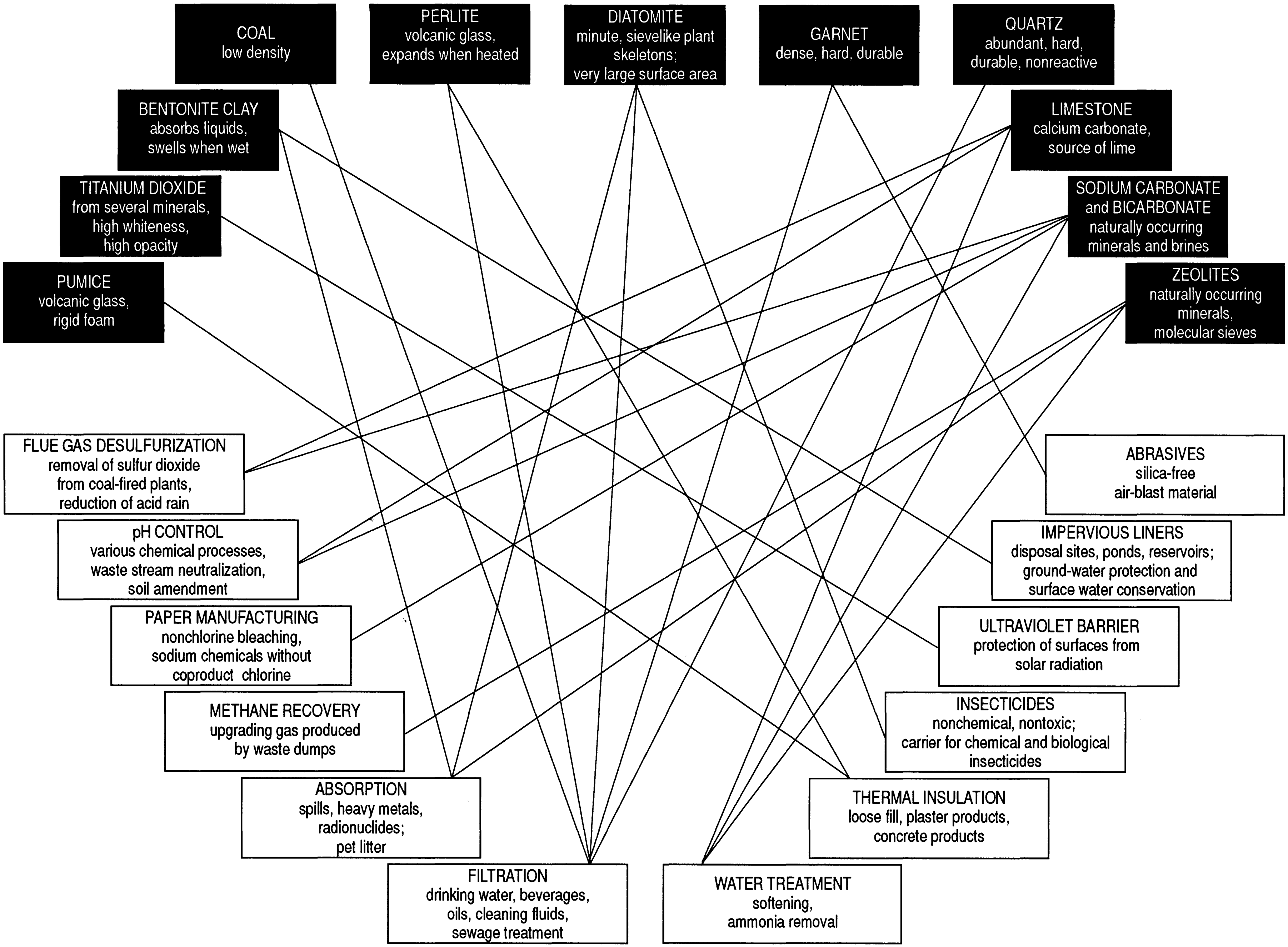

Figure 2. Examples of industrial minerals (top, shaded) used in environmental protection and resource conservation (bottom).

well as in sandstones, sand dunes, and beaches. Its principal use is in the manufacture of glass products. Quartz, both crushed and as sand, is widely used in filtration systems, where its durability and relatively low cost are major assets. Very finely ground or chemically precipitated silica is used as a filler in many plastic, rubber, and latex products—both to reduce the amount of more expensive chemicals required and to impart strength and durability. It is the presence of silica that so quickly dulls scissors used to cut plastic sheeting.

SODIUM CARBONATE

Sodium carbonate and sodium bicarbonate can be mined from bedded deposits, extracted from alkali brines, or manufactured from limestone and salt by the Solvay process. The Solvay process is very energy-intensive and produces a coproduct, chlorine, that must be marketed or otherwise disposed of. Since the United States has extensive bedded deposits as well as alkali lakes, the Solvay process is no longer used in this country.

Two major concerns of environmental protection offer a growing market for sodium carbonate and bicarbonate: flue gas desulfurization and paper manufacturing. For flue gas desulfurization, although the processes differ in specific details, sodium carbonate and bicarbonate are used in coal-fired burners in a manner similar to the use of limestone and lime. The resulting product, however, is sodium sulfate, which is a more marketable product than the limestone/lime product calcium sulfate. All four systems differ in capital and operating costs, and the one chosen for a specific plant must represent the economic and ecological optimum for that location.

Sodium chemicals are necessary for various processes in paper manufacturing. Historically, these chemicals were produced from salt (sodium chloride), and the unavoidable coproduct chlorine was used to bleach the paper as well as to produce plastics and other chemicals. However, various chemical reactions involving chlorine can generate the highly toxic dioxin family of compounds—and we know today of strong environmental reasons for reducing or eliminating dioxin production. Bleached paper can be produced without the use of chlorine; in fact, some sodium chemicals themselves can aid in bleaching. Producing sodium carbonate and bicarbonate from sodium mines and alkali brines rather than from salt avoids the generation of the coproduct chlorine, and so the use of these sources is increasing.

TITANIUM DIOXIDE

Several minerals contain titanium dioxide in sufficient quantity for commercial extraction. All these minerals are dark, hard, and chemically resistant, and these qualities make them occur commonly in black sands or mineral sands. Although these sands are a source for titanium metal as well, only about 5 percent of the production from sands is used for metal; 95 percent is used to produce titanium dioxide, a brilliantly white powder that is highly opaque to both visible and ultraviolet light. Its primary use is as an opacifying agent in paper, paints, and plastics, where it reduces the total volume of material required to produce an opaque sheet or coating. One of its conspicuous uses (or perhaps inconspicuous) is in typewriter correction fluid. The opacity of titanium dioxide to ultraviolet radiation reduces the deterioration by sunlight in paints and plastics and makes it an essential component of some sunscreen lotions.

ZEOLITES

The zeolites are a group of minerals characterized by a cagelike structure, with holes and passages whose dimensions are specific to each mineral. Zeolites readily exchange atoms (such as sodium, potassium, and calcium) in their structures for other atoms in contact with them in gases or in solution. They can also absorb gas molecules within their framework structures. Which atoms or molecules can be exchanged or absorbed is a function of their size and the size of the openings in the zeolite structure. For this reason, both naturally occurring and synthetic zeolites are referred to and function as molecular sieves. Early water-softener systems used natural zeolites to exchange sodium in their structure for calcium in hard water. Synthetic equivalents are now used. When the zeolite is fully loaded with calcium, a sodium chloride solution is flushed through the system to remove the calcium and recharge the zeolite with sodium. Synthetic zeolites that remove calcium from water are also used to replace the phosphate that is used for the same purpose in detergents.

Natural zeolites often occur as exquisite crystal clusters and fillings in the holes in lavas. However, the zeolites mined commercially occur as bedded deposits of altered volcanic ash. The properties of natural zeolites have been studied for decades, but in spite of their demonstrable utility and even occasionally exotic applications, very few deposits have been developed commercially, and the total market for natural zeolites remains small. This is due in part to the fact that synthetic zeolites can be manufactured to perform very specific tasks, although at much higher cost than natural zeolites, and in part because large-scale demand for some of the capabilities of natural zeolites has not yet developed. Considering their numerous potential applications in environmental protection, a growth in demand may not be far in the future.

Some zeolites selectively absorb nitrogen, others oxygen. An air stream passed through an appropriate zeolite bed can then be enriched in one and the zeolite in the other. This can provide a low-cost source of nitrogen gas for inert gas applications or oxygen for applications ranging from steel furnaces and sewage treatment to portable personal respirator units. A zeolite that absorbs methane is used to enrich to commercial quality the gas collected from covered solid-waste disposal sites. A zeolite that readily absorbs odors, particularly ammonia, is used in several commercial products including deodorizers for shoes, pet litter, and animal stables.

Natural zeolites can also absorb ammonia from water solutions and have been used in water-treatment systems for drinking water and aquariums and aquaculture ponds. This ammonia-absorption capability has also been beneficial in animal feed. The rate of weight gain in certain farm animals is in part dependent on the residence time of ammonia in their intestinal tracts. Zeolite in animal feed absorbs ammonia produced in the gut, slows its loss, leads to more rapid weight gains, and reduces odors at the conclusion of the process. Large volumes of zeolite could be used in feed and as treatment for feedlots and animal buildings.

Zeolites can be impregnated with fertilizers such as potash and nitrogen and then used as slow-release dispensers. Fertilizer application rates can be reduced, since the zeolites keep the nutrients in the root zone, and leaching is reduced—which both benefits the plant and decreases effluent from the fields, particularly in areas of sandy soils. Some natural zeolites selectively absorb heavy metals such as lead and zinc, and laboratory-scale experiments have demonstrated their effectiveness in reducing the heavy-metal content in mine drainage waters and reducing their availability to plants in contaminated soils.

Certain radionuclides are also absorbed and isolated by natural zeolites. Experiments in soils contaminated with radioactive cesium have shown that zeolite can markedly reduce uptake of cesium by food plants. Zeolites may also be useful in reducing the migration of radionuclides from waste disposal sites and from both contaminated surface sites and ground water.

CONCLUSION

All of the industrial rocks and minerals described above occur in Oregon. Some are currently produced for various end uses, including environmental applications; others, including bentonite and zeolite, are mined specifically for environmental-protection markets, and still others are not yet explored or developed.

Environmental protection and environmental cleanup are increasingly necessary activities. As standards are raised and stricter regulations are enacted, certain industrial minerals must be mined in greater volumes to both minimize environmental degradation and mitigate existing hazards. As with all natural-resource-based industries, the social and economic benefits of mining any commodity must be weighed in part against its environmental cost. The environmental costs of mining minerals for environmental protection must be viewed in terms of their environmental benefits.

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IN MEMORIAM

Harold J. Buddenhagen (1903-1991)

By Parke D. Snavely, Jr., Menlo Park, California, and Grant M. Valentine, Olympia, Washington

Harold Johnson "Bud" Buddenhagen passed away on November 3, 1991, at his ranch on Murphy Creek Road in southwestern Oregon.

Bud was born August 23, 1903, in Springfield, Illinois. He married the former Pearl (Pat) Marie Masteller of Selby, South Dakota, on March 15, 1928, in Hollywood, California. After graduating from Stanford University, he joined Shell Oil Company in 1926 as a petroleum geologist. He worked for Shell for 29 years in various western states, as well as in Venezuela for three years, and in the Netherlands at Shell headquarters in the Hague for 17 months.

After his retirement from Shell Oil Company in 1955, Bud and his family lived on Murphy Creek Road in southwestern Oregon on a ranch he and Pat had purchased in 1938. During 1970 and 1971, he and Pat traveled in a Volkswagen bus throughout Europe, the former Soviet Union, and Africa. Working out of the ranch, Bud consulted nationally and internationally for several major oil companies. He also was employed part-time with the Oregon Department of Geology and Mineral Industries to map the structurally complex geology of the John Day uplift in east-central Oregon. Bud relished this challenging assignment because it provided him an opportunity to apply his considerable expertise to unravel the tectonic and stratigraphic framework of this poorly exposed, faulted, and folded terrane that involves rocks ranging in age from Devonian to Cretaceous. Bud's geologic maps of this complex terrane are exceptionally detailed, with stratigraphic sections provided for each well-exposed outcrop. To constrain his formational contacts in areas covered by screens of colluvium, he enlisted the aid of his sons, John and James, to dig holes to the bedrock. In a 1967 report, Bud briefly described the lithostratigraphic units in the John Day uplift and stated that "deciphering the geology of this Paleozoic area is akin to working a jigsaw puzzle with many of the pieces missing." Despite constraints of poor exposures, faulted contacts, and chaotically intermixed volcanic and sedimentary rocks, Bud produced his exceedingly detailed geologic map of the Suplee-Izee area. This map was included in the compilation of the new geologic map of Oregon, filling a significant void in our knowledge of the geologic framework of east-central Oregon. Drafted copies of the geologic maps are kept at the Oregon Department of Geology and Mineral Industries in Portland, Oregon.

Bud's love affair with nature and geology found a common ground on his ranch along Murphy Creek on the north side of the Siskiyou Mountains of southwestern Oregon. For his last 35 years, he was fortunate to live with his beloved wife, Pat, in this forest-covered countryside that he enjoyed so much. Bud is survived by his wife; a daughter, Barbara Winkelstein of San Francisco, California; three sons, Ivan of Davis, California; John of Alcan, Alaska; and James of University city, Missouri; his dear sister, Kathryn Wilson of Oakland, California; and 15 grandchildren and one great-grandson, who added much joy to his life.

Harold Buddenhagen will be remembered by his friends here and abroad for his steadfast dedication to the geologic profession, his independent attitude and contagious sense of humor, and his unwavering pursuit of excellence. He was a member of the American Association of Petroleum Geologists and the Geological Society of America.

Bud's family and friends suggest a memorial contribution be made to the American Cancer Society.

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THESIS ABSTRACTS

The Department 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.

Subsurface and geochemical stratigraphy of northwestern Oregon, by Olga B. Lira (M.S., Portland State University, 1990), 97 p.

Lithological, geophysical, paleontological, and geochemical methods were used in order to define the contact relationship between the Keasey and Cowlitz Formations in northwestern Oregon. Drill cuttings from six wells located in Columbia County were analyzed by the Instrumental Neutron Activation Analysis (INAA) method. The concentrations of K, Th, Rb, and the Sc/Co ratio in the samples established four different groups: (1) High K, Rb, and Th, with low Sc/Co ratio, typical of Cowlitz sediments. (2) Low K, Th, and Rb and high Sc/Co ratio, more characteristic of the Keasey Formation. (3) Very low concentrations of Rb and high Sc, which is indicative of basaltic volcanism. (4) Vertically varying K, Th, and Rb concentrations. The provenance of group four is uncertain, but it may represent reworked sediments or the interfingering of the Keasey and Cowlitz Formations. Plots of these elements vs. depth define the geochemical contacts between the formations.

The contact was also determined by interpretations of geophysical logs, the gamma ray log being the most useful. This log responds to chemical differences between the Cowlitz and Keasey Formations or local volcanic sediments. The apparent interfingering of the two formations is observed in wells drilled off the Nehalem arch. In the upper part of the arch, the Cowlitz Formation has been eroded. Therefore, the contact between the Cowlitz and Keasey Formations can be defined as conformable where they apparently interfinger and as unconformable where erosion or nondeposition is evident.

The contact between the Keasey and Cowlitz Formations, as interpreted from the geochemical data and gamma ray logs, is the same, and both data sets seem to reflect a lithologic break. However, the paleontological time boundary between the Refugian and Narizian stages does not in all the wells coincide with the formational boundary but occurs within the Keasey Formation. Therefore, Keasey Formation was deposited during both Narizian and Refugian time. In localities where the geochemical, paleontological, and lithological contacts coincide an unconformity is defined.

Late Quaternary tectonic development of the northwestern part of the Summer Lake Basin, south-central Oregon, by Gary D. Simpson (M.S., Humboldt State University, 1990), 121 p.

The Summer Lake basin is an extensional graben forming in the High Lava Plains of south-central Oregon, along the northwestern boundary of the Basin-and-Range province. The basin was occupied in the Pleistocene by pluvial Lake Chewaucan. Structure of the northwestern part of the basin is defined by three distinct fault sets: northwest-trending faults, the Winter Rim fault system, and a set of arcuate offsets within the volcanic highlands immediately north of the Summer Lake basin.

Cross-cutting relations with the other fault sets suggest that the northwest-trending faults are the oldest faults in the region. Available relations with Quaternary deposits demonstrate that these faults are largely inactive.

The Winter Rim system is defined by the main east-facing escarpment that forms Winter Rim and by numerous scarps at the base of the rim (Jacks Lakes, Summer Lake, and White Rock segments). The White Rock segment of the Winter Rim system offsets late Pleistocene or Holocene alluvial deposits and forms a strong photo lineament with the Jacks Lakes segment. The Jacks Lakes fault offsets shallow lacustrine deposits.

Stratigraphy in a fault-bounded depression within the arcuate pattern north of the Summer Lake basin suggests that sedimentation (and therefore development of the arcuate complex) was initiated between approximately 60 and 120 ka. Block reconstruction across this arcuate system suggests that the faults formed in a setting analogous to the head scarp of a landslide, as individual blocks of the Picture Rock basalt slid or toppled toward the encroaching extensional graben (i.e., the Summer Lake basin). These blocks may be sliding along a relatively shallow porous tuff layer.

Sediments within the northwestern part of the Summer Lake basin were extensively deformed 12-19 ka. Compressional folding and thrust faulting of the lacustrine sediments indicate a widespread compressional stress event that affected post-19 ka strata while the sediments were under saturated conditions. Because Lake Chewaucan presumably dried up about 12 ka, the age of the deformational episode must have occurred between 12 and 19 ka. Deformation occurs in localized areas as small- to large-scale isoclinal (often recumbent) folds and thrust features. Deformation often occurs along discrete bedding planes, often overlying (or sandwiched between) undeformed layers. Silt layers typically responded in a fluid, ductile manner, while intercalated tephra layers behaved plastically or brittlely.

Recent compression of valley fill sediments in a predominantly extensional environment is difficult to explain. Attitudes of exposed structures suggest that the compressive stresses may have been generated along the northern Winter Rim range front. Soft-sediment deformation resulting from a faulting event of the northern Winter Rim range front may be the mechanism that displaced the saturated sediments in the northwestern part of the basin. In any case, the sediments, which had remained submerged for over 300,000 years, were uplifted wihtin the past 19,000 years and exposed to weathering and dissection by the Ana River.

The petrologic evolution of the Holocene magmatic system of Newberry volcano, central Oregon, by Scott R. Linneman (Ph.D., University of Wyoming, 1990), 293 p.

This study tests the hypothesis that the bimodal basalt-rhyolite Newberry volcanic suite of central Oregon was formed by a combination of repeated, small-volume, mafic magma injections into the crust and by subsequent crustal partial melting. During the Holocene at Newberry, basaltic andesite lavas were erupted on the flanks, whereas rhyolitic tephras and lavas were erupted within the summit caldera. No simple model of fractional crystallization, single-component assimilation, or two-component mixing can account for the chemical variations observed in the Holocene mafic lavas. Rather, the data require that at least two very different components were assimilated by the parental basaltic andesite. The linear compositional trends were produced by assimilation of silicic material, either evolved crust or rhyolitic liquid. The isotopic characteristics of the suite were strongly influenced by a Sr-rich, radiogenic component, possibly a local sediment. The Holocene mafic lavas reflect the compositional variety of the upper crustal lithologies at Newberry.

Petrologic details from the Holcene rhyolites provide a compelling case for the existence, during the Holocene, of small, short-lived, possibly unconnected reservoirs of silicic crustal melts. These include (1) the lack of temporal correlations of geochemical variables, (2) possible geographic correlations of geochemical and isotopic variables, (3) physical evidence of crustal melting, (4) the lack of evidence connecting bimodal end members, and (5) evidence that the rhyolitic liquid(s) were superheated.

Physical evidence for a complex scenario of assimilation occurs within the Holocene lavas as mingled lavas and magmatic inclusions. The textural features and mineral compositions of the mingled lavas indicate xenocryst formation by (1) shear-induced folding of the silicic portion into the mafic portion and (2) mafic magmatic inclusion formation and subsequent disaggregation. The characteristics of the mafic magmatic inclusions of the caldera rhyolites can be explained by the mechanical disaggregation of larger, semi-rigid inclusions trapped in the BOF rhyolitic magma. Therefore, the coarse-grained inclusions are not petrologically significant cumulates.

Newberry volcano of central Oregon and Medicine Lake volcano of northern California have remarkable similarities, which suggests that the dominant petrologic processes acting at the two volcanoes are the same. Primitive high-alumina basalt is allowed into the upper crust by frequent episodes of extension associated with the volcanoes' location behind the Cascade volcanic arc. As an alternative to the widely accepted model of single, large, long-lived magma chambers, I propose that bimodal igneous suites are produced by repeated injection of small volumes of mafic magma into the crust. These small-volume bodies cause localized partial melting of the crust. In this manner, silicic magmas are generated in a series of small, nonconnected reservoirs. Evolved lavas erupted within a given volcanic system over a short time period may, therefore, be related only by their common anatectic origin, and their compositional and isotopic characteristics reflect preexisting crustal variability. □

AGI offers book on field safety

The American Geological Institute (AGI) has published a new book on safety for field geologists, campers, hikers—anybody who needs familiarity with the hazards of the outdoors and information about how to be prepared for and face these hazards.

Planning for Field Safety, AGI publication item no. 308, ISBN 0-913312-93-2, 197 p., soft cover, $14.95 plus $4.00 shipping and handling charges. Volume discounts are available for 10 or more copies. Orders may be mailed to AGI Publications Center, P.O. Box 205, Annapolis Junction, Maryland 20701, or phoned to (301) 953-1744.

The book will also be sold at the Nature of Oregon Information Center of the Oregon Department of Geology and Mineral Industries in Portland. See the ordering information on the back cover of this issue.

Planning for Field Safety describes hazards and pitfalls one may encounter in the field, suggests ways to avoid them, and tells what to do if they occur. It does so in well-organized, mostly brief sections and subsections (including some checklists), so that it is easy to find items even without the help of the very useful index at the end.

The introduction's announcement to deal with "the more common" hazards is somewhat of an understatement. The ten chapters cover a considerable range: from planning before the trip (e.g., weather, equipment, medicine, food, regulations for employees) to field risks (e.g., marijuana growers, contaminated food, pack animals, oceanic research vessels, thunderstorms, bears, spiders, poisonous plants), to particular regions (e.g., urban environment, high altitudes, tundra, tropics, caves, foreign countries) to emergency and evacuation procedures, instructions to group leaders, and how to ship rock samples. An appendix listing sources of information includes both printed materials and addresses of important agencies and organizations.

Even the brief description in the preface of how this book came into existence is impressive. □

New publications from DOGAMI describe geology of part of Jackson County and northwestern Oregon to margin of continent

The Oregon Department of Geology and Mineral Industries (DOGAMI) has released two new publications: a quadrangle map for a part of Jackson County and a cross section for a strip of land extending west from Columbia County to the continental margin offshore.

Geology and Mineral Resources Map of the Boswell Mountain Quadrangle, Jackson County, Oregon, by Thomas J. Wiley and Frank R. Hladky. DOGAMI Geological Map Series GMS-70, one full-color geologic map, scale 1:24,000, one separate sheet with geochemical data. Price $7.

The Boswell Mountain quadrangle is located north of Medford and covers a region with a history of significant mining activity. It contains areas with some of Oregon's oldest rocks (more than 145 million years) as well as the western edge of the Western Cascade Range.

The geologic map is accompanied by a geologic cross section and brief discussions of geologic history and mineral and water resources. A separate sheet contains four tables listing geochemical data.

This map is the first of a series of maps planned to provide hazard and mineral-resource data as well as bedrock geology to aid regional planning in the Medford-Ashland area, which is experiencing rapid population growth. Two more quadrangle maps, Cleveland Ridge and Shady Cove, are nearing completion and are available for inspection at the DOGAMI field office in Grants Pass (5375 Monument Drive, phone (503) 476-2496).

Onshore-Offshore Geologic Cross Section, Northern Oregon Coast Range to Continental Slope, by A.R. Niem, N.S. MacLeod, P.D. Snavely, Jr., D. Huggins, J.D. Fortier, H.J. Meyer, A. Seeling, and W.A. Niem. DOGAMI Special Paper 26, 10 pages, one plate, geology at scale 1:100,000. Price $11.

The geologic cross section is constructed along a line that begins in Columbia County, crosses the Coast Range, and extends offshore across the continental shelf and slope, for a distance of about 80 miles from the coast. It presents an important perspective on structure and other aspects of regional geology.

Along with the cross section, the 5- by 3½-foot sheet includes gravity and magnetic profiles and a geologic strip map for the onshore portion as well as both onshore and offshore seismic reflection profiles. The accompanying 10-page text discusses stratigraphy and structure of the area the section line crosses.

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MAJOR MINERAL EXPLORATION ACTIVITY

County, date	Project name, company	Project location	Metal	Status
Baker 1990	Cracker Creek Mine Bourne Mining Corp.	T. 8 S. R. 37 E.	Gold	Expl
Baker 1991	Aurora Ridge Western Cons. Mines	T. 10 S. Rs. 35.5, 36	Precious metals	Expl
Baker 1991	Cave Creek Nerco Exploration	Tps. 11, 12 S. R. 42 E.	Gold	App
Baker 1991	Gold Hill Golconda Resources	T. 12 S. R. 43 E.	Gold	App
Baker 1991	Gold Powder Kennecott Expl. Co.	Tps. 9, 10 S. Rs. 41, 42 E.	Gold	Expl
Baker 1991	Gold Ridge Mine Golconda Resources	T. 12 S. R. 43 E.	Gold	Expl
Baker 1992	Pole Creek Placer Dome U.S.	T. 13 S. R. 36 E.	Gold, silver	Expl
Baker 1992	Bigelow prospect Yellow Eagle Mining	T. 7 S. R. 45 E.	Gold	Expl
Coos 1991	Seven Devils Oreg. Resources Corp.	Tps. 2, 7 S. R. 4 W.	Chromite, zircon	Expl com
Crook 1988	Bear Creek Independence Mining	Tps. 18, 19 S. R. 18 E.	Gold	Expl
Curry 1992	Mindoro Project Mindoro Corporation	T. 36 S. R. 12½ W.	Precious metals	Expl
Grant 1991	Buffalo Mine American Amex	T. 8 S. R. 35½ E.	Gold	App
Grant 1992*	Quartzburg Placer Dome U.S., Inc.	T. 12 S. R. 33 E.	Precious metals	Expl
Harney 1990	Pine Creek Battle Mtn. Exploratn.	T. 20 S. R. 34 E.	Gold	Expl
Harney 1991	Flagstaff Butte Noranda Exploration	Tps. 3, 9 S. R. 37 E.	Gold	App
Harney 1992	Celatom Mine Eagle-Picher Minerals	Tps. 19, 20 S. Rs. 35-37 E.	Diatoms	App
Jackson 1991	Al Sarena Project Fischer-Watt Gold Co.	T. 31 S. R. 2 E.	Gold	App
Josephine 1992	Eight Dollar Mountain Doug Smith	T. 38 S. R. 8 W.	Gold	Expl
Lake 1988	Quartz Mountain Wavecrest Resources.	T. 37 S. R. 16 E.	Gold	Expl
Lake 1990	Glass Butte Galactic Services	Tps. 23, 24 S. R. 23 E.	Gold	Expl
Lake 1991	8th Drilling Series Wavecrest Resources	T. 37 S. R. 17 E.	Gold	Expl
Linn 1991	Hogg Rock Oreg. St. Highw. Div.	T. 13 S. R. 7½ E.	Rock	App
Linn 1991	Quartzville Placer Dome U.S.	T. 11 S. R. 4 E.	Gold, silver	App
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Malheur 1988	Jessie Page M.K. Gold Co.	T. 25 S. R. 43 E.	Gold	Expl
Malheur 1988	Kerby Malheur Mining	T. 15 S. R. 45 E.	Gold	Expl, com

MAJOR MINERAL EXPLORATION ACTIVITY (continued)

County, date	Project name, company	Project location	Metal	Status
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Malheur 1990	Ali/Alk Atlas Precious Metals	T. 17 S. R. 45 E.	Gold	Expl
Malheur 1990	Cow Valley Butte Cambiex USA, Inc.	T. 14 S. R. 40 E.	Gold	Expl
Malheur 1990	Freezeout Western Mining Corp.	T. 23 S. R. 42 E.	Gold	Expl
Malheur 1990	Goldfinger Site Noranda Exploration	T. 25 S. R. 45 E.	Gold	Expl
Malheur 1990	Grassy Mtn. Regional Atlas Precious Metals	T. 22 S. R. 44 E.	Gold	Veg
Malheur 1990	Katey Claims Atlas Precious Metals, Inc.	Tps. 24, 25 S. Rs. 44, 46 E.	Gold	Expl
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Malheur 1991	Sagebrush Gulch Kennecott Exploration	Tps. 21, 22 S. R. 44 E.	Gold	App
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Explanations: App=application being processed. Expl=Exploration permit issued. Veg=Vegetation permit. Com=Interagency coordinating committee formed, baseline data collection started. Date=Date application was received or permit issued. *=New site

Major mineral exploration activity

No major changes in mineral activity have taken place since the May issue of *Oregon Geology*.

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