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*Oregon Geology* is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Manuscript contributions are invited on both technical and general-interest subjects relating to Oregon geology. Two copies of the manuscript should be submitted. If manuscript was prepared on common word-processing equipment, a file copy on diskette should be submitted in place of one paper copy (from Macintosh systems, high-density diskette only). Graphic illustrations should be camera ready; photographs should be black-and-white glossies. All figures should be clearly marked; figure captions should be together at the end of the text.

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

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, letters, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office (address above).




## Cover photo

Aerial view of rockfall that occurred on Oregon's coastal Highway 101 about 2 mi north of Manzanita in Tillamook County on October 23, 1994. A second rockfall scar, to the right (south), is from a rockfall in January 1994. The events that originated in highly jointed Miocene gabbro both caused extended closures of the highway and hundreds of thousands of dollars in damage.

The Oregon Department of Transportation initiated an intensive evaluation of the stability of the section of the road cut that includes the rockfall sites and is between 80 and 200 ft high. A staged mitigation program was developed: Preliminary rock scaling (removal of loose rock) was performed immediately, and a comprehensive hazard reduction program is proposed for late 1995. Oregon Highway Division photo by Bergman Photographic Services, Portland. Photo and text courtesy Dan Meier, Woodward-Clyde Consultants, Portland.

## Information center expanded

The Nature of the Northwest Information Center, operated jointly by the State of Oregon natural resource agencies and the USDA Forest Service, opened on December 5, 1994, on the first floor of the State of Oregon Office Building at 800 NE Oregon Street in Portland. It replaces the Nature of Oregon Information Center, which had been operating at the 800 NE Oregon Street location since 1992. Hours of the new center are 8:00 a.m. to 5:00 p.m. on weekdays. The phone number is 503-872-2750, and fax number is 503-731-4066.

Numerous publications, including a wide selection of maps, books, and brochures designed to enhance an experience in the great outdoors, are available at the Center. An expanded staff is available to respond to phone, fax, and mail inquiries."Visitors to the new Nature of the Northwest Information Center are able to obtain a vast range of information about natural, cultural, and outdoor recreational resources in Oregon and Washington in a centrally located, 'one-stop shopping' environment," says John Lowe, Regional Forester, USDA Forest Service.

Located centrally in Portland near Interstate Highways I-5 and I-84 and the 7th Ave. stop of MAX, three blocks east of the Convention Center, and three blocks south of the Lloyd Center, the Nature of the Northwest Information Center is ideally situated to serve both Oregonians and visitors to the area. "This partnership between the USDA Forest Service and the State of Oregon enables us to serve our customers more efficiently," says Don Haines, manager of the Nature of the Northwest Information Center, who anticipates adding new services to the center because of the partnership. □

## Madin transferred to Baker City office

Ian P. Madin, Earthquake Geologist for the Oregon Department of Geology and Mineral Industries (DOGAMI), has been transferred from the Portland area to DOGAMI's field office in Baker City. He began his new duties in Baker City on November 21. Madin spearheaded DOGAMI's early work with Metro to alert Oregonians to the potential hazards posed by earthquakes and helped develop the DOGAMI program for determining relative earthquake hazards based on liquefaction, ground motion amplification, and slope stability. He will be using his considerable expertise on earthquakes to round out DOGAMI's earthquake program in eastern Oregon, which covers two-thirds of the state. He will be working with Mark Ferns, DOGAMI's Baker City Regional Geologist, to map and identify faults in eastern Oregon.

In addition to his new duties, Madin will continue to perform as part of DOGAMI's earthquake team. Work in western Oregon will be continued by DOGAMI's earthquake specialists Matthew Mabey, Mei Mei Wang, and Jerry Black, who are currently completing relative earthquake hazard maps for the Portland area, conducting relative earthquake hazard studies in the Salem area, and completing catastrophic earthquake hazard studies in the greater Siletz Bay area along the coast. George Priest is spearheading cooperative assessments of tsunami risk along the Oregon coast. □

## BLM State Office moved to new location

The Bureau of Land Management Oregon/Washington State Office has moved to the 1515 Building at 1515 SW 5th Avenue between Clay and Market Streets in downtown Portland. Parking is available for visitors on the first floor of the parking garage located within the building, and members of the public can receive parking validation in the public room located on the 7th floor. Mail should be addressed as before to P.O. Box 2965, Portland, OR 97208-2965. For further information, call BLM's public information line at (503) 952-6002, the public room at (503) 952-6001, or public affairs at (503) 952-6027. □

# Magnitude and frequency of subduction-zone earthquakes along the northern Oregon coast in the past 3,000 years

*by Mark E. Darienzo and Curt D. Peterson, Department of Geology, Portland State University, P.O. Box 751, Portland, Oregon 97207*

**ABSTRACT**

Similarities in number, depth, sequence stratigraphy, and radiocarbon ages characterize buried peats of seven estuaries along 175 km of the northern Oregon coast. We use these peats to infer the extent of earthquake-induced subsidence, earthquake magnitudes, and average recurrence intervals for late Holocene earthquakes at the Cascadia Subduction Zone. Synchroneity of earthquake-induced subsidence from Alsea Bay to the Necanicum River over a coastal distance of 175 km is inferred most confidently for the most recent (first) event and the third through sixth events. In contrast, earthquake-induced subsidence for the second event was lacking in at least three of the seven estuaries. However, tsunamis generated by the second event deposited sands in the unsubsided estuaries. Therefore, the second event is also considered synchronous between Alsea and Necanicum. A segment boundary between Yaquina and Netarts is inferred for the second event.

From these findings of synchroneity, we estimated the length of rupture for the late Holocene earthquakes. The corresponding magnitudes are at least 8.0, based on a rupture length of 175 km, a rupture width of at least 60 km, an average recurrence interval of 400 years, an average convergence rate of 4 cm/yr, and a shear modulus of $3x10^{11}$ dynes/cm$^2$. Using a range of convergence rates (3.5–4.5 cm/yr) and average recurrence intervals (300–500 years), rupture lengths (105–175 km), and rupture widths (60–90 km), calculated magnitudes for five of the last six earthquakes are greater than 8.0 for the central 175 km of the Cascadia Subduction Zone.

Average recurrence intervals between earthquakes for the estuaries on the northern Oregon coast range between 200 and 600 years. The wide range is due to the uncertainties associated with radiocarbon ages. Although more accurate recurrence intervals are desirable, these average recurrence intervals provide a useful estimate for assisting coastal communities with their disaster planning and for determining probabilities for future subduction-zone earthquakes off the northern Oregon coast.

## INTRODUCTION

In the past ten years, several geophysicists have called attention to the potential for great earthquakes (greater than magnitude 8) related to the Pacific Northwest subduction-zone known as the Cascadia Subduction Zone (Heaton and Hartzell, 1987; Savage and Lisowski, 1991; Hyndman and Wang, 1993) (Figure 1). Although there have been large (up to magnitude 7.5) earthquakes in the region during historic times (last 150 years), there is no historical record of Pacific Northwest subduction-zone earthquakes, which are often greater than magnitude 8—with the possible exception of the 1992 Cape Mendocino earthquake (G. Carver, personal communication, 1994). However, evidence for subduction-zone earthquakes in the late Holocene has been found in the deposits of coastal wetlands of estuaries in British Columbia, Washington, Oregon, and northern California (Atwater, 1987, 1992; Darienzo and Peterson, 1990; Peterson and Darienzo, 1991; Clarke and Carver, 1992; Nelson, 1992a; Clague and Bobrowsky, 1994; Darienzo and others, 1994).

Now that subduction-zone earthquakes have been recognized in the stratigraphic record, questions arise as to what are the magnitudes of these Holocene earthquakes and the frequency with which they occur. Knowledge of the magnitudes and frequency is necessary to calculate the probability of the next earthquake and to help communities with disaster planning and the building of new and upgrading of existing structures.

In this study, we compare the stratigraphy and associated radiocarbon ages of seven estuaries along the northern Oregon coast: at Alsea Bay, Yaquina Bay, Siletz Bay, Nestucca Bay, Netarts Bay, Ecola Creek, and Necanicum River—an along-coast distance of 175 km (Figure 1). We selected these estuaries because we have made detailed studies of marsh stratigraphy at each of them. Results have been published for Alsea by Peterson and Darienzo (1991); for Netarts by Darienzo and Peterson (1990) and Darienzo (1991); for Yaquina, Siletz, Nestucca, and Necanicum by Darienzo (1991), Darienzo and others (1993), and Darienzo and others (1994); and for Ecola by Gallaway and others (1992). Stratigraphic patterns and radiocarbon ages were used to calculate possible ranges for paleomagnitudes and average recurrence intervals. These results can potentially be compared with similar patterns and ages of paleoseismic events recorded in estuaries of other segments of the Cascadia Subduction Zone.

## ESTIMATION OF MAGNITUDE

### Establishment of event synchroneity

We used the late Holocene stratigraphic records in individual estuaries to assess the synchroneity of the paleoearthquakes among the estuaries along the northern Oregon coast. In this study, we examined and compared the following stratigraphic patterns in the paleoseismic record: the number and stratigraphic location of inferred tsunami deposits and the number, age, and stratigraphic position (depth) of earthquake-buried peats recorded within a specific period of time. If the events are synchronous, the magnitudes of the Holocene earthquakes can be estimated for rupture segments of at least the length of the northern Oregon coast. Synchroneity of coseismic events between estuaries provides information on the length of earthquake rupture along the coast. Therefore, the rupture length, as determined by synchroneity of events, would be a key parameter in paleomagnitude determinations. Formulas that use rupture length (coastline distance of event synchroneity) and estimates of rupture width and seismic slip could then be used to describe paleoearthquakes (Kanamori, 1977; Abe, 1981, 1984; Rogers, 1988; Byrne and others, 1990; Geomatrix, 1993).

A possible alternative to synchroneity of events along the northern Oregon coast is segmentation. In other words, ruptures occur along smaller segments of the locked subduction zone at different times, producing earthquakes of lesser coastline extent and magnitude. For example, a pair of earthquakes off Japan in the Nankai Trough resulted from rupture of adjacent segments in 1944 and 1946, while the 1707 Nankai Trough earthquake resulted from rupture of both segments simultaneously (Ando, 1975). The use of prehistoric dating, no matter how sensitive the dating technique, could not conclusively prove earthquake synchroneity because of the range of possible ages associated with conventional radiocarbon (±100 yrs), high-precision radiocarbon (±10 years), or dendrochronology (±10 years) (Yamaguchi and others, 1989). However, synchroneity of the 300-yr-B.P. (before present) paleoseismic event between widely separated estuaries is suggested by similarities between high-precision radiocarbon ages and tree-ring ages of buried trees in coastal wetlands of Washington, Oregon, and northern California (Yamaguchi and others, 1989; Atwater and others, 1991; Carver and others, 1992; Nelson and Atwater, 1993). Further evidence for synchroneity has come from similarities in stratigraphic patterns of marsh deposits. For example, Atwater (1992) inferred correlations largely on the basis of appear-

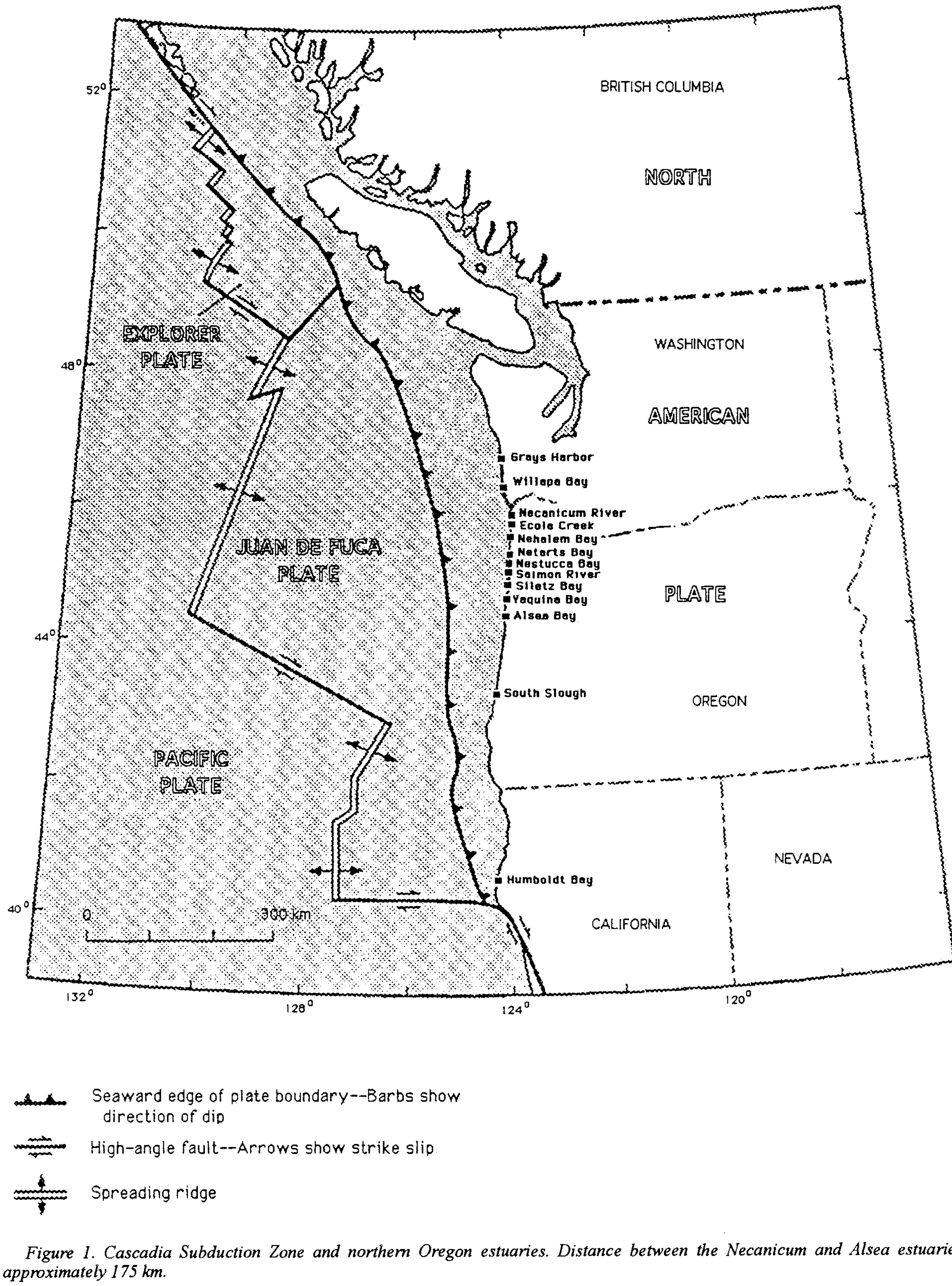


*Figure 1. Cascadia Subduction Zone and northern Oregon estuaries. Distance between the Necanicum and Alsea estuaries is approximately 175 km.*

ance and stratigraphic position of buried soils among estuaries on the southern Washington coast.

Other stratigraphic criteria, such as the number and position of tsunami sands, might also be useful in synchroneity determinations. If the northern Oregon coast ruptured as one segment during the earthquakes, one would expect a one-to-one correspondence of buried peats to overlying tsunami deposits and a similar number of tsunami deposits within each of the individual estuaries. If the northern Oregon coast ruptured in smaller segments, then some estuaries should contain more tsunami sand layers than buried peats, because tsunamis produced in adjacent ruptured segments would propagate to unruptured segments and deposit sands in estuaries that did not experience coastal subsidence. In contrast, if all of the estuaries contained only one tsunami layer for each recorded subsidence event, then there would be no evidence for segmentation of the margin (Peterson and Darienzo, 1991). However, earthquakes that occur less than one year apart and in adjacent segments would be difficult to tell apart in the geologic record. Marsh plants might not have become sufficiently reestablished above the tsunami sand to leave a peat record prior to deposition of the next tsunami sand. In estuaries with slow sedimentation rates, sediments may take decades to accumulate in sufficient quantities to be distinguishable in the stratigraphic record and thus allow differentiation between separate tsunamis. Therefore, the two events might not be sufficiently distinguishable to indicate segmentation. In summary, a similar number of tsunami sands and a one-to-one correspondence of tsunami sands with peats (buried due to coseismic subsidence and postseismic sedimentation) in several estuaries suggests synchroneity of earthquakes among adjacent estuaries.

### Calculating paleomagnitude

We estimated earthquake magnitudes in two ways. First, we estimated the moment magnitude (MW) of an earthquake by using the equation $M_W = 2/3 \times \log_{10} M_O - 10.7$ (equation 1) (Kanamori, 1983). $M_O$ is the seismic moment and is equal to the product of the area of rupture, the amount of slip along the fault, and a constant called the shear modulus, which is a measure of a rock's ability for or resistance against deformation when stressed. We assumed a shear modulus of $3 \times 10^{11}$ dynes/cm$^2$, a value used to calculate the magnitude of the 1960 Chilean and 1964 Alaskan subduction-zone earthquakes (Kanamori and Anderson, 1975). Second, we used the equation $M = \log A + 3.99$ (equation 2), where A is the area of rupture (Abe, 1981, 1984).

To use both magnitude equations, we made further assumptions:

(1) Equation 1 requires an average slip per event that can be estimated from recurrence intervals of coseismic subsidence events and the rate of convergence (approximately 4.0 cm/yr) of the Juan de Fuca plate with the North American plate (Riddihough, 1977). For the calculations in this paper, we assumed the seismic slip to be 90 percent of the total, with the remaining 10 percent considered aseismic (Rogers, 1988).

(2) Both equations require a rupture width that comes from (a) other subduction zones that have characteristics similar to the Cascadia Subduction Zone (approximately 100 km, according to Rogers, 1988) or (b) estimated rupture widths for the Cascadia Subduction Zone. Savage and Lisowski (1991) estimated a rupture width off the northern coast of Washington of at least 100 km. A two-dimensional dislocation fit model of coseismic vertical movement for the central Cascadia Subduction Zone was run by J. Savage (U.S. Geological Survey, Menlo Park, California), who used subsidence estimates of marsh burial events from northern Oregon and calculated a rupture width of 90 km for Oregon (Peterson and others, 1991). Clarke and Carver (1992) estimated a rupture width of 70–80 km for the Gorda segment of the Cascadia Subduction Zone. Hyndman and Wang (1993) estimated a 70-km locked zone for Oregon on the basis of predicted temperatures on the thrust plane. Finally, in central Oregon a locked zone of 60 km was estimated, in one case by use of a change in orientation of upper plate deformation on the Oregon continental margin (outer edge of the locked zone) (Goldfinger and others, 1992) and in another case on the basis of an apparent position of the zero isobase at the coast (inner edge of the locked zone) (Peterson and Darienzo, 1991). The 60-km locked zone is thought by these authors to represent the minimum rupture width for a Cascadia Subduction Zone earthquake occurring off the northern Oregon coast. Therefore, from the above information, an approximate rupture width would range from 60 km to 90 km for the northern Oregon coast.

## FREQUENCY OF EARTHQUAKES

In this study, we used radiocarbon ages of samples taken from the stratigraphic record of earthquakes in seven estuaries on the northern Oregon coast to calculate average recurrence intervals for Holocene earthquakes in the last 3,000 years (Figure 2). In calculating the average recurrence intervals for each estuary, we used only the last six inferred earthquakes in each estuary, because the preservation potential of buried peats diminishes over time, due, in part, to erosion by migrating tidal and river channels. The age of the youngest buried peat was subtracted from the age of the oldest buried peat and divided by the number of intervals between the oldest and youngest events. For example, if the oldest buried peat yielded a radiocarbon age of 3,000 years B.P. and the youngest 300 years B.P. and there were five intervals in between, then the average recurrence interval is 540 years.

The actual age of each buried peat falls within a range of values based on two standard deviations (2 $\sigma$), a range in which there is a 95-percent chance that the age of the peat falls within that range. Therefore, the average recurrence intervals will also fall within a range of values. We used an error multiplier of two to insure that the actual radiocarbon age of the buried peat is included within the range of values (B. Atwater, personal communication, 1994). The range was calculated by quadrupling the laboratory error and adding and subtracting that value to and from the raw radiocarbon age. For example, if the raw radiocarbon age is 400±60, then 240 is added to and subtracted from 400 to produce a range of 160–640. We also calculated calibrated ages from raw ages, using the computer calibration program of Stuiver and Reimer (1986). The ranges of calibrated ages (only those values used to calculate recurrence intervals) are included in Table 1 along with the raw radiocarbon ages and the age ranges calculated with the methods described in this paper.

The lowest value of the average recurrence interval range is determined by subtracting the greatest age of the youngest event from the smallest age of the oldest event and dividing by the number of intervals between inferred earthquakes. The highest value is determined by subtracting the smallest age of the youngest buried peat from the largest age of the oldest buried peat and dividing by the number of intervals between inferred earthquakes. For example, if the age range of the youngest buried peat is 200–500 radiocarbon-calibrated years B.P. and the age range of the oldest buried peat is 2,900-3,200, then the average recurrence interval ranges from 480 to 600 years.

The ages of the earthquakes were determined from peat samples taken from the top 5–10 cm of the buried peat. These ages represent the maximum ages of the earthquakes unless the peat is contaminated with younger descending roots. Given no contamination, the actual age of an earthquake is therefore younger than the age of the buried peat. However, this should not create any further systematic errors in average recurrence interval calculations.

Different materials taken from the same depth within the same peat can differ in radiocarbon age by hundreds of years (Nelson, 1992b). Dating bulk peat samples from the top 5–10 cm of the peat horizon (almost all radiocarbon ages in this study) could average out these differences. However, the range of ages for individual samples of peats can be greater than the recurrence interval calculated for

***(Continued on page 8)***

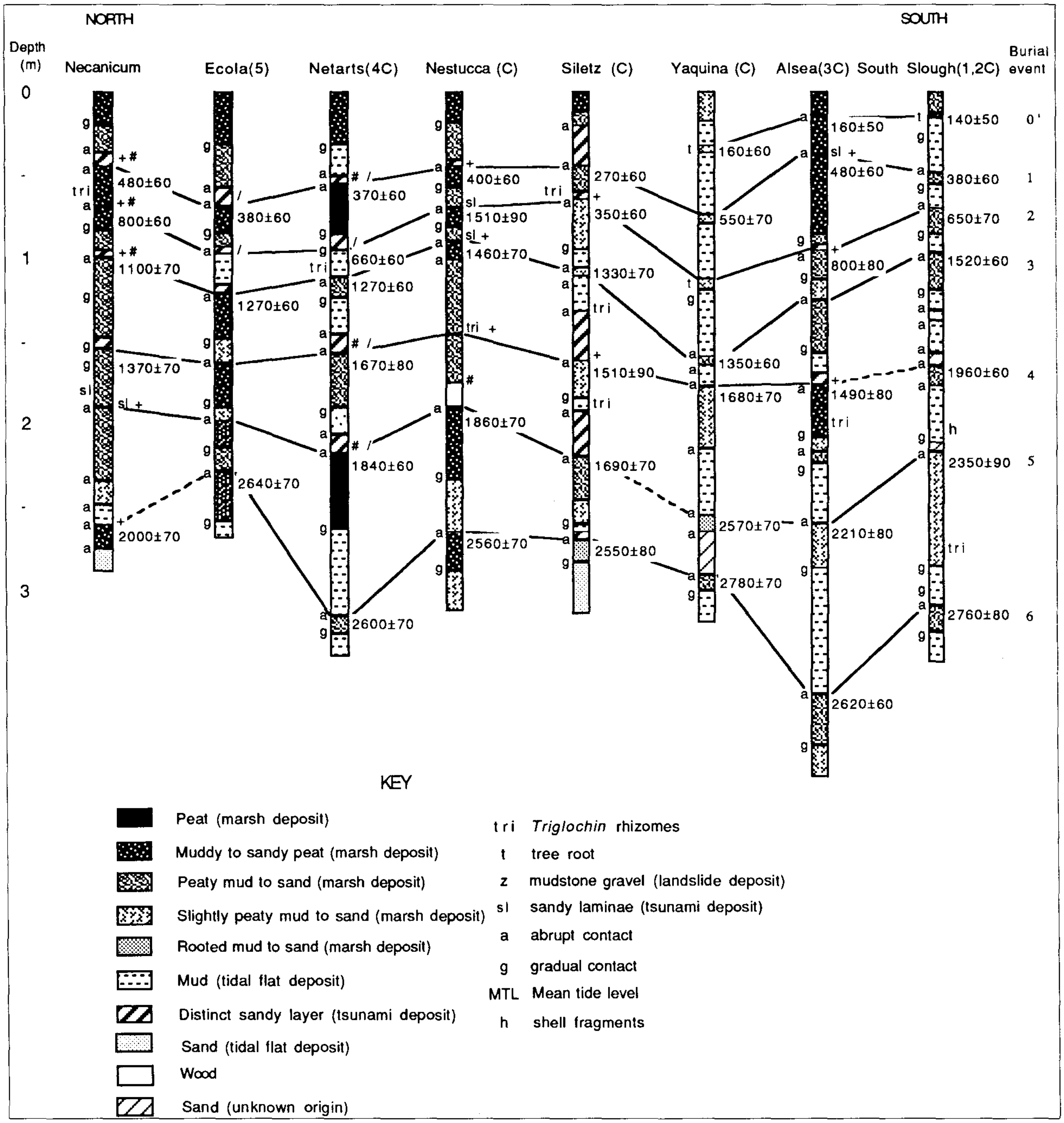


*Figure 2. Representative stratigraphic columns with evidence for subduction-zone earthquakes and radiocarbon ages for all estuaries studied along the northern Oregon coast as well as South Slough, an estuary at Coos Bay on the south-central Oregon coast. Necanicum, Nestucca, Yaquina, and South Slough stratigraphic columns are composites. "#" indicates an increase or first appearance of brackish or marine diatoms from the buried peat to overlying sediments; "+" indicates an increase or first appearance of beach sand from the peat to overlying sediments; "/" indicates >50 percent beach sand in a probable tsunami deposit above the peat. Unnumbered stratigraphic columns are from Darienzo (1991) and Darienzo and others (1994). Columns numbered 1–5 are from (1) Nelson (1992b), (2) Peterson and Darienzo (1989), (3) Peterson and Darienzo (1991), (4) Darienzo and Peterson (1990), and (5) Gallaway and others (1993). "C" indicates that column is a composite of two or more sites.*

Table 1. *Radiocarbon ages of materials (peats unless otherwise noted) from estuaries along the northern Oregon coast that have produced evidence for Holocene subduction-zone earthquakes*

| Estuary (sources) | Site, location | Depth in cm (burial event no.) | Age in radiocarbon yrs B.P. | Age range in yrs B.P. 2 error multiplier (Cal. age range at 2 σ) | Laboratory no. (Beta) |
|---|---|---|---|---|---|
| Necanicum (Darienzo and others, 1994) | Neawanna 2, UTM428900, 5092300, zone 10, N | 48 (1) | 480±60 | 240-720 (300-680) | 42112 |
| | | 70 (2) | 800±60 | 560-1,040 | 42113 |
| | | 111 (3) | 1,100±70 | 820-1,380 | 42088 |
| | | 158 (4) | 1,370±70 | 1,090-1,650 | 44595 |
| | | 268 (6) | 2,000±70 | 1,720-2,280 (1,610-2,340) | 42114 |
| | Neawanna 5, UTM 428900, 5092600, zone 10, N | 78 (2) | 680±80 | 360-1,000 | 43127 |
| | | 167 (6) | 2,200±90 | 1,840-2,560 | 42115 |
| Ecola (Gallaway and others, 1992) | 115-R, UTM 426000, 5083300, zone 10, N | 70 (1) | 380±60 | 140-620 (0-590) | 56402 |
| | | 120 (3) | 1,270±60 | 1,030-1,510 | 56401 |
| | | 230 (6) | 2,640±70 | 2,360-2,920 (2360-3050) | 56404 |
| Netarts (Darienzo and Peterson, 1990; Darienzo, 1991) | 5, UTM 424400, 5024200, zone 10, N | 55 (1) | 370±60 | 130-610 (0-578) | 24933 |
| | | 111 (3) | 1,270±60 | 1,030-1,510 | 24934 |
| | | 157 (4) | 1,670±80 | 1,350-1,990 | 24520 |
| | | 220 (5) | 1,840±60 | 1,600-2,080 (1490-2030) | 24521 |
| | | 316 (6) | 2,600±70 | 2,320-2,880 (2360-3050) | 41668 |
| | Oyster farm, UTM 426800, 5029900, zone 10, N | 97 (2) | 660±60 | 420-900 | 41638 |
| Nestucca (Darienzo and others, 1994) | Nestucca Duck, UTM 425500, 5004200, zone 10, N | 80 (1) | 400±60 | 160-640 (0-620) | 43123 |
| | Little Nestucca 5, UTM 426800, 5000500, zone 10, N | 70 (2) | 1,510±90 | 1,150-1,870 | 42000 |
| | | 90 (3) | 1,460±70 | 1,180-1,740 | 42084 |
| | | 190 (5) | 1,860±70 | 1,580-2,140 (1,460-2,110) | 41637 |
| | | 266 (6) | 2,560±70 | 2,280-2,840 (2,320-2,920) | 41671 |
| Siletz (Darienzo and others, 1994) | Salishan House, UTM 418700, 4971500, zone 10, N | 47 (1) | 270±60 | 30-510 (0-520) | 42089 |
| | | 67 (2) | 350±60 | 110-590 | 42090 |
| | | 163 (4) | 1,510±90 | 1,150-1,870 | 42001 |
| | | 220 (5) | 1,690±70 | 1,410-1,970 (1,310-1,900) | 42091 |
| | | 273 (6) | 2,550±80 | 2,230-2,870 (2,200-2,970) | 42002 |
| | Millport Slough 1, UTM 421500, 4970800, zone 10, N | 48 (1) | 480±60 | 240-720 (300-680) | 42085 |
| | | 135 (3) | 1,330±70 | 1,050-1,610 | 43126 |
| | | 159 (4) | 1,630±70 | 1,350-1,910 | 43125 |
| | | 210 (5) | 1,850±70 | 1,570-2,130 (1,440-2,100) | 42086 |
| Yaquina (Darienzo and others, 1994) | Hatfield, UTM 417400, 4940200, zone 10, N | 30 (0′) | 160±60 | 0-400 | 41991 |
| | Outcrop B, UTM 428300, 4938400, zone 10, N | 77 (1) | 550±70 | 270-830 (310-720) | 38862 (wood) |
| | Slack 1, UTM 427800, 4938000, zone 10, N | 62 (3) | 1,350±60 | 1,110-1,590 | 42092 |
| | | 81 (4) | 1,680±70 | 1,400-1,960 | 42093 |
| | | 160 (5) | 2,570±60 | 2,330-2,810 (2,340-2,890) | 42094 |
| | | 196 (6) | 2,780±70 | 2,500-3,060 (2,530-3,260) | 42095 |
| Alsea (Peterson and Darienzo, 1991) | Outcrop, UTM 419500, 4918700, zone 10, N | 50 (1) | 480±60 | 240-720 (300-680) | 39181 (wood) |
| | AB 8, UTM 419000, 4918800, zone 10, N | 87 (2) | 800±80 | 480-1,120 | 27184 |
| | | 177 (4) | 1,490±80 | 1,170-1,810 | 26791 |
| | | 242 (5) | 2,210±80 | 1,890-2,540 (1,830-2,710) | 27185 |
| | | 327 (6) | 2,620±60 | 2,380-2,860 (2,370-2,960) | 26792 |
| South Slough | Winchester 12, UTM 3931000, 4792400, zone 10, N (Nelson, 1992b) | 47 (1) | 380±60 | 140-620 (0-590) | 26289 |
| | Day Creek, UTM 393800, 4796500, zone 10, N (Peterson and Darienzo, 1989) | 15 (0′) | 140±50 | 0-340 (0-450) | 41639 (wood) |
| | | 72 (2) | 650±70 | 370-930 | 27675 |
| | | 98 (3) | 1,520±60 | 1,280-1,760 | 34280 |
| | | 167 (4) | 1,960±60 | 1,720-2,200 | 27744 |
| | | 220 (5) | 2,350±90 | 1,990-2,710 (1,920-2,800) | 27743 |
| | | 310 (6) | 2,760±80 | 2,440-3,080 (2,440-3,300) | 34278 |

repeated earthquakes. This suggests that conventional radiocarbon dating is poorly suited for determining individual recurrence intervals at the Cascadia Subduction Zone (Nelson 1992b). A more accurate estimate of the age of an earthquake can be obtained from the dating of matter that was killed as a result of the earthquake, such as tree roots or herbaceous leaves in growth position (Nelson and Atwater, 1993). This method avoids the problems associated with dating bulk peat and also narrows the range of individual radiocarbon ages and average recurrence intervals. Although more accurate recurrence intervals are desirable, the average recurrence intervals calculated here will provide a useful estimate for hazard planning.

## RESULTS AND DISCUSSION

### Synchroneity of events

The stratigraphy in each estuary records six burial events associated with subduction-zone earthquakes during the last ~3,000 years. The buried peats that identify the events are usually found in the top 3 m. Figure 2 compares stratigraphy between the estuaries with respect to depth below the modern marsh surface, using representative cores from each estuary.

The depth to the tops of the buried peats for the last six events is similar among estuaries and falls within distinct ranges (Figure 3). This depth consistency possibly reflects a similar response by the marshes to coseismic subsidence and postseismic burial within the framework of eustatic sea-level rise in the late Holocene. Nontectonic burial of marshes with sediment from floods or storm surges would not be consistent between estuaries over 175 km of coastline because of the greater variability of effects from rainfall and storm activity along the coast. Major storms and floods occur much more frequently than subduction-zone earthquakes. Thus, buried peats would be more abundant in the stratigraphic record of coastal marshes if storms and floods were included as causes of marsh burial. Therefore, the consistency in depth and number of buried peats among estuaries on the northern Oregon coast in the last 3,000 years favors a burial mechanism of coseismic subsidence and postseismic sedimentation from subduction-zone earthquakes. The ranges in depth for each event are probably the result of differences in the amount of subsidence, the postseismic sedimentation rate, the rate of postseismic rebound, and eustatic sea-level rise.

The range of radiocarbon ages for each of the six buried peat horizons is fairly consistent among estuaries (Figure 4). A few events have no radiocarbon ages, because the peat was not dated (Darienzo and others, 1994). The radiocarbon age of one event from the Hurliman site at Nestucca was excluded because of the inconsistency of its age in relation to the ages above and below (event 4: 3,113–3,619 cal. $^{14}C$ yrs B.P.). Similarity in age ranges among buried peats supports synchroneity of events among the estuaries. However, not all buried peat age ranges overlap at 2 $\sigma$ (95-percent confidence that the age of the peat is within the range). Based solely on radiocarbon dating, past subduction-zone earthquakes along the northern Oregon coast could have been either subduction-zone earthquakes that occurred synchronously among all estuaries on the northern Oregon coast or subduction-zone earthquakes that occurred among estuaries within two or more segments. Nevertheless, the radiocarbon dating shows that a similar number of earthquakes occurred within similar time intervals throughout the northern Oregon coast.

Three to five tsunami sand layers have been deposited in each estuary within the last 3,000 years. Almost all sand layers immediately overlie buried peats, which is indicative of earthquake subsidence and tsunami deposition. The sand layers of the second event in at least the three northernmost estuaries do not overlie buried peats, because the sands are not associated with subsidence in those areas. This consistency in numbers of tsunami sands among the estuaries, along with the almost one-to-one correspondence of tsunami sands with subsidence, supports synchroneity of the events between Alsea and Necanicum.

The evidence for synchroneity among estuaries along the northern Oregon coast will be discussed separately for each event.

The **first (youngest) burial** event appears to have been the most consistent and clearly represented event with respect to age and presence of tsunami-deposited sands in all the northern estuaries (Figures 2–4) (Darienzo and others, 1994). The representative stratigraphy and radiocarbon ages of the Yaquina Bay estuary in Figure 2 are from sites in the upper reaches of the estuary and do not contain tsunami sands above any of the six buried peats. However, tsunami sands overlie the youngest peat at sites in the lower to middle reaches of that estuary (Figure 2) (Darienzo and others, 1994; Peterson and Priest, in preparation). A relatively young burial event in the lower reaches (160±60 $^{14}C$ yrs B.P. and 0–310 cal. $^{14}C$ yrs B.P.) was identified as a separate event (0') by Darienzo and others (1994), based on radiocarbon age, depth, and comparison with similar horizons in Alsea Bay and South Slough (Figure 2). However, this 0' designation is very tentative. The 0' age could possibly represent this first event at all three estuaries, based on age overlap at 2 $\sigma$. The younger ages could also be due to descending modern roots that were incorporated into the uppermost peat (Figure 4). For example, buried horizons with radiocarbon ages of 380 and 140 years B.P. at South Slough could signify the same burial event rather than two separate events, even though they are from two different sites (Figure 2). Based on ages, evidence of subsidence (Darienzo and others, 1994), and one-to-one correspondence of tsunamis with subsidence, the first event probably occurred synchronously among the estuaries on the northern Oregon coast.

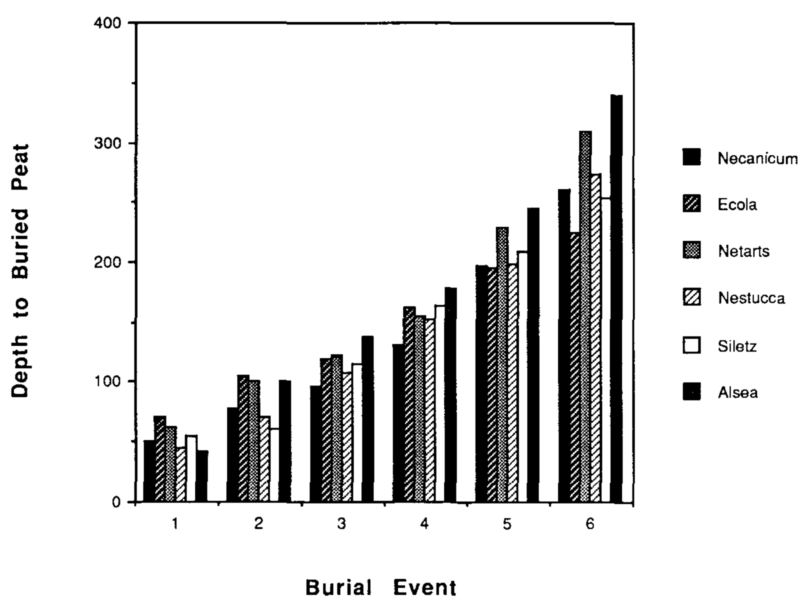


*Figure 3. Depths to the tops of buried peats for the last six earthquakes in six of the seven estuaries discussed. Yaquina is excluded, because events from two sites were combined to create composite stratigraphy. From Darienzo and others (1994).*

The **second burial event** is characterized by (1) tsunami sand and lack of subsidence evi-

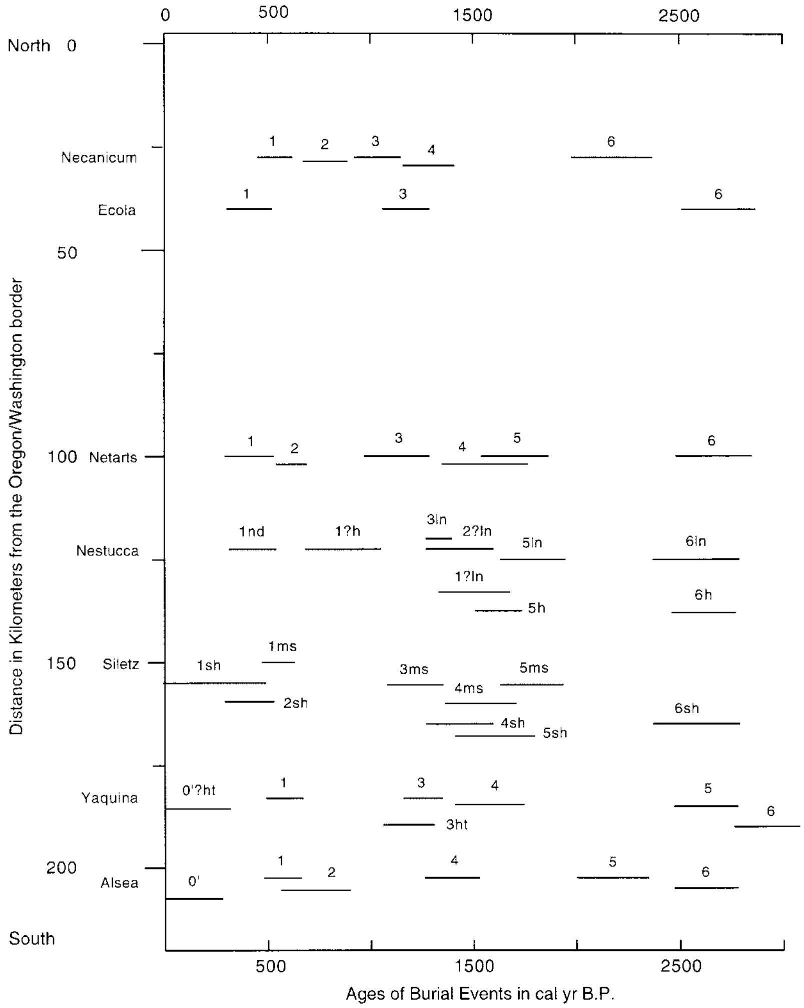


*Figure 4. Ranges of calibrated radiocarbon ages with two deviations (2 σ) of the last six earthquake events for all estuaries. Numbers designate events. Question marks indicate event designation uncertainties. Lower-case initials designate specific sites within the estuary where materials were radiocarbon dated (nd = Nestucca duck; ln = Little Nestucca; h = Hurliman; sh = Salishan House; ms = Millport Slough; ht = Hatfield). See Darienzo and others (1994) for stratigraphy of the Nestucca and Siletz cores.*

dence in Netarts, Ecola, and possibly Necanicum; (2) tsunami sand and subsidence in Alsea, Nestucca, and Yaquina; and (3) tsunami sand at several sites and possible evidence of subsidence at a few sites in Siletz Bay (Figure 2) (Darienzo and others, 1994; Peterson and Darienzo, 1994; Peterson and Priest, in preparation). Age control for the second event is weak. The ages of the buried peats for the second event overlap at 2 σ for Necanicum, Netarts, and Alsea (Figure 4). However, the age from Nestucca is much older than these, and it is not clear if this event, documented at four estuaries in northern Oregon, affected Nestucca Bay. The age of the second buried peat at Nestucca might be suspect and require additional dating to solve this problem (Darienzo and others, 1994).

In contrast to Nestucca, the age of the second peat from Siletz is younger and does not overlap at 2 σ with the peats from Necanicum, Netarts, and Alsea. The young age is perhaps due to root contamination from above. The second buried peat at Ecola and Yaquina was not dated. The sands without accompanying subsidence stratigraphy that record the second event at the three northernmost estuaries suggest deposition by a tsunami generated by an offshore subduction-zone earthquake off an adjacent segment of the Oregon coast to the south. The lack of evidence for this second event along the Washington coast further supports a segment rupture limited to the southern Oregon coast (Atwater, 1992). Possible segment boundaries are located either between the Netarts and Nestucca bays or between Siletz and Yaquina (Figure 1). Supporting a segment boundary between Netarts and Nestucca is the fact that there is evidence of subsidence for the second earthquake burial event at Nestucca but no such evidence at Netarts. Support for a segment boundary between Yaquina and Siletz includes evidence of subsidence at Yaquina, weak subsidence evidence at Siletz, and a possible segment boundary at this same location for the fifth earthquake burial event. Further work is necessary to accurately locate the boundary. Nevertheless, all estuaries were affected by this second paleoearthquake either directly, by subsidence and a tsunami, or indirectly, by a tsunami only. Therefore, the record of the second event could be considered synchronous among the estuaries on the northern Oregon coast.

The **third burial event** is recognized in all estuaries, and the ages of the buried peats at nearly all estuaries overlap at 2 σ (Alsea was not dated) (Figure 4). The exception is the age of the third buried peat at Nestucca, which overlaps all estuaries except Necanicum. A distinct sandy layer is present over the third buried peat at four of the seven northern estuaries but absent at Alsea, Siletz, and Netarts (Figure 2). The Hatfield site in the lower reaches of Yaquina Bay had tsunami sand deposited over what is considered the third buried peat, based on radiocarbon age (Figure 4). However, the third buried peat at other sites in Yaquina Bay is not capped by tsunami sands (Peterson and Priest, in preparation). The tsunami sand in the lower reaches of Yaquina Bay is not shown in Figure 2, because the representative stratigraphy for Yaquina in Figure 2 is from the upper reaches of the estuary (Darienzo and others, 1994). Based on ages, evidence of subsidence, and one-to-one correspondence of tsunami sand from the Hatfield site with subsidence, this third event possibly occurred synchronously from the Necanicum River to Alsea Bay.

The **fourth burial event** is recognized in all seven estuaries. At five of the estuaries, the ages of the event overlap at 2 σ (no age from Ecola or Nestucca). Tsunami sands overlie peats in four out of seven estuaries but are absent at core sites in Ecola and Nestucca. Based on ages, evidence of subsidence, and one-to-one correspondence of tsunamis with subsidence, this fourth event possibly occurred synchronously from the Necanicum River to Alsea Bay (Figures 2 and 4) (Darienzo and others, 1994; Peterson and Priest, in preparation).

The **fifth burial event** is recognized in all estuaries. Only three of the seven estuaries were observed to record tsunami sands above buried peats (Figure 2), and the age ranges for the fifth event overlap in only three out of the five estuaries dated (Figure 4). The ages of the event at Alsea and Yaquina, the two southernmost estuaries, are greater than at the other dated estuaries. This suggests a separate event (or more) for them and a segment boundary between Yaquina and Siletz. Or, buried peats with similar ages have not been identified in adjacent estuaries because of nondeposition or erosion. Ages of the fifth buried peats at Ecola and Necanicum are needed to support synchroneity of the event northward from Netarts (Figure 1). However, Netarts, Ecola, and Necanicum show evidence for subsidence. If there is a segment boundary between Netarts and Ecola, one would expect tsunamis produced from earthquakes north and south of the boundary to deposit tsunami sand on nonsubsided marshes in estuaries of adjacent segments. If sands had been deposited, the stratigraphy would show these sands within the peat rather than on top of a peat that is buried by estuarine sediments. No evidence of a tsunami deposit from an adjacent earthquake was identified in the cores, which suggests synchroneity for the fifth event from Siletz to Necanicum, a distance of 123 km, rather than segmentation. The same arguments apply for southward extension of the event to Alsea Bay. This lack of tsunami sands unrelated to subsidence supports synchroneity of the fifth event between Alsea and Necanicum. However, tsunamis do not always leave a deposit. Therefore, the absence of a tsunami sand in horizons other than those immediately overlying a buried peat can not rule out segmentation. Nonetheless, tsunami sand layers not associated with buried peats have been recognized for the second event. In estuaries such as Netarts, where marshes are separated from the Pacific Ocean by a thin sand spit, the potential is high for sand deposition by a tsunami that was generated by an adjacent segment rupture. Only one tsunami deposit of this type was found in the proximal marshes of Netarts. Therefore, this implies no segmentation on the northern Oregon coast for five out of the six events.

The **sixth burial event** is recognized in all estuaries, with tsunami sands overlying peats in three estuaries (including two sites at Netarts not depicted in Figure 2). The ages overlap, with the exception of Necanicum, which supports synchroneity of the event from Alsea to Ecola. Extension to Necanicum is still possible, given that the distance from Ecola to the Necanicum is only 14 km. At Necanicum, there is evidence for subsidence but no evidence of tsunami sand not connected with subsidence, that is, there is no sand directly overlying a buried peat. This suggests synchroneity of the event between Alsea and Necanicum and no segment boundary between Ecola and Necanicum.

In summary, synchroneity between Alsea and Necanicum is supported for all events, except events number two and possibly number five, based on the one-to-one correspondence of tsunami sands and earthquake-buried peats. Event two is also synchronous between Alsea and Necanicum but does not show subsidence in at least three of the seven estuaries. A segment boundary for the second earthquake possibly exists between either Siletz and Yaquina or between Netarts and Nestucca. Based on radiocarbon ages only, there is the possibility of a segment boundary between Yaquina and Siletz for event five.

Synchroneity of events could possibly extend far to the north and south of the seven estuaries discussed here. Based on radiocarbon ages and similar peat development, the last three events recorded in Grays Harbor and Willapa Bay, Washington, are comparable to the first, third, and fourth events of this study (Atwater, 1987, 1992). Extension of event synchroneity to Grays Harbor would add approximately 110 km to the northern rupture length (Figure 1). Synchroneity could also be tentatively extended south to southern Oregon and northern California. For example, South Slough in southern Oregon contains six buried peats within 3 m of the surface from the last 2,800 years (Figures 1 and 2) (Peterson and Darienzo, 1989; Nelson, 1992a). This extension would add 100 km to the rupture length. Clarke and Carver (1992) document four or five probable coseismic subsidence events in the Mad River Slough of Humboldt Bay in the last 1,423 to 1,690 years (Figure 1). The ages and the number of events resemble the data from northern Oregon. This would add approximately another 275 km (distance from South Slough to Humboldt Bay) to the rupture length. However, further work in the estuaries between Alsea and Humboldt is needed to test this southward-extension hypothesis.

### Paleomagnitudes

Coseismic subsidence from subduction-zone earthquakes probably occurred synchronously among seven estuaries at least four and possibly five times in the past 3,000 years along the northern Oregon coast. Magnitudes were based on a rupture length of 175 km (distance between Alsea Bay and Necanicum), a rupture width of 60 km, a convergence rate of 4 cm/yr, and an average recurrence interval of 400 years.

We calculated paleomagnitudes with two different equations, (1) the magnitude equation of Abe, which is based on ruptured area only, and (2) the moment magnitude ($M_W$) equation, which combines rupture area, convergence rate, and recurrence interval.

According to the magnitude equation of Abe, the magnitude of the Holocene earthquakes for the first event and the third to sixth events would be 8.0. With a range of lengths (105–175 km) and widths (60–90 km) on the northern Oregon coast, the magnitudes would be between 7.8 and 8.2. If extended to Grays Harbor, Washington (rupture length of 285 km), the events one, three, and four would yield magnitudes between 8.2 and 8.4.

According to the moment magnitude equation, the magnitudes of paleoearthquakes one and three to six between Alsea and Necanicum (rupture length of 175 km) would be $M_W$ 8.4, based on a rupture width of 60 km (Figure 1). If the length was shortened to 105 km (the distance from Netarts to Alsea), the magnitude would be $M_W$ 8.2. Extending events one, three, and four to Grays Harbor, Washington, would yield a magnitude of $M_W$ 8.6. With a range of convergence rates of 3.5–4.5 cm/yr (Nishimura and others, 1984), average recurrence intervals of 200–600 yrs (Darienzo and Peterson, 1994), rupture lengths of 105–285 km,and rupture widths of 60–90 km, the range of magnitudes for paleoearthquakes between Alsea and Necanicum would be $M_W$ 8.1–8.8 and between Alsea and Grays Harbor $M_W$ 8.4–8.9.

### Average recurrence intervals

Each estuary records six earthquake events within the last ~3,000 years. Representative stratigraphy and associated radiocarbon ages are shown in Figure 2. From ages and numbers of earthquakes, the range of average recurrence intervals is calculated for each estuary, using both five and six events (Table 2). The average recurrence interval for each estuary falls between 200 and 600 years (to the nearest 50 years). One exception is in averaging the last five events at Yaquina Bay, which increased the upper value in the range to 650 years. The average recurrence intervals, calculated from calibrated ranges of ages generated by a computer program, are not significantly different from the average recurrence intervals calculated by the method in this paper. The average interval range (350–700 years) for South Slough, a southern Oregon estuary included for comparison, is relatively consistent with these results (Figures 1 and 2; Tables 1 and 2) (Peterson and Darienzo, 1989). The next-to-youngest event (burial event two) at Netarts and Ecola does not represent an earthquake with associated subsidence, rather a tsunami deposit from an earthquake produced in an adjacent segment (Darienzo, 1991; Gallaway and others, 1992). However, this event was included in recurrence interval calculations, because a tsunami from an adjacent segment will be very destructive along the coast, even in the unsubsided segment. Therefore, the second event at Netarts and Ecola shows evidence for earthquakes and should not be removed from the recurrence interval calculations.

## CONCLUSION

Evidence for great Holocene subduction-zone earthquakes is documented in individual estuaries along the northern Oregon coast. Stratigraphic evidence, such as number of events in the top 3 m, depth of buried peats, presence of distinct tsunami layers, and radiocarbon ages, is similar among seven estuaries. This similarity suggests synchroneity of earthquake-induced subsidence along the

Table 2. *Ranges of average recurrence intervals of estuary burial events*

| No. of intervals averaged | Nec* | Eco* | Net* | Nes | Sil | Yaq | Als | SS |
|---|---|---|---|---|---|---|---|---|
| 4 | | | 250-490<br>(230-510) | 240-500<br>(210-530) | 230-490<br>(200-480)<br>210-470<br>(190-450) | 380-640<br>(400-650) | 290-570<br>(290-600) | 340-640<br>(330-700)<br>410-680<br>(370-700) |
| 5 | 200-410<br>(190-410) | 350-550<br>(350-610) | 340-550<br>(350-600) | 330-540<br>(340-580) | 340-570<br>(340-590) | 330-560<br>(360-590) | 330-520<br>(340-530) | 360-590<br>(370-660)<br>420-620<br>(400-660) |

* The second event, which contains evidence for a tsunami but no evidence of subsidence (except perhaps at Necanicum), is included in range calculations.

Ranges in parentheses are based on calibrated ages from Table 1. The two sets of values for Siletz in the four-interval row include Salishan (upper set) and Millport; the two sets of values for South Slough in both four- and five-interval rows represent calculations based on Winchester and Day Creeks (upper set in each row) and Day Creek only.

Nec = Necanicum, Eco = Ecola, Net = Netarts, Nes = Nestucca, Sil = Siletz, Yaq = Yaquina, Als = Alsea, and SS = South Slough.

northern Oregon coast. Synchroneity of events from Alsea Bay to the Necanicum River, covering a distance of 175 km, is best documented for the first, third, and fourth and reasonably documented for the fifth and sixth events. The second event may be synchronous from Alsea to Necanicum, based on the presence of tsunami sands, even though evidence of earthquake-induced subsidence for this event is absent in at least the three northernmost estuaries.

The magnitudes of the Holocene earthquakes recorded along the northern Oregon coast are probably at least 8.0, based on a rupture length of 175 km, a minimum rupture width of 60 km, a recurrence interval of 400 years, and a convergence rate of 4 cm/yr. If the magnitudes are calculated with a range of convergence rates, average recurrence intervals, rupture lengths, and rupture widths, the magnitudes are no less than 7.8 and possibly as large as 8.8. The average recurrence interval for earthquakes recorded in each estuary ranges from 200 to 600 years.

## ACKNOWLEDGMENTS

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## DOGAMI PUBLICATIONS

Released November 9, 1994

***Geologic Map of the Tenmile Quadrangle, Douglas County, Oregon***, was published in the DOGAMI Geological Map Series as map GMS-86 (price $6). The Tenmile quadrangle includes Tenmile Valley and a major portion of Olalla Creek to the south. The quadrangle is at the southeast corner of a block of eight quadrangles for which geologic maps have been already produced by DOGAMI or are in progress. The quadrangle maps published so far are Camas Valley, Kenyon Mountain, Mount Gurney, Remote, Reston, and the new release Tenmile.

The new, two-color geologic map and cross section were produced by Thomas J. Wiley and Gerald L. Black of DOGAMI. At a scale of 1:24,000 (1 inch = 2,000 feet), it depicts the geology in greater detail than any previous map, identifying 16 rock units and showing faults and landslides. A five-page text discussing rock units, structural geology, and geologic history accompanies the map sheet.

The Tenmile quadrangle is underlain by complex geology that includes rocks ranging in age from Jurassic (about 200–140 million years ago) to early Eocene (about 50–40 million years ago).

Released December 20, 1994

***Oregon's Mineral Industries: An Assessment of the Size and Economic Importance of Mineral Extraction in 1993,*** Open-File Report O-94-31 (price $6). According to the study, in 1993 the value of minerals produced in Oregon totaled $239.9 million. This value was measured at the point of production and does not include shipping and special processing costs. If these were added in, the total value would nearly double. Oregon's mineral industries directly supported 2,039 full-time jobs in the state. In addition, over 3,000 other workers were employed in related activities such as trucking and the manufacturing of concrete products.

Written by DOGAMI minerals economist Robert Whelan, the report is the most complete measurement of the State's mineral industry ever made. Whelan sent survey questionnaires to 878 mineral producers in Oregon and received a response from 84 percent. According to Whelan, "This survey represents the first comprehensive accounting of Oregon's mineral output ever done. Now, questions about the size and ecomonic importance of mineral production in Oregon can be answered with real data."

Construction aggregates, such as crushed rock and sand, accounted for 89 percent of Oregon's mineral production. Ranking second in value was natural gas. Most of the remaining production was attributed to industrial minerals, the most important of which were limestone, pumice, and diatomite. Gemstones valued at over $1.3 million were mined. Gold production, all of which came from small seasonal operators, totaled $778,000.

The survey indicates that Oregon consumed 51.2 million tons of construction aggregate in 1993. This figure is much higher than previously thought.

Released December 29, 1994

***Geologic Map of the Damascus Quadrangle, Clackamas and Multnomah Counties, Oregon***, by Ian P. Madin, has been published in the DOGAMI Geological Map Series as map GMS-60 (price $8). The full-color geologic map identifies 28 different bedrock and surficial rock units and many previously unrecognized faults and is accompanied by three geologic cross sections. A separate sheet provides geochemical data for over 80 samples taken in the quadrangle. A nine-page text contains rock-unit explanations, discussions of structure and geologic history, an aeromagnetic map of the quadrangle, and location maps for geochemical samples and the many water wells used to interpret the structure of the area.

The main portion of the map area lies between the Clackamas River and Johnson Creek. It has been shaped by basalt, first in gigantic flows from eastern Oregon and later in faulting-related eruptions, and by extensive accumulations of sediments from the Columbia River, the once-glaciated Cascade Mountains, and the catastrophic floods that inundated the area during the late ice age.

Flood-deposited agricultural soil, sand, gravel, stone, and clay attracted people to this area. Large deposits of basalt and aggregate remain throughout the quadrangle, but their use faces competition from other land uses. The varied geology provides unique recreation opportunities for rock climbing as well as river running. The topography, born of faulting and volcanic eruptions, offers striking scenery that attracts increasing interest by housing developers. The complex deformation of the area complicates the understanding and managing of ground-water resources, while residences and a growing nursery industry are placing increasing demand on ground water.

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# Oregon's mineral industries—An assessment of the size and economic importance of mineral extraction in 1993

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*This report was recently released by the Oregon Department of Geology and Mineral Industries as Open-File Report O–94–31. It is reprinted here in an abbreviated and slightly updated form.* —*ed.*

## INTRODUCTION

The Oregon Department of Geology and Mineral Industries has completed the most comprehensive survey of mineral production ever done in Oregon. The total value of products extracted from Oregon's mineral properties in 1993 was $239.9 million. The industry contributed $102.4 million to the State's economy in the forms of wages, profits and taxes.

The survey counted output from mines, quarries, sand and gravel pits, river dredges, gemstone deposits, public lands, and natural gas wells.

Production was measured at its point of removal—that is, before any processing by which physical properties, other than particle size and cleanliness, were changed. So-called downstream products, such as cement or cut gemstones, were not counted.

Our production data differ from figures reported by the U.S. Bureau of Mines (USBM) in its annual *Mineral Industry Surveys*. This is largely the result of differences in the types of mineral products covered in the surveys. The USBM data for Oregon include many downstream products, but they exclude natural gas. Our survey measures only raw mineral output, and it includes natural gas.

We received replies from 84 percent of the 878 surveys that were mailed. We estimated the values of nonrespondents using combinations of site visits, public data, and third-party information. Estimates were also made for informal miners. These include farmers, ranchers, loggers, gemstone collectors, and other small producers.

Table 1. *1993 Oregon mineral production (in short tons, unless otherwise noted)*

| Product | Quantity | | Dollar value |
|---|---|---|---|
| Crushed rock and shale | 23,888,974 | | $115,456,068 |
| Pit run rock | 2,103,315 | | 3,418,975 |
| Decomposed granite | 362,763 | Combined[1] | 2,346,856 |
| Cinders | 299,689 | | |
| Sand and gravel from waterways | 3,096,980 | Combined[1] | 90,895,172 |
| Sand and gravel from pits | 17,732,489 | | |
| Fill material | 1,255,907 | | 1,890,705 |
| Common clays and bentonite | 300,018 | | 2,070,792 |
| Other industrial minerals[2] | N/A | | 14,625,877 |
| Gold (in troy ounces) | 2,021 | | 788,000 |
| Gemstones | N/A[3] | | 1,336,743 |
| Natural gas (thousand cu.ft) | 3,534,243 | | 7,072,554 |
| **STATE TOTAL** | | | **$239,901,742** |

[1] Values were combined so that individual producer data can be kept confidential.
[2] Other industrial minerals are agricultural and industrial limestone, dolomite, diatomite, perlite, zeolites, emery, dimension stone, building stone, decorative stone, industrial silica sand, and soapstone.
[3] Not available.

## MINERAL PRODUCTION IN OREGON IN 1993

Total mineral production value in Oregon during 1993 was $239.9 million. Sand, crushed stone, gravel, and other construction aggregates accounted for 89 percent of the total. Ranking second was natural gas. Industrial minerals, such as clay, limestone, and pumice, accounted for most of the rest. These totals are shown on Table 1.

Half of all the active private mining businesses in 1993 had no more than one full-time worker. A small operation is an advantage in mining. Single-person operators can often opt out of workers' compensation coverage. That insurance is expensive, costing a minimum of $9.89 for every $100 paid to mine workers.

Oregon was the only western U.S. state, other than Hawaii, with no major working metal mines in 1993. Oregon did produce 2,021 troy ounces of gold, but all of it came from recreational and small seasonal mining operations. No gold mine provided year-round employment in 1993.

**Crushed rock and shale** production totaled 23.9 million tons and was valued at $115.5 million. The average selling price was $4.83 a ton. Prices varied greatly, however, depending on local conditions. Prices tended to be higher in the Portland and Bend markets, where construction activity was strong.

Crushed rock is used in roads and buildings. A familiar crushed rock product is asphalt pavement used in many parking lots and roads. Rock is mined in quarries and then fed into special rock crushing equipment. After crushing, it is cleaned, sorted by size, and stored for eventual blending to customer specifications.

Most crushed rock quarries in Oregon are idle except when local construction activity picks up. Then, portable rock-crushing equipment is brought in and operated as needed. Other quarries, especially in large markets, have permanent rock-crushing equipment nearby, which runs regularly.

The term "shale" is used in Oregon for both actual shale and some types of layered volcanic rock that break apart easily. This characteristic makes production of shale less expensive than production of the more common types of crushed rock. In Oregon, volcanic shale is used as a substitute for crushed rock, which is why we include it here. Most of it is mined in southwestern Oregon.

The production of **pit run rock** totaled 2.1 million tons and was worth $3.4 million in 1993. Pit run rock is rock that is quarried but not crushed. At an average price of $1.63, it is a low-value product. Pit run rock is used in construction where bulk, rather than product consistency, is important. Logging companies are also big consumers. Pit run rock makes rough, yet inexpensive logging roads that are adequate for log trucks. The USDA Forest Service, on the other hand, uses only crushed rock because it wants smooth roads that are accessible to smaller vehicles operated by recreational visitors.

Production of **decomposed granite** in the state totaled 362,763 tons. Decomposed granite is an unusual aggregate material found in Jackson County and surrounding areas. It is a deeply weathered granite. It compacts so readily that it is used in local construction for high-quality fill. One common use for fill is preparing and leveling ground for new buildings.

**Cinder** is a lightweight volcanic rock. It is usually reddish colored. In 1993, a total of 299,689 tons of cinder was mined. Cinder is crushed into small gravel that is used for sanding icy roads. Commercial landscapers use larger cinder gravel as a type of mulching stone. In central Oregon, where most of the cinder is mined, it is used for road pavement. Because it is so easily crushed, cinder gravel is considered a low-cost but inferior alternative to crushed rock.

**Sand and gravel** production totaled 20.8 million tons and was worth $90.8 million. Just under 3.1 million tons of the sand and gravel produced in Oregon came from waterways such as the Columbia and Willamette Rivers. The average mine price from all sources was $4.36 a ton.

Sand and gravel are mined from pits or are extracted from waterways by dredges. The material is then cleaned, sorted by size, stored, and later blended to customers' orders. Some producers will crush any large pieces they extract. This way, they can better match the demands of the local market for different particle sizes.

Unlike sand and gravel that are manufactured from crushing rock, natural sand and gravel tend to have particles with rounded edges and hard surfaces. This makes them ideal for concrete. Particle roundness allows the concrete to flow better when it is poured. Hard surfaces keep the particles from absorbing expensive cement.

Concrete is a mixture of cement, aggregate, and a few other ingredients. Cement is expensive. When you make concrete, it is worth while to mix in as little cement as possible. Using rounded sand and gravel, especially material mined from rivers, lets you economize on the amount of cement you have to add. Natural sand and gravel also usually make a concrete of better quality.

**Fill**, as defined in our survey, is unprocessed loose material that is sold for low-value applications such as road embankments and leveling-off land at construction sites. Soil and unprocessed sand are two common forms of fill. At some rock crushing plants, they sell very fine rock particles as fill. In 1993, 1.3 million tons of fill worth $1.9 million were produced in Oregon. The average price was $1.51 per ton. Prices varied from a few cents to over $2 a ton.

**Natural gas** production totaled 3,534,243 thousand cubic feet (MCF) and was worth $7.1 million. All of it was produced from the Mist Gas Field in Columbia County. Besides contributing to local employment, the County earned royalties from the wells and used the money to help fund its public schools.

The Northwest Natural Gas Company sells the production from the Mist field to its customers in Oregon. The company also uses the field to store gas bought from producers in other places when prices are low. Then it takes the gas out of storage during cold periods when demand rises and out-of-state gas prices become prohibitively high. Doing this helps save money and assures the state that it will have enough gas on hand for emergencies.

Oregon produced 300,018 tons of **common clays and bentonite** in 1993, with a value of $2.1 million. Most of the common clays were made into bricks. Bentonite, which is a special class of clay, went into engineering projects such as ponds and waste-disposal sites.

Collectively, $14.6 million worth of other industrial minerals was mined in Oregon. Industrial minerals are mined products that are not made into metals or used as common construction aggregate. The individual quantities and values cannot be shown because there are too few producers of each of them in Oregon. We can say, however, that over 90 percent of the production is attributable to three industrial minerals. They are diatomite, limestone, and pumice.

**Diatomite** is mined in Lake, Harney, and Malheur Counties. It is a rock that is formed from the skeletons of single-celled algae. Diatomite is used for filters in water purification and as an absorbent material. One well-known diatomite product is cat litter.

Most of the state's **limestone** is mined in Baker County. It is made into cement and agricultural lime. Some of it is also used in local beet sugar refineries.

**Pumice** is an air-filled volcanic rock common to central Oregon. Pumice is used in construction, landscaping, and horticulture, for stone-washing clothes, and as an additive for lightweight concrete.

Oregon produced several other industrial minerals in 1993. **Silica sand**, which is a quartz-rich sand, was mined in two places in the state. Most of it is used for making glass bottles. **Dimension and decorative stone** were produced in small amounts throughout Oregon and are used for landscaping and construction of buildings and walkways. **Zeolites** were mined in eastern Oregon. They are an unusual class of minerals used in certain chemical and industrial applications for their selective absorption properties. **Soapstone** was mined in southwestern Oregon. Soapstone is soft, attractive, and easy to carve. It is used by artists as a sculptural stone. **Perlite** was mined in eastern Oregon. Perlite is an unusual rock that puffs up when heated. You will find it in potting soils sold at most gardening shops. **Emery** was mined in Linn County. It is used for skid-resistant surfaces on sidewalks and bridges.

**Gold** production in 1993 totaled 2,021 troy ounces valued at $788,000. These are rough estimates based on surveys of producers, geologists, gold buyers, and various field experts. Most of Oregon's gold came from Baker and Grant Counties. All of Oregon's gold came from small seasonal operations. They physically extract gold from soil and gravel. Only a handful of gold producers mined more than 10 oz of gold in 1993.

**Gemstone** mining totaled $1.3 million. That makes Oregon the seventh largest producer in the United States. The output of gemstones is expected to more than triple in 1994 because of expanding markets for sunstones and opals. Those two gemstones accounted for 65 percent of Oregon's output in 1993.

Sunstones are clear feldspar crystals. They are found in Harney and Lake Counties. Sunstones come in a wide range of colors. They sometimes contain minuscule flecks of natural copper metal. The most valuable sunstones are red with copper flecks. Most Oregon sunstones are sent to Asia for faceting. The cut stones are then sold to jewelry makers around the world.

Oregon produces precious fire and blue opals. Most of the production comes from Morrow and Lake Counties. Small amounts are found elsewhere in the state.

Other gemstones mined in Oregon include agates, geodes, picture rock, jasper, obsidian, thunder eggs, and quartz crystals. Most of these are collected by individuals and are not extracted from regular mines.

## REGIONAL ECONOMIC IMPACTS

In 1993, mineral production added $102.4 million in taxes and income to Oregon's economy. This came in the forms of payroll, employee benefits, operating profits, taxes, royalties, and fees. Worker payrolls and benefits accounted for 57 percent of the total. The industry had the equivalent of 2,039 full-time employees engaged in mineral extraction. In addition, it employed many workers for related activities such as trucking, operating asphalt plants, and marketing.

Economic impact is an appraisal of the increased sales or income in an economy due to an activity. It is an estimate of the benefits and costs. In this analysis, we measure the economic impact by estimating the value added by Oregon's mineral industries. It is the sum of wages, profits, rents, royalties, and indirect business taxes.

In our analysis, we used industry averages, contacts with producers, state payroll data, and proprietary consolidated financial statements. With this information and our own survey we were able to estimate economic impacts.

Employment is a key variable. Most mines are seasonal. A mine with six workers may run, for instance, for two months. That equals 12 months of work in total or the equivalent of one full-time employee. For this analysis, we converted all part-time and seasonal labor into the equivalent of full-time employees working for a whole year.

Our survey revealed that while 2,938 people worked at Oregon's mines and natural gas field in 1993, the total amount of work done equaled 2,039 full-time workers.

Our estimate of mining and natural gas employment is 56 percent higher than the figure reported by the Oregon Employment Division. One reason for the difference is that the state collects data only on workers covered by unemployment insurance. Several hundred mining proprietorships and partnerships are not covered. The state agency also does not count all the county road and forestry workers, who engage in mining. They are classified as public workers rather than miners.

Unlike the Employment Division, we counted all the mine and natural-gas well employees, including part-time workers. The difference in coverage between our survey and the Division's is substantial. The number of mines reporting to the Employment Division in 1993 was about 100. Over 600 establishments reported workers to our survey.

Mining occurs in every county in Oregon, but most of it is concentrated along the Interstate 5 corridor. The highest dollar value of mineral production in 1993 occurred in the Portland metropolitan area. Washington County led the state in the value of minerals produced.

Statewide, besides the $102.4 million directly added to the economy, the mineral industry created indirect benefits. These result from the money spent in local communities that, in turn, creates more employment and spending.

One of the most important indirect impacts is found in transportation. From the survey, we estimate that 973 workers (mostly truck drivers) were used to ship Oregon's mineral products. Another large indirect impact is the work created at asphalt and concrete plants. These businesses depend on construction aggregates and employed 2,071 workers in 1993.

We cannot calculate total indirect benefits because of limitations on economic data. However, it is clear that local mining creates downstream jobs in shipping, concrete products, and many other areas.

Another way to view the economic impact is to consider what Oregon would be like if no mineral extraction occurred. The state would have to import all its minerals. Immediately, 2,039 direct jobs would be lost, as would $102.4 million in taxes and income. The indirect losses would also be great as customers would have to pay more for minerals imported from out-of-state.

Table 2 shows the direct economic impact of mining around Oregon. The state is divided into 11 groups of counties (Figure 1). This was done to ensure the anonymity of survey respondents.

Table 2. *Regional economic impacts of 1993 mineral production in Oregon*

| Region (counties) | Employment[1] | Value of production | Economic impact |
|---|---|---|---|
| **Central** (Crook, Deschutes, Jefferson, Wheeler) | 188 | $20,061,110 | $10,325,911 |
| **Inland southwest** (Douglas, Jackson, Josephine) | 228 | 21,312,023 | 9,894,261 |
| **North-central** (Hood River, Gilliam, Morrow, Sherman, Wasco) | 51 | 4,673,430 | 2,089,123 |
| **North coast** (Clatsop, Lincoln, Tillamook) | 115 | 9,724,597 | 4,620,201 |
| **Northeast** (Baker, Grant, Umatilla, Union, Wallowa) | 198 | 20,043,523 | 8,730,037 |
| **North Willamette Valley** (Marion, Polk, Yamhill) | 199 | 28,713,306 | 11,500,240 |
| **Portland Area** (Clackamas, Columbia, Multnomah, Washington) | 451 | 76,806,862 | 26,967,950 |
| **South-central** (Lake, Klamath) | 125 | 9,549,764 | 5,187,960 |
| **South coast** (Coos, Curry) | 115 | 7,541,531 | 4,216,523 |
| **Southeast** (Harney, Malheur) | 101 | 11,599,750 | 5,376,862 |
| **South Willamette Valley** (Benton, Lane, Linn) | 270 | 29,875,845 | 13,505,071 |
| **STATE TOTAL** | **2,039** | **$239,901,741** | **$102,414,141** |

[1] The equivalent number of full-time, year-round jobs directly in mining and mine supervision.

Table 3. *How Oregon's minerals were shipped in 1993*

| Mode of transportation | Value of minerals | Percent of total |
|---|---|---|
| Truck owned by producer | $113,635,658 | 47.4 |
| Truck owned by other entity | 97,265,499 | 40.5 |
| Railroad | 7,983,062 | 3.3 |
| Water | 13,928,842 | 5.8 |
| Other[1] | 7,088,680 | 3.0 |
| **TOTAL** | **$239,901,741** | **100.0** |

[1] Shipment by natural-gas pipeline, U.S. mail, air freight, and delivery services. Also includes minerals used at production site.

## HOW MINERALS WERE SHIPPED IN 1993

Our survey asked producers about shipping. This was done because transportation is the biggest cost in marketing some minerals. Often mineral deposits can only be economically developed if they are close to shipping routes or consumers.

By far, trucking is the principal way minerals are shipped. Almost half of the state's output goes on trucks owned by mine operators. Another 41 percent is loaded on trucks owned by customers and independent haulers.

Water transportation, which is mainly by river barge, had a 5.8-percent share of the mineral market in 1993. Railroads carried only 3.3 percent. Another 3.0 percent was shipped by other means or not shipped at all. Most of this was natural gas being transported by pipelines from Columbia County.

Table 3 is a summary of how Oregon's mineral production was shipped in 1993. The shares and amounts are based on dollar values.

Table 4 is a compilation of how construction aggregates were shipped from production sites. Unlike the previous table, amounts and percentages on Table 4 are based on tons of aggregates shipped.

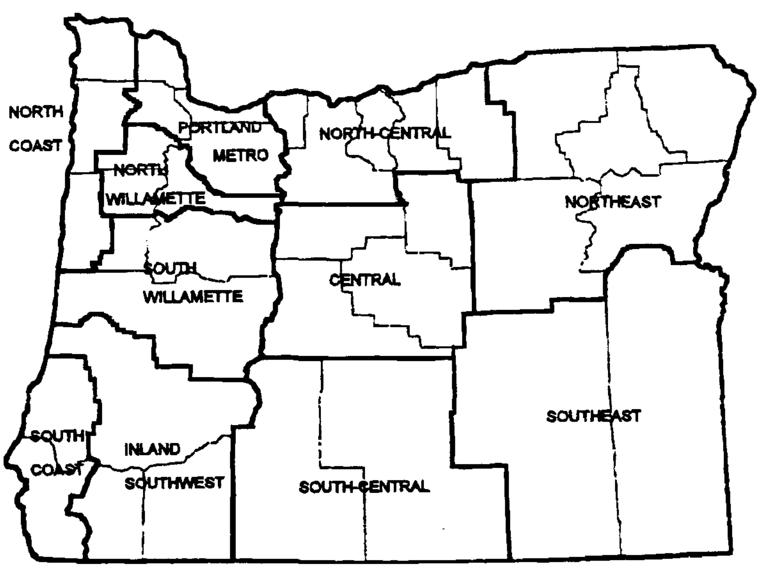


*Figure 1. Regions of the state as used in Tables 2 and 5.*

In 1993, 92.1 percent of Oregon's aggregate production was shipped by truck. Nearly 44.9 million tons went on trucks. If the average load was 20 tons, that would amount to 2,244,843 individual truck shipments. This has a direct effect on road congestion and pavement damage. In addition to shipments from Oregon mines, much of the aggregate coming into the state from Washington was trucked in. These shipments are not counted in Table 4.

Most aggregate is trucked less than 15 miles. Shipping distances have been growing, however, because mines that are close to markets are being replaced by mines farther away. Consumers are compromising by using a combination of lower quality aggregate and shipping-in material from more distant mines. This directly increases the cost of road and building construction for communities.

Table 4. *How aggregate was shipped in 1993*

| Mode of transportation | Tons | Percent of total | Est. number of loads[1] |
|---|---|---|---|
| Truck owned by producer | 25,212,424 | 51.7 | 1,260,621 |
| Truck owned by other entity | 19,684,435 | 40.4 | 984,222 |
| Subtotal for all trucks | 44,896,859 | 92.1 | 2,244,843 |
| Railroad | 1,029,265 | 2.1 | 10,293 |
| Water | 2,813,134 | 5.8 | 1,875 |
| Other[2] | 860 | 0.0 | 0 |
| TOTAL | 48,740,117 | 100.0 | 2,257,011 |

[1] This assumes that the average truck carried 20 tons of aggregate, the average rail car carried 100 tons, and the average barge took 1,500 tons. The number of loads equals the number of one-way shipments.
[2] Aggregate that was mined and used on-site.

## CONSUMPTION OF AGGREGATES

In Oregon, construction aggregates are usually used within a few miles from where they are produced. We do know, however, that aggregate crosses state lines. Some of it comes in by rail from long distances.

In an informal survey, we estimated the amount of construction aggregate that moved between regions in our state. This gave us apparent consumption figures for 11 regions in the state (Table 5).

Apparent consumption equals production plus imports and minus exports. Actual consumption can differ from this because of inventory fluctuations. For construction aggregates, however, such variations are rarely significant.

The biggest flow of aggregates across regional borders happens in the Portland area. That region imports, on a net basis, about 3.3 million tons of aggregate from Clark County in Washington and from Oregon counties to the south. Most of the aggregate from Washington State is trucked down Interstate 205 to Clackamas County.

Eastern Oregon exports sizable amounts of sand and gravel to Washington and Idaho. Southern Oregon exports a small amount to California. Railroads also ship aggregate across state lines. These shipments are mostly crushed rock that the railroads use themselves.

Aggregate consumption in Oregon totaled 51.2 million tons in 1993. That equals 16.8 tons per capita. The intensity of use ranged widely from area to area. It was generally greater in rural counties with low population densities. Consumption in southeastern Oregon, which includes Harney and Malheur Counties, was 34.1 tons per capita. In urban areas, it was much less. In the Portland metropolitan area, the per capita consumption totaled 12.7 tons.

## SUPPLY OF AGGREGATES

In addition to the aggregate produced by privately owned mines, large quantities are mined by or for public agencies. Significant amounts are also produced by forest products companies and Indian Reservations. This is an important part of the state's aggregate supply.

In 1993, a total of 902,080 tons of aggregate was mined from BLM, USFS, and State Forest land. This does not include private, county, and State Highway Division mine production on those lands.

Table 5. *1993 apparent consumption of aggregates (in tons) for 11 regions in Oregon*[1]. *Regions and county allocation same as in Table 2 and Figure 1*

| Region | Local production | Net imports (exports) | Apparent consumption | Per capita consumption[2] |
|---|---|---|---|---|
| **Central** | 3,808,519 | 62,000 | 3,870,519 | 32.7 |
| **Inland southwest** | 5,470,082 | (30,000) | 5,440,082 | 17.0 |
| **North-central** | 973,788 | 56,000 | 1,029,788 | 19.6 |
| **North coast** | 2,213,547 | 55,000 | 2,268,547 | 23.5 |
| **Northeast** | 3,446,588 | (317,100) | 3,129,488 | 26.4 |
| **North Willamette Valley** | 6,607,330 | (613,500) | 5,993,830 | 16.2 |
| **Portland area** | 13,346,057 | 3,292,500 | 16,638,557 | 12.7 |
| **South-central** | 2,098,955 | 0 | 2,098,955 | 31.0 |
| **South coast** | 1,688,712 | 40,000 | 1,728,712 | 20.6 |
| **Southeast** | 1,273,312 | (100,000) | 1,173,312 | 34.1 |
| **South Willamette Valley** | 7,813,227 | (12,000) | 7,801,227 | 16.7 |
| **STATE TOTAL** | **48,740,117** | **2,432,900** | **51,173,017** | **16.8** |

[1] Includes crushed rock, pit run rock, sand and gravel from all sources, cinder, fill, and decomposed granite.
[2] Apparent consumption divided by mid-1993 population.

The Oregon Department of Transportation (ODOT) produced 2,011,120 tons in 1993. ODOT uses its own aggregate whenever commercial supplies are impractical. This tends to happen in eastern and central Oregon. That is where over 92 percent of ODOT's mining took place.

County road departments are major aggregate producers. Some counties also have forestry departments that occasionally run mines. A few cities and local governments have mines or river dredging operations. All of these counties and local agencies mined 1,952,723 tons of aggregate in 1993.

Table 6 is a list of these producers broken down by major regions.

Forest products companies need rock for their roads. Even if they are not logging, companies will put rock on roads that they use for forest management, fire prevention, and thinning.

Their need is greatest on main hauling roads that cross rough terrain in rainy areas. The need for aggregate by the timber industry is, therefore, greatest in the Coast Range. It is particularly high in the central Coast Range where the poor-quality local rock is soft and weathers quickly. It must be replaced often. As you move further east, the amount of aggregate needed for every mile of road declines. In parts of eastern Oregon, some logging roads use no mined aggregate at all.

**Table 6.** *1993 aggregate mining by public agencies (in tons)*

| Region | BLM, USFS, State Forests[1] | ODOT | Counties and local governments |
|---|---|---|---|
| **Eastern Oregon**[2] | 308,188 | 1,031,900 | 648,730 |
| **Central Oregon**[3] | 101,631 | 853,605 | 835,320 |
| **Western Oregon**[4] | 492,261 | 125,615 | 468,637 |
| **STATE TOTAL** | 902,080 | 2,011,120 | 1,952,687 |

[1] Excludes production captured elsewhere in the survey from ODOT, county road departments, local governments, and commercial mines operating on BLM and USFS lands.
[2] Baker, Grant, Harney, Malheur, Umatilla, Union, and Wallowa Counties.
[3] Crook, Deschutes, Gilliam, Hood River, Jefferson, Klamath, Lake, Morrow, Sherman, Wasco, and Wheeler Counties.
[4] Clatsop, Columbia, Clackamas, Multnomah, Tillamook, Washington, Yamhill, Marion, Polk, Lincoln, Linn, Benton, Lane, Douglas, Coos, Curry, Jackson, and Josephine Counties.

Because forests are usually far from commercial mines and quarries, timber companies often mine their own aggregates. As long as the company does not sell the aggregate, it can mine without filing mining permits. It still must abide by forestry practices and regulations. Production of this type totaled 2,283,843 tons in 1993. The industry probably bought an additional 1,344,000 tons of aggregate from commercial mines.

Much of the aggregate produced on USFS and BLM land is used for logging roads. Together, these agencies' use in forestry is about 600,000 tons. Oregon's Forestry Department uses all its aggregate for logging roads. In 1993, the agency mined 243,538 tons. Indian Reservations mined 107,200 tons for their logging roads.

We estimate that, in total, the timber industry consumed 3,984,581 tons of aggregate in 1993. Of that total, 1,209,349 tons were approximated statistically and not directly surveyed. This was based on information from forest products companies, regulators, and consultants. We also relied on forest ownership and harvest data.

Indian Reservations mined a total of 176,276 tons of aggregate in 1993. The Warm Springs and Umatilla Reservations produced nearly all the aggregate from Reservations in Oregon.

**MINING ON USFS AND BLM LANDS**

USDA Forest Service lands are an important source of minerals. We believe that, in 1993, the true market value of minerals mined on USFS lands was $3.5 million. This does not include mining by ODOT, county road departments, and a few commercial operators. Much of the net production of aggregates is used for maintaining and building roads on USFS land. Production for roads is down sharply from previous years because of budget constraints.

USFS lands were the main source of gold mined in Oregon. A small amount of decorative stone and perlite were also taken from USFS lands. This production is summarized in Table 7.

Table 7. *1993 mining on USDA Forest Service lands (in tons, unless otherwise noted)*

| Commodity | Production |
|---|---|
| **Net production of aggregates**[1] | |
| Crushed rock | 562,898 |
| Pit run rock | 33,792 |
| Sand, gravel, and fill | 30,997 |
| Cinders | 16,027 |
| All aggregates (net) | 643,714 |
| Estimated production by counties, ODOT, and private mines counted elsewhere | 315,000 |
| Gross production of aggregates | 958,714 |
| **Other minerals** | |
| Decorative stone | 2,096 |
| Perlite | 50 |
| Gold (in troy ounces) | 1,657 |

[1] Net production includes output for USDA Forest Service internal use on its roads, mining done by small producers, material taken from community pits, material removed by individuals with free-use permits, and production tied to timber sales. Production by ODOT, county road departments, local governments, and some commercial mining companies is not included in net production. These amounts are reported elsewhere in the survey.

Production on BLM lands in 1993 was well below the levels of past years. The estimated market value of net mineral production totaled only $272,887. The BLM used to be a major aggregate producer, but output has been sharply curtailed due to budget cuts and falling timber harvest revenues.

The agency uses money from timber sales to pay for the crushed rock it produces for its own roads. The BLM, for several years now, has relied on old stockpiles of crushed rock and has supplemented it with small purchases from commercial sources.

Table 8 is a summary of BLM mineral production for 1993.

Table 8. *1993 mining on Bureau of Land Management properties (in tons, unless otherwise noted)*

| Commodity | Production |
|---|---|
| **Net production of aggregates1** | |
| Crushed rock | 17,593 |
| Pit run rock | 5,238 |
| Sand and gravel | 2,221 |
| Fill | 3,060 |
| Cinders | 26,716 |
| All aggregates (net) | 54,828 |
| Estimated production by counties, ODOT, and private mines counted elsewhere | 259,880 |
| Gross production of aggregates | 314,708 |
| Of which | |
| Negotiated sales | 31,840 |
| Timber sales | 2,065 |
| Commercial, free-use, and community pits | 259,880 |
| Other | 20,923 |
| **Other minerals** | |
| Decorative stone | 52 |
| Clay (free-use and community pits) | 2,925 |
| Gold (in troy ounces) | 219 |

[1] Excludes production for ODOT, county road departments, local governments, and commercial mining, which are included elsewhere in the survey.

**ACKNOWLEDGMENTS**

The author thanks Bruce Weber, Department of Agricultural and Resource Economics, and Stanley Miles, Economic Information Office, both at Oregon State University, for helpful reviews of this paper. □

# DOGAMI honors volunteers at dinner

The Oregon Department of Geology and Mineral Industries (DOGAMI) has an active volunteer program. During the last year, 14 volunteers have donated 2,110 hours, or 263.75 working days, to DOGAMI. To show its appreciation, DOGAMI honored its volunteers at a dinner in Portland on November 30, 1994. Eleven of the volunteers who were present were given certificates of appreciation by State Geologist Donald Hull. Four of the volunteers, Wally McClung, Rosemary Kenney, Archie Strong, and Margaret Steere, who have donated more than 500 hours of volunteer service over the years to DOGAMI, also received engraved clocks.

Speaker for the evening was Robert Whelan, Minerals Economist for DOGAMI. He talked about the place of minerals in Oregon's economy, describing his work with DOGAMI and presenting some of the results of his recent survey of mineral producers in the state.

DOGAMI has had an active volunteer program since 1990. The two original volunteers, Margaret Steere and Rosemary Kenney, are still active in the program and were among the four given clocks for having donated more than 500 hours. Volunteers work primarily in the Nature of the Northwest Information Center or in the DOGAMI library but have contributed in other ways such as helping with field projects, office work, or mailings. New volunteers are always welcome, particularly in these days of dwindling budgets and heavier DOGAMI responsibilities, so anyone who would like to help is urged to contact Beverly Vogt, Volunteer Coordinator (phone 503-731-4100). □

# Episodic flooding of prehistoric settlements at the mouth of the Coquille River

*by Roberta L. Hall, Department of Anthropology, Oregon State University, Corvallis, Oregon 97331, and Stefan Radosevich, Department of Anthropology, University of Oregon, Eugene, Oregon 97401*

The archaeological record left behind by people who lived near the mouth of the Coquille River as long as 3,000 years ago provides evidence of past geologic events (Figure 1). The site chosen by Euro-American settlers for the initial commercial district of Bandon has proved through several archaeological investigations in recent years to have been intensively occupied in previous times by Native Americans who relied on the bounty of the forests, river, and ocean. The stratigraphy of the site also reveals interruptions in the human occupation, presumably signifying periods when the population had moved elsewhere, perhaps because the place became temporarily inhospitable. Besides these evident gaps, our investigation has also found evidence of human habitation at levels below the current water table and near the present sea level. These data suggest that significant changes in land and water relationships occurred due to sea level fluctuation, subsidence, uplift, or a combination of factors.

Site 35CS43 (35 designates the State of Oregon, CS designates Coos County, and 43 indicates that this was the 43rd site recorded in the county) on the Coquille River estuary is shown in Figure 2. Test excavations in 1988 (Hall and others, 1990) and in 1990 revealed thick layers of sand covering some of the occupation layers, which are rich in stone tools, shells, and bone fragments from fish, birds, and land and sea mammals. In one of eight 2-m by 2-m excavation units studied in 1990, two very large bowl-shaped objects made of unfired clay were uncovered from a depth of more than 1 m. Charcoal from a nearby unit of equivalent depth gave an estimated radiocarbon age of 1,890 ± 170 years B.P. (Beta-41017). Preservation of the clay vessels is surprising—although their walls are several centimeters thick, the unfired vessels were not portable and would have been subject to breakage if left without protection for a length of time. Their preservation led us to postulate that the sand layer more than 30 cm thick that covered them had been deposited rapidly and had preserved the structure of the vessels (Hall, 1994).

Studies of geology and archaeology along the Pacific Coast have suggested that periodic earthquakes could produce such a deposit by inducing a tsunami or by causing rapid subsidence and the deposition of river-borne sediment (Atwater, 1987; Yeats, 1989; Darienzo and Peterson, 1990; Woodward and others, 1990; Komar and others, 1991; Nelson and Personius, 1991; Clarke and Carver, 1992; Komar, 1992; Nelson, 1992b). Evidence in the Coquille estuary of abrupt subsidence within the past 500 years that is believed to be related to earthquakes comes from analysis of buried peat in the Bandon marsh (Nelson, 1992a). Surveys of the head of tidewater over the past 150 years indicate that uplift is currently occurring in the lower Coquille basin (Benner, 1991).

Because of historic disturbance at Site 35CS43 at Bandon, information about very recent geologic events has not been found, but the site tells a long story of repeated flood and human occupation cycles over the past several thousand years. The resolution of whether the flood episodes that are evident at the archaeological site are episodes of tsunamis or of subsidence that are earthquake related could be advanced by geologic studies in the estuary and at other sites on the Pacific Coast, but studies at the Strait of Juan de Fuca (Mathewes and Clague, 1994) have shown that uplift and subsidence effects can vary greatly at nearby sites. Alternative hypotheses that could account for the strata of water-deposited sediment and the thick layers of sand include ocean storms, river floods, and dune movement.

To obtain additional data with which to explore these possibilities, a field project to remove cores from the site for detailed analysis of the stratigraphy and soils was carried out in August 1993. In addition, Unit 17, one of eight 2-m by 2-m excavation units studied in 1990, was reopened, and its north wall was stratigraphically analyzed. Figure 3 shows the location of the excavation units and the cores; Figure 4 shows the stratigraphy of Unit 17. A Giddings probe (Figure 5) was used to obtain the five cores. Samples from the cores and from the north wall of Unit 17 were tested for a battery of chemical elements and properties, most importantly for phosphorus, carbon (through loss on ignition), strontium, barium, calcium, and soil pH. In addition, mineralogic and grain size analyses were performed, and four radiocarbon tests were made.

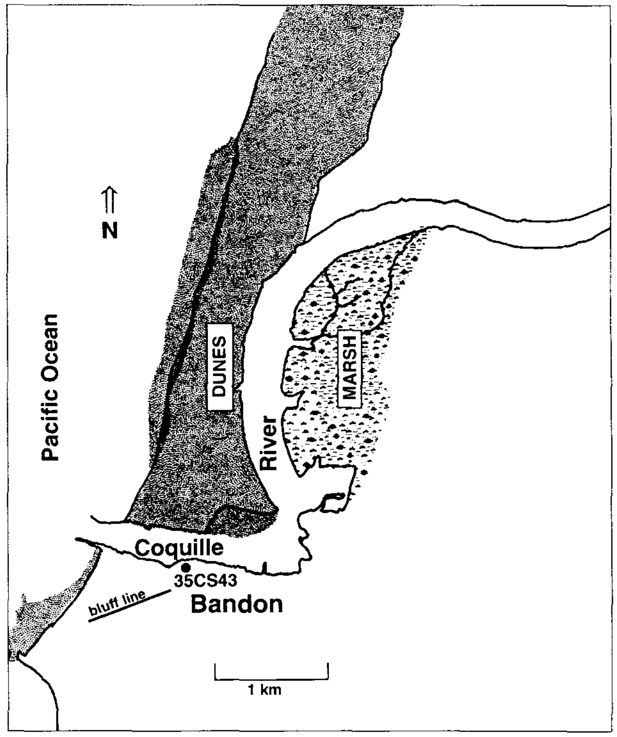


*Figure 1. Map showing location of study area, Site 35CS43, on the Coquille estuary.*

Because the site was the location of Bandon's first commercial district, the upper 50 cm is disturbed; this has essentially removed stratigraphic information about the past 1,000 years. Below 50 cm, however, many pristine patches of deposits exist. All five cores gave indication of changes over time in the degree and intensity of human occupation and indicate variation in the topography, stratigraphy, and probably also in land and water relationships. Extending almost 3 m below the surface, cores went below the current water table and near the level of high tide at the river's edge. Cores 4 and 5 contained beds several centimeters thick that include relict bedding planes (Figure 6) giving visual evidence of past floodwater deposits. These deposits became the parent material of the resulting Inceptisols that constitute the site.

The beds in Cores 4 and 5 do not represent the same flood event, however. Considering all depths relative to the a single datum, the relict bedding plane in Core 5 lies 70 cm deeper than that in Core 4. In both cores, thick strata of shell-midden deposits occur below as well as above the flood deposit strata. Radiocarbon dates made from bulk soil samples of core several centimeters above each of the bedding planes confirmed their separation in time. The deeper sample from Core 5 produced a radiocarbon age of 3,550 ± 90 years B.P. (Beta-69464), whereas the sample from Core 4 produced a radiocarbon date of 1,250 ± 60 years B.P. (Beta-69462).

The 29 samples analyzed by Chemex Labs, Inc., of Sparks, Nevada, confirmed that soil formation processes at the site have included intense anthropogenic episodes separated by periods lacking human occupation. Strata that contained degraded midden deposits of invertebrates and vertebrates were very high in phosphorus (in several samples greater than 10,000 parts per million) as well as carbon, calcium, and strontium; pH was neutral to slightly alkaline (7.0-7.5). In contrast, two samples taken from soil on the bluff above the site and one sample from a previously excavated site on the estuary that does not contain midden deposits (Hall and others, 1992) were somewhat acidic (5.0-6.0) and relatively low in phosphorus, strontium, and calcium, but high in carbon (Table 1). Samples from parts of the cores that were not middens were low in phosphorus, strontium, calcium, and carbon, but were similar to midden samples in pH. The most intensely anthropogenic strata had a much greater concentration of phosphorus and carbon than archaeological sites in other areas that have been tested (Eidt, 1977; Moss, 1984; McDowell, 1988, 1989; McDowell and Willson, 1991). Chemical tests thus confirm the episodic nature of human occupation at 35CS43 and tell a story of repeated occupation episodes, apparently separated by overbank depositions from floods.

In addition to radiocarbon tests on bulk soil in two cores, charcoal from level K from the north wall of Unit 17 (Figure 4) yielded a radiocarbon age of 1620 ± 60 years B.P. (Beta-67695). Shell fragments also from level K yielded a radiocarbon age of 2,270 ± 60 years B.P., which was reduced to 1,880 ± 70 years B.P. after a standard adjustment was made to correct for upwelling that affects marine organisms (Beta-69461). These two estimates are in line with previous dates obtained in Area B (Hall, 1994). The lone, very old date of 3,550 years (noted previously) from a depth of over 2 m in Core 5 on the north side of First Street needs corroboration but is potentially of great interest, particularly since it lies above a relict bed of flood deposits, which itself overlies a shell midden.

Samples were analyzed for mineralogy by Sam Boggs and Pete Condon of the University of Oregon Department of Geology. Thin sections of soil samples from two of the cores and from depths of 70 to 168 cm below the surface at the north wall of Unit 17 were subjected to point-count analysis. After the fine-grained matrix that surrounded the clasts was removed, single quartz grains predominated, representing from 33 to 40 percent of the samples. Two other categories of quartz grains, polycrystalline quartz with abundant clay or iron oxide and coarse polycrystalline quartz with two or more crystals per grain, represented an additional 17 to 30 percent of each sample. Condon reported that the heterolithic nature and high grain

*Figure 2. View from the bluff south of Site 35CS43, showing archaeological excavations conducted in the summer of 1990. This site was occupied by Native Americans periodically over the last several thousand years; it also was the location of the Coquille Ferry, which began operations in 1853, and was the site of the first commercial district of Bandon, which was developed in the late 1880s.*

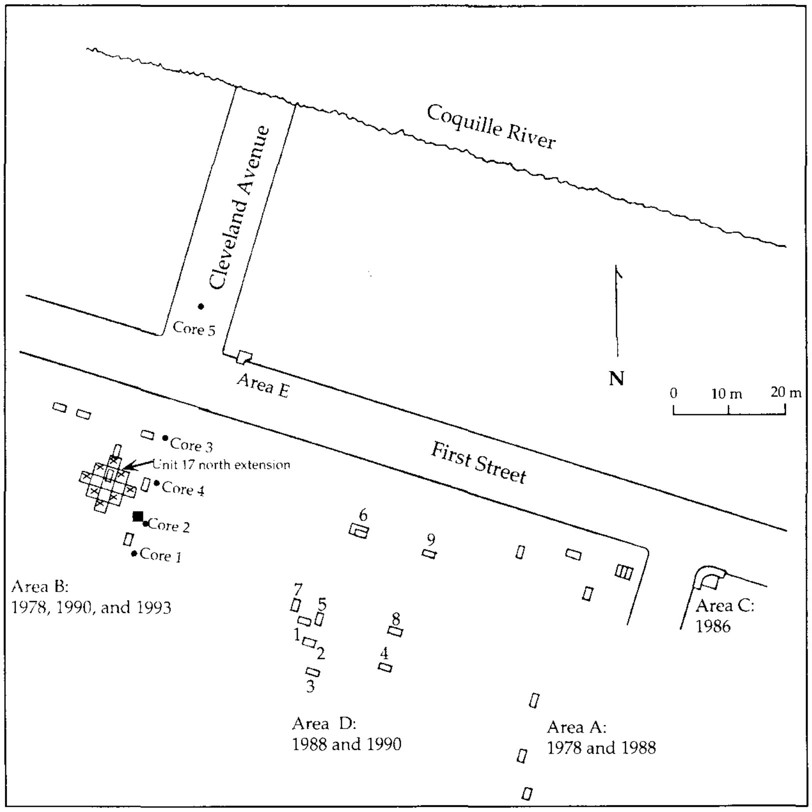


*Figure 3. Map of excavation units and cores at Site 35CS43. This report draws on samples taken in August 1993 from the five cores and the north wall of Unit 17.*

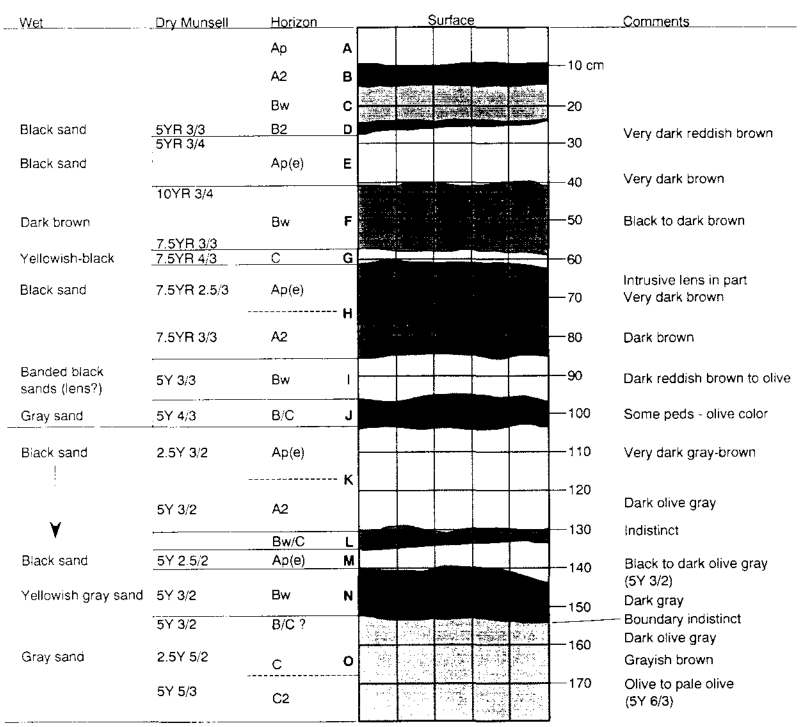


*Figure 4. Schematic drawing of strata of the north wall of Unit 17. Color classifications are based on Munsell Soil Color Charts (Macbeth, 1990).*

angularity of the samples suggests that they are immature, probably derived from erosion of several types of rock, and were not transported a great distance. Boggs and Condon concluded that the materials represent fluvial overbank sediments deposited at times of high water.

Grain-size analysis performed by Chemex Labs, Inc., indicated a bimodal distribution and great uniformity in all samples. The predominant fraction of 50 percent or more was of coarse sand to pebble sized clasts, while another sizable fraction of about 35 percent was of medium to fine sand, with little material falling between these extremes. Both the mineralogic and the grain-size analyses showed that site samples differed greatly from the soil samples taken from the bluff above the site and gave several indications of a riverine origin. The implication is that the parent materials for the site lie not far upriver in the Coquille River basin. Determining the cause of the overbank deposits requires further inference, however. A historic flood such as was observed in 1861 (Komar and others, 1991, p. 15) could move deposits downriver, or an ocean storm could move into the estuary and upriver, where it could pick up sediments for deposition near the mouth. Similarly, a tsunami set off by a subduction-zone earthquake would be expected to produce a great surge of water that could move up the estuary, pick up sediment from upriver, and deposit it near the mouth on its return.

Radiocarbon tests provide a basic framework for understanding archaeologic or geologic events but not a precise history, because they define a range of years rather than an exact date (Nelson, 1992a). Ideally, it would be useful to determine whether the flood events recorded in our cores are correlated with evidence of subsidence or floods elsewhere in the estuary or along the southern Oregon coast. Data from Bradley Lake, 5 km south of the Coquille estuary, suggest three earthquake subsidence episodes at approximately 300, 1,000 and 1,600 years ago (Nelson and others, 1994). Because our date from Core 4 is based on bulk material above the flood deposit bed, we infer that the flood recorded in Core 4 occurred before 1,250 years ago and thus could refer to the subsidence event of 1,600 years ago at Bradley Lake. The flood deposit evident in Core 5 precedes recorded subsidence events and offers lines of study for geologists in nearby areas. While these results are suggestive, they are far from conclusive. To establish the contemporaneity of geologic events, more radiocarbon dates would be required both above and below the flood-deposition strata. Thus, while we have made a case for the existence, over the past several thousand years, of a series of changes in land and water relationships at the mouth of the Coquille River, we have not been able to select or eliminate any of the hypotheses that singly or together could account for the episodes.

Multiple forces working at the river's mouth have made the geological and archaeological records difficult to interpret. Natural factors that make the site complex include the Coquille River, which has been known to flood in historic time; the presence of a bluff to the south of the site that stands about 25 m above sea level and includes 100,000-year-old marine terraces; a creek that flows down the bluff to the west of the site but in early historic time probably passed near or through the site and could have caused erosion; dune movement and changes in the river's course and the position of its mouth; processes of subsidence and uplift that could have been sudden or gradual; ocean storms that may have surged up the estuary and onto the site; and tsunamis that may have been generated by earthquakes. In addition, human activities have contributed to the complexity of the site. Upper levels have been disturbed by the construction of footings and basements for buildings, laying of water and sewer lines, and two devastating fires that swept Bandon in 1914 and 1936 and resulted in deposition of large amounts of debris. The effect of early native communities is evident below the debris left by settlers in historic time. At the time of contact with Europeans, native homes were dug as much as a meter into the ground, and this practice likely dates back into prehistoric time as well. In addition to construction activities, the natives' extensive food-gathering and food-preparation activities changed soil characteristics. Shellfish middens built up the soil and also raised the pH, retarding decomposition of animal bone refuse.

Greater specificity in dates from site 35CS43 and from buried tidal-wetland soils along the coast may help to resolve historic questions regarding the cycles of human settlement and geologic questions regarding the incidence and effects of floods and earthquakes. Whatever the causes for the periodicity of settlement and floods, the prehistoric data are consistent with other studies of coastal margins, which indicates the need for caution in coastal and river-front development in Bandon and other towns of Oregon's Pacific coast (Komar, 1992). While development of the Bandon

Table 1. *Phosphorus, pH, loss on ignition, strontium, and calcium in selected samples*

| Samples | Phosphorus (P) (ppm) | pH | Loss on ignition (percent) | Strontium (Sr) (ppm) | Calcium (Ca) (percent) |
|---|---|---|---|---|---|
| **Midden in Unit 17, level K** | >10,000 | 7.5 | 7.0 | 467 | 6.43 |
| **Near bed in Core 4** | 690 | 7.7 | 2.6 | 187 | 1.22 |
| **Bluff, 50 cm** | 350 | 5.2 | 5.8 | 162 | 0.61 |
| **Ferry Creek site**[1] | 520 | 5.2 | 9.6 | 132 | 0.74 |

[1] Sample from excavated trench at Ferry Creek waste-water treatment site, 1 km upriver from 35CS43, which on investigation proved not to be a prehistoric human settlement (Hall and others, 1992).

*Figure 5. Stefan Radosevich and Roberta Hall watch as David Liberty uses the Giddings probe to remove a core for soil analysis in the field project at Site 35CS43 in August 1993.*

*Figure 6. Portion of Core 5 containing distinct bedding plane. Note shell midden below it (to the right in the picture).*

jetty 100 years ago (Hall, 1992) has stabilized the mouth of the river in the short run, it may not protect the coastal area from major hazards. Archaeological data indicate that prehistoric people also had a major impact on the lands they occupied, but, like contemporary societies, their continuation ultimately depended upon natural forces. Data from geology and archaeology together provide insights into the struggles and solutions of people in the past and should be used to anticipate and prepare for geologic forces in the future (Yeats, 1989).


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## Cover photo

George Priest, western regional geologist for DOGAMI, discusses details of new geologic marker describing tsunamis and their occurrences in the Reedsport area. The marker is located at the Tourist Information Center in Reedsport and was unveiled and dedicated February 4, 1995. Similar markers have been placed in Seaside and Newport. This issue contains several articles that address the subject of tsunamis as a coastal catastrophic hazard.

## In memoriam: Margaret Steere

Margaret Steere, geologist and geologic editor with the Oregon Department of Geology and Mineral Industries (DOGAMI) for almost 30 years, died of pneumonia on January 29, 1995. A native of Muskegon, Michigan, Margaret received her bachelor's and master's degrees in geology from the University of Michigan. She came to Oregon during World War II and worked as a cartographer for the U.S. Army Corps of Engineers. She joined the DOGAMI staff in October of 1947, working first as a librarian and later as geologist and geologic editor. She retired from DOGAMI in 1977 but returned in 1991 as a volunteer, donating 691 hours of volunteer service.

*Margaret L. Steere*

During her working years with DOGAMI, Margaret produced over 300 issues of the *Ore Bin*, DOGAMI's monthly publication, and edited almost 60 Bulletins, plus numerous other Short Papers, Miscellaneous Papers, Oil and Gas Investigations, geologic maps, and open-file reports. Her knowledge of geology, ability to organize, mastery of language, sense of humor, and endless patience enabled her to bring these detailed publications to press, often under difficult circumstances. Although paleontology was not her original focus in geology, she became the resident expert because there was a need for paleontological knowledge in DOGAMI. Her articles on fossils were some of the most popular articles in the *Ore Bin*. Bulletin 92, *Fossils in Oregon*, which contains reprints of many of her articles, is still one of DOGAMI's most popular publications.

In addition to her work on publications, she had responsibility for maintaining the DOGAMI museum and devoted many hours to curating the collection. Her work with publications, the museum collection, and paleontology put her in contact with many of the major geologists of her time. Correspondence found in her files shows the respect and appreciation that many of these geologists felt for her work.

During her retirement, she was an active member of the Geological Society of the Oregon Country, often working behind the scenes to see that work that needed to be done was done properly. She also developed considerable skill as a water colorist. When

*(Continued on page 32)*

# Oil and gas exploration and development in Oregon, 1994

*by Dan E. Wermiel, Petroleum Geologist, Oregon Department of Geology and Mineral Industries*


## ABSTRACT

Oil and gas leasing activity was about the same during 1994 as it was in 1993. Four U.S. Bureau of Land Management (BLM) lease sales were held, but no leases were purchased. No over-the-counter filings for BLM leases were received during the year. A total of seven federal tracts were under lease at year's end and consisted of a total of 3,728 acres. The State of Oregon conducted no lease auctions during the year. A total of 16 State of Oregon tracts were under lease at year's end and consisted of 25,520 acres, which is the same as in 1993. Columbia County held an auction during the year at which 17 tracts comprising a total of 5,060 acres were leased. Bids ranged from $2.50 to $41.00 per acre, and Nahama and Weagant Energy Company, Bakersfield, California, acquired the majority of the acreage.

During 1994, no exploratory wells were drilled, primarily due to the fact that Nahama and Weagant Energy Company, operator of the Mist Gas Field, filed for bankruptcy under Chapter 7 of the Federal Bankruptcy Code. Operations at Mist Gas Field included reclaiming three dry-hole drill sites and plugging and reclaiming the drill site of a depleted former gas producer. Carbon Energy International, Dallas, Texas, plugged and reclaimed the drill sites of two wells in the Coos Basin during the year.

At the Mist Gas Field, 21 wells were productive during the year, and three suspended wells awaited pipeline connection at year's end. One of the most significant developments during 1994 was the installation of a Nitrogen Rejection Unit (NRU) at Mist Gas Field, which enabled three low-Btu (British thermal unit) wells to be put into production. As a consequence, a total of 4.2 billion cubic feet (Bcf) of gas was produced during 1994, an increase over the 3.5 Bcf produced during 1993. Value of the gas produced during the year declined to $6.4 million from the $7.1 million during 1993, due to a drop in the price per therm for the gas.

The Oregon Department of Geology and Mineral Industries (DOGAMI) completed a study of the Tyee Basin located in Douglas and Coos Counties. Final data, reports, and maps on the oil, gas, and coal resources of the area are expected to be published by the end of 1995.

During 1994, DOGAMI conducted its triennial review of the administrative rules related to oil and gas operations. As a result, the agency has proposed a number of changes, the most significant of which is the elimination of drilling units. In addition, DOGAMI has proposed 1995 legislation that would allow cost recovery for extraordinary expenses related to oil and gas regulatory activities in Oregon.


## LEASING ACTIVITY

Oil and gas leasing activity was about the same during 1994 as it was in 1993. This is the continuation of a generally declining trend in leasing activity that began during the late 1980s. Activity included four public sales by BLM; however, no bids were received at these sales. BLM received no over-the-counter lease-filing applications during the year.

A total of seven federal tracts were under lease at year's end and consisted of a total of 3,728 acres. This is a decrease from the 5,491 federal acres under lease at the end of 1993. Total rental income was $3,769. At year's end, applications on 39,942 federal acres were pending.

*Nahama and Weagant Energy Co. abandoned the Longview Fibre 23–25 well, a depleted gas producer at the Mist Gas Field. During its 6-year productive period, the well produced about 0.3 Bcf gas, which sold for over one million dollars.*

The State of Oregon held no lease sales during the year; it had held no lease sales during 1993, either. With no changes during the year, a total of 16 State of Oregon tracts (25,520 acres) were under lease at year's end, and total rental income was about $25,520—the same as in 1993.

Columbia County held an auction during July, at which 17 tracts representing a total of 5,060 acres were leased. Nahama and Weagant Energy Company was the highest bidder on 13 tracts consisting of 3,196 acres, with bids ranging from $2.50 to $3.50 per acre. Oregon Natural Gas Development Company, Portland, Oregon, made a successful bid of $2.50 per acre on two tracts consisting of 830 acres. Anders Elgard, Lakewood, Colorado, placed the highest bids at the auction, offering $22.00 and $41.00 per acre and acquiring two tracts totaling 1,034 acres.

Table 1. *Oil and gas permit activity in Oregon, 1994*

| Permit no. | Operator, well, API number | Location | Date issued | Status, depth (ft) TD=total depth PTD=proposed TD | Date canceled, reason |
|---|---|---|---|---|---|
| 338 | Nahama and Weagant<br>Longview Fibre 23-25<br>36-009-00179 | SW¼ sec. 25<br>T. 6 N., R. 5 W.<br>Columbia County | 9-30-85 | Abandoned,<br>depleted producer;<br>TD=1,979 | — |
| 472 | Nahama and Weagant<br>CC 41-33-75<br>36-009-00297 | NE¼ sec. 33<br>T. 7 N., R. 5 W.<br>Columbia County | 7-6-92 | — | Canceled,<br>7-6-94;<br>expired. |
| 479 | Nahama and Weagant<br>CC 42-32-74<br>36-009-00304 | NE¼ sec. 32<br>T. 7 N., R. 4 W.<br>Columbia County | 4-25-93 | — | Canceled,<br>4-26-94;<br>expired. |
| 480 | Nahama and Weagant<br>CC 43-8-64<br>36-009-00305 | SE¼ sec. 8<br>T. 6 N., R. 4 W.<br>Columbia County | 5-19-93 | — | Canceled,<br>5-19-94;<br>expired. |
| 484 | Nahama and Weagant<br>CC 42-34-65<br>36-009-00309 | NE¼ sec. 34<br>T. 6 N., R. 5 W.<br>Columbia County | 5-19-93 | — | Canceled,<br>5-19-94;<br>expired. |
| 486 | Carbon Energy<br>WNS- Menasha 32-1<br>36-011-00026 | SW¼ sec. 32<br>T. 26 S., R. 13 W.<br>Coos County | 9-30-93 | Abandoned,<br>dry hole;<br>TD=1,594 | — |
| 487 | Carbon Energy<br>Coos Co. Forest 7-1<br>36-011-00027 | SE¼ sec. 7<br>T. 27 S., R. 13 W.<br>Coos County | 9-7-93 | Abandoned<br>dry hole;<br>TD=3,993 | — |
| 488 | Nahama and Weagant<br>Adams 14-31-74<br>36-009-00310 | SW¼ sec. 31<br>T. 7 N., R. 4 W.<br>Columbia County | 6-28-93 | — | Canceled,<br>6-28-94;<br>expired. |
| 489 | Nahama and Weagant<br>HNR 42-27-64<br>36-009-00311 | NE¼ sec. 27<br>T. 6 N., R. 4 W.<br>Columbia County | 6-28-93 | — | Canceled,<br>6-28-94;<br>expired. |
| 491 | Nahama and Weagant<br>HNR 31-21-64<br>36-009-00313 | NE¼ sec. 21<br>T. 6 N., R. 4 W.<br>Columbia County | 7-6-93 | — | Canceled,<br>7-6-94;<br>expired. |
| 492 | Nahama and Weagant<br>CFW 23-33-74<br>36-009-00314 | SW¼ sec. 33<br>T. 7 N., R. 4 W.<br>Columbia County | 6-28-93 | — | Canceled,<br>6-28-94;<br>expired. |
| 494 | Nahama and Weagant<br>Hemeon 13-14-65<br>30-009-00316 | SW¼ sec. 14<br>T. 6 N., R. 5 W.<br>Columbia County | 9-27-93 | — | Canceled,<br>9-27-94;<br>expired. |
| 497 | Nahama and Weagant<br>LF 21-32-75<br>36-009-00319 | NW¼ sec. 32<br>T. 7 N., R. 5 W.<br>Columbia County | 10-20-93 | — | Canceled,<br>10-20-94;<br>expired. |

## DRILLING

For the first year since 1974, no exploratory oil and gas wells were drilled in Oregon. This is largely attributed to the fact that Nahama and Weagant Energy Company, operator of the Mist Gas Field and driller of thirteen exploratory gas wells and three redrills in 1993, filed for bankruptcy under Chapter 7 of the Federal Bankruptcy Code during the year. A court-appointed trustee has been assigned to sell the assets of Nahama and Weagant Energy Company, including the Mist Gas Field. It was reported that several bids for the Mist Gas Field were received and that the successful bidder, who will become the field operator, would be named during 1995.

Operations at the Mist Gas Field during 1994 included the reclaiming by Nahama and Weagant Energy Company, in partnership with Oregon Natural Gas Development Company, of three drill sites of abandoned wells drilled during 1993. In addition, Nahama and Weagant Energy abandoned and reclaimed the drill site of a depleted former gas producer, the well Longview Fibre 23–25, located in SW¼ sec. 25, T. 6 N., R. 5 W., Columbia County.

In the Coos Basin, Carbon Energy International during 1994 completed testing operations and abandoned the two exploratory

*Carbon Energy International well Coos County Forest 7–1, which was drilled during 1993. Testing showed only noncommercial quantities of gas, and the well has now been abandoned.*

coal-bed methane gas test wells drilled during 1993. These wells, the Coos County Forest 7–1, located in SE¼ sec. 7, T. 27 S., R. 13 W., and the WNS-Menasha 32–1, located in SW¼ sec. 32, T. 26 S., R. 13 W., had reported shows of natural gas, but test results failed to establish economically productive rates. The wells were plugged and abandoned, and the drill sites were reclaimed.

During 1994, DOGAMI did not issue any permits to drill, while 10 permits were canceled. Permit activity is listed in Table 1.

### DISCOVERIES AND GAS PRODUCTION

Despite the bankruptcy filing by Nahama and Weagant Energy Company, the Mist Gas Field operated normally during the year. One of the most significant developments during 1994 was the installation of a Nitrogen Rejection Unit (NRU) at the Mist Gas Field. The NRU is operated as a joint venture between Nahama and Weagant Energy Company, Oregon Natural Gas Development Company, and BCCK Engineering, the company that designed and installed the unit. The NRU operates by lowering the temperature of the produced gas, which consists of a mixture of methane and noncombustible nitrogen. The methane, having the higher freezing temperable of the two gases, freezes first, and the nitrogen gas is vented to the atmosphere. The result is almost pure methane gas. The NRU has enabled three low-Btu wells to go into production. A Btu is the measure of the heating value of natural gas; pure methane has a Btu of 1,012.

The three low-Btu wells that Nahama and Weagant Energy Company put into production during 1994 are located in the southern portion of the Mist Gas Field. The wells are the CFI 23–15, located in SW¼ sec. 15, T. 5 N., R. 4 W., with a Btu of 651; the CFI 31–16, located in NE¼ sec. 16, T. 5 N., R. 4 W., with a Btu of 537; and the CC 42–8–54, located in NE¼ sec. 8, T. 5 N., R. 4 W., with a Btu of 691. With the installation of the NRU, the gas produced from these wells is increased to approximately 1,000 Btu by the removal of the noncombustible nitrogen.

The Mist Gas Field had 21 productive gas wells during 1994, and three wells awaited pipeline connection at year's end. Gas production for the year totaled 4.2 Bcf of gas, an increase from the 3.5 Bcf produced during 1993. The cumulative field production as of the end of 1994 was 54.0 Bcf. The total value of the gas produced for the year was $6.4 million, a decline from the $7.1 million during 1993. This decline is the result of a drop in gas prices during the year to a range from 11 to 23 cents per therm, which is less than the 16 to 25 cents per therm for which gas sold last year. Cumulatively, the total value of gas produced since the Mist Gas Field was discovered in 1979 is about $111 million.

### GAS STORAGE

The Mist Natural Gas Storage Project remained fully operational during 1994. The gas storage project has nine injection-withdrawal service wells, five in the Bruer Pool and four in the Flora Pool, and thirteen observation-monitor service wells. The two pools have a combined storage capacity of 10 Bcf of gas. This allows for the cycling of about 6 Bcf in the reservoirs at pressures between approximately 400 and 1,000 psi and will provide for an annual delivery of 1 million therms of gas per day for 100 days. During 1994, about 5,956,409 cubic feet of gas was injected,, and 5,236,505 cubic feet was withdrawn at the Mist Gas Storage Project. Plans are underway to develop a third gas storage unit at the Mist Gas Field. Two gas wells, the Nahama and Weagant Energy

*Nahama and Weagant Energy reclaimed the drill site of the well Libel 32–15–65, drilled at the Mist Gas Field during 1993 as a dry hole.*

Company CC 14–23 located in SW¼ sec. 23, T. 6 N., R. 5 W., and CC 23–22 located in SW¼ sec. 22, T. 6 N., R. 5 W., were shut in during 1994 and will be part of the new gas storage project.

## OTHER ACTIVITIES

DOGAMI completed a five-year study of the oil, gas, and coal resource potential of the Tyee Basin located in Douglas and Coos Counties in the southern Coast Range. The study, which was funded by landowners in the study area and by county, state, and federal agencies in a public-private partnership, is an investigation of source rock, stratigraphy, and structural framework for those characteristics that are needed to generate and trap oil and gas. The final data, reports, and maps are expected to be published by DOGAMI by the end of 1995. A series of maps and preliminary reports that present a revised understanding of the geologic framework of the Tyee Basin have already been published (see publication list at end of report).

DOGAMI and the Northwest Petroleum Association (NWPA) sponsored a series of meetings at which the U.S. Geological Survey and Minerals Management Service discussed work on a national assessment of undiscovered oil and gas reserves including the Pacific Northwest. The assessment is using a methodology in which oil and gas plays are evaluated for their future potential reserves. Work continues on the assessment, and a draft report is expected to be released during 1995. Individuals interested in oil and gas resources in the Pacific Northwest should contact DOGAMI or the NWPA for details.

The NWPA remained active for the year and has over 100 members. At its regular monthly meetings, speakers give talks generally related to energy matters in the Pacific Northwest. The 1994 symposium was held in Port Angeles, Washington, on the geology of the Strait of Juan de Fuca, and plans are now underway for the 1995 symposium.

For information, contact the NWPA, P.O. Box 6679, Portland, OR 97228.

DOGAMI completed its triennial review of the administrative rules related to oil and gas operations in Oregon and proposed a number of changes. The most significant change is eliminating the requirement for drilling units, which was considered an unneeded regulation. Other revisions proposed by DOGAMI, the oil and gas industry, and interested individuals are generally associated with administrative changes. In addition, DOGAMI has proposed 1995 legislation that would allow cost recovery for extraordinary expenses related to oil and gas regulatory activities. Examples of extraordinary expenses are the cost of of engineering and geologic documents and legal expenses; administrative costs related to regulatory work for public hearings, for administering spacing units, integration orders, or unit operations when requested by an operator. Contact DOGAMI for details regarding proposed changes either to the administrative rules or the 1995 legislation.

## PUBLICATIONS FROM THE TYEE BASIN STUDY


Black, G.L., 1990, Geologic map of the Reston quadrangle, Douglas County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS–68, 4 p., map scale 1:24,000.

———1994, Geologic map of the Kenyon Mountain quadrangle, Douglas and Coos Counties, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series


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# Tsunami survey conducted by DOGAMI

*by Angie Karel, Oregon Department of Geology and Mineral Industries, Portland OR 97232*

The Oregon Department of Geology and Mineral Industries (DOGAMI) is becoming increasingly concerned about the risk to people and property posed by large offshore earthquakes that can be expected to result in damaging tsunamis ("tidal waves").

The Department was interested in determining if any type of tsunami preparedness education or evacuation drills were currently being taught in Oregon coastal schools. Proposed survey questions were developed by Department staff and peer reviewed by Al Shannon, Oregon Department of Education; Sherry Patterson, Earthquake Preparedness Network; and Peg Reagan, Curry County Commissioner serving on the Oregon Seismic Safety Policy Advisory Commission. In August 1994, the tsunami survey was mailed to school principals in 96 selected Oregon coastal schools in Clatsop, Coos, Curry, Douglas, Lane, Lincoln, and Tillmook Counties. Responses were received from 39 schools (41 percent).

Of the 39 coastal schools that responded, 16 stated that some form of tsunami preparedness is currently taught in all grades K–12 levels. Survey responses indicate that grades 6, 7, and 8 receive slightly less tsunami preparedness education than grades K–5 or 9–12.

Teaching methods and materials varied from school to school. Responses indicate that tsunami preparedness is generally taught during science class or in conjunction with earthquake preparedness education. Tsunami evacuation areas include "small hill away from the school," "next to the school," "in front (east) of the school," "up the mountain," or "to higher ground." Tillamook County has a county-wide warning system that is reviewed as part of the schools' preparedness training. Teaching materials include earth-science curriculum materials, building-safety plans, teacher-prepared materials, information obtained from the Red Cross and Oregon State University, a tsunami handout provided by Clatsop County, and local information received from emergency government agencies.

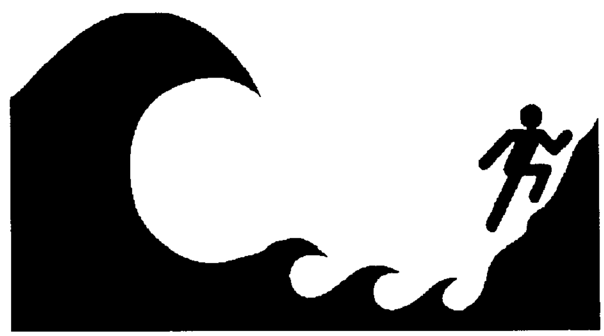
Schools were asked to list teaching materials that would be beneficial in relation to tsunami preparedness. Generally, schools suggested that any type of information on tsunami hazards would be beneficial for them as they prepare an education plan. Specific information on timing and alternative escape routes, off school property, was also suggested as beneficial.

Of the 39 schools that responded, only 15 practice tsunami evaculation drills during the school year. Seven of the schools conduct tsunami drills monthly, while other schools conduct drills bimonthly, two times a year, or yearly. Documentation of tsunami drills is maintained in 15 schools. Tsunami drills are being conducted at the same time as earthquake drills in 12 schools. Of those 12 schools, 8 evacuate to high ground or go to an inland location off the school grounds. Limited responses were received for questions relating to evacuation routes, evacuation drills, and differences between tsunami drills and earthquake drills.

A total of 19 schools expressed interest in receiving training on how to conduct a tsunami evacuation drill, and 17 schools were not interested in receiving training.

Schools were asked whether a local workshop on tsunami hazards for teachers would be beneficial. Fifteen schools were not interested in a local workshop on tsunami hazards. From the 13 schools where it was felt that a workshop would be beneficial, topics suggested included presentation of factual information on tsunami hazards, an overview of procedures for classroom instruction and evaluation drills, inland impacts, safety issues, and information on age-appropriate curriculum materials.

A copy of the tsunami survey results was requested by 22 schools. A complete set of survey responses will be maintained at the Portland office of the Oregon Department of Geology and Mineral Industries. For further information contact the Oregon Department of Geology and Mineral Industries, 800 NE Oregon Street, Suite 965, Portland, Oregon 97232, phone 503-731-4100, FAX 503-731-4066. □



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GMS–83, 9 p., map scale 1:24,000.

———1994, Geologic map of the Remote quadrangle, Coos County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS–84, 8 p., map scale 1:24,000.

Black, G.L., and Priest, G.R., 1993, Geologic map of the Camas Valley quadrangle, Douglas and Coos Counties, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS–76, 4 p., map scale 1:24,000.

Niem, A.R., Niem, W.A., and Baldwin, E.M., 1990, Geology and oil, gas, and coal resources, southern Tyee Basin, southern Coast Range, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O–89–3, 95 p., 3 plates.

Ryu, I.C., Niem, A.R.,and Niem, W.A., 1993, Schematic fence diagram of the southern Tyee Basin, Oregon Coast Range, showing stratigraphic relationships of exploration wells to surface measured sections: Oregon Department of Geology and Mineral Industries Oil and Gas Investigation 18, 48 p., 1 plate.

Wiley, T.J., and Black, G.L., 1994, Geologic map of the Tenmile quadrangle, Douglas County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS–86, 5 p., map scale 1:24,000.

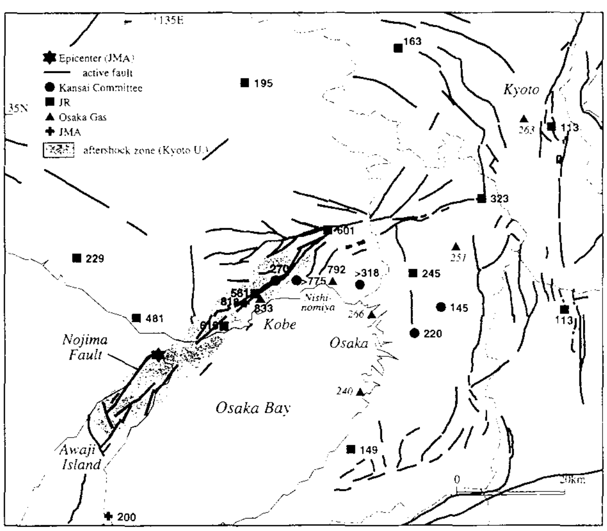
Wiley, T.J., Priest, G.R., and Black, G.L., 1994, Geologic map of the Mount Gurney quadrangle, Douglas and Coos Counties, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS–85, 5 p., map scale 1:24,000. □

## Some notes on the Kobe, Japan, earthquake of January 17, 1995

On January 17, 1995, a magnitude 6.9 (moment magnitude, $M_W$) earthquake struck Kobe, Japan, a port city on the Pacific shore of Japan's Honshu Island. The epicenter of the Kobe earthquake was located about 20 km (12 mi) southwest of downtown Kobe. The devastating ground shaking resulted in extensive loss of life and damage to property and disrupted commerce throughout the country. Ground accelerations due to shaking reached at least 0.8 *g*, which means that the forces of shaking were 80 percent of the force of gravity. What follows is a brief discussion of the earthquake effects, based on preliminary reports. In coming issues of *Oregon Geology*, more details of what is learned from this latest "urban earthquake" will be reported.

The Kobe earthquake resulted from a rupture of the northeast-southwest-oriented Nojima fault zone. The rupture began at a depth of about 10 km (6 mi). Approximately 30 to 50 km of the fault ruptured, producing 1–1.5 m (3–5 ft) of horizontal surface displacement. The sense of motion on the fault was right-lateral, strike-slip. This means that the west side of the fault moved 1–1.5 m to the northeast, compared to the east side. A duration of 10–12 seconds of strong ground shaking has been reported. These few seconds of shaking resulted in over 5,000 deaths and over 26,000 injuries, and approximately 300,000 people required shelter. All this happened in a city with a population of 1.5 million.

Western Japan lies on the Eurasian plate and has a historic record of moderate to large crustal earthquakes. Thanks to Japan's long historic record, it was known that Kobe had suffered large, damaging earthquakes in the past. However, damaging earthquakes have occurred much less frequently in the region of Kobe than in other parts of Japan. Consequently, some Japanese perceived the area as being immune to earthquakes, an attitude is not unlike that of comparing the Pacific Northwest to the San Francisco Bay area. Damage statistics are still being compiled, but it appears that over 100,000 buildings were destroyed or severely damaged. Reportedly, only 20 percent of Kobe's downtown buildings were usable following the earthquake. Estimates of the cost to rebuild have climbed to at least $100 billion, over five times the latest estimates for the magnitude-6.8 earthquake in Northridge, California, in 1994.




*Map showing the area of Osaka Bay and Kobe, Japan; the location of the epicenter of the earthquake of January 17, 1995; the aftershock zone which gives some indication of the length of the fault rupture; locations of acceleration measurements; and the system of known faults in the area. Reproduced from EOS, v. 76, no. 6 (February 7, 1995), p. 49.*

Damage to buildings, roads, railroads, ports, and pipelines resulted in loss of life and shelter and will continue to disrupt lives and commerce for many months to come. This damage and the difficulties Japan experienced in launching and carrying out emergency response measures following the earthquake highlight the importance of advance planning, preparation, and the mitigation of hazards. The port of Kobe, which reportedly supports 12–30 percent of Japan's exports, suffered damage to nearly all of its berths. Liquefaction of saturated, loose, silty soils was a major contributor to this and other damage. □

## April is Earthquake Preparedness Month in Oregon

The saddening extent of suffering which the Kobe earthquake inflicted on the people in Japan also reminds us that we are not free from such disasters in Oregon—and not safer here than the people in San Francisco, either! Our scientists are working to give us more and more insight into earthquake phenomena, and even the Kobe earthquake will add to what we know about earthquakes and how to deal with them. Still, we cannot stop the mighty forces with which the Earth shapes and reshapes itself. However, we can **be prepared** to cope with them and their aftermath.

The Oregon Trail Chapter of the American Red Cross offers a pamphlet called "Before Disaster Strikes." It offers help in preparedness for home fires, severe winter weather, and floods on one page each; wildfires on two pages, but earthquakes on five!

Just a few leading questions may serve here to remind us that we should be ready to face events that could happen any time:

- How will our family reunite following a disaster?
- What can we do if the water supply is contaminated?
- If electricity is out, how will we get emergency information?
- Who will give first aid to my family if medical workers can't?

The pamphlet that answers these and many more questions can be obtained from the American Red Cross, P.O. Box 3200, 3131 N. Vancouver Ave., Portland, OR 97208-3200, phone 503-284-1234, extension 238. □

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*(**Margaret Steere**—continued from page 26)*

she returned to DOGAMI as a volunteer, she reorganized the photo file and brought it up to date and made an index of *Oregon Geology* articles from 1982 to the present. She then tackled learning to use a computer and entered over 700 titles of theses in the bibliographic database. Prior to her death, she was working on a way to enter data on site-specific reports into DOGAMI's bibliographic database.

She was a great friend to all of us at DOGAMI, and her skills, knowledge, quiet humor, and competency will be missed. She is survived by her nieces Lois Beattie of Portland and Alice Coulombe of Pasadena, California, a nephew, several cousins, and numerous friends. At her request, remembrances are to be sent to the Community Music Center in Portland or to the Library Fund of OMSI's Camp Hancock. □

# Preliminary reconnaissance survey of Cascadia paleotsunami deposits in Yaquina Bay, Oregon

*by Curt D. Peterson, Department of Geology, Portland State University, Portland, Oregon 97207-0751, and George R. Priest, Oregon Department of Geology and Mineral Industries, Portland, Oregon 97232*

## SUMMARY

Preliminary evidence of Cascadia paleotsunami deposits has been found in at least 14 latest Holocene marsh sites from the lower and middle reaches of Yaquina Bay. The near-field paleotsunami deposits are recognized as thin sand layers draped over paleomarsh surfaces that were buried by bay muds and peats. At least three events of Cascadia coastal subsidence and tsunami inundation are recorded in the lower Yaquina Bay marsh deposits.

The amount of coastal subsidence associated with paleotsunami deposition at the western end of the bay is small, e.g., 0–0.5 m for the last event and less than 1 m for the remaining two to three events. Subsidence is estimated from abrupt decreases in peat content, indicating subsidence to levels favoring fewer marsh plants than at intertidal-mud levels. The paleotsunami sands were recognized by their occurrence as discrete sand layers immediately atop peat-rich layers.

The 50:1 ratio of tidal versus river discharge in the estuary makes it unlikely that river flooding deposited sand sheets on the buried peats in the lower estuary. Paleotsunami sands show local variability in thickness (2–10 cm) and thin with distance above a bay constriction of the estuary about 9 km from the bay mouth. Paleotsunami sand deposits thicken at the terminal end of one large blind slough but thin with distance from the main channel in several other small embayments.

Evidence of paleotsunami deposition associated with the last Cascadia earthquake is found at least 14 km upriver from the mouth. The maximum distance of upriver inundation for this event has yet to be established. Geologic records of Cascadia tsunami deposition in the sinuous Yaquina Bay are best preserved in tidal-marsh settings within protected embayments branching off the main channel.

## INTRODUCTION

An effort to warn the public about Cascadia tsunami hazards in Oregon has been initiated by a variety of county emergency managers, state agencies, and educational institutions. Part of this effort includes the placement of historical marker signs at strategic locations along the Oregon coast by the Oregon Department of Geology and Mineral Industries (DOGAMI) and the Oregon Travel Information Council. The first three signs were placed in Seaside, Newport, and Reedsport (Figure 1). The signs include maps of core-site locations, where Cascadia paleotsunami deposition is recorded in the adjacent bays.

Of the three localities selected, only Yaquina Bay had not previously been surveyed for paleotsunami deposition. By comparison, paleotsunami runup has been well documented in the Neawanna wetlands in Seaside (Darienzo, 1991; Peterson and others, 1993; Darienzo and others, 1994). Preliminary investigations of paleotsunami inundation have been conducted in the Umpqua estuary (Briggs and Peterson, 1992). The tsunami deposits there have been traced from Winchester Bay upriver to the Scholfield Slough near Reedsport (Briggs, 1994). Finally, latest Holocene paleoseismic events of coastal subsidence and associ-

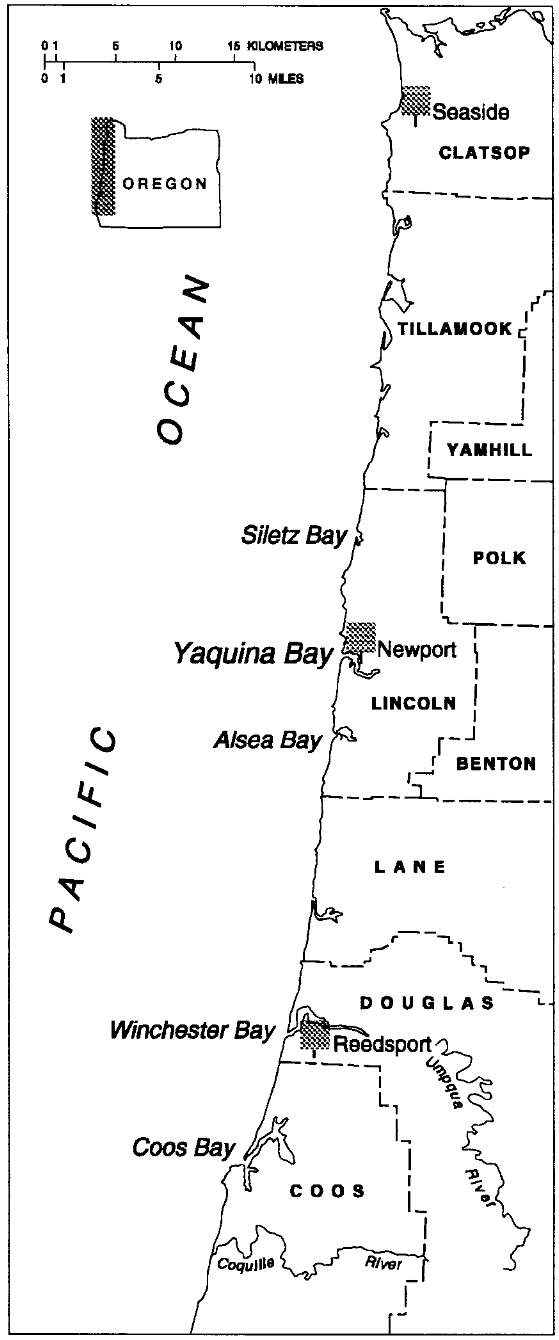


*Figure 1. Map showing a portion of the Oregon coast and its counties and the locations of the study area (Yaquina Bay) and other river estuaries and bays discussed in this paper. Patterned squares indicate locations of tsunami information signs newly installed in Seaside, Newport, and Reedsport.*

ated tsunami runup have been well documented in two bays immediately adjacent to Yaquina Bay, including Alsea Bay to the south (Peterson and Darienzo, 1991) and Siletz Bay to the north (Darienzo, 1991; Darienzo and others, 1994).

The primary objective of this study is to establish representative sites of paleotsunami deposition in Yaquina Bay. Specific wetland sites were selected for investigations of cutbanks or shallow gouge cores to establish the distribution of paleotsunami runup evidence in the bay. Two additional objectives include documenting tsunami propagation and deposition in a sinuous bay morphology and evaluating the preservation potential of tidal marsh sites that are sensitive to paleotsunami deposition.

The Yaquina Bay mouth has been significantly narrowed by jetty construction, which will possibly decrease future Cascadia tsunami runup in the bay. However, the paleotsunami evidence in Yaquina Bay is relevant to tsunami hazard planning in the Cascadia Subduction Zone (CSZ). It is relevant as a proxy warning about tsunami runup at all central Oregon beaches, bay mouths, and bay constrictions, where runup is likely to be amplified. Furthermore, the extensive development of the Yaquina Bay waterfront makes this locality an area of special concern with regard to tsunami evacuation planning. Finally, it is hoped that paleotsunami inundation data in Yaquina Bay can be compared to computer models of tsunami inundation in the bay, including pre-jetty and post-jetty conditions, to verify the accuracy of such runup models.

## METHODS OF STUDY

Owing to limitations of time and budget, only a preliminary reconnaissance survey was completed. Tidal-marsh deposits in the lower reaches of Yaquina Bay were examined in June 1994 by analysis of cutbank gouge cores. This survey was performed to verify reported evidence of paleotsunami runup near the Hatfield Marine Science Center (Darienzo, 1991; Darienzo and others, 1994). We extended the survey area to the middle reaches of the estuary to establish whether paleotsunami inundation was recorded up the Yaquina River channel. We selected survey sites to cover as much of the bay as possible and to test various modes of paleotsunami sand deposition and preservation. Targeted sites included marshes near the bay mouth, along the length of a blind slough, at a major constriction in the lower bay, and at point bars of major channel bends in the middle bay.

Only shallow subsurface records (1–2 m below modern marsh tops) were examined for evidence of the last several paleotsunami events (expected ages of 300–1,500 years B.P.) in the central CSZ (Darienzo and others, 1994). Gouge cores were examined, photographed, and logged in the field. No subsampling was performed for either deposit mineralogy, grain-size analysis, microfossil paleotidal-level indicators, or event radiocarbon dating. Distinct events of paleosubsidence and/or paleotsunami deposition in Yaquina Bay are tentatively correlated to previously dated horizons in this and adjacent bays (Figure 2). However, additional radiocarbon dating of detrital organics in the paleotsunami deposits is required to confirm the tentative correlation of the paleoseismic events in the lower reaches of Yaquina Bay.

Coseismic subsidence events were recognized by the following criteria:

1. Abrupt decrease of organic content upward in the stratigraphic section, generally passing from an organic-rich peat to an organic-poor silty mud.
2. Persistent occurrence at the same depth (±5 cm) below the surface over a wide area.

Tsunami sands were recognized by the following criteria:

1. Sandy layer in sharp depositional contact with an underlying buried organic-rich soil and an overlying silty mud with much less organic content than the underlying soil.
2. Persistent occurrence at the same depth (±5 cm) below the surface over a wide area.
3. Thinning of the sand layer up the estuary in sites located nearest the main channel.
4. In some cases, thickening of the deposits toward the apex of V-shaped reentrants in the bay. An example is the King Slough area.
5. Lack of any other obvious mechanism for deposition of the sand layer.

The last criterion requires some explanation. The ratio of tidal to river discharge in the bay is on the order of 50:1 (Peterson and others, 1984), so there is little or no opportunity for river flooding to achieve the current velocities necessary to pick up and deposit sand layers at the sites sampled. Likewise, storm surges are unlikely to have enough energy to deposit sediment in high marsh sites, especially at distances in excess of 2 km inland, where most samples were taken. There is some uncertainty about this latter observation, since the bay was clearly more open to the sea before jetty construction, which allowed storm surges more access (Figure 3). However, criterion 1 makes river- or storm-surge depositions unlikely, since these phenomena should produce random occurrences of sand layers rather than consistent sequences of sand depositional events upon coseismic subsidence events, with no tidal-mud deposition intervening.

Finally, core sites thought to show unequivocal evidence of paleotsunami deposition were plotted on a base map for preparation of the tsunami sign for the Yaquina Bay area. These core sites represent known distances of paleotsunami inundation in Yaquina Bay. Maximum distances of recorded paleotsunami inundation in the middle reaches of Yaquina Bay have yet to be established.

## RESULTS

Fourteen core sites were logged for stratigraphic evidence of coastal subsidence and/or paleotsunami deposition (Figure 3). These core logs (YB-1 to -14) and one log from previous work (HF 1–3; Darienzo, 1991) are shown in Figure 4. The depth sections are measured to the nearest 1 cm. The core tops are set at ground surface, which is estimated to be between 1 and 2 m above modern mean tidal level (MTL) for these marsh settings (Table 1). No anomalous sand layers or laminae were found in gouge cores of the uppermost 25 cm of marsh deposits, the interval that is thought to represent deposition during historic time. Historic events of catastrophic river flooding (100-year flood of 1964), storm surges (up to 1 m above predicted tide in the lower bay; Pittock and others, 1982), or distant far-field tsunamis (1964 Alaskan tsunami; Lander and others, 1993) are not recorded at any of the high-marsh core sites observed in lower or middle reaches of Yaquina Bay.

Two cores, one each from the lower bay (YB-9) and middle bay (YB-11), were taken to a subsurface depth of 2 m. These cores record the last four or five coastal subsidence events in Yaquina Bay as abrupt decreases in peat content upcore. Events 1, 2, and 4 in the two cores (YB-9 and -11) are associated with anomalous sandy layers, interpreted to be paleotsunami deposits. Event 3 is conspicuous in its lack of corresponding paleotsunami deposits in Yaquina Bay and in the two adjacent bays, Alsea and Siletz (Figure 2), as well as in other northern Oregon bays (Peterson and others, 1993). The last four subsidence events are assumed to cor-

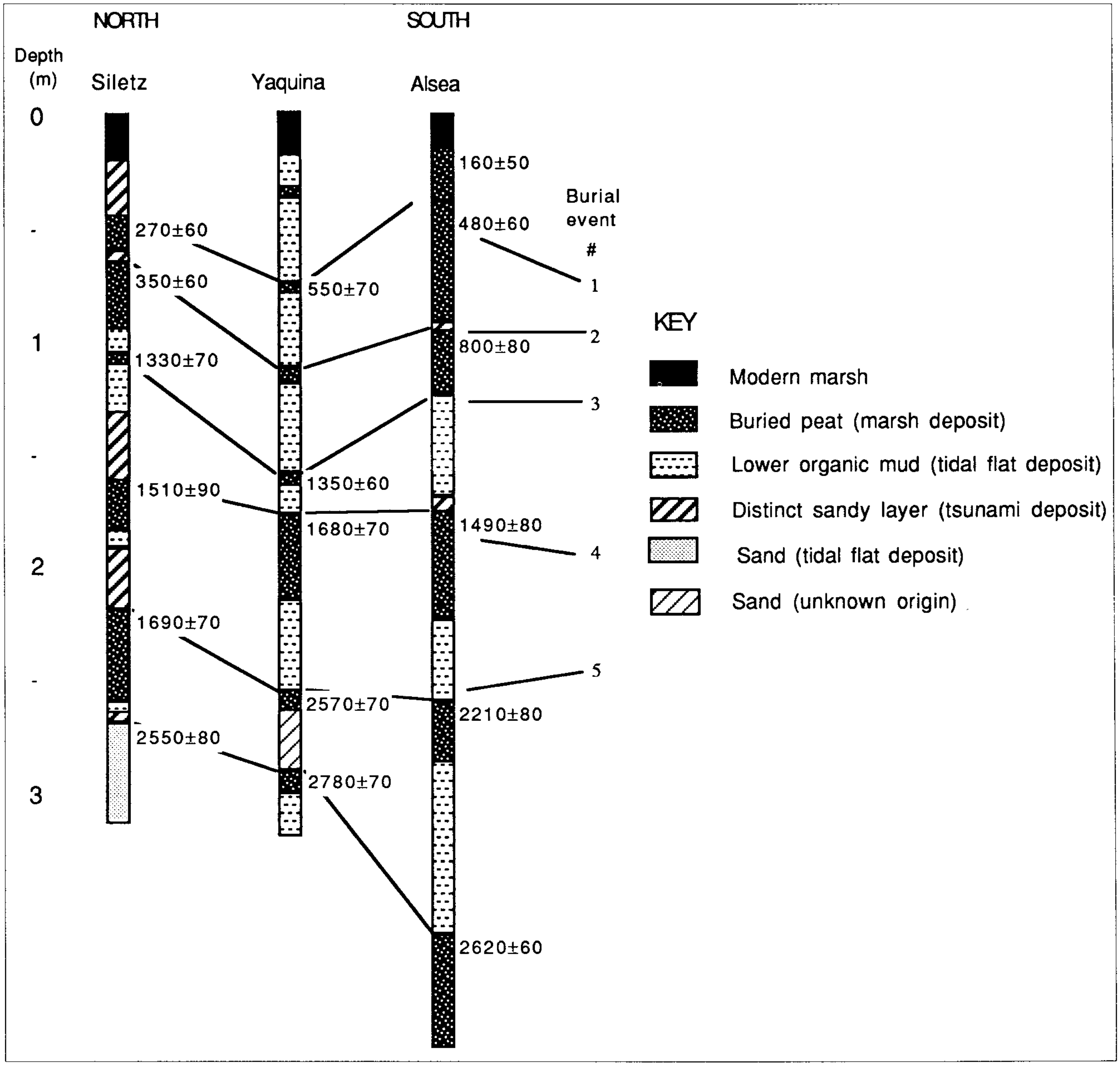


*Figure 2. Generalized event stratigraphies from Alsea, Siletz, and Yaquina Bays. Radiocarbon dates are from buried peaty sections that likely predate the coastal subsidence events. Paleotsunami deposits are regionally associated with central Cascadia events 1, 2, and 4, but not 3. The second Cascadia subsidence (event 2) is not recorded at Siletz Bay. Assuming that coseismic subsidence occurs only above ruptured portions of the locked interface between the North American and subducting Juan de Fuca plates, this evidence suggests that the event 2 rupture included the Alsea and Yaquina Bays but did not extend as far north as Siletz Bay.*

respond to the central CSZ subsidence events: Event 1 at 300 calibrated years before present, event 2 at ~800 radiocarbon years before present (RCYBP), event 3 at about 1,100 RCYBP, and event 4 at about 1,400 RCYBP (Peterson and others, 1993; Darienzo and others, 1994).

The two deeper cores (sites YB-9 and -11) might straddle the projection of a possible west-east trending fault reported to offset Quaternary marine terraces on opposite sides (north and south) of Yaquina Bay (Ticknor, 1993). The two core sites do not appear to show any significant stratigraphic differences for the last four subsidence events, either in terms of the number of events or the depths of event horizons. Subsidence events recorded in marshes of the middle and upper reaches of Yaquina Bay (Darienzo, 1991) have been tentatively correlated to central Cascadia dislocation events in northern Oregon (Darienzo and others, 1994). However, corresponding tsunami deposition with subsidence events had not been established for Yaquina Bay. The results shown here confirm that the subsidence events in Yaquina Bay are associated with paleotsunami deposition, linking them to regional dislocations of the Cascadia megathrust.

The remaining 13 cores sites were cored to subsurface depths of about 1 m. Five of these cores (YB-2, -4, -6, and -10; HF 1-3) contain sand-deposit records of two CSZ tsunamis, with another seven cores showing evidence of only one paleotsunami. The shallowest paleotsunami deposit in each core is presumed to represent the last Cascadia dislocation (event 1), based on (1) depth in core, and (2) lack of overlying subsidence sequences or, for the westernmost core sites, a lack of subsidence associated with the youngest paleotsunami event (see below). Additional radiocarbon dating is required to verify the presumed youngest ages for these shallowest paleotsunami deposits.

Several core sites that were located along the entrance shore-

Table 1. *Wetland settings, elevations, and peat abundance in central Oregon bays*[1]

| Marsh settings in central Oregon bays | Elevation in meters above mean tidal level (MTL) | Percent peaty material (relative to core surface area; visual estimate) | Percent organics (weight fraction from loss on ignition—LOI) | Core log key |
|---|---|---|---|---|
| Forest/shrub | 2.0±0.25 | >80 | >50 | Peat |
| High marsh | 1.5±0.25 | 50–80 | 20–50 | Muddy peat |
| Transitional marsh | 1.25±0.25 | 20–50 | 10–20 | Peaty mud |
| Low marsh | 0.75±0.25 | 5–20 | 5–10 | Slightly peaty mud |
| Colonizing marsh / mud flat | 0.5±0.25 | 1–5 | <5 | Rooted mud / mud |

[1] There is significant overlap of marsh setting elevations shown in this regional compilation. Marsh settings at individual marsh sites typically show less variability in tidal elevation. The marsh settings, tidal elevations, percent peaty, and percent organics used in this table are compiled from data from several central Oregon bays including Yaquina Bay (Darienzo and Peterson, 1990; Darienzo, 1991; Peterson and Darienzo, 1992; Briggs, 1994).

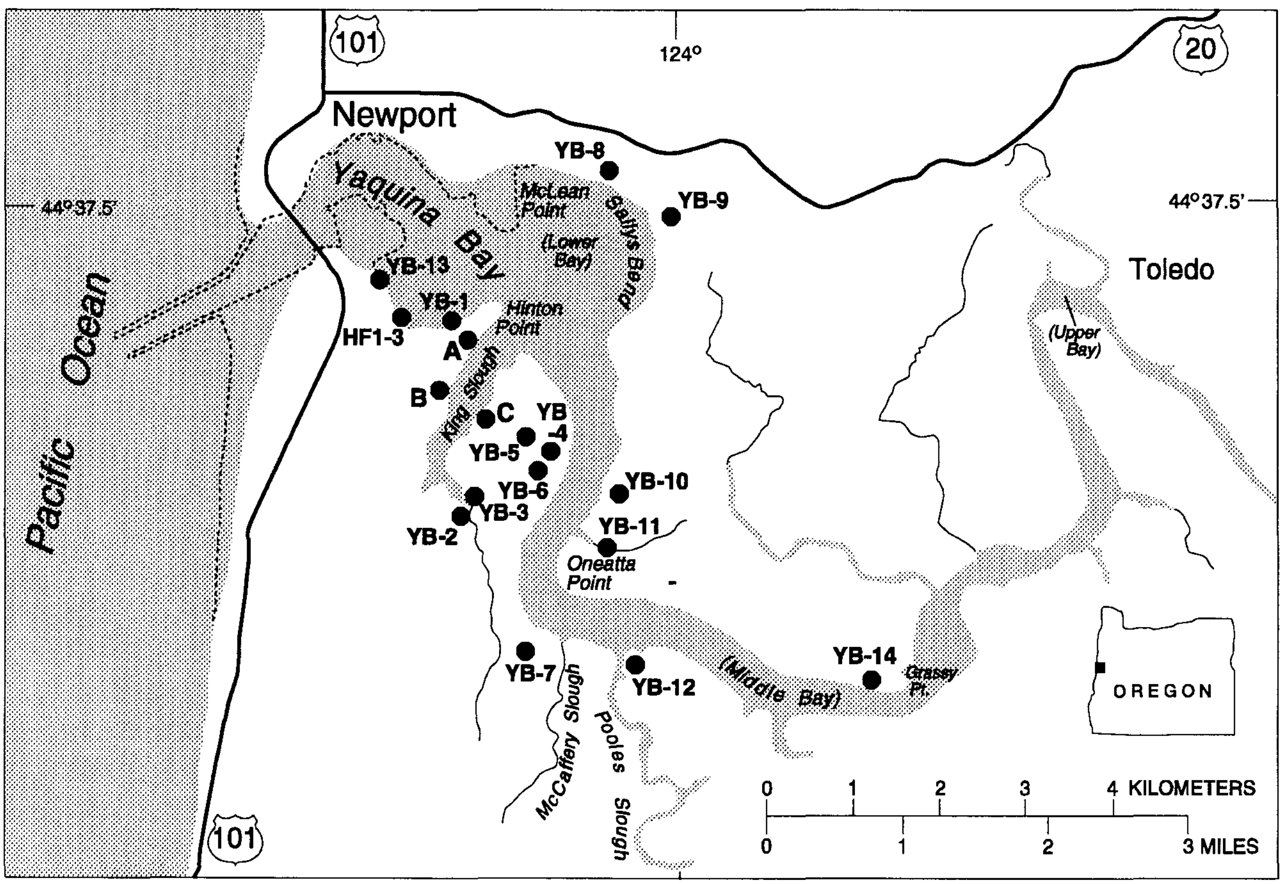


*Figure 3. Bay morphology and core site locations in Yaquina Bay before jetty construction and fill changed the entrance to the bay (after U.S. Coast Survey, 1868); dotted lines indicate today's conditions. Core sites containing some evidence of paleotsunami deposition are numbered YB-1 to YB-14. The site of a previously cored marsh that contains paleotsunami sands (HF 1-3; Darienzo, 1991) is also shown. Several sites containing relatively deep marsh records but no paleotsunami sands (A, B, and C) are shown for Kings Slough. Sites cored along fringing marshes of the exposed bay shorelines and the Yaquina River channel that did not contain any evidence of any paleosubsidence events, i.e., abruptly subsided peats, are not included here.*

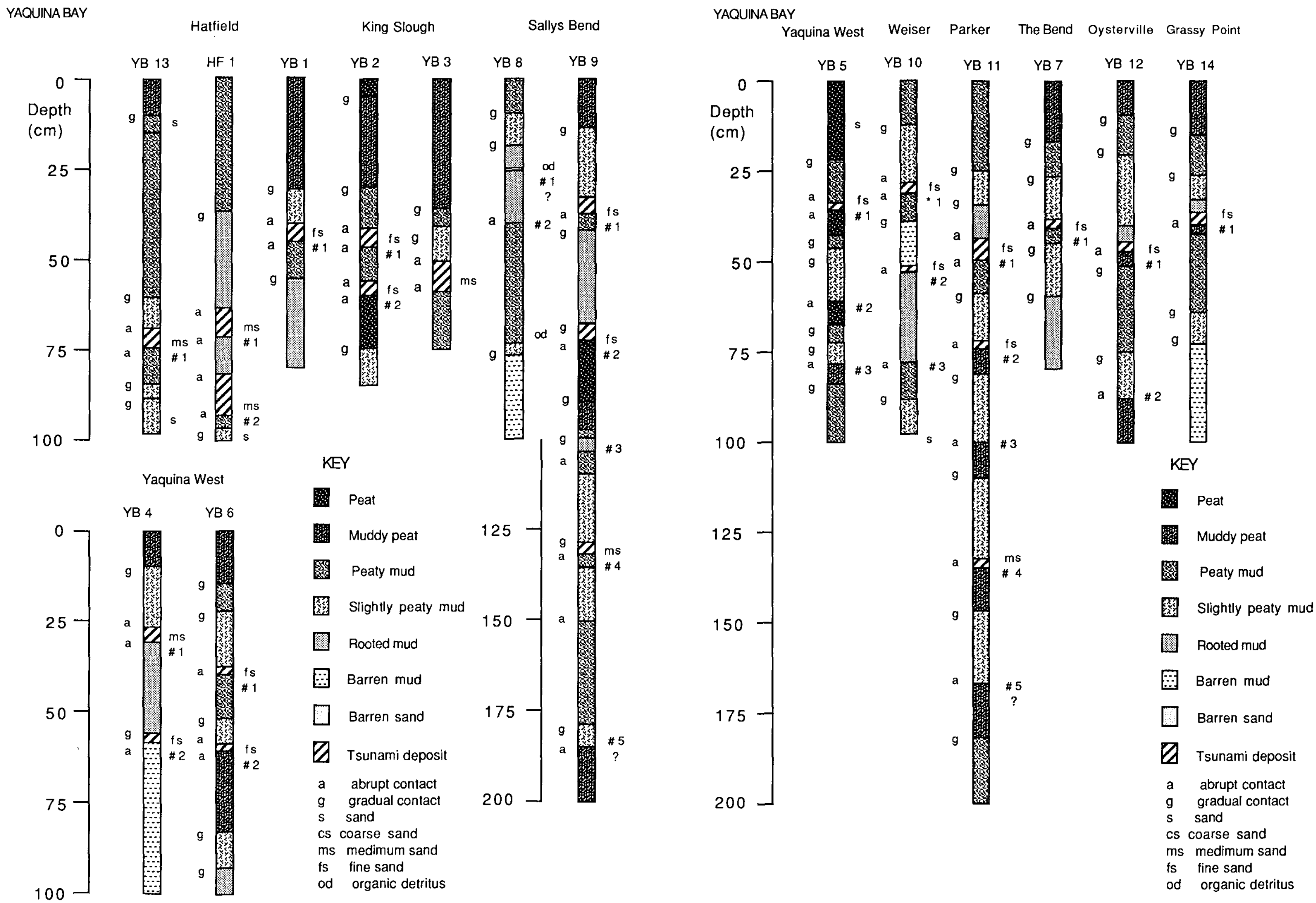


*Figure 4. Core logs from 15 core sites in Yaquina Bay. Core site locations are shown in Figure 3. Mean grain-size estimates as recorded in logs are based on visual comparison with particle-diameter size cards: medium sand (0.25–0.50 mm), fine sand (0.125–0.25 mm), and very fine sand (0.062–0.125 mm). See Table 1 for paleotidal elevation interpretations of the core logs as based on relative peat abundance.*

lines to King Slough did not show any evidence of tsunami deposition (YB-A, YB-B, and YB-C, Figure 3). One additional core site from the north side of the lower bay (YB-8) also failed to show evidence of tsunami sand deposition. An anomalous silty layer capped by detrital woody debris at about 30 cm of depth in YB-8 might represent a flooding event associated with the last Cascadia dislocation. The paleotsunami-deposit sands directly overlying the buried peaty horizons range from 2 to 10 cm in thickness and are dominated by fine sand-size fractions (Figure 4). Multiple cores or cutbank observations taken at each core site, within a radius of 5–10 m, show that the sand layers were deposited as thin sand sheets draping the wetland surfaces. Layering and/or fining-upward sequences were observed in some of the paleotsunami deposits, but they require coring at larger diameter for verification. The amount of coastal subsidence associated with the paleotsunami deposition is discussed below.

CSZ event 1 shows relatively little or no subsidence at the western end of Yaquina Bay in core sites YB-13, -1, -2, and -3 (Figure 4; Table 1). In the cores that lack intervening tsunami sands, the upper contacts between the buried peaty muds and the slightly peaty muds are gradational and at least several centimeters in thickness. By comparison, there is evidence of at least 0.5–1 m of coseismic subsidence associated with event 1 in the more landward core sites YB-11, -12, and -14 from the middle bay reaches. Furthermore, the upper contacts associated with this buried peaty horizon in the upper bay reaches, upstream of Toledo, are sharp (less than 1 cm in thickness), as described by Darienzo (1991). These relations suggest that the western end of Yaquina Bay might have been very near, or within, the zero-isobase zone for the last CSZ dislocation (event 1). (The zero isobase is the area between regions that subside and those that rise up during a great subduction zone earthquake. Zero-isobase position can shift from earthquake to earthquake, hence the term "zero-isobase zone.") By comparison, events 2, 3, and 4 do show significant coseismic subsidence (0.5–1 m) in the lower bay reaches, where their records are preserved. None of the subsidence events recorded in the lower reaches of Yaquina Bay show upcore transitions of forest to colonizing marsh or high marsh to barren mudflat (Figure 4). The lack of such transitions indicates that subsidence in the western parts of Yaquina Bay probably did not exceed 1 m for the last four Cascadia earthquakes (Table 1).

The second objective addressed in this reconnaissance survey is to gain a better understanding of tsunami propagation and deposition in a sinuous fold-belt bay. Little is known about Cascadia tsunami propagation and attenuation in sinuous bay morphologies. Yaquina Bay represents the northernmost coastal drainage to be influenced by coastal fold-belt tectonics (Peterson and Briggs, 1992). Sinuous bay morphologies of the Umpqua, Coos, and Coquille Rivers more strongly reflect the roughly north-south striking structures of the south-central Oregon coast. However, these bays are apparently located over the zero-isobase zone (Briggs, 1994). As a result, they lack consistent subsidence records by which to help identify Cascadia tsunami deposits. Several critical conditions are necessary for the resuspension, transport, and deposition of sand by tsunami surges. The most important factors are sediment supply and grain size, surge velocity, turbulence, and bottom roughness. In addition, deposits must escape postdepositional erosion by subsequent tsunami surges, tides, storm surges, and tidal or estuary channel migration. These conditions are likely to vary greatly with location along meandering channels and blind sloughs of the sinuous bays. Yaquina Bay offers an opportunity to test some basic assumptions about tsunami deposition in these sinuous bay settings. For instance, does a constriction in the estuary create high enough current velocity to neutralize the continuously falling velocity of the tsunami as it dissipates inland? Do blind sloughs create a thickened deposit at their apex from piling up of water and suspended sediment?

In order to establish the potential spatial variability of tsunami deposition in Yaquina Bay, several paired or clustered core sites were examined for paleotsunami sand thickness. Specifically, paired sites were cored at YB-13 and -1 and at YB-8 and -9 to test for surge directionality inside the bay mouth (Figure 3). Clustered sites, including A, B, C, YB-2, and -3 were examined in King Slough, a blind slough that ends in a terminal marsh at its southern end. Another cluster of sites, YB-4, -5, -6, -10, and -11, was examined in the area of bay constriction, between Yaquina and Oneatta Point, that separates the lower and middle bay reaches. Finally, several sites (YB 7, 12, and 14) were cored at channel meander bends of the middle bay.

The lower bay marsh sites (YB-13, -1, and -9 and HF 1–3) show relatively similar thicknesses of paleotsunami sands (Figure 4). Assuming that, for a restricted area, deposit thickness corresponds in some way to current velocity, paleotsunami propagation was apparently very effective in "turning the corner" south of the paleotidal inlet (Figure 5). The event 1 layer thins with distance to the west of site YB-13 (reconnaissance gouge coring transect not shown), indicating that this marine surge probably propagated inshore via the paleotidal inlet rather than over the spit. A minor topographic depression at site HF 1–3 might account for the slightly thicker event 1 tsunami sand layer there, relative to the adjacent high-marsh sites at YB-13 and -1. More importantly, YB-8 north of Sallys Bend contains little or no evidence of paleotsunami sand deposition. This was unexpected because YB-8 is only a short distance (about 500 m) from well-developed paleotsunami deposits at a similarly exposed site (YB-9, Figure 3). These results demonstrate the local variability of tsunami sand deposition, likely the result of differences in available sand supply and/or surge hydrodynamics. Computer modeling of tsunami inundation together with additional close-spaced coring of the bay marshes is required to better understand the local variability of tsunami deposits in the lower reaches of Yaquina Bay.

In King Slough several sites (A, B, C) were cored in fringing marshes along the entrance shorelines to the slough (Figure 3). None of the three sites contained discreet sand layers within the peaty sections. The ages of two sites (A and C) were not well constrained due to the lack of an obvious subsidence event recorded in the peaty muds, about 1 m thick at each site. By comparison, site B did show an apparent subsidence event, likely to be event 2, at about 70 cm depth (not shown in core logs). In contrast to the lack of paleotsunami deposition recorded in the fringing marsh sites of King Slough, the terminal marsh area (sites YB-2 and -3) did show consistently thick paleotsunami deposits. The paleotsunami sand deposit in site YB-3 (possibly event 1) is nearly 10 cm in thickness. One interpretation of these results is that a surge "funneling effect" in King Slough amplified runup height at the terminal marsh sites, leaving anomalously thick deposits there (Figure 5). Alternatively, greater surge turbulence along the entrance shorelines might have precluded sand deposition in these more exposed sites. In any case, the best developed and/or preserved paleotsunami deposits occurred at the terminal end of the blind slough.

There is some evidence of sand layer thinning with distance (about 100 m) from the main channel (sites YB-4 to -6) in a small embayment just below the bay constriction (Figures 3 and 4).

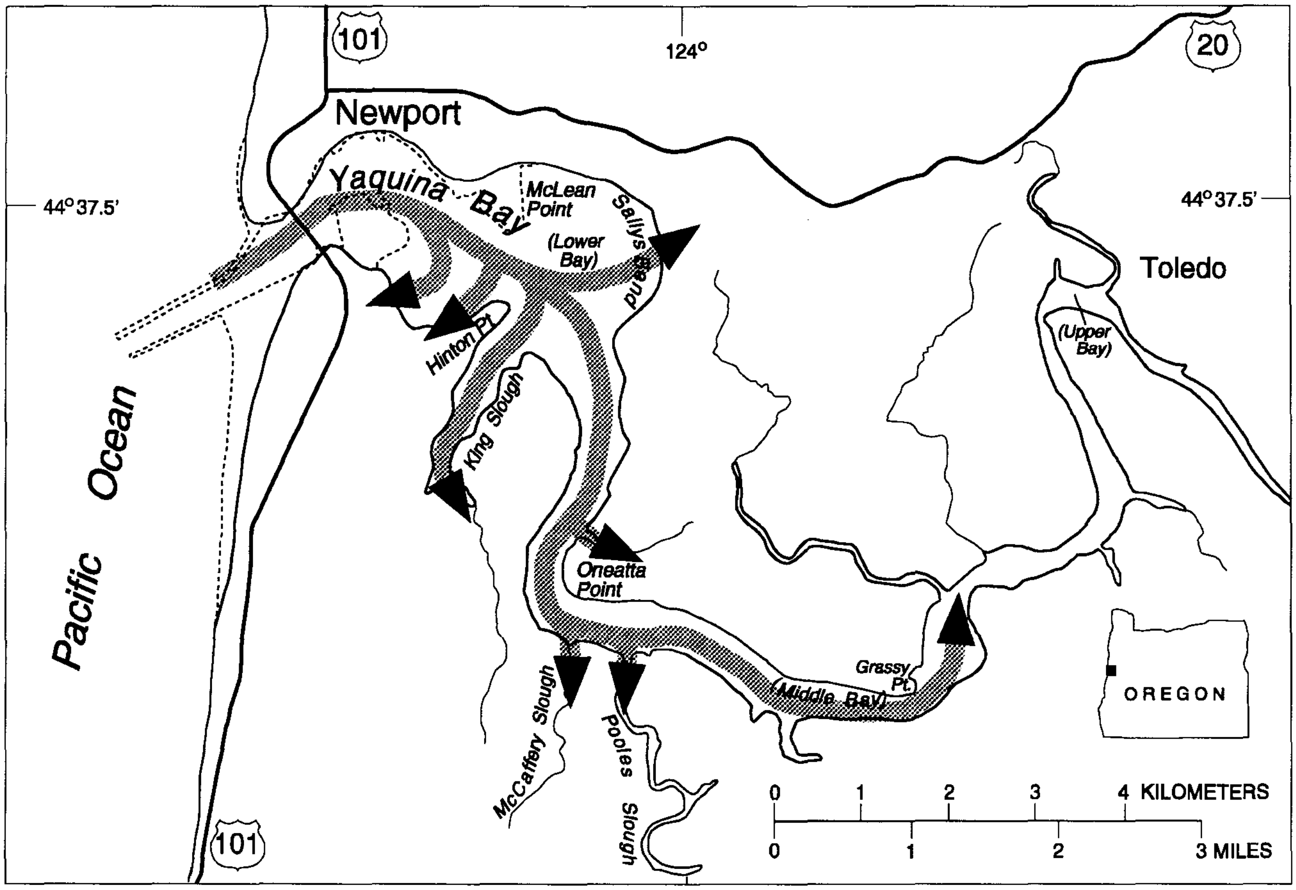


*Figure 5. Map of paleotsunami surge propagation in Yaquina Bay based on evidence of tsunami deposition associated with the last Cascadia dislocation (event 1). Bold lines show the 1868 shoreline as in Figure 3. This shoreline is probably similar to the shoreline when the last tsunami struck about 300 years ago. Arrows show assumed surge paths based on shortest distances to inundated marsh sites. The paleotsunami inundation shown here represents only the minimum "known" distance of Cascadia tsunami flooding. Maximum distances of Cascadia tsunami inundation recorded in geologic deposits or estimated from numerical modeling have yet to be established for Yaquina Bay.*

However, paleotsunami sand deposition is well recorded for events 1, 2, and 3 at several hundred meters distance off the main channel in Parker Slough (site YB-11). Both sites YB-10 and -11 are located in small blind sloughs in the narrowest area of the bay constriction, between Yaquina and Oneatta Point. The bay marshes and tributary sloughs widen just above Oneatta Point. Paleotsunami deposits were not well developed off the main channel in the embayments at McCaffery Slough and Poole Slough. For example, the event-1 paleotsunami sand sheet pinches out just several tens of meters south of YB-7. Extensive coring did not yield any evidence of event-2 paleotsunami sands in the vicinity of YB-12, and only very-fine sand was found in the event-1 tsunami deposit. These results suggest some tsunami surge choking in the area of bay constriction. Further upstream, the attenuation of the event-1 surge(s) is demonstrated by narrowly localized sand deposition at YB-14, which reached only the outer edge of the point bar marsh at Grassy Point (Figure 5). The maximum distance of paleotsunami sand deposition recorded for the last Cascadia earthquakes has not been established in Yaquina Bay. However, possible evidence of paleotsunami deposition from earlier Cascadia earthquakes was found in marsh sites adjacent to the Yaquina River just above Toledo (Darienzo, 1991).

The third objective of this study is to add to our growing knowledge of the long-term preservation potential of tsunami deposit sites. Tsunami deposits are initially preserved in protected wetlands and supratidal and pond sites, where sediment resuspension and bioturbation are minimized. However, little is known about the long-term (hundreds to thousands of years) preservation potential of such sites in active-margin bays. These wetland sites and their paleoseismic stratigraphic records can be lost or altered by a variety of processes. Such processes include erosion by lateral channel migrations, wind-wave erosion of bay shorelines, and burial by debris flows or encroaching eolian-dune fields. The preservation potentials of tsunami record sites are likely to vary between bays as functions of their relative size, tidal:fluvial discharge ratios, and strain cycles of uplift and subsidence. Yaquina Bay provides intermediate conditions for all three variables relative to other bays in the central CSZ (Peterson and others, 1984; Darienzo and others, 1994).

Fringing marshes of the lower bay shorelines were found to have very young histories, recording only the last, or none, of the central CSZ subsidence events. These marshes have prograded over tidal flats that are particularly susceptible to wind-wave erosion. Wind-wave erosion is likely to be enhanced following coseismic subsidence events. Following such events the relative sea-level rise can increase wave fetch in the lower bay reaches, thereby increasing wave attack on exposed bay shorelines. Longer marsh records are limited to small tidal-creek marshes that are protected in embayments set back from the exposed bay shorelines (YB-8 and -9) or in terminal marshes of the larger blind sloughs (YB-3 and -4). Similarly, fringing marshes along the main channel of the middle bay generally contained very young peaty sections, typically younger than the last CSZ event (event 1; field evidence not shown). Presumably, lateral channel migrations in the narrow bay constrictions have episodically eroded marsh deposits back to the ancestral valley walls. One important exception is the Grassy Point marsh developed on a large point bar (Figure 3). Two subsidence events, probably central CSZ events 1 and 2, are recorded near the back (hillside edge) of this marsh. However, only subsidence event 1 was found preserved near the marsh-channel edge, where paleotsunami runup and/or sand supply was sufficient to deposit a distinctive tsunami sand layer. In summary, the short stratigraphic records of young fringing marshes tend to disfavor the preservation of paleotsunami runup evidence near exposed bay shorelines and upriver channel margins.

### CONCLUSIONS

Reconnaissance coring in the lower and middle reaches of Yaquina Bay demonstrates widespread paleotsunami deposition in this tidal basin. Paleotsunami inundation is evident for three of the last four central CSZ dislocation events in latest Holocene time. The thicknesses of the paleotsunami deposits differ greatly between some of the core sites, presumably due to variation in local sand supply and/or surge hydrodynamics. However, there is a general trend of decreasing tsunami deposit thickness with distance upriver, particularly above the bay constriction at Oneatta Point. The furthest upstream evidence of paleotsunami deposition on a paleomarsh surface is located at Grassy Point about 14 km upriver of the bay mouth. This deposit lies atop a peaty soil buried as a result of coseismic subsidence during the last great Cascadia earthquake (event 1). Low preservation potential of fringing marshes along the exposed shorelines of the lower bay and the main channel meanders requires that coring for older paleotsunami runup records be performed in small embayments off the main channels.

### ACKNOWLEDGMENTS

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## SSA calls to annual meeting in El Paso

The 1995 meeting of the Seismological Society of America (SSA) will take place March 22 through March 24 in El Paso, Texas, on the campus of the University of Texas. Seismologists, geologists, engineers, and educators from around the world will present their recent findings.

The program will include, among many other presentations and events, sessions on the following topics:

- Preliminary findings on the 1995 Kobe, Japan, earthquake.
- Microearthquake behavior in incipient rupture zones. Large earthquakes are sometimes preceded by an increasing number of small earthquakes. Data that are being collected at the monitoring experiment at Parkfield, California, will be presented.
- Seismology in K–12 education. Presentations will focus on using seismology as a thematic tool in science education as well as for increasing earthquake awareness and preparedness.
- Volcanic seismology. This session will focus on the relationship between seismic activity and volcanic activity, including findings related to the December 1994 eruption of the Popocatepetl volcano.

Further information is available from Nancy Sauer, RDD Consultants, Inc., 1163 Franklin Avenue, Louisville CO 80027, phone (303) 665-9423, FAX (303) 665-9413 (9 a.m. to 5 p.m. MST), and E-mail nksauer@dash.com.

*—SSA news release*

## BLM and cavers join forces in Medford

The U.S. Bureau of Land Management in Oregon's Medford District has signed a Memorandum of Understanding with the Southern Oregon Grotto of the National Speleological Society for joining efforts to manage the caves on BLM land. BLM has recently acquired a significant cave (No Name Cave) and hopes to add Marble Mountain Cave. The cavers will assist BLM as volunteers in cave monitoring, exploration surveying, mapping and other efforts to manage caves as natural resources. □

# Yes, we had bananas

*by Steven R. Manchester, Department of Natural Sciences, Florida Museum of Natural History, University of Florida, Gainesville, Florida 32611-2035*

**ABSTRACT**

A fossil banana has been recovered from the middle Eocene Clarno Formation, Wheeler County, Oregon. The fruit is preserved as an impression in lacustrine shale from the West Branch Creek assemblage. It is 4 cm long, 1.5 cm wide, and slightly curved and has well-defined longitudinal and transverse striations. Three rows of about ten seeds are evident, and these seeds correspond in external form to permineralized seeds that occur elsewhere in the Clarno Formation. The new information from fruit morphology, together with previous investigations of seed structure, indicate that the Clarno banana belongs to *Ensete*, a genus that is native to the Old World tropics today. The presence of this and many other tropical to subtropical fruits in the Clarno Formation indicates that Oregon experienced a warm, humid climate about 43 million years ago.

**INTRODUCTION**

The Eocene Clarno Formation of north-central Oregon contains one of the richest fossil fruit and seed assemblages in North America, with more than 170 species described from a single locality (Scott, 1954; Manchester, 1994). Some of the fruits have wings, indicating that they were adapted for dispersal by wind, while others were nuts and berries evidently eaten and dispersed by birds and mammals. Many of the Clarno fruit and seed genera are extinct, but at least a fourth of them belong to genera that are still living today (Manchester, 1994). Although the Clarno Formation predates the appearance of humans by about 40 million years, some of the Clarno fruits represent genera that have been brought into human cultivation during recent millennia. Clarno fruits that would be familiar to the modern human palate include walnuts (*Juglans clarnensis*), cherries (*Prunus olsonii, P. weinsteinii*), grapes (*Vitis tiffneyi, V. magnisperma*), kiwi (*Actinidia oregonensis*), and bananas (*Ensete oregonense*). Usually all that remains of these fruits in the fossil state are the hard parts, such as the seed or pit, but details of internal structure are often so well preserved that they may be identified through careful comparison with modern examples.

The presence of bananas in the Clarno Formation was recently determined on the basis of seeds showing internal morphology identical to that of extant *Ensete* (Manchester and Kress, 1993; Manchester, 1994). Modern bananas (Musaceae family) belong to three genera: *Musa, Ensete, Musella*. Although the familiar table banana (*Musa acuminata*) has been bred for small, infertile seeds and is grown from cuttings, wild bananas have hard seeds with distinctive morphology. Comparison of fossil seeds from the Clarno Nut Beds with those of modern Musaceae enabled Manchester and Kress (1993) to identify the Clarno banana as a representative of *Ensete* (Manchester and Kress, 1993). However, remains of the fruit itself were not known. The recent recognition of a complete banana fruit impression corroborates the determination from seeds and is presented for the first time in this article.

**GEOLOGIC OCCURRENCE**

The banana fruit and seed fossils occur in the Clarno Forma-

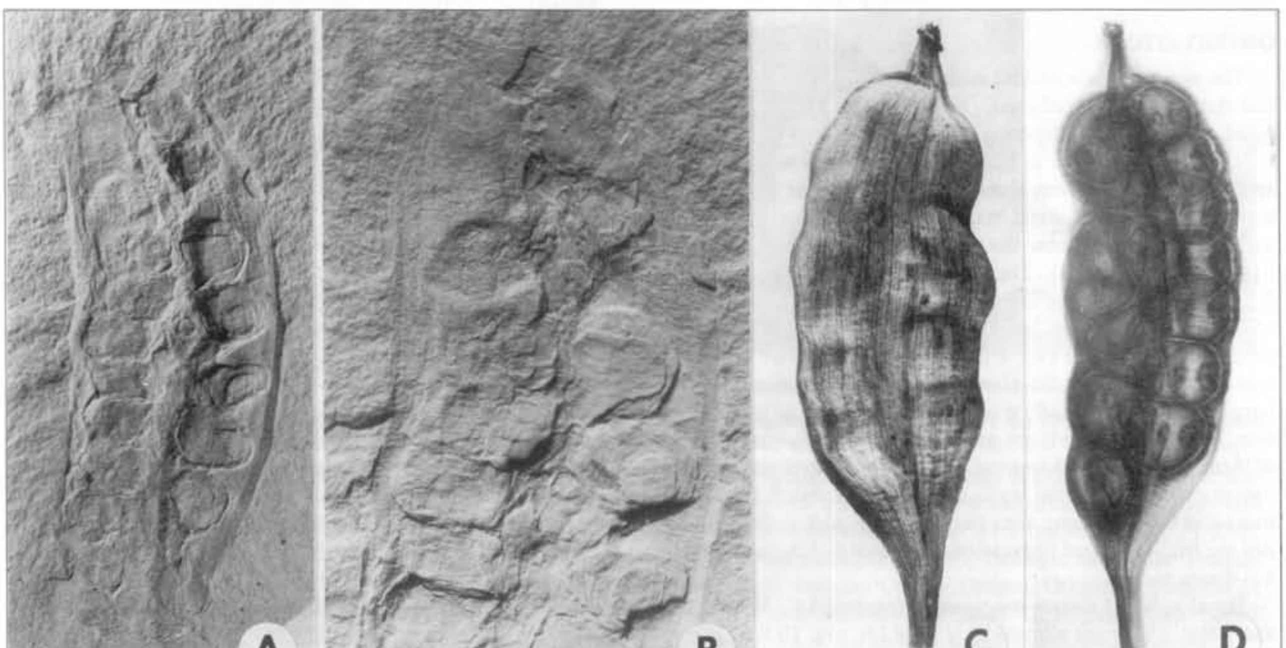


*Figure 1. Fossil and modern fruits of the genus* Ensete. *A.* Ensete *sp. fruit impression in shale (UF 15072), x2. B. Detail of same, showing longitudinal and horizontal striations of the fruit wall and shapes of the seed impressions, x3. C. Fruit of the living species,* Ensete calosperma *(New Guinea, coll. L.J. Brass 32476), x1. D. Same specimen as in C, X-rayed to show arrangement of seeds inside, x1.*

tion in Wheeler County, Oregon. The Clarno Formation includes volcanic flows, intrusions, lahars, and tuffs and is mostly middle to late Eocene in age (55–40 million years; Walker and Robinson, 1990; Suayah, 1990). At many locations, the tuffs yield well-preserved fossil plants (Hergert, 1961; Manchester, 1986, p. 224; 1994, p. 10).

The banana fruit impression was collected from lacustrine shales exposed in "Alex Canyon," a tributary of West Branch Bridge Creek about 6 mi west of Mitchell, Oregon (UF loc. 229c; SE¼ sec. 25, T. 11 S., R. 20 E.). This site carries the informal name "Alex Canyon," referring to Alexander Atkins, who first called my attention to the occurrence of fossil leaves at this site in 1981. The locality is on privately held land, and permission to collect was obtained at that time from the owner. Fossil leaves, winged fruits, and disarticulated fish remains are similar to those accessible to the public along road cuts of Highway 26 near the Ochoco divide (Cavender, 1968; Retallack, 1991). The West Branch Bridge Creek shales are known mostly for fossil leaves (Hergert, 1961; Manchester, 1986), but winged fruits (Manchester, 1991) and occasional flowers (Manchester, 1986, 1992) are also found. Based upon floristic comparisons with radiometrically dated Clarno deposits in the Cherry Creek drainage, the age of these sediments is probably within the range of 43–46 million years (Manchester, 1990).

The silicified seeds of *Ensete oregonensis* were recovered from the Nut Beds locality on the western edge of the Clarno Unit of the John Day Fossil Beds National Monument, about 20 km west of Fossil, Oregon (UF loc. 225; Manchester, 1981, 1994). Most of the specimens were collected by the late Thomas J. Bones, whose diverse collection forms the basis of a monographic treatment of the flora (Manchester 1994). This locality is middle Eocene in age, based upon the Bridgerian vertebrate fauna (Stirton, 1944; Hanson, 1973) and radiometric dates of 43–44 million years (Vance, 1988; Turrin *in* Manchester, 1994, p. 13).

## OBSERVATIONS

The specimen is a natural mold of a banana that was buried and flattened in the sediment (Figure lA,B). The fruit is elongated, slightly curved, tapering toward both ends, 4 cm long, and 1.5 cm wide. The apex is bluntly rounded; the base is torn but appears also to have been bluntly rounded; however, it is not certain if there was a distinct stalk. Well-defined lengthwise and transverse striations show the position of fibrous bundles in the fruit wall (Figure 1B). The longitudinal striations are about 0.5–0.8 mm apart; the horizontal ones more closely spaced, 0.3–0.5 mm apart. Two longitudinal rows of ten seeds each are clearly visible (Figure lA); a third row of seeds with their long axes perpendicular to the plane of the compression may be inferred from the irregularly thickened middle zone of the impression. Although the seeds are not well preserved, the impressions of them indicate that they were more or less barrel shaped with convex-cylindrical lateral walls and bluntly rounded apices and bases and that their long axes were perpendicular to the long axisof the fruit. The seed impressions are about 5–5.5 mm long and 3.5–4 mm wide).

Fossil seeds of *Ensete oregonense* (Figure 2A-C; Manchester and Kress, 1993) are ellipsoidal, 10.0–12.0, avg. 10.8 mm long, and 5.3–7.2, avg. 5.8 mm wide with a rounded base and truncate attachment end; they are circular to subangular in transverse section. The seeds are smooth to finely striate longitudinally (Figure 2A, C). At the attachment end they have a wide depression with a rim about 1 mm high and a central plug about 1.2 mm in diameter. Longitudinal sections (e.g, Figure 2B) reveal a large, barrel-shaped central chamber (containing the embryo and endosperm) that is separated by a partition from a small chalazal chamber at the distal end; the embryo (preserved in only a few specimens) ascends into the central chamber from the attachment end of the seed and is 2.5 mm long, straight, and bulbous.

## DISCUSSION

Based upon similarities of external form, a modern fruit of *Ensete calosperma* was selected for detailed comparison with the fossil and was X-rayed (Fig. 1C,D) to show the arrangement and shape of seeds. Although the modern fruit and its seeds are about twice as large as the fossil, the morphology is very similar. The modern specimen has three rows of seeds, and they are shaped and oriented similar to the seed impressions of the fossil. Two sets of striations, some running lengthwise and others running transversely, are characteristic of bananas. Fruits of extant *Musa* species usually have six or more rows of many seeds, and the presence of just three rows of seeds in the Clarno fossil supports the determination as *Ensete*.

The fossil fruit is small in relation to living species of *Musa* and *Ensete*. Note that the fossil specimen magnified two times in Figure 1A matches the natural size of the modern fruit in Figure 1C. Nevertheless, the fossil conforms in shape—including the slight curvature of the long axis and the length/width ratio—and in structural details—including both longitudinal and horizontal striations and more or less barrel-shaped seeds attached toward the central axis of the fruit (axile placentation).

The beautifully preserved silicified seeds of *Ensete oregonensis* from the Clarno Nut Beds locality (Figure 2A-C) have already been described and illustrated in more detail elsewhere (Manchester and Kress, 1993; Manchester, 1994). These studies indicate that the seeds represent *Ensete* and not *Musa*. The close similarities between the fossil seed and modern seeds of *Ensete* are readily apparent from a comparison of longitudinal sections (Figures 2A and 2D).

It should be noted that the seed impressions of the fossil fruit from West Branch Bridge Creek (Fig. 1A,B) are about half the size of seeds from the Nut Beds (10.0–12.0, avg. 10.8 mm long, 5.3–7.2, avg. 5.8 mm wide vs. 5–5.5 mm long, 3.5–4 mm wide). This size discrepancy may be significant, because more than 70 seeds from the Nut Beds were studied, and none were small enough to fall in the range of those in the fossil fruit. It may be that this particular fruit was immature, although the seeds appear to have been fully hardened. Possibly, the different modes of fossilization may have resulted in shrinkage of seeds in the impression fossil vs. swelling of the permineralized seeds. Taking the size differences at face value would suggest that the fruit specimen represents a different species, distinct from the one represented by the isolated seeds. With only one specimen of the fruit, however, I hesitate to establish a new species.

## CONCLUSIONS

*Ensete* is a genus of seven species native today to the Old World tropics. The presence of this and many other tropical to subtropical fruits in the Clarno Formation indicates that Oregon experienced a warm, humid climate about 43 million years ago. The Clarno flora also contains many genera common to temperate areas today, yet the evidence from frost-intolerant plants such as bananas, palms, and cycads, together with the occurrence of crocodilian remains attests to a climate that was significantly warmer than that of today (Manchester, 1994). This information

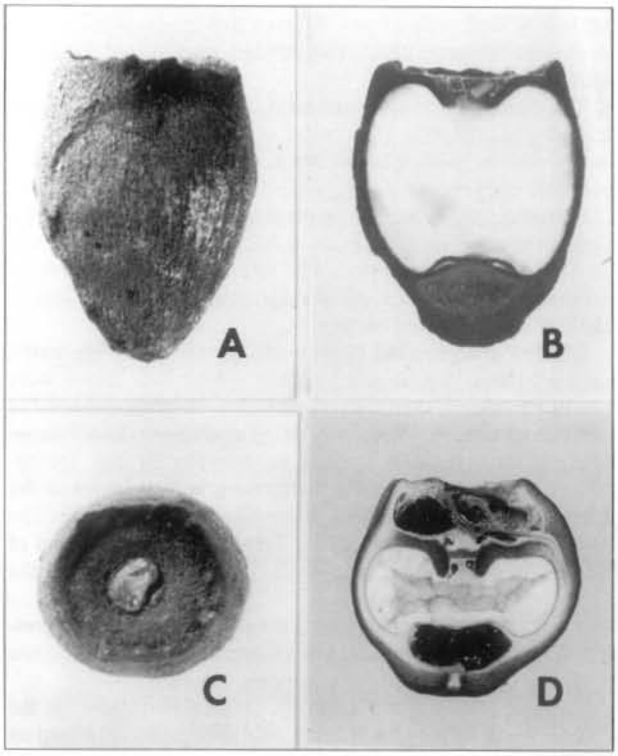

*Figure 2. Fossil and modern seeds of* Ensete. *A-C. The fossil species* Ensete oregonense *from Clarno Nut Beds locality, x5. A. Lateral view showing striate seed coat and apical truncation from which the operculum has detached (holotype, UF 6621). B. Same specimen, sectioned longitudinally showing silica-filled central endosperm chamber. C. Apical view of the specimen from A, prior to sectioning. D. Modern* Ensete glaucum, *sectioned longitudinally for comparison with the fossil seeds (New Guinea, coll. Kress 83-1554), x3.*

is in accord with evidence from many other quarters, indicating that global climate was significantly warmer in the Eocene than at any time later (e.g., Wolfe, 1994).

The occurrence of *Ensete* in the fossil record of North America also is biogeographically significant, because *Ensete* grows natively today in Africa and Asia but not in the Americas. The Oregon record shows that the genus was formerly more widely distributed. The occurrence of this *Ensete* today in southeast Asia fits a pattern observed for other Clarno fossil plants as well. Among the modern genera identified from the Nut Beds assemblage (Manchester, 1994), 37 (or 90 percent) occur today in southeast Asia. This percentage is higher than that for other regions and is taken as an indication that southeast Asia served as a refugium for once-widespread thermophilic genera that could not withstand the effects of climatic cooling later in the Tertiary and during the Quaternary.

## ACKNOWLEDGMENTS

The banana specimen was collected and donated by Ian Gordon in 1983, and it lingered in storage, unidentified until recently. Modern fruits for comparison were provided by W.J. Kress. Permission to collect at the West Branch Bridge Creek locality was kindly granted at that time by Mr. Wilson. X-radiographs were prepared with equipment at the C.A. Pound Laboratory, University of Florida. This project was supported in part by grants DEB-81-11-89, EAR-8707523, and EAR-8904234 from the National Science Foundation. This paper represents number 456 in *Florida Contributions to Paleontology*.

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# California now certifies hydrogeologists

Effective August 17, 1994, all qualified registered geologists in California who want to become "Certified Hydrogeologists" may take the hydrogeology examination scheduled for Sacramento and Riverside March 28 or October 3, 1995, or every six months thereafter. Final filing date for the October 1995 exam is July 7.

For qualifications or other information, contact the address below. If you are qualified and interested in taking the exam, you may ask for the examination packet: State Board of Registration for Geologists and Geophysicists, 400 R Street, Suite 4060, Sacramento, CA 95814, phone (916) 445-1920, FAX (916) 445-8859. □

# Gold dredges in the Sumpter Valley

*by Bert Webber, Research Photojournalist, P.O. Box 11, Medford, OR 97501*

That antique gold dredge sitting in its pond at Sumpter, Oregon, resembles a dilapidated and abandoned five-story hotel. But it was not always that way. This Yuba-type dredge started life in 1935, was forced to shut down during World War II, then resumed churning the soil in the Sumpter Valley until August 1954.

In the history of dredging for gold, the Sumpter Dredge was not the largest, but it was certainly at the "large" end for size, on a list of dredges. It is 120 ft long and 52 ft wide. Its overall length, with its stacker, makes this engineering contraption 216 ft long.

The Sumpter Dredge worked as many as 23 men but not all of them at any one time. A large crew was necessary as the dredge worked 24 hours a day and nearly seven days a week. The time off line was for knockdown of the jigs and sluices once a week to remove the gold.

The gold dredge, also called a "dredger," is a weird-appearing apparatus that some claim resembles a giant praying mantis. It creaks, clatters, and emits horrendous groans and screams as it digs rocks and sand from the bottom of a river or pond. After digesting this muck in its bowels, it keeps what it seeks, gold, then spews the residue out its back side leaving mountains of rocks.

As to the potential effectiveness of dredging, which is a method of operating a large number of sluice boxes at one time, the *Encyclopedia Britannica* declared its sluice "considered to be the best contrivance for washing gold gravels."

The gold dredge is indeed a complicated system of motors and/or engines, winches, miles of cable, hydraulically operated devices, sluice boxes, quicksilver recovery units, shaking jigs, water pumps, sand- and water-discharge plumbing, and a conveyor stacker that dumps the leftovers far out behind the dredge.

Although some early dredges worked in rivers, most worked in their own ponds. When a dredge-master decided to change digging sites, the dredge moved and took its pond with it.

The Sumpter Dredge pumped 3,000 gallons of water per minute from its pond. The water was supplied by one 6-in. and two 10-in. pumps to six 24-in. American jigs and sluice boxes for gold recovery.

A dredge works on the principle of the bucket line. The Sumpter dredge used 72 cast-iron buckets, each holding 9 cubic feet and weighing a ton. The rate-of-dig was 25 buckets per minute. At this rate, an average month's dredging moved 280,000 cubic yards of earth.

Various dredges used various sources of power. The earliest were steam driven, using cord wood for fuel. Some were gasoline powered, then came diesel. But the most dependable fuel was electricity. When a dredging operation was off somewhere in the mountains, such as the Sumpter Dredge, the operators built a power house, then strung miles of wire to the dredge. For this dredge, the power line was 12 mi long. The bucket line was powered with a 250-hp motor on the end of the 23,000-volt power line from the portable substation at the edge of the pond.

To be historically accurate, one should point out that the present dredge, the potentate of the new Sumpter Valley Dredge State Park, is actually the third Yuba dredge in this valley.

Sumpter No. 1 started digging, moving downstream, in the Powder River on January 13, 1913. It finally ground to a stop on July 23, 1924. The bones of its hull can be seen at the present time right where it stopped: in the swamp just a few feet from the "Dredge Depot" of the Sumpter Valley Restoration Railroad. This is a few hundred yards south of the ghost town of McEwan on Highway 7. As of this writing, no interpretative sign tells the visitor what this scrap pile of old timbers represents.

Sumpter No. 2 operated between October 1915 and 1923. It worked upstream from the town of Sumpter on Cracker Creek in the direction of Bourne. After its work was finished, it was carefully dismantled, except for the hull, and its parts were shipped in 18 railroad cars to a buyer near Liberty, Washington. Here the dredge was reassembled on a new hull. This location is just off Highway 97, a short distance north of Ellensburg. The dredge, now renamed "Liberty Dredge," started scooping up muck on February 22, 1926. But alas, the dredge proved too big for the job, so it was moved to another site close by. Liberty Dredge could bite through a 65-ft bank, but it worked only 71 days, until it was confronted by a 200-ft bank of heavy rock, which it could not conquer. That mining venture folded. The equipment from the dredge was sold and the hull left to the elements. Substantial remains of the structure, now collapsed but still sitting in its pond, are easily found.

*Sumpter Dredge No. 3 is the attraction of the new Sumpter Valley Dredge State Park, in Sumpter, Oregon. The State Parks Department bought the rare 1,250-ton machine for $195,000 in 1994. Photo taken June 1994.*

Dredge No. 3, the dredge that is now the center of the new State Park at Sumpter, had for its machinery the parts from the original No. 1 dredge. After the final shutdown in 1954, much of the machinery was removed. Because of the huge costs involved in setting up a dredge, it takes years of digging to pay off the investment before profits can be taken. Not all dredge operations are profitable. For Sumpter Valley Dredge No. 3, the setting-up cost was $300,000, but it took out $45 million in gold.

When the Oregon State Parks people complete their reclamation project, the dredge will be a monumental triumph for their rejuvenation efforts and will allow visitors to tour this magnificent, giant Rube Goldberg apparatus. Already, the town of Sumpter is visited by thousands of people who just like to walk around the perimeter of the dredge's pond and gawk at the quiet monster.

Dredging continues today. In California, the Yuba Dredge No. 21 operates 24 hours a day, seven days a week in the Yuba Gold Field about 50 miles northeast of Sacramento. This operation of Cal Sierra Development, Inc., has been there for 16 years. The Yuba No. 21 makes Sumpter Dredge seem a miniature, for No. 21 is 453 ft long and 101 ft high. Its present dig is in its own pond 48 ft below the surface of surrounding terrain. The buckets, 20 cubic feet each (Sumpter Dredge buckets are 9 cu. ft.), dig 140 ft below water level, which makes the dig reach 187 ft below the surrounding land, one of the deepest in the world. □

*The beautiful alpine Sumpter Valley was transformed into a gigantic gravel pit, as the dredge moved across the land digging out its gold—$45 million worth of it. Photo taken in July of 1993.*

***The author, Bert Webber, has also written a book on the subject of dredges,* Dredging For Gold—Documentary, *which was published by Webb Research Group Publishers in 1994.*** —*ed.*

## New index of geologic mapping in Oregon released

The Oregon Department of Geology and Mineral Industries (DOGAMI) has released a new index of geologic mapping in Oregon that helps a researcher to identify all geologic maps ever produced by DOGAMI, the U.S. Geological Survey, and the Oregon Water Resources Department for any given area in the state.

**Index to Geologic Maps of Oregon by U.S. Geological Survey Topographic Quadrangle Name, 1883-1994** is the title of the new index that has been released as Open-File Report O–95–4. It was compiled by Peter L. Stark, Head of the Map and Aerial Photography (MAP) Library at the University of Oregon Library in Eugene.

The index has 67 pages with over 3,450 entries in an alphabetic list of all 15-minute and 7½-minute topographic map quadrangles in Oregon for which geologic mapping has been done. Quadrangles whose names have been changed over the years are listed under each of their names. Each quadrangle name is followed by references to publications by DOGAMI, the U.S. Geological Survey (USGS), or the Oregon Water Resources Department. Entries also include the scale of mapping and comments on the extent of coverage in the quadrangle. Only those geologic maps are listed that are at a scale of at least 1:125,000 (one inch = two miles), most commonly 1:62,500 or 1:24,000.

While it is first and foremost a library tool, the index can serve as a useful, up-to-date bibliographic reference for geologic information. Many publications that include geologic maps are comprehensive studies of particular subjects or areas. The required quadrangle name for a given area of interest can be easily obtained from the U.S. Geological Survey or any place where maps are used or sold.

For ordering instructions, see the last page of this issue. □

## Workshop on Ames structure in Oklahoma

A workshop on "Ames Structure and Similar Features" will be held at the University of Oklahoma on March 28–29, 1995. The program will present research and studies dealing with meteorite-impact craters (such as the Ames structure in northwestern Oklahoma), exploration, reservoir characterization, geochemistry, remote sensing, and other subjects related to development of petroleum resources.

The Ames structure in Oklahoma was formed by meteorite impact, volcanic activity, or dissolution/collapse. It is 6–10 mi across, buried beneath 9,000 ft of sediments, and is a prolific source of oil and gas. Similar structures have been found in various parts of the United States as well as worldwide.

The workshop, which will also include a poster session, is sponsored by the Oklahoma Geological Survey and the Bartlesville Project Office of the U.S. Department of Energy. For the two-day workshop, 1.5 Continuing Education Units (CEUs) are available. Further information is available from the Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019-0628, phone 405-325-3031. □

# 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.*

**Geology and mineralization of the Ochoco gold prospect, Crook County, Oregon**, by Dana C. Willis (M.S., Oregon State University, 1992), 97 p.

The Ochoco gold prospect is located in the Ochoco Mountains of central Oregon, 26 mi east of Prineville. Small-scale placer and lode mining in the Howard Mining District of central Oregon began in the early 1800s, with the principal placer workings along Scissors Creek and Ochoco Creek. Lode production from the district was mainly from the Ophir-Mayflower mine (Ochoco mine), with minor production from several other small workings. Placer mining decreased in importance as the placers were worked out in 1883; lode mining continued until the last reported production in 1923.

The Ochoco gold deposit is within the Ochoco Mountains subprovince of the western part of the Blue Mountains province. Generally, the Ochoco Mountains are a broad uplifted region of Miocene-Eocene volcanic rocks that uncomformably overlie Cretaceous and older marine sedimentary and metamorphic rocks. The deposit is roughly halfway between the Blue Mountain anticlinorium to the northwest and the Post anticlinorium to the southeast. These broad, parallel, folded uplifts account for much of the deformation in the region. Several smaller, parallel-fold axes are found between the large anticlinoria and are roughly parallel to the Ochoco Creek fault zone, which bounds the study area on the northwest.

The Clarno Formation, which hosts the deposit, is a terrestrial calc-alkaline assemblage of flows, plugs, dikes, volcanic breccias, mudflows, ash flows, and tuffaceous sedimentary rocks and lahars of widely variable thickness, probably erupted from stratovolcanoes. The Clarno Formation varies in composition from alkali olivine basalt on the basis of isotopic ages and faunal evidence and ranges in age from 54 to 37 Ma. K-Ar age determinations place the age of the host rocks at 50.8 Ma and mineralization at 46.4 Ma.

Volcanic rocks within the project area are chiefly intercalated andesite tuffs, breccias, andesite to basaltic andesite flows, and flow breccias. These rocks, subdivided by mineralogy and texture, are confined to a few map units because of limited exposure and the effects of hydrothermal alteration.

Structures in the study area are predominantly high-angle normal faults that offset Clarno Formation volcanic rocks. There appear to be two, possibly three, different sets of faults based on their strike and cross-cutting relationships. Ochoco Creek follows the main fault along a N. 40°–60° E. strike, with secondary faults in Scissors Creek striking at N. 40° E. and N. 60° E. These en-echelon faults cut and offset small faults that strike N. 60° W. Several late-stage breccia pipes cut across the early andesite flows.

Hydrothermal alteration and mineralization in the project area are probably related to Eocene-age intrusions that acted as a heat source for the hydrothermal system. This hydrothermal system was centered above and around an intrusion of intermediate composition. A broad zone of weak alteration is characteristic of the area, with local zones of moderate to strong alteration in and around structures and breccia pipes. On a broad scale, the areal distribution of alteration displays a crude zonation, with intensity of alteration decreasing away from the center of mineralization. Weak propylitic alteration is pervasive throughout most rocks in the area and intensifies with proximity to faults, fractures, and breccia bodies. The propylitic assemblage is characterized by secondary minerals of calcite + chlorite + pyrite ± sericite. Mineralogy of the intermediate argillic alteration is characterized by sericite + calcite + pyrite ± clay ± chlorite. The intensity of argillic alteration ranges from incipient, in which modest amounts of sericite and calcite replace feldspar, to advanced, where the feldspar and hornblende are completely replaced by sericite ± clay. Advanced argillic alteration is characterized by clay minerals and sulfides replacing the host rocks within narrow structural zones.

Ore mineralogy at the deposit is fairly simple, consisting of ubiquitous pyrite and subordinate amounts of sphalerite, galena, chalcopyrite, tetrahedrite, pyrrhotite, maracasite, stibnite, cinnabar, realgar, argentite, and minor supergene minerals. The bulk of the gold is associated with pyrite, although visible gold is scarce. Mineralization is of two types: pyrite occurring as dissemination and veinlets and calcite veinlets with intergrown pyrite, sphalerite, galena, chalcopyrite, and tetrahedrite(?), with minor rhodochrosite.

Exploration drilling in the area has yielded over 11,000 assays for gold, silver, antimony, lead, zinc, arsenic, and copper. Concentrations of these metals range up to 5 ppm Au, 90 ppm Ag, 0.2 percent Sb, 0.6 percent Pb, 0.6 percent Zn, 0.2 percent As, and 450 ppm Cu. There is a median gold-to-silver ratio of 1:11.

Geologic characteristics of the deposit place it into the volcanic-hosted Au-Ag epithermal deposit category, with some features found in the Cordilleran vein-type deposit. This deposit is unusual in that it has anomalously higher base-metal concentrations and lower precious-metal concentrations than are found in typical Au-Ag epithermal deposits.

**Coastal crossing of the elastic strain zero-isobase, Cascadia margin, south-central Oregon coast**, by Gregory George Briggs (M.S., Portland State University, 1994), 251 p.

The analysis of marsh cores from the tidal zones of the Siuslaw, Umpqua, and Coos River systems on the south-central Oregon coast provides supporting evidence of coseismic subsidence resulting from megathrust earthquakes and reveals the landward extent of the zero-isobase. The analysis is based on lithostatigraphy, paleotidal indicators, microfossil paleotidal indicators, and radiocarbon age. Coseismic activity is further supported by the presence of anomalous thin sand layers present in certain cores. The analysis of diatom assemblages provides evidence of relative sea-level displacement on the order of 1 to 2 m. The historic quiescence of local synclinal structures in the Coos Bay area together with the evidence of prehistoric episodic burial of wetland sequences suggests that the activity of these structures is linked to megathrust releases. The distribution of cores containing non-episodically buried marshes and cores that show episodically buried wetlands within this area suggests that the landward extent of the zero-isobase is between 100 km and 120 km from the trench. The zero-isobase has a minimum width of 10 to 15 km. Radiocarbon dating of selected buried peat sequences yields an estimated recurrence interval on the order of 400 years. The apparent overlapping of the landward margin of both the upperplate deformation zone (fold and/or thrust fault belt) and the landward extent of the zero-isobase is interpreted to represent the landward limit of the locked zone width of 105 km. The identification of the zero-isobase on the south-central Oregon coast is crucial to the prediction of regional coseismic subsidence and tsunami hazards, the testing of megathrust dislocation models, and the estimation of megathrust rupture areas and corresponding earthquake magnitudes in the Cascadia Margin. □

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Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, letters, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office (address above).



## Cover photo

"With eyes only a few feet above the ground the observer today must travel back and forth repeatedly and must record his observations mentally, photographically, by sketch and by map before he can form anything approaching a complete picture. Yet long before the paper bearing these words has yellowed, the average observer, looking down from the air as he crosses the region, will see almost at a glance the picture here drawn by piecing together the ground-level observations of months of work. The region is unique: let the observer take the wings of the morning to the uttermost parts of the earth: he will nowhere find its likeness." —*J Harlen Bretz, 1928.*

This somewhat whimsical photo of Bretz was taken some time around 1940. His work opened the way to our understanding of the cataclysmic Missoula floods that created the Channeled Scabland. A field trip guide to Missoula flood features begins on the next page and will be continued in subsequent issues.

## In memoriam: Volunteer Martha Carlson

Martha Carlson, volunteer with the Oregon Department of Geology and Mineral Industries (DOGAMI) since 1992, died at her home on March 9, 1995, of cancer. Born in Denver, Colorado, Martha and her husband Lennert were long-time residents of Oregon. They loved the out-of-doors, and both were Mazamas.

After her family was raised and Lennart died, Martha expanded her interest in travel to places outside Oregon, visiting other parts of the United States, Canada, England, Russia, Greece, Switzerland, Mexico, and Egypt. Her interest in art and history enabled her to serve as a docent for the Portland Art Museum and the Oregon Historical Society.

As a DOGAMI volunteer in the Nature of the Northwest Information Center, Martha was able to share her knowledge of Oregon and the out-of-doors with the public. More than that, she worked hard at marking and filing maps, helping to maintain the inventory of brochures, dusting and arranging stock on shelves, and even assembling publications so they could be available to the public when they were needed in a hurry.

Always cheerful and interested in what was going on around her, Martha made a real contribution to the lives of all of those of us who worked with her. She gave 461 hours of service to DOGAMI, but she also gave us much more—friendship, warmth, and encouragement. We miss her in many ways. She is survived by her daughter Eleanor, son David, both of their spouses, and five grandchildren whom she loved dearly. □

## Policy Working Group presents final report on coastal natural hazards

The Oregon Coastal Natural Hazards Policy Working Group (PWG) has published its findings and recommendations in a book recently released by the Oregon Sea Grant program of Oregon State University. The 128-page book is entitled *Improving Natural Hazards Management on the Oregon Coast*. The report outlines 23 issues along with 78 recommendations, dealing with hazard assessment, beach and shore protection, land use planning, and earthquake and tsunami disaster preparedness.

The book is available for $12 from the publisher, Sea Grant Communications of OSU, phone (503) 737-2716, or the DOGAMI offices in Baker City, Grants Pass, and Portland. See information on this page and on page 72. □

# Beyond the Channeled Scabland

## A field trip to Missoula flood features in the Columbia, Yakima, and Walla Walla valleys of Washington and Oregon—Part 1

*by James E. O'Connor* and Richard B. Waitt, U.S. Geological Survey, David A. Johnston Cascades Volcano Observatory, 5400 MacArthur Blvd., Vancouver, Washington 98661. With contributions by Gerardo Benito, Centro de Ciencias Medioambientales, Serrano, 115 dpdo, Madrid, Spain 28006; and David Cordero and Scott Burns, Department of Geology, Portland State University, P.O. Box 751, Portland, Oregon 97207*

*A preliminary version of this field trip guide was prepared for the first annual field conference of the Friends of the Pleistocene, Pacific Northwest Cell, May 13–15, 1994. This first part includes the introductory discussion and the list of references. The guide for the three-day trip will begin in the next issue. —ed.*

### INTRODUCTION

#### Field trip route

This trip along the Columbia, Walla Walla, and Yakima River valleys highlights Missoula flood features southwest of the classic Channeled Scabland of eastern Washington. The road log for each day begins at Deschutes River Recreation Area, an Oregon State Parks facility with camping and picnicking areas at the mouth of the Deschutes River, 3.4 mi west of Biggs and 12 mi east of The Dalles. Day 1 focuses on features on the Oregon side of the Columbia River between The Dalles and Arlington. Day 2 is a high-mileage loop up the Columbia River valley, through Wallula Gap and the lower Walla Walla valley, and up the lower Yakima valley, returning via Satus Pass. Day 3 concludes the trip by traveling downstream through the Columbia River Gorge to the Bonneville Landslide near Cascade Locks and Bonneville Dam (Figure 1).

#### Field trip guide organization and units

The guidebook includes introductory and background material, which is then followed by descriptions of each day's stops and discussions of features viewed while traveling between stops. A detailed road log for each day is at the end of the field-trip guide. The metric system is used for all scientific aspects of the guidebook except for altitudes, which are given in meters and in feet. Travel distances and mileages in the road log are given in miles.

#### Guide responsibility

The introductory material was written mainly by O'Connor, except for the last section by Waitt. The material for Day 1 is mostly from work by O'Connor and Benito, influenced by discussions and field visits with Waitt. Day 2 is mostly the work of Waitt, except for the discussion of the hydrology at Wallula Gap by O'Connor. Day 3 was compiled by O'Connor, based on work by O'Connor, Benito, Cordero, and Burns and previously published accounts of Columbia River Gorge geology.

* *Current affiliation: USDA Forest Service; current address: 3055 NE Everett, Portland, OR 97232.*

### THE MISSOULA FLOODS

Floods from cataclysmic releases of glacially dammed Lake Missoula produced a suite of spectacular flood features along multiple flowpaths between western Montana and the Pacific Ocean (Figure 2). In northern Idaho and eastern Washington, flow exiting glacial Lake Missoula overwhelmed the normal drainage routes, resulting in a plexus of flowpaths as the water spread out over the vast loess-covered basaltic plains. As the Missoula floods crossed eastern Washington, they eroded large and anastomosing coulee tracts into the basalt surfaces and left immense gravel bars. Far-travelled crystalline rocks, first picked up and carried by the Cordilleran ice sheet, were floated downstream by huge icebergs borne by the floods, and finally deposited in valleys and stranded on high hillslopes to define a "bathtub ring" of maximum flood stages. Tributary valleys like the Snake, Yakima, Walla Walla, Tucannon, John Day, Klickitat, and Willamette Rivers were mantled with sand and silt carried by water backflooding up these valleys and then receding from them again.

In south-central Washington, the myriad flow routes from the east and north converged onto the Pasco basin before funneling through Wallula Gap. Downstream, the Missoula floods continued, filling the valley of the Columbia River to depths greater than 275 m and leaving spectacular erosional and depositional features that dominate many parts of the present landscape between Wallula Gap and Portland.

Weaving together a story that linked the bizarre topography, the far-travelled exotic rocks, the immense and rippled gravel bars, and the valley-mantling bedded sand and silt has tested the creative abilities of countless scientists since the first decades of this century. Famous is J Harlen Bretz for his efforts during the 1920s and into the 1950s to persuade a skeptical geologic community of the merits of his "outrageous hypothesis" of cataclysmic flooding for genesis of what he named the "Channeled Scabland." More recent debate has centered on the number of floods, especially the idea that scores of colossal floods may have coursed through the Channeled Scabland (Waitt, 1980a, 1985b), rather than just one or a few envisioned by Bretz and other earlier workers. Discussion has also extended to the role that such multiple flows may have had in creating the flood features that we see today. Recent reports that review and

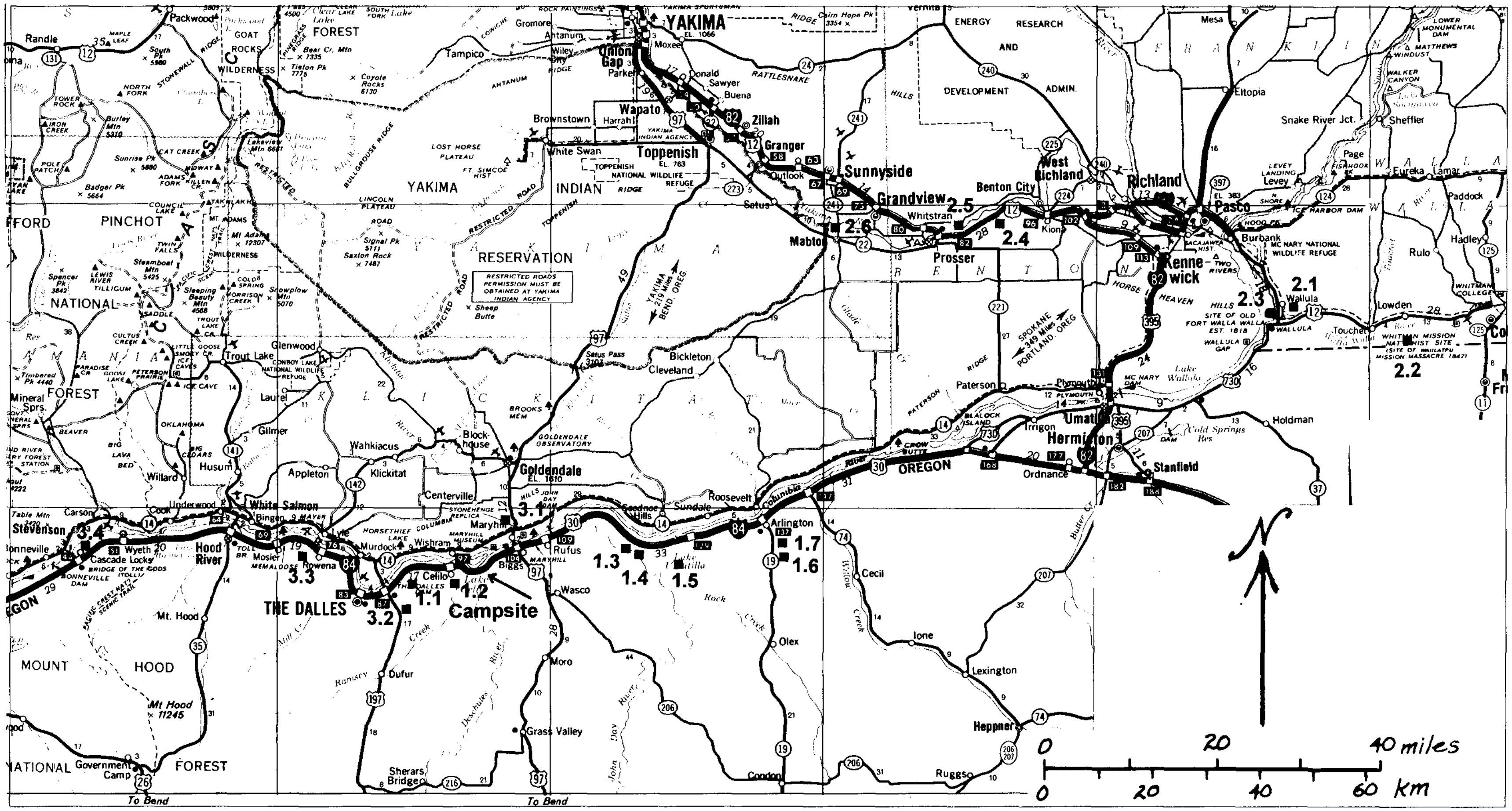


*Figure 1. Road map showing approximate locations of field trip stops.*

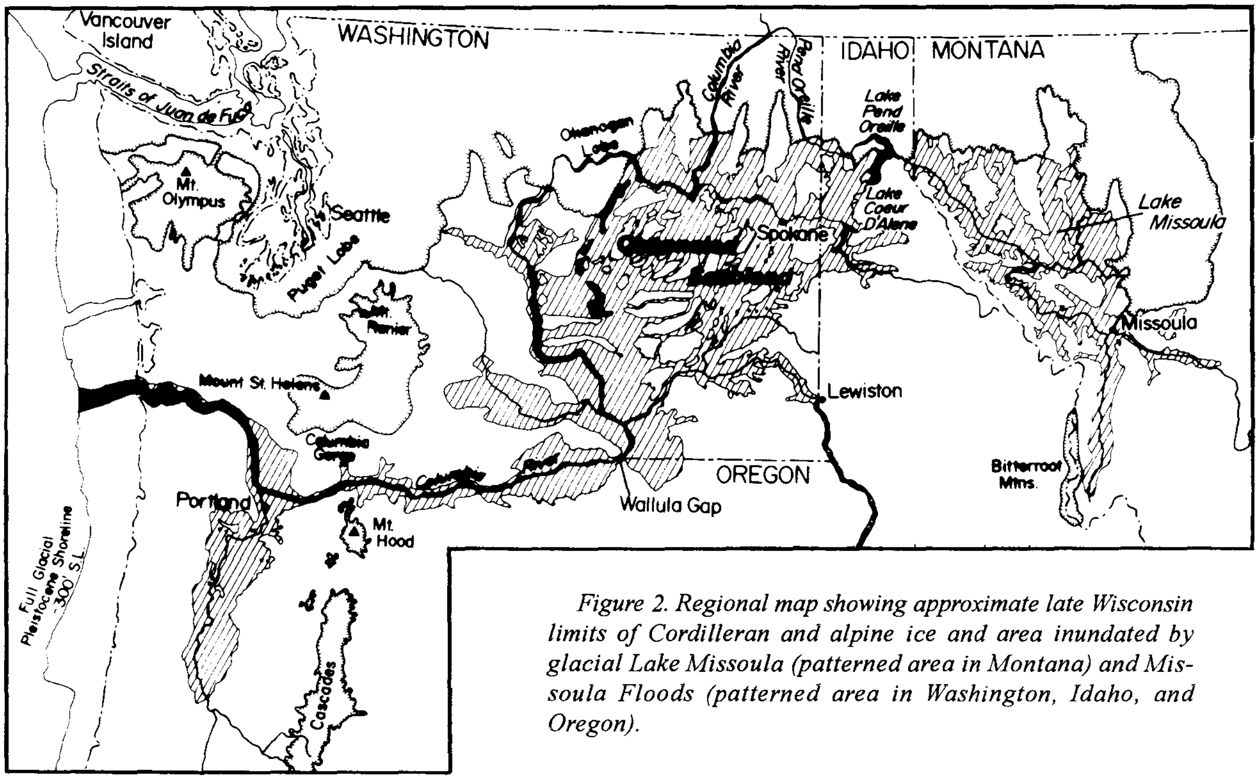


*Figure 2. Regional map showing approximate late Wisconsin limits of Cordilleran and alpine ice and area inundated by glacial Lake Missoula (patterned area in Montana) and Missoula Floods (patterned area in Washington, Idaho, and Oregon).*

touch on debated aspects of the Missoula floods include Waitt (1985a,b; 1994), Baker and Bunker (1985), Atwater (1986), O'Connor and Baker (1992), and Smith (1993).

## BEYOND THE CHANNELED SCABLAND

### Early studies of the Columbia River valley

Geomorphic features relevant to Missoula flooding in the Columbia River valley downstream from Wallula Gap were studied by Bretz (1924, 1925, 1928), Hodge (1931, 1938), and Allison (1933, 1941). These papers presented classic descriptions and discussions of features and ideas regarding the genesis of the extraordinary landscape of the valley of the Columbia River between Wallula Gap and Portland. Bretz described the bars and eroded scabland topography, arguing that they were the product of huge discharges from a then-unknown source, pointing out with clear descriptions and logic that many of these features resulted from channel processes at a valley scale. Gravel deposits with smooth and rounded forms flanking the valley were not terraces, but flood bars of immense height deposited in reaches of slacker currents or in zones of recirculation. The scabland and eroded rock benches were the result of plucking and erosion in channels beneath deep, vigorous currents that covered the entire valley bottom and sides to depths of hundreds of meters. Bretz's ideas were strongly disputed, but he responded with prose that remains relevant today:

> "Geology is plagued with extravagant ideas which spring from faulty observation and misinterpretation. They are worse than 'outrageous hypotheses,' for they lead nowhere. The writer's Spokane Flood hypothesis may belong to the latter class, but it can not be placed there unless errors of observation and direct inference are demonstrated. The writer insists that until then it should not be judged by the principles applicable to valley formation, for the scabland phenomena are the product of river channel mechanics. If this is in error, inherent disharmonies should establish the fact, and without adequate acquaintance with the region, this is the logical field for critics." (Bretz, 1928, p. 701)

E.T. Hodge (1931, 1938) suggested that the high gravel deposits, ice-rafted erratics, and divide crossings flanking the Columbia River valley recorded not a brief cataclysm, but the gradual entrenchment of the Columbia River through the Cascade Range since the middle Pliocene, stating:

> "The Columbia in its down-cutting was often choked by icebergs, which caused temporary or permanent local diversions. Many rock benches, chasms, and pot holes were cut, and stranded deposits were left at the successive levels of entrenchment. The river is not yet graded, and the methods by which it produces these curious, but by no means exceptional, features may still be observed." (Hodge, 1938, p. 836)

Ira S. Allison (1933) examined in some detail field relations between Portland and Wallula Gap and recognized the indisputable evidence for extremely high water levels. He clearly, however, struggled with the notion of catastrophic floods, and proposed a "new version" of the Spokane Flood, believing,

> "that the ponding was produced by a blockade of ice in the Columbia River Gorge through the Cascade Mountains; that the rise of the Columbia River to abnormally high levels began at the gorge and not on the plateau of

eastern Washington; the blockade gradually grew headward until it extended into eastern Washington; that, as the waters were dammed to progressively higher levels, they were diverted by the ice into a succession of routes across secondary drainage divides at increasing altitudes, producing scablands and perched gravel deposits along the diversion routes, distributing iceberg-rafted erratics far and wide, and depositing pebbly silts in slack-water areas. This interpretation of the flood does not require a short-lived catastrophic flood but explains the scablands, the gravel deposits, diversion channels, and divide crossings as the effects of a moderate flow of water, now here and now there, over an extended period of time. It thus removes the flood from the 'impossible' category." (Allison, 1933, p. 676–677)

### Recent work in the Columbia River Gorge

Since the mid-1950s, J Harlen Bretz's "impossible" story has become widely accepted by the scientific community. In recent decades, research has focused on understanding details of the Missoula floods, mostly from work in eastern Washington—where stratigraphic, glacial, and hydraulic studies have refined our understanding of the chronology, magnitude, and sequence of events. Nevertheless, many questions linger, and our work between Portland and Wallula Gap has focused on these. For example, it is clear from backflooded sites all along the flood path that there were tens of late Wisconsin flows, perhaps as many as 90 (Waitt, 1980a,b, 1984, 1985a,b; Atwater, 1986). But are these flows, mostly recorded by deposits at low-elevation sites, correlative with the high gravel deposits and evidence of maximum flood stages? How many flows got how high? Were all of these flows triggered by subglacial releases from the ice dam (gigantic jökulhlaups)? Were some perhaps due to catastrophic mechanical failure of the ice dam? What was the late-glacial flood chronology? Within the Columbia River valley, some additional questions include: What were the hydraulic characteristics of the floods and their relation to resultant flood features? Is there a record of pre-late Wisconsin floods like that in eastern Washington? How did the Missoula floods affect the Columbia River Gorge? The Columbia River valley is a good place to ask such questions: the features are dramatic and commonly well exposed, and all floods followed the same route downstream from Wallula Gap, thereby avoiding the possible hydraulic and stratigraphic complexity in eastern Washington that could have resulted from the anastomosing and evolving channel patterns of the Channeled Scabland in eastern Washington.

### Flood hydraulics and hydrology

We have compiled evidence of maximum flood stages between Portland and Wallula Gap from previous workers and our own observations and have used this information to estimate the peak discharge of the largest flow(s). Good evidence of maximum flood stages comes from the altitudes of ice-rafted erratics, divides crossed and divides not crossed, and loess scarps. The compiled high-water evidence indicates that the water-surface profile dropped substantially—almost 200 m—in the Columbia River Gorge between The Dalles and Portland (Figure 3). This was one of the steepest drops along the entire flood route, and hydraulic ponding behind the constricted gorge probably affected flow at maximum stages as far upstream as the Pasco basin. We have calculated water-surface profiles, using the step-backwater method (U.S. Army Corps of Engineers, 1990), for a 200-km reach between Arlington and Portland. A water-surface profile for a ten million $m^3/s$ discharge is consistent with the highest evidence of flooding along the entire flood route (Figure 3a). This value is similar to results from earlier studies that estimated the peak discharge at Wallula Gap (O'Connor and Baker, 1992). By comparison, ten million $m^3/s$ is about 300 times the flows of the 1993 Mississippi River flood as well as the largest historic Columbia River flood of 1894. The calculated water-surface profile for the largest Missoula flood indicates that flow was critical to supercritical in the lower part of the Columbia River Gorge, near Crown Point, with substantial hydraulic ponding upstream. Other constrictions that were apparently important in controlling the water-surface profile were near Mitchell Point, downstream from Hood River, and at Rowena Gap downstream from The Dalles, where the Columbia River flows through the Ortley anticline.

Using the results from these flow calculations, we have attempted to evaluate a couple of different questions. One research avenue has been trying to estimate discharges at sites where deposits of multiple floods are preserved, with the aim of answering the question: "How many floods were how big?" Another question we have evaluated is the relation of the calculated flood hydraulics with erosional features left by the floods.

### Radiocarbon dating and flood chronology in the Columbia River valley

While examining exposures between Wallula Gap and Hood River, we found various organic materials incorporated within and below Missoula flood deposits. Most of these samples were from gravel deposits or backflood deposits at high altitudes, which, we hoped, would help determine the chronologic relation of the larger floods to the lower-elevation rhythmites. The sampled material included charcoal, soil-organic material, dung, bones, and clasts of organic-rich silt of unknown origin. We obtained results on 25 samples from various sites, yielding dates spanning quite a large range of time—from >40,000 to 13,700 $^{14}C$ yr B.P. (Figure 4). Because all of these dates are from clasts in or below deposits, they are maximum limiting ages for the deposits, and their wide range is not totally unexpected considering the diversity of the samples collected. Because of the common occurrence of very different age determinations from (1) different samples collected from within the same deposits, (2) analyses of parts of individual samples subject to different pretreatments, and (3) analyses of subsamples of individual samples, we infer that there was abundant old carbon existing on the landscape and that only the very youngest age determinations (those dates <20 ka [20,000 years]) are helpful in determining the ages of the floods. Some of the "charcoal" samples that gave >40-ka ages are probably pre-Quaternary coal. Other very old charcoal samples, including one friable charcoal sample that cleaved along growth rings, were probably from sites where they had been protected from decay for many thousands of years. The many samples between 20 and 30 ka were probably entrained from sites of sediment accumulation and soil formation prior to the floods, and their dates reflect carbon photosynthesized during several thousands of years prior to the floods. Consistent with this, humate extracts and plant fragments, isolated from larger bulk samples, gave substantially younger dates than the ages of the bulk samples; thus they more closely limit the age of the floods. We emphasize that many of the older dates came from horizons above or at the same stratigraphic level of those that contained materials yielding <15-ka ages, indicating that there was a lot of old organic material being transported by the floods. Consequently, we doubt that radiocarbon dating of these types of transported materials can be considered reliable evidence of

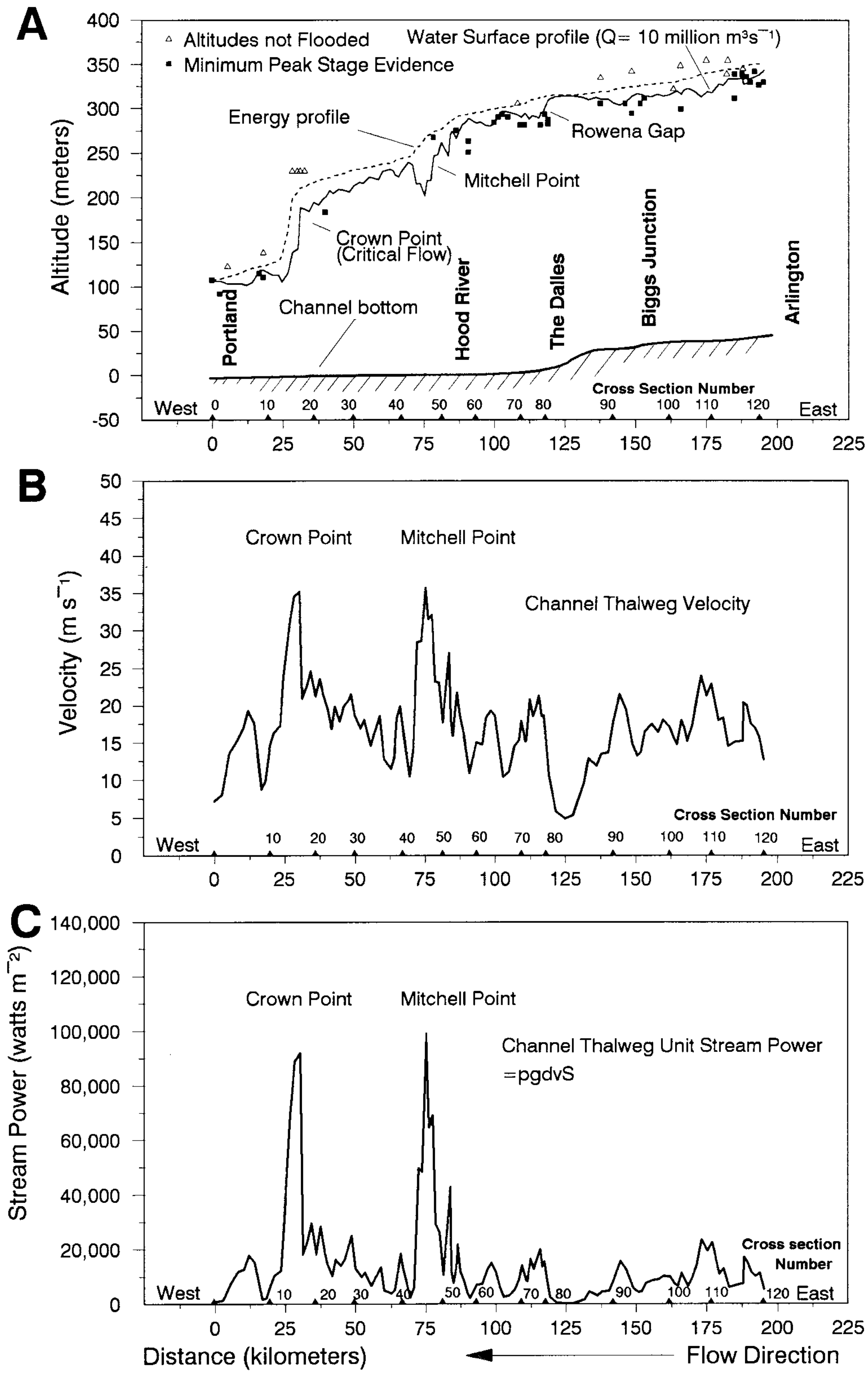


*Figure 3. Profiles of calculated hydraulic conditions between Portland and Arlington. All profiles determined on the basis of step-backwater calculations for a 10 million $m^3/s$ discharge for 120 cross sections. A: Water-surface and energy-surface profiles (and field evidence of maximum flood stages). B: Channel velocity. C: Unit area stream power.*

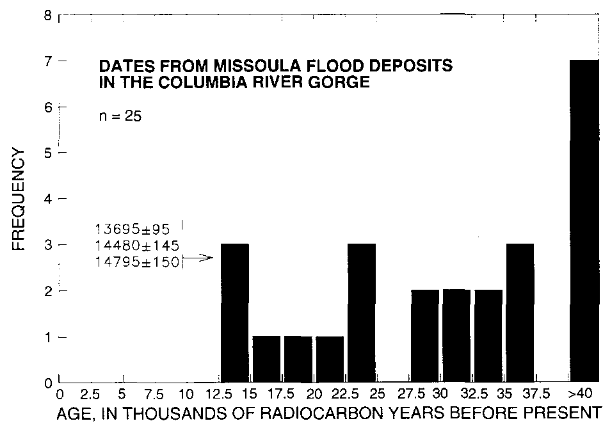


*Figure 4. Histogram of radiocarbon ages from samples collected (by Benito and O'Connor) from within or below Missoula flood deposits. All samples were collected between Hood River and Arlington, and most were from high-altitude gravel bars. We emphasize that all of these ages are maximum limiting ages for the deposits that contain or overlie the samples.*

middle Wisconsin flooding, as some have suggested (e.g., Kiver and others, 1991).

Weak soils cap the high gravel bars. This evidence, coupled with the radiocarbon dates, indicates that most, if not all, the coarse Missoula flood deposits in the Columbia River valley date from the last glacial (late Wisconsin) period of flooding, postulated earlier (Waitt, 1980a, 1985b; Atwater, 1986; Waitt and Atwater, 1989) to have been between 12.7 and 15 ka on the basis of radiocarbon dates, varve counts between flood deposits, and tephra relations in eastern Washington. We have not yet found any coarse deposits that have soils or radiocarbon results that indicate deposition during earlier periods of flooding. The question of pre-late Wisconsin floods through the Columbia River Gorge will be further addressed at Stop 3.4.

A key stratigraphic marker that can be seen at several sites along the trip is the Mount St. Helens "set S" tephra. Exposed in various places as a singlet, couplet, or triplet, the age of this tephra has been bracketed between radiocarbon dates of 12,120±120 and 13,650±120 $^{14}$C yr B.P. (Mullineaux and others, 1978). Dates of 13,130±350 and 12,910±160 $^{14}$C yr B.P. from samples within the tephra units and associated volcanic units near Mount St. Helens indicate that the tephra was probably erupted near 13 ka (Crandell and others, 1981). Another important stratigraphic relation, outside the field trip area near Lewiston, is that about 21 Missoula flood rhythmite layers overlie Bonneville flood deposits (Waitt, 1985b). The overflow of Pleistocene Lake Bonneville was some time between 14.3 and 15.3 ka (Oviatt and others, 1992).

## THE QUESTION OF REPEATED GIANT LATE-WISCONSIN FLOODS

In a justly famous report that forever vindicated Bretz's controversial 1920s' great-flood theory of the Channeled Scabland, Bretz and others (1956) announced that as many as seven great late Wisconsin floods had occurred. The evidence was geomorphic and mostly from the Quincy basin and environs. For instance, the Quincy basin gravel plain, deposited by large floods, was channeled by lesser floodflow to form a sinuous depression occupied by Moses Lake. Yet such geomorphic relations could be accomplished by just one colossal flood and its waning flow. Wielding Occam's proverbial razor, V.R. Baker in the Quincy basin and R.B. Waitt along the adjacent Columbia River valley shaved off several of Bretz's floods, explaining almost all late Wisconsin features by one or two great floods and their waning flows (Waitt, 1972, 1977a,b; Baker, 1973, 1977, 1978).

Just beyond the Channeled Scabland, rhythmic flood beds of gravel, sand, and silt in southern Washington had been briefly described and photographed over the years (Bretz, 1929; Allison, 1933, 1941; Flint, 1938; Lupher, 1944; Glenn, 1965), but their significance remained obscure. It had been suggested (Bretz, 1969; Baker, 1973) that perhaps these beds bespoke some sort of pulsation in the supply of a flood, or that perhaps transient hydraulic surges during a flood were responsible. And perhaps these beds were repeated turbidites into continuously ponded water.

When rhythmic stacks of sand-silt beds in the Walla Walla valley were revisited in late 1977, the Mount St. Helens "set-S" ash couplet was found within the sequence, atop one particular bed that was not substantially different from any other bed in the section. Yet how could this be, if all beds were deposited by just one great flood? By June 1978, several features observed while measuring sections at Burlingame Canyon suggested that long subaerial pauses had intervened after deposition of each bed, that each graded bed there thus represented a separate flood, and that therefore at least 40 separate gigantic Missoula floods had backflooded the Walla Walla valley from the Columbia valley (Waitt, 1979). Burlingame Canyon thus became the "Rosetta stone" for deciphering similar beds all over the region. Within a few years, many side valleys scattered all across the north, west, southeast, and southwest parts of the flooded region were found to reveal similar evidence for scores of separate great floods (Waitt, 1980a,b, 1983a,b, 1984, 1985a,b; Atwater, 1984, 1986). The widely dispersed locations of these sites—nearly surrounding the Channeled Scabland—seemed to reveal that dozens of floods swept not only up the several valleys harboring these deposits but also through the entire Channeled Scabland itself (Waitt, 1980a, 1983b, 1985b).

These conclusions are affirmed by records of flooding in proglacial lakes in northern Washington, where varved lake sediment of glacial lakes separates successive flood-laid beds at many localities. The number of varves between successive flood beds indicates durations of six decades to a few years, generally becoming fewer upsection (Figure 5) (Waitt and Thorson, 1983; Atwater, 1984, 1986, 1987; Waitt, 1984, 1985a,b, 1987). The bottom sediment of glacial Lake Missoula is also varved; it constitutes dozens of fining-upward sequences, each the record of a gradually deepening then swiftly emptying lake (Chambers, 1971, 1984; Waitt, 1980a). Figure 6 shows the inferred relation of Lake Missoula's bottom deposits to the interbedded lake and catastrophic-flood deposits in northern Idaho and Washington and to the flood-laid beds in southern Washington. The behavior of repeated discharge every few decades or years suggests that glacial Lake Missoula emptied due to the same type of hydraulic instability that causes relatively small glacier-outburst floods (jökulhlaups) from present-day glaciers in Iceland and elsewhere (Waitt, 1980a, 1985b).

One differing interpretation is that the rhythmites may reflect numerous floods—but only late, fairly small ones, confined to low courses like Grand Coulee and the Columbia valley. Baker (1991), for instance, bases his objection on what he styles low-energy rhythmites:

> "The physical evidence of a low-energy flood deposit is linked by a chain of reasoning to a hypothesized cataclysmic event. Baker and Bunker (1985) reject this argument as proof of the 40 or more cataclysmic floods, noting that high-energy flood facies must be found to prove the existence of multiple cataclysms." (Baker, 1991, p. 250)

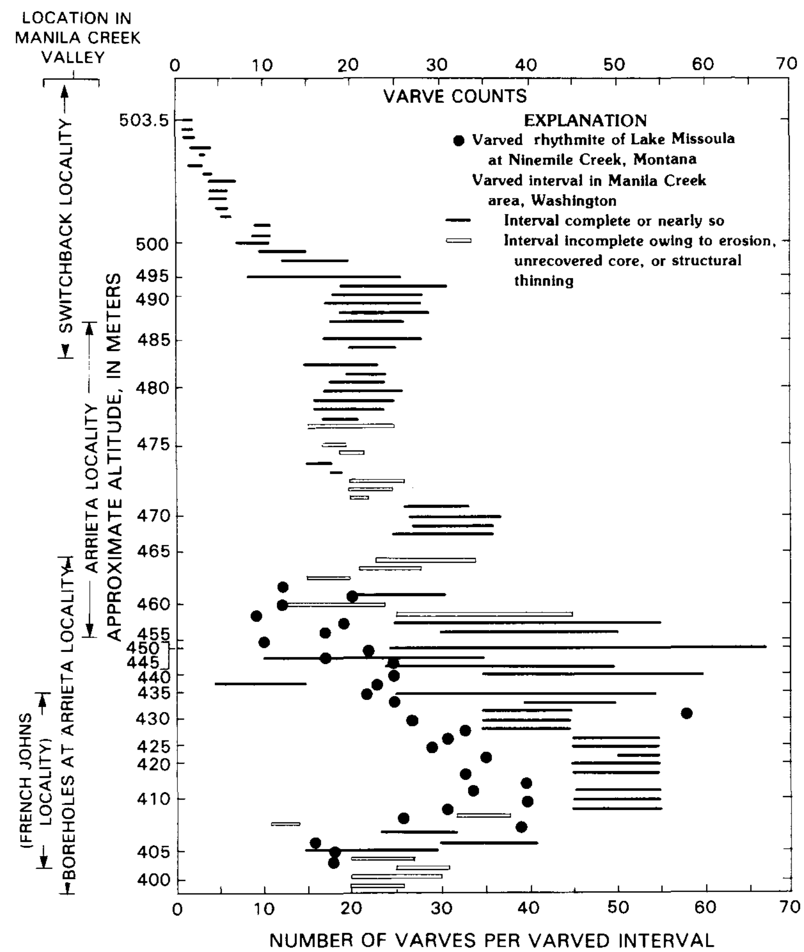


*Figure 5. Data on varves (of glacial Lake Columbia) interbedded between 89 beds laid by Missoula floods, at the composite section at Manila Creek, Sanpoil valley, northern Washington (from Atwater, 1986, Figure 17). The bar range of a varve bed reflects the difference between a stingy count (dubious ones ignored) and a generous count (everything possibly a varve included).*

To this statement and analogous ones (e.g., Baker, 1989b, p. 54, 1989c, p. 63; Busacca and others, 1989, p. 62; Kiver and others, 1991) it must be said that some identified rhythmite sections lie at fairly high altitude (e.g., Priest valley, Pine valley at Malden, Snake valley at Lewiston, Yakima valley at Union Gap), that some include high-energy (gravel) flood facies (e.g., Touchet, Mabton, Latah Creek, lower Tucannon valley [backflooded Snake tributary]), and that some rhythmic deposits (Malden, Tucannon valley, Snake valley near Lewiston) could not even exist except by general flooding of the Cheney-Palouse and other high scabland tracts. Nor does the claim of "linked by a chain of reasoning" fairly characterize the scores-of-cataclysms thesis, for it is firmly rooted in regionally distributed field evidence, and the paths from field deposit to giant-flood inference are fairly direct.

A second critical claim is that some multiple major rhythmites are products of intraflood surging (Baker and Bunker, 1985; Bjornstad and others, 1991, p. 237; Kiver and others, 1991, p. 241). These reports and cited supporting works in fact offer no new evidence—field or otherwise—but merely reiterate earlier opinion (Baker, 1973, 1978; Bjornstad, 1980; Bunker, 1982; Rigby, 1982) that has been refuted by field evidence (Waitt, 1985b).

A third recurrent claim (Moody, 1987; Baker, 1989b; Busacca and others, 1989, p. 62; Kiver and others, 1991, p. 238, 241–243) is that radiocarbon dates between about 32,600 and 41,300 yr B.P. and observations of "smectite" capping soils are evidence that many flood bars and rhythmically bedded backflood deposits—including sections at Latah Creek, Malden, the Tucannon valley, and others on which the scores-of-cataclysms theory has relied—are of middle Wisconsin age and thus irrelevant to Waitt's thesis of repeated colossal late Wisconsin floods. And yet, (1) the radiocarbon dates are from clasts and therefore are but

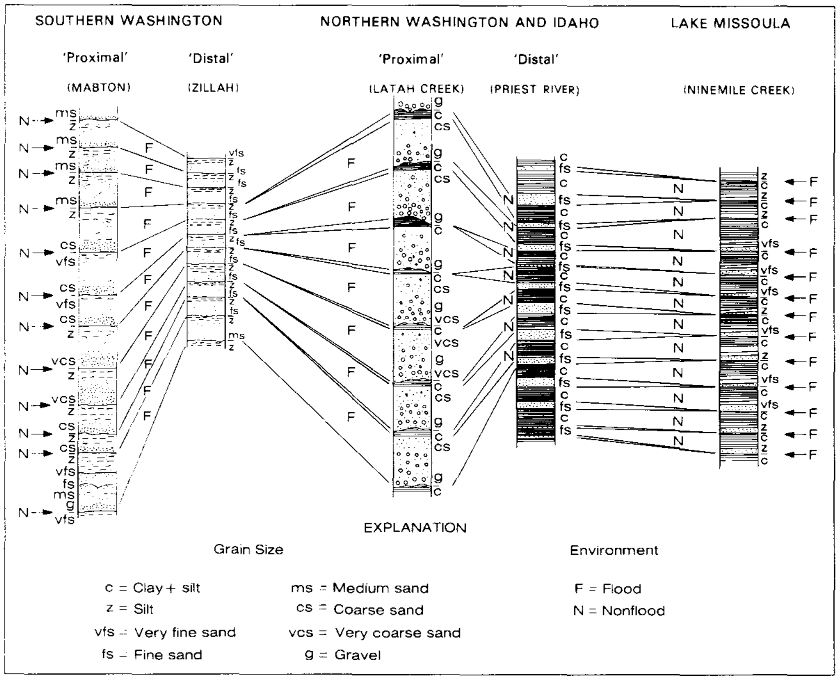


*Figure 6. Inferred relations between flood rhythmites in southern Washington, flood rhythmites interbedded with varved glacial-lake deposits in northern Washington and Idaho, and rhythmic and varved glacial Lake Missoula sediments in western Montana. From Waitt (1985b, Figure 17).*

maximum-limiting ages; (2) the "charcoal" of the 41,300-yr-B.P. date has been found to be Eocene lignite, while the "wood" of a 37,000-yr-B.P. date has been found to be petrified and devoid of carbon (P.E. Carrara, U.S. Geological Survey, personal communication, 1993); (3) the identification of "smectite" soil has not been confirmed by anyone else; (4) rhythmites in the Tucannon valley that were dated as middle Wisconsin contain the Mount St. Helens "set-S" tephra (e.g., Smith, 1993), confirming their late Wisconsin contemporaneity with those in the Walla Walla, Yakima, and other valleys; and (5) several dozen radiocarbon dates in continuous stratigraphic context in south-central British Columbia reveal continuously nonglacial conditions there from 19,000 $^{14}$C yr B.P. back to 44,000 $^{14}$C yr B.P. (Clague, 1980, Table 2; 1981, p. 6–8) and even 59,000 $^{14}$C yr B.P. (Clague, 1989, Figure 1.17 and p. 57): At a time when southern British Columbia was unglaciated, there could have been no glacial Lake Missoula, and therefore no Missoula floods.

Over the last decade, scores of high-level and (or) high-energy flood bars have been examined in exposures scattered about the Channeled Scabland, its high-discharge intakes and outlets, the Columbia Gorge, and the vast Portland-Vancouver composite delta-bar. Where exposures are at least several meters deep, most pebble- and cobble-gravel bars show intercalated fine beds, ripup clasts of these fine beds in overlying gravel, and other evidence that they were composited by at least several separate floods. Such evidence seen in two pits in the Columbia Gorge (Stops 1.1 and 3.1) is typical of the internal stratigraphy of gravel bars distributed throughout the region including the Cheney-Palouse scabland tract (Waitt, 1994 and unpublished data).

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!!! And try to see the article "The floods that carved the West" in the April 1995 issue of the *Smithsonian* (p. 48–59), written by Michael Parfit and impressively illustrated with photos by Ted Wood. —*ed.* □

***To be continued with Day 1 field trip in next (July) issue***

### We regret!

A slight computer "glitch" around the end of 1994 caused us to lose temporarily some of your addresses. We apologize sincerely!
If you missed your January issue of *Oregon Geology*, please let us know. We shall be glad to send you the missing copy.

## DOGAMI PUBLICATIONS

Released March 28, 1995:

***Inventory of Critical and Essential Facilities Vulnerable to Earthquake or Tsunami Hazards on the Oregon Coast*** was published as Open-File Report O–95–2. It can be purchased for $9.

The study was prepared by James W. Charland and George R. Priest and consists of a 52-page text and a 3½-inch diskette containing the collected data both as dBase (.dbf) files and in spreadsheet format for Microsoft Excel (.xls files).

The inventory covers 47 communities on shorelines within about nine miles of the open coast. It includes such critical and essential facilities as hospitals, schools, fire and police stations, emergency shelters and communication centers, hazardous sites, and major structures—all as they are defined in Oregon law and the Uniform Building Code. Tables show summary estimates of risk from ground shaking and tsunami inundation for individual counties and major communities and comparisons of total existing facilities with those at risk. Also included is a table showing preliminary estimates of tsunami runup elevations. These data are presented in greater detail in digital databases on the diskette.

Because of limited funding and time, the study is preliminary in nature, and its results are intended as a general guide to potential problems that need more detailed study. Still, the authors state, "It is apparent that over half of the critical and essential facilities on the coast could possibly be vulnerable to collapse during shaking. This is particularly worrisome with respect to schools. Should a great earthquake occur during class time, children in as many as 64 of the 117 schools might find themselves in collapsing buildings. When the additional hazard of tsunami inundation is added to the earthquake threat, 86 of the 117 schools (74 percent) may be vulnerable." As the "good news," the authors point out that, fortunately, "Current estimates of the likelihood of a great earthquake and locally generated tsunami are on the order of 10-20 percent in the next 50 years. This means that there is an 80- to 90-percent chance that we have those 50 years to prepare" by taking action now.

***Chronic Geologic Hazard Maps of Coastal Lincoln County, Oregon*** is a pilot report by DOGAMI geologists George R. Priest, Ingmar Saul, and Julie Diebenow and describes coastal erosion rates and landslide hazards for 31 miles of the Lincoln County coast, from Salmon River to Seal Rocks, and for about 1½ miles inland from the shore. The data are published in the form of maps, text, and a computer database. They serve as basic resources for land-use planning decisions, emergency management planning, and insurance purposes.

The results of the study are printed on 19 photo maps, each of them covering a small stretch of coastline. Explanations and an abbreviated erosion-rate table are published in
*(Continued on page 68, **Publications**)*

# Mineral industry in Oregon, 1993–1994

*by Ronald P. Geitgey, Industrial Minerals Geologist, Oregon Department of Geology and Mineral Industries*

## INTRODUCTION

Nonfuel mineral production has continued to increase in both quantity and value, due primarily to increasing consumption of aggregate materials as the result of population and construction growth. Oregon continues to be a leader in pumice production, and increasing amounts of gemstones, principally sunstones, are being produced. Metal production was minimal, with no major metal mines operating at the end of 1994. Gold production was almost exclusively from small seasonal and recreational placer operations.

Exploration and development programs continued for perlite, soda ash, silica sand, and heavy-mineral sands. Metal exploration was moribund, reflecting several factors including the general flight of exploration funds out of the U.S. in recent years, changes in the U.S. Bureau of Land Management requirements for claim staking and maintenance, and the threat from a ballot measure of more stringent requirements on bulk metal mining, processing, and reclamation.

## PRODUCTION STATISTICS

The U.S. Bureau of Mines reported a nonfuel mineral production value of $226 million in 1993 and a preliminary estimate of $254 million in 1994. These data have been collected from producers on a voluntary basis for many years and include some manufactured material such as cement and lime. They are based on producer responses and estimates made by U.S. Bureau of Mines commodity experts. Unlike for oil, gas, coal, and certain other leasable minerals, there is no federal or state statutory requirement to report production amounts for most mineral operations. The past 20 years of these statistics as well as the natural gas production for Oregon are summarized in Table 1.

In order to refine mineral production data for Oregon for 1993 and gauge its economic impact, the Oregon Department of Geology and Mineral Industries (DOGAMI) conducted a canvass by mail and by telephone of all mineral producers. This survey, done by DOGAMI Minerals Economist Robert Whelan, was published as Open-File Report O–94–31. Over 84 percent of all mineral producers responded, representing approximately 85 percent of the total value of production. Total value was about $240 million. Data were collected in groups by county, but to protect the confidentiality of individual companies in counties with a limited number of producers, values were summarized in groups by 11 regions. Total value of mineral production by these regions is summarized in Figure 1.

Production was measured as raw material at its point of removal: that is, before processing other than crushing, screening, or cleaning. For example, the value reported for limestone does not include its value as cement—a manufactured product. Neither does the value for diatomite include processing as a filter aid, nor is the final value of cut or faceted gems included. While these data cannot be compared directly with the U.S. Bureau of Mines data, they do represent a much more detailed approach to collecting production statistics, and they suggest that surveys by the federal government have underestimated the total value of mineral production from Oregon.

## PRODUCTION HIGHLIGHTS

As noted earlier, mineral production in Oregon is primarily aggregate materials. Demand and production continue to increase as do competing land uses. Concrete-

*Table 1. Summary of mineral production value (in millions of dollars) in Oregon for the last 21 years. Data for 1994 derived from U.S. Bureau of Mines annual preliminary mineral-industry survey and DOGAMI statistics are based on voluntary reporting and should be considered as minimums.*

| Year | Rock materials[1] | Metals and industrial minerals[2] | Natural gas | Total |
|---|---|---|---|---|
| 1974 | 75 | 29 | 0 | 104 |
| 1975 | 73 | 33 | 0 | 106 |
| 1976 | 77 | 35 | 0 | 112 |
| 1977 | 74 | 35 | 0 | 109 |
| 1978 | 84 | 44 | 0 | 128 |
| 1979 | 111 | 54 | <1 | 165 |
| 1980 | 95 | 65 | 12 | 172 |
| 1981 | 85 | 65 | 13 | 163 |
| 1982 | 73 | 37 | 10 | 120 |
| 1983 | 82 | 41 | 10 | 133 |
| 1984 | 75 | 46 | 8 | 129 |
| 1985 | 91 | 39 | 10 | 140 |
| 1986 | 96 | 30 | 9 | 135 |
| 1987 | 102 | 52 | 6 | 160 |
| 1988 | 130 | 48 | 6 | 184 |
| 1989 | 131 | 55 | 4 | 190 |
| 1990 | 148 | 85 | 4 | 237 |
| 1991 | 139 | 131 | 4 | 274 |
| 1992 | 130 | 111 | 4 | 245 |
| 1993 | 160 | 66 | 7 | 254 |
| 1994 | 181 | 73 | 6 | 260 |

[1] Includes sand, gravel, and stone.
[2] For 1992–1994 this includes cement, clays including bentonite, copper-zinc, diatomite, gemstones including Oregon sunstone, gold-silver, nickel, perlite, pumice, quarts, silica sand, talc including soapstone, and zeolites.

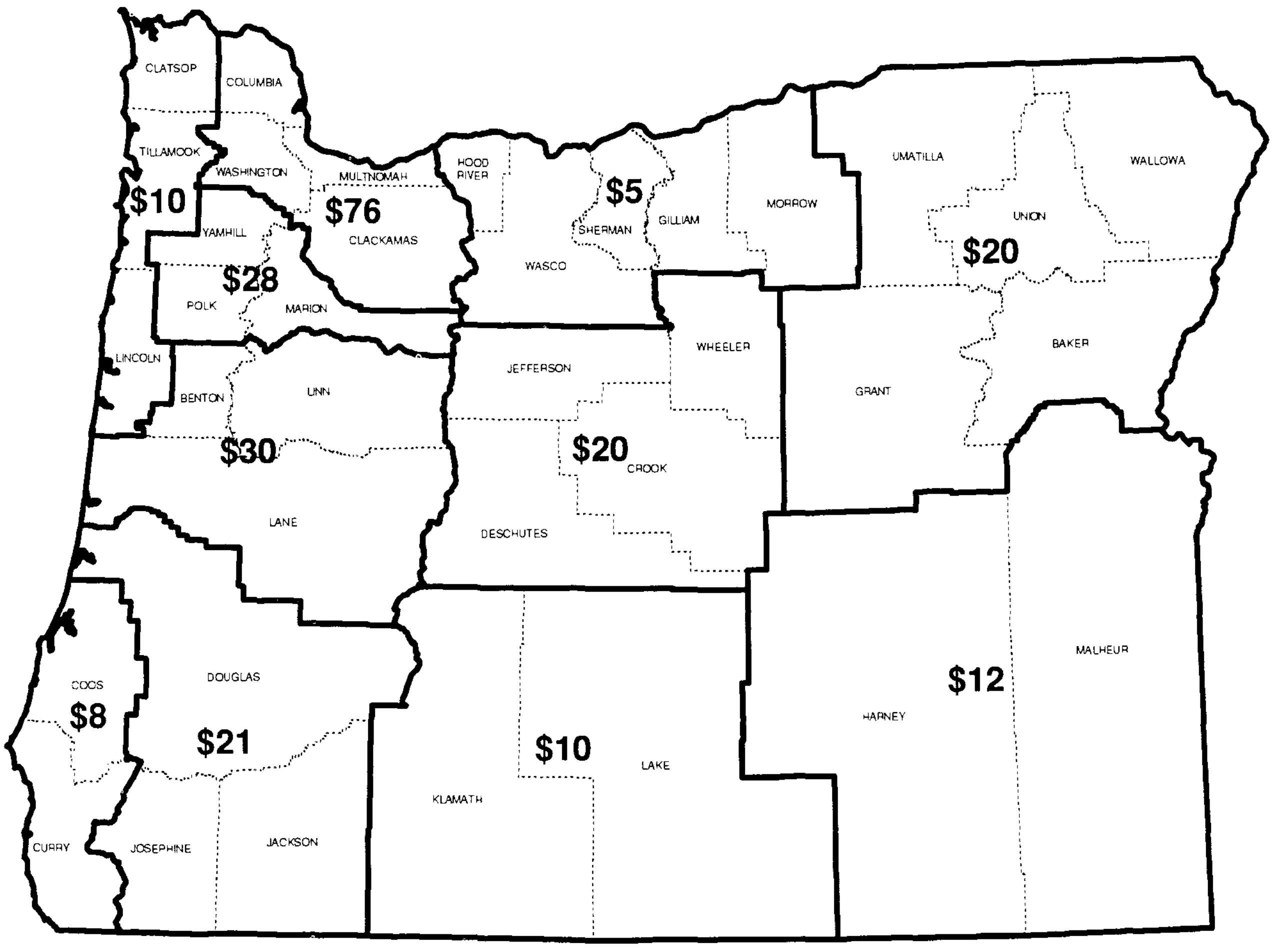



*Figure 1. Total value in millions of dollars of mineral production (excluding natural gas) in Oregon in 1993, summarized by multiple-county regions.*

quality sand and gravel sources are increasingly difficult to develop, and many crushed rock resources are being overtaken by urban growth.

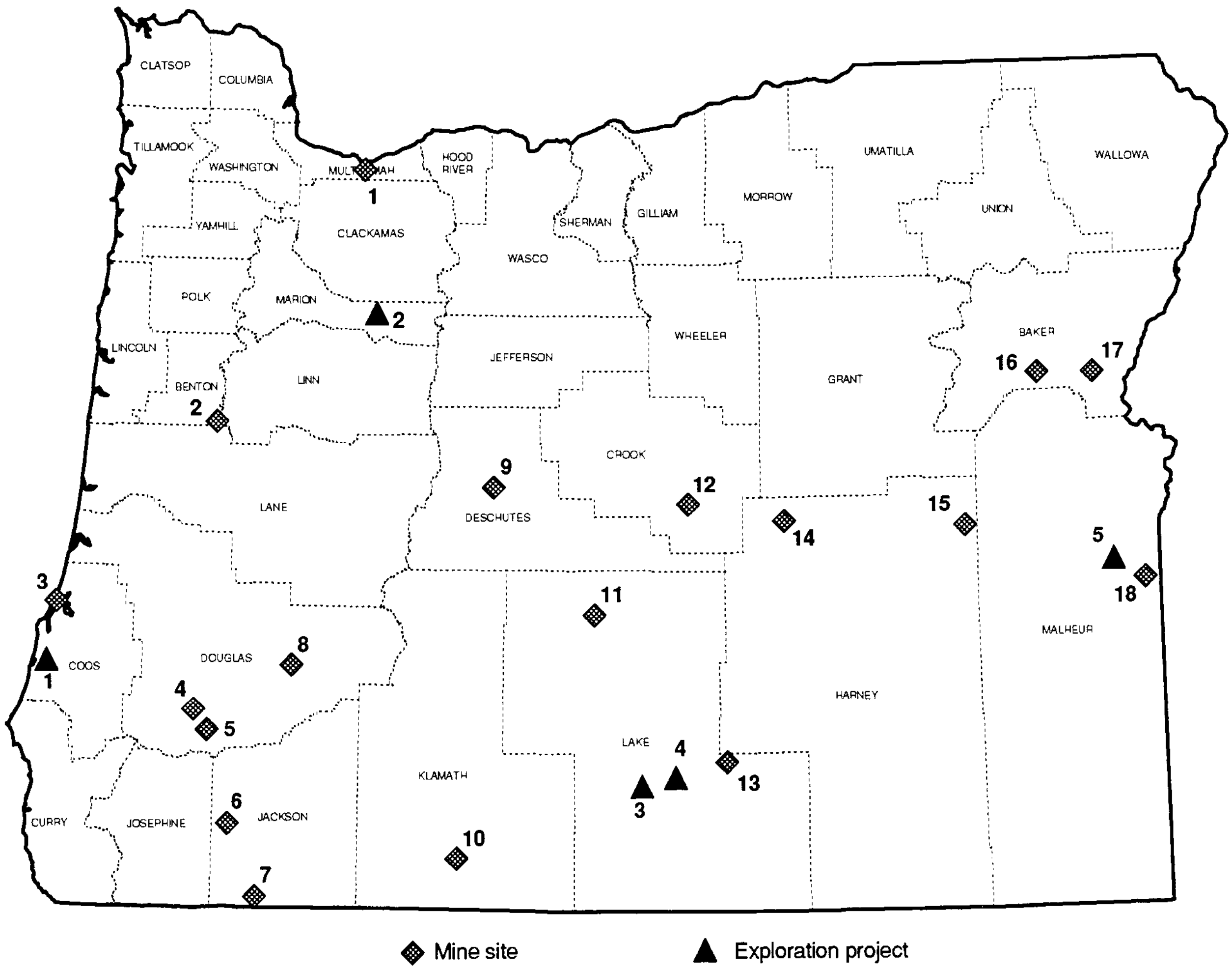
During the last two years, Karban Rock, Inc., of Hillsboro tried a novel approach to supplying the metropolitan Portland area with crushed rock. The company developed a quarry on a rail line in the far northwestern corner of Washington County and brought pit run material into its Hillsboro crushing plant by unit trains carrying three thousand tons, often on a daily basis. The project demonstrated the technical feasibility of aggregate importation by rail, which will become a necessity in the future, but in the short term the operation did not remain profitable and has been closed.

Major producers other than for aggregate are indicated on Figure 2. There has been no major metal production in Oregon for the last two years. Gold production is estimated to be about 2,000 oz annually; almost all of it from recreational placer operations. Formosa Exploration's Silver Peak mine in Douglas County has been closed, the mill dismantled, and the site reclaimed.

Glenbrook Nickel at Riddle in Douglas County has been operating on only a care and maintenance basis but has announced plans to reactivate the smelter in the spring of 1995, initially using ore mined at Nickel Mountain and later also ore imported from New Caledonia through the port of Coos Bay. Full operating work force will be about 300 employees, as well as company and contract truckers. During this idle period, the Green Diamond subsidiary of Glenbrook has continued to produce air blast abrasives and roofing granules from nickel slag. These abrasive products meet or exceed requirements for respirable silica and leachable metals, and reserves are sufficient for many years at current production levels.

Brick production has continued, although with several changes. Columbia Brick Works of Gresham was purchased by Mutual Materials of Bellevue, Washington, the major brick producer in the Pacific Northwest. Klamath Falls Brick and Tile in Klamath Falls, a producer of a wide range of brick colors for over 70 years, ceased operation. Monroe Brick in Benton County has been reopened after many years and is again producing red brick.

Steatite of Southern Oregon continues to produce carv-




## EXPLANATION

### MINE SITES

1. Mutual Materials (formerly Columbia Brick Works)
2. Monroe Brick
3. CooSand Corporation (glass sand)
4. Glenbrook Nickel, Green Diamond (abrasives, roofing granules)
5. Formosa Exploration Silver Peak Mine (copper, zinc, gold, silver; closed)
6. Bristol Silica (quartz)
7. Steatite of Southern Oregon (soapstone)
8. Quartz Mountain (quartz; idle)
9. Cascade Pumice and Central Oregon Pumice
10. Klamath Falls Brick and Tile (closed)
11. Oil-Dri Production (diatomite)
12. Central Oregon Bentonite (bentonite clay)
13. Rabbit Hills area (sunstones)
14. Ponderosa Mines (sunstones)
15. Eagle-Picher Minerals (diatomite)
16. Supreme Perlite Dooley Mountain mine (perlite)
17. Ash Grove Cement Company (portland cement, limestone)
18. Teague Mineral Products (bentonite clay, zeolite)

### EXPLORATION PROJECTS

1. Oregon Resources, Oregon Mineral Sands Project (garnet, chromite)
2. Kinross Copper Corporation, Bournite Project copper, gold, silver)
3. Atlas Corporation, Tucker Hill Project (perlite)
4. Canadian Occidental Chemical, Lake Abert Project (sodium salts; terminated)
5. Newmont Mining, Grassy Mountain Project (gold)

*Figure 2. Mine sites and major exploration projects in Oregon, 1993-1994, excluding sand, gravel, and crushed stone.*

ing and sculptural-grade soapstone from its quarries in Jackson County. Bristol Silica, also in Jackson County, produces decorative material and filter media from a quartz replacement body, and the Quartz Mountain deposit in Douglas County remains idle. CooSand Corporation produces container-grade glass sand from dunes north of Coos Bay.

Oregon remains the leading domestic producer of pumice. Cascade Pumice and Central Oregon Pumice produce lightweight aggregate and horticultural materials from mines in the Bend area. Neither was ever a major supplier of pumice for stone-washing garments, so neither has suffered from the collapse of that market.

Oil-Dri Production Company produces pet litter and absorbent products from its Christmas Valley diatomite operation in Lake County, and Eagle-Picher Minerals produces diatomite filter aids from mines near Juntura and a plant near Vale. Bentonite, primarily for civil engineering purposes, is produced by Central Oregon Bentonite in Crook County and Teague Minerals in Malheur County. Teague Minerals also produces the zeolite mineral clinoptilolite for odor control and heavy-metal absorption applications.

Gemstone production has increased significantly. Opals and various forms of silica (jasper, agate, thundereggs) are produced from small-scale operations, and sunstones (calcic feldspar) are increasingly being mined on a commercial basis by Ponderosa Mines in Harney County and several operators in the Rabbit Hills area in Lake County. Sunstones have long been mined and cut on a small scale, but during the last few years Ponderosa has developed wider markets. The rare, highly colored varieties have always had a specialty market, but now the more common yellows are being successfully marketed by Ponderosa, encouraging more Lake County producers to operate on a commercial scale.

Ash Grove Cement Company continues as a major employer in Baker County. In addition to portland cement, the company supplies lump limestone to sugar refineries in Oregon and Idaho.

## MINING CLAIMS

In the fall of 1993, the U.S. Bureau of Land Management (BLM) initiated new policies on mining claim filing and maintenance. A total of $235 is now charged for filing each new claim. The Bureau now charges an annual maintenance fee of $100 per claim rather than accepting labor on the claim as qualifying for assessment work. However, anyone owning 10 or fewer claims can apply for a waiver allowing performance of labor in lieu of the maintenance fee. There has been a sharp drop in the number of active mining claims. BLM does not maintain records by individual states, so statistics for Oregon and Washington are compiled together. Early in 1993, the agency had 36,852 claims recorded in the two states. After September 1, 1993, the number fell to 14,683, and after September 1, 1994, rose to about 16,400.

## EXPLORATION HIGHLIGHTS

No new major metal exploration programs were initiated in 1993 or 1994. Many large claim blocks were abandoned or greatly reduced, and many holders of smaller blocks also chose not to pay the new fees. At the end of 1994, drilling permits were in effect for 15 projects (down from 44 in 1991), but the writer is aware of no project, other than Grassy Mountain, on which drilling was actually done in 1994.

Newmont Mining continued investigations at its Grassy Mountain gold project in Malheur County to further define the ore body and engineering and environmental requirements. Announced reserves include 1.5 million oz of gold and 2.5 million oz of silver. The company diverted its attention was from the project itself during 1994 to present its views on a ballot measure that would have created additional environmental and reclamation requirements. The ballot measure was subsequently defeated, and at year's end Newmont was evaluating and planning its future permitting requirement.

Kinross Copper Corporation continues to maintain its Bornite copper, gold, and silver project in eastern Marion County. Engineering and environmental operating plans for an underground mine have been completed for more than a year and approved by all but one state agency. The project has generated both strong support and opposition, and at this writing its future remains uncertain.

Oregon Resources Corporation has brought its mineral sands project in Coos County partially through the required permitting process and is preparing for a final feasibility study. Heavy-mineral sands (black sands) containing ilmenite, chromite, garnet, and small amounts of rutile and zircon occur as thin, elongate deposits covered by dune sand on elevated beach terraces. The various minerals would be separated from the sands by magnetic and gravity methods. Garnet would be marketed for water-jet cutting abrasive, and chromite for metallurgical or chemical uses.

Atlas Corporation continued drilling and bulk testing of the Tucker Hill perlite deposit near Paisley in Lake County. The perlite has expanded satisfactorily in both bench and bulk testing, and the company has begun the permitting process with the hope of starting production during 1995. Pit run material will be trucked to Lakeview for crushing and screening and shipped from Lakeview by rail. A total work force, including contractors, of 10–15 workers will be employed at the mine and mill. Supreme Perlite has produced small amounts of ore from its Dooley Mountain deposit in Baker County for its own use for many years. The Atlas Corporation Tucker Hill property will be the only operation in the Pacific Northwest states supplying the open market.

For the last four years, Canadian Occidental Chemical Group, Ltd., has been evaluating Lake Abert in central Lake County as a possible sodium salt source, but the company has now withdrawn its lease applications and has terminated the project. The lake water is approximately three times more saline than sea water, and has a very high proportion of sodium and bicarbonate. Either soda ash (sodium carbonate) or caustic soda (sodium hydroxide) could be produced from this re-

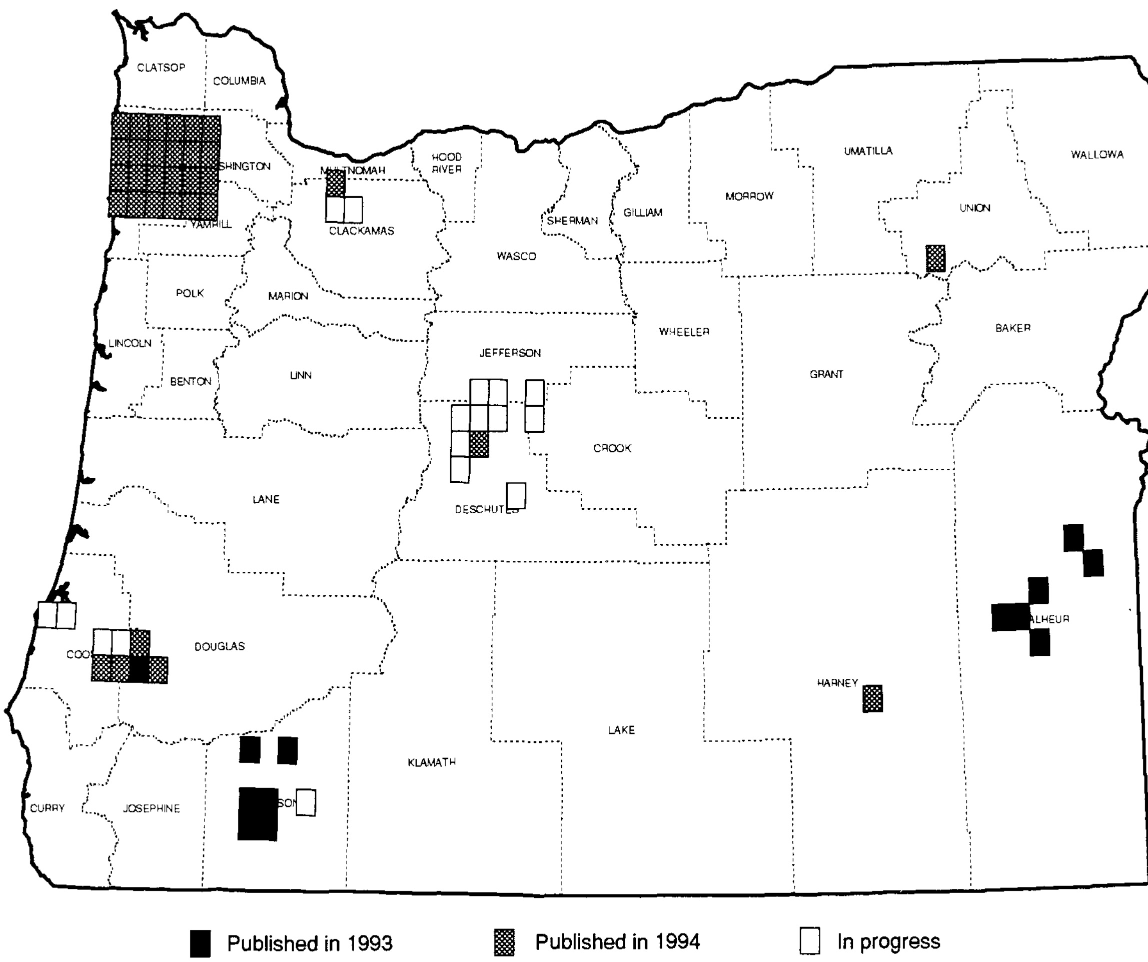



*Figure 3. Statewide overview of geologic maps published in 1993 and 1994 by DOGAMI and other agencies.*

source. Both compounds are widely used in the chemical and paper industries and are currently supplied from saline lakes in California and from the huge bedded deposits in the Green River basin of southwestern Wyoming. Canadian Occidental concluded that it was not economically feasible at this time to develop the Lake Abert resource.

## OTHER DOGAMI ACTIVITIES

DOGAMI's statewide survey of pumice resources was presented to the public in 1993 with the publication of Special Paper 25, *Pumice in Oregon*. Updated versions of the Mineral Information Layer of Oregon by County (MILOC) and the Directory of Mineral Producers were also published in 1993.

DOGAMI has continued its earthquake hazard, coastal hazard, and geologic mapping programs. Geologic mapping of the gold region in Malheur County has resulted in the release of 28 maps of 7½-minute quadrangles (scale 1:24,000), partly as GMS-series maps, partly as open-file reports, and partly for library inspection only. The project concluded with the publication of two 1:100,000-scale full-color compilation maps—of the Vale (GMS-77) and Mahogany Mountain (GMS-78) 30×60-minute quadrangles—that cover the entire Oregon portion of the Boise 1°×2° sheet. Other geologic and mineral-resource mapping has produced maps of 14 quadrangles, mostly in the Medford and Roseburg areas in southwestern Oregon but also in Deschutes and Union Counties.

Various types of studies, databases, and maps have been published as open-file reports and as GMS-series maps, and many of them are listed on the back cover of this publication. Some studies are available for purchase; others are on file in various department offices as well as other public offices in the state. Databases include mineral occurrences, low-temperature geothermal occurrences, a beach-shoreline database, and earthquakes in Oregon. A relative hazard earthquake map has been published for the Portland 1:24,000 quadrangle, and a series of maps depicting chronic geologic hazards of coastal Lincoln County has been released. Geologic mapping on a scale of 1:24,000 published in 1993 and 1994 is shown on Figure 3. Mapping in progress is also shown. A current list of publications (1995) is now available from the Nature of the Northwest Information Center (see order form on back cover). □

# Summary of major DOGAMI activities in 1995

The mission of the Oregon Department of Geology and Mineral Industries (DOGAMI) is to serve as the cost-effective centralized source of geologic information in Oregon for the public and for government. Its mission is also to serve as a cost-effective steward of mineral production with attention paid to environmental, reclamation, conservation, engineering, and technical issues.

With regard to geologic information, emphasis is placed on geologic mapping, cost-effective earthquake mitigation, geologic hazards, and mineral resources. With regard to mineral stewardship, authorities are in place for the exploration, production, and reclamation of oil, gas, geothermal, aggregate, and nonaggregate mineral resource activities. The emphasis in DOGAMI activities is placed on the prevention of hazards and waste, the benefits of long-range planning, and the efficiency of using land and mineral knowledge in policy decision making in government and the private sector.

## GEOLOGIC MAPPING

**Statemap program:** In contractual relationship with the U.S. Geological Survey, DOGAMI develops geologic maps of priority areas of the state for problem solving, guided by an advisory group of users in the public and private sectors. Major areas of effort are focused on three 1:100,000-scale quadrangles, the Bend, Medford, and Roseburg sheets. The three-year program for each sheet includes a mix of complete mapping, reconnaissance mapping, and compilation. Current focus is on mapping of the 7½-minute quadrangles Dora and Sitkum in the Roseburg area, Lakecreek and Grizzly Peak in the Medford area, and O'Neil and Gray Butte in the Bend-Prineville area.

Contact person: John Beaulieu.

**Coastal mapping:** With funding from the U.S. Minerals Management Service through a contract with the University of Texas, DOGAMI participates in developing needed geologic data bases in coastal zones. The specific current project is mapping the Coos Bay 7½-minute quadrangle.

Contact person: Jerry Black.

**Geologic map index:** This is an effort to create and maintain an index of geologic maps for the state. The goal is to provide current information about all geologic maps and their availability at sale counters and to develop database resources that provide various types of access to such information. For 1995, a first product has been released as Open-File Report O–95–4, an index of mapping through 1994 by topographic quadrangle name.

Contact person: Beverly Vogt.

## EARTHQUAKE STUDIES

**ODOE power-plant siting:** This program involves the responsibility of DOGAMI to provide peer review of the seismic-hazard portions of siting documents for power plants, whenever such documents are submitted to the Oregon Department of Energy (ODOE). Peer review generally involves early meeting with the applicant, followed by review of the application document to assure true site-specific analysis, proper attention to site-specific data collection, and proper attention to preexisting information on seismic risk. Also included is the need for clear definition of acceptable seismic risk. Consequently, this also involves DOGAMI in any development of rules in this area that is initiated by the Energy Facility Siting Council.

Contact person: Dan Wermiel.

**Oregon City quadrangle:** Robert Yeats of Oregon State University and Scott Burns of Portland State University are providing maps and data to produce a generalized display of earthquake-related information for the west half of the Oregon City 1:100,000-scale quadrangle. Key elements include earthquake epicenters, fault identification, surficial geologic units, depth to bedrock, and other information considered of interest to the general public.

Contact person: Beverly Vogt.

**Metro maps:** The Federal Emergency Management Administration (FEMA) and Metro (Portland) are supporting efforts to develop ground response data that will lead to the publication of relative earthquake-hazard maps for the Mount Tabor, Gladstone, Lake Oswego, and Beaverton 7½-minute quadrangles, which surround the already completed downtown-area Portland quadrangle on the east, south, and southwest. These maps will each include smaller maps of the individual hazards (amplification, liquefaction, and landslides) that are combined to produce the main relative-hazard maps. The Mount Tabor quadrangle map has just been published as map GMS–89. In addition, procedures and methods are being developed to make digital files of these data available to a technical audience.

Similar projects are to cover all quadrangles within the urban growth boundaries of the metropolitan area. It is planned to match the collected ground-response data with Metro's building-inventory data, so that, for instance, loss evaluation can be performed.

Contact person: Matthew Mabey.

**PSU studies:** Portland State University is the partner in two earthquake hazard studies. The first is to develop recommendations for retrofitting buildings. It is coordinated with the Portland School District and is to benefit particularly Portland's public schools. The second effort is the organization of a series of seminars presented by distinguished lecturers on selected engineering topics that are relevant to earthquake mitigation.

Contact person: John Beaulieu.

The joint effort to combine the expertise gained in current field work with the educational needs of the technical community dealing with earthquake hazards is continuing with the shared DOGAMI/PSU support for the position of Matthew Mabey, who devotes one-third of his time to teaching earthquake-engineering classes at PSU.

**Seismograph net:** DOGAMI is working with the Department of Higher Education to expand the seismograph net by upgrading selected recording stations in the state. In this context, the three major universities will cooperatively develop research focused on hazard mitigation.

Contact person: John Beaulieu.

**Salem area:** Similar to the efforts in the Portland area, this project aims at modeling ground response for, initially, two 7½-minute quadrangles in the Salem area (Salem West and Salem East). It may be expanded eventually to include the entire area within the Salem urban growth boundary. The published products will be similar to those for the Portland metropolitan area, with regard to both maps and digital data.

Contact person: Mei Mei Wang.

**Liquefaction study**: DOGAMI staff is joining geologists from Alaska and Washington in a training program for the study of earthquake-related liquefaction features that occurred in the 1964 Alaska earthquake. This expertise is needed for technology transfer and sharing of earthquake data between Oregon, Washington, and Alaska in cooperation with the U.S. Geological Survey.

Contact person: Jerry Black.

**Scotts Mills earthquake follow-up**: In the survey conducted by DOGAMI on observed effects of the Scotts Mills earthquake in 1994, over 4,000 responses were returned. These responses are being analyzed now for the production of a felt-intensity map that can be compared to ground response models developed in the ongoing studies of the Portland and Salem projects.

Contact person: Jerry Black.

**Regional maps**: DOGAMI is involved in the development of three Northwest area maps that are focused on earthquake hazards. Two, a geologic map of the Damascus quadrangle in the Portland area and a relative earthquake hazard map of the Vancouver urban area, have been released. A geologic map of the Charleston quadrangle in the Coos Bay region is to conclude these efforts during the current year.

Contact person: Ian Madin.

## COASTAL HAZARD STUDIES

Coast research is focused on two categories of hazards: chronic hazards, such as landslides and coastal erosion, and catastrophic hazards, such as earthquake and tsunami damage. DOGAMI is involved in four pilot projects for the central Oregon coast. This work involves cooperation with the Oregon Department of Land Conservation and Development and FEMA.

**Lincoln City/Siletz Bay** is the center of an area for which full delineation of all hazards is intended and will be made available to the public in published maps and digital data.

**A pilot project for the use of imagery** (taken from the air and from space) and computer tools attempts to evaluate chronic hazards for closely spaced transects along a 50-km stretch of the central Oregon coast. It will produce preliminary maps showing landslide hazards and erosion rates. However, the complex terrain and geology of the Oregon coast required extensive observation and geologic interpretation in the field. Open-File Reports O–94–11 through O–94–30 are the most recent products that have been released in conjunction with this project.

**Modeling of ground response** to earthquakes in the Siletz Spit area of the central coast stretch will be used to produce maps at a scale of 1:12,000 for separate ground response types and relative earthquake hazard.

**A joint project with Portland State University and the Oregon Graduate Institute** is designed to link information on the modeling of tsunami inundation with the physical evidence of (paleo-) tsunami inundation in Oregon and to develop maps of tsunami inundation in the future. Given the record of past inundations in the coastal area, Oregon's geology provides a unique opportunity for calibration of inundation models.

Contact person for these projects: George Priest.

## MINERAL RESOURCES

**Demand for aggregate**: An economic-demand model is being developed for the use of aggregate in Oregon. This model focuses on end use of the commodities, so that it can be used to forecast demand for specific market regions of the state.

Contact person: Robert Whelan.

**Geothermal resources**: The geothermal potential of southeastern Oregon is being investigated with a focus on geologic parameters such as lineaments and faults, after the completion of data-collecting from wells. This largely computer-driven modeling project will integrate geologic information more fully and will also use data on terrain factors and satellite imagery.

Contact person: Ian Madin.

**State agency assistance**: DOGAMI is providing technical information to the State Forestry Department to help in the evaluation of land transactions. In a similar manner, the Department provides technical review and assistance to the Department of State Lands on transactions that involve mineral rights. DOGAMI's assistance toward making the most prudent decisions for the State of Oregon and the school fund focuses specifically on the two goals of maximizing revenue and of protecting the environment.

Contact person: Ron Geitgey.

**Tyee Basin**: The investigation of the Tyee Basin in the southern Coast Range is being concluded with an analysis of its natural gas potential.

Contact person: Alan Niem, Oregon State University.

**Data bases**: Two mineral-resource databases are being developed: One, developed in cooperation with the Oregon offices of the U.S. Bureau of Land Management and the USDA Forest Service, includes all information from earlier federal and other data collections and combines it with the data DOGAMI published earlier as the Mineral Layer of Oregon by County (MILOC). The result is a database called "MILO," which can be linked to digital maps and includes data from DOGAMI's Mined Land Reclamation Program.

Contact person: Ron Geitgey.

The second database will follow the same structural and application principles for a collection of data on drilling activity for hydrocarbons and geothermal resources.

Contact person: Dennis Olmstead.

## OUTREACH EFFORTS

Together with other state and federal offices, DOGAMI is involved in three major efforts to convey earth-science knowledge and experience to government staff in other fields of specialization and to the Oregon citizens.

**Mine regulation training**: The first program is aimed at providing seminars and on-the-ground training opportunities for mine regulators from various states and regulatory agencies. This multi-state training effort is spearheaded by the Environmental Protection Agency and is administered by DOGAMI.

Contact person: Gary Lynch.

**Tsunami historic signs**: Along the coast, historic signs are being placed in cooperation with the Oregon Department of Transportation, selected communities, and the Oregon Travel Information Council. DOGAMI's involvement extends to the media and political outreach as well as to technical assistance.

Contact person: Angie Karel.

**Earthquake outreach**: This is an effort to bring the results of ground-response studies and related technical activities to the attention and within reach of a broader public audience. This involves, for instance, providing guidance in broader efforts for open-space planning, lifeline routes and other emergency response strategies, evaluations prior to any construction, or retrofitting existing structures. Damage scenarios will be developed to guide budget decisions related to earthquake hazard reduction and emergency response.

Contact persons: Beverly Vogt and Angie Karel. □

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*(**Publications**, continued from page 60)*

a 45-page text, titled *Explanation of Chronic Geologic Hazard Maps and Erosion Rate Database, Coastal Lincoln County, Oregon: Salmon River to Seal Rocks*. All data are stored on a 3½-inch diskette in two DOS formats, for Lotus 1–2–3 (.WK1 file) and for dBase III+ or higher (.DBF file). Text and diskette have been released as DOGAMI Open-File Report O–94–11. The maps have been released individually as Open-File Reports O–94–12 through O–94–30.

Chronic geologic hazards are mass movement hazards such as landslides, slumps, rock toppling, and soils or rock flows. These, along with shoreline geology and shoreline erosion rates, are shown on the maps. The database contains estimated erosion rates and other information for a series of transect points spaced approximately 150 feet apart along the shoreline. The transect points are also marked on the maps.

The report was funded in part by the Federal Emergency Management Agency (FEMA) and the Oregon Department of Land Conservation and Development (DLCD) with support from the National Oceanographic and Atmospheric Administration (NOAA). The project is to serve as a pilot for the entire Oregon coast.

Complete sets of Open-File Reports O–94–11 through O–94–30 have been made available by DOGAMI in public libraries of Lincoln City, Newport, and the Lincoln County Library District, the libraries of the Hatfield Marine Science Center, and the Oregon Coast Community College in Newport. Other libraries that have complete sets are the State Library in Salem, the Multnomah County Library in Portland, and the academic libraries of the University of Oregon, Eugene; Oregon State University, Corvallis; Portland State University, Portland; Southern Oregon State College, Ashland; and Eastern Oregon State College, La Grande. Partial sets including the maps appropriate for the region are in the city planning offices of Lincoln City, Depoe Bay, and Newport.

The open-file report numbers of individual maps are as follows:

| | |
|---|---|
| Salmon River area | O-94-12 |
| Roads End area | O-94-13 |
| Lincoln City-Wecoma Beach area | O-94-14 |
| Lincoln City-D River area | O-94-15 |
| Taft-Siletz Spit area | O-94-16 |
| Gleneden Beach-Siletz Spit area | O-94-17 |
| Fogarty Creek-Lincoln Beach area | O-94-18 |
| Boiler Bay area | O-94-19 |
| Depoe Bay area | O-94-20 |
| Cape Foulweather-Whale Cove area | O-94-21 |
| Otter Crest area | O-94-22 |
| Beverly Beach area | O-94-23 |
| Moolack Beach area | O-94-24 |
| Moolack-Agate Beach area | O-94-25 |
| Newport area | O-94-26 |
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All reports can be purchased. Report O-94-11, containing the explanations and the database diskette, costs $9 and should always be purchased together with any maps. Maps cost $6 each. The complete set of maps, database, and explanatory text costs $109. The maps must be ordered in Portland and will be printed on demand.

*(Continued on page 70, **Publications**)*

# An overview of seismic analysis and retrofit recommendations for Portland Public School buildings

*by Franz Rad, Department of Civil Engineering, Portland State University, Portland, Oregon*

## BACKGROUND

Little was known about design and construction to resist seismic forces during the first part of the century. In particular, unreinforced masonry (URM) buildings have come under criticism in recent years due to their poor structural performance in earthquakes. Additionally, URM structures often exhibit hazards that may be nonstructural or cosmetic in nature.

The problem has become more acute in Oregon now that geologic evidence has shown that the Pacific Northwest region has probably experienced much larger earthquakes than can be gleaned from the historic record. Quite a large number of unreinforced masonry structures now must be investigated as to whether they could withstand a major earthquake.

Many old unreinforced masonry structures, while seemingly sturdy and well built, are heavy and often poorly tied together. The floors and roofs are either wood framing or concrete slab-and-joist systems with a fractional inset connection to the masonry exterior walls. The construction of the masonry walls varies in design and quality; often the exterior layer of bricks, or wythe, is tied to the rest of the wall by the vertical collar joint only, which may be of poor quality.

School buildings with an H- or U-shaped floor plan were popular in the 1910s and 1920s. The H- or U- shaped plans tend to perform poorly in earthquakes, because they provide poor torsional resistance to the earthquake forces. The wings tend to displace in a direction perpendicular to the displacement of the center of the building. The result of this action is that large stresses and consequent distress are concentrated at the intersections.

### DOGAMI/PSU 1994 STUDY

As a joint venture project between Portland State University (PSU) and the Oregon Department of Geology and Mineral Industries (DOGAMI), a study was undertaken in 1994 to estimate potential seismic hazards in four existing URM public school buildings in Portland and to suggest possible upgrade strategies for each of the four buildings. The four buildings analyzed were Rose City Park Elementary School, Fernwood Middle School, Franklin High School, and Roosevelt High School. [*The complete report from this project is available for inspection in the DOGAMI Portland library. —ed.*]

The scope of the study was to investigate the buildings to establish the general configuration and construction type, to analyze the magnitude and distribution of seismic forces on each structure according to 1994 Uniform Building Code (UBC), to calculate the degree of overstress induced by the seismic forces in the URM walls and roof/floor diaphragms, to suggest a possible structural upgrade strategy for the four buildings, and to determine potential nonstructural hazards. The buildings selected for this study were chosen as representative of a number of old URM buildings in the city of Portland. These four buildings are not necessarily any more or less dangerous than many other public and private URM buildings in the city.

The seismic hazards in the existing structures were analyzed by UBC Static Lateral Force Procedure, UBC Dynamic Lateral Force Procedure, and UCBC analysis of URM walls and piers. The Uniform Building Code, the legal building code for the State of Oregon, was used as a general reference for developing the required seismic design forces for the static and dynamic procedures.

The Uniform Code for Building Conservation (UCBC), Appendix Chapter 1: Seismic Strengthening Provisions for Unreinforced Masonry Bearing Wall Buildings, was used to analyze the stresses in the unreinforced masonry walls and piers. The UCBC is the latest compilation of provisions developed by the Structural Engineers Association of California and California Building Officials (SEAOC/CALBO). These provisions have been developed in the last five years by engineers in the Los Angeles area for the required upgrade of unreinforced masonry structures.

Another reference used is the National Earthquake Hazards Reduction Program (NEHRP) Handbook for the Seismic Evaluation of Existing Buildings, published by the Federal Emergency Management Agency (FEMA). The section of the manual that covers the evaluation of unreinforced masonry buildings is very similar to the UCBC guidelines, having originated from the same document. The NEHRP design forces coincide more with the design forces found in the UBC.

A finite element response spectrum analysis (computer analysis technique) was made of two of the schools: Rose City Park Elementary and Franklin High School. This was done to verify the base shear and force distribution obtained in the static analyses and to study the effects of the irregular H- and U-shaped floor plans

### SUMMARY OF RESULTS

#### Nonstructural hazards

The buildings analyzed generally have three significant nonstructural seismic hazards: tall parapet walls, chimneys, and clay tile partitions. Generally the parapet height-to-thickness ratios exceed the UCBC limit, requiring parapets to be braced.

Clay tile partitions in various locations in the buildings pose an out-of-plane wall-failure hazard. For example, a 12-ft wall of 4-in. clay tile has a height-to-thickness ratio of 36. The UCBC recommends a maximum height-to-thickness ratio between 14 and 18 (depending on the wall location) in seismic zone 3. All these partitions should be either strengthened or removed and replaced.

At Fernwood Middle School, the exterior wythe (unit thickness of material) of bricks is a veneer course and is most likely unanchored or poorly anchored. Veneer failure is similar to an out-of-plane wall failure; when the acceleration on the veneer causes excessive deflections, the wall will fail. The 1994 UBC requires that veneer be anchored every 2 $ft^2$, or about 16 in. each way.

### URM wall and pier analysis

In the UBC Static Lateral Force Analysis, seismic story forces were distributed to the shear walls (walls acting as the structural members that resist horizontal forces, such as earthquake shaking, that tend to cause shear deformation in the structure) assuming rigid diaphragm action. A UCBC-type analysis was used to calculate the pier capacities. This analysis showed all the piers to be overstressed. The piers with the highest overstress values were located on the first floor. Considering all buildings, the range of values was from a few hundred percent to several hundred percent overstress for the first floor piers.

### Diaphragms

Because U- and H-shaped buildings have modes of vibration where the wing motion opposes the center motion, large tension and shear forces were anticipated in the slabs in the areas where the wings connect to the center of the main building. Complicating the situation were the stairwell openings, which pinched these areas even further. Generally the calculated stresses are significantly higher than allowed by UBC.

### Upgrade strategy

The upgrade recommendations for the various structures include the following:

1. Provide the structure with shear walls in both directions to provide the most direct path for the earthquake forces to follow.
2. Provide tie elements to minimize the stress in the floor diaphragms (horizontal structural members, such as floors and roofs, that can transfer stresses between and to beams and columns), and to provide a force path along the walls.
3. Provide shear walls at the extremities of the wings to minimize the effects of the torsional modes of vibration. Sections of buildings should also have torsional stability, with good connections between the segments.
4. Brace parapets, chimneys, hung ceilings, mechanical equipment, and tall bookshelves.
5. Strengthen or remove clay tile partitions.

## OBSERVATIONS AND CONCLUSIONS

The four schools investigated show that critical weaknesses in earthquake resistance exist in the buildings. The investigators assume that these four schools would be typical of the unreinforced masonry school buildings found in Portland. We strongly recommend that all school buildings built or retrofitted prior to about one or two decades ago be given high priority to be investigated for seismic strength. □

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*(**Publications**, continued from page 68)*

Released April 28, 1995

***Geothermal Gradients in Oregon, 1985-1994*** contains previously unpublished geothermal temperature-depth data from wells in southeastern Oregon that complete the currently available information for geothermal energy research for the state. Released as DOGAMI Open-File Report O–95–3, the report contains, for each well, location maps; depth, temperature, and gradient of each measurement; and graphic plots of the gradients. The report can be purchased for $7.

The dates of the title place this report in the continuous series of nine similar DOGAMI open-file reports for geothermal gradient data since 1970. The complete list now includes the following:

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| 1981 | O–82–4 |
| 1982 through 1984 | O–86–2 |
| 1985–1994 | O–95–3. |

The 132-page report is comprised of three groups of data. The first is a set of data logs from seven wells in the central and southern parts of Lake, Harney, and Malheur Counties. These wells were logged during 1993. The second set of data comes from a group of 18 wells in the vicinity of Vale, Malheur County, drilled and logged during 1986 for a study of the Oregon Water Resources Department. The third set of data presents results of an exploration project conducted by Hunt Energy Corporation in the general area of the Lake Owyhee thermal area in Malheur County. This data set was collected during 1980 and 1981 and covers 16 wells.

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

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, letters, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office (address above).



## Cover photo

The quarry at Yaquina Head during mining operations in 1976 (top) and after reclamation in 1994 (bottom) by the U.S. Bureau of Land Management (BLM) as "Quarry Cove," a public tide-pool area. The DOGAMI Mined Land Reclamation program (MLR) honored this effort as outstanding reclamation by a government agency. See report on MLR awards on page 91.

Top picture Oregon Highway Division photo, courtesy MLR. Bottom photo courtesy BLM/Chuck Forinash, Newport, copyright 1995.

## Oregon Department of Geology and Mineral Industries and USDA Forest Service receive Hammer Award

The Oregon Department of Geology and Mineral Industries (DOGAMI) and the USDA Forest Service (USFS) together received the Hammer Award, Vice President Al Gore's special recognition to teams that have made significant contributions in support of the National Performance Review principles. The award was presented on May 30 at the Jantzen Beach Red Lion in Portland by Doug Farbrother of the Vice President's National Performance Review Team.

The Hammer Award was given to DOGAMI and the USFS for their partnership in running the Nature of the Northwest Information Center, a one-stop center for information about outdoor recreation and natural resources in the Pacific Northwest. The Center is located on the first floor of the State Office Building at 800 NE Oregon St. in Portland. It carries brochures, publications, and maps from a variety of state, federal, and local governments, as well as commercial publications related to outdoor recreation.

Begun in 1992 by DOGAMI as the Nature of Oregon Information Center, the Center changed its name and scope of operations in the fall of 1994, when the USFS closed its information center in downtown Portland and moved in as a partner with the State of Oregon. Today, the newly expanded Nature of the Northwest Information Center serves several hundred people each day, making it easier for them to get outdoor recreation information.

The principles of the National Performance Review emphasize putting customers first, cutting red tape, empowering employees, and cutting government back to basics. The award is named for the notorious hammer that once cost the government $600. The tangible award consists of a plain hammer placed on black velvet background, decorated with a red-white-and-blue bow, and framed together with a handwritten citation by Vice President Gore that reads "Thanks for building a government that works better and costs less."

According to Don Haines, Nature of the Northwest Information Center manager, "People come to us or call us when they need information about the out-of-doors. In many cases they don't know who runs their favorite recreation site. They don't want to have to go to several different agencies to find out. They just want to get where they want to go. So we help them in our one-stop information center—in the fastest, simplest way possible."

Information about how to contact the Nature of the Northwest Information Center is listed in the box on the left. □

# Beyond the Channeled Scabland

## A field trip to Missoula flood features in the Columbia, Yakima, and Walla Walla valleys of Washington and Oregon—Part 2: Field trip, Day one

*by James E. O'Connor and Richard B. Waitt, U.S. Geological Survey, David A. Johnston Cascades Volcano Observatory, 5400 MacArthur Blvd., Vancouver, Washington 98661. With contributions by Gerardo Benito, Centro de Ciencias Medioambientales, Serrano, 115 dpdo, Madrid, Spain 28006; and David Cordero and Scott Burns, Department of Geology, Portland State University, P.O. Box 751, Portland, Oregon 97207*

*A preliminary version of this field trip guide was prepared for the first annual field conference of the Friends of the Pleistocene, Pacific Northwest Cell, May 13–15, 1994. Part 1 of the guide appeared in the May 1995 issue of this magazine. This second part includes the first day of the three-day field trip. Days two and three will be printed in the next issue. —ed.*

**DAY ONE**

Day 1 includes stops at some of the most spectacular Missoula flood features between The Dalles and Arlington. Trip route remains on the Oregon side of the river for the entire day. (Maps: U.S. Geological Survey (USGS) The Dalles 1°×2° sheet; USGS Hood River and Goldendale 1:100,000 sheets)

**En route to Stop 1.1**

From the Deschutes River Recreation Area, head west to The Dalles and then up the valley of Fifteenmile Creek. The local geology is dominated by the Columbia River Basalt Group, a thick sequence of middle and late Miocene (regionally, 17–6 Ma, locally 17–12 Ma) basalt flows that were issued from vents in northeastern Oregon and adjacent Washington and Idaho. In this region, the Columbia River Basalt Group has been deformed by a series of east-trending folds and high-angle reverse faults and by northwest-trending right-lateral strike-slip faults. Between the Deschutes River and the Hood River, the Columbia River Basalt Group is overlain by the Dalles Formation, a late Miocene (mainly 9–7 Ma) volcaniclastic and alluvial fan shed northeast from the Cascade Range. The Dalles Formation, with its several-meter-thick cover of loess, forms the rolling topography of the uplands, interrupted locally by gullies, landslides, and Missoula flood features.

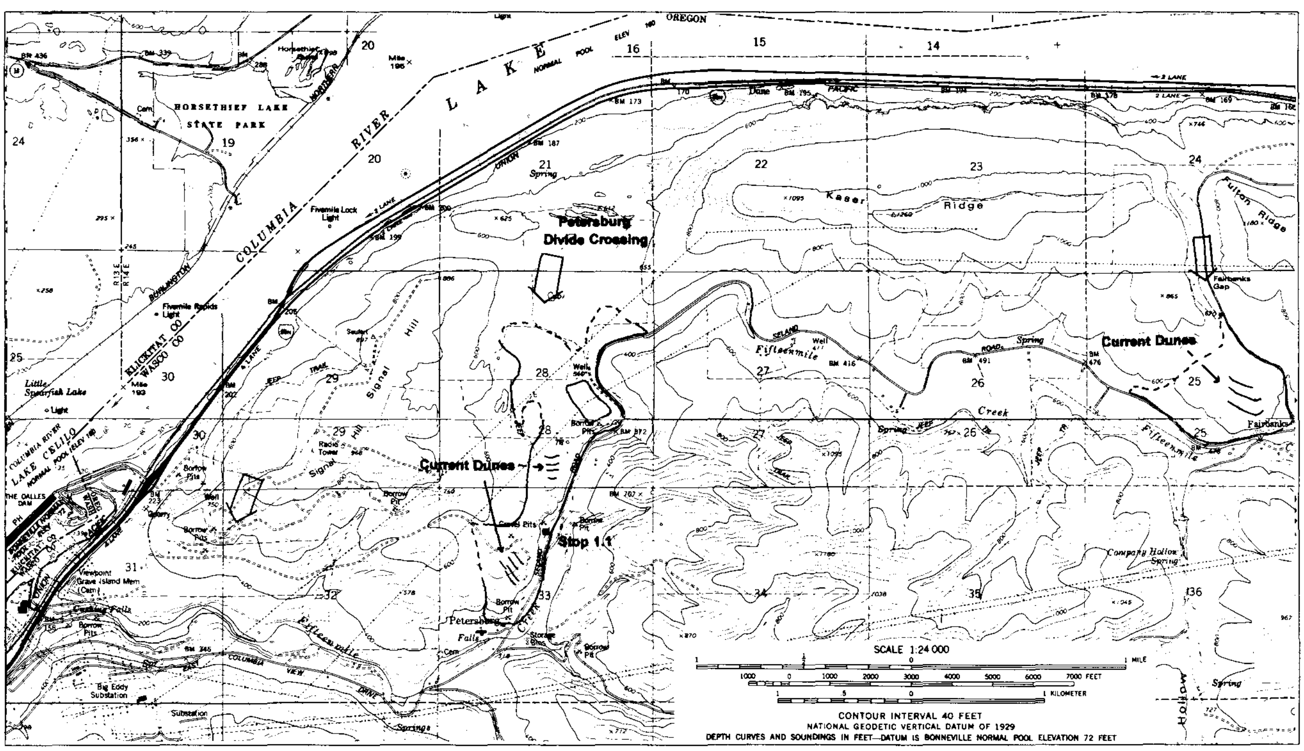



*Figure 7. Topographic map of the settings of Petersburg and Fairbanks divide crossings, with approximate extent of the gravel bars that were deposited as flow (arrows) spilled into the valley of Fifteenmile Creek. Topographic base from Stacker Butte and Petersburg USGS 7½′ quadrangles.*

Fifteenmile Creek parallels the Columbia River for about 15 km before joining it near The Dalles. Flow from the Missoula floods overtopped the ridge between the Columbia River and Fifteenmile Creek and spilled south into the valley of Fifteenmile Creek at two locations, forming two large "flood deltas" (Figure 7).

### Stop 1.1. Petersburg bar

**This is a privately owned gravel pit. Please do not enter without permission of the property owner!** This large gravel pit exposes deposits from flow(s) spilling south into the valley of Fifteenmile Creek (Figure 7). Boulders, gravel, and sand were deposited in steeply dipping foresets, apparently as this "flood delta" prograded southward. Many of the contacts between thick gravel beds are unconformable, indicating erosion of the underlying unit before subsequent deposition. The topmost gravel bed is distinctly coarser with a more openwork texture. The entire deposit is capped with about 1 m of loess that contains a weakly developed soil typical of late Pleistocene age. The surface of the bar displays two small sets of giant current dunes. Exposures 0.5 km to the northeast at the east edge of the bar also show several units that are finer, thinner, and more gently dipping than the deposits here.

One question here is: Do each or any of these unconformity-bound units represent individual floods? Without definitive evidence of subaerial exposure between units or good chronologic information, it is difficult to answer this with certainty. Yet, based on other exposures of coarse-grained deposits that do have evidence of subaerial exposure (such as loess deposition) between units, we tentatively infer that each of the coarse depositional units here, some capped with fluvially deposited sand, is the result of a separate flood. If true, depending on how one counts, there are 6–10 floods. Hence, perhaps at least that many separate floods overtopped the divide. A similar number of unconformity-bound gravel and sand couplets are exposed in the pit to the northeast.

The present altitude of the divide crossing is about 180 m (600 ft). According to our modeling, a discharge of at least 3 million $m^3/s$ would be required to overtop this divide (Figure 8). So we conclude tentatively that there were at least 6–10 separate floods that had peak discharges greater than 3 million $m^3/s$.

Radiocarbon dates from this exposure, all from low in the stratigraphic sequence, yield ages between 16,720±210 $^{14}C$ yr B.P. to >40,000 $^{14}C$ yr B.P. The youngest date (16,720±210 $^{14}C$ yr B.P.) came from a plant fragment within an organic-rich silt clast, which yielded a bulk date of 24,200±1,900 $^{14}C$ yr B.P. Additional bulk analyses from similar clasts of organic-rich silt at this site yielded ages of 23,400±250, 31,870±650, and 45,500±2700 $^{14}C$ yr B.P. We have also dated a soil clast high in the stratigraphic sequence at the east end of the bar. The stratigraphic relation between the deposits at the east end of the bar and those exposed at the trip stop is uncertain, although the deposits at the east end of the bar may simply be a finer facies.

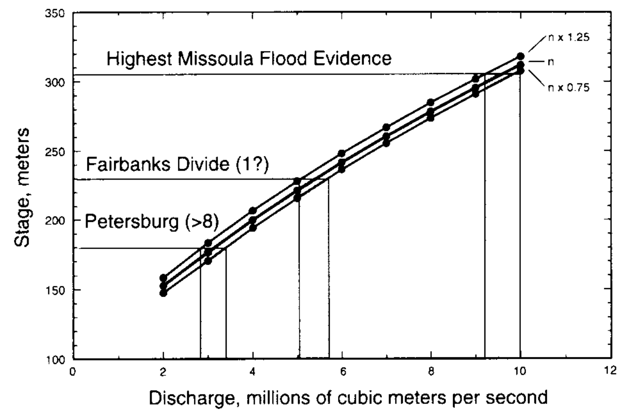



*Figure 8. Stage-rating curves constructed on the basis of step-backwater calculations for the reach near the Fairbanks Gap and Petersburg divide crossings. The sensitivity of the step-backwater calculations to uncertainty in Manning **n** values is shown by the three separate curves, one based on a best guess of roughness, the other two based on adjusting those values by ±25 percent. At sites such as these that are upstream of critical-flow sections, sensitivity to Manning **n** values is usually small. The numbers after the names of the divide crossings are the number of unconformity-bound depositional units exposed in the downstream delta bars.*

A whole-sample analysis of the sample from the east end of the bar yielded an age of 32,920±650 $^{14}C$ yr B.P.; an analysis of the separated humic acids (NaOH extract) gave an age of 14,480±145 $^{14}C$ yr B.P., which is probably a close age for the deposit.

### En route to Stop 1.2

From Petersburg bar continue east along the valley of Fifteenmile Creek. In valleys to the south, ice-rafted erratics and a thin layer of sandy silt 0–4 m thick were deposited over the loess-covered landscape to an altitude of at least 285 m (940 ft).

About 5 km up Fifteenmile Creek, another large bar was deposited by flow diverging from the valley of the Columbia River across the divide through Fairbanks Gap (Figures 7 and 9). This bar has large crescentic current dunes on its surface, expressed by crenulations in the contour lines. An exposure of the delta front near the intersection with Company Hollow Road reveals coarse gravel deposits that lack the sweeping unconformities and interbedded sand layers of the deposits at Petersburg bar. A possible explanation for the coarseness is that the Fairbanks Gap divide crossing is much narrower than the Petersburg crossing and produced higher flow velocity as water passed through. Possible explanations for the lack of unconformities in the exposed section include that (1) stratigraphic exposure is too shallow; (2) the contacts are just not visible where bouldery units are amalgamated together; and (3) only one flood overtopped the divide here. Two radiocarbon analyses of organic-rich silt clasts gave >40,000 $^{14}C$ yr B.P. dates. The weak soil, however, indicates that this deposit is of late Wisconsin age.

Turn left on Old Moody Road and climb up the east margin of the bar. The undulating topography on the bar surface (wheat field) is created by giant current dunes. Proceed through Fairbanks Gap, a divide crossing cut through the Dalles Formation down to the contact with the Columbia River Basalt Group. The upper limit of erosion is about at altitude 300 m (1,000 ft). The col of the Fairbanks Gap divide is at altitude 250 m (820 ft), some 70 m higher than the Petersburg divide, requiring a minimum discharge of about 5 million $m^3/s$ for overtopping (Figure 8). Note that the apex of the bar is higher than the divide crossing, which indicates that the flow was tens of meters deep through the divide as the bar was being formed.

Continue about 2 km east, high along the south side of the Columbia River valley, traveling across a small pendant bar. Stop 1.2 is at a promontory above the railroad bridge. Beware of traffic on this narrow gravel road.

**Stop 1.2. Celilo Falls overlook**

Before closure of The Dalles Dam in 1956, one had a good view of Celilo Falls from here (Figure 10). Altogether the sets of rapids between Celilo Falls and The Dalles were known by the name "The Dalles of the Columbia," the steepest section of the Columbia River, where the water-surface dropped 25 m in the 19 km between the head of Celilo Falls and The Dalles. At low water, Celilo Falls had a sheer drop of about 6 m. The topography of this reach consisted of narrow chutes, several kilometers long and locally less than 50 m wide, separated by large holes. The holes at Big Eddy and at the head of Fivemile Rapids are more than 40 m deep, with bottoms more than 30 m below sea level. At low water, the Columbia River was confined to the chutes and holes, but at high water, the entire basalt-floored valley bottom was inundated. It is not clear to us whether the channel-bottom topography here is largely a relict of the Missoula floods or whether Holocene flows sculpted the present channels as suggested by Bretz (1924). Nevertheless, Bretz (1924) felt that the processes and topography at this site served as a good analogy for Missoula flood features in the Channeled Scabland.

Topography clearly related to the Missoula floods can be seen across the river above the town of Wishram, where Columbia River Basalt Group flows have been stripped of their surficial cover and eroded into a butte-and-basin "scabland" topography. A local set of northwest-aligned joints or minor faults has been preferentially excavated. At higher altitudes, the basalt has been stripped of loess and regolith but not much eroded. Alluvial fans, talus, and landslide debris shed southward off the Columbia Hills anticline were locally trimmed back, which resulted in Holocene entrenchment of many of the small streams draining the valley slopes. Landslides are ubiquitous on both sides of the river and in major tributary valleys throughout this reach of the Columbia. Many of the most visible of these landslides have pristine morphology, which indicates that they probably postdate passage of the flood peak(s). Nevertheless, they were perhaps triggered by the floods because of excavation of supporting sediment and saturation and excess pore pressures caused by a few days of inundation and subsequent dropping of the water level.

On the north side of the river, forming the high part of the ridge to the east, is Haystack Butte (towers on top). This Quaternary volcano erupted basalt that flowed south into the Columbia River valley at about 900 ka (Bela, 1982). The lowest exposure of these flows is along the southeast margin of Miller Island, a mid-channel island south of Haystack Butte. These rocks at Miller Island, less than 60 m above sea level, indicate that (1) regional base level has not changed much during the last million years and thus the Missoula floods caused little or no overall downcutting of the river bed, at least not more than a few tens of meters; and (2) because the basalt of Haystack Butte must have flowed down a continuous slope to its present position, the entire intervening channel north of Miller Island must have been carved in the last half of the Quaternary, probably by erosion during the Missoula floods. If this channel was carved by flood, it is a huge example of a landform that Bretz noted in various parts of the Channeled Scabland and termed "trenched spurs." Trenched spurs are analogous to flood chutes cut across alluvial meander bends but are instead cut through bedrock.

Along this stretch of the Columbia valley, the floods left a wide spectrum of other erosional features, ranging from streamlined hills formed in the surficial loess and sedimentary deposits, to stripped, plucked, and channelized surfaces on the basalt flows. We compare flow velocities from our modeling (Figure 11) to mapped erosional features for a 30-km reach extending upstream from Celilo Falls to the John Day River confluence. Figure 12 shows how these erosional features plot with respect to the flow depth and velocity calculated for the peak stage of the largest flood. Hills composed of loess and semiconsolidated alluvial deposits were streamlined and channelled under flow depths of 0–40 m and velocities less than 5 m/s. In areas of more intense flow, the loess and alluvial deposits were completely removed, exposing surfaces of the Columbia River Basalt Group. Intact but stripped and grooved basalt surfaces correspond to maximum flow depths between 25 and 125 m and flow velocities of 3–9 m/s. Local erosion of these basalt surfaces into a butte-and-basin morphology was probably a result of unsteady and complex flow phenomena such as vertical flow vortices and cavitation that cannot be directly described by the step-backwater results. Nevertheless, average flow conditions at these sites are characterized by depths of 100–270 m and velocities of 6–24 m/s. Hydraulic conditions at sites of inner channel formation were most intense; flow depths exceeded 250 m at maximum discharge and velocities were greater than 13 m/s. Because many of the features may have been the cumulative product of several floods with hydrographs that spanned a large range of dura-


*Figure 9. Panorama view generally north of the delta bar (not cultivated, dark) deposited by water spilling out of the*

tions and discharges, the depth and velocity fields of specific "facies" of erosional landscapes should not be viewed as definitive. Yet it is apparent from the high spatial correlation between flood features and local flow conditions that there are important thresholds that must be exceeded for certain types of erosional features to be produced. Did all, a few, or perhaps just one flood cause most of the erosion along the flood route? Different parts of the Channeled Scabland would probably give different answers.

**En route to Stop 1.3**

Continue east on Old Moody Road, passing over high-level and locally high-relief butte-and-basin scabland before descending into the valley of the Deschutes River. A prominent trimline cut into the slopes above indicates that maximum flood stage exceeded altitude 315 m (1,040 ft). At river level, a large pendent bar extends downstream from the southeastern edge of Miller Island.

A large bar lies along the west side of the Deschutes valley, extending upcanyon about 3 km. An Oregon Department of Transportation gravel pit near the top of it previously exposed seven alternating sand and gravel couplets, ranging from 1 m thick near the bottom to less than 30 cm at the top. Each couplet consists of well-sorted micaceous medium sand deposited in north-dipping foresets unconformably overlain by openwork coarse sand and gravel deposited in south-dipping foresets. Most of the sand units are partly to nearly completely truncated by the gravel unit, except for a trace of sand between the gravel units. The upper 0–3 cm of each coarse unit has a silt matrix that indurates the upper few centimeters of each unit. We infer that this silty matrix resulted from loess deposition between separate floods. The distinct change in texture and current direction within the couplets may result from changing eddy circulation patterns as each flood waxed and waned. If each of these seven units were deposited by individual floods, they all achieved discharges of greater than about 2 million $m^3/s$, based on their altitude relative to our modeling results.

Proceed east along the frontage road to Biggs Junction and enter Interstate 84 eastbound. Continue 19 mi east, passing the John Day Dam and the mouth of the John Day River, exiting at Philippi Canyon (Exit 123).

Ascend Philippi Canyon, where a large eddy bar has been deposited along the eastern valley margin. Near the road junction is the col of a major divide crossing between the Columbia and John Day River valleys (Figure 13). Bretz (1928, p. 686–690) described this region in detail, using it as a cornerstone in building a case for huge flows downs the Columbia.

**The following section is on private property. Be sure to obtain permission before entering!** (If you wish to bypass the private land, go on to Stop 1.4.)

*valley, through Fairbanks Gap, and into the valley of Fifteenmile Creek (foreground). USGS photograph by A.M. Piper.*

Turn right (west) at the intersection and follow the private road that flanks the north edge of a channel and cataract complex that has been eroded through the Columbia River Basalt Group and overlying Tertiary gravel. To the west, a large flood entering the John Day valley from the Columbia deposited an immense bar, 150 m (500 ft) high and mantled with rounded boulders 2–3 m in diameter.

**Stop 1.3. Columbia River overview**

This superb view of the valley of the Columbia River is from 310 m (1,020 ft) above what used to be the normal river level but is now submerged 25 m due to the John Day Dam. Some 15–30 m (50–100 ft) above the maximum flood stage, this site would have been a good if somewhat frightful place to watch the largest Missoula flood(s). In this area, the maximum flood stage can be confidently constrained as being less than 340–350 m (1,120–1,150 ft) by a divide 300 m to the east that was apparently not crossed. However, about 5 km west, laminated sand and silt mantle loess to an elevation of at least 330–340 m (1,080–1,120 ft). Another divide crossing, 2 km west, has a minimum elevation of more than 310 m (1,020 ft), with evidence of erosion as high as 340 m (1,120 ft).

A tremendous current must have developed between the Columbia and John Day River valleys to erode the scabland of this divide. Such a current indicates a substantial difference in the water surface elevations between the flooded Columbia River valley and the backflooded John Day River valley, a rather quick rise in flood stage. The travel distance over which this gradient was developed was only about 30 km. We can speculate about what the rate of rise may have been by assuming that the divide crossing was not eroded significantly below the level of backflooded water in the John Day River valley at the time of the initial crossing, hence putting that water level at about 230 m (750 ft). The water level at initial overtopping of the divide may have been about 300 m (1,000 ft). Assuming that the flood wave moved downstream at the celerity of the flow velocity at peak stage (about 10–15 m/s), it would have taken 50–75 minutes for water levels to translate down the Columbia River valley and back up the valley of the John Day River. Considering the ~70-m elevation difference between the water levels tenuously indicated by the field evidence, this translates into a water level rise of about 1 m/min.

**En route to Stop 1.4**

Continue westward on the peninsula between the John Day and Columbia Rivers and turn around at the divide crossing at about the 310-m (1,020 ft) elevation. Here, flow overtopped a low point in the ridge between the two rivers,

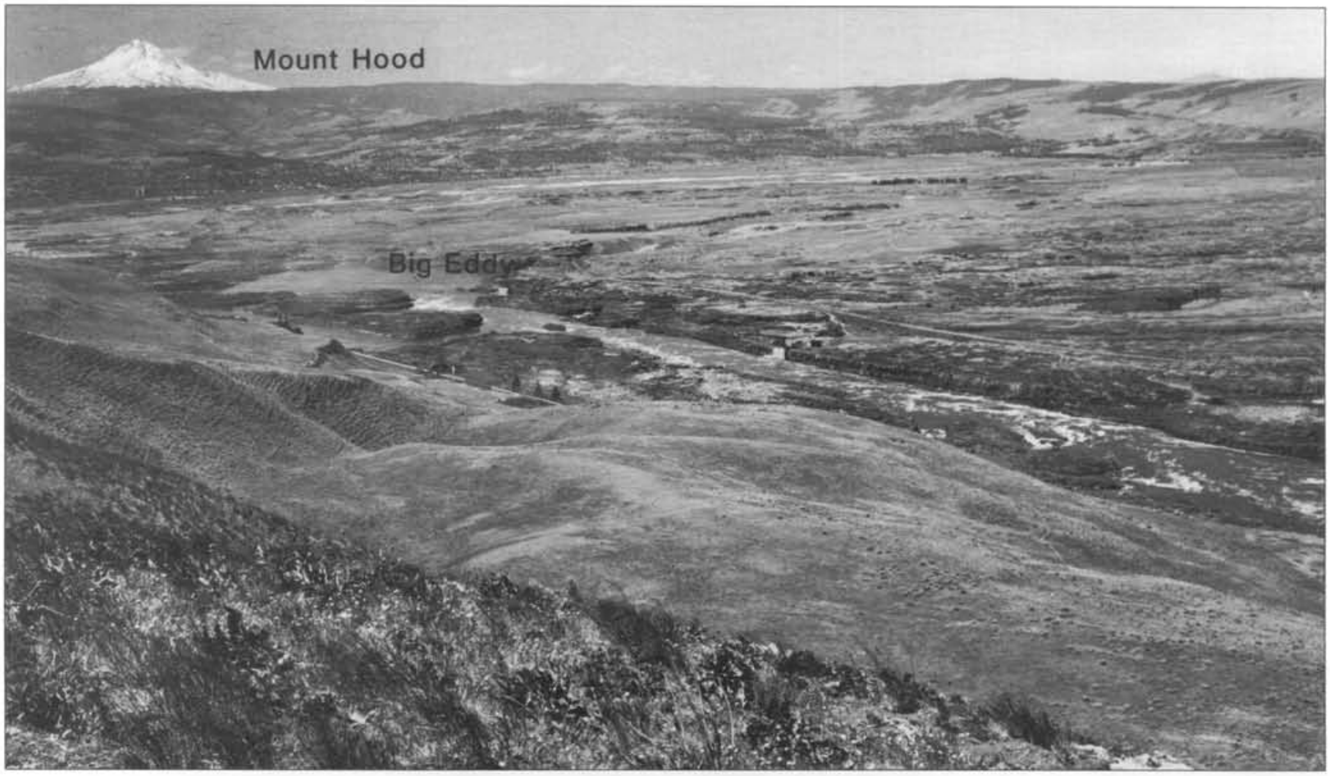
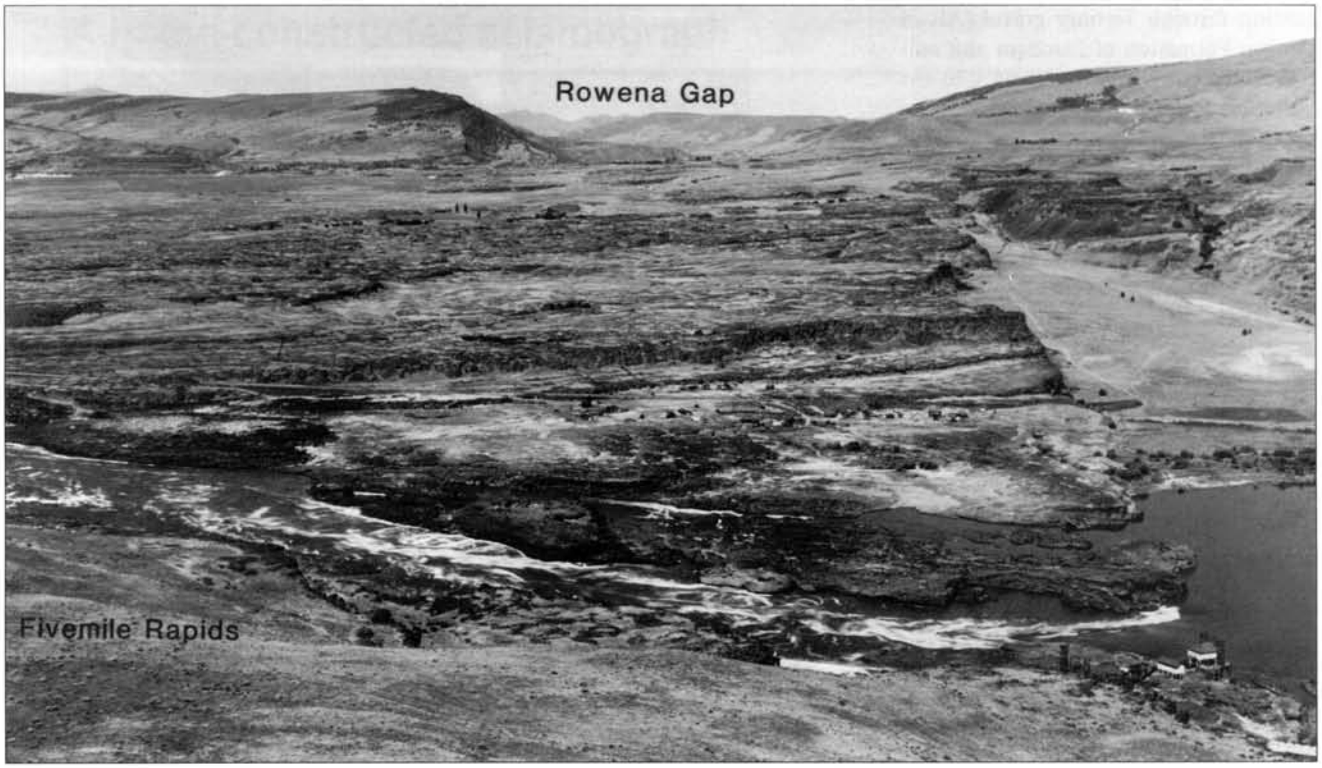
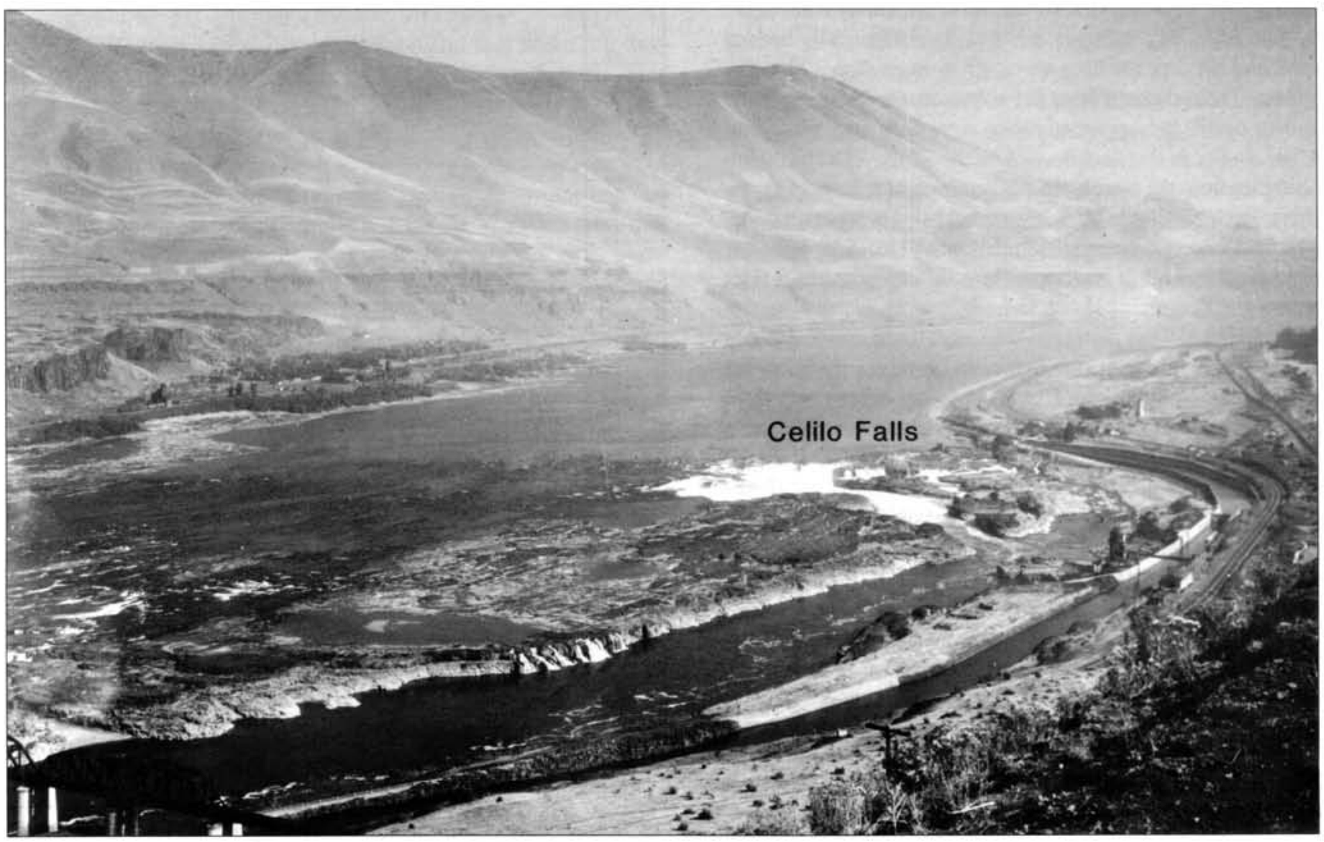



*Figure 10. Panoramas of "The Dalles of the Columbia" before inundation by The Dalles Dam. Views are from south valley side and*




*generally west-southwest in the upper panorama, generally north from near Stop 1.2 in the lower. USGS photos by A.M. Piper.*

eroding through Tertiary gravel (Alkali Canyon Formation of Farooqui and others, 1981) but not entrenching into the Columbia River Basalt Group that floors the channel.

Turn around and drive back to Philippi Canyon road. Stop 1.4 is just south of the intersection on that road.

### Stop 1.4. Scabland

Take some time to walk around this "amazingly wild scabland" (Bretz, 1928, p. 688). Note the closed rock basins and the basalt protrusions, the steep-sided canyons with floors that slope in various directions. Imagine what the landscape looked like before the floods.

Much of the coarse debris eroded from this scabland was deposited in two large bars whose apices lie just downcurrent from each of the two sets of cataracts formed by water overflowing into the John Day valley (Figure 13). The smaller bar, south of the southeastern flow route, has giant crescentic current structures on its surface. Together, these bars displaced the John Day River southward onto a shelf of basalt that forms the south valley side.

The John Day valley is mantled by rhythmically bedded sand and silt deposits from its mouth to more than 30 km upstream. These deposits have not been examined systematically and in detail, but apparently they were deposited by several Missoula floods that backflooded up the valley. At a site 30 km upstream from the mouth, there is a section of at least 14 rhythmites, each rhythmite probably representing a separate flood. The field evidence includes bioturbation and loess deposition at contacts. The eighth rhythmite from the top contains a faint tephra couplet, probably the 13-ka Mount St. Helens "set S." The relation of these rhythmite sequences to the coarse deposits at the divide crossings is not clear, but it seems doubtful that rhythmites along the John Day River valley downstream from the large bars near the point called the "Narrows" could have survived a deluge traveling down the John Day River from the Philippi Canyon divide crossings. We speculate that the rhythmites in the John Day River valley, especially those in the lowest reaches, postdate the flows that formed the scabland and great bars resulting from overflow at Philippi Canyon.

According to our flow-modeling results, flow over the divide at Philippi Canyon requires a minimum of about 5 million $m^3/s$. In contrast, emplacement of the 14 rhythmites requires minimum discharges of only about 1.5 million $m^3/s$.

The only chronologic information we have regarding the deposits at the Narrows is a radiocarbon age from a soil clast in a colluvial deposit below a single Missoula-flood deposit north of the large bar. The bulk radiocarbon analysis of the clast yielded a result of 29,845±470 $^{14}C$ yr B.P. An analysis of the humic acids (NaOH extract) resulted in

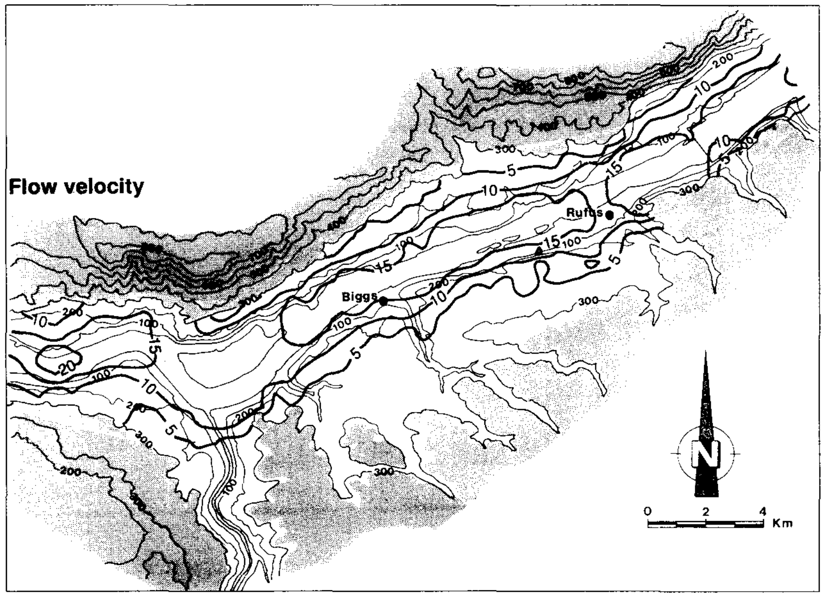



*Figure 11. Isovel (equal velocity) map for a 10 million $m^3/s$ discharge near the confluence of the Columbia and Deschutes Rivers. Velocity values are in m/s. Area above flood limits shown by stipple pattern.*

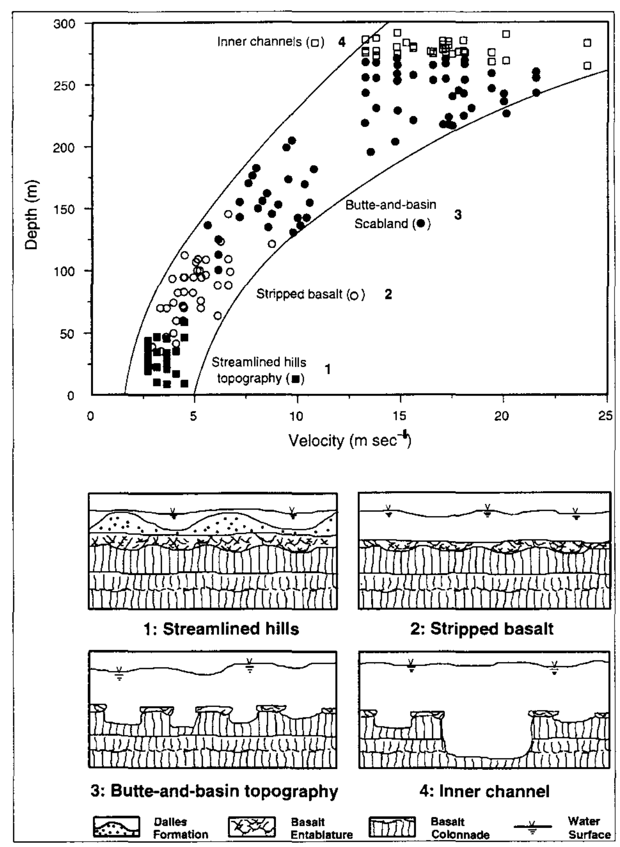



*Figure 12. Relation of erosional features in the area of Figure 11 to local flow depths and velocities calculated for a 10 million $m^3/s$ discharge. The various "facies" of erosional features are portrayed in lower part of figure.*

19,015±145 $^{14}C$ yr B.P. In this case, these dates provide a maximum age for the overlying flood deposit and simply confirm that the most recent flow(s) over this divide were during the late Wisconsin.

### En route to Stop 1.5

Continue east, traveling up Philippi Canyon. From this point eastward, almost to Wallula Gap, the largest Missoula floods spilled well out of the Columbia River valley, inundating large tracts of upland surfaces. These high surfaces are underlain by basalt gravel and tuffaceous sediment of the late Miocene to early Pliocene Alkali Canyon Formation (Farooqui and others, 1981; Smith and others, 1989), which in turn overlies the Columbia River Basalt Group.

### Stop 1.5. Ice-rafted erratics

Near the telephone pole are some ice-rafted erratics. Commonly, accumulations of diverse rocks are found in concentrated zones, locally forming mounds. Many, like these, are on the east sides of ridges that stood up above the maximum flood stage. The erratics here have been cleared from the fields but probably have not been moved far. They are at an elevation of about 325 m (1,060 ft), consistent with the high-water evidence discussed at Stop 1.3 and local divide crossings and trimlines up to an altitude of 335 m (1,100 ft). For the next 80 km upstream, to the downstream end of the constricted reach at Wallula Gap, maximum stage evidence closely hovers about the 1,100-ft contour (335 m), indicating that there was little gradient to the largest flood at peak stage. The flatness of the water-surface profile in this reach fueled Allison's (1933) speculation that physical damming downstream was the cause of the high water levels in the Columbia valley.

### En route to Stop 1.6

Continue east to Blalock Canyon road, then southwest to Alkali Canyon and north to Oregon Highway 19. Alkali Canyon was the largest of several overland flow routes from the north that spilled water into the John Day valley. A gravel eddy bar at the junction of Blalock Canyon and Alkali Canyon roads attests to the flow velocity. Westward travelers of the Oregon Trail ascended out of Alkali Canyon via this eddy bar after following the south side of the canyon for several kilometers.

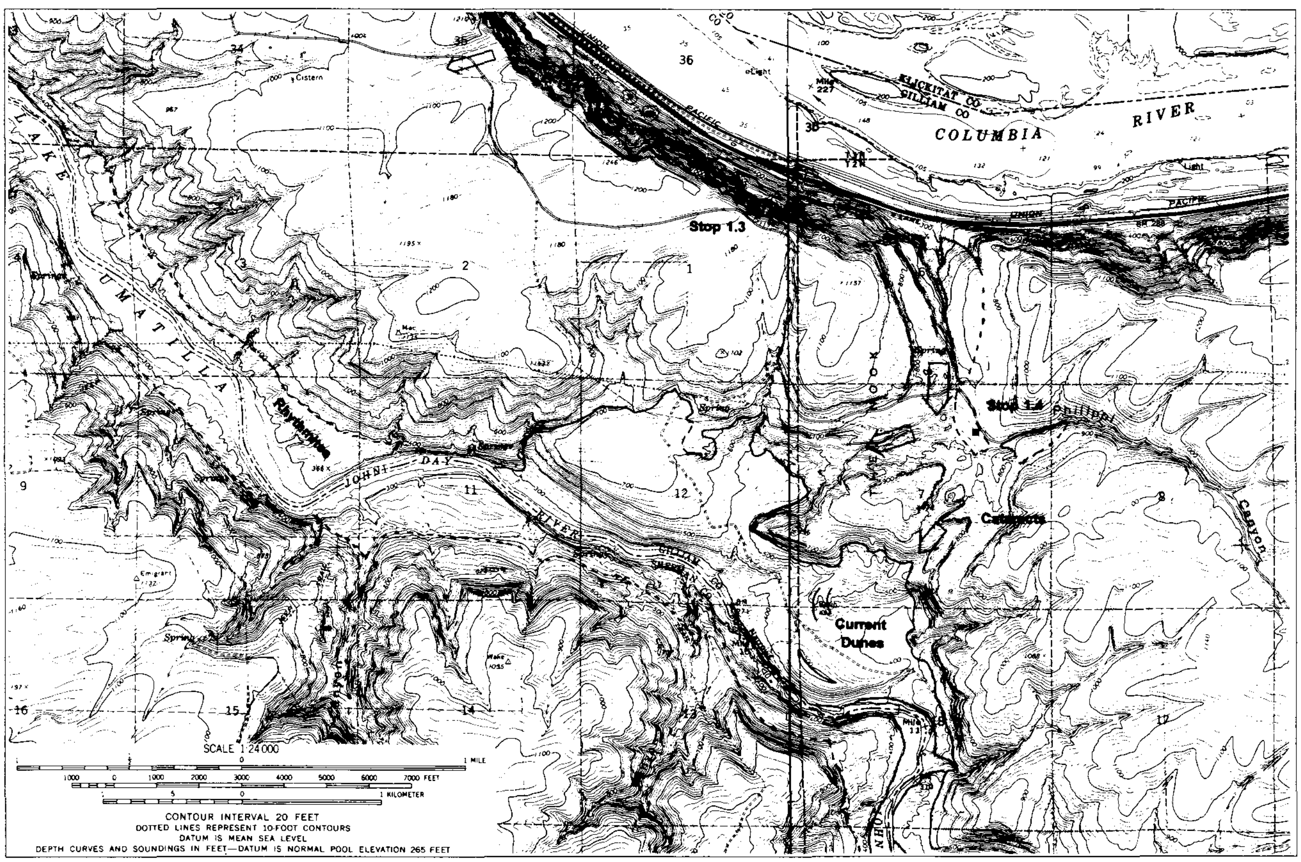



*Figure 13. Topographic setting and approximate distribution of Missoula flood deposits in the area of the divide crossing between the Columbia and John Day valleys near the "Narrows." Topographic base from Quinton and Sunrise NW USGS 7½′ quadrangles.*

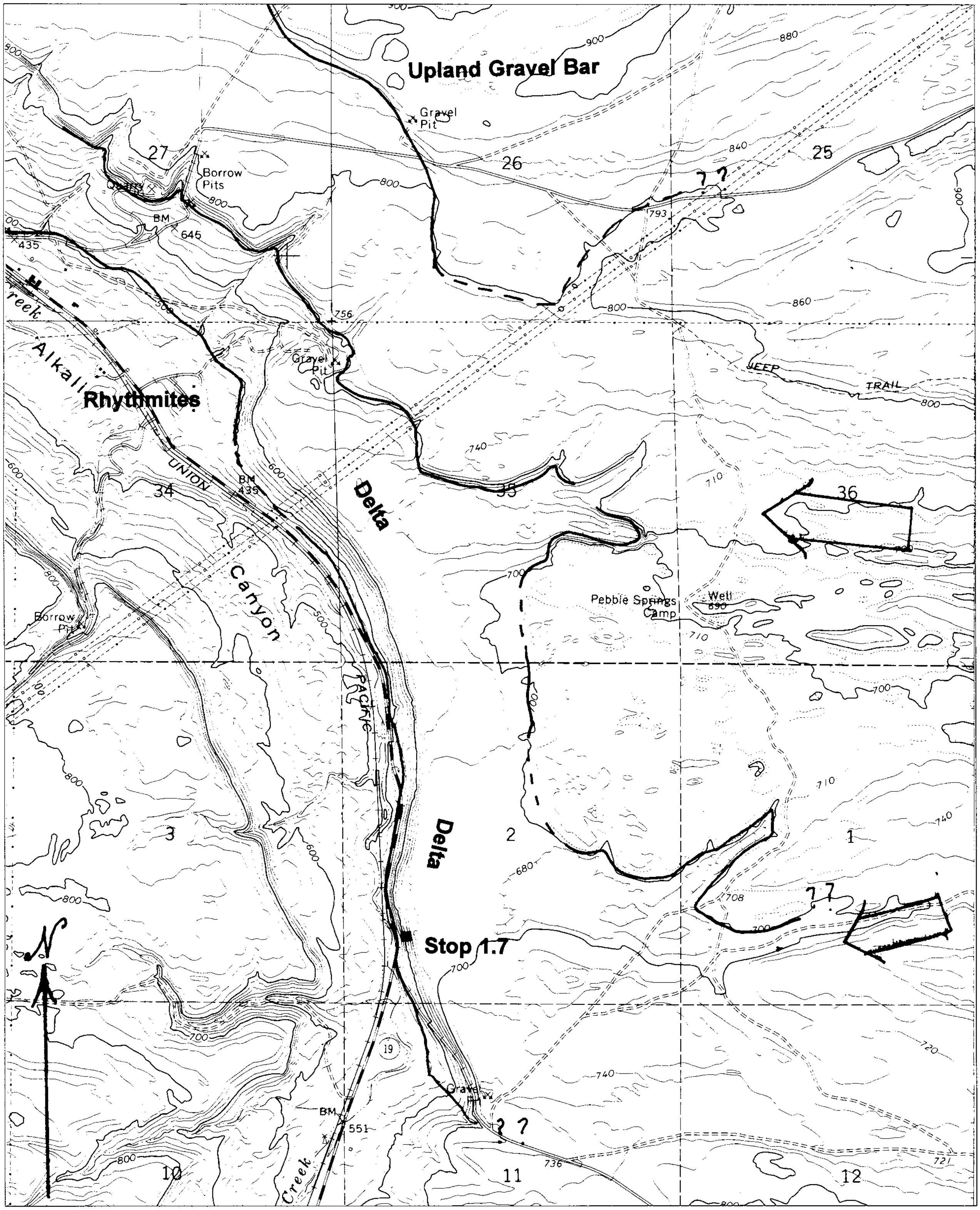



*Figure 14. Topographic setting and approximate distribution of Missoula flood deposits southeast of Arlington. The delta bars were mainly deposited by flow spilling into Alkali Canyon from the two upland channels to the east. There was substantial flow over the entire upland surface, however, as evidenced by the large gravel bar deposited on the upland surface that is depicted on the north part of the map. Topographic base from Arlington USGS 7.5′ quadrangle. Land sections (numbered) are 1 mi (1.6 km) across.*

### Stop 1.6. Arlington rhythmites

This stop is an appetizer for the stops on Day 2. About 15 fining-up sand-to-silt beds are deposited over preexisting landscape. Thin stringers of Mount St. Helens "set S" tephra lie at the top of about the fourth bed from the top. Is it possible that each of these beds was deposited by a separate flood? Day 2 stops will address this question in detail.

### En route to Stop 1.7

As you continue north on Highway 19, you gain a view of a large delta that enters and partially fills Alkali Canyon from overland flow routes to the east.

### Stop 1.7. Arlington flood delta

The final stop is at an exposure of a large delta complex of bouldery gravel deposited in Alkali Canyon about 4 km southeast of Arlington (Figure 14). Bretz (1925, p. 243–244) described this feature in his first report on Missoula flood features in the lower Columbia River valley. Bretz did not fully understand how high the water had risen here, even in his last report on the lower Columbia valley (1928, p. 681–686). But Allison (1933) did, and the question was one element of the contest between those two.

The entire upland surface south of the Columbia River was in fact submerged by water during the largest Missoula floods, although two channels (Figure 14) identified by Bretz (1925) that eroded through the Alkali Canyon Formation down to the surface of the Columbia River Basalt Group probably conveyed most of the upland flow. The exposure here lies at the south end of a large delta complex that was deposited as flow dropped into Alkali Canyon from those overland channels. The exposed part consists of 30°-W.-dipping foresets of gravel with clasts as large as small boulders. Many of the clasts are well-rounded basalt cobbles, 10–20 cm in diameter; these were probably reworked from the Alkali Canyon Formation. Coarser and angular to subrounded Columbia River Basalt Group clasts, as well as clasts of soil and loess, were clearly transported only short distances. The steep dip of the foresets precludes viewing much of the stratigraphic sequence in this exposure. Nevertheless, there are no sweeping unconformities like those in some other delta deposits, such as at Petersburg. Perhaps the forsets exposed here were deposited by just one flow. Other exposures in this delta complex, however, both near the apex of the northern channel and down near the toe, indicate that perhaps at least two flows were vigorous enough to transport gravel over the 215-m-high upland surfaces to the east.

An exposure 5 km to the southeast, also at an altitude of 215–220 m (710–720 ft), gives more clues to the number and magnitude of floods that inundated this area. A roadcut exposes silt and fine sand deposited in six or seven cycles of fining-up sequences. The cycles themselves thin and fine upwards from 20–30 cm thick near the bottom of the exposure to a few centimeters thick at the top. Three stringers of tephra are also exposed, two near the top of the fifth cycle down, and one at the top of the fourth cycle from the top. Similar in setting and stratigraphy to exposures to be discussed on Day 2, these tephras are probably also Mount St. Helens "set S." If each of these rhythmites was deposited by separate floods, then there were at least seven floods that achieved stages of 215–220 m (710–720 ft), equivalent to a discharge of 3–4 $m^3/s$, with four of these flows postdating 13 ka. Many of these flows, however, may not have had the strength to transport gravel across the upland surfaces and contribute to formation of the Arlington delta.

### En route back to Deschutes State Park

Proceed northwest on Oregon Highway 19 toward Arlington. For the first couple of kilometers, we follow the curved delta front of deposits from the overland channels to the east. The west side of the valley is covered with numerous landslides and is locally mantled with Missoula flood sand and silt. Shortly after leaving the delta front, we pass an exposure of rhythmically bedded sands and silts that compose the flat but gullied surface along part of the valley floor (Figure 14). These deposits, apparently inset against the gravel delta bars, were left by tens of floods that probably postdate the delta bars. Although we have not done a thorough search, we have not found the "set S" tephra, so the floods represented by these deposits may all postdate 13 ka.

Enter Interstate 84 westbound and head back to Biggs Junction. Along the way note the abundant bars deposited on the downstream side of valley protrusions and in tributary mouths. Bretz (1924, 1928) described many of these, noting:

> "In this part of its valley are numerous deeply trenched tributary canyons. . . Deposits of fresh, dominantly little-worn basalt gravel occur at various altitudes in this canyon portion. If they are remnants left by dissection of a once complete fill, they should be most extensive between the tributary mouths, not in them. If they are original deposits left by a very great flood and individually determined by local conditions, tributary mouths would be logical places for them." (Bretz, 1928, p. 684)

## DAY 1 ROAD LOG (mileage is approximate)

**Miles**

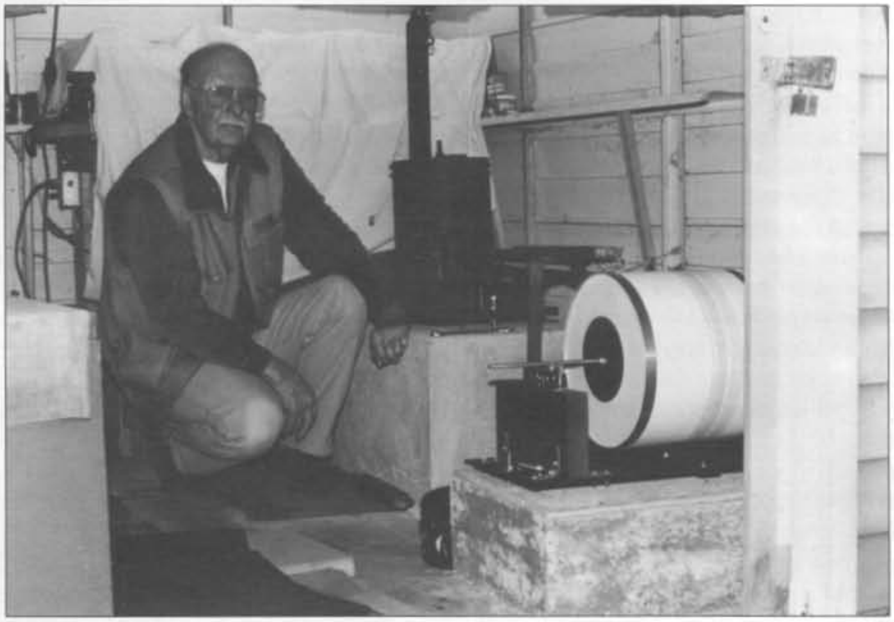
- 0.0 Deschutes State Park overflow area.
- 0.2 Turn left (west) onto Oregon Highway 206 (old US 30).
- 3.4 Turn right (north) and pass under I-84.
- 3.6 Turn left (west) and enter I-84 westbound.
- 14.0 Exit I-84 at Exit 87. Turn left (south) onto Oregon 197.
- 14.3 Stop sign at junction of Oregon 197 and US 30. Turn left, continuing south on Oregon 197.
- 14.6 Turn sharply left onto Columbia View Drive, proceed up the hill with good views of The Dalles Dam, including fish ladders on the east and west sides of the dams. To the west, on Sevenmile Hill (northwest of The Dalles), a prominent trimline is visible about halfway up the slope.
- 16.0 Cross under power lines from The Dalles Dam.

16.4 Stop sign. Turn right (east) onto Seland Road.
17.6 Cross bridge over Eightmile Creek. Bear left at yield sign, continuing on Seland Road.
18.1 Cross bridge over Fifteenmile Creek.
18.2 Abandoned gravel pit on left, south margin of Petersburg Delta. Site of Petersburg settlement and school.
18.7 **Stop 1.1**, Petersburg Bar. Pull off and park on gravel parking strip on the right side of the road. When you leave, continue north on Seland Road.
19.9 North margin of Petersburg delta exposed along road. Roadcuts for next few miles are in the Columbia River Basalt Group.
22.8 Roadcuts expose western margin of Fairbanks bar.
23.7 Junction with Company Hollow Road from the south. Large exposure of Fairbanks bar in the gravel pit on the north side of the road.
23.9 Turn left on Old Moody Road (one-lane gravel road).
24.5 View left to surface of Fairbanks bar. Hills and swales on bar surface are giant crescentic current dunes.
24.7 Fairbanks Gap.
25.3 View down to the Columbia River (Lake Celilo), 180 m below.
27.1 **Stop 1.2**, Celilo overlook. Pull off as far as possible on right side of road. Watch for traffic on narrow road. When you leave, continue east on Old Moody Road.
27.8 Traveling across high-altitude basin-and-butte scabland surface.
29.3 Ranch on right.
29.9 Begin descent into Deschutes River valley.
30.5 Oregon Department of Transportation gravel pit.
30.9 Pass under Burlington Northern railroad.
31.2 Heritage Landing (restrooms).
31.4 Stop sign at junction with Oregon 206/US 30. Turn right (east).
31.6 Cross over Deschutes River.
31.8 Turnoff to Deschutes River State Park camping area.
33.2 Junction with Oregon 206. Continue east on US 30.
35.8 Enter Biggs Junction.
36.2 Four-way stop. Turn left onto US 97.
36.3 Turn right and enter I-84 eastbound.
43.9 John Day Dam.
46.1 Cross John Day River.
54.9 Exit I-84 at Philippi Canyon (Exit 123)
55.2 Stop sign. Turn right onto Philippi Canyon Road.
57.0 Top of large eddy bar deposited in east side of Philippi Canyon.
57.1 Pavement ends. Turn right onto Philippi Lane (private road).
57.7 View down into John Day valley and large bar.
57.8 Pass under power lines.
58.9 **Stop 1.3**, Columbia River overview. When you leave, continue west on Philippi Lane.
60.0 Exposure of the Alkali Canyon Formation and old soils in road cut on right.
60.6 Divide crossing (sec. 35, T. 3 N., R. 18 E.)
60.7 Turn around.
64.2 Junction of Philippi Lane with Philippi Canyon Road (signed as Quinton Lane and Heritage Road). Turn right (south).
64.4 **Stop 1.4**, Scabland of the "Narrows" divide crossing. Park on right side of road and hike about 500 m southwest to the knob of basalt with the power line standard for views of the divide crossings between the John Day and Columbia Rivers. When you leave, continue south and then east, following Philippi Canyon Road up Philippi Canyon.
64.4 Small eddy bar.
69.1 **Stop 1.5**, Ice-rafted erratics (next to first utility pole on north side of road). Park on right side of road. When you leave, continue west.
69.3 Junction with Hoag Road. Pavement begins. Proceed straight ahead.
71.1 Turn right (south) onto Blalock Canyon road. (Turn left to rejoin I-84.)
72.6 Pavement changes to gravel.
74.2 Bear left, continuing on Blalock Canyon Road.
75.9 Pass under power lines.
76.5 Exposure of the Alkali Canyon Formation.
76.8 Descent into Alkali Canyon, crest of small eddy bar on left.
77.0 Left at Y, join Alkali Canyon Road eastbound.
79.8 Junction with road to chemical waste dump on left.
80.7 Railroad crossing.
84.2 Junction with Oregon 19. Turn left (north) toward Arlington.
85.4 **Stop 1.6**, rhythmically bedded sand and silt. Park on left side of highway. Watch for traffic. When you leave, continue north on Oregon 19.
86.6 View of delta front from upland channels to the east.
87.5 **Stop 1.7**, delta from upland channels to east. (Just past junction with Eightmile Road.) Park in gravel area on right side of highway. When you leave, continue north on Oregon 19 toward Arlington.
89.3 Exposure of several rhythmites on left (east) side of highway.
90.3 Exposure on right side of road of two gravel units, capped by rhythmites.
91.2 Railroad crossing. Follow signs to I-84 westbound.
91.6 Enter I-84 westbound.
124.5 Exit I-84 at Biggs Junction (exit 104).
124.7 Stop sign. Turn left onto US 97.
124.8 Four-way stop. Turn right onto old US 30.
129.2 Turn left into Deschutes State Park camping area.

***End of Day 1.***
***To be continued in next issue***

# A home-constructed seismograph

*by John L. Rhudy, amateur seismologist, 35752 East Wills Road, Creswell, Oregon 97426*



*Author John L. Rhudy and his most recent seismograph.*

My interest in seismology developed while I was completing my first course in geology in 1947—by correspondence. Among the many fascinating events that I studied was the great Lisbon earthquake of November 19, 1756. Other outstanding seismic events that captivated my imagination were the San Francisco earthquake of 1906 and the great Kanto earthquake in Japan (near Tokyo) of 1923. As I continued to study historical and present-day earthquakes, I began to think what a wonderful experience it would be to build a seismograph. At the time, that was quite an ambitious idea, considering that I had never seen one!

Through the following years my interest was kept alive by going on field trips, taking geology classes, and building my geology library. In 1960, my wife and I purchased a house that had a full daylight basement and was heated by a sawdust furnace. This basement provided a dry environment and uniform temperature for my first attempt at building a seismograph.

Studying schematic drawings in my textbooks on geophysical prospecting and other geology texts that touched on the subject of seismology, I began to understand that most seismographs utilize a pendulum of some type. Some use a horizontal pendulum, others a vertical pendulum, and some a torsion pendulum. From the schematic drawings, it seemed to me that the Bosch-Omori-type mechanical seismograph (German-Japanese design) had the simplest elements to try and reproduce. So I decided to make my instrument as closely as possible after that general design.

The seismograph of the Bosch-Omori type uses a horizontal pendulum weighing 200 lb that is suspended by piano wire from a vertical mast. A pendulum this heavy requires a substantial base, so I started with a ¾-in. steel plate, 12 in. in width and 24 in. in length and equipped with three leveling screws. For a mast, I welded a 24-in. length of 2-in. channel iron to a triangular steel plate that was also provided with leveling screws. The pendulum was a ¾-in. steel bolt, 12 in. in length, with an 8-in.-diameter disc of steel for the center, lead discs slipped along the bolt on each side of the center steel disc, and the assembly suspended with the discs in horizontal position. A 1½-in. length of steel rod with a sharp point on one end was screwed to the steel center disc, with the point of the rod fitting into a small steel cup at the base of the mast. This provided a pivot for the pendulum.

A mechanical seismograph amplifies the ground motion by means of a lever system. We may illustrate this with an ordinary lead pencil. If we place a pivot in the center of the pencil and move one end back and forth around the pivot, it will be observed that both ends of the pencil travel the same distance. On the other hand, if the pivot is located near one end of the pencil, then, when the pencil is maneuvered in the same manner, it will be obvious that the long end travels a much greater distance than the short end. Another way of illustrating this phenomenon is by the "swinging door principle." When the door is opened and closed, the outer edge of the door moves a much greater distance than the edge where the hinge is located.

To my pendulum I fastened a 30-in. length of electrical conduit pipe, the "boom." After reducing the inside diameter of one end of the pipe to the proper size, I inserted a short length of 3/16-in. rod and fastened it in place with set screws. To the end of the rod I soldered a ¼-in. ball bearing. The ball bearing was made to fit into a slot on the short end of the arm that was to carry the recording pen, with contact screws on each side of the bearing. I placed a pivoting support for the pen arm within 1 in. of the ball bearing and made the other end of the arm with the pen attached about 8 in. long. For the pivot I used the balance wheel of an ordinary windup clock; and for the recording pen I used a modified hypodermic needle. With a short length of rod pivoted by the pendulum at the base of the mast I had amplified the pendulum motion many times.

Theoretically, when an earthquake occurs, the pendulum, because of its suspension, remains at rest, while the earth and the supporting apparatus move beneath it. However, if the ground motion continues long enough the pendulum will begin to swing. Consequently, a damping device is needed to restore the pendulum to the rest position as soon as the ground motion ceases. For a damper I attached a vane beneath the 30-in. boom. The vane moves in a laterally elongated cup that I filled with ordinary motor oil. I placed the assembly on a 16-in.-high concrete pier.

Now I had a seismo*meter*. The seismometer detects the earthquake, but without a recording component there would be no way of knowing that the earthquake had occurred. I had to have a seismo*graph*.

I fashioned two drums out of ordinary tin cans about 6 in. in diameter and mounted them on shafts of $\frac{3}{16}$-in. rod with bearings made from .22-caliber shell casings in proper supports. After aligning the drums and spacing them the proper distance apart, I placed a stainless steel table between them. The entire length of the 2-in.-wide paper tape on which I intended to record would be wound around the feeder drum. The end of the tape would be pulled across the table and attached to the drive drum with a small piece of masking tape. The table was designed so that it could be raised and lowered to adjust the pressure of the pen on the tape. To one end of the drive drum shaft I fastened a crank device made from the minute hand of an electric clock. The electric clock would rotate the drive drum as its minute hand came in contact with the crank I had mounted on the drive shaft.

To make my recording tape, I cut some tracing paper into 2-in.-wide strips and glued the ends together, until I had a strip of tape long enough to last twelve hours. As I glued the paper strips together, I marked the hours on the tape at intervals that I had determined experimentally.

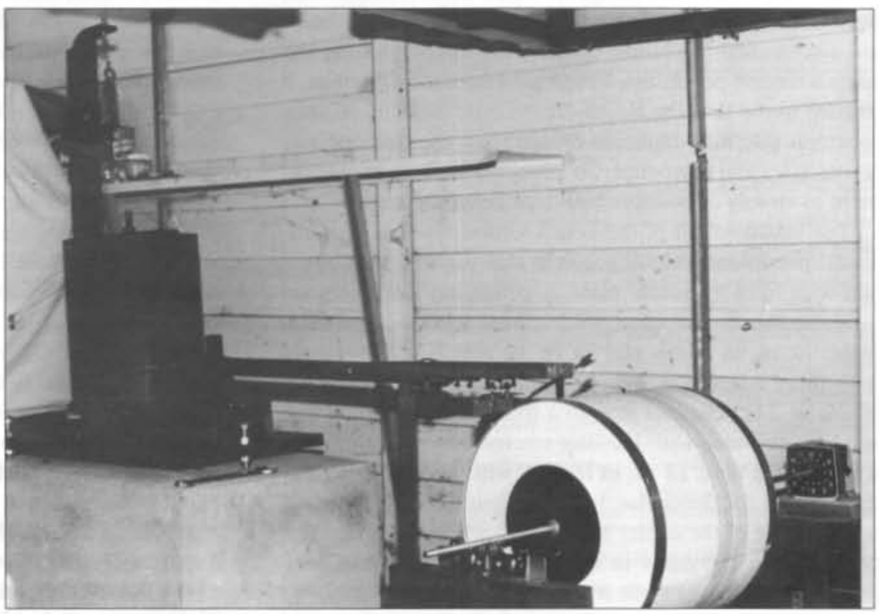
In 1963, my wife and I visited Lassen Park, California, where I was able to view a working seismograph for the first time. Two mechanical seismographs of Bosch-Omori type were operating in the visitor center, monitoring Mount Lassen and recording on smoked paper. No one was allowed in the vault where the instruments were set up, but they could be observed through a window. I was able to see enough to realize that although I was on the right track, important changes would have to be made in my own instrument.

I continued to use the instrument I had built in 1962 until 1967, when we bought property southeast of Creswell, Oregon. During the five-year period while we lived in Eugene, I recorded several earthquakes and was very happy with the results—but the Alaska quake of 1964 was something else! During this earthquake, my pen swung several inches off the recording tape on both sides. I knew then that the only practical way to record was on a rotating drum 10 in. or more in length. Another problem in trying to record on tape was the time element. As the tape built up on the drive drum, its speed increased, making the time inaccurate. The pendulum also was not a good design. It was not like the pendulum on the instruments I had observed at Lassen Park.

My instrument remained stored away for a number of years, while I searched for a suitable place to set it up again. I was looking for bedrock, because I was convinced that it is the ideal foundation for a seismograph. Unfortunately, we live on a glacial deposit. The first 16–18 in. of clayey soil down from the surface is filled with subangular rocks with glacial striae on them. I did not find the solid rock I was looking for.

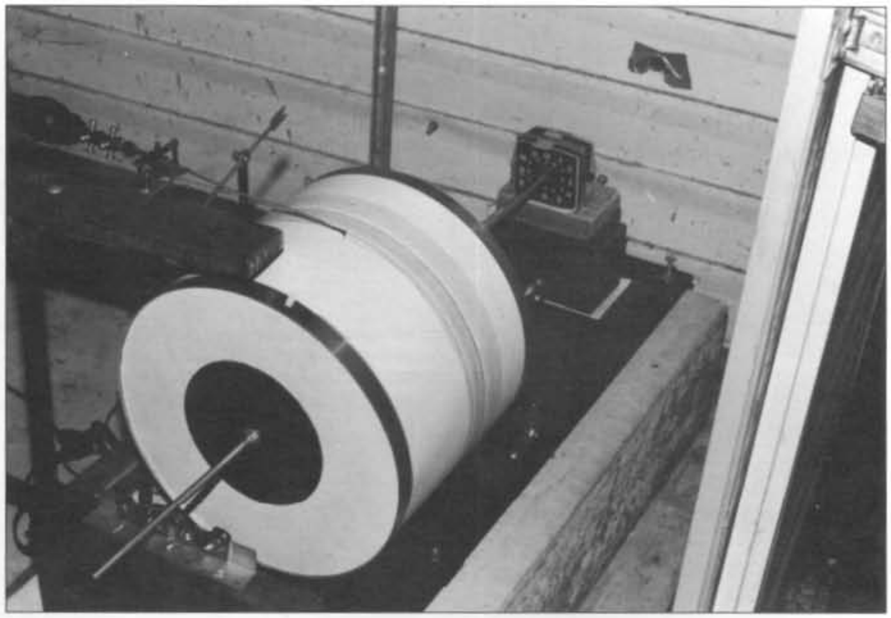
Seven years ago, I decided to remodel my instrument and set it up in the building that houses my water-pressure tank. This building had a concrete floor, which provided a fairly good foundation for my seismograph.

The two instruments I had observed operating at Lassen Park used a cylinder filled with lead discs for a pendulum. I purchased a pipe 12 in. long and 9 in. in diameter from a scrap dealer. To the bottom of the pipe I welded a 9-in. piece of 2-in.-wide flat steel with a $\frac{1}{2}$-in. hole drilled in the center. Another piece of flat steel of the same dimension and with the same hole in the center would be used on top



*Complete seismograph assembly.*

of the cylinder. A ½-in. machine bolt was inserted in the hole of the bottom steel strap and welded in place. Lead discs were cast with a ½-in. hole in the center and lowered down over the machine bolt to rest on the flat steel strap welded across the bottom of the cylinder. Finally, the steel strap for the top of the cylinder was put in place and tightened down to hold the lead discs firmly in place. When I added the boom and short pivot rod to the cylinder, I had a pendulum like the ones I had observed at Lassen Park. I used the same setup as before to suspend this pendulum.



*Closeup of recording section of seismograph.*

Next, I turned my attention to the problem of building a recording drum. I did not know how to build a drum, and I was sure the cost of purchasing one would be prohibitive. By this time I was retired. Retirement income does not leave much money to spend on hobbies.

At a local craft store I found two styrofoam discs, 12 in. in diameter and 1 in. thick. They appeared to be perfectly round, but I needed to find the center of the discs. So, with my compass I drew circles on four pieces of poster card (thin cardboard), cut them out, and glued one to each side of the styrofoam discs. I now had the center of the discs. It seemed that a ⁵⁄₁₆-in.-diameter shaft would be about the right size. In a hardware store I found a ⁵⁄₁₆-in. threaded rod, 36 in. long. After drilling a ⁵⁄₁₆-in. hole in each of the discs, I slipped them on the shaft, spacing them the distance that I wanted the length of my drum to be (10 in.), and then secured each disc with a nut and washer on each side. I purchased a piece of sheet aluminum 10 in. wide and 38 in. long. The dealer was kind enough to roll it for me, without charge, to cylinder with a 12-in. diameter. When I slipped the shaft with its styrofoam discs through the cylinder of rolled aluminum and taped the ends of the aluminum tightly together, I had a recording drum.

The next problem that puzzled me for some time was how to rotate the drum? I knew that in order for the clock to turn the drum, the drum would have to be rotated on knife-edge wheels so as to eliminate as much friction as possible. I did not have the faintest idea where one would get knife-edge wheels, except to have a machinist make them; and I was sure the expense of this would be outside a retirement budget.

One day, my wife and I were shopping in a Fred Meyer store, when I noticed some ordinary kitchen can openers on display in the household department. Instantly, I knew I had found my knife-edge wheels! I modified the frames of the four can openers I purchased and moved the wheels to the end of each frame. Then I mounted two of the frames to a piece of 1-in. aluminum angle, so that the wheels were opposed to each other, repeated this procedure on another piece of aluminum angle, and placed the pieces on each side of the frame I had built for the recording drum. The threaded shaft then rested on the knife-edge wheels, and the knife edge of each wheel ran in the threads of the shaft.

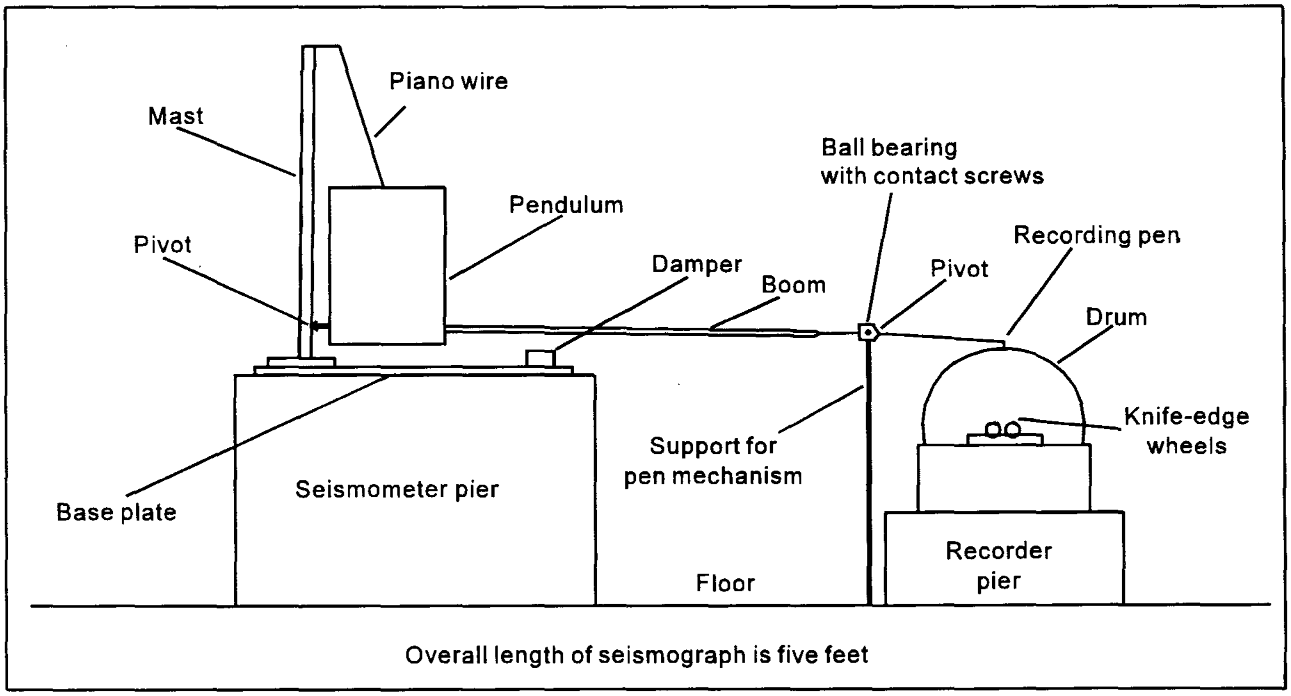
This arrangement not only held friction to a minimum but also provided the necessary "translation" of the drum (movement of the drum along its axis): With each revolution, the drum was moved sideways by the width of the shaft's thread, always providing clear paper for the trace of the recording pen.

A final problem was to connect the drum shaft to the minute hand of the clock. I fashioned a sleeve from a length of aluminum tubing with a slot running almost the entire length of the sleeve and a notch cut in the end of the sleeve to fit on each side of the minute hand of the clock. I inserted a small brass pin in the drum shaft near the end. When I slipped the sleeve onto the shaft, the pin followed the horizontal slot, allowing the drum to move as it was rotated by the clock. All of the recorder parts were mounted on a steel plate with leveling screws, and then the assembly was placed on a concrete pier about 8 in. in height.

I record on roll copy paper, 8½ in. in width. I now use a pen like the ones used on recording barometers. The pen made from the hypodermic needle clogged too easily. I use standard recorder ink, and my instrument operates 24 hours a day, 7 days a week.

Having constructed another drum like the first one, I now have a replacement drum ready when space runs out on the one in operation. I change drums every three days.

I have amplified the pendulum's movements more than




*Schematic representation of seismograph built by John Rhudy.*

200 times. With such relatively low amplification, my seismograph would be classified as a strong-motion instrument. However, I am pleased with the results. Of the numerous earthquakes my seismograph registered, I want to mention only a few that gave me particular satisfaction:

I recorded the Landers, California, earthquake on June 28, 1992, which had a magnitude of 7.5. This earthquake occurred 800 mi from my location. Several quakes from the Gorda Ridge area off the coast of California were recorded as well. At least two earthquakes were recorded from the Eureka, California, area. I obtained a beautiful record of the earthquake at Scotts Mills, Oregon, on March 25, 1993, with a magnitude of 5.4 to 5.7. I recorded both sister shocks and one strong aftershock of the earthquake at Klamath Falls, Oregon, on September 17, 1993, and another aftershock on December 4, 1993, with a magnitude of 5.2. I was even fortunate enough to watch the instrument in operation while receiving one of the strong sister shocks from the Klamath Falls earthquakes on September 17, 1993.

I have encountered some problems involved with keeping the instrument in continuous operation. Heavy rains will cause the pen to drift, probably due to saturation of the subsoil beneath the seismometer pier. Evidently, this causes the mast to tilt, which results in a slight swing of the pendulum. I believe this problem can be corrected with better drainage. The seismometer is extremely sensitive to the temperature differential between day and night, particularly during the summer months. When these deviations occur, the pendulum must be readjusted. I accomplish this maneuver with one of the leveling screws on the mast base.

I have other hobbies but none quite as satisfying as amateur seismology. □

## Museum guide available in new edition

The *Pocket Guide to Oregon Museums* has been published in a new edition accurate as of April 1995. It lists more than 130 museums all over the state. The list is alphabetical by city, and the cities are keyed to a map.

The brochures are available at the Nature of the Northwest Information Center and the DOGAMI field offices.

## Amateur paleontologists invited

The Northwest Museum of Natural History Association will be conducting investigations of fossil vertebrate mammal faunas in Baker and Malheur Counties this coming month, August 3–23. The investigations will be led by Dr. David Taylor. People interested in paleontological work are invited to participate. Information about details of the program are available from the Museum office at (503) 725-5900 or Dr. Taylor at (503) 297-7415.

## PSU honors geology educator Allen

John Eliot Allen, professor emeritus of geology at Portland State University, received a Presidential Citation from PSU President Judith A. Ramaley at the university's spring commencement. He was honored for his "outstanding service and dedication" to the university.

*(Continued on page 94, Allen)*

# Outstanding reclamation by mine operators recognized

The Mined Land Reclamation (MLR) program of the Oregon Department of Geology and Mineral Industries presented reclamation awards at the annual meeting of the Oregon Concrete and Aggregate Producers Association (OCAPA) on May 20 in Seaside.

By law, most Oregon mines must be reclaimed to a second beneficial use after mining. During mining, they must be operated in such a way that they comply with the requirements of their permits. Each year, the MLR program of the Oregon Department of Geology and Mineral Industries recognizes operators that perform outstanding reclamation, sometimes voluntarily and beyond the requirements of their permits, sometimes through innovative approaches to reclamation.

The awards selection committee consisted of Dorian Kuper, David Newton Associates, Portland; Bill Levens, LTM (Lininger Tru-Mix), Medford; David Haight, Oregon Department of Fish and Wildlife, Central Point; Diane Stone, Linn County Planning Department, Albany; and Cole Gardiner, Oregon Trout, Portland.

Categories of awards and winners are as follows:

**Outstanding Operator Award—Ellendale quarries, Valley Concrete and Gravel Company, Inc.**: Another owner began mining this site, which consists of two quarries, in 1956. When Valley Concrete assumed ownership of the quarries in 1993, the site was in disarray. The new owners, however, rapidly solved existing problems, such as runoff of waste water into nearby Ellendale Creek and an accumulation of oversize rock produced by poor blasting practices. Valley Concrete quickly broke down the oversize material, reshaped the floor of the upper quarry to improve drainage, redirected storm water so none of it flows into Ellendale Creek, and improved blasting techniques so that neighbors no longer complain of noise or vibration.

**Outstanding Reclamation Award—Oil-Dri Production Company**: Oil-Dri changed its mining plan approximately three years ago so that mined land is now reclaimed while mining is still occurring elsewhere in the operation. Topsoil and overburden are hauled directly to areas where mining has been completed, which reduces the amount of disturbed soil at the site, increases species diversity by using residual seed already in the soil, and saves money and time otherwise spent in double handling of the material. Oil-Dri has chosen to revegetate the site with a mix of native seeds costing $80/acre, whereas revegetation is normally done with crested wheatgrass seed that costs only $12/acre. The company also changed the original design of a waste-water pond so that it now has islands and an irregular shoreline to attract waterfowl. Finally, Oil-Dri has given the U.S. Bureau of Land Management a $17,500 grant to analyze and salvage nearby archeological sites.

**Good Neighbor Award—Farmington quarry of Baker Rock**: This hard-rock quarry has been in operation since 1956. When it originally began operating, few houses were nearby, but as the quarry is near Beaverton, residential housing has gradually spread up to the permit boundary. To minimize the effect of mining on their new neighbors, Baker Rock now meets with all people thinking of buying property adjacent to the Farmington quarry, showing them the quarry and explaining the operation. The company also negotiates and pays for a noise and dust easement for new houses in the area. This "good neighbor policy" has minimized fears and concerns of neighbors and has given potential property buyers the information they need to make informed decisions about their home purchases.

**Outstanding Reclamation by a Government Agency—Yaquina Head, lower quarry, Salem District of the Bureau of Land Management (BLM)**: In 1980, BLM was given responsibility of reclaiming two large rock quarries located at the Yaquina Head Outstanding Natural Area located 3 mi north of Newport. The seawall keeping the ocean

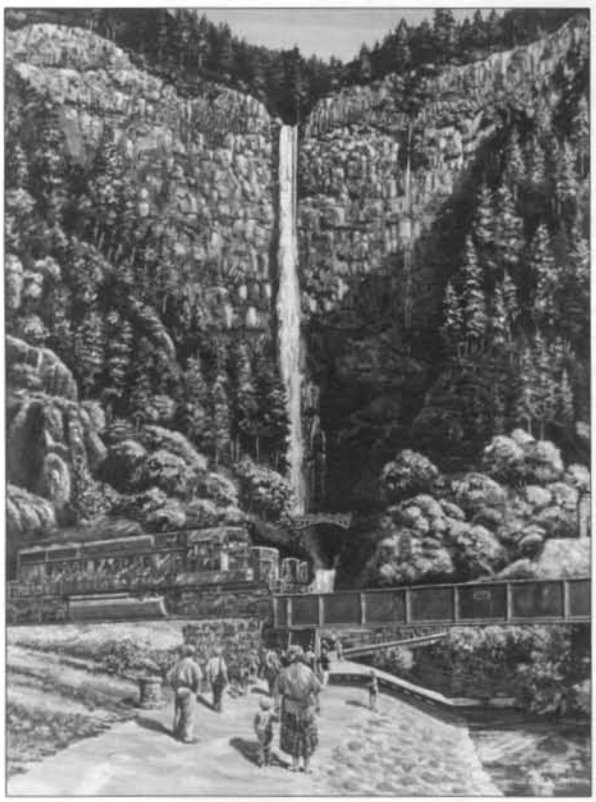
*Quarry Cove tide pools, the outstanding reclamation project of the U.S. Bureau of Land Management at Yaquina Head, on opening day, Sept. 23, 1994.*

out of the lower quarry was gradually removed, and the abandoned quarry was converted to a rocky intertidal area with tide pools, rock outcrops, and surge channels. A gently sloping pathway now allows visitors, including those with mobility impairments, to pass through the intertidal area. The upper quarry was converted into a parking area. A rich community of organisms characteristic of the Pacific Northwest is rapidly developing in the lower quarry, which saw almost 20,000 visitors by Nov. 1, 1994.

**Exploration Award—Jessie Page quarry, MK Gold Company**: This site, which is in a relatively remote location 45 mi southwest of Vale and west of the Owyhee Reservoir, has been successfully reclaimed to the pre-exploration topography. Revegetation has been accomplished, and reshaping of the topography has been done in a manner that prevents erosion by rain and snow. Over time, slight differences between the vegetation on the reclaimed roads and surrounding rangeland will disappear. □

## Columbia Gorge art to be on display

Mike Kelly, technical illustrator and artist from Portland, will exhibit paintings and drawings of the Columbia Gorge starting August 5 at the Indian Heaven Art Gallery, 280 SW Second Street, Stevenson, Washington. Kelly, who is an avid outdoorsman with a serious interest in geology, focuses on geologic details as he produces his drawings and paintings. His work as technical illustrator with Portland geotechnical firms has provided him with the foundation, interpretive skills, and patience necessary for his brand of representational art.



*Multnomah Falls, by Mike Kelly*

Kelly's artwork will be on display through September 5. Hours at the Indian Heaven Art Gallery are from 10:30 a.m. to 5:30 p.m., Monday through Saturday, and from noon until 4:00 p.m. on Sunday. The gallery's phone number is (509) 427-7754. □

# DOGAMI PUBLICATIONS

## Relative earthquake hazards now mapped for Mount Tabor quadrangle

The Oregon Department of Geology and Mineral Industries (DOGAMI) has released *Relative Earthquake Hazard Map of the Mount Tabor Quadrangle, Multnomah County, Oregon, and Clark County, Washington*. This map is now available as DOGAMI map GMS-89 for the price of $10.

The new publication is the first full-color earthquake hazard map of the Portland metropolitan area that combines four maps on one sheet: A large-scale map (1:24,000, map size approximately 16×23 in.) depicts the relative earthquake hazard in a manner that assists nongeologic and nonengineering users in working more effectively toward reducing the risk to life and property through planning policy and mitigation measures. Three smaller maps (1:55,000, map size approximately 7×10 in.) depict the single hazards of ground motion amplification, liquefaction, and slope instability that were combined in developing the larger, composite hazard map. The single-hazard maps assist users in identifying the specific sources of hazards at a given site.

The Mount Tabor quadrangle covers an area bounded, roughly, on the west by 37th Avenue, on the north by Mill Plain Boulevard in Vancouver, Clark County, Washington, on the east by 155th Avenue (SE Fisher Road in Clark County), and on the south by SE Division Street. It is situated adjacent to the eastern edge of the Portland quadrangle, for which similar maps were published earlier: the composite relative hazard map by Metro/DOGAMI and the single-hazard maps by DOGAMI (GMS-79). DOGAMI map GMS-79 also includes a text that explains in technical detail how the various maps were developed.

The new map is now available over the counter, by mail, FAX, or phone from the Nature of the Northwest Information Center, Suite 177, State Office Building, 800 NE Oregon Street #5, Portland, Oregon 97232-2109, phone (503) 872-2750, FAX (503) 731-4066; and the DOGAMI field offices: 1831 First Street, Baker City, OR 97814, phone (503) 523-3133, FAX (503) 523-9088; and 5375 Monument Drive, Grants Pass, OR 97526, phone (503) 476-2496, FAX (503) 474-3158. Orders may be charged to Visa or Mastercard. Orders under $50 require prepayment except for credit-card orders. □

# The Diamond Lake fireball of March 28, 1994

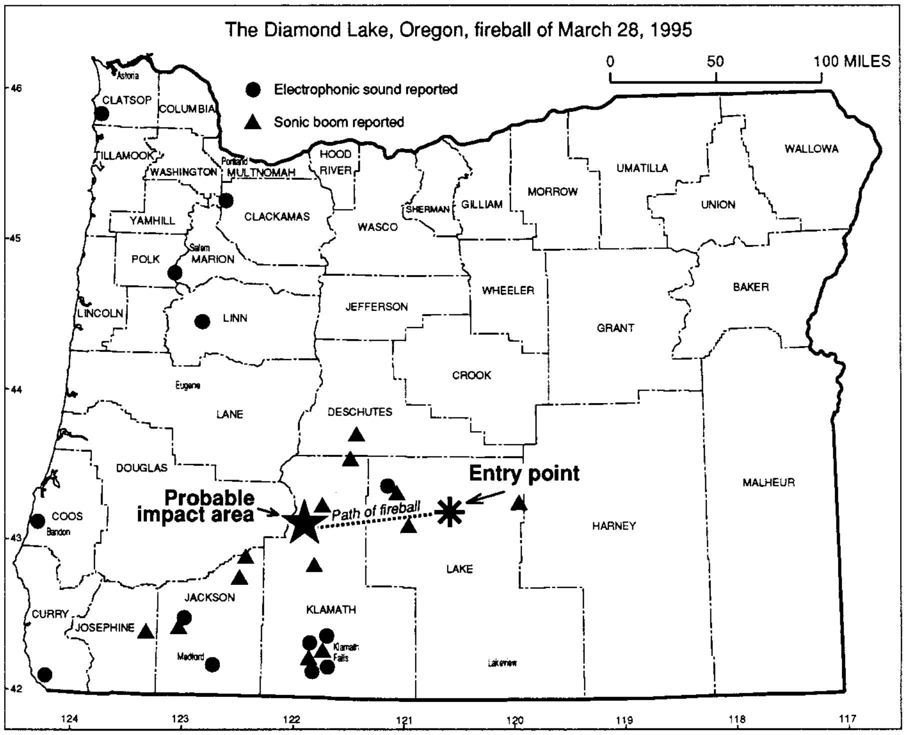
*by Richard N. Pugh, Science Department, Cleveland High School, Portland, Oregon 97202*

The following report is the result of interviews with more than 150 people who saw, heard, or felt the event.

The fireball occurred at 9:16 p.m. PST, March 28, 1994. It was seen from Goldendale, Washington, lat 45°49′N., long 120°49′W., in the north to Reno, Nevada, lat 39°32′N., long 119°49′W. in the south and from Wagontire, Oregon, lat 43°15′N., long 119°52′W., in the east to Bandon, lat 43°07′N., long 124°24′W., in the west.

The fireball entered the atmosphere just south of Bunchgrass Butte, lat 43°23′N., long 120°34′W., 5 mi east of Christmas Valley, Lake County, Oregon. The end point of the fireball was 5 mi east of the north end of Diamond Lake, near Mount Thielsen, lat 43°09′N., long 122°04′W., in Douglas County, Oregon.

The angle of descent was about 30°, steepening to near-vertical when the fireball extinguished.




*Map showing locations of fireball event and reported sounds.*

The duration of the fireball was 5–6 seconds. Most people reported a fireball from one to five times the diameter of a full moon. The brightness was reported as brighter than a full moon to too bright to look at, the shape as round to teardrop with a long tail. As the fireball slowed down in the atmosphere, the color changed from blue-white to green to yellow ending with orange and red just before it exploded. The tail was mostly yellow-white. Sparks and flames were seen in the tail, which appeared to be twisted.

The fireball exploded up to three times near the end of its path, producing at least twenty fragments. There were several reports of "black objects" that came out of the last flash. Sonic booms were heard from Arrow Gap (near North Lake School/Silver Lake) and Hole-in-the-Ground in Lake County to Prospect and Union Creek in Jackson County. Some of the booms were so heavy that they shook houses. There were many reports of electrophonic sound (sound heard at the same time the fireball was seen). These sounds were reported as popping, snapping, squealing, swishing, crackling, and whirring sounds. In most cases, the people who heard these sounds were standing near a truck, wire fence, or other metal object. Three people reported the hair on the back of the neck stood up, while one person reported she felt pressure on her body. There was one report of a radar detector in an automobile that was set off by the fireball. There were several reports of birds that stopped singing, coyotes that stopped howling, and dogs and cats running into their houses.

It is interesting to note that sonic booms were heard at a maximum distance of 165 km away, whereas electronic sound was heard as far as 385 km away. This is a very long distance for electrophonic sound to be detected.

Electrophonic sound is produced at high altitude in the turbulence behind the fireball. Very low frequency (VLF) electromagnetic energy excites sounds in nearby objects, producing acoustic waves (Keay, 1980; Keay and Ceplecha, 1994).

It is believed that this fireball produced meteorites in the area northeast of Diamond Lake. The meteorites would be black or brown stony objects, ranging in size from marbles to basketballs and with a thin black fusion coating.

## REFERENCES CITED

Keay, C.S., 1980, Anomalous sounds from the entry of meteor fireballs: Science, v. 210 (October 3, 1980), p. 11–15.

Keay, C.S., and Ceplecha, Z., 1994, Rate of observation of electrophonic meteor fireballs: Journal of Geophysical Research, v. 99, no. E6, p. 13163–13165. □

## In memoriam: Carol Brookhyser

Carol S. Brookhyser, retired staff member of the Oregon Department of Geology and Mineral Industries (DOGAMI), died June 21 at age 74.

She worked with DOGAMI as an editor and librarian from 1971 through 1976. Her many contributions to the Department's efforts in communicating geology to the citizens of Oregon are still well remembered by those who worked with her. In 1973, she participated in the compilation of DOGAMI Bulletin 78, a major bibliography of the geology and mineral resources of Oregon.

Mrs. Brookhyser was born October 25, 1920, in Timber Lake, South Dakota as Carol Schlonga. She married Robert Brookhyser on June 22, 1947.

Survivors are her son Donald of Las Vegas, her daughter Ann Eichelberg of Portland, her brother Richard Schlonga of Vancouver, Washington, her sister Charlotte Rivell of Ormond Beach, Florida, and five grandchildren.

Donations in her memory may be given to the Habitat for Humanity, Planned Parenthood, or the Resurrection Lutheran Church Memorial Fund. □

## NESTA offers tools and opportunities for teachers

The National Earth Science Teachers Association (NESTA) was chartered in April 1982 to promote, extend, and support earth science education and offers membership to anyone interested in earth science education. NESTA is divided into ten regions and elects a Regional Director for each region. For the Pacific Northwest, a new Regional Director will be elected during May 1995. Each state also has a State Contact Person who is responsible for promoting earth science at science teacher meetings and for maintaining contact among the state's NESTA members. Oregon's State Contact Person is Michael Goodrich, who teaches earth sciences at Lake Oswego High School. His address is 42 Churchill Downs, Lake Oswego, OR 97035, phone (503) 635-5123, and internet msgneiss@aol.com.

NESTA conducts a membership meeting as well as a Board of Directors meeting each year at the NSTA national convention. NESTA coordinates Share-a-thons at all NSTA meetings. NESTA members demonstrate of their favorite activities at Share-a-thons. One of the most popular sessions at the conventions, Share-a-thons draw a large number of the convention attendees. A second NESTA session at NSTA meetings is the Rock Swap and Coffee Social Hour. NESTA members and other supporters donate quality rock and mineral specimens which are raffled off during the session. NESTA Rock Swap attendees at the 1995 NSTA Philadelphia meeting took home over 100 specimens along with several boxes of free samples.

NESTA's publication, *The Earth Scientist*, is published four times a year with a special "Summer School Opportunities for Teachers" issue. Each issue of *The Earth Scientist* contains a topical theme along with association news, reviews, and teaching tips. The summer school issue is a compilation of a geoscience department survey reporting summer school opportunities. In addition to journal publications, NESTA markets scripted slide sets that have been developed by NESTA members. The slides sets range in size from 10 to 30 slides and include a number of subjects of interest to the earth science teacher.

NESTA sponsors summer field trips coordinated by NESTA members. Past trips have traveled to the Southwest, Great Lakes, Yellowstone, and the Grand Canyon among other locations. Trip guidebooks, special tours, and college credit are available, and families are encouraged to attend when appropriate. New field trip locations are being sought. For information on how to develop a NESTA field trip, contact NESTA's Executive Advisor (address below). NESTA is currently developing a National Summer Field Conference series that will be inaugurated during the summer of 1996. The summer field conference will encourage family participation in a week-long summer vacation excursion. The conference will include sessions with contributed papers, speakers, field trips, family-oriented activities, and exhibits.

For further information about NESTA contact: Dr. M. Frank Watt Ireton, NESTA Executive Advisor, 2000 Florida Avenue NW, Washington, DC 20009, phone (202)-462-6910 ext. 243, internet fireton@kosmos.agu.org. □

*(**Allen**, continued from page 90)*

Allen began his professional career in 1935 as a park ranger/naturalist at Crater Lake National Park. He was part of the beginnings of the Oregon Department of Geology and Mineral Industries and served on its staff for nearly a decade. He also guided the early steps of the PSU geology department, serving as its head for 18 years. In 1972, the National Association of Geology Teachers honored him for his teaching with the Neil Miner Award.

Since retiring 22 years ago, he has concentrated his writing about geology on the lay reader. He authored or coauthored books about the Columbia Gorge (*The Magnificent Gateway*, 1979; and *Cataclysms on the Columbia*, 1986)* —an area he had studied first for his master's degree in 1932. In the 1980s he wrote more than 200 articles on Northwest geology for *The Oregonian* in a weekly column called "Time Travel." He has authored and contributed to numerous DOGAMI publications and is still an ardent contributor to *Oregon Geology*.

We are glad to see John Eliot Allen honored in this way and congratulate him sincerely.

*Allen, J.E., 1979, The magnificent gateway. A layman's guide to the geology of the Columbia River Gorge: Forest Grove, Oreg., Timber Press, 144 p.

Allen, J.E., Burns, M., and Sargent, S.C., 1986, Cataclysms on the Columbia. A layman's guide to the features produced by the catastrophic Bretz floods in the Pacific Northwest: Portland, Oreg., Timber Press, 211 p. □

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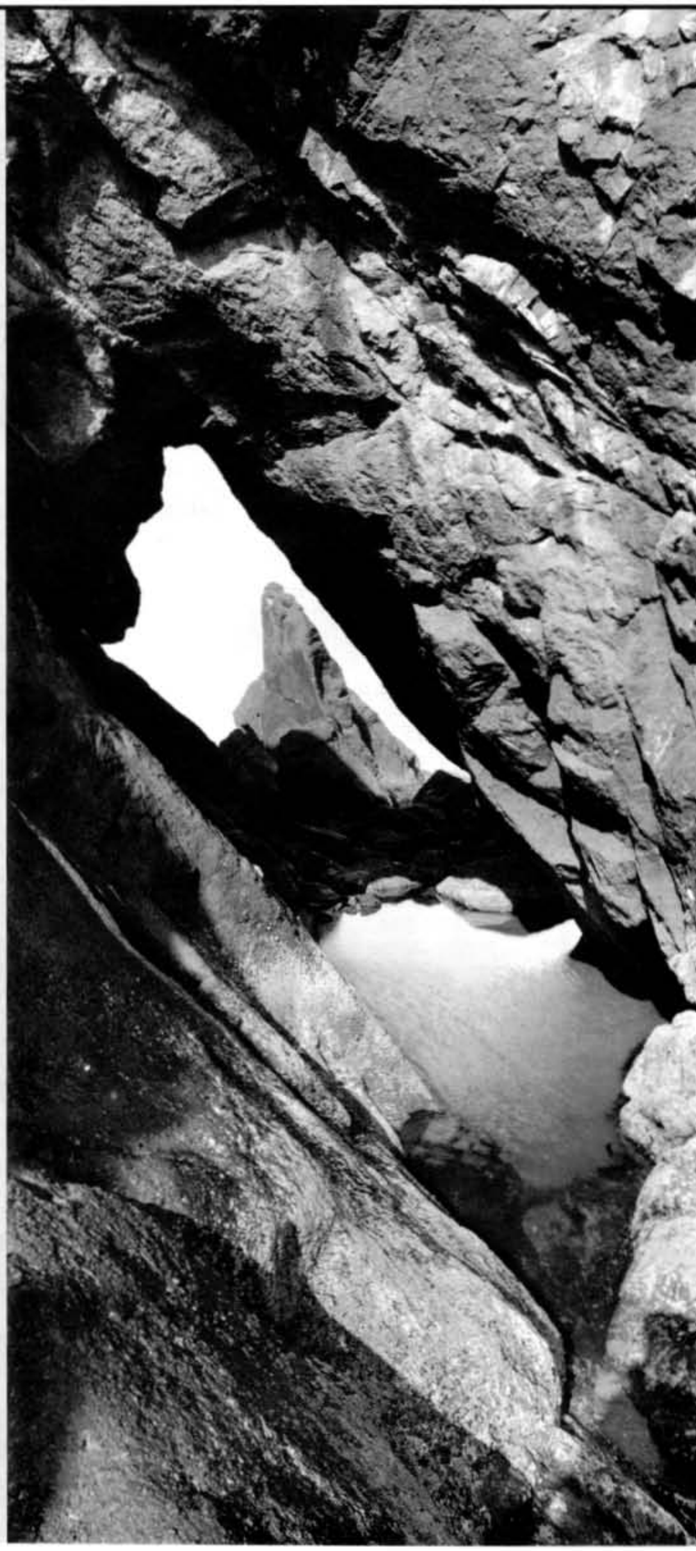

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J.E. ALLEN
ON
EQUILIBRIUM PUNCTUATIONS

# OREGON GEOLOGY

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## Cover photo

This photograph, entitled "Archway and basalt headland, Lincoln County, taken in 1993," is one of the photos by Terry Toedtemeier to be exhibited in his show "Basalt Exposures" that opens September 24 at Marylhurst College. See related announcement in the right column on this page. Photo courtesy Terry Toedtemeier, copyright 1995.

## Governing Board invites participation in the planning for DOGAMI's future

At its July 17, 1995, meeting in Portland, the Governing Board of the Oregon Department of Geology and Mineral Industries (DOGAMI) took its first step in mapping out DOGAMI's mission and goals for the five-year period starting in 1997. The Board announced that it was beginning the planning process, which is expected to take almost a year. Input from the public, other agencies, and industry is invited during that time.

Following its July meeting, the Board met with DOGAMI staff members to review their suggestions for DOGAMI's mission and goals. The next step will be a strategic planning session to be held on Sunday afternoon, September 24, 2:00 p.m. to 6:00 p.m., at the Newport Shilo Inn, 536 SW Elizabeth Street, Conference Room Pacific I, in Newport, OR 97365-5098. Anyone in that area who would like to discuss with the Board DOGAMI's future activities is invited to attend or submit suggestions in writing. The Board will be meeting in other parts of the state during the planning process. The public will be invited to take part in those meetings and to offer suggestions that can be used by the Board.

We in DOGAMI know that our activities affect many aspects of life in Oregon. We hope those of you who have opinions on how we can best serve Oregonians will share their ideas with the Board during this planning process. If you wish to send your written suggestions or ideas, please address them to Angie Karel, Oregon Department of Geology and Mineral Industries, 800 NE Oregon Street #28, Portland, OR 97232-2162. □

## Terry Toedtemeier to exhibit basalt photographs at Marylhurst

Terry Toedtemeier, curator of photography at the Portland Art Museum, will exhibit 80 photographs in a show entitled "Basalt Exposures" at Marylhurst College this fall. Toedtemeier, who has a degree in geology, has long been fascinated by the shapes basalt takes in the varied climates of the Pacific Northwest. The black-and-white photographs on display have been taken over the past 15 years as he has toured the area, observing the landforms produced by the erosion-resistant basalt.

According to Toedtemeier, "From the monumental flows of the Columbia Plateau to the Hawaiian-style volcanic rocks of the High Lava and Snake River Plains, this region abounds with a remarkable range of basalt exposures. The photographs reproduced in this show were made in response to the diversity of basalt structures and settings I have found in my travels throughout the region."

The photographs will be on display between noon and 4:00 p.m. on Tuesdays through Saturdays from September 24 through December 9 at the Art Gym on the third floor of the B.P. John Administration Building, Marylhurst College. The college is located 20 minutes south of Portland on Highway 43, just between Lake Oswego and West Linn. The opening reception, which will be held at the Art Gym from 3:00 p.m. to 5:p.m. on Sunday, September 24, is also open to the public. □

## 1995 NWMA convention announced

What is billed as "The western United States' premier international convention and exposition" has been announced by the Northwest Mining Association (NWMA) for December 5 through 8, 1995, in Spokane, Washington, with pre-convention short courses on December 4 and 5. Registration forms and information are available from NWMA, 10 N. Post, Suite 414, Spokane, WA 99201-0772, phone (509) 624-1158, FAX (509) 623-1241. □

# Beyond the Channeled Scabland

## A field trip to Missoula flood features in the Columbia, Yakima, and Walla Walla valleys of Washington and Oregon—Part 3: Field trip, Days two and three

*by James E. O'Connor* and Richard B. Waitt, U.S. Geological Survey, David A. Johnston Cascades Volcano Observatory, 5400 MacArthur Blvd., Vancouver, Washington 98661. With contributions by Gerardo Benito, Centro de Ciencias Medioambientales, Serrano, 115 dpdo, Madrid, Spain 28006; and David Cordero and Scott Burns, Department of Geology, Portland State University, P.O. Box 751, Portland, Oregon 97207*

*A preliminary version of this field trip guide was prepared for the first annual field conference of the Friends of the Pleistocene, Pacific Northwest Cell, May 13–15, 1994. Parts 1 and 2 of the guide appeared in the May and July 1995 issues of this magazine. This concludes the three-day field trip. References in the text refer to the list of references printed at the end of Part 1 in the May issue, p. 58–60. —ed.*

### DAY TWO

Day 2 entails driving east 100 mi (160 km) up Columbia River valley into Washington. After passing through Wallula Gap, the trip proceeds into Pasco basin and east up tributary Walla Walla valley, then back west across Pasco basin and up tributary Yakima valley. In these valleys are examined sections of rhythmites deposited by flood waters that backflooded from Pasco basin into these large side valleys. The trip returns to Deschutes State Park via Satus Pass on Highway 97. Much of Day 2 has been described and discussed in Waitt (1980a, 1985b, 1987) and O'Connor and Baker (1992), but new data and arguments will also be had.

Maps: The Dalles, Pendleton, Walla Walla, and Yakima 1°×2° sheets; Hermiston, Pendleton, Walla Walla, Richland, and Toppenish 1:100,000 sheets.

### En route to Stop 2.1

Drive the frontage road to Biggs Junction and enter Interstate 84 eastbound. Follow Interstate 84 east, and then Highway 730 to Wallula Junction near the confluence of Walla Walla River with the Columbia. En route we pass through the Umatilla basin, where floodwaters covered a swath as wide as 50 km and an area of about 3,500 $km^2$. As discussed in Day 1, between John Day River and just downstream of Wallula Gap, the maximum stage evidence defines a water-surface profile that was nearly flat at an altitude of about 335 m (1,100 ft) for this entire reach of the flood route.

About 43 mi from Biggs Junction, we cross over Willow Creek. In June 1903, a flash flood in a tributary of Willow Creek thundered into the mill town of Heppner, about 50 km upstream, killing 230 people. This has been the most lethal flood ever in the Columbia basin.

Just before crossing the Oregon-Washington border, the basalt cliffs flanking the river become higher as we proceed towards the center of the Horse Heaven Hills anticline. Wallula Gap, a 1,200- to 1,500-m-wide chasm cut through the fold, was a fundamental constriction along the flood route, separating the vast upstream ponded area of the Pasco basin, in earlier times termed "Lake Lewis," from that of the Umatilla basin downstream.

Upon passing through Wallula Gap we enter the vast Pasco basin, where the trunk Columbia River receives three major tributaries: Yakima River from the west and Snake and Walla Walla Rivers from the east. Of these the Snake was one of the major inflow conduits for Missoula flood to Pasco basin, whereas Walla Walla and Yakima were dead ends as flood routes. As immense floodwater hydraulically ponded behind Wallula Gap and Columbia Gorge downriver, it backflooded 240 m (800 ft) deep and more up the Walla Walla and Yakima (Figure 15).

Important to the setting of rhythmic beds upvalley in both Walla Walla and lower Yakima valleys is the fact that a sharp narrows constricted invading floodwaters. Three specified drive-by views (not actual stops) will point out coarse deposits of floods emerging from these narrows into the broad valley above. The geomorphic setting and features of the Yakima valley narrows is rather more spectacular than those of Walla Walla valley.

### Stop 2.1. Narrows of Walla Walla valley

U.S. Highway 12 in lower Walla Walla valley allows a view of the setting of backfloods. Unlike slopes surrounding most of Pasco basin, the narrows of Walla Walla and Yakima valleys are washed clean of regolith. The narrowing, rinsed-off valley sides carved in basalt were the intake for floods that, rising in Pasco basin, backflooded Walla Walla valley. The valley narrows acted as a valve, limiting and regulating the rate at which water could backfill the valley. The nozzlelike geometry also imparted particularly swift currents through the narrows (Figure 15) and just upvalley. The highway avoids the curving course of the canyon, but closer views can be had by the "alternate" return route from Stop 2.3.

Rhythmic flood-slackwater sand-silt beds lying on the floor of the intake to the valley narrows and also immediately downcurrent may seem rather incongruous. The internal stratigraphy of these low-altitude beds is scarcely studied, and so exactly how they correlate to beds at Stops 2.2 and 2.3 is uncertain, but at least part of the answer probably lies in the beds at Stop 2.3.

### En route to Stop 2.2

After descending the basalt spur into Walla Walla valley, on the right in the distance along Walla Walla River can be seen a long and tall exposure of rhythmites including coarse gravelly beds. Here the flood currents, after shooting through the valley nozzle, backflooded into the broad valley and dramatically slackened. The eddy and backflood environments were highly important to preserving durable records of floods of all sizes.

**Eddy and backflood environment:** The main scabland floodways with their great abandoned cataracts, plucked rock basins, and other features are evidence of erosional stream power almost without parallel on Earth. Yet even within these great floodways, currents were somewhat slower in places, allowing coarse debris to accumulate as bouldery bars. These features may be spectacular evidence of huge discharges, but exceedingly high-energy reaches are poor places to expect a continuous sequence of events, for one colossal flood tends to erase evidence of previous ones.

The sediment-charged floodwaters also circulated into hundreds of topographic dead-end tributary valleys like Walla Walla (Figure 15), water driven into the valleys by the deep torrent along the main channel. In each of these dead-end areas, currents in the transitory hydraulic pond had generally far less velocity than the main-channel torrents. Here a waxing and waning sediment-charged flood could deposit almost continuously—and with far less erosion than the high-energy sites in adjacent main channels. A few valleys like the Walla Walla are further influenced by a

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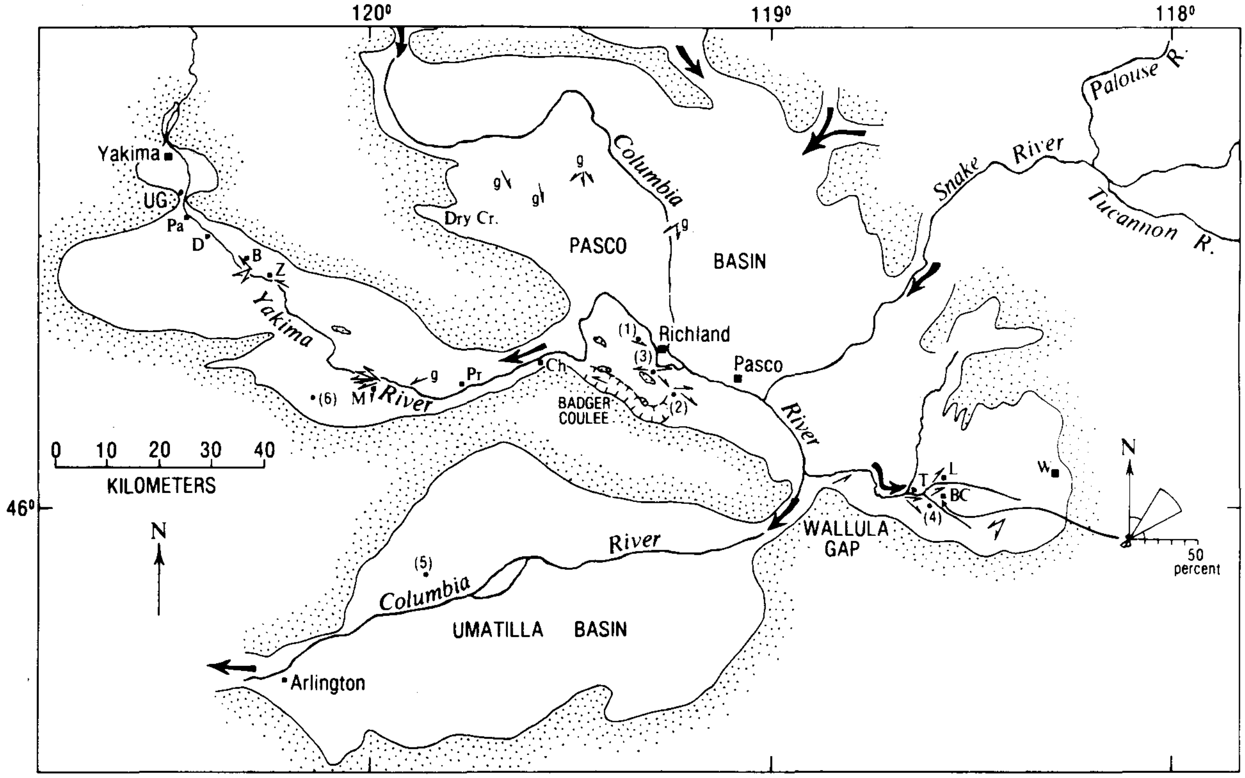


*Figure 15. Map of Pasco basin and vicinity, showing area innundated by lake hydraulically ponded to altitude 350 m (1,150 ft). Largest hydraulic lake surface was about at altitude 366 m. Heavy arrows indicate main inflow conduits for Missoula floodwater, the outflow through Wallula Gap, and narrows of large backflooded tributary valleys. Rose diagram (90 measurements at Burlingame canyon) and lighter arrows depict paleocurrent indicators from slackwater sand and silt, or in foreset tractive gravel (g). (1) through (6) are localities of vertebrates within Missoula-flood slackwater facies. B=Buena, BC=Burlingame canyon, Ch=Chandler, D=Donald, L=Lowden, M=Mabton, Pa=Parker, Pr=Prosser, T=Touchet, UG=Union Gap, W=Walla Walla, Z=Zillah. From Waitt, 1980a, Figure 2.*

bottleneck above which the valley broadens out five- to twenty-fold. Invading such a valley through the narrows, currents may be swift; but above the nozzle the sediment of a flood can accumulate with little or no disturbance by that flood—or for that matter by later floods of like or larger magnitude.

Bedded sand and silt characterize every backflooded dead-end valley of the flooded system. In Walla Walla valley between Touchet and the city of Walla Walla, several outlier mounds can be seen, some sectioned by road cuts or by Walla Walla River. The thickest, coarsest, most distinctly bedded, and generally best exposed tend to lie in downvalley reaches and at low altitudes. But in every valley studied, including the Walla Walla, they also lap up onto valley sides and gain altitude upvalley along the floor, mantling preflood deposits and topography.

**Stop 2.2. Burlingame "canyon"**
(Please see Waitt, 1980a, 1985b)

Burlingame "canyon" (informal name) is off South Lowden Road, 200 yards south of an irrigation ditch.

***Canyon has steep, unprotected, collapsible walls: Heads up!!***

This is private property of the Gardena Irrigation District. Please do not enter without obtaining permission and before signing a written, notarized "hold harmless" agreement. (Please see Ditchmaster at house near irrigation ditch).

Rhythmically bedded deposits in southern Washington have been variously attributed to (1) fluctuations within ordinary lacustrine and fluvial environments (Flint,1938; Lupher, 1944); (2) fluctuating currents within a transient lake during only one or a few great floods (Bretz and others, 1956; Baker, 1973; Mullineaux and others, 1978; Bjornstad, 1980); and (3) several dozen floods, each of which deposited one graded bed (Waitt, 1980a, 1984, 1985b). By the last hypothesis, floodwater backed up dead-end valleys off the main scabland floodways to form transient ponds in which suspended load settled. Because the side valleys were protected from violent currents, flood-laid strata were not eroded by later floods but became buried and preserved.

Burlingame "canyon," 30 m deep and 500 m long, was mostly cut in 6 days in March 1926, when the 2.3-$m^3$/s flow of the nearby irrigation ditch was crowded by severe wind into a diversion ditch. The canyon exposes one of southern Washington's most complete and accessible stratigraphic sections of slackwater deposits of the late Wisconsin floods from glacial Lake Missoula, the keystone exposure from which the one-graded-bed-per-flood hypothesis emerged (Waitt, 1979, 1980a,b). Yet soon after, these same beds were used to advocate that rhythmic deposits in southern Washington are of but one or a few fantastically pulsating floods (Bjornstad, 1980). The canyon exposes a stratigraphic section of 39 superposed, normally graded beds. Most beds grade upward from sand to silt, concomitant with an upward sequence of sedimentary structures—conspicuous plane laminae to ripple-drift laminae to drapes to obscure plane laminae or massive—crudely comparable to that of distal turbidites (Figure 16; Figure 17, A,B,C). Sparse crystalline, quartzite, and metasedimentary-rock erratics show that the depositing water invaded from the Columbia valley, for Walla Walla valley lies entirely within the Columbia River Basalt Group. Ripple-drift laminae in the rhythmites climb and dip east-northeast, indicating paleocurrents that flowed generally upvalley.

If the rhythmicity at Burlingame canyon is obvious, the cause is less apparent. The visitor may debate whether many successive beds were deposited by fluctuating currents during one or two floods (Bjornstad's [1980] view) or whether instead each bed represents a separate flood followed by decades of subaerial exposure (Waitt's view). If the many rhythmites accumulated during one

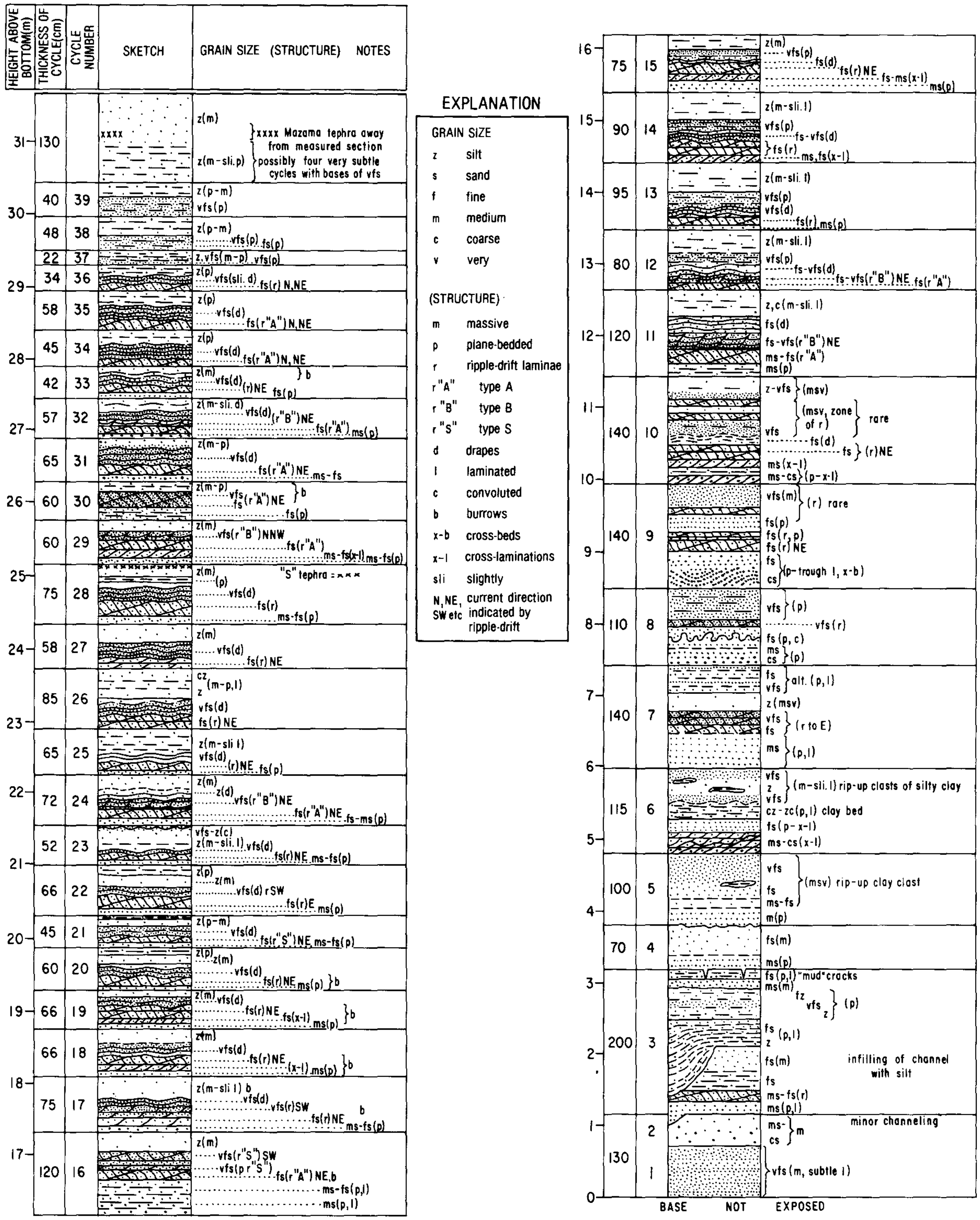


*Figure 16. Measured section of 39 rhythmites at northwest end of Burlingame canyon, Walla Walla valley. From Waitt (1980a, Figure 5).*

flood, certain conditions would have controlled sedimentation and the character of the deposits: the water would have remained ponded as much as 185 m (600 ft) deep above the top of the exposure, and the accumulating sediment would have had to remain loose and saturated. If on the other hand terrestrial environments intervened for decades between successive floods, other dominating conditions would have influenced the character of deposits: the sediment would become dewatered, eolian processes would be possible, and animals could repopulate the area. Much of the diagnostic evidence, summarized in the next few paragraphs, lies at the contacts between graded beds:

**Loess** between any two beds indicates that a terrestrial, eolian environment intervened between the floods that deposited the two beds. But the occurrence of loess has been debated, for the water-laid tops of most graded beds are texturally nearly identical to loess, from which the flood-laid sediment was indeed derived.

**Channels** between rhythmites indicate that erosion interrupted the accumulation of flood sediment. One conspicuous channel exposed near the canyon bottom (beyond allowed limits of this trip) has near-vertical sides: is this likely if the sediment had remained continuously saturated during rapid accumulation?

**Slopewash** (inferred) partly infills some of the channels. This material is finer and darker (organic coloring?) than is the flood-laid sediment.

**Volcanic ash** lies within inferred loess atop the 12th rhythmite below the top of section (Figure 16). This characteristic tephra couplet is identified as "set S" from Mount St. Helens, dated at about 13,000 $^{14}C$ yr B.P. (Mullineaux and others, 1978; Waitt, 1980a). Both tephra layers are structureless and nearly pure, but the upper part of the thicker ash member is locally contaminated (post-emplacement rainwash and eolian reworking?). Would the very existence or the nearly pure state of the ash be possible had the ash settled through deep, turbid water during a flood episode? Or must the ash instead have settled onto a dry interflood environment—as did the May 18, 1980, Mount St. Helens ash fall across eastern Washington?

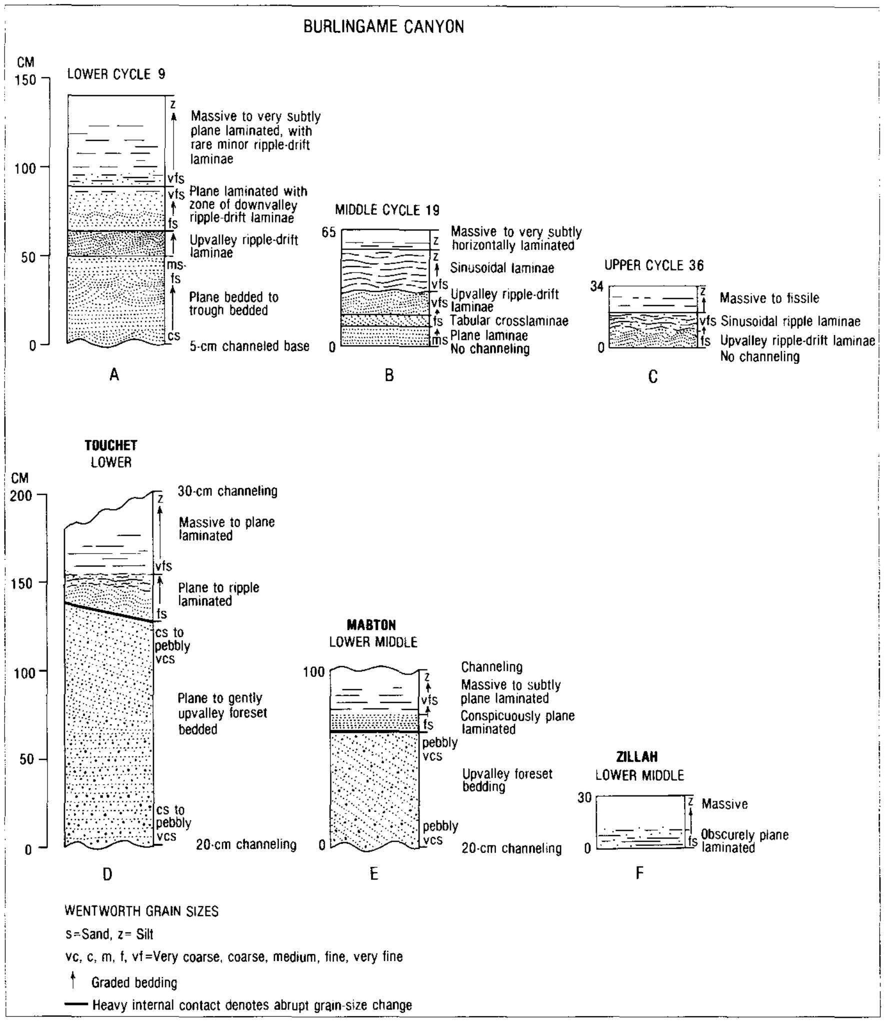


*Figure 17. Sketches of typical Missoula-flood rhythmites in southern Washington. A, Burlingame canyon, downsection; B, Burlingame canyon, midsection; C, Burlingame canyon, upsection; D, low in Walla Walla River bluffs southwest of Touchet (stratigraphically ≈ A); E, Mabton, lower midsection (stratigraphically ≈ B); F, Zillah, midsection (stratigraphically ≈ E). From Waitt (1980a, Figure 3).*

**Rip-up clasts** of the fine material that forms or overlies rhythmite tops may be found low in the section. Rip-up clasts imply that the sediment had dewatered and become coherent before it was reworked by a subsequent current into a new bed.

**Rodent burrows** filled with reworked flood-laid sediment may be found throughout the entire 30 m of section. Because rodents burrow less than 2 m below the ground surface, the filled burrows imply that rodents repopulated the surface numerous times during the accumulation of this 30 m of sediment.

**The striking similarity of graded beds** to each other suggests a common origin, not a mixture of two or more different origins. Thus if several horizons—like that containing the ash couplet—demand a terrestrial environment, then all other nearly identical horizons in this strikingly rhythmic sequence probably also demand a similar origin. But it is difficult to prove a terrestrial episode at the top of each and every rhythmite, especially the thinner and finer ones near the top of section.

An overall pattern is apparent here as in other sections: **a general upsection thinning and fining** of rhythmites, especially in the upper part of the section (Figure 16; Figure 17, A,B,C). This regional characteristic is attributed to the ice dam becoming thinner and therefore glacial Lake Missoula and floods becoming smaller during deglaciation. The bases of the upper 10 or so beds are relatively fine, like those at Zillah (Yakima valley), used as examples of "distal" flood beds in Figure 17 (C and F).

The 30-m section of rhythmic graded beds is capped by about 1 m of loess. The loess is of Holocene age, as can be seen near the southwest end of the canyon where the loess encloses Mazama (Crater Lake) ash whose radiocarbon age is about 6,850 $^{14}C$ yr B.P. (Bacon, 1983).

Some have argued even in recent years, albeit without offering new evidence, that multiple major graded-bed rhythmites can be produced during a single flood and that far fewer than 40 separate floods are represented by Burlingame canyon (e.g., Baker and Bunker, 1985, p. 24; Kiver and others, 1991, p. 243). But until these assertions are provided a basis in actual evidence, they are but unsubstantiated speculation. On the other side of the argument, much field evidence has been supplied repeatedly to support the hypothesis that every major, easily countable graded bed here is the deposit of a separate flood.

Waitt (1980a, 1985b) inferred that the rhythmite sections at Burlingame, Touchet, and elsewhere in Walla Walla valley record the very largest scabland-sweeping floods and that the pattern of upsection thinning and fining of rhythmites records that these floods became generally smaller with time. Since about 1985 a competing interpretation has been that the Burlingame and other rhythmite sections represent only a series of late small floods supposedly confined to the Columbia valley and Grand Coulee but not affecting the channeled scablands generally, which were supposedly swept earlier by one great flood (Baker and Bunker, 1985, Baker, 1989a, p. 27; 1989b, p. 54). And yet if these beds do not represent the largest floods, then what does? Walla Walla River is graded to Columbia River now as during the late Wisconsin episode of Missoula flooding. It is geometrically difficult or impossible that there could be much else below the base of this section. Indeed at higher altitude, where the rhythmites lapped up on the valley sides and toward the valley head, rhythmites similar to these directly overlie weathered fan gravel. If the largest Missoula floods are not represented by these rhythmites, then the largest flood(s) of all passed without a trace.

Some recent workers (Busacca and others, 1989, p. 62; Kiver and others, 1991, p. 243) suggest that Burlingame canyon represents only a series of small, late floods that do not correlate with rhythmites in settings such as Snake valley and its tributaries like the Tucannon that clearly were backflooded from floodwater channeled by the Cheney-Palouse tract, though Waitt (1983a,b, 1985a, 1985b) regionally united them. These workers suggest that truly cataclysmic flood(s) represented by the Tucannon rhythmites are middle Wisconsin in age and vastly predate rhythmites in the Walla Walla and Yakima valleys. Yet the Mount St. Helens "set-S" tephra is intercalated within several separate rhythmite sections in Tucannon valley and apparently in Snake valley at Lewiston (Smith, 1993; Waitt, unpublished data), which shows unarguably that most or all rhythmites in Snake valley and its tributaries are contemporaneous with those at Burlingame canyon. In other words, the floods represented by the deposits at Burlingame canyon and those that poured down the Cheney-Palouse tract and the rest of the channeled scabland are identical.

**En route to Stop 2.3**

Near mile 130 along both sides of road can be seen occasional crystalline erratic cobbles and small boulders culled from the adjacent irrigation ditch during its construction and repair.

At mile 130.7, road south: The sharp-eyed may glimpse the top of a granite ice-rafted erratic in a wheat field east of the road 0.5 mi to the south measuring 2.2×2.3×3.2 m and weighing some 32 tons. To float this block, a sphere of ice would have to be at least 6.2 m in diameter. The presence of this block near the top of this silt-covered surface suggests that very large ice blocks were carried into Walla Walla valley even during the later several floods represented by the upsection thinner rhythmites.

Rhythmites near Touchet (again). Traction bed-load deposit of beds in the lower midsection is much thicker and coarser (and contains outsized boulders) than in the probably contemporaneous rhythmites at Burlingame canyon (Figure 17, D).

**Stop 2.3. Wallula Junction railroad cut**

**1. Rhythmic deposits:** In Columbia valley at the mouth of Walla Walla valley is a coarse flood bar bearing bed-load boulders as large as 1.5 m. Banked against its west side is a deposit of fine sand to silt, and a long railroad cut in it exposes at least 14 couplet beds of fine sand grading up to very fine sand (Figure 18). Con-

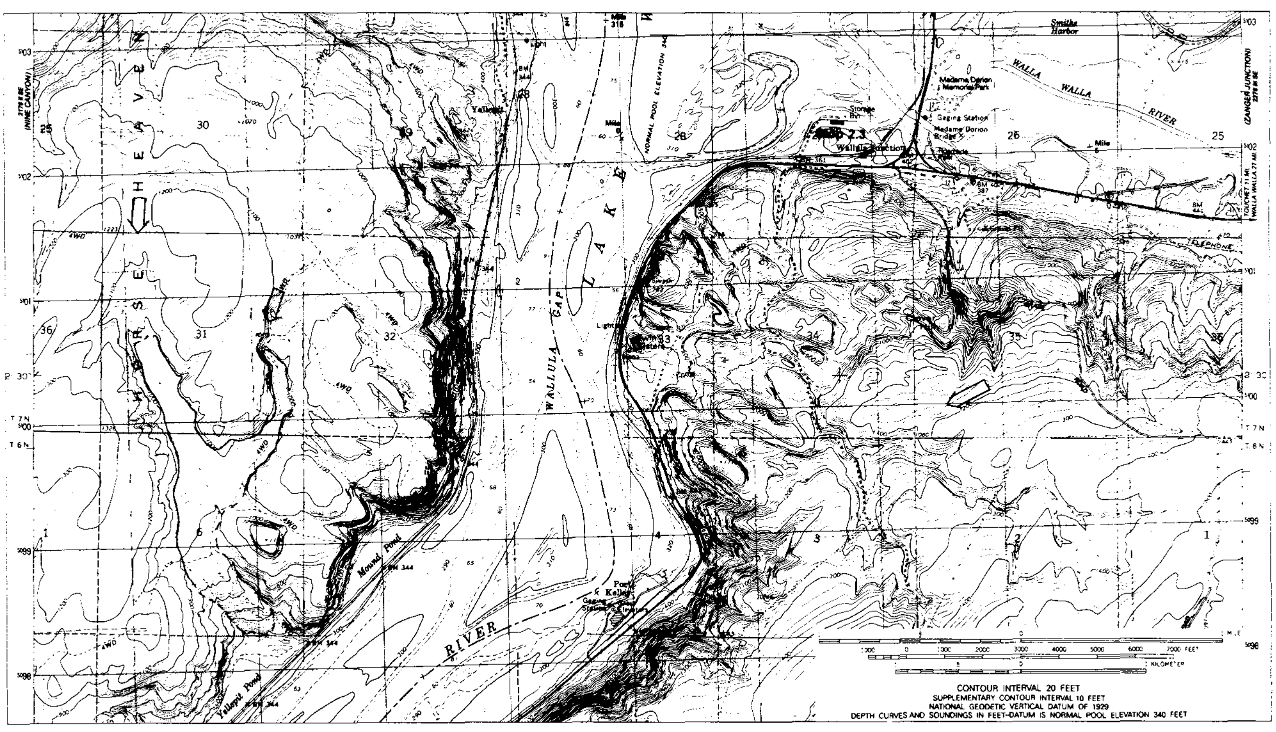


*Figure 18. Topographic setting of Wallula Gap. To the west of Wallula Gap, outlined area delineates extent of Missoula flood deposits (dashed where approximate). Arrows indicate high-level flood flow. Topographic base from Wallula USGS 7.5′ quadrangle.*

tacts between beds are notably wavy, partly from depositional relief, partly from erosion by the next overlying bed. Contacts between the fine top of a couplet and the coarser base of the overlying bed are very sharp, whereas the contact between the coarser main bed and the finer top are gradational over as much as a few centimeters. About 14 such couplet beds are easily countable in the tallest parts of the exposures; as many as 21 to 25 have been counted by piecing sections together and by trenching. These beds are texturally identical to fine rhythmic beds near the tops of rhythmite sections or far upvalley. They probably represent as many separate floods.

These beds are generally finer, thinner, and far more lenticular than are rhythmites 2–50 km up the Walla Walla valley in which can be found the Mount St. Helens "set-S" tephra. Nor has the tephra been found here despite almost continuous long exposure. These low-level rhythmites seem to be of floods that left some of the thin and fine rhythmites above the ash at Burlingame canyon; they almost surely include floods that were much smaller and later and not represented at Burlingame and Mabton but coeval with flood beds at the top of Manila Creek section in Sanpoil valley (Atwater, 1986) and the floor of upper Grand Coulee (Atwater, 1987; Waitt and Atwater, 1989).

Ripple-drift laminae dip northeast, indicating northeast paleocurrents away from nearby Wallula Gap. These are evidence of a counterclockwise eddy alongside the main flow that was racing out through Wallula Gap. Because of the slower currents of the eddy, sediment accumulated; whereas in the faster main current just westward the sediment was swept along downvalley with the water.

Opinion about the exposure at the Wallula railroad cut and nearby beds has been repeatedly billed as damaging to the scores-of-cataclysms hypothesis, thus:

> "Particularly damaging to the hypothesis that the rhythmites represent 'periodic, colossal jökulhlaups' (Waitt, 1985) is the fact that these low-energy deposits commonly occur at sites that would have experienced high velocities and stream power during a cataclysmic flood. A sequence of two dozen or more rhythmites, deposited under low-energy conditions, is preserved at the mouth of Wallula Gap, an environment that would have been subject to phenomenal flow-velocity conditions at the onset of any cataclysmic flood (Bjornstad, 1980)." (Bjornstad and others, 1991, p. 237–238).

Waitt feels that this reiterated claim (e.g., Bjornstad, 1980, p. 75; Baker, 1989c, p. 63–64; Baker and others, 1991, p. 250) is but deductive speculation whose premises fail to include elemental field relations. First, the northeast dip and climb of ripple-drift laminae show that here is the site of a an eddy off the main floodway—an eddy that spun counterclockwise along the left side of the main current. While generally water velocities "should" increase as flow approaches and enters the throat of a sharp constriction like Wallula Gap, exceptions are many. Every sharp channel irregularity along every river causes flow separation (eddies); one here in this sharp valley reentrant during great flood is hardly unexpected. Second, the rhythmites at Wallula seem not to contain the "set-S" tephra and probably are the record only of floods late in the sequence, floods perhaps as much as an order of magnitude or more smaller than earlier maximal ones represented by the coarse bar against which the fine rhythmites are banked. The beds at Wallula do not at all "damage" the scores-of-cataclysms hypothesis: they are compatible and support it.

**2. Hydrology at Wallula Gap:** The evidence of maximum stages and hydrologic studies near Wallula Gap have been described in O'Connor and Baker (1992), of which some aspects will be summarized here. At the entrance to the constriction, cols of divide crossings and a small boulder bar indicate that the maximum flood stage was at least 350 m (1,150 ft) (Figure 18). Loess scarps on both sides of the entrance to the constriction indicate that flow may have been as high as 365–370 m (1,200–1,220 ft). These values are consistent with the 370–380-m (1,220–1,250-ft) maximum altitude of ice-rafted erratics found in the Pasco basin (Bjornstad and others, 1991). At the downstream end of the constriction, the maximum flood stage was close to 335 m (1,100 ft).

From this evidence it seems that there was very little descent of maximum flood stage through the constriction, at the most only about 30–50 m. This difference was undetectable for Allison (1933), which led him to argue that the ponding in the Pasco basin was not related to hydraulic damming at Wallula Gap but due instead to ponding behind a great ice jam in the Columbia River Gorge. While Allison postulated physical damming by ice jams, hydraulic ponding not only would have had about the same effect but would also allow the assumption of a 30–50-m water-surface drop through Wallula Gap.

That the largest Missoula floods at maximum stage were hydraulically impeded by constrictions downvalley complicates the hydraulic analysis here. The simplest hydraulic situation to evaluate would be if Wallula Gap acted as a free constriction, and discharge from Pasco basin depended solely on the water level in Pasco basin and the geometry of the Wallula Gap constriction —similar to reservoir/weir arrangements that are commonly used to measure discharge. In hydraulic terms, flow would pass through critical depth in the constriction as it funneled out of the Pasco basin, similar to flow conditions in the Columbia River Gorge. This has been the premise for most of the discharge calculations at Wallula Gap. If one assumes critical flow through the constriction and a maximum ponding altitude of 370–385 m (1,220–1,260 ft) in the Pasco basin, the resulting discharge calculates to 13.5–15 million $m^3$/s (Figure 19). Because critical flow through the constriction is the maximum possible flow, this value is the maximum possible discharge through Wallula Gap, given our present knowledge of maximum flood stages in the Pasco basin.

The high-water evidence, however, indicates that at maximum flood stage the constriction at Wallula Gap was partially drowned by backwater effects from constrictions downstream in the Columbia River Gorge; consequently, Wallula Gap did not act as an entirely free constriction. This type of hydraulic situation is more difficult to analyze, because choices of energy-loss coeffi-

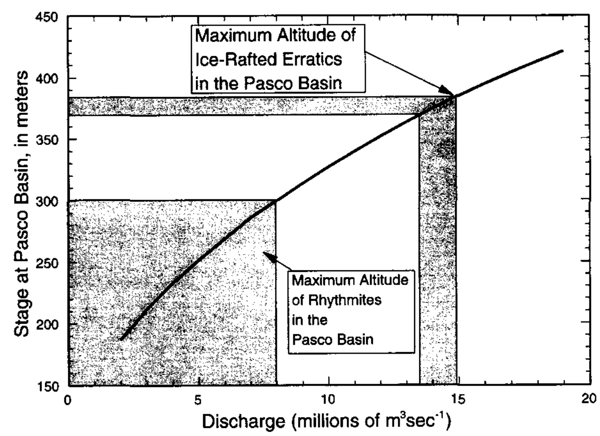


*Figure 19. Stage-rating curve for Pasco basin calculated on the basis of assuming critical flow through Wallula Gap. Because critical flow is the maximum possible discharge for a given stage, this curve defines the maximum flow possible for a given ponding level in Pasco basin. Because flow may have been impeded by ponding behind downstream constrictions, the actual discharge associated with a given stage in Pasco basin was probably somewhat less. The maximum altitude of rhythmites is from a 300-m-(980-ft) altitude exposure of a deposit at Union Gap that has been described by Allison (1935) (not seen by us) and appears to be composed of several cycles of fining-up deposits.*

cients and possible flow unsteadiness introduce much larger uncertainties to the results. Nonetheless, for Wallula Gap we have attempted to calculate a discharge for the profile defined by the highest flood evidence. For these conditions, a discharge of 10±2 million $m^3/s$ is calculated (Figures 20 and 21). The uncertainty values reflect uncertainties introduced by imprecise knowledge of the maximum ponding level in Pasco basin and reasonable ranges of Mannings ***n*** values. Because flow was undoubtedly not steady and peak discharge at Wallula Gap was reached probably before maximum stages were achieved downstream, the actual maximum discharge was probably somewhere between the values determined for the critical flow and fully impeded cases. It is also likely that the maximum discharge through Wallula Gap occurred before water levels reached maximum altitudes in Pasco basin.

If one considers that 10 million $m^3/s$ was about the peak discharge at Wallula Gap, a simple hydrograph can be calculated for the largest flood by assuming a triangular hydrograph and accounting for the 2,184-$km^3$ volume of glacial Lake Missoula at its maximum level. For a peak discharge of 10 million $m^3/s$, flow duration would have been about 120 hours (five days). Because Pasco basin contained some 1,210 $km^3$ of water at peak stage, the hydrograph must have been somewhat asymmetrical, the waxing phase being <54 hours, the waning period >67 hours (Figure 22). For Wallula Gap and Pasco basin, this would translate into a minimum average rate of water-level rise of about 0.1 m/min. Because the geomorphic evidence downstream indicates a much greater rate of rise (1 m/min), the actual time of the waxing hydrograph was probably much shorter, perhaps just a few hours.

These discharge values relate to the highest evidence of flood features adjacent to Wallula Gap and in Pasco basin. What are the possible discharges associated with evidence of multiple floods? In Pasco basin, the highest described rhythmite sections that clearly represent numerous floods are at about 255–260 m (840–850 ft) altitude (Waitt, 1980a, p. 672; 1985b, p. 1285; Bunker, 1980, p. 60). A section at an altitude of 300 m (980 ft) at Union Gap, photographed and briefly described by Allison (1933, p. 682–683) has 15 or more "regularly alternating beds of sand and silt," perhaps the record of as many floods. If critical (maximum) flow is assumed through Wallula Gap, deposits at 260 m (850 ft) require a discharge of at least 5.5 million $m^3/s$. A stage of 300 m (980 ft) requires about 8 million $m^3/s$ (Figure 19).

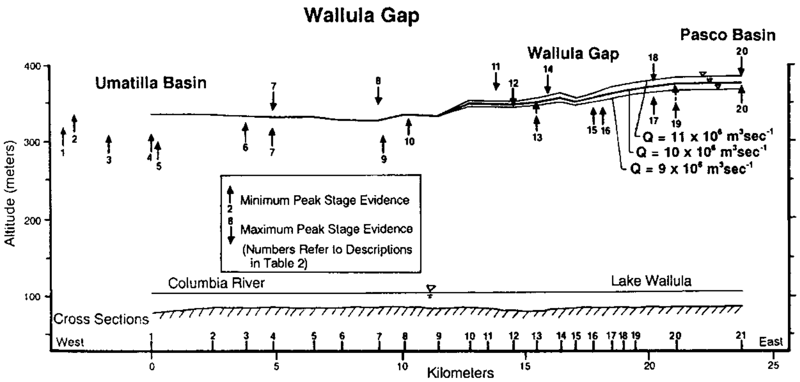


*Figure 20. Step-backwater calculated water-surface profiles through Wallula Gap. A 10 million $m^3/s$ discharge results in a calculated profile that matches most of the high-water evidence along the reach and results in a ponding level in Pasco basin consistent with altitudes of the highest ice-rafted erratics. From O'Connor and Baker (1992).*

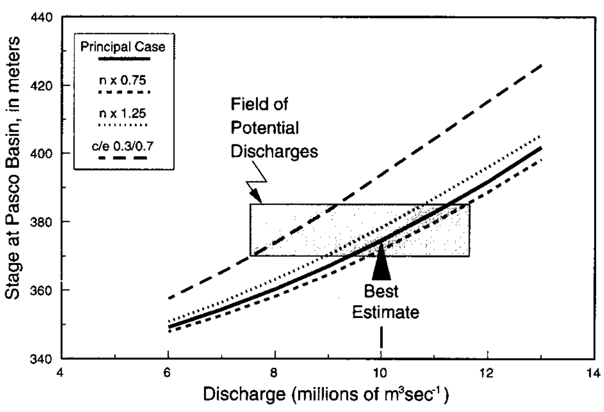


*Figure 21. Rating curves for calculated stages in the Pasco basin for different values of energy-loss coefficients and for a ponding level of 335 m in the Umatilla basin. The effects of varying Manning roughness coefficients are minimal. The principal case was calculated with contraction and expansion energy-loss coefficients of 0.0 and 0.5. Using larger coefficients reduces the discharge required to achieve a 375 m stage in the Pasco basin to about 8 million $m^3/s$. Considering the high-water evidence identified in this study and the uncertainty of maximum Pasco basin stages and reasonable ranges of the energy-loss coefficients, the maximum Missoula flood discharge through Wallula Gap was between 7.5 and 12 million $m^3/s$. From O'Connor and Baker, 1992.*

**En route to Stop 2.4**

During each of numerous large floods, Missoula floodwater poured into Pasco basin through several conduits that had diverged from each other at several key divide spillovers in the channeled scabland complex. The three main inflow conduits (north to south) are Columbia River, Esquatzel coulee, and Snake valley (Figure 23). Where currents diverged and slackened, several inconspicuous broad mounds of gravel—flood bars—were deposited (Figure 23) (Bretz, 1928, p. 678–681). Across wide tracts of the Pasco basin the Pleistocene flood deposits are buried (and smaller scale landforms obscured) by late Pleistocene and Holocene (including recent) eolian dune sand 1–15 m thick.

At the Snake River crossing: Much of Missoula floodwater that descended the Cheney-Palouse scabland tract overflowed from the scablands into the Snake valley 60–90 km upriver and reentered the Columbia valley here.

Near and east of junction of U.S. 395: Inflow from Esquatzel coulee, which disgorged floodwater collected mostly from the Cheney-Palouse tract via Washtucna coulee but also divergent strands from Quincy basin.

Between the railroad yards west of U.S. Highway 395 and the Columbia River crossing at Richland: Interstate182 crosses southern part of gravel bar covering 40 $km^2$ and as much as 45 m above adjacent swales (Figure 23) (Bretz, 1928).

After crossing Columbia and Yakima Rivers, the highway gradually climbs to a line of northwest-trending quaquaversal (doubly plunging) en echelon anticlines that define the regional Olympic-Wallowa Lineament (OWL), probably a dextral shear. On approach to Goose Gap, Badger Mountain is left, Candy Mountain right.

On long, descending road grade: Ridge ahead is Horse Heaven Hills anticline (actually an anticlinorium). Fault scarp along base trends northwest, parallel to OWL. Also on this trend to the northwest is a minor anticline topographically expressed as a line of low hills.

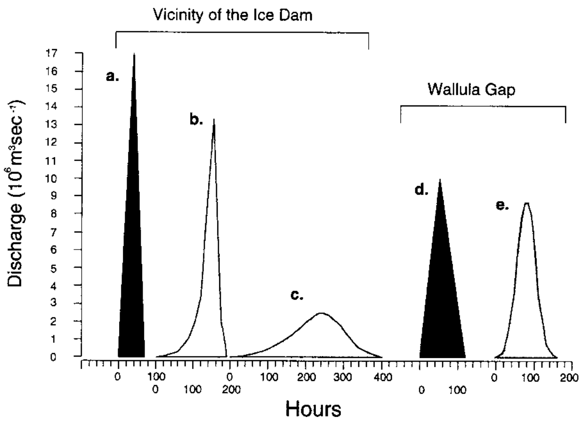


*Figure 22. Postulated hydrographs for the largest Missoula flood(s) (assuming complete emptying of Glacial Lake Missoula from its maximum level). All of the hydrographs represent the same total volume (2,184 km$^3$). Graphs **a** and **d** are those postulated by O'Connor and Baker (1992) on the basis of maximum discharges near the outlet and at Wallula Gap. Graphs **b** and **c** are those proposed by Clarke and others (1984) as resulting from a jökulhlaup release. Graph **b** represents the extreme case of no "tailwater ponding" (flow impeded by downstream ponding in the Spokane valley) and immediate conveyance of all of the lake water to the breakout location. Case **c** is the more realistic situation of downstream hydraulic conditions affecting the rate of release as well as the delayed response at the breakout point because of the complex lake geometry. Case **e** is the hydrograph proposed for Wallula Gap by Craig (1987).*

### Stop 2.4. View of Chandler narrows

Bretz (1930, 1969), inferring violent backflooding of lower Yakima valley, focused on spectacular scabland and bars in a valley bottleneck near Chandler, scarcely mentioning the extensive backflood deposits upvalley. Spectacularly rhythmically graded backflood deposits in the lower Yakima valley near Mabton were among the first detailed evidence for scores of separate great Missoula floods (Waitt, 1979; 1980a,b; 1985b). Yet because the top of the Mabton section lies at altitude 215 m (710 ft), some 150 m below the maximum flood level (365 m [ 1,200 ft]) in Pasco basin at Wallula Gap, some critics have imagined these beds to represent only late, small floods confined to valley floors.

Water rising in Pasco basin by hydraulic ponding streamed into Yakima valley through a structurally determined constriction 6 km long and only 4 km wide (at 305 m [1,000 ft] altitude) at Chandler (Figure 24), where the flood channel is a trench 70 m deep. A cross-valley anticlinal crest is eroded into spectacular scabland ("the badlands") with sharp local relief as much as 60 m extending as high as 135 m above the channel floor, minor scabland extending 65 m higher (Bretz, 1930, p. 413–419; 1969).

At Prosser, 17 km upvalley from Chandler, the valley is 8 km wide, and at Mabton 34 km above Chandler the valley has widened to 24 km—a six-fold increase in width and enormous increase in cross-sectional area (below flood level) between Chandler and Mabton (Figure 25). Scabland and huge boulders along the constriction at Chandler and the absence of any slackwater deposits, show that backfloods here were vigorously erosional. Floodwater sweeping the opposite bedrock upland 60–170 m above Yakima River here deposited "delta bars" into sharp north-south (current-transverse) tributary valleys, filling the east sides of valleys like Snipes Creek 8 km west of here (Figure 24) (Bretz, 1930). At the widening mouth at Prosser, eroded material was also dumped on the valley floor as coarse rubble many meters

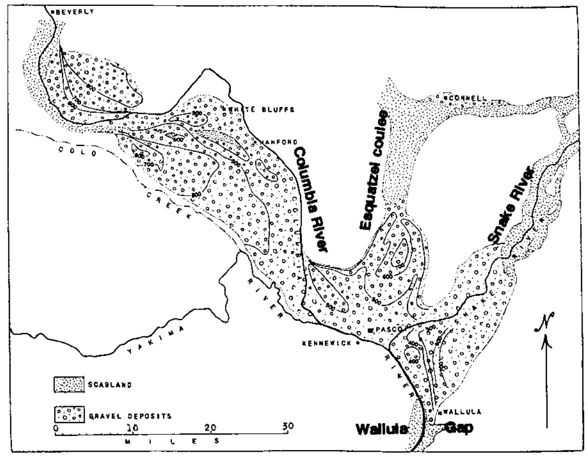


*Figure 23. Sketch map of Pasco basin depicting major gravel bars and associated topography (contours on gravel deposits generalized). Route of Day 2 skirts south edge of large pendant bar northwest of Pasco. Note great mound of gravel where floodwater emerged into basin from Esquatzel coulee. Most of inflow from Cheney Palouse was via Snake valley and Esquatzel coulee. From Bretz (1928, Figure 11).*

thick, including angular basalt boulders as large as 1 m.

At a distance of 10 km west-northwest upvalley of Prosser, the deposits fine to cobble-pebble gravel deposited in tall foreset beds dipping 25°–35° upvalley. And 8 km farther upvalley at Mabton the deposit becomes conspicuously rhythmic, and the tractive bases have fined to basaltic fine gravel and coarse sand but with isolated outsized angular basalt clasts as large as 25 cm (Figure 17, E). By 30 km still farther upvalley at Zillah (65 km upvalley from Chandler), the coarse, basaltic tractive bases have dropped out, and arkosic fine sand composes the rhythmite bases (Figure 17, F). This is a contemporaneous facies tract (Waitt, 1980a, p. 660–661) in which thickness and grain size of tractive load systematically decrease upvalley from the Chandler narrows—from boulder gravel to pebble gravel to coarse sand to fine sand. This pattern reflects the enormous increase in cross-sectional area and a consequent order-of-magnitude decrease in current velocity that any one colossal flood expanding into such a broadening valley experienced.

### En route to Stop 2.5

At the railroad underpass at Prosser please note coarse, poorly sorted Missoula-flood debris carrying angular basalt boulders as large as 1 m. Largest boulder is on right just past railroad. This material illustrates the coarseness of the transported clasts as floodwater expanded out of the Chandler narrows. These coarse deposits are not overlain by fine slackwater deposits, which apparently could not accumulate here because the currents were far too swift.

A few miles west of the airfield: Here and intermittently for the next few miles are locally derived flood-borne basalt cobbles and boulders recently culled from vineyards. Viewed in the distance are discontinuous outcrops of basalt with skim of flood-borne boulders.

### Stop 2.5. Scabland northwest of Byron

Just west of the valley narrows and extending northwest from Byron, a 12-km$^2$ area of isolated sharp basalt scabland between altitudes 205 and 220 m (670 and 720 ft) has a local relief of 8 m (Figure 26) (briefly noted by Bretz, 1924, p. 145). The scabland is littered by angular basalt boulders as large as 3 m and is mantled by postflood loess but apparently not by flood-slackwater deposits. Yet just 5 km farther upvalley near Mabton, graded rhythmites are at least 10 m thick at a similar altitude. Floods that deposited the rhythmites at Mabton had just upcurrent eroded a classic scabland! Floods that deposited rhythmites as high as 300 m (980 ft) near Union Gap were at least 70 m deep over this scabland. Neither are the coarse proximal boulder and pebble-gravel deposits at Prosser overlain by any such "low-energy" silt. The coarse deposits at and west of Prosser and the scabland west of Byron are in fact the "high-energy proximal" component of the rhythmite facies demanded by those who would infer that the Yakima valley rhythmites are only of low-altitude, low-energy floods (e.g., Baker, 1991, p. 250).

**En route to Stop 2.6**

Just after the turn west onto W. Robinson Road, gravel pits on both sides of the road expose steep west-dipping (up Yakima valley) foreset beds of pebble-cobble gravel subfluvial "delta" shed by great flood(s) off the sharp west edge of the bedrock platform on which we have travelled for the last several miles (Figure 26). The substantial content of subangular to subround nonbasaltic stones is enigmatic but likely derived from a nearby coarse sedimentary interbed between basalt layers. ***Private pit, permission required.***

After crossing the bridge over Yakima River, drive slowly to view adjacent scabland on left (Figure 26), which is sparsely littered with flood-borne, locally derived basalt boulders including many 1–2 m in diameter. The scabland is apparently devoid of overlying silt slackwater deposit that would be evidence of feeble floods following scabland-carving floods.

After road ascends to level of scabland, this surface gradually passes west into silt (note hops growing) at about the same altitude as the thick rhythmites at Mabton (Figure 26).

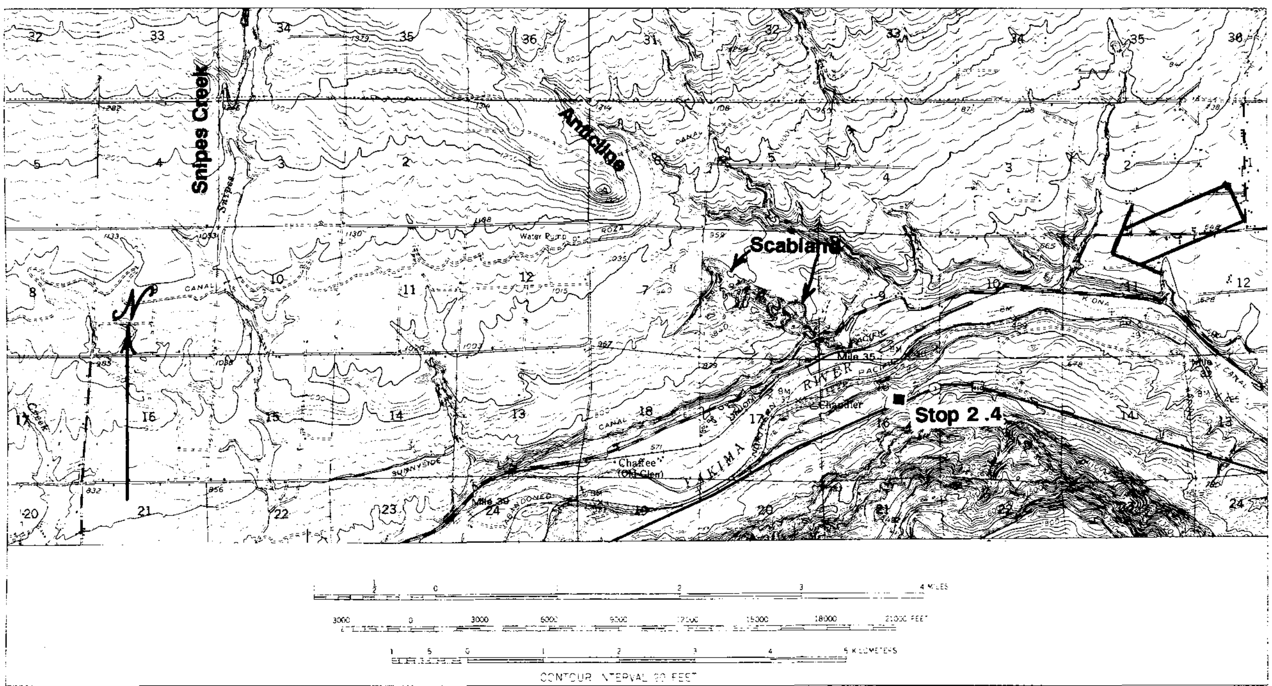


*Figure 24. Part of 1:62,500-series USGS Corral Canyon topographic quadrangle, showing area near Chandler, lower Yakima valley, Washington. Map vintage 1951, predating modern highways. The large arrow shows general direction of water movement as stage was rising in the Pasco basin to the east.*

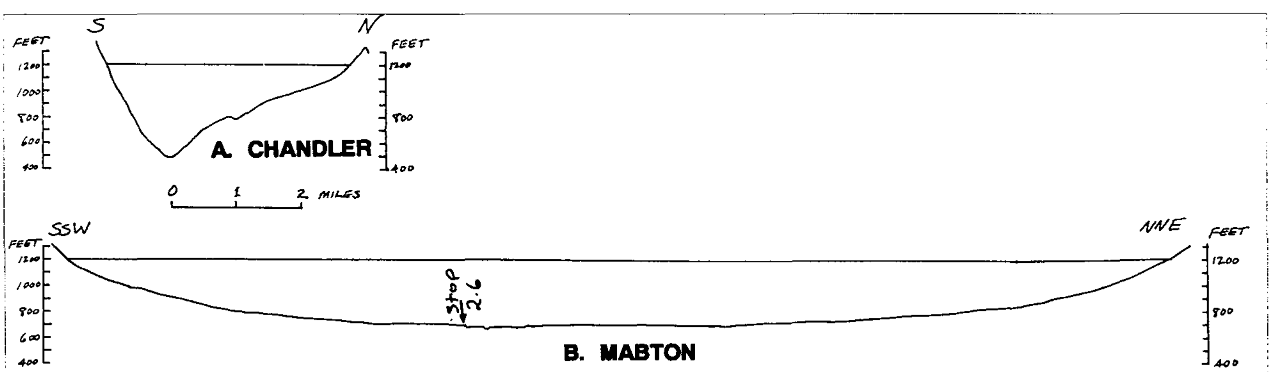


*Figure 25. Cross sections of lower Yakima valley showing enlargement by 5.5 to 6 times the width and cross-sectional area between Chandler and Mabton.*

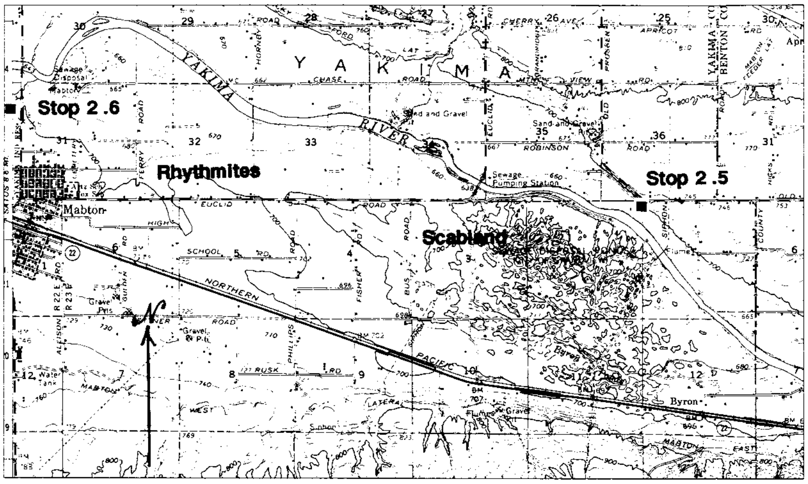


*Figure 26. Part of 1:62,500-series USGS Prosser topographic quadrangle, showing area between Prosser and Mabton, lower Yakima valley, Washington. Map vintage 1965, predating modern highways.*

**Stop 2.6. Mabton**
(please see Waitt, 1980a, 1985b)

The section is located in the lower Yakima valley, south-central Washington, 1 mi north of Mabton, Washington, along the main road to Sunnyside. Conspicuous exposure is continuous along bluffs defining the south side of Yakima River valley for 200 ft on the west side of the road (former exposures on the east side are now mostly buried). ***Please obtain permission from landowner Don Desmaris (through gate on west and up driveway).***

About 25 Missoula backflood rhythmites are exposed but are now far more slumped over and obscured than in the late 1970s. Many features in the succession of graded beds here are similar to those at Burlingame canyon, including upsection thinning and fining of rhythmites and the fact that exactly 11 rhythmites overlie the conspicuous ash couplet. Differences include: (1) paleocurrent indicators are west directed (but that is upvalley here); (2) a coarse bed-load deposit of locally derived basalt forms the base of many rhythmites, especially those low in section (Figure 17, E); (3) the Mount St. Helens "set-S" ash couplet is much thicker, Mabton being about halfway between the volcano and Burlingame canyon; bases of both ash layers are uncontaminated; (4) two additional thin ash laminae lie at top of the rhythmites that overlie and underlie the rhythmite capped by the prominent ash couplet; (5) dunes at the base of several rhythmites are composed partly of freshwater shells; the shells must have been concentrated in an adjacent pond—accumulated there over years or decades before being swept up by an incoming flood. Shells from the base of the second rhythmite below the ash couplet give radiocarbon ages of 14,060±450 $^{14}$C yr B.P. (USGS–684) and 13,130±350 $^{14}$C yr B.P. (W–2983).

Yakima valley rhythmic and nonrhythmic "slackwater" deposits locally overlie weathered gravel along the banks of the Yakima River, which is graded to the Columbia now just as during the Pleistocene great-floods episode. If the coarser beds low in the rhythmite sections do not represent the largest scabland floods, then these giant debacles left nothing, for there are no other deposits. Arguments that these represent only late, small floods are fatally inconsistent: numerous allegedly late, low-level floods left rhythmic deposits, yet the largest scabland-sweeping floods deposited nothing. Rather, the rhythmites record all floods: many gigantic near-maximal ones followed by many successively smaller ones.

**En route back to Deschutes State Park:**

The marvelously rhythmic beds in the Walla Walla and lower Yakima valleys record successive huge backfloods from the Pasco basin. Many of the coarser and thicker rhythmites that underlie the Mount St. Helens "set-S" tephra at Mabton extend upvalley, thinning and fining, as a silt terrace that forms the banks of the Yakima River just below and above Union Gap at altitude 300 m (980 ft), only 65 m below the maximum flood limit at Pasco basin, where backflooding originated. If the barely discernible post-ash rhythmites in the shallow exposures at Donald record floods that barely backflooded that far and high, the much thicker succession of pre-ash rhythmites here and farther upvalley as far as Union Gap record more robust, higher backfloodings. For floodwater to reach the Union Gap sections requires ponding of at least 450 km$^3$ of water behind Wallula Gap. To account for at least 15 graded beds just above Union Gap, this ponding occurred at least 15 separate times.

Near the top of the rhythmite sections, the beds typically become markedly thinner and finer, progressively so upsection. Of the 11 flood beds that overlie the Mount St. Helens "set-S" tephra at Burlingame canyon (altitude 185 m [610 ft]) and at Mabton (215 m [710 ft]), the upper 7 are much thinner and finer than the lower 4 or any other bed downsection. The upper part of rhythmite sections in Yakima valley surely represent progressively smaller floods (Waitt, 1985b, p. 1284). Of 11 relatively thin and fine-grained rhythmites that overlie the ca. 13,100-yr-old Mount St. Helens "set-S" ash at Mabton (altitude 215 m [710 ft]), only 5 overlie the ash farther upvalley at Zillah (altitude 245 m [800 ft]), 4 at Buena (altitude 255 m [840 ft]), and 3 at Donald (265 m [870 ft]). Thus the last 10 or so floods represented at Mabton clearly were successively smaller and ponding not deep enough to flood up to the maximum-flood limit.

The height of the tops of these rhythmite sections above the level of Columbia River at Wallula Gap are: Burlingame canyon, 95 m; Mabton, 125 m; Zillah, 170 m; Buena, 178 m. Floods recorded by the upper seven of the post-ash flood beds exposed at Burlingame and Mabton ponded in Columbia valley as deep as 120–150 m (at Wallula Gap) but apparently not as deep as 170 m. Even a flood ponding to a depth of "only" 125 m (which would flood the top of the Mabton section), while 150 m below the limit of the largest floods, was enormous: behind Wallula Gap, the Pasco basin and the backflooded valleys contained a minimum of 155 km$^3$ of ponded water (Waitt, 1980a; Table 4). Floods capable of such extravagant backflooding out of the Pasco basin could not but have also invaded the channeled scabland.

At U.S. Highway 97 near Toppenish: Fine rhythmites with intercalated Mount St. Helens "set-S" tephra extend at least another 18 km upvalley; the rhythmites at Union Gap are 30 km upvalley.

Approaching Goldendale: Round-stone pebble gravel rich in quartzite clasts is seen in cuts on both sides of road for half a mile. This represents an old (but younger than an underlying 10.5-Ma basalt) course of Columbia River directly across what later became the Horse Heaven and Columbia Hills anticlinorium. The rise of these great anticlines diverted Columbia and Yakima Rivers east to the Pasco basin some time after 10 Ma. A few miles farther, the pebble gravel is overlain and baked by an overlying Simcoe alkali-basalt flow.

Approaching Columbia River, descending off the Columbia Hills anticline: Views of south (Oregon) side of Columbia valley showing basalt benches stripped of regolith as high as about 275 m (900 ft) above the river.

## DAY 2 ROAD LOG (mileage is approximate)

| Miles | |
|---|---|
| 0.0 | Deschutes State Park overflow area. |
| 0.2 | Turn right (east) onto old U.S. 30. Miller Island on left, on whose SE side is 1-Ma alkali-basalt lava flow draping down over north valley side from Haystack Butte. |
| 1.6 | Junction with Oregon Hwy. 206. |
| 4.2 | Entering Biggs Junction. |
| 4.6 | Junction with U.S. Hwy. 97. Turn left (north). |
| 4.7 | Ramp to Interstate 84 east. Take it. |
| 10.1 | Rufus. |
| 12.3 | John Day Dam. Aluminum plant across river. |
| 18.5 | Scabland. |
| 19.8 | View ahead of eddy bar at mouth of Philippi Canyon. |
| 23.3 | Exit 123, Philippi Canyon. Stay on I-84. |
| 37.0 | Arlington, Junction with Oregon 19. |
| 47.0 | Willow Creek. |
| 59.3 | Rest area exit. |
| 61.0 | Boardman. |
| 66.1 | Exit 168 to U.S. 730. Take it toward Umatilla. |
| 73.7 | Irrigon. |
| 81.1 | Enter Umatilla. |
| 82.8 | Pass under I-82. Continue east on U.S. 730. |
| 87.2 | Scabland on left. |
| 92.0 | Junction with Oregon 37. Wallula Gap ahead. |
| 104.6 | Walla Walla Grain Growers grain elevators on left. |
| 107.8 | Wallula Gap. |
| 108.1 | Intersection with U.S. 12. Take it east. |
| 108.4 | East arm of U.S. 12 "Y." Proceed east on U.S. 12. |
| 113.2 | Turnoff left onto abandoned segment of old highway parallel to present one. Pull ahead and form single line. |
| 113.3 | **Stop 2.1.** View of narrows of Walla Walla valley. When you leave, continue east on U.S. 12. |
| 114.8 | Intersection with Byrne Road through valley narrows (alternate return route). Stay on U.S. 12, which heads up over basalt spur on north valley side. |
| 116.0 | Road cuts on both sides show very old calcified colluvium draped over a high of bedrock basalt. |
| 120.1 | On right in distance along Walla Walla River is a tall exposure of rhythmites. |
| 120.5 | Entering Touchet. |
| 125.0 | Just upon entering Lowden, turn right onto South Lowden Road at landmark of big isolated mound of bedded slackwater deposit. |
| 125.3 | Cross Walla Walla River. |
| 126.2 | Road intersection. Stay on main road. Ascend Gardena silt "terrace." |
| 127.3 | Just before irrigation ditch, turn right into gravel parking area: **Stop 2.2.** Burlingame canyon. |
| 127.4 | Continue south across irrigation ditch on South Lowden Road and descend off "terrace." |
| 128.1 | T-shaped intersection at Frost Ranch. Turn right. |
| 129.1 | Road intersection. Turn right onto Gardena Road. |
| 129.5 | As road ascends back up onto Gardena silt "terrace," rhythmites are exposed in roadcuts. |
| 130.0 | Occasional crystalline erratic stones culled from irrigation ditch. |
| 130.7 | Road south. Ice-rafted granite erratic, 2.3 m in diameter, in wheat field east of road ½ mi to the south weighs 32 tons. |
| 132.6 | Road intersection. Take sharp turn to right. |
| 134.0 | Touchet, Washington. Stone building on left was bank. |
| 134.1 | At "T" intersection, turn left. |
| 134.2 | At intersection, turn right and cross railroad tracks. |
| 134.3 | Junction with U.S. 12. Turn left onto it westbound. |
| 134.7 | In distance to south is tall rhythmite exposure (again). |
| 135.3 | **Alternate route**. At right curve in Highway 12, turn onto Byrne Road. Follow it about 5 mi through the narrows of Walla Walla valley. Byrne Road rejoins Highway 12 where indicated (mileage 114.8 above) inbound to Walla Walla valley. This alternate route adds about 1 mile to recorded mileage. |
| 146.5 | East limb of U.S. 12 "Y" at Wallula. Continue straight past weigh station on right. |
| 146.7 | Turn right onto west limb of U.S. 12 "Y." |
| 147.8 | Pull to right shoulder, parking as far off pavement as possible: **Stop 2.3.** Wallula rhythmites site is across this road 200 yards or so west, a cut along railroad. ***Please beware of traffic while crossing road.*** When you leave, continue on U.S. 12. |
| 147.9 | Intersection of U.S. 12 from east. Turn left, continuing west on U.S. 12. |
| 148.0 | Walla Walla River bridge. |
| 161.3 | Bridge over Snake River. |
| 164.8 | U.S. 395 to Spokane. Continue straight. U.S. 12 becomes I-182 here. |
| 167.4 | U.S. 395 south to Kennewick. Continue on I-182. |
| 173.7 | Cross Columbia River. |
| 174.5 | Exit to Richland. Continue west on I-182. |
| 176.1 | Cross Yakima River. We start up Yakima valley, but at first up and over structural high. |
| 178.0 | Line of doubly plunging anticlines defines regional Olympic-Wallowa Lineament (OWL). Badger Mountain left, Candy Mountain right. |
| 179.1 | Goose Gap, a structural sag between anticlines. Get into right lane. |
| 179.4 | Intersection with I-82. Take it (also U.S. 12) west toward Prosser and Yakima. |
| 184.7 | Long descending road grade. Ridge ahead is Horse Heaven Hills anticline with fault scarp along base. |
| 188.4 | Take Exit 93, Yakitat Road. |
| 188.7 | Turn left (south) on Yakitat Road. |
| 188.9 | Turn right (west) at yellow arrow. |
| 189.4 | Power lines. |
| 190.5 | **Stop 2.4.** Chandler narrows. Pull to left (south) shoulder. When you leave, continue west on road. |
| 194.0 | Turn right onto Gibbon Road and cross freeway overpass. |
| 194.1 | Turn left onto I-82 westbound on-ramp. |
| 195.5 | Yakima valley begins to widen out above (upvalley of) Chandler narrows. |
| 196.8 | Road cuts through landslide debris. |
| 197.2 | Road cut on right shows broken-up flows of the Columbia River Basalt Group with slabs of sedimentary interbed in landslide block. |
| 197.9 | Mount Adams ahead. |
| 199.7 | Take Exit 82 to Prosser. |
| 200.1 | At stop, turn left (west) on Wine Country Road (Washington Highways 22 and 221). |
| 200.5 | Enter Prosser. Be prepared for road cut ahead at railroad underpass (no stop). |
| 201.3 | Pass railroad underpass slowly. Coarse, poorly sorted Missoula-flood debris carrying angular basalt boulders. |
| 201.5 | Tenth Street intersection. |
| 201.8 | Intersection with flagpole. Veer right, continuing on Wine Country Road. |
| 202.0 | Yakima River bridge. |
| 202.4 | Small airfield on left. |
| 202.5 | Just beyond airfield, turn left (west) onto Old Inland Empire Highway. |
| 203.8 | For next few miles, flood-borne basalt stones culled from vineyards, then discontinuous basalt outcrops with skim of flood boulders. Mount Adams ahead. |
| 206.9 | Intersection of Old Prosser Road with Canyon Road. Pull off left into clear area just beyond intersection, just before curve in highway: **Stop 2.5.** Byron scabland. When you leave, continue on Old Prosser highway around right curve to north. |
| 208.2 | Turn left (west) onto West Robinson Road. |
| 208.3 | Gravel pits exposing upvalley-dipping foreset gravel beds. |
| 208.8 | Hops fields (tall lined poles). |
| 209.2 | Stop sign. Turn left (south) onto S. Euclid. |
| 209.4 | Scabland ahead is a part of that which we viewed from Stop 2.5. |
| 209.6 | Bridge over Yakima River. Road turns west and becomes E. Euclid. Note adjacent scabland. |
| 209.7 | Drive slowly to allow views of adjacent scabland littered with flood boulders but devoid of slackwater silt. |
| 213.2 | Entering Mabton. |
| 213.9 | Stop intersection. Turn right (north) onto Washington 241 (First Avenue). |
| 214.5 | Just after starting downhill, turn left into unmarked driveway through gate. Proceed up driveway. |
| 214.6 | Turn around at house and head back down driveway. |
| 214.7 | Park on drive as far to right as practical (If there are many cars, some may have to park in middle of drive heading up.): **Stop 2.6.** Mabton rhythmites. ***Private property. Please ask permission of landowner Don Desmaris. Please beware of stock*** |

*fences, which are "hot." Close any fence you open.* When you leave, turn right (south) back toward Mabton on Washington 241.

215.3 Entering Mabton.
215.5 Veer right, staying on main road through town.
215.7 Railroad crossing.
215.8 Intersection. Turn right onto Washington 22 toward Toppenish and Yakima.
217.0 Views ahead of Mount Adams volcano (left) and Mount Rainier volcano (right).
221.2 Nice stone house on left.
229.9 Conspicuous landslide off Toppenish Ridge anticline.
233.7 Cutoff left to U.S. 97. Continue on highway.
234.9 Stop light at Toppenish. Turn left onto U.S. 97.
237.8 Youthful small stream valleys cut north flank of Toppenish Ridge anticline.
239.7 Begin ascent of Toppenish Ridge anticline.
242.8 Crest of Toppenish Ridge anticline. Roadcuts expose Columbia River Basalt Group.
244.0 Simcoe volcanic field (Pliocene), a shield of alkali basalt.
269.4 Satus Pass.
276.2 Alkali basalt of Simcoe volcanic field on right.
277.9 Round-stone pebble gravel rich in quartzite clasts in cuts on both sides of road here and for next half mile. This represents an old (but younger than an underlying 10.5-Ma basalt) course of Columbia River directly across what since has become the Horse Heaven and Columbia Hills anticlinorium. The rise of these great anticlines diverted the Columbia and Yakima Rivers east to Pasco basin some time after 10 Ma.
278.7 Baked base of Pliocene alkali-basalt flow.
279.5 More quartzitic pebble gravel.
282.0 More cuts in alkali basalt.
282.5 Baked substrate beneath alkali-basalt flow.
283.5 Intersection with highway to Goldendale. Continue south on U.S. 97 across Klickitat valley. Mount Adams to west.
289.0 Volcano viewpoint (Mount Hood, Adams, Rainier).
290.0 Begin descent to Columbia valley off Columbia Hills anticline.
292.0 Here and for next 1.5 mi views of scabland benches on south side of Columbia valley, stripping by flood as high as 900 ft above river.
293.7 At intersection turn left, continuing on U.S. 97 south.
294.0 At intersection turn left, continuing on U.S. 97.
294.4 Turn right, continuing on U.S. 97.
296.5 Center of bridge over Columbia River.
297.0 After crossing I-84, turn right into Biggs (old U.S. 30). Deschutes State Park campground is 4.5 mi to west.

***End of Day 2.***

## DAY THREE

Day 3 includes stops looking at a variety of features, including Missoula flood deposits, older soils that may relate to pre-late Wisconsin episodes of Missoula flooding, and recent landslides. The road log ends at Cascade Locks near the west end of the Columbia River Gorge. The route crosses the Columbia River to the Washington side, then follows Washington Highway 14 until crossing back to Oregon at The Dalles. From The Dalles, continue west, driving part of the historic Columbia River Scenic Highway, ending at Cascade Locks. Maps: The Dalles 1°×2° sheet; Hood River and Goldendale 1:100,000 sheets.

### En route to Stop 3.1

Proceed east to Biggs Junction, enter U.S. Highway 97 northbound, and cross the Columbia River. Ascend U.S. 97, past replica "stonehenge" on the knob to the east, to Washington Highway 14 and turn left (west). Proceed about ¼ mi west, pull over, and park on the large gravel area south of Highway 14 near its junction with the northbound continuation of U.S. 97.

### Stop 3.1. Maryhill gravel bar

***Private property! Please obtain permission before entering.***

This is a high longitudinal bar, 1 km long with a crest at an altitude of 255 m (840 ft). A gravel pit provides a three-dimensional exposure of west-dipping foresets of alternating sand and gravel containing clasts as large as 30–40 cm. The top of the section is only locally exposed.

This high coarse deposit contains evidence of subaerial exposure between several of the depositional units. The tops of some foresets are composed of concentrations of cobbles with a silty matrix, zones that appear armored and have a slightly browner cast. The silt matrix is inferred to be the result of postdeposition loess that migrated down into interstices at the top of the gravel bar. The contacts with overlying gravel are commonly unconformable, the cobbly lag having been partly eroded in the course of subsequent deposition. There are about six of these units separated by contacts like this, indicating that at least six floods were capable of transporting gravel at this elevation. According to our modeling results, a discharge of at least 6 million $m^3/s$ would be required to inundate this bar. This is the highest discharge value we have yet been able to associate with evidence of multiple floods in the lower Columbia Valley.

Within many of these depositional units separated by the contacts described above are several foresets with no evidence of depositional hiatus. These foresets may reflect flow pulses or gravelly bed forms moving over the surface during a single flood. A charcoal sample from the lowest stratigraphic unit exposed in the east wall yielded a radiocarbon date of 32,630±610 $^{14}C$ yr B.P.

### En route to Stop 3.2

Continue west on Highway 14, traveling along a bench immediately south of the tight, southward verging, overturned anticline and thrust fault that forms the Columbia Hills to the north. Several landslides and thick colluvial and alluvial-fan deposits have been shed south off of this structure. About 2 mi from Stop 3.2, we pass Maryhill Museum, containing an eclectic collection of European and American art, Native American artifacts, and the former crown jewels of Romania. Maryhill Museum was originally a residence of Sam Hill, who started building it in 1914, apparently to fulfill a desire to live in a castle like those he had seen along the Rhine River.

About 1.25 mi past the museum, Highway 14 crosses steeply dipping lava flows from Haystack Butte. Continue west, having good views of the extensive butte-and-basin scabland across the Columbia River just downstream of the Deschutes River confluence. Road cuts show alluvial fan and landslide deposits from the Columbia Hills. Continue through Wishram Heights and on toward the wide, open synclinal valley of The Dalles. Prominent trimlines are carved into the alluvial fans at several levels, the highest ones consistently at altitude 290±10 m (960±40 ft). There are good views of the Fairbanks Gap and Petersburg divide crossings on the south side of the river. In good lighting, a pronounced trimline can be seen on the southwest flank of Sevenmile Hill on the far (west) side of The Dalles.

The course of the Columbia River follows structural lows. From The Dalles eastward to the John Day confluence, the path of the river largely follows the Dalles-Umatilla syncline, flanked on the north by the Columbia Hills anticline. The wide valley of The Dalles is a large synclinal valley. The rapids and holes of "The Dalles of the Columbia" corresponded with the area where the river intercepts resistant basalt units that dip gently to the southwest into the syncline.

Turn left (south) onto U.S. 197, crossing alternating areas of gravel and scabland. Continue across the Columbia River, follow U.S. 197 south across Interstate 84. On the east side of the road is a nice exposure of pillow basalts. The next stop is about 1.25 mi southeast of I-84 on U.S. 197.

### Stop 3.2. Late Wisconsin rhythmites and pre-late Wisconsin rhythmites(?)

(By David Cordero and Scott Burns)

**Site stratigraphy:** The oldest unit in the immediate study area is the Dalles Formation, well exposed in the next roadcut northwest of this stop. Resting unconformably on the Dalles Formation are fine sand and silt beds, which we believe to be ancient Missoula flood deposits, slackwater facies, possibly interbedded with loess (Figure 27). Unlike the composition of the Dalles Formation, mica is a common mineral in these younger deposits, indicating a Columbia River source. The presence of sparse pebbles of varied lithology, including some granitic, is the strongest evidence for the fluvial, instead of eolian, origin of these deposits. The deposits contain five well-developed paleosols with strong carbonate horizons and extensive bioturbation (Figure 27). They are in turn unconformably overlain by late Wisconsin Missoula flood deposits, also fine sand and silt. Scattered pebbles, again in groups, serve as evidence for flood origin. The late Wisconsin deposits appear massive at first glance, but actually consist of several rhythmites deposited by separate late Wisconsin floods. Thin, discontinuous layers of coarse basaltic sand can be traced at several levels within the "massive silt." At the top of the section is latest Pleistocene loess on which the modern soil is developing.

**Significance of the site:** Besides the Missoula flood deposits of latest Pleistocene age, deposits we attribute to much older Missoula flood events are preserved here. Evidence for the antiquity of these latter deposits are the well-developed paleosols they contain. Each paleosol contains a Bk or K horizon ranging in carbonate development from Stage II to Stage IV, in contrast to the modern soil, developed on the most recent flood deposits and loess, which contains virtually no carbonate and has been forming for close to 10,000 years. Each of the five paleosols must consequently represent a much longer period of soil formation—much more than 10,000 years—during which carbonate could be concentrated in the soil. Thus several floods must have occurred, before the 15- to 12-ka period of late Pleistocene jökulhlaups began, and long periods of time occurred between each of these ancient floods.

We are not the first to suggest the occurrence of pre-late Wisconsin Missoula floods. Bretz and others (1956), Baker (1978), and McDonald and Busacca (1988) are among those who have recognized evidence of older episodes of catastrophic flooding. Tephras found within these older flood deposits at this site have not yet been dated or correlated with certainty with tephras of known age. The most abundant tephra at the site has a chemistry most closely resembling the Dibekulewe tephra of Morrison and Davis (1984), a 400-ka fine ash of unknown source found in western Nevada. As the tephra here is fairly coarse, this correlation, if correct, may help to reveal the source of this ash.

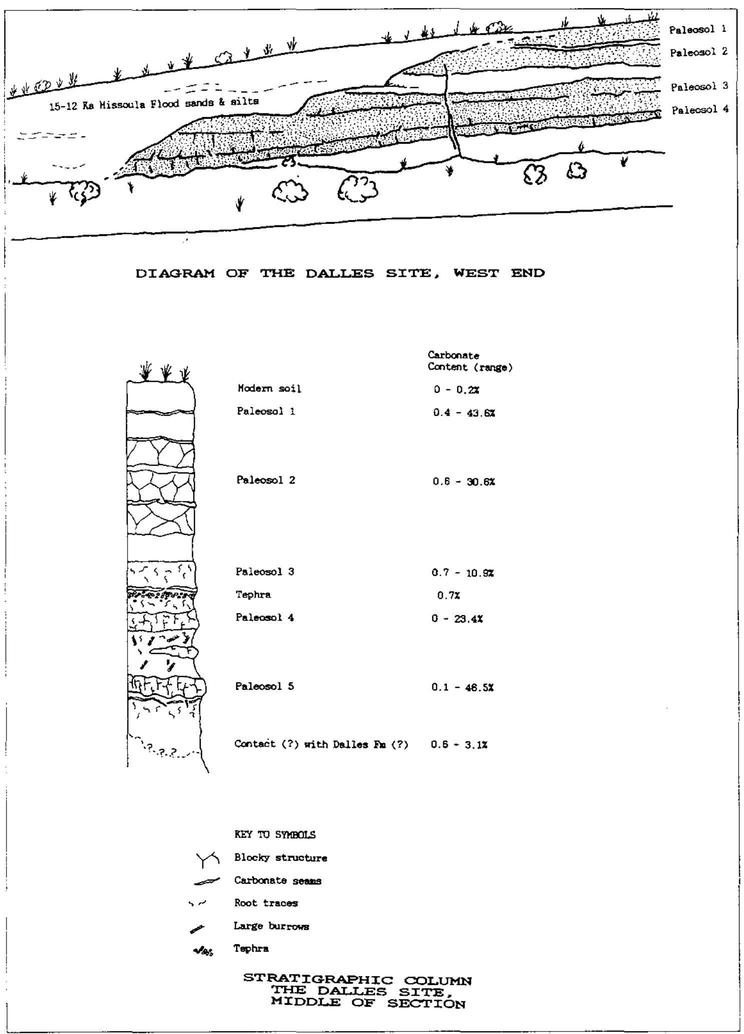


*Figure 27. Sketch and stratigraphic column of exposure at Stop 3.2.*

**En route to Stop 3.3**

Proceed back to Interstate 84 and head west, passing through The Dalles. The Columbia River takes a broad sweep to the south and then north, as it leaves the structural basin and crosses the Columbia Hills anticline that trends southwest across the river's path. Capping the Columbia River Basalt Group locally is the Dalles Formation, which dips down to form the bluffs south of the city. Some recently active landslides with movement as great as 5 cm/yr have affected the eastern portion of The Dalles (Rosenfield, 1992).

Past The Dalles, where the highway and river turn north, is butte-and-basin scabland at highway level. To the west is the rising flank of Sevenmile Hill and Crates Point, defining the south limb of the Columbia Hills anticline (also called the Ortley Anticline) where it has been breached by the Columbia River. A prominent trimline has been etched into the hill slope, below which floods stripped loess from the top of the Columbia River Basalt Group. This trimline is at 315±12 m (1,000±40 ft) at the southwest end of the slope and descends to 290±12 m (960±40 ft) at the Rowena Gap constriction near Crates Point. Small granitic erratics lie as high as 285±12 m (940±40 ft) at Crates Point.

The Columbia River Gorge National Scenic Area, managed by the U.S. Forest Service, extends as far east as the Deschutes River confluence. The true physiographic gorge is between The Dalles and Portland, where the Columbia River crosses the Cascade Range. The core of the range has been uplifted several hundred meters during the late Neogene, raising the Columbia River Basalt Group and exposing older Tertiary volcanic, volcaniclastic, and sedimentary rocks below. These uplifted rocks, locally faulted and folded, are capped by the products of numerous small late Tertiary and Quaternary volcanoes.

Pass through Rowena Gap and exit Interstate 84 at Rowena (Exit 76). From here, proceed east on a segment of the historic Columbia River Scenic Highway. The scenic highway, the first successful highway to cross the Cascade Range, was constructed between 1913 and 1915, largely by the inspiration of Sam Hill. It was essential to Hill and Chief Engineer Samuel Lancaster that the road harmonize with the beauty of the Gorge. It was also important that the highway serve as a functional crossing of the Cascade Range: the engineering specifications dictated a minimum width of 24 ft, a maximum grade of 5 percent, and a minimum curve radius of 100 ft. The result was graceful sets of curves, separated by viaducts, bridges, and tunnels, all faced with natural stone worked by European masons, as the road clung to the cliffs on the Oregon side of the river.

### Stop 3.3. Rowena Crest

Across the river, a large pendant-eddy bar was deposited downstream of a basalt salient at the downstream end of Rowena Gap. This bar underlies most of the town of Lyle (Figure 28) and originally extended across the present mouth of the Klickitat River. Similar pendant bars flank expansions downstream from each constriction in the Gorge.

Stratigraphy in exposures of eddy deposits northwest and across the Klickitat River from Lyle, near the 513-ft benchmark, indicate that several floods achieved stages of 180 m (600 ft). In particular, an exposure in the gravel pit north of the bench mark exposes at least seven sets of east-dipping foresets of granule gravel to coarse sand. These sets of foresets are capped by pebbly lags that have silty matrices. We interpret these silt-gravel horizons to be the result of loess deposition between separate Missoula floods. Some of the foreset sets are unconformably overlain by as much as 25 cm of steeply dipping loose sand and gravel that may be scree deposited between floods. This gravel deposit is apparently inset against a slightly higher (to altitude of 195 m [640 ft]) and coarser unit to the north (Figure 28) that apparently represents an older and larger flood. The minimum discharge required to inundate an altitude of 180 m (590 ft) is about 4 million $m^3/s$, which indicates that there have been a least eight floods to surpass that discharge, with at least one that was perhaps substantially larger.

The surface on which we stand at an elevation of 220 m (720 ft) has been stripped of its preflood cover. Locally, such stripped basalt surfaces and trimlines are evident to about 290±12 m (960±40 ft)—an altitude about 25 m lower than maximum flood stage near The Dalles.

### En route to Stop 3.4

Continue west on the historic highway, passing Rowena Dell and dropping into the town of Mosier, which lies in a synclinal valley. Like the bars at Petersburg and Fairbanks, flow spilling over a divide between the Columbia River and Mosier Creek deposited a large delta composed of southwest-dipping foresets of cobble-pebble gravel and sand. A discharge of at least 2.5 million $m^3/s$ was required for flow to overtop the divide. Similar to the delta at Petersburg, several depositional units are separated by erosional unconformities, perhaps evidence of multiple flows. One exposure shows at least seven such units. The second unit from the top contained a piece of dung(?) that yielded a radiocarbon date of 13,695±95 $^{14}C$ yr B.P., indicating that at least two flows subsequent to this date were capable of transporting gravel over this divide.

West of the town of Mosier, a large eddy bar was deposited on the west flank of the Mosier syncline. The bar is composed of well-sorted sand and fine gravel deposited in east-dipping foresets. We infer that this sediment was part of the suspended load of the flood, deposited in a large recirculation zone; that zone developed as a part of the flow was diverted into the topographic low that follows the southwest-trending axis of the Mosier syncline. Exposures in this bar do not show the sweeping unconformities or zones of loess-impregnated sand that can be seen in lower altitude eddy bars, which suggests that perhaps flood flow was only large enough to emplace this deposit. The altitude of this deposit requires a discharge in excess of 4.5 million $m^3/s$ to be overtopped. A piece of charcoal contained in the deposit has a radiocarbon age of 14,795±150 $^{14}C$ yr B.P., which perhaps indicates that this deposit was emplaced relatively early in the flood sequence.

Return to Interstate 84 at Mosier and follow it to Cascade Locks. We first pass through Bingen Gap, a constriction formed by the river's passage through the Bingen anticline. The town of White Salmon is built upon a large pendant bar in the lee of the downstream end of Bingen Gap on the north side of the river. One of the larger bars in the Columbia River Gorge, White Salmon bar (Bretz, 1925) rests on a basalt platform, is about 2 km long, and ascends from 120 m (400 ft) at its apex to almost 240 m (800 ft) at its downstream end.

The Hood River valley was inundated by backwater from the Missoula floods. Newcomb (1969, p. 6) reported "fine-grained lacustrine deposits" as high as altitude 245 m (800 ft), probably slackwater deposits of Missoula floods. The highest ice-rafted er-

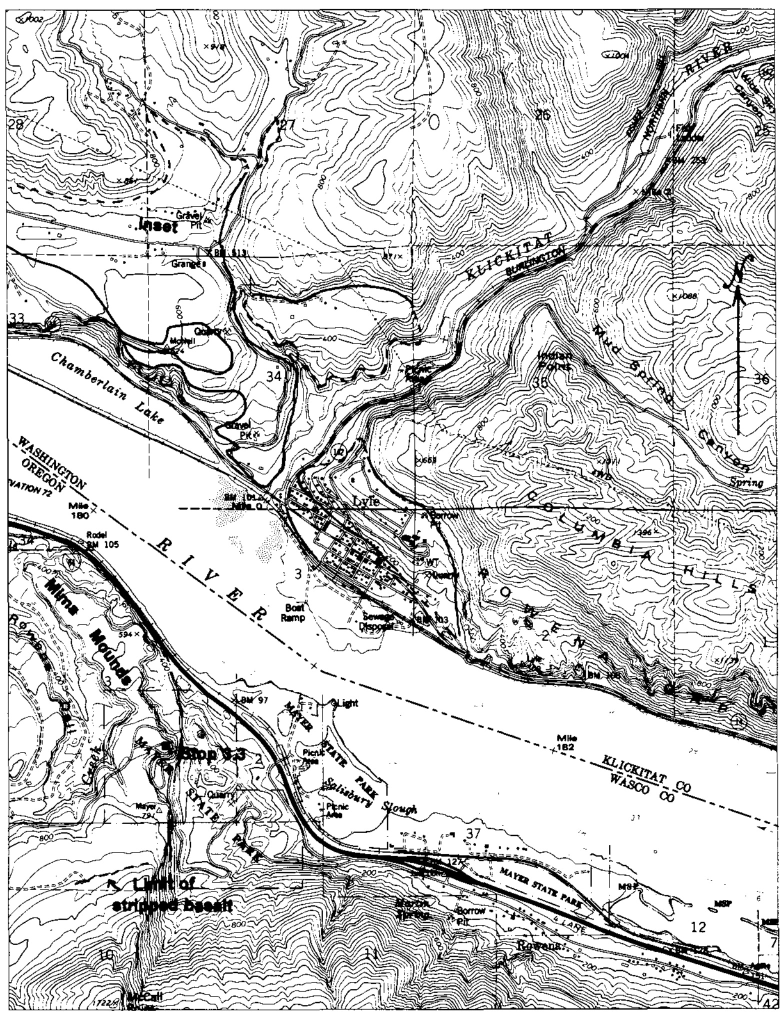


*Figure 28. Topographic setting, geomorphic features, and approximate distribution of Missoula flood deposits (outlined by heavy lines) near Lyle. Topographic base from Lyle USGS 7.5′ quadrangle. Land sections (numbered) are 1 mile (1.6 km) across.*

ratics in the Hood River valley are between altitudes of 255 and 270 m (840–880 ft). If this was the maximum stage achieved by the largest flood, the water surface dropped substantially through Bingen Gap.

The best examples of polished, fluted, and scoured basalt surfaces known in the Columbia River Gorge are in the gardens of the Columbia River Gorge Hotel, a 1921 structure listed on the National Historic Register.

Between Hood River and the downstream end of the Gorge below Crown Point, we find little conclusive evidence of maximum

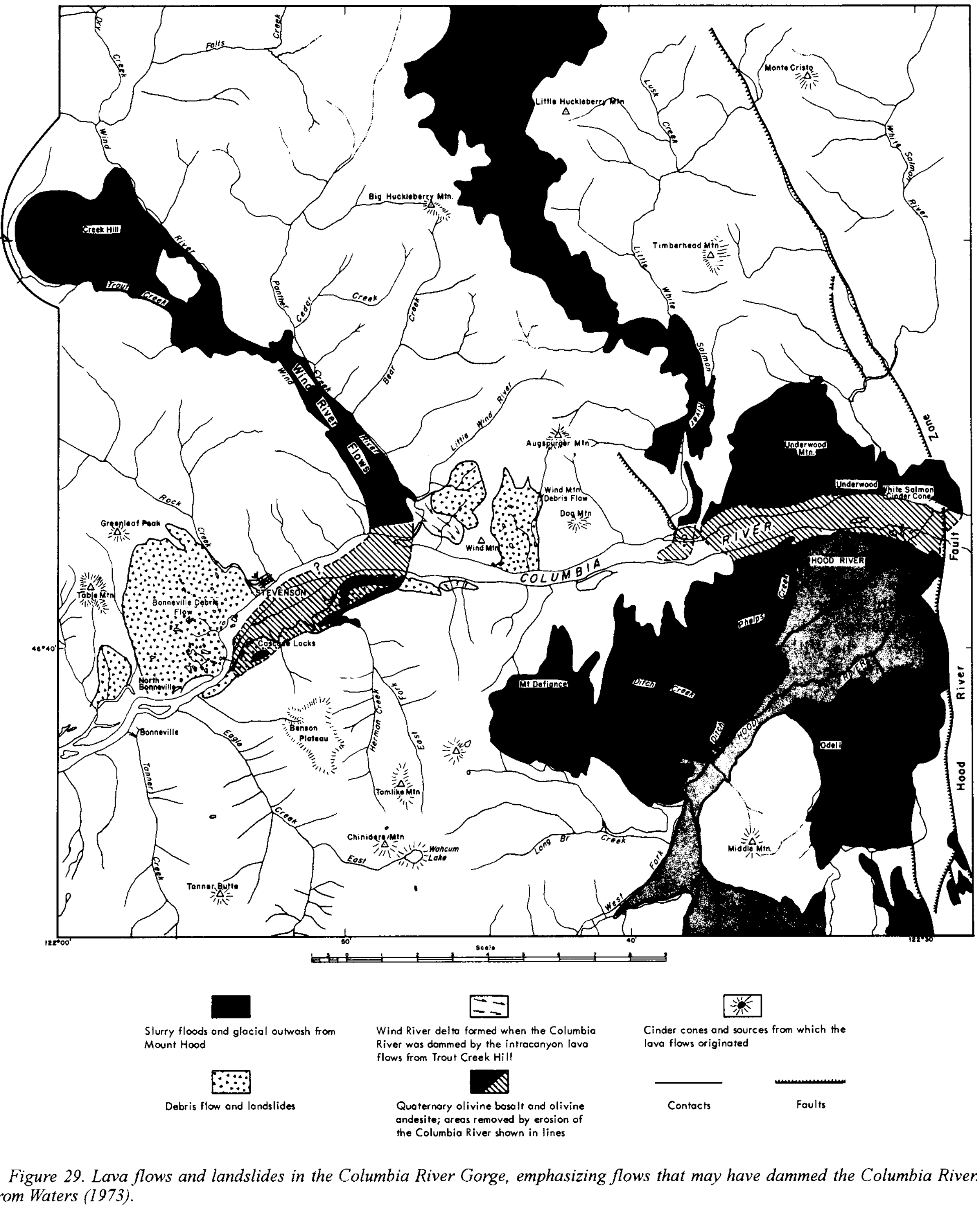


*Figure 29. Lava flows and landslides in the Columbia River Gorge, emphasizing flows that may have dammed the Columbia River. From Waters (1973).*

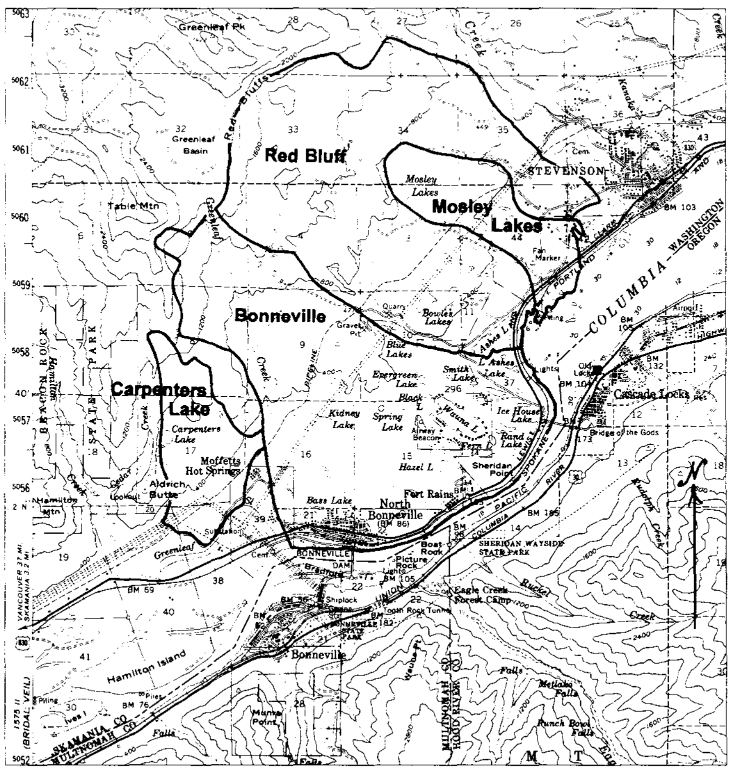


*Figure 30. Landslide complex near Cascade Locks. The Bonneville landslide was the most recent one and may have temporarily dammed the Columbia River about 500 years ago. Topographic base is the Bonneville 15′ quadrangle. Land sections (numbered) are 1 mi (1.6 km) across. After Minor, 1984.*

flood stage. The combination of dense vegetation and abundant mass wasting hinder the search. It is clear that by Portland, however, the maximum water surface descended to 120 m (400 ft) (Allison, 1935), indicating an average gradient of 0.003. Most of the drop probably occurred near Crown Point, at the downstream end of the Columbia River Gorge.

For several kilometers downstream of Hood River, the valley of the Columbia River is particularly constricted, generally narrower than 2 km. About 5 km downstream of Viento State Park, the Columbia River is encroached upon by the Wind River landslide, one of several recent or presently active landslides in the Columbia River Gorge (Figure 29). The upper part of the Wind River landslide moves as fast as 15 m/yr (Allen, 1984).

Downstream of the Wind River landslide, the Columbia River valley funnels between the twin granodiorite intrusions of Shellrock and Wind Mountains. Shellrock Mountain, with its constant raveling of platy rubble at a repose angle of 42°, was a major obstacle to early road building through the Gorge. On the north side of the river, between Wind Mountain and Wind River, a large pendant bar was deposited in the lee of Wind Mountain as flow expanded out of the constriction. This bar is about 2 km long and 125 m high.

The broad, flat surface west of Wind River and under the town of Carson is underlain by basalt flows: several lava flows that originated from Trout Creek Hill (Figure 29) and moved down the Wind River valley about 340±75 ka (Korosec, 1987), temporarily damming the Columbia River to a depth of at least 45 m (Waters, 1973). The evidence that these basalt flows and related fluvial deposits fill valleys that were entrenched to near-present grades, along with the local presence of pre-flood Columbia River gravel near the present margins of the Gorge, indicate that the Missoula floods did not substantially widen or deepen the Columbia River Gorge. The famous waterfalls of the Columbia River Gorge were probably not formed by the passage of the Missoula floods, though they were probably somewhat enhanced by erosion of talus and other unconsolidated deposits from their bases. The falls exist more likely because of the layered heterogeneities within the south-dipping Columbia River Basalt Group.

Exit Interstate 84 at Cascade Locks and proceed to Cascade Locks Marine Park.

**Stop 3.4. Bonneville landslide**

Cascade Locks and Canal were completed in 1896, permitting steamboat navigation between the coast and The Dalles. Previously, the Columbia River dropped 10–15 m within about 400 m in a set of rapids called the "Cascades of the Columbia," the namesake of the Cascade Range. The rapids as well as most of the Cascade Locks and Canal were drowned after completion of Bonneville Dam in 1938.

These rapids were the remnants of the toe of the Bonneville (or "Cascade") landslide complex that probably once completely crossed the Columbia River. The landslide complex consists of four separate mass movements (Wise, 1962; Minor, 1984); the largest ones, the Red Bluff and Bonneville landslides, head from the 500-m escarpment that runs southeast at the flanks of Table Mountain and Greenleaf Peak (Figure 30). The total area of landslide debris is about 35 km$^2$. The Bonneville landslide has most recently affected the Columbia River, pushing it to the south side of the valley and constricting it to a width of less than 400 m.

According to Waters (1973, p. 147), the cause for most of the landslides along the north side of the river in the Gorge is a thick clay saprolite developed on zeolitized rocks of the Ohanapecosh Formation. Rainwater, penetrating the joints of the Columbia River Basalt Group and the sand and gravel of the underlying Eagle Creek Formation, is concentrated at the saprolite layer capping the Ohanapecosh Formation, raising the pore pressure and converting the saprolite to slippery clay. The contact at the top of the Ohanapecosh Formation slopes 2°–10° south toward the Columbia River, acting as a "well-greased skidboard" upon which the Bonneville landslide and others within the Gorge have slid.

The Bonneville landslide gave rise to the Native American legend of the "Bridge of the Gods." Oral histories of the region, summarized by Lawrence and Lawrence (1958, p. 33), indicate that the Native Americans "could cross the river without getting their feet wet" and that "the falls are not ancient, and that their fathers voyaged without obstruction in their canoes as far as The Dalles". The Natives also said "that the river was dammed up at this place, which caused the waters to rise to a great height far above, and that after cutting a passage through the impeding mass down to its present bed these rapids first made their appearance."

Early explorers noted large stands of partially submerged tree stumps between Cascade Rapids and The Dalles. The origin of this "submerged forest" was controversial among explorers, settlers, and geologists (Lawrence and Lawrence, 1958), but eventually it became clear that they resulted from the permanent 10- to 15-m rise in river level after formation and incision of the Bonneville landslide dam. Lawrence and Lawrence (1958), on the basis of radiocarbon ages of 670±300 $^{14}$C yr B.P. and 700±200 $^{14}$C yr B.P. for two submerged stumps, concluded that the landslide occurred about A.D. 1100.

Since then, there has been additional dating, summarized by Minor (1984), in connection with archaeologic investigations and drilling done during construction of the second Bonneville Dam powerhouse. Five wood samples inferred to be in or below landslide debris near the site of the second powerhouse yielded radiocarbon ages of 5550±90 to 400±70 $^{14}C$ yr B.P. Radiocarbon dates on 26 samples of material found at five archaeologic sites on landslide debris near Bonneville Dam range from modern to 740±100 $^{14}C$ yr B.P.

We have converted all of the dates reported by Minor (1984) to calendar years with CALIB 3.0.3, a calibration program distributed by the Quaternary Isotope Laboratory at the University of Washington (Stuiver and Reimer, 1993).

The following assumptions were made in the calibration and interpretation of the results:

1. The stratigraphic context of all the samples was correctly reported, and furthermore (a) there was no contamination of prelandslide samples with modern or recent carbon, and (b) there was no old carbon in the post-landslide samples. It is, however, possible that old wood was used at archaeological sites.

2. All dates were corrected for $^{13}C$ activity. Violation of this assumption would not make a significant difference on the wood samples from trees that predated the landslide, but it could make a substantial difference for the material (unknown to us) dated at the archaeologic sites.

3. A lab error multiplier factor of 2, as recommended for nonhigh-precision dates. This yields larger but more realistic calendar-year ranges for the samples.

Results:

1. Considering 1$\sigma$ uncertainty in calendar-year age for each sample, the ranges of stratigraphically bracketing samples indicate that the landslide postdates A.D. 1409 and predates A.D. 1410.

2. Considering 2$\sigma$ uncertainty in calendar-year age for each sample, the ranges of stratigraphically bracketing samples indicate that the landslide occurred after A.D. 1300, and before A.D. 1650.

3. Considering 2$\sigma$ uncertainty in calendar-year age for each sample and the age of a tree growing on the landslide that apparently postdates the landslide (Lawrence and Lawrence, 1958), the landslide occurred between A.D. 1300 and A.D. 1562.

These results place the landslide a few hundred years later than previously thought. This is primarily due to a 400±70 yr B.P. radiocarbon date obtained on wood from Columbia River sediment below the landslide. This date was regarded as anomalously recent in Minor's (1984) report and was not included in that report's age derivation.

It is interesting to speculate about what might have happened when the landslide dam was overtopped. In view of the morphology of the landslide at Cascade Locks, the river may have been dammed to an elevation of 75 m (240 ft), and water may have been impounded as far upstream as Arlington. Breaching may have been catastrophic; the whaleback forms of Bradford, Robins, Hamilton, and Ives Islands, just downstream from the landslide suggest flood-formed features. A flood from the Bonneville landslide is accepted by archeologists studying the lower Columbia valley. For example, Pettygrew (1981, p. 121) inferred that "the flood destroyed many aboriginal settlements; it also may have caused major changes in the topography of river channels and land surfaces. As a consequence, villages may have been reestablished at new sites, in response to shifted salmon migration routes and alterations in the river and slough channels used for transportation." Pettygrew (1981, p. 122) stated that there was only one known site that shows evidence of occupation before and after the flood, and at this site there was a thick layer of "sterile" [artifact-free] silt deposited above strata containing organic material that yielded a radiocarbon date of 850±180 $^{14}C$ yr B.P.

In the Sandy River drainage 30 km downstream, Tom Pierson and Jim O'Connor (USGS-Vancouver, unpublished data) have found Columbia River sand deposited more than 30 m higher than any historic Columbia River flood stage. These deposits are substantially higher than conceivable stages of snowmelt- or rainfall-runoff floods and may have resulted from breaching of the Bonneville landslide. Samples of charcoal immediately below this sand at Dabney County Park and Oxbow State Park yielded dates of 520±110 and 440±60 $^{14}C$ yr B.P. The more precise date equates to a 1$\sigma$ range of A.D. 1405–1635 and a 2$\sigma$ range of A.D. 1300–1953. If this sand was indeed deposited by a flood from the failed landslide dam, then breaching of this dam was probably closer to 500 years ago rather than the 800–900 years ago generally cited.

**DAY 3 ROAD LOG** (mileage is approximate)

| Miles | |
|---|---|
| 0.0 | Deschutes State Park overflow area. |
| 0.2 | Turn right (east) onto Oregon 206 (old U.S. 30). |
| 1.6 | Junction with Oregon 206 southbound, continue east on U.S. 30. |
| 4.2 | Entering Biggs Junction. |
| 4.6 | Junction with U.S. 97. Turn left (north). |
| 4.9 | Bridge over Columbia River. |
| 7.1 | Junction with Washington 14, turn left (west). |
| 7.5 | Junction with U.S. 97 (north), continue west on Washington 14. |
| 7.8 | Stop sign at junction with U.S. 97. Pull into large gravel area on left (south) side of Washington 14: **Stop 3.1.** Maryhill Bar ***(Private property!)*** When you leave, continue west on Washington 14. |
| 9.9 | Maryhill Museum on left. |
| 11.0 | Enter Columbia River Gorge National Scenic Area. |
| 11.2 | In next 1.4 mi, pass through outcrops of 0.9-Ma basalt from Haystack Butte. |
| 13.0 | Flood-transported boulders of basalt from Haystack Butte. |
| 15.0 | Celilo Falls overlook, good view of scabland across river. |
| 15.9 | Wishram Heights. |
| 17.2 | Good view to south of Fairbanks Gap divide crossing. |
| 19.8 | View to south of Petersburg divide crossing. |
| 20.7 | View of Columbia River following axis of The Dalles syncline. |
| 22.1 | Basin-and-butte scabland. |
| 23.6 | Turnoff to Horsethief State Park (restrooms available). |
| 25.2 | Junction with U.S. 197. Turn left (south). |
| 28.0 | Cross Columbia River, note scabland in channel. |
| 28.4 | Fishing platforms on right. |
| 28.6 | Pass over I-84. |
| 28.9 | Stop sign and junction with U.S. 30. Turn left to continue south on U.S. 197. |
| 30.2 | Road cut through the Dalles Formation. |
| 30.3 | **Stop 3.2.** Pre-late Wisconsin loess and flood(?) stratigraphy. Park on gravel area on right (west) side of road. When you leave, turn around (***Watch for traffic!***) and return north on U.S. 197. |
| 31.7 | Junction with U.S. 30, bear right. |
| 32.0 | Enter I-84 westbound. |
| 34.2 | View of trimline about halfway up Sevenmile Hill. |
| 37.7 | Enter Rowena Gap, cut through the Columbia Hills anticline. |
| 42.3 | Exit I-84 at Rowena (Exit 76). |
| 42.5 | Stop sign, turn left. |
| 42.6 | Bear left onto frontage road. |
| 42.7 | Two right turns to end up heading west on old U.S. 30. |
| 43.4 | Bear left toward Rowena Crest. |
| 45.3 | Turn left at Rowena Crest overview. |
| 45.5 | **Stop 3.3.** Rowena Crest. Park on right. When you leave, continue west on old U.S. 30. |
| 45.6 | Left onto old U.S. 30. |
| 47.8 | Gravel bar. |
| 51.6 | Enter Mosier. |
| 51.8 | Cross Mosier Creek. |
| 52.3 | Cross I-84 and enter westbound. |
| 56.4 | Rest area. |
| 58.2 | Hood River. |
| 60.4 | Columbia Gorge Hotel on right. |
| 63.6 | Mitchell Point. |
| 69.2 | Wind River landslide on north side of Columbia River. |
| 69.9 | Shellrock Mountain, on south side; Wind Mountain on north side of Columbia River. Both are granodiorite stocks. |
| 77.2 | Exit I-84 at Cascade Locks (Exit 44), continue west on U.S. 30. |
| 78.3 | Turn right at Marine Park, continue west under the railroad. |
| 78.6 | **Stop 3.4.** Bonneville Landslide at Cascade Locks. |

***End of trip.*** □

# Meditations on equilibrium punctuations in Oregon

*by John Eliot Allen, Emeritus Professor of Geology, Portland State University, P.O. Box 751, Portland, OR 97207*

**ABSTRACT**

Periodicity of abrupt geologic changes can occur on all scales from days to millions of years. Many examples of landform changes can be illustrated by features in Oregon that have been produced not only by earthquakes and volcanism but also by erosion and glaciation.

## INTRODUCTION

Quite recently in this old-timer's life, Eldredge and Gould (1972) proposed that instead of evolving slowly and evenly, life forms remain static for long periods of time and then are "punctuated" by sudden abrupt and obvious change. This revolutionary new idea of "punctuated equilibrium" caused me to rethink several features in Oregon that had puzzled me.

In the 1920s and 1930s, my generation was taught "uniformitarianism": the concept that the past is to be interpreted through what we see going on in the present. Evolution and geologic processes were thought to progress more or less evenly and steadily, except for earthquakes and volcanic activity.

Although William Morris Davis had early (1909) proposed the anthropomorphic periodic stages of "youth, maturity, and old age" in geologic processes, it was not until the 1960s that quantitative geomorphologists (Strahler, 1969, 1971; Leopold and others, 1964) began to demonstrate that periodicity could be important in landform development. At that time, I too began to realize that the idea of a "punctuated equilibrium" can be applied to more than evolution and that landforms can change abruptly instead of slowly and with regularity.

By the 1960s, "absolute" dating methods were supplementing the "relative" determinations of geologic age by fossil and stratigraphic correlation. Today, numerous techniques, including studies of U/Pb and K/Ar ratios, amounts of carbon 14, paleomagnetic reversals, rates of lichen growth, fission tracks of cosmic rays in obsidian, obsidian hydration, and dendrochronology (studies of annual growth of tree rings) are available to be used by geologists to determine periodicities in geology. Now we are even searching for periodicities in earthquakes and volcanic events.

## CATASTROPHIC EVENTS

On a large scale, the suggestion by Alvarez and others (1980) of dinosaur extinction caused by a comet impact at the end of the Cretaceous led to another hypothesis of twelve periodic mass extinctions with a periodicity of 26 million years (Raup and Sepkoski, 1984). Their extinction hypothesis was explained by another hypothesis that the earth was periodically bombarded by comets and meteorites pulled out of the "Oort Cloud" by a "Nemesis" passing star.

Atwater (1987), Peterson and Darienzo (1989), and Darienzo and Peterson (1995) recognized that occurrences of tsunami-generated sand layers alternating with peat in the swamp deposits of Oregon and Washington coastal estuaries supply ample evidence of past giant (more than Richter 8) subduction zone earthquakes. More than six of these have occurred at approximately 400-year intervals (actually varying from 200 to 600 years) during the last several thousand years.

## EROSION

Erosion is easily the most obvious and yet perhaps the most neglected geologic candidate for recognition of sudden rapid change. Equilibrium in erosion by water is a delicate balance, easily disturbed by changes in any one of a number of variables. The "profile of equilibrium" of a graded stream was emphasized by Mackin (1948). Erosion and deposition in humid regions, except for areas with large amounts of limestone with characteristic karst topography, are accomplished during heavy periodic rainfalls, floods, and landslides that occur for only a few days a year—or that in arid climates may not occur for many years. The U.S. Army Corps of Engineers has actually calculated the effects of 10-, 50-, and 100-year floods.

A common sight along roads in the residential Portland Hills such as Terwilliger Boulevard are trees that have a distinct bend near their base, which I was taught to attribute to soil creep in which the trees had been tilted downhill by creep and then had straightened themselves up. I no longer think that creep is a continuous slow process; I am sure it occurs almost entirely after periodic rainstorms.

As a long-time student of the Columbia River Gorge (Allen, 1932, 1984), I only recently realized that the narrow, deeply-incised chutes that occupy much of the canyon walls between the main tributary canyons were almost entirely eroded by periodic gully washouts after heavy rains during the last 12,000 years (Holocene). This is evident when every few years after rainstorms the culverts on the scenic highway are blocked with coarse debris and mudflows that may even cover most of the roadway.

Landslides are sudden and effective periodical erosional events, frequently caused in Oregon by rainstorms but also undoubtedly sometimes by earthquakes. During many years of teaching physical geology at Portland State University, while discussing the chapter on mass wasting, I would predict that if Portland had ten days of steady rain, there would be a million dollars worth of damage done by slides in the Portland Hills. In 18 years I never missed.

During the last few years, Oregon highways have been blocked by slides east of Tillamook, on the coast south of Bandon, and at Neahkahnie Mountain north of Nehalem. In the long run, many major landslides in the Pacific Northwest may have been caused by earthquakes. The mud slide that covered a Native American village at the northwest tip of the Olympic Peninsula about 400 years ago and the Cascade or Bonneville landslide that occurred a few hundred years ago may well have been initiated by great earthquakes. Earthquake-generated slides probably dammed Triangle Lake northwest of Eugene and Loon Lake south of Scottsburg. Periodicity of these landslides might be correlated with the evidence of coastal tsunamis.

Oregonians have been justly proud of their crystal-clear mountain streams, never asking how the tree-covered canyons through which the streams flow were cut by erosion. Clear water does not erode (except in limestone), so the canyons must have been deepened primarily during periodic flooding, when the debris supplied from the valley walls by creep and landslide was scoured out. This debris moved downstream during great floods, eventually to be deposited in flood plains, alluvial fans, or deltas.

A longitudinal section of a gravel bar shows that it is entirely composed of "foreset beds" dipping downstream. Only during floods does the gravel bar progress downstream by having debris rolled along its surface and down the sloping front of the bar.

Ice, of course, is another effective and frequently periodic erosional agent. During a particularly hard freeze in 1970, so much ice collected below Multnomah Falls that a miniature glacier more than 500 ft long and 50 ft thick moved down the canyon below the falls and broke the abutments of the highway bridge east of the lodge (Allen, 1984, p. 65).

Multnomah Falls is only one of many waterfalls in the Gorge that drop over cliffs now lying at the back of 100- to 500-ft-wide amphitheaters that are recessed several hundred feet from the main cliffs produced by the Bretz floods 12,000 years ago. It was only after seeing Multnomah Falls in 1970 after a severe freeze that I could explain this erosion: Freezing winds during periodic extra-cold winters blow the spray back and forth; it freezes in the joints of the brickbat basalt and pops the blocks out.

### VOLCANISM

The High Cascade volcanoes suggest periodicity of volcanic activity. Their relative ages can be determined by the degree of glaciation to which they have been subjected. Since most of their rocks are magnetically normal, most of the volcanoes are less than 700,000 years old.

Mount Thielsen, Mount Washington, Three-Fingered Jack, and the North Sister are older than Middle Sister, Mount Hood, Mount Shasta, Mount Adams, and Mount Baker. The youngest are Mount St. Helens, Mount Mazama, South Sister, and Lassen Peak. Detailed studies of Mount St. Helens have shown periodicity. Retallack (1981) has also described thick sections of volcanic ash or tuff of the Clarno, John Day, and Mascall Formations in central Oregon that show numerous periodic (and colorful) fossil soil horizons.

### PERIODICITY OF PUNCTUATIONS OF EQUILIBRIUM

**Hours to days:** Earthquake aftershocks.

**Days to months:** Earthquakes; rainstorm floods; some small landslides; bent trees.

**Years:** Minor faulting earthquakes; annual floods; small landslides; gully washouts; gravel bar progression.

**Decades:** Major faulting earthquakes; 10-year floods; numerous landslides; volcanic debris flows; glacial flash floods or "jökulhlaups"; "El Nino" climatic changes.

**Hundreds of years:** Subduction-zone earthquakes; great landslides; hundred-year floods; glacial bursts; volcanic activity; climatic change.

**Thousands of years:** Glacial intervals (Little Ice Age); climatic change; paleosoils.

**Millions of years:** Extinctions; "Nemesis" (comet impacts?); great basaltic floods; new species.

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**Editor's footnote**

Recent research may have added another candidate to the phenomena affected by "punctuation": geomagnetic field reversals, i.e., the periodic reversals of the polarity of the Earth, when north became south and vice versa. In an article of the April 20, 1995, issue of *Nature* (v. 374, p. 687–692), R.S. Coe, M. Prévot, and P. Camps describe their study of lava flows at Steens Mountain in Harney County. Their findings suggest that, at times, the geomagnetic field was changing direction so rapidly that the effect was recorded in some individual flows while they were cooling. The calculated speed of 3° per day is on the order of 1,000 times faster than previously observed variation rates. The authors conclude "that rapid jumps of field direction occur many times during reversal of polarity." Their final assessment states: "This is not to suppose that geomagnetic reversals take place much more quickly than the several thousand years currently supposed, but rather to suggest that polarity transitions may be punctuated by episodes of extraordinarily rapid field change." □

## Camp Carson mine in Union County successfully reclaimed

Federal and state agencies and a La Grande-based construction firm worked cooperatively this summer to clean up and stabilize an abandoned placer mine site at Camp Carson along Tanner Gulch Creek in the Wallowa-Whitman National Forest. The site is approximately 20 mi south of La Grande. The project was completed in July and will protect critical salmon habitat in the upper Grande Ronde River. Cooperating agencies included the USDA Forest Service (USFS), who contributed $45,000 to the project; the Bonneville Power Administration, who contributed $20,000; and the State of Oregon Watershed Health Program, whose contribution of $45,000 was administered by the Oregon Department of Geology and Mineral Industries (DOGAMI).

Gold mining at the Camp Carson mine site, one of the largest hydraulic placer gold mines in Union County, began in 1872. The site was mined intermittently over a period of many years, with the most intense mining taking place in 1893 and 1894. Recently, gravel that had been placed on the edge of a steep hillside over Tanner Gulch Creek began washing down into the creek. From there the sediment was carried into the upper Grande Ronde River, where it began affecting critical salmon-spawning habitat. In addition, deep cracks forming at the top of the hill indicated that a massive landslide was likely to occur.

The USFS, with technical help from DOGAMI, designed a reclamation plan to rehabilitate the site and prevent further damage to the fish habitat. The actual reclamation work was done during July under contract by Mi-Trac Construction Company of La Grande. Mi-Trac controlled sediment runoff at the site, stabilized the steep slope that was threatening to slide into the creek, recontoured the site so that vegetation could grow on the hillside, dewatered the landslide, and built structures to contain any sediment that might come off the site in the future.

The work was supervised by the USFS working with DOGAMI. According to Ben Mundie, reclamationist from DOGAMI's Mined Land Reclamation Program, "Because the reclamation was completed quickly and successfully, critical salmon-spawning habitat in the upper Grande Ronde River has now been protected." □

## DOGAMI PUBLICATIONS

**Released July 27, 1995:**

***Relative Earthquake Hazard Map of the Beaverton Quadrangle, Washington County, Oregon***, by M.A. Mabey, I.P. Madin, and D.B. Meier. Geological Map Series map GMS-90, 1 map, 6 p. text, $10.

***Relative Earthquake Hazard Map of the Lake Oswego Quadrangle, Clackamas, Multnomah, and Washington Counties, Oregon***, by M.A. Mabey, I.P. Madin, and D.B. Meier. Geological Map Series map GMS-91, 1 map, 6 p. text, $10.

***Relative Earthquake Hazard Map of the Gladstone Quadrangle, Clackamas and Multnomah Counties, Oregon***, by M.A. Mabey, I.P. Madin, and D.B. Meier. Geological Map Series map GMS-92, 1 map, 5 p. text, $10.

Each of these relative earthquake hazard maps outlines areas that are most susceptible to damage from earthquakes. These maps are particularly useful in a time of limited resources, for they provide a good indication of where earthquake mitigation efforts should be focused. Also shown on each map sheet, which is approximately 27 by 40 in., are three smaller maps that show relative liquefaction, ground-motion amplification, and slope instability hazards that were combined to develop the large relative hazard maps. The scale of each larger relative hazard map is 1:24,000; the smaller maps are at a scale of 1:55,000.

The three maps are part of a series of maps produced by a DOGAMI/Metro partnership in a study partially funded by the Federal Emergency Management Agency. The first map in this series was published by Metro as the *Relative Earthquake Hazard Map of the Portland Quadrangle*, with supporting data maps published by DOGAMI as GMS-79. The *Relative Earthquake Hazard Map of the Mount Tabor Quadrangle* was published earlier this year by DOGAMI as GMS-89. Through the same grant, Metro has also developed an inventory of buildings, critical facilities, and lifelines in the Portland metropolitan area for assessing seismic risk. Similar relative earthquake hazard maps of the Vancouver, Washington, area were prepared jointly with the Washington Division of Geology and Earth Resources and have already been released to the public as that agency's map GM-42.

These maps are available from the all the usual DOGAMI publication outlets in Baker City, Grants Pass, and Portland (see addresses below) and also from the Metro Data Resource Center, 600 NE Grand Avenue, Portland, OR 97232, phone (503) 797-1742, FAX (503) 797-1909.

**Released September 1, 1995:**

***Geologic Map of the Charleston Quadrangle, Coos County, Oregon***, by Ian P. Madin, Galan W. McInelly, and Harvey M. Kelsey. Geological Map Series map GMS-94, 1 map, 8 p. text, $8.

The Charleston 7½-minute quadrangle covers the area around Barview, Charleston, and South Slough, just south of the city of Coos Bay in Coos County. The new map was developed with particular emphasis on the geologic structure of the area, to provide basic geologic information about potential earthquake hazards in coastal Oregon. Such information can be used by private citizens as well as local and state government in making well-informed decisions on land use, earthquake-hazard mitigation, and emergency planning. The project was funded by the U.S. Geological Survey and the National Earthquake Hazard Reduction Program.

The full-color geologic map is at a scale of 1:24,000 (one inch on the map corresponding to 2,000 ft on the ground) and is accompanied by three geologic cross sections. In addition to showing the distribution of various geologic units, the map shows complex folding and faulting and identifies numerous faults that have been active in geologically recent time and may be active in the future. The map area includes the first Quaternary thrust fault in western Oregon, the Winchester fault, that has been confirmed by the digging of trenches, up to 150 feet long and 15 feet deep, across the fault.

The map also provides the most up-to-date depiction of the geology responsible for the spectacular scenery along this stretch of the Oregon coast and the geologic framework for the formation of South Slough, an estuary whose importance was recognized by the creation of the South Slough National Estuarine Reserve.

The eight-page text that accompanies the map contains rock-unit explanations, an extensive discussion of geologic structure, and brief descriptions of geologic history, resources, and hazards.

***Mist Gas Field map***, rev. 1995, with 1993-1994 production figures. DOGAMI Open-File Report O–95–1, 1 map, 9 p., $8.

Production figures of earlier years (1979–1992) are available as Open-File Report O–94–6 for $5.

**Released September 15, 1995:**

***An Economic Analysis of Construction Aggregate Markets and the Results of a Long-Term Forecasting Model for Oregon***, by DOGAMI mineral economist Robert M. Whelan. DOGAMI Special Paper 27, 123 p., $15.

Between 2001 and 2050, about 2.8 billion tons of aggregate will be needed by Oregon's economy. Recycling will satisfy about 200 million tons (about 7 percent) of that demand. The remaining 2.6 billion tons will have to come from mines and quarries. Five counties—Multnomah, Washington, Clackamas, Lane, and Marion—will account for half of the state's aggregate consumption. About 16 percent of the aggregate will be used for housing. Infrastructure will take up 19 percent of the total. Most of the rest will be used for nonresidential buildings and roads. This forecast is based on the assumption that Oregon's population growth rate will slow to 1.01 percent per year, while consumption will rise 0.53 percent per year, so that the overall per capita aggregate consumption will actually decline.

These are some of the results of the study that represents the first complete analysis of aggregate consumption in Oregon ever done. It answers many important questions that apply not only to Oregon but to other states as well.

The report is based on a large-scale economic model with extensive amounts of data. It explains how urbanization, population growth, and personal income affect aggregate consumption and why this study goes beyond the method of using per capita consumption as a basis of forecasting. It examines such issues as shipping costs, recycling, differences in road-aggregate needs between rural and urban counties, and the risks of regional monopolies. The second part of the report presents individual consumption forecasts, divided by end uses, for every county in the state.

The new publications are now available over the counter, by mail, FAX, or phone from the Nature of the Northwest Information Center, Suite 177, State Office Building, 800 NE Oregon Street #5, Portland, Oregon 97232-2109, phone (503) 872-2750, FAX (503) 731-4066; and the DOGAMI field offices: 1831 First Street, Baker City, OR 97814, phone (503) 523-3133, FAX (503) 523-9088; and 5375 Monument Drive, Grants Pass, OR 97526, phone (503) 476-2496, FAX (503) 474-3158. Orders may be charged to Visa or Mastercard. Orders under $50 require prepayment except for credit-card orders. □

## October 11 to be National Landslide Awareness Day

On that day, the Association of Engineering Geologists (AEG) will hold special public forums in 22 AEG sections across the country to share the landslide information known to engineering geology professionals with the general public. For more information, contact Jerome V. DeGraff, Fresno, California, phone (209) 297-0706 or FAX (209) 294-4809. □

# AVAILABLE PUBLICATIONS
# OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

## GEOLOGICAL MAP SERIES

| | Price | ☑ |
|---|---|---|
| **GMS-5** Powers 15' quadrangle, Coos and Curry Counties. 1971 | 4.00 | |
| **GMS-6** Part of Snake River canyon. 1974 | 8.00 | |
| **GMS-8** Complete Bouguer gravity anomaly map, central Cascades. 1978 | 4.00 | |
| **GMS-9** Total-field aeromagnetic anomaly map, central Cascades. 1978 | 4.00 | |
| **GMS-10** Low- to intermediate-temperature thermal springs and wells. 1978 | 4.00 | |
| **GMS-12** Oregon part, Mineral 15' quadrangle, Baker County. 1978 | 4.00 | |
| **GMS-13** Huntington/Olds Ferry 15' quads., Baker/Malheur Counties. 1979 | 4.00 | |
| **GMS-14** Index to published geologic mapping in Oregon, 1898-1979. 1981 | 8.00 | |
| **GMS-15** Gravity anomaly maps, north Cascades. 1981 | 4.00 | |
| **GMS-16** Gravity anomaly maps, south Cascades. 1981 | 4.00 | |
| **GMS-17** Total-field aeromagnetic anomaly map, south Cascades. 1981 | 4.00 | |
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| **GMS-29** NE¼ Bates 15' quadrangle, Baker/Grant Counties. 1983 | 6.00 | |
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| **GMS-31** NW¼ Bates 15' quadrangle, Grant County. 1984 | 6.00 | |
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| **GMS-33** Scotts Mills 7½' quad., Clackamas/Marion Counties. 1984 | 5.00 | |
| **GMS-34** Stayton NE 7½' quadrangle, Marion County. 1984 | 5.00 | |
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| **GMS-38** NW¼ Cave Junction 15' quadrangle, Josephine County. 1986 | 7.00 | |
| **GMS-39** Bibliography and index: ocean floor, continental margin. 1986 | 6.00 | |
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# OREGON GEOLOGY

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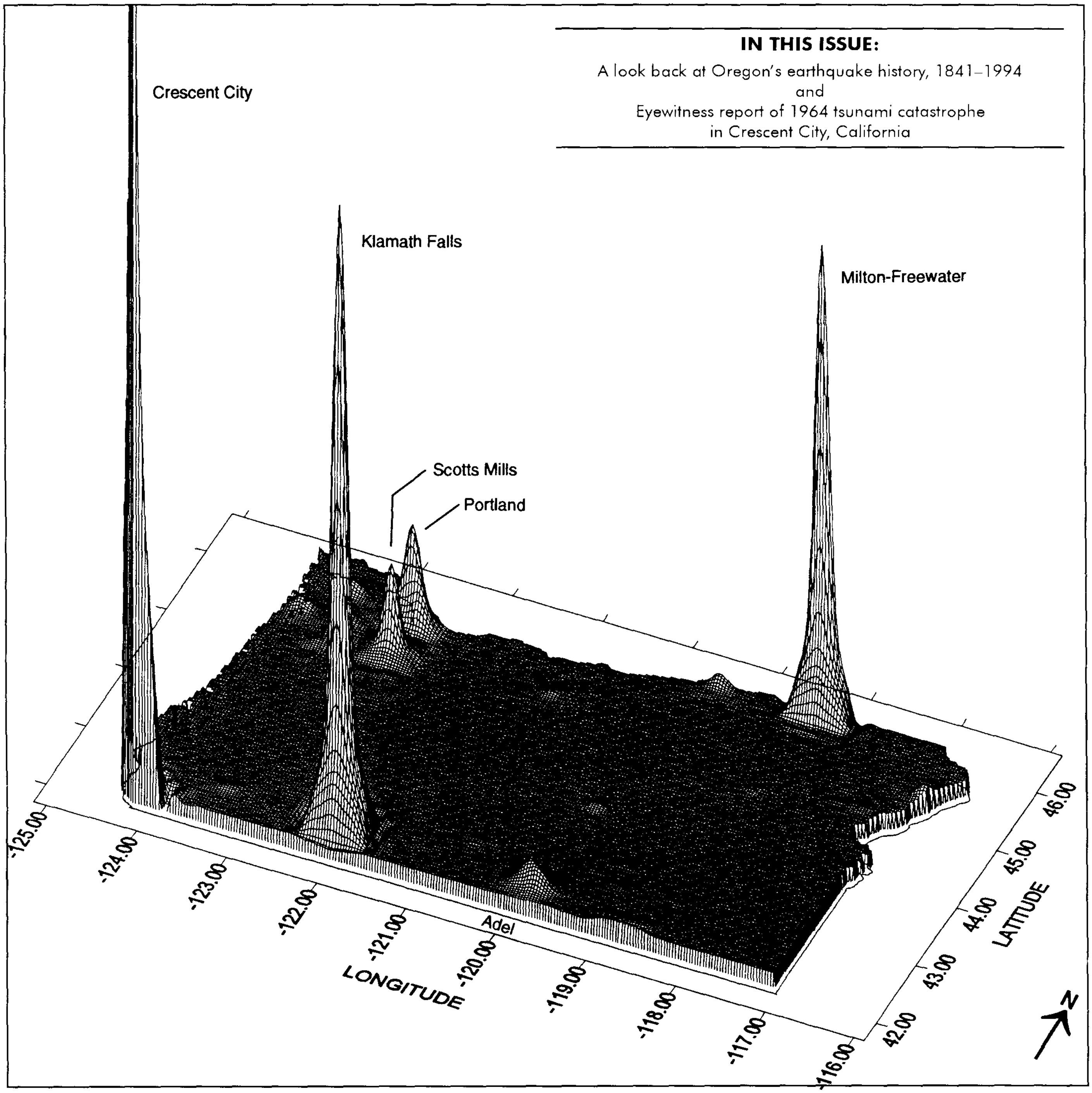
**IN THIS ISSUE:**

A look back at Oregon's earthquake history, 1841–1994
and
Eyewitness report of 1964 tsunami catastrophe
in Crescent City, California



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### Cover illustration

Relative historical (1841–1994) seismic moment release in Oregon. The highest peaks represent the moment release by the state's largest earthquakes including the 1873 and 1936 Milton-Freewater earthquakes; the Portland region, site of the 1962 earthquake; and the 1968 Adel epicentral area. The peak for the 1873 Crescent City earthquake has been truncated: It should be 16 times higher than the 1993–1994 Klamath Falls peak. Illustration by Doug Wright. Related article on Oregon's earthquake history begins on page 125.

# Summary of 1995 State legislation

*by Donald A. Hull, Oregon State Geologist*

The 1995 Oregon Legislature passed several bills that may be of interest to geologists and geotechnical engineers. These bills reflect concerns about the impact of geologic hazards, particularly tsunamis, and the public practice of geology by registered professional geologists and certified engineering geologists. A total of 14 bills dealing with seismic and related hazards were considered by the Legislature.

The growing awareness that Oregon faces large subduction zone earthquakes and resulting tsunamis has led to the formulation of strategies to mitigate risk to people and property. In the recent regular session of the Legislature two bills were passed to assist in the mitigation of tsunamis. Senate Bill 378 introduced by Portland Senator Ron Cease requires coastal schools to provide tsunami training and evacuation drills in grades kindergarten through eight. Senate Bill 379, also introduced by Senator Cease, will limit the construction of new essential facilities such as schools, hospitals and fire stations in the zone of expected tsunami inundation along low-lying portions of the Oregon coast. The legislation provides exceptions and exemptions for certain local communities and districts with boundary or topographic constraints. The bill includes a consultation process with the Department of Geology and Mineral Industries (DOGAMI) to evaluate alternative sites for the facilities that fall under the siting provisions. DOGAMI will propose a tsunami inundation line for the purposes of the act in formulating administrative rules to implement SB 379. The line will not necessarily be appropriate for other applications.

House Bill 2095 limits the practice of engineering geology to certified engineering geologists. Introduction of this bill reflected a concern that uncertified individuals were engaged in engineering geologic work. Another measure that relates to professional practice is HB 2135, which adds negligence to the activities such as incompetence, misconduct, or gross negligence for which professional registration can be suspended or revoked. This bill also gives the Board of Geologist Examiners the authority to reprimand a registrant who is found to be negligent.

Senate Bill 132 increases the membership of the Oregon Seismic Safety Policy Commission by adding a representative from Metro, the Portland regional government, a researcher on seismic issues from higher education, a representative of the commercial building owners and managers, and a member of the public at large.

A bill of possible future importance with respect to seismic hazards is HB 3087, which deals with licensing of hydroelectric facilities. The legislation provides for a hydroelectric task force, including a representative of DOGAMI, to develop recommendations for standards. The purpose of DOGAMI participation is to call attention to seismic hazards and design factors as privately operated hydroelectric dams are evaluated for relicensing. □

# Crescent City's destructive horror of 1964

*The view of the tidal wave from the lighthouse as described by Peggy Coons, curator of Battery Point Lighthouse in 1964. Reprinted here with permission from the Del Norte Historical Society files.*

Good Friday, March 27th, 1964, the morning was mild. The trade winds that prevail along the Pacific Coast had subsided. Little did I realize, as my husband Roxey and I went about our chores at the lighthouse, that before the next day had dawned high on Battery Island, we would watch four waves play havoc with the town and its people, smashing the city's business center along with some of the beach front homes in Crescent City, CA, and we would have a spectacular view of the whole performance. And as curators here at the lighthouse we would be called on by friends and tourists alike to relive this one night of horror almost every day since.

Perhaps I should stop to explain that Battery Island, three hundred yards from the mainland, is solid rock at the base and about three quarters of an acre, fifty-eight feet at the highest point near the flagpole. The lighthouse, completed in 1856, is 74 feet above mean sea level. The only access to this Historical Monument is walking across the ocean floor at low tide.

We spent the early part of the day planting a garden. Friday was our shore leave, so we crossed to the mainland at three o'clock to shop for Easter. Late that evening we struggled back across the rocky ocean floor with our supplies and stopped to rest before climbing another two hundred yards to the lighthouse. Exhausted, we turned in shortly after nine o'clock, unaware an earthquake and tidal wave had devastated Alaska.

We might have slept through the whole thing if I hadn't gotten up to go to the bathroom a little before midnight. I stood at the window, a full moon shining on the water below me. Somehow the first moment I saw the ocean I sensed something was wrong, for all the rocks around the island had disappeared. They were covered with water. I realized it was almost time for high tide, but the rocks are always visible even in the severest of storms. Suddenly I became alarmed and called Roxey. We quickly slipped on some clothes, rushed down the stairs, and grabbed our jackets as we ran outside.

The air was still, the sky had an unusual brightness about it. It was light as day. The water shimmering in the moonlight was high over the outer breakwater. We headed for the highest point overlooking the town. The first wave was just reaching the town. Giant logs, trees and other debris were pitching and churning high on the crest of the water as it raced into the city. "My God, no!" I cried, "It will flood the town."

As the impact began, the loud blast of breaking glass and splintering wood reached us, buildings crumpled, cars overturned, some smashed through plate glass windows, while the water plowed down the streets. Within minutes the water came back just as fast as it had gone in, bringing all manner of things with it. It drained away with terrific speed. The whole beach front was strewn with logs, cars, buildings, trash of every description. Some of the fishing boats were tossed high on the land, others drifted to sea. A few cars and two small buildings that were swept off Citizen's Dock floated away with the water. The water was gone. We could see it piling up a half mile or more beyond the end of the outer breakwater, higher and higher as the minutes passed.

We stood there stunned with fright for we knew there was no way out of here if the water came this high. The lighthouse, serene in the moonlight, had been battered with severe storms for over a century: could it protect us now? We have lived on the island since 1962 and watched the


*DOGAMI staff member MeiMei Wang recently visited Crescent City, California. Note sign indicating high-water line from 1964 tsunami.*

storms come and go, but this was unlike anything we had ever experienced. The light flashed in the tower. We knew we would have to notify the Coast Guard if there was any failure or discrepancy in it. I don't know how long we stood there for we were just too frightened to move, when the second wave churned swiftly by us, gobbling everything in its wake. It picked up all the ruins along the beach front and shoved them right back into town. It didn't seem as large as the first one to us, but it caused considerable damage. Some of the lights faded out along Front Street. As the backflow began we raced frantically around the place, watching the water drain from the bay. We glanced at the tower: the light was still flashing.

We watched the Coast Guard Cutter, a big lumber tug, and some of the fishing boats that had received warning and left the harbor riding the tides a good three miles or more off shore. We were getting more frightened now, for the water had receded farther out than before. We knew it had to come back, but when? We screamed at one another in our fright, wondering if it would ever stop, for there was an ominous stillness about it, warning us of more to come.

As the third wave raced swiftly by us, it was much larger than the second, a horrifying thing, crushing everything in its path. When it reached the south end of town, sparks started flying in the air, igniting a fire. It spread rapidly, lighting up the water and sky around the bay. All of the lights faded out along Highway 101.

The water withdrew suddenly, as though someone had pulled the plug out of the basin. The water was here, then gone. We ran around the lighthouse again wondering if we were safe. We kept anticipating something more violent would happen, for the water had receded far out, three fourths of a mile or more beyond the end of the outer breakwater. We were looking down as though from a high mountain into a black abyss of rock, reefs, and shoals, never exposed even at the lowest of tides. A vast labyrinth of caves, basins and pits undreamed of in the wildest of fantasy.

In the distance a dark wall of water was building up rapidly, so the Coast Guard cutter, the lumber tug, and small craft appeared to be riding high above it, with a constant flashing of white at the edge, as the water kept boiling and seething, caught in the rays of the moonlight. The basin was dry. At Citizen's Dock the large lumber barge, loaded with millions of board feet of lumber, was sucked down in the bay. The fishing boats still in the small craft harbor, were pulled down on the floor of the ocean. We clung to one another, asking God to have mercy on us. We prayed for the town and its people. We realized the water would return with more destruction to follow. We kept straining ourselves trying to visualize what would happen next, while the water piled higher and higher in the distance.

Suddenly there it was, a mammoth wall of water barreling in toward us, a terrifying mass of destruction, stretching from the floor of the ocean upwards: it looked much higher than the island, black in the moonlight.

Roxey shouted, "Let's head for the tower." It was too late. As we turned toward the tower, he yelled, "Look out!" We both ducked. It struck, split and swirled around both sides of the island with such speed we felt like we were sailing right along with it. It took several minutes for us to realize the island hadn't moved. It crashed the shore, picking up the driftwood logs and other debris lodged in our roadway and along the beach front. It looked as though it would push them on the pavement at the end of A street leading past the Seaside HoPeninsulaal. Instead it shoved them around the bank and over the end of the outer breakwater. Through Dutton's Lumber Yard it tossed big bundles of lumber, some splitting up with planks like matchsticks flying in the air, while others sailed gracefully away. The water overflowing Dutton's Dock was high above it. At Citizen's Dock, the large lumber barge loaded with lumber came up and sat on top of the dock. The dock humped up, then relaxed right off its pilings. The fish storage houses, on the fish wing, were dancing around in the fury. The fishing boats still at their moorings were bobbing around like corks. Some sank right where they were, while others flew onto the beach, while others came out, careened about, and flew on the other side of the bay. One boat took off up Elk Creek at the end of town as though someone was at the helm.

When the tsunami assaulted the town it was like a violent explosion, a thunderous roar mingled with all the confusion. Everywhere we looked, buildings, boats, lumber, everything was shifting around like crazy. The whole front of town moved, changing before our eyes. By this time the fire had raced across the water to the ruptured Texaco Bulk tanks: they started exploding one after the other. The whole sky lit up. It was fantastic.

As the tide turned it was sucking everything back with it: cars, buildings were moving seawards. The old covered bridge, from Sause Fish Dock, that had floated high on the land, came back to drop almost in place. Furniture, beds, mattresses, TVs, radios, clothing, bedding, and other objects were moving by us so fast we could barely discern what some of it was. A siren was blowing. There were lights now in the front of town or along Highway 101. The light in the tower continued to burn. The block on this end of town near the Seaside HoPeninsulaal was unharmed.

Across the bay the fire was still raging higher and higher as each tank exploded. Time passed quickly, for everywhere we looked was a shambles; houses, buildings, lumber, boats, all smashed or moved blocks from where they had been by the onrush of water.

The fifth wave rushed swiftly by us back into town. It just pushed things around. We could observe no noticeable damage this time, but off and on the rest of the night the water kept surging in and out and slopping around in the harbor. At daybreak we made coffee and fixed our breakfast, but we kept checking each change of the tide. We had never seen so many in our knowledge of the sea. The boats continued to ride the surf offshore, waiting for another big one. A fishing craft careening around in the harbor finally

*(Continued on page 140, **Crescent City**)*

# A look back at Oregon's earthquake history, 1841–1994

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## ABSTRACT

More than 6,000 earthquakes, the vast majority smaller than local (Richter) magnitude ($M_L$) 3, have occurred in Oregon dating back to 1841. About 75 percent of these events have been recorded since March 1993 as part of the 1993–1994 Klamath Falls and 1993 Scotts Mills sequences. The state's largest earthquakes have been the 1873 $M_L$ 6¾ Crescent City, 1936 $M_L$ 6.1 Milton-Freewater, 1962 $M_L$ 5½ Portland (epicenter actually in Vancouver, Washington), 1993 $M_L$ 5.6 Scotts Mills, and 1993 $M_L$ 5.9 and 6.0 Klamath Falls earthquakes. Significant historical seismicity has also occurred near the town of Adel in south-central Oregon in 1968 and in the Deschutes Valley in north-central Oregon in 1976. Persistent areas of seismicity have been the Portland region, probably the state's most active, and the Pine Valley graben-Cuddy Mountain area near the Oregon-Idaho border. Because the historical record for Oregon is so brief, the earthquake potential of the state has not been fully revealed. Recent and future paleoseismic studies have and will likely show that the state was shaken by prehistoric crustal earthquakes up to $M_L$ 7+ in many more areas than was previously believed. The damages from the moderate-size 1993 Klamath Falls and Scotts Mills main shocks indicate that compared to larger but more distant earthquakes occurring within the Cascadia subduction zone, shallow crustal earthquakes may pose the greatest hazard to the Willamette Valley and eastern Oregon.

## INTRODUCTION

A look back at 1993 reveals that it was one of the most significant years in terms of seismic energy release in Oregon based on the state's brief historical earthquake record which dates back to 1841. This 1993 energy release was dominated by the very active Klamath Falls main shock-aftershock sequence, which began in late September and was highlighted by events of $M_L$ 5.9 and 6.0 and, to a lesser extent, the March 25 $M_L$ 5.6 Scotts Mills earthquake. A heightened interest in seismic hazards in Oregon in the past decade has led to increased interest and involvement in earthquake research and has resulted in a greater understanding of Oregon's seismic potential, particularly that of the Cascadia subduction zone[1]. In this paper, we review the state's historical seismicity and some recent research on some of its most significant events and discuss their implications for future earthquake occurrence. Because very few earthquakes are known to have occurred in the Cascadia subduction zone[2] beneath westernmost Oregon, our review focuses on seismicity generated by faults located within the North American crust beneath the state.

Three previous significant studies have provided the basis for constructing the historical earthquake record of Oregon: a compilation by Holden (1898) for the Pacific Coast and the period 1769–1897; the well-known Townley and Allen (1939) catalogue, also for the Pacific Coast (1769–1928); and an Oregon catalogue by Berg and Baker (1963) for 1841–1958. Subsequent efforts by the National Earthquake Information Center (NEIC), the University of Washington (UW), Oregon State University (OSU), and Woodward-Clyde Consultants have further refined the state's historical record.

A historical earthquake record usually provides the sole basis for assessing earthquake frequency or recurrence in a region, which is crucial in evaluating seismic hazards on a probabilistic basis. However, a significant aspect of historical records in the western United States, including California, is that they are all very brief in the context of geologic time. The frequency of large earthquakes occurring on a particular fault in the western United States can range from a few hundred to more than 100,000 years; so observing an earthquake from a specific seismic source in a period of 154 years is, more often than not, fortuitous. Hence the historical record seldom totally reveals a region's full seismic potential. This is where the relatively new science of paleoseismology[3] has become so very important in extending the earthquake history of a region back into prehistoric times. Significant advancements in the instrumental detection of "microearthquakes" (events smaller than $M_L$ 3), which are much more frequent than larger events, have also provided important information on previously unknown seismic sources. Such sources would likely have gone undetected without the use of sensitive instruments and expanded seismographic coverage.

## PREHISTORIC EARTHQUAKES

In the past decade, geologic evidence has been mounting that great megathrust earthquakes have repeatedly occurred

[1] The region encompassing the boundary between the descending or subducting Juan de Fuca (oceanic) plate (or the Gorda plate at the southern end) and the overlying North American (continental) plate. The zone stretches for a distance of 1,000 km from northwest of Vancouver Island in British Columbia southward to Cape Mendocino in northern California.

[2] Two types of earthquakes have occurred and can occur within the Cascadia subduction zone: (1) great "interplate" events of moment magnitude ($M_W$) 8 and larger which rupture along the megathrust boundary between the two plates and (2) "intraplate" events which rupture within the subducting plate. An example of the latter includes the 54-km deep 1949 magnitude 7.1 Olympia, Washington, earthquake.

[3] Geologic studies of prehistoric earthquakes through evaluating their surface faulting effects or their impacts on the environment (e.g., liquefaction features, tsunami deposits, buried marshes, etc.).

within the Cascadia subduction zone beneath the coasts of Oregon and Washington. The evidence has been developed from a variety of studies (Rogers and others, 1991; Atwater and others, 1995), but the most convincing has been the discovery of multiple buried soils in coastal intertidal lowlands (e.g., Atwater, 1987, 1992; Darienzo and Peterson, 1990). The presence of these soils suggests that these areas have been subjected to sudden subsidence resulting in submergence of the land surface. The most plausible explanation for these observations is that large megathrust earthquakes have ruptured the Cascadia subduction zone, which resulted in coastal subsidence.

Multiple lines of evidence including buried peats, tsunami sands, and trees killed by salt-water inundation have been observed at several locations along the Oregon, Washington, and northern California coasts. This evidence also indicates the date of the most recent subduction-zone earthquake to be about A.D. 1700 (Atwater and others, 1995). Possibly the most dramatic evidence for this earthquake is the recent discovery by Satake and others (1995) that a 2- to 3-m-high tsunami reached the shores of Japan on January 27–28, 1700. On the basis of the historical accounts of the event and computer modeling, these authors believe the tsunami was the result of an earthquake of about moment magnitude ($M_W$)[4] 9 that ruptured the Cascadia subduction zone at about 9 p.m. on January 26. The size of the event implies that most, if not all, of the subduction zone was ruptured. Because of the difficulties and uncertainties in dating deposits in the coastal marshes, the ages of earlier events are not as well known. The available data indicate, however, that large earthquakes appear to have struck the Pacific Northwest coast at intervals ranging from a few centuries to about 1,000 years (Atwater and others, 1995).

## HISTORICAL RECORD AND EARTHQUAKE DETECTION

The time span covered by the historical earthquake record can be divided into pre-instrumental and instrumental periods. Prior to adequate seismographic coverage, the detection of earthquakes was generally based on human observations and reported effects. This capability is strongly dependent on the geographic distribution and density of population. Both have generally increased with time in Oregon. The Modified Mercalli (MM) intensity scale, described in Table 1, is the best known of several attempts to quantify earthquake effects. Written documentation of pre-instrumental observations, particularly for events from before the turn of the century, is crucial in piecing together the historical record. Oregon, like of much of the western United States, was sparsely populated in the 1800s, and thus the detection of pre-instrumental earthquakes has been of variable completeness as described below.

Table 1. *Abridged Modified Mercalli intensity scale. Equivalent Rossi-Forel (RF) intensities in parentheses*

| | |
|---|---|
| I | Not felt except by a few under especially favorable circumstances. (RF I). |
| II | Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (RF I–II). |
| III | Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like passing of truck. Duration estimated. (RF III). |
| IV | Felt indoors by many, outdoors by few during the day. Some awakened at night. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably. (RF IV–V). |
| V | Felt by nearly everyone, many awakened. Some dishes, windows, and other fragile objects broken; plaster cracked in a few places; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (RF V–VI). |
| VI | Felt by all, many are frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster and damaged chimneys. Damage slight. (RF VI–VII). |
| VII | Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars. (RF VIII). |
| VIII | Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Falling of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well-water levels. Persons driving cars disturbed. (RF VIII+ to IX). |
| IX | Damage considerable in specially designed structures, great in substantial buildings; with partial collapse; well-designed frame structures thrown out of plumb. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (RF IX+). |
| X | Some well-built structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Sand and mud shifted. Water splashed, slopped over banks. (RF X). |
| XI | Few, if any, [masonry] structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly. |
| XII | Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into the air. |

Comprehensive and recoverable written documentation of historical events did not begin in Oregon until about the 1840s. This was about 35 years after the Lewis and Clark expedition reached the Pacific coast at the mouth of the Columbia River and opened up the Pacific Northwest to set-

[4] The moment magnitude scale has become the scale of choice among seismologists because it is based on seismic moment and is the best measure of earthquake size. Seismic moment is a function of the area of the fault which ruptures, the average displacement on the fault, and the shear modulus, a parameter which is related to the rigidity of the rocks in the fault zone. The units of seismic moment are dyne-cm (grams-cm$^2$/sec$^2$).

tlement from pioneers traveling the Oregon Trail. Oregon's first towns were established principally west of the Cascades, including Salem in 1844, Portland around 1845, Roseburg in 1851, Eugene in 1852, Coos Bay in 1854, and Medford in 1883. In central and eastern Oregon, settlement began later: Pendleton in 1851, The Dalles in 1857, Baker and Klamath Falls in 1866, and Burns and Lakeview in 1884. The publication of newspapers, which are a major source of documentation, began soon after the establishment of these major towns. Based on this population growth and distribution, we estimate that the pre-instrumental historical record for earthquakes of $M_L \geq 5.0$ is complete for western Oregon since about 1850 and for most of eastern Oregon since around 1890.

Although seismograph stations were established in the Pacific Northwest as early as 1906 in Seattle, adequate seismographic coverage of Oregon, at least for smaller events ($M_L \leq 4$ to 5), did not begin until 1979, when the UW expanded its regional network into northwestern Oregon (Figure 1). Few stations operated in Oregon before this time. The seismograph station at OSU in Corvallis (COR) appears to have been the first station installed in the state in 1946.

In 1962, stations at Klamath Falls (KFO) and Pine Mountain (PMT) were also installed by OSU together with the Blue Mountains Seismological Observatory (BMO), originally a 10-station array operated by Teledyne Geotech Corporation and transferred to the U.S. Geological Survey (USGS) in 1966 (Figure 1). The Longmire (LON) station in Washington, installed in 1958, became part of the Worldwide Network of Standard Seismograph (WWNSS) stations in late 1962 as did COR. Both stations have been significant in recording some of Oregon's larger events. We estimate the level of detection from the late 1920s to 1962 was about $M_L$ 4 in western Oregon and $M_L$ 5 in eastern Oregon.

The most significant improvement in instrumental monitoring of Oregon's earthquakes was the installation of stations by UW. By 1980, five UW stations were operating in northernmost Oregon. Today, 44 stations are operating in the state, including those operated by UW, OSU, Boise State University (BSU), and the University of Oregon (UO) (Figure 1). The current detection threshold in northwestern and north-central Oregon is about $M_L$ 1.5 to 2.0 (T. Yelin, USGS, personal communication, 1994). Small-magnitude seismicity in much of eastern Oregon, however, remains relatively unmonitored, with the exception of the northernmost portion of the state adjacent to the Columbia Plateau and the area around Hells Canyon that is being monitored by BSU (Figure 1).

The improvement in earthquake detection is dramatically illustrated in Figure 2. From 1841 to the mid-1960s, fewer than five earthquakes per year were typically recorded in the state, with many years having no known events. As the UW network expanded, the number of recorded and located earthquakes (principally microearthquakes) increased exponentially, culminating in the year 1993 when more than 2,500 events were recorded, most of which were aftershocks of the Klamath Falls and Scotts Mills main shocks. In 1994, more than 2,100 earthquakes were recorded and located as Klamath Falls aftershocks continued to occur but at a steadily decreasing rate.

The historical catalogue for Oregon from 1841 through the end of 1994 contains more than 6,000 earthquakes ranging in

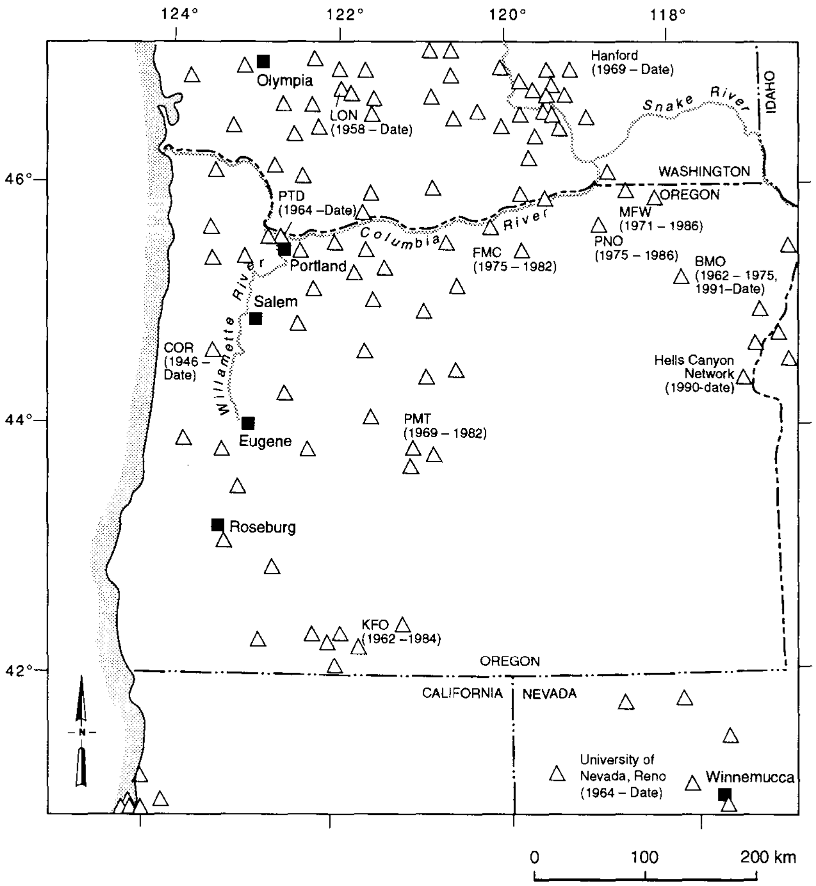


*Figure 1. Historical seismographic coverage of Oregon. Stations or networks are represented by open triangles. Abbreviations for these: BMO = Blue Mountains Seismological Observatory; COR = Corvallis; FMC = Fourmile Canyon; KFO = Klamath Falls; LON = Longmire; MFW = Milton-Freewater; PMT = Pine Mountain; PNO = Pendleton; PTD = Portland. Periods of operation are also shown. Unlabeled stations are part of the University of Washington network, which was initially installed in Oregon in 1979.*

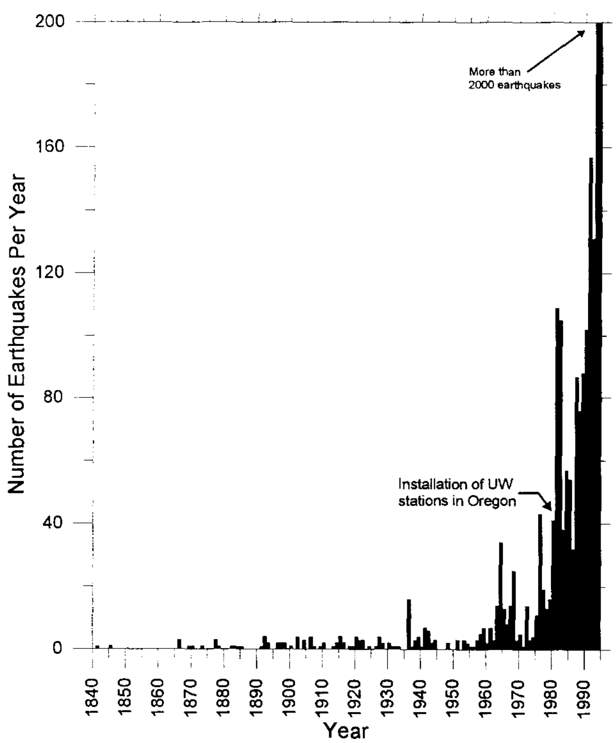


*Figure 2. Histogram of recorded and located earthquakes in Oregon, 1841 through 1994. The dramatic increase in seismicity in 1993–1994 was due to the Klamath Falls sequence.*

size from less than $M_L$ 1 up to 6¾. Data sources for this catalogue include compilations from Townley and Allen (1939); Berg and Baker (1963); the Decade of North American Geology (Engdahl and Rinehart, 1988); NEIC; UW; Woodward-Clyde Consultants; and BSU (e.g., Zollweg and Wood, 1993).

Within the historical catalogue, a range of magnitudes assigned to a single earthquake is not unusual. For example, the 1962 Portland earthquake has been assigned values of $M_L$ 5.0 to 5.5 and $M_W$ 5.2 (Bott and Wong, 1993). In addition to the existence of several magnitude scales, differences in instrumentation and seismic-wave travel-path effects between events and their recording stations can lead to different magnitude estimates for the same earthquake.

## SIGNIFICANT HISTORICAL EARTHQUAKES

The first earthquake in Oregon's historical record was felt with a maximum intensity of MM III and occurred at 4:00 p.m. on December 2, 1841, near Fort Vancouver along the Oregon-Washington border (Berg and Baker, 1963). The first known earthquake in the eastern half of the state reportedly occurred near Umatilla on March 6, 1893 (Figure 3a). This event, described as a "succession of shocks," knocked down one wall of a large stone building (MM VI or VII?) (Townley and Allen, 1939). The 1893 earthquake may have been one of Oregon's largest events, according to its reported maximum intensity. However, very little is really known about this earthquake. Reports of the event outside Umatilla are apparently unknown, which suggests that it was only locally felt and thus not that large.

Since 1841, five earthquakes larger than $M_L$ 5.5 are known to have occurred in Oregon (Table 2). There have been an additional six events of about $M_L$ 5 to 5.5 in size (excluding the 1962 Portland earthquake; see following discussion). Three earthquakes of approximate $M_L$ 5, whose source was near Portland (1877, 1892, and 1961), have been recently described by Bott and Wong (1993). Twenty-eight events have occurred within the state in the approximate range of $M_L$ 4.5 to 5.0 (MM V or VI, if no magnitude assigned) (Table 2). The following describes the most significant releases of seismic moment in Oregon during historical times.

### 1873 Crescent City earthquake

On November 23, 1873, at about 9:00 p.m., an earthquake of estimated $M_L$ 6¾ occurred near the Oregon-California border east-southeast of Brookings (Toppozada and others, 1981) (Figure 3a). The maximum reported intensity of the event was MM VIII in the Smith River Valley north of Crescent City, California (Figure 4). Chimneys were knocked down in Crescent City, Port Orford, Grants Pass, and Jacksonville. Ground cracking was observed east of Crescent City. The earthquake was felt as far north as Portland (MM III–IV) and as far south as San Francisco (Townley and Allen, 1939). Because the location of the 1873 earthquake can only be estimated from the center of the isoseismal contours (Figure 4), its uncertainty is large, and the event could have occurred in northernmost California or southernmost Oregon. The lack of aftershocks led Ludwin and others (1991) to suggest that the earthquake may have occurred within the subducting Gorda (or Juan de Fuca) plate of the Cascadia subduction zone. Such intraplate earthquakes are rare in Oregon. Alternatively, the event may have been crustal in origin and occurred far enough offshore such that no aftershocks were felt (Ludwin and others, 1991).

### 1936 Milton-Freewater earthquake

The largest and most significant earthquake in northeastern Oregon, known as the Milton-Freewater or Stateline earthquake, occurred at 11:08 p.m. on the night of July 15, 1936 (Neumann, 1938) (Figure 3a). The maximum intensity was MM VII+, and it was felt over an area of 275,000 $km^2$ (Figure 5). In a reevaluation of the event, Woodward-Clyde Consultants (1980) (also Foxall and Turcotte, 1979) calculated a magnitude of $M_L$ 6.1, as recorded at 17 seismographic stations. Based on the isoseismal map (Figure 5) and an empirical relationship between magnitude and total felt area developed by Toppozada (1975) (see Bott and Wong [1993] for further discussion), the event was estimated to be a $M_L$ 6.4. The main shock was preceded by

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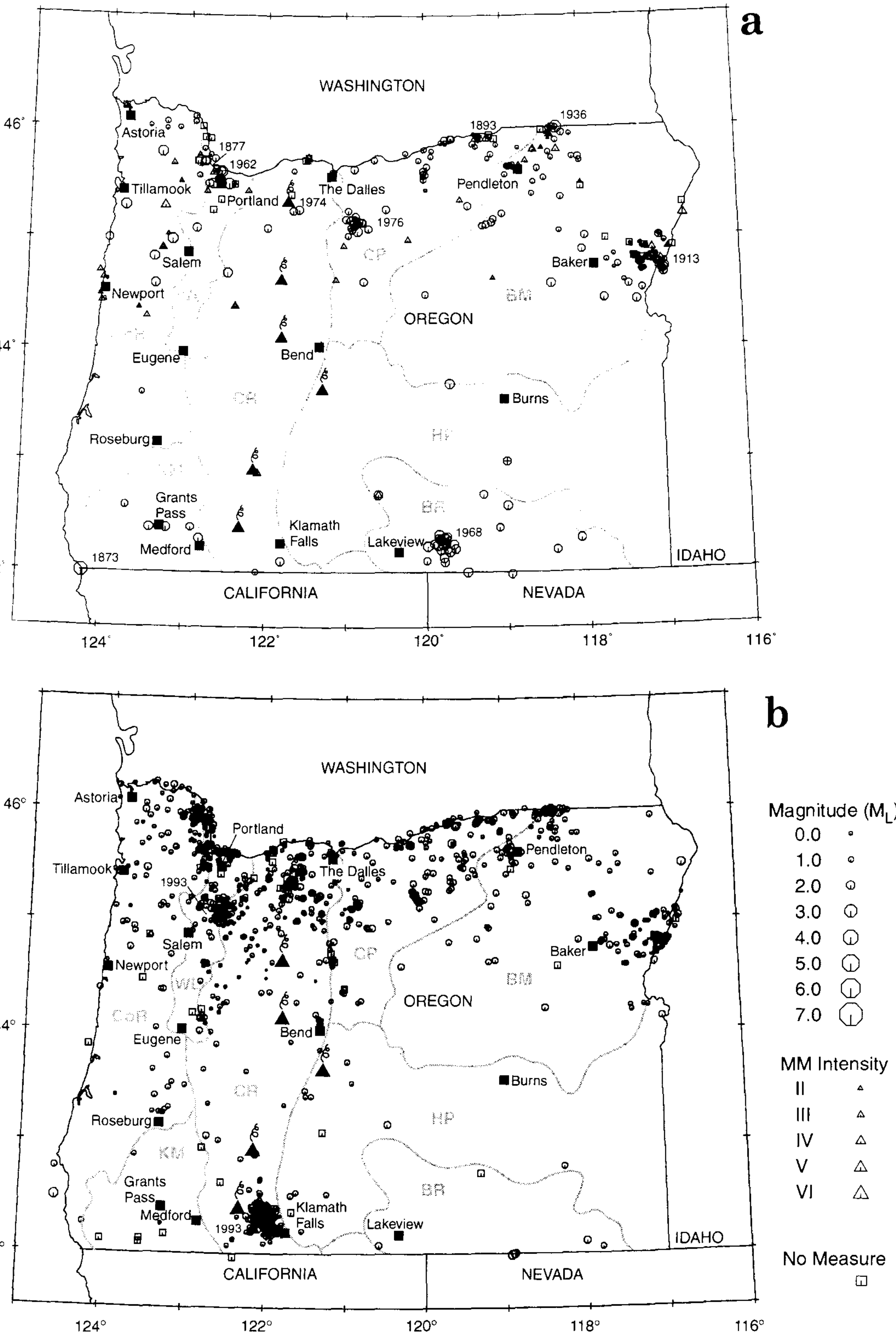


*Figure 3. Historical seismicity and geologic provinces of Oregon: (a) 1841 through 1978 and (b) 1979 through 1994. Major Cascade volcanoes are shown as erupting triangles. Abbreviations: CoR = Coast Range; WL = Willamette Lowlands; KM = Klamath Mountains; CR = Cascade Range; CP = Columbia Plateau; BM = Blue Mountains; HP = High Lava Plains; BR = Basin and Range.*

Table 2. *Significant historical earthquakes in Oregon, magnitude 4.5 or MM intensity V and greater*

| Date | Time (GMT) | Magnitude | Maximum MM intensity | Location | Comments |
|---|---|---|---|---|---|
| Nov. 23, 1873 | 05:00 | $M_L$ 6¾ | VIII | Crescent City | Largest historic event |
| Oct. 12, 1877 | 17:00 | $M_L$ 5¼ | VII | Portland | Portland's second largest event |
| Feb. 4, 1892 | 04:30 | $M_L$ 5 | VI | Portland | "Severe shock" |
| Mar. 5, 1893 | ? | — | VI or VII | Umatilla | |
| Apr. 2, 1896 | 11:17 | $M_L$ 4 | VI | McMinnville | |
| Apr. 19, 1906 | 09:30 | — | V | N of Lakeview | Three felt aftershocks |
| Oct. 14, 1913 | 23:00 | — | VI | Hells Canyon | |
| May. 18, 1915 | 03:00 | — | V | Portland | One of three shocks |
| Apr. 14, 1920 | 23:45 | — | V | Crater Lake | One of three shocks |
| Feb. 25, 1921 | 20:00 | — | V | E of Sweetwater | |
| Jan. 11, 1923 | 04:29 | — | VI | Lakeview | |
| Jan. 6, 1924 | 23:10 | — | V | Milton-Freewater | |
| Apr. 9, 1927 | 05:00 | — | V | Pine Valley-Cuddy Mountain | |
| Jul. 19, 1930 | 02:38 | $M_L$ 4 | V-VI | 20 km NW of Salem | Cracked plaster |
| Jul. 16, 1936 | 07:07 | $M_L$ 6.1 | VII+ | Milton-Freewater | Eastern Oregon's largest event |
| Jul. 18, 1936 | 16:30 | — | V | Milton-Freewater | Aftershock |
| Aug. 4, 1936 | 09:19 | — | V | Milton-Freewater | Aftershock |
| Aug. 28, 1936 | 04:39 | — | V | Milton-Freewater | Aftershock |
| Dec. 29, 1941 | 18:37 | $M_L$ 4½ | VI | Portland | Minor damage |
| Jun. 12, 1942 | 09:30 | — | V | Pine Valley-Cuddy Mountain | Minor damage |
| Nov. 1, 1942 | 17:00 | — | V | Portland | |
| Jan. 7, 1951 | 22:45 | — | V | Hermiston | |
| Dec. 16, 1953 | 04:32 | $M_L$ 4½ | VI | Portland | Minor damage in Portland |
| Nov. 17, 1957 | 06:00 | $M_L$ 4½ | VI | S of Tillamook | Felt strongest near Salem |
| Mar. 12, 1958 | 12:09 | $M_L$ 4.5 | — | SE of Adel | |
| Jun. 2, 1959 | 18:49 | $M_L$ 4.7 | — | NW of Burns | |
| Aug. 19, 1961 | 04:56 | $M_L$ 4½ | VI | SE of Salem | Minor damage in Albany |
| Nov. 7, 1961 | 01:29 | $M_L$ 5 | VI | NW of Portland | Minor damage in Portland |
| Nov. 6, 1962 | 03:36 | $M_W$ 5.2, $M_L$ 5½ | VII | Vancouver-Portland | Damage in Portland |
| Mar. 7, 1963 | 23:53 | Body wave ($m_b$) 4.6 | V | West of Salem | Minor damage in Salem |
| Dec. 27, 1963 | 02:36 | $M_L$ 4½ | VI | Vernonia NW of Portland | Minor damage near epicenter |
| May. 30, 1968 | 00:35 | $M_L$ 5.1 | V | Adel | Swarm |
| Jun. 3, 1968 | 13:27 | $M_L$ 5.0 | V | Adel | Damage |
| Jun. 4, 1968 | 02:34 | $M_L$ 4.7 | VI | Adel | Swarm |
| Jun. 5, 1968 | 04:51 | $m_b$ 4.7 | — | Adel | Swarm |
| Apr. 13, 1976 | 00:47 | $M_L$ 4.8 | V-VI | Deschutes Valley | Minor damage |
| Mar. 25, 1993 | 13:34 | $M_L$ 5.6 | VII | Scotts Mills | $28 million in damage |
| Sep. 21, 1993 | 03:28 | $M_L$ 5.9 | VII | Klamath Falls | Two deaths |
| Sep. 21, 1993 | 05:45 | $M_L$ 6.0 | VII-VIII | Klamath Falls | $7.5 million in damage |
| Dec. 4, 1993 | 22:15 | $M_L$ 5.1 | VII | Klamath Falls | Aftershock |

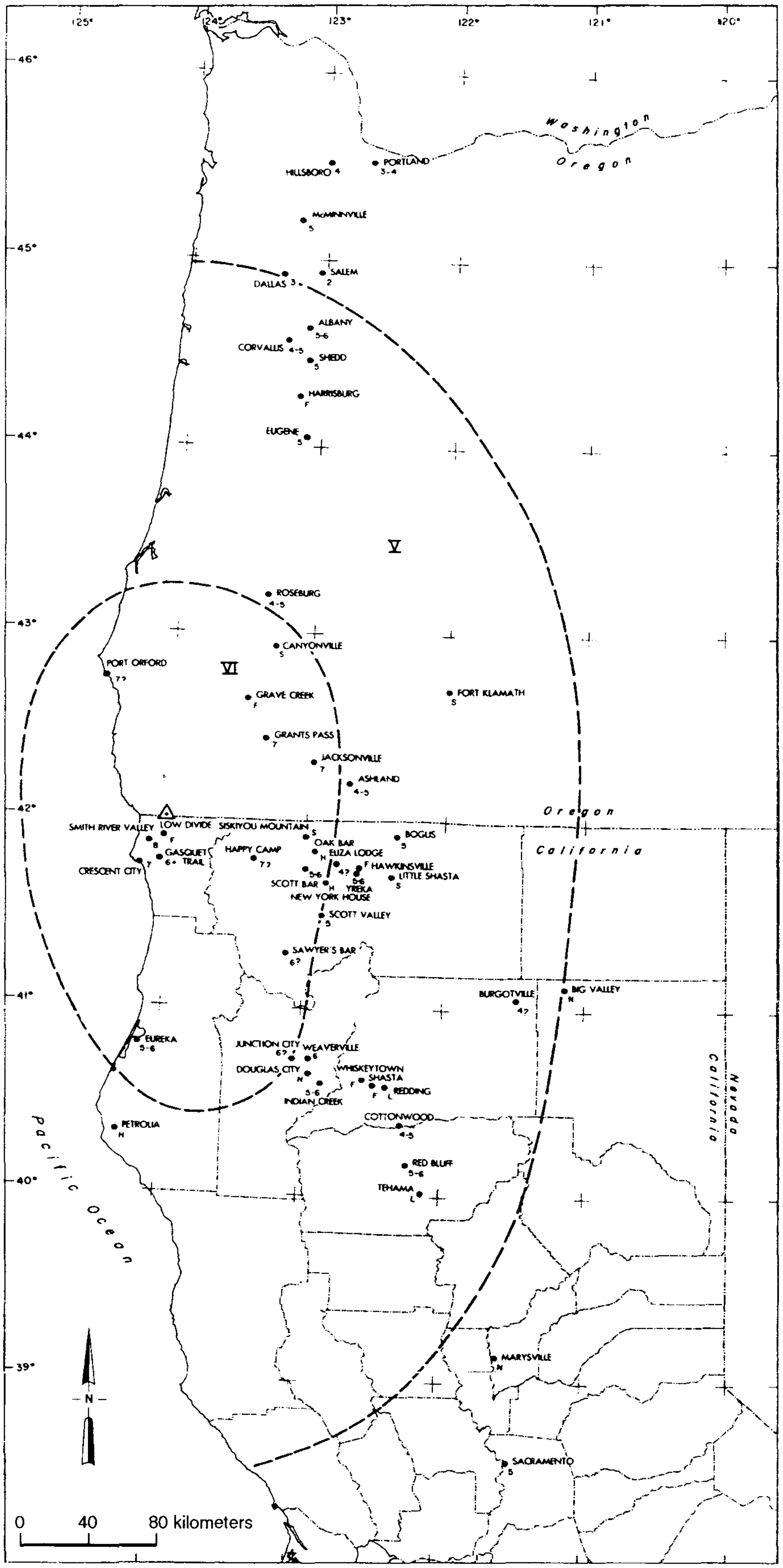


*Figure 4. Isoseismal map of the 1873 Crescent City earthquake. Smoothed isoseismal contours, centered around estimated epicenter (triangle), define zones with reported MM intensities V and VI (see Table 1). Individual sites reporting effects either show Arabic numerals for (equivalent Roman numeral) intensities or letters for indeterminate intensities as follows: N = not felt, F = felt, L = light, H = heavy, S = severe. From Toppozada and others (1981).*

two felt foreshocks at 10:30 p.m. and 11:20 p.m. and was followed by numerous aftershocks (Neumann, 1938).

The main shock was felt most strongly and caused damage in and around Milton-Freewater, Umapine, and Stateline, Oregon (Figure 5). It was also strongly felt in Walla Walla, Washington, just north of the border. Total damage amounted to $100,000 in 1936 dollars. Many chimneys were damaged, houses were moved off their foundations, canned goods were scattered in a cannery, plaster cracked, windows broke, and school buildings were damaged (Neumann, 1938).

Intense ground cracking occurred in a zone 25 m wide and 500 m long extending west-northwest along the base of a hill west of Milton-Freewater. Some cracks were 1–2 m wide, and in one place the ground dropped by 2.4 m. Water emerged from some of these cracks, indicating that liquefaction as well as ground slumping and landsliding had occurred. Ground-water flow generally increased in wells, and several springs were revived (Brown, 1937).

The epicentral location of this earthquake has been difficult to determine. An epicenter based on the isoseismal data gave a location about 10 km northeast of Milton-Freewater (Neumann, 1938). The International Seismological Centre and the U.S. Coast and Geodetic Survey calculated instrumental epicenters in southeastern Washington north-northeast of Walla Walla. Woodward-Clyde Consultants (1980) relocated the event after rereading arrival times and determined a similarly placed epicenter. They suggested that the 1936 earthquake may have occurred on the Hite fault. In contrast, Mann and Meyer (1993) suggested the source of the 1936 earthquake was the Wallula fault zone near the zone of ground cracking just south of Umapine and west of Milton-Freewater, based on their reassessment of the maximum reported intensities.

We believe, however, the large epicentral uncertainties of both the felt and instrumental locations of the 1936 earthquake make any interpretations of its source tenuous. Earthquake locations based on maximum intensities can be erroneous by tens of kilometers because of site or seismic-wave propagation effects on ground shaking (e.g., Wong and Savage, 1978). Errors are also often large (also tens of kilometers) when locating pre-1960 instrumentally-recorded earthquakes, because clock errors were common, and recording stations few and distant. For example, the closest station recording the 1936 event was in Spokane, about 250 km away, and clock error appears to have been large. The majority of the stations recording the earthquake were in California, which resulted in possible azimuthal bias in the seismographic coverage.

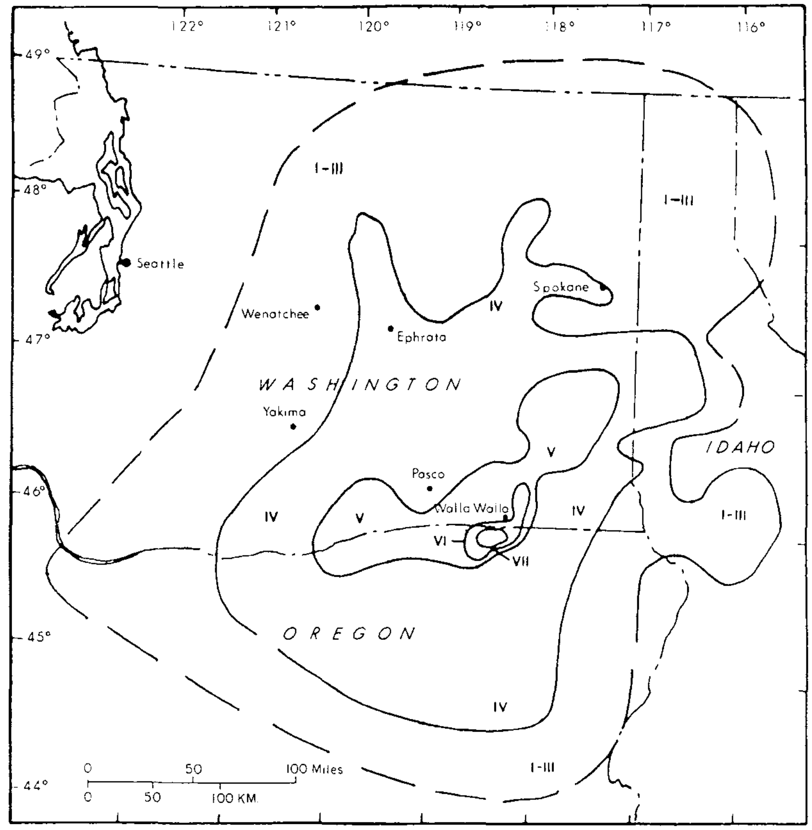


*Figure 5. Isoseismal map of the 1936 Milton-Freewater earthquake. From Washington Public Power Supply System (1974).*

**1962 Portland earthquake**

One of the best-known earthquakes in Oregon history occurred at 7:36 p.m. on November 5, 1962, near Portland ($M_L$ 5.2 to 5.5) with a maximum intensity of MM VII (Coffman and others, 1982; Yelin and Patton, 1991; Bott and Wong, 1993) (Figures 3a and 6). The earthquake was felt over a large area of 70,000 km$^2$ in northwestern Oregon and southwestern Washington (Figure 6). In Portland, many chimneys cracked or fell down, windows broke, tile ceilings fell, and plaster cracked (Dehlinger and Berg, 1962). In Vancouver and Battleground, Washington, furnishings and small objects shifted. Rumbling sounds were heard just before the earthquake was felt, and the shaking lasted from a few to 30 seconds (Dehlinger and Berg, 1962). Numerous aftershocks occurred, but none were large enough to be felt in Portland.

Yelin and Patton (1991) recomputed the location of the 1962 earthquake and placed it 15 km northeast of downtown Portland and at a depth of 16 km. This epicenter is 7 to 8 km northeast of the original location of Dehlinger and others (1963). This location makes this earthquake a Washington event, although it clearly warrants inclusion in any discussion of Oregon seismicity. Yelin and Patton (1991) calculated several possible earth-

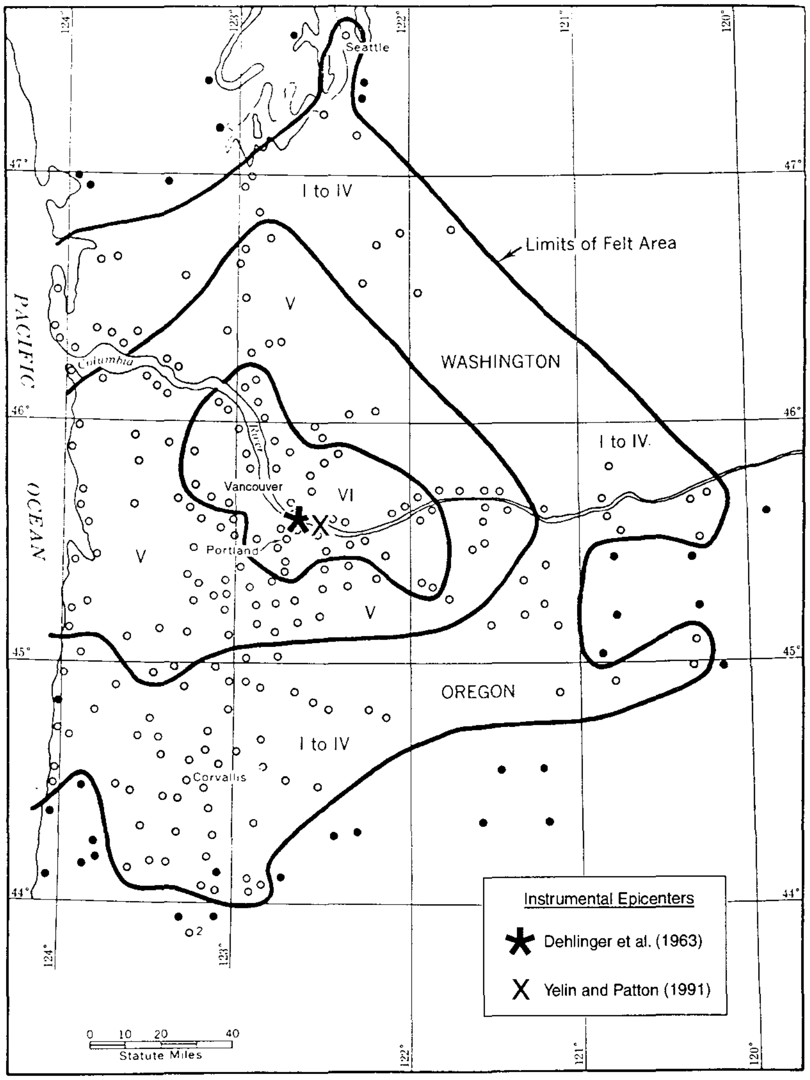


*Figure 6. Isoseismal map of the 1962 Portland earthquake. Modified after Lander and Cloud (1964)*

quake focal mechanisms[5] for the event but favor the mechanism that exhibits normal faulting on a northeast-trending fault plane. This is consistent with the model of a Portland pull-apart basin (Beeson and others, 1985), although the stress directions exhibited by the focal mechanism are not consistent with the regional stress pattern of approximately north-south maximum compression. Alternatively, Unruh and others (1994) have suggested that the Portland area lies within the Portland fold belt, a region characterized by northwest-trending anticlines[6], possibly indicative of fault motion at depth. We favor the reverse faulting focal mechanism of Yelin and Patton (1991), because it is more consistent with the contemporary stress field and other focal mechanisms in the region.

### 1968 Adel earthquake swarm

An intense sequence of earthquakes began on May 26, 1968, in the vicinity of the town of Adel near the Oregon-Nevada border (Coffman and Cloud, 1970) (Figure 3a). No historical events are known to have occurred in the epicentral area before this sequence. The activity reflected typical characteristics of an earthquake swarm: a sequence of events concentrated in space and time with no single dominant event. The largest events of the swarm occurred within the first 10 days of activity; the largest earthquake ($M_L$ 5.1) occurred at 4:36 p.m. on May 29 (Schaff, 1976). A $M_L$ 5.0 event occurred at 5:27 a.m. on June 3 and was felt with a MM V intensity in Lakeview, Oregon, and Fort Bidwell, California. The strongest felt earthquake ($M_L$ 4.7) reported at Adel (Coffman and Cloud, 1970) occurred at 6:34 p.m. also on June 3 with a maximum intensity of MM VI. It was felt over an area of 18,400 km$^2$, causing damage to many chimneys in Adel and producing ground fissures near Fort Bidwell (Couch and Johnson, 1968). Grocery items were thrown to the floor in a local store, and a rock wall of a storage building collapsed. In the library, books on the west wall were thrown to the floor. Geologic effects included rockfalls from the western wall of Warner Valley and cracks in State Highway 140, about 2 km west of Adel (Coffman and Cloud, 1970). Increased flow at a hot spring was also reported (Couch and Johnson, 1968). The swarm continued through June and July, decaying exponentially in intensity and occurrence with time.

Portable seismographs were deployed in the vicinity of Adel from June 6 to July 25 by the University of Nevada at Reno, to monitor the swarm activity. Analysis of 169 aftershocks (Schaff, 1976) indicates a 15-km-long, 6-km-wide, north-trending zone located northwest of Adel between the depths of 3 and 12.5 km (Schaff, 1976). A focal mechanism computed by Patton (1985) indicates that the largest earthquake was the result of normal faulting on an approximately north-striking plane. That plane is consistent with the trend of aftershocks and the structural grain of the northern Basin and Range province. Thus an unmapped fault near Adel appears to have been the source of the 1968 swarm.

[5] A stereographic projection plot resulting from an analysis of seismic waves as recorded on seismograph stations. A focal mechanism displays two possible orientations for the causative fault and associated slip directions and the pattern of the tectonic stresses initiating the earthquake rupture.

[6] A geologic structure where layered rocks have been folded or arched upwards by compressive forces. The Portland Hills may be an anticline.

## 1976 Deschutes Valley earthquake

On April 12, 1976, a $M_L$ 4.8 earthquake shook an area of 35,000 $km^2$ centered near the town of Maupin in north-central Oregon (Figure 3a). Although the epicentral area had exhibited no prior seismicity, historical earthquakes were reported in adjacent areas such as The Dalles as early as 1866 (Figure 3a). Maximum intensities of MM V–VI were observed along the Deschutes River Valley, where houses were shaken, resulting in cracked plaster (Couch and others, 1976) (Figure 7). Some objects were thrown to the floor in Maupin, South Junction, and Warm Springs. Sounds described as "distant thunder, sonic booms, and strong wind" were also reported in this event.

An epicentral location was determined by Couch and others (1976) based on the P-wave readings from 48 seismograph stations in the western United States and Canada (Figure 7). The focal depth of the main shock was estimated to be 15 km. The main shock was preceded by nine foreshocks and followed by 13 aftershocks, of which the largest was a $M_L$ 4.2 (Figure 3a). A composite focal mechanism of the main shock and other events in the sequence suggest that the source of the Deschutes Valley earthquakes was a west-northwest-striking reverse fault (Couch and others, 1976). The presence of such a fault is consistent with several similarly oriented anticlines in the epicentral area.

## 1993 Scotts Mills earthquake

On March 25, 1993, at 5:35 a.m., a strong earthquake ($M_L$ 5.6, maximum MM VII intensity) struck western Oregon and Washington (Madin and others, 1993; Dewey and others, 1994). This event, which is the fourth largest earthquake to occur in western Oregon in historical times, was felt over an area of 97,000 $km^2$ (Dewey and others, 1994). The earthquake occurred 5 km east of the town of Scotts Mills (Figure 3b). Damage to property was estimated at $28 million, mostly to older, unreinforced masonry structures such as the Molalla High School (Dewey and others, 1994). Numerous chimneys were damaged, and broken plaster and bricks were common. Despite the strength of this earthquake, only minor injuries were incurred.

The earthquake was recorded throughout the UW regional seismographic network. A focal depth of 15 km was determined for the main shock, although this value is poorly constrained. Aftershocks recorded by a portable network installed in the epicentral region within 12 hours of the main shock align along a northwest-striking, moderately north-northeast-dipping plane at depths of 8 to 15 km (Thomas and others, in preparation). The main-shock focal mechanism indicates oblique-reverse slip on a northwest-striking, northeast-dipping nodal plane in response to a north-south compressive stress. The earthquake locations and focal mechanism are all consistent with the sequence occurring on the Mount Angel fault (Thomas and others, in preparation). Werner and others (1992) earlier suggested that a sequence of six small earthquakes ($M_L \leq 2.5$) in August 1990 near Woodburn could have occurred on the northern end of the Mount Angel fault. Through 1994, a total of about 300 aftershocks had been recorded by either the UW regional or portable networks.

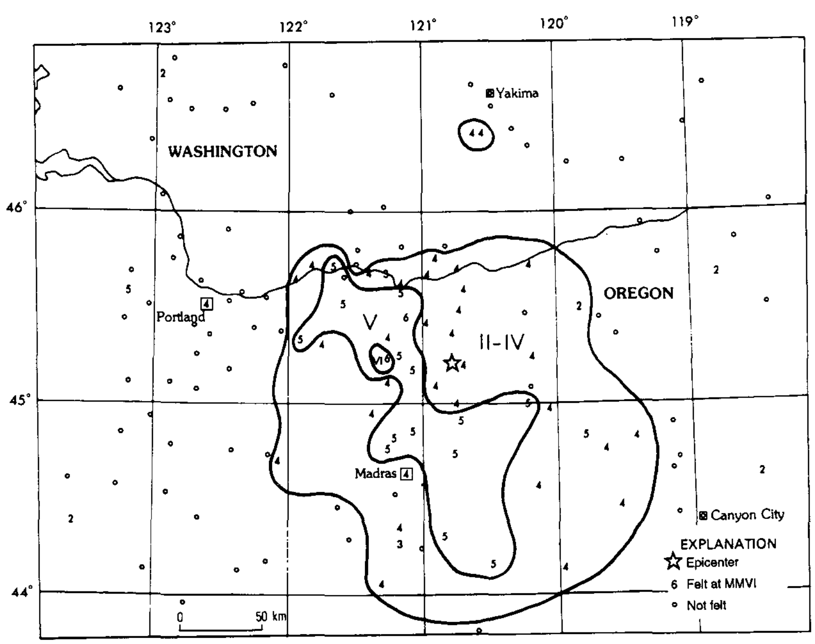


*Figure 7. Isoseismal map of the 1976 Deschutes Valley earthquake. Note that epicenter is located east of the area of maximum reported intensity (MM VI). From Coffman and Stover (1978).*

## 1993 Klamath Falls earthquakes

On the evening of the September 20, 1993, two moderate-sized earthquakes struck the Klamath Falls area (Figure 3b), causing two deaths and extensive damage. The casualties were the first reported to result from an earthquake in Oregon. The two largest events, $M_L$ 5.9 at 8:28 p.m. and $M_L$ 6.0 at 10:45 p.m., and the ensuing aftershocks were centered approximately 20 km northwest of Klamath Falls (Figure 8). (Braunmiller and others [1995] estimated $M_W$ 6.0 for both events.) Focal depths of the events were generally less than 12 km (Braunmiller and others, 1995). A foreshock of $M_L$ 3.9 occurred 13 minutes before the $M_L$ 5.9 event. A portable network was deployed in the epicentral area by the USGS, OSU, and UO within days of the largest events.

Damage from the Klamath Falls earthquakes amounted to about $7.5 million, mostly to various residential, commercial, and government buildings, including the Klamath County Courthouse buildings

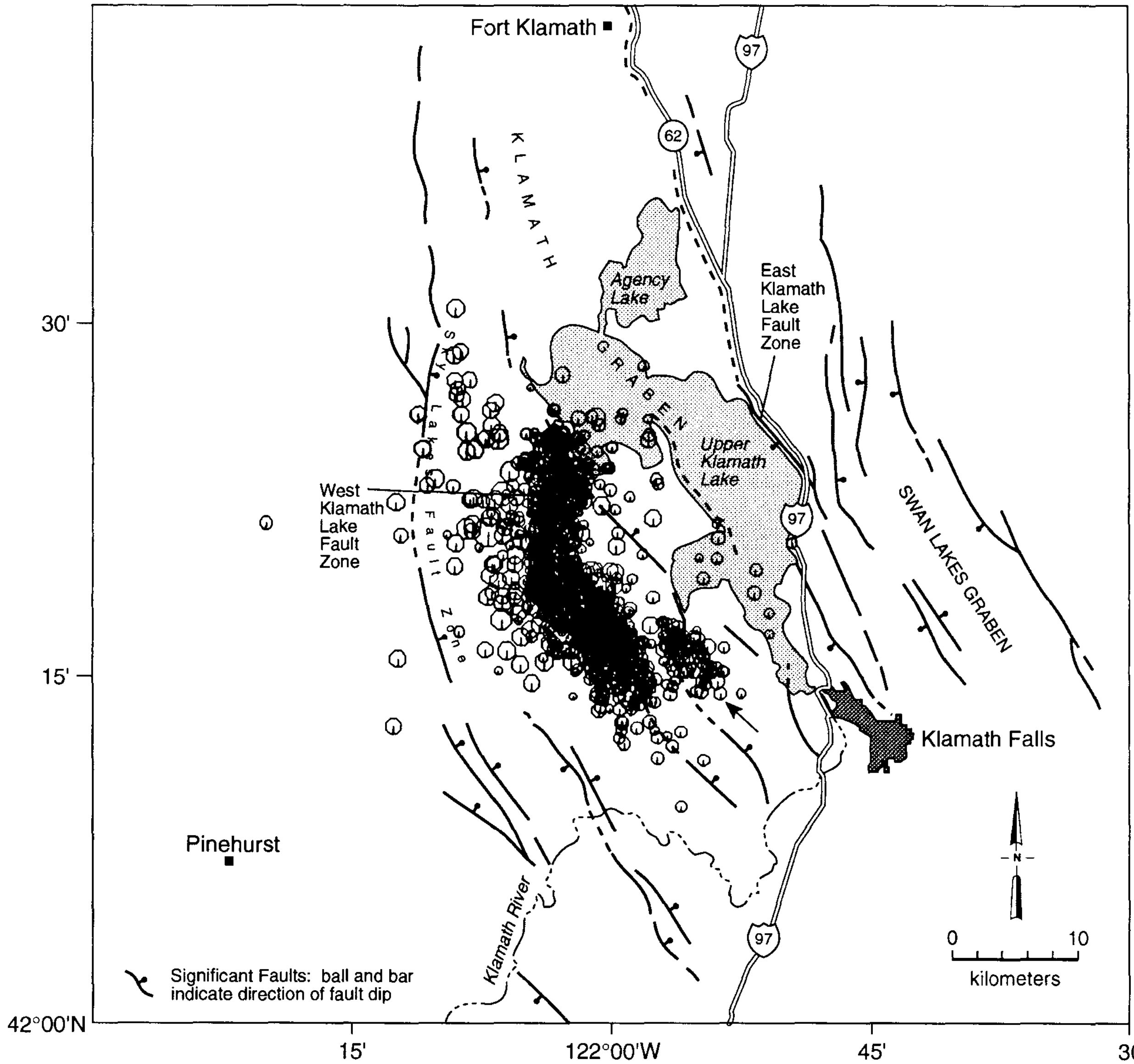


*Figure 8. Epicentral map of the 1993 Klamath Falls sequence. Seismicity data courtesy of the University of Washington. Faults taken from Hawkins and others (1992).*

(Wiley and others, 1993). Some unreinforced masonry buildings were severely damaged, while wood-frame buildings sustained little or no damage (Wiley and others, 1993). Modern buildings, including two reinforced concrete buildings on the Oregon Institute of Technology campus, also sustained considerable damage. Surface cracking within artificial fill along roads and landslides/rockfalls were induced by the earthquakes. No evidence for surface faulting was found.

The Klamath Falls area has experienced only low levels of historical seismicity, but geologic evidence shows late Quaternary (past 500,000 years) fault activity in the epicentral area (Hawkins and others, 1992) (Figure 8). The earthquake sequence was located between the fault bounding the western side of the Klamath graben and the Sky Lakes fault zone, both of which are east-dipping normal faults. Analyses to date indicate three source zones of seismicity: a northwest-trending zone that included the $M_L$ 6.0 earthquake; a north-trending zone including the $M_L$ 5.9 event; and a shallow northwest-trending zone to the east near Klamath Lake (Braunmiller and others, 1995).

A focal mechanism for the $M_L$ 6.0 event exhibits north-northwest-striking planes; the preferred plane being the east-dipping normal fault with a small component of left-lateral motion (Wiley and others, 1993; Braunmiller and others, 1995). The focal mechanism is consistent with approximately northeast-southwest-oriented tectonic extension typical of the northern Basin and Range province. Based on several focal mechanisms and the aftershock distribution, Braunmiller and others (1995) suggested that the Lake of the Woods fault zone (part of the Sky Lakes fault zone; Figure 8) may have been the source of the two main shocks.

A relatively late aftershock ($M_L$ 5.1) in the Klamath Falls sequence occurred on December 4, 1993, causing minor damage. It was the largest of more than 4,200 aftershocks that were recorded and located through 1994; it caused a parapet to fall onto an adjacent building on Main Street, resulting in the collapse of the roof of a new comic book store.

## AREAS OF SIGNIFICANT SEISMICITY

Before 1979, the historical record shows seismicity, consisting principally of earthquakes of $M_L \geq 3$, occurring rather sparsely throughout Oregon. The few concentrations were centered on Portland, in the epicentral areas of the 1968 Adel and 1976 Deschutes Valley earthquakes, in the Pine Valley graben-Cuddy Mountain area east of Baker, and the area between Hermiston and Milton-Freewater, northwest and northeast of Pendleton (Figure 3a). Since 1979 and the southward expansion of the UW seismographic network, seismicity, particularly microearthquake activity, appears to be concentrated in northernmost Oregon and in the Pine Valley graben-Cuddy Mountain area (Figure 3b). To some degree, this pattern may be an artifact of station coverage (Figure 1).

A map of the seismic moment released in Oregon based on the 153-year historical record dramatically reveals the sites of the state's largest earthquakes as well as its most active areas (cover illustration). The 1873 earthquake, which may have occurred within the Cascadia subduction zone as an intraplate event, has dominated the seismic moment release in Oregon. Areas of significant crustal seismic moment release include, in order of decreasing moment, the epicentral areas of the 1993–1994 Klamath Falls and 1936 Milton-Freewater earthquakes and the Portland region (cover illustration).

The apparent low level of seismicity in most of southeastern Oregon may be largely due to the absence of seismograph stations (Figure 1). As previously stated, a region of notably few earthquakes has been the Cascadia subduction zone beneath western Oregon (Ludwin and others, 1991). This lack of seismicity is in contrast with the seismically active subducting Juan de Fuca plate beneath western Washington. The reason for this quiescence in Oregon is perplexing.

### Portland region

As recognized by Couch and Lowell (1971) and Bott and Wong (1993), the Portland region (the 100-by-100-km area centered on Portland, including Vancouver) is the most seismically active area in Oregon (Figures 3a and 3b). At least 17 earthquakes of $M_L$ 4 and larger and six events of $M_L$ 5 and larger (including the 1877 and 1962 earthquakes) have occurred in the region in historic time. As noted earlier for the 1962 earthquake, Yelin and Patton (1991) explain seismicity in the area within the context of the Portland pull-apart basin. The basin is bounded on the southwest by the right-lateral, strike-slip Portland Hills fault zone and on the northeast by a postulated right-lateral, strike-slip Frontal fault zone (Yelin and Patton, 1991).

Since 1982, when seismographic coverage of the Portland basin became sufficient to detect events as small as $M_L$ 1, the Portland Hills fault zone has been nearly aseismic (Yelin, 1992). However, a composite focal mechanism for four events that occurred at the south end of Sauvie Island between 1982 and 1985 exhibited predominantly strike-slip faulting on a northwest-striking plane consistent with the Portland Hills fault zone (Yelin and Patton, 1991). From July to October 1991, a small earthquake swarm of about 40 events (three of $M_L$ 3.0 to 3.5) occurred at depths of 15 to 18 km at the northern end of the Portland Hills fault zone. Focal mechanisms for two of the largest earthquakes exhibited mixed reverse and right-lateral strike-slip faulting along a plane that coincides with the postulated Portland Hills fault, similar to what is observed elsewhere in the Portland basin (Yelin, 1992). A composite mechanism for several small events, 4 km south of Battleground, Washington, exhibited oblique-strike-slip faulting on a near-vertical, northwest-striking plane possibly associated with the Frontal fault zone (Yelin and Patton, 1991). In none of these cases, however, is the evidence definitive that the Portland Hills or the Frontal fault zones are seismically active because of the uncertainties in associating the relatively deep crustal seismicity in the Portland area with these structures whose depth extent is unknown (Blakely and others, 1995).

### Mount Hood

Seismicity has occurred at Mount Hood, a Cascade volcano east of Portland (Figure 3b). The largest known earthquake was a $M_L$ 4.0 event that occurred on December 13, 1974. Based on a 16-station temporary network operated at Mount Hood from November 1977 to December 1978, a total of 10 earthquakes were recorded and located, with the largest event reaching approximately $M_L$ 3.4 (Weaver and others, 1982). All events occurred above a depth of 15 km. Focal mechanisms for five of six events exhibited predominantly right-lateral, strike-slip faulting on a north-northwest-striking plane (Weaver and others, 1982). Weaver and others (1990) suggested that some of this activity and earthquakes in 1989 and 1990 may be associated with a north-northwest-striking seismic zone beneath Mount Hood, similar to one under Mount St. Helens in Washington. The 90-km-long St. Helens seismic zone has been one of the most seismically active areas in the Pacific Northwest in historical times (Weaver and Smith, 1983; Ludwin and others, 1991). Geomatrix Consultants (1990) suggested that the Mount Hood seismic zone may coincide with the Mount Hood fault.

### Pine Valley graben-Cuddy Mountain

The most active area in eastern Oregon appears to be the Pine Valley graben-Cuddy Mountain area along the Oregon-Idaho border (Figures 3a and 3b). The first recorded earthquake in the area occurred at 3:00 p.m. on October 14, 1913 (Figure 3a). The earthquake was assigned a maximum intensity of MM VI and was felt most severely in Landore, Idaho, where windows broke, furniture rocked, and dishes were thrown from shelves. Zollweg (BSU, personal communication, 1992) estimates the size of the event was $M_L$ 4¾, based on a review of historical seismograms.

A number of additional small earthquakes (MM IV–V) have occurred in the Pine Valley graben area (Mann, 1989) (Figures 3a and 3b). The abundant microseismicity shown on Figure 3a is the result of an analysis of events recorded at the BMO array from 1962 to 1967 (Zollweg and Wood, 1993). None of these events can be definitively associated with any mapped faults.

Zollweg and Jacobson (1986) operated a portable five-station microearthquake network, which recorded 15 aftershocks of two $M_L$ 3.8 earthquakes that occurred on August 10 and September 19, 1984, in the Cuddy Mountain area (Figure 3b). A composite focal mechanism exhibited normal faulting on north- to northwest-striking planes, suggesting that the area is being subjected to Basin and Range-like extensional stresses (Zollweg and Jacobson, 1986). Mann and Meyer (1993) suggested that the seismicity in the area is associated with a portion of the Olympic-Wallowa lineament which includes the Pine Valley graben and Brownlee fault. Conversely, we speculate that the Pine Valley graben-Cuddy Mountain area may represent the westernmost extent of the east-west-trending Centennial Tectonic Belt (Stickney and Bartholomew, 1987).

## EARTHQUAKES AND ACTIVE FAULTS

All earthquakes of tectonic origin, no matter their size, are the result of sudden displacement on a fault. The larger the fault area that is displaced or ruptured, the larger the event. For example, a $M_W$ 7 earthquake will typically rupture a fault or portion of a fault that is about 1,000 $km^2$ in area, such as a fault 50 km long and 20 km wide.

Few late Quaternary crustal faults have been identified in Oregon, particularly in the western half of the state (Pezzopane and Weldon, 1993). The dense vegetation and rapid erosion rates make it difficult to find evidence of young faulting in western Oregon. Active faults may also be more deeply seated west of the Cascades because of a thicker seismogenic crust (Wong and others, 1994). Thus they would not be as well expressed at the earth's surface as in other regions in the western United States (e.g., Basin and Range province) where the seismogenic crust is on the order of 15 km thick. To many, the 1993 Scotts Mills earthquake was an unexpected event for western Oregon, possibly because it occurred on a "blind" or hidden fault. Earthquakes of similar or larger magnitude, however, will likely occur on other blind structures elsewhere in this half of the state.

In eastern Oregon, like much of the western United States, late Quaternary faults are more prevalent or more visible at the surface, although few have been studied in detail. Faults that have been investigated include, for example, two Basin and Range-like structures: the Alvord fault along Steens Mountain (Hemphill-Haley and others, 1993) and the Goose Lake graben faults near Lakeview (Pezzopane and Weldon, 1993).

Because there have been so few large historical earthquakes in Oregon and seismic monitoring has been generally sparse, only a small number of events has been associated with known active faults in the state. These include possibly the 1936 Milton-Freewater, 1993 Scotts Mills, and 1993–1994 Klamath Falls earthquakes, which may have been associated with the Wallula or Hite faults, Mount Angel fault, and Lake of the Woods fault zone, respectively. As previously stated, the Portland Hills and Frontal fault zones may also have associated seismicity (Blakely and others, 1995).

Because of the incomplete historical record for the state, our understanding of the earthquake potential for Oregon will probably be quantified only through future paleoseismic fault studies and continued earthquake monitoring. Unfortunately for much of western Oregon, this quantification may never be complete because of its few known faults.

## CONCLUSIONS

Although Oregon is not generally thought of as being "earthquake country," especially compared to the neighboring states to the north and south, the historical record clearly indicates that the state faces a level of earthquake hazard that requires further quantification. Realistic estimates of the state's earthquake potential must rely heavily on future geologic studies. Crustal earthquakes as large as $M_L$ 6 and possibly intraplate earthquakes up to $M_L$ 6¾ within the Cascadia subduction zone have occurred in Oregon according to the observations of the past 153 years and will undoubtedly occur in the future. Additionally, paleoseismic studies along the Oregon coast indicate that the state has been shaken in the past by great Cascadia subduction zone megathrust earthquakes, possibly as large as $M_W$ 9. Paleoseismic investigations along late Quaternary faults also indicate that events as large as $M_L$ 7 have occurred repeatedly in several locations in eastern Oregon (e.g., Hemphill-Haley and others, 1993; Pezzopane and Weldon, 1993).

Although very few detailed paleoseismic studies have been performed on the few known late Quaternary faults in western Oregon, circumstantial evidence suggests that crustal earthquakes as large as $M_L$ 7 are possible in some areas, such as near Portland (Wong and others, 1994). Such events may pose the greatest hazard to the urban areas in the Willamette Valley and eastern Oregon because of the severe ground shaking that could result from such relatively nearby earthquakes, as compared to larger earthquakes which may occur at greater distances within the Cascadia subduction zone (e.g., Weaver and Shedlock, 1991; Wong and others, 1993).

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## ABSTRACTS OF PAPERS

*The following abstract is of a paper given at an international conference in May 1995 at the University of Washington. The conference, titled "Tsunami deposits—geologic warnings of future inundation," was sponsored by the Quaternary Research Center, the National Oceanic and Atmospheric Administration, and the U.S. Geological Survey. Among the 80 registered participants were scientists from Canada, Germany, Japan, Norway, the Philippines, the United Kingdom, and the United States.*

***The use of microfossils (diatoms) in mapping paleotsunami deposits,*** by Eileen Hemphill-Haley, U.S. Geological Survey, University of Oregon

Diatoms are aquatic microscopic plants that secrete silt- to sand-sized siliceous hard parts. They can indicate a freshwater, estuarine or marine origin for sedimentary deposits. Diatoms are typically abundant in Holocene coastal sediment, including tsunami deposits, of the Pacific Northwest.

Tsunami deposits, attributed to both subduction-zone and shallow crustal earthquakes during the past several thousand years, have been identified at numerous sites in Oregon and Washington. Along the Niawiakum River (at Willapa Bay, southwestern Washington) a sandy interval overlies a soil that was submerged during an earthquake along the Cascadia subduction zone (CSZ) about 300 years ago. Diatoms within this interval are indicative of sandy tidal flats, and refute a fluvial source for the deposit. At Cultus Bay, (Whidbey Island, Northern Puget Sound), a sand wedge interbedded with salt-marsh peat attests to a tsunami generated by an earthquake on the Seattle fault about 1000 years ago. Diatoms found in the sand distinct from species in the underlying and overlying peat, and are indicative of estuarine tidal flats. At Bradley Lake (south-central Oregon coast), tsunamis generated by earthquakes in the CSZ may have occasionally overtopped a coastal barrier and deposited anomalous marine planktonic diatoms in the freshwater lake about 300, 1,000, and 1,400 yr B.P.

Diatom biostratigraphy alone can not differentiate deposition by a tsunami from other mechanisms such as seiches or storm surges. However, in conjunction with stratigraphic and chronologic data, it provides valuable paleoecological insight for studies of paleo-tsunami deposition. □

## 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.*

***Vertical component of present-day deformation in the western Pacific Northwest,*** by Clifton Edwards Mitchell (M.S., University of Oregon, 1992), 103 p.

This thesis maps the regional pattern of vertical deformation of the Pacific Northwest west of the Cascade Range and, using long-term tidal records from Crescent City, Astoria, and Neah Bay, assigns uplift rates to that pattern to reference it to the geoid. Relative uplift profiles along the coast are constructed from two independent data sets that indicate crustal motion: comparison of records from eight tide gauges, and comparison of releveling surveys. Both methods detect only relative motion, but the two entirely independent data sets produce comparable profiles along the coast. The releveling data set allows construction of profiles inland from the coast, and these various profiles are assembled into a network of relative uplift rates. A contoured map of this relative network is combined with uplift rates at three long-term tidal stations to contour a map of regional uplift rates relative to the geoid. □

## "Ask-A-Geologist" — USGS offers new Internet Service

Ask-A-Geologist is an experimental service of the U.S. Geological Survey (USGS) Branch of Pacific Marine Geology, with participation from several other branches. General questions on earth sciences may be sent by electronic mail to: **ask-a-geologist@octopus.wr.usgs.gov**.

All electronic mail received at this address will be routed to the geologist of the day. The geologist will reply to your question within a day or two or provide referrals to better sources of information if you include an Internet-accessible return address in the body of your message.

The USGS encourages grade school and high school students with electronic mail access to send in questions.

For any questions about this service, but not about geology, contact Rex Sanders, rex@octopus.wr.usgs.gov. □

*(**Crescent City**, Continued from page 124)*

sank. The boat up Elk Creek had settled among the ruins of the new Olympic Pool. The cars along with the two small buildings that were swept off the dock had faded from sight. Logs, boats, furniture along with the buildings all tossed helter-skelter. The lumber from three big yards was tossed high on the land or floating in the water. Some of the landing and small craft floats were sailing away in a dizzy pattern.

Isolated on the island we watched the search begin along Elk Creek for the bodies of the victims. The demolition crews started clearing the streets and burning the debris along the beach front and Highway 101. The silent killer had left after taking its toll of life and property, but the vacant lots, the broken fish docks, along with abandoned fishing boat hulls still remind us of the gruesome night the tsunami destroyed 56 blocks of Crescent City, CA.

It still seems hard to believe that with all the salvage that floated by us out to sea, the only bit to reach the island was one spool of lavender thread. □

# The Oregon vortex phenomenon

*by John Eliot Allen, Emeritus Professor of Geology, Portland State University, P.O. Box 751, Portland, OR 97207*

In June, a full page in *The Oregonian* was devoted to the tourist attraction known as "The Oregon Vortex," which lies north of the Rogue River, about halfway between Grants Pass and Medford.

While living in Grants Pass in 1937, I visited this reportedly anomalous location, which apparently violated the physical laws of gravity and magnetism. The phenomenon centered in a small weather-beaten and dilapidated wooden cabin, which stood at an angle on a gently sloping hillside, apparently the surface of a landslide. And yes, balls did appear to roll uphill. And when one stood erect, one appeared to lean at an angle from the vertical—and all of this was attributed to a mysterious "magnetic vortex."

A field geologist always carries a compact surveying instrument known as a "Brunton," which consists of both an accurate compass and a bubble level. With the compass, I could find no local horizontal or vertical magnetic anomaly; with the bubble level I convinced myself that the balls rolled downhill, not up.

I had a faint memory from a lecture in my Psych 202 class at Oregon in 1927, which reminded me of a skewed room that has a weird optical illusion of shape and size and slope, so I decided that the "Vortex" cabin represented such a skewed structure.

Since reading the *Oregonian* article, I have checked out that memory with a modern psychology text (Bernstein and others, 1994) and find that this illusion is well known as the "Muller-Lyer Illusion." However, the "Vortex" is a fun thing to see, and I strongly urge everyone to take this short, side trip from I-5 on the next trip south. And take your Brunton with you!

**REFERENCES**


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# Tsunami legislation calls for rules

The Governing Board of the Oregon Department of Geology and Mineral Industries is charged with developing administrative rules for implementing Senate Bill 379. The bill prohibits the siting of certain types of buildings in coastal tsunami inundation zones and will come into effect on January 1, 1996.

Public hearings were held in Seaside, Newport, Reedsport, and Coos Bay October 24–27. A final hearing will be held December 11, 1995, at the Hatfield Marine Science Center in Newport. Draft maps and rules are available for inspection in public libraries along the coast and in DOGAMI's Grants Pass and Portland offices. □

## DOGAMI PUBLICATIONS

**Released October 27, 1995:**

***Downhole and seismic cone penetrometer shear-wave velocity measurements for the Portland metropolitan area, 1993 and 1994***, by M.A. Mabey and I.P. Madin. Open-File Report O–95–7, 69 p., $6.

Geologic subsurface data collected during the investigations that led to the publication of seismic hazard maps for the Portland metropolitan area are now available in this new report. The data will be of use to geologists and geotechnical engineers who conduct site-specific seismic investigations.

During the years 1993 and 1994, DOGAMI conducted a major subsurface investigation program as part of the Relative Earthquake Hazards Mapping Project funded through the Federal Emergency Management Agency. The program included the measurement of shear-wave velocities at 65 locations around the Portland metropolitan area.

The measurements have been assembled in a printed graphic catalog that contains one page for each location's profile, showing graphics of shear-wave velocity, raw Standard Penetration Test blow counts, and drill hole lithology. A location map shows the distribution of the profiles over eight 7½-minute quadrangles and their relationship to the urban growth boundary.

For details on the lithologic data readers are referred to the hazard maps published in the Geological Map Series as GMS–79 and GMS–89 through GMS–92. □

# DOGAMI field offices get new telephone area codes

The introduction of a second area code for Oregon affects all offices of the Oregon Department of Geology and Mineral Industries located outside Portland.

Please note that, as of November 5, the telephone number for any of the offices in Albany, Baker City, and Grants Pass now begins with the area code **541**. See page 121 of this issue for complete address and phone information. □


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

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Klaus K. Neuendorf, Editor

# Index to *OREGON GEOLOGY*, volume 57, 1995

*Numbers refer to issue and beginning page of entry. Most subject entries include cross-references to author entries (in parentheses).*

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