

OREGON GEOLOGY

published by the
Oregon Department of Geology and Mineral Industries



VOLUME 59, NUMBER 1

JANUARY/FEBRUARY 1997



IN THIS

ISSUE:

AGE OF THE
PLANT-BEARING
TUFFS OF THE
JOHN DAY
FORMATION AT
FOSSIL

GUIDELINES
FOR
SITE-SPECIFIC
SEISMIC
HAZARD
REPORTS

FIELD TRIP
GUIDE TO THE
EASTERN
MARGIN OF THE
OREGON-
IDAHO GRABEN
AND THE
CALDERAS OF
THE LAKE
OWYHEE
VOLCANIC
FIELD

OREGON GEOLOGY

(ISSN 0164-3304)

VOLUME 59, NUMBER 1 JAN./FEB. 1997

Published bimonthly in January, March, May, July, September, and November by the Oregon Department of Geology and Mineral Industries (Volumes 1 through 49 were entitled *The Oregonian*).

Governing Board

Jacqueline G. Haggerty, Chair	Enterprise
Donald W. Christensen	Depoe Bay
John W. Stephens	Portland
State Geologist	Donald A. Hull
Deputy State Geologist	John D. Beaulieu
Publications Manager/Editor	Beverly F. Vogt
Production Editor	Klaus K.E. Neusendorf
Production Assistants	Geneva Beck Kate Halstead

Main Office: Suite 965, 800 NE Oregon Street # 28, Portland 97232, phone (503) 731-4100, FAX (503) 731-4066.

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

Mark L. Ferns, Regional Geologist.

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

Thomas J. Wiley, Regional Geologist.

Mined Land Reclamation Program: 1536 Queen Ave. SE, Albany 97321, phone (541) 967-2039, FAX (541) 967-2075.

Gary W. Lynch, Supervisor.

The Nature of the Northwest Information Center: Suite 177, 800 NE Oregon Street # 3, Portland, OR 97232-2162, phone (503) 872-2750, FAX (503) 731-4066, Donald J. Haines, Manager.

Second class postage paid at Portland, Oregon. Subscription rates: 1 year, \$10; 3 years, \$22. Single issues, \$3. Address subscription orders, renewals, and changes of address to *Oregon Geology*, Suite 965, 800 NE Oregon Street # 28, Portland 97232. POSTMASTER: Send address changes to *Oregon Geology*, Suite 965, 800 NE Oregon Street # 28, Portland 97232-2162.

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

Permission is granted to reprint information contained herein. Credit given to the Oregon Department of Geology and Mineral Industries for compiling this information will be appreciated. Conclusions and opinions presented in articles are those of the authors and are not necessarily endorsed by the Oregon Department of Geology and Mineral Industries.

Cover photo

Slab of shale with fossil plant remains from the locality at Fossil, Oregon, at 85 percent of natural size. Impressions include leaves of *Juglans*, *Parrotia*, *Paracarpinus*, *Alnus*, and *Quercus*, fruit valves of *Croton*, and an *Acer* samara. Specimen collected 1988 and housed at Florida Museum of Natural History, Gainesville, Florida. Article beginning on next page dates locality at about 32.6 million years.

In memoriam: John Eliot Allen

He was one of the "grand old men" of Oregon geology, well known as geologist, teacher, and author.

John Eliot Allen began his professional career in 1935 as a ranger-naturalist at Crater Lake National Park. In 1937, he became part of the beginnings of the Oregon Department of Geology and Mineral Industries, first as a "Field Geologist," finally as "Chief Geologist." He was one of three geologists with a doctoral degree (along with Wallace D. Lowry and Ewart M. Baldwin) whose simultaneous departure for better positions in industry or the academic world hit the agency hard in 1947.



John Eliot Allen, 1908-1996

Aside from his regular duties, field mapping continued to be a favorite occupation of his until 1954, and he conducted field studies in California, Washington, Nevada, New Mexico, Arizona, and Pennsylvania as well as in Oregon. His last geologic quadrangle map was produced on air-photo mosaics—"perhaps the first time they had been used that way," he wrote in his autobiography. (A brief summary appeared in *Oregon Geology* in the May 1994 issue.)

He guided the first steps of the Portland State University Geology Department, building its program and serving as its head for 18 years, from 1956 to 1974. For his outstanding and enthusiastic teaching, the National Association of Geology Teachers honored him with the Neil Miner Award in 1972. In his lectures, he was using a multimedia approach already in the 1960s. In 1995, he received a Presidential Citation from Portland State University for his "outstanding service and dedication."

When he retired from teaching in 1974, he concentrated on writing about geology for the lay reader. PSU commented on this start of his "third career" with the words, "And he has yet to slow down." The latest of his hundreds of articles and books is reviewed on page 21 of this issue.

John Eliot Allen died November 17, 1996, at age 88. He never slowed down. □

Age of the plant-bearing tuffs of the John Day Formation at Fossil, Oregon, based upon $^{40}\text{Ar}/^{39}\text{Ar}$ single-crystal dating

by William C. McIntosh, New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico 87801; Steven R. Manchester, Department of Natural Sciences, Florida Museum of Natural History, University of Florida, Gainesville, Florida 32611; and Herbert W. Meyer, Florissant Fossil Beds National Monument, Florissant, Colorado 80816.

ABSTRACT

The age of the fossil plant locality in the town of Fossil, Oregon, is estimated based upon $^{40}\text{Ar}/^{39}\text{Ar}$ analysis of sanidine crystals from the fossil-bearing tuffaceous shale. The resulting date of 32.58 ± 0.13 Ma provides a more reliable date for the locality than previous whole-rock K-Ar dates of the underlying basalt (29.7 ± 1.6 Ma and 33.8 ± 1.7 Ma). The new date confirms an early Oligocene age for the flora, shows that the assemblage is approximately coeval with that of the Bridge Creek flora at the Painted Hills locality, and indicates that hardwood deciduous forest similar to that found today in eastern North America and eastern Asia was established less than 1.5 million years following the Eocene-Oligocene transition.

INTRODUCTION

A well-known locality for fossil plants occurs in the lower part of the John Day Formation in the town of Fossil, Oregon. A general overview of the plant assemblage from this locality, including brief descriptions and illustrations of the characteristic species, was presented by Manchester and Meyer (1987). Many additional taxa have been collected subsequently, and the assemblage is now known to contain more than 65 plant species (Meyer and Manchester, in press) as well as skeletal remains of bat (Brown, 1959), salamander (Naylor, 1979), and frog (T. Dillhoff, T. Fremd, oral communication, 1994). The fossil leaves, cones, flowers, and fruits represent a hardwood deciduous forest similar in composition to present-day forests of temperate eastern North America and eastern Asia. Based upon floral similarities with other fossil assemblages of the John Day Formation, the Fossil locality has been assigned to the Bridge Creek flora and has been considered to be Oligocene (Brown, 1959; Manchester and Meyer, 1987), but direct radioisotopic data have only recently become available.

The fossils occur in tuffaceous lake sediments. In the summer of 1995, we collected a sample of the fossil-bearing tuff from the Wheeler High School locality for radioisotopic age determination. Relatively large euhedral sanidine crystals were isolated from the sample and then dated using the single-crystal laser-fusion $^{40}\text{Ar}/^{39}\text{Ar}$ dating method. Such age determinations, obtained directly from fossil-bearing rocks, provide an important link between biostratigraphic and radioisotopic geologic time scales. The purpose of this report is to summarize the $^{40}\text{Ar}/^{39}\text{Ar}$ dating technique, present age results, compare the results with earlier K-Ar

dates, and discuss the relevance of the date to the fossil plant assemblage at Fossil.

$^{40}\text{Ar}/^{39}\text{Ar}$ DATING TECHNIQUE

The argon-argon ($^{40}\text{Ar}/^{39}\text{Ar}$) dating technique offers several advantages over conventional potassium-argon (K-Ar) dating (Maluski, 1989). Both methods rely on the natural radioactive decay of ^{40}K to ^{40}Ar (the half-life of ^{40}K is 1.25 Ga [giga-annum= 10^9 years]). Assuming that all ^{40}Ar gas escaped from the volcanic melt prior to formation of sanidine crystals, any measurable ^{40}Ar gas found in the sanidine crystals of a rock sample may be attributed to the decay of ^{40}K . Accordingly, the ratio of parent ^{40}K to daughter ^{40}Ar can be measured and used to calculate the age of the rock. In the conventional K-Ar dating technique, K and Ar are measured on separate aliquots of sample. In the $^{40}\text{Ar}/^{39}\text{Ar}$ technique, the sample is irradiated with neutrons in a nuclear reactor, converting some of the K into ^{39}Ar , which then serves as a proxy for the K. The ratio of parent to daughter isotopes is then measured as the ratio of ^{39}Ar to ^{40}Ar in a single aliquot of sample. This approach allows ages to be measured far more precisely than the conventional K-Ar technique and uses much smaller sample sizes. Laser-heating enables precise ages to be measured on individual, sand-sized mineral grains, permitting identification and rejection of contaminant or altered grains. This method is known as single-crystal laser-fusion $^{40}\text{Ar}/^{39}\text{Ar}$ dating. One constraint of the $^{40}\text{Ar}/^{39}\text{Ar}$ dating technique is that all samples must be irradiated with "monitor" minerals of known age in order to accurately determine the flux of neutrons received.

METHODS

A crystal-rich sample of tuffaceous sediment bearing fossil leaf impressions was collected from the Wheeler High School fossil locality (SW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 33, T. 6 S., R. 21 E.). The sample was prepared by crushing and sieving to 120-500 μ (micron), followed by ultrasonic cleaning in dilute (7-percent) hydrofluoric acid. A sanidine separate was produced, using a Franz magnetic separator, density liquids (nontoxic lithium metatungstate), and hand-picking. A 20-mg aliquot of the sanidine separate was packaged with flux monitors of Fish Canyon Tuff sanidine (27.84 Ma, relative to Mmhb-1 hornblende at 520.4 Ma; Samson and Alexander, 1987) and irradiated at the Texas A&M Nuclear Research Center for 14 hours.

$^{40}\text{Ar}/^{39}\text{Ar}$ analyses were performed at the New Mexico Geochronology Research Laboratory of the New Mexico Institute of Mining and Technology. This facility includes an MAP 215-50 mass spectrometer attached to a fully automated all-metal argon extraction system equipped with a 10-watt CO_2 laser. A total of 31 sanidine crystals from the sample and four to six sanidine crystals from each monitor were individually analyzed. Sanidine crystals were fused by CO_2 laser for 15 seconds; then reactive gases were removed with an SAES GP-50 getter prior to expansion into the mass spectrometer. Extraction line blanks during these analyses ranged from 5×10^{-17} to 2×10^{-16} moles ^{40}Ar and 5×10^{-19} to 2×10^{-18} moles ^{36}Ar . The neutron flux values (J-values) within irradiation packages were determined to a precision of ± 0.25 percent by averaging results from six sanidine crystals from each sanidine monitor.

RESULTS AND DISCUSSION

Single-crystal laser-fusion results are summarized in Table 1 and Figure 1. The 31 analyzed crystals range in age

from 32.30 to 33.04 Ma, with analytical precisions (± 1 standard deviation) generally between ± 0.09 and ± 0.15 Ma. The K-Ca ratios of individual sanidine crystals (calculated from $^{37}\text{Ar}/^{39}\text{Ar}$ measurements) range from 22.4 to 39.4, consistent with their derivation from a single eruptive source. The mean age of 30 crystals (excluding crystal 5887-23, which, at 33.04 Ma, is slightly but distinctly older than the other crystals) is 32.58 ± 0.13 Ma. This mean was calculated by equally weighting the values from each crystal, and the error is a simple ± 1 standard deviation.

The resulting age of 32.58 ± 0.13 Ma for the leaf-bearing tuff at Fossil provides a refinement over previous unpublished ages obtained for the locality. Our age falls between two whole-rock K-Ar ages presented in a master's thesis by Riseley (1989) from an andesitic basalt immediately underlying the tuffaceous shales. These ages, from Geochron Laboratories, were 29.7 ± 1.6 Ma and 33.8 ± 1.7 Ma. A suite of ten crystals extracted from the same tuff as that treated in the present paper gave a slightly younger $^{40}\text{Ar}/^{39}\text{Ar}$ age of 32.24 ± 0.18 Ma in an earlier un-

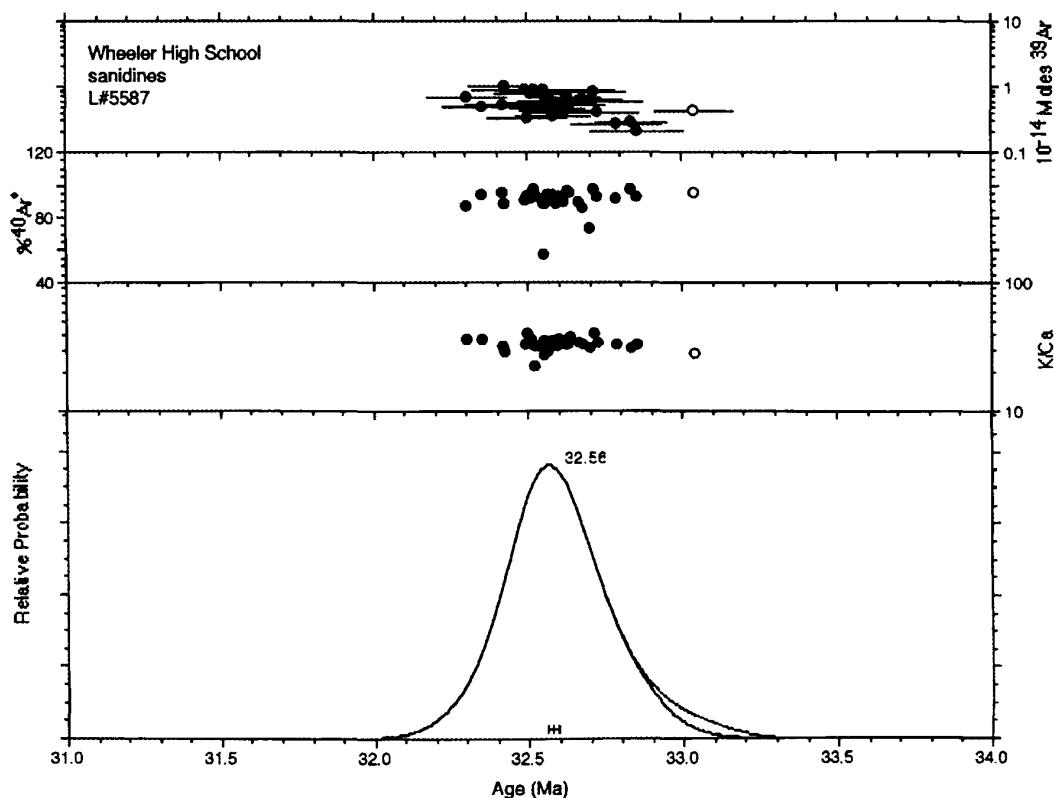


Figure 1. Single-crystal laser-fusion results from sanidines from Wheeler High School sample. Values plotted versus age are signal size in moles ^{39}Ar , radiogenic yield, K-Ca ratio, and relative probability. Analyses used in the mean age calculation are shown as solid circles, and the one analysis excluded from the mean is shown by an open circle. Age uncertainty of each analysis (± 1 standard deviation) is shown as horizontal bars on age versus moles ^{39}Ar . The relative probability curve, or ideogram, is the sum of the gaussian probabilities of the individual age determinations.

Table 1. Single-crystal laser-fusion $^{40}\text{Ar}/^{39}\text{Ar}$ results. All ages of single sanidine crystals. Errors expressed as $\pm 1 \sigma$. Results in italics excluded from mean values

Run ID no.	$^{40}\text{Ar}/^{39}\text{Ar}$	$^{37}\text{Ar}/^{39}\text{Ar}$	$^{36}\text{Ar}/^{39}\text{Ar}$	^{39}K moles	K/CA	% $^{40}\text{Ar}^*$	Age (Ma)	\pm Err
5587-20	14.41	1.43E-02	6.39E-03	6.9E-15	35.6	86.9	32.30	0.11
5587-32	13.38	1.41E-02	2.83E-03	4.9E-15	36.2	93.8	32.35	0.11
5587-25	13.26	1.63E-02	2.34E-03	5.2E-15	31.4	94.8	32.42	0.10
5587-40	14.33	1.77E-02	5.96E-03	9.8E-15	28.8	87.7	32.43	0.10
5587-37	13.96	1.55E-02	4.63E-03	8.8E-15	33.0	90.2	32.49	0.10
5587-39	13.56	1.29E-02	3.25E-03	3.3E-15	39.4	92.9	32.50	0.11
5587-28	13.52	1.40E-02	3.12E-03	4.9E-15	36.5	93.2	32.51	0.10
5587-10	13.86	1.49E-02	4.28E-03	7.5E-15	34.2	90.9	32.51	0.10
5587-33	12.92	1.59E-02	1.05E-03	8.6E-15	32.0	97.6	32.52	0.09
5587-36	13.19	2.29E-02	1.99E-03	8.6E-15	22.3	95.6	32.52	0.09
5587-04	13.66	1.64E-02	3.57E-03	8.0E-15	31.2	92.3	32.53	0.09
5587-07	22.16	1.44E-02	3.23E-02	8.8E-15	35.4	57.0	32.55	0.21
5587-30	14.30	1.89E-02	5.69E-03	8.1E-15	26.9	88.2	32.55	0.11
5587-03	14.28	1.56E-02	5.63E-03	5.7E-15	32.8	88.4	32.56	0.11
5587-22	13.51	1.79E-02	3.02E-03	4.5E-15	28.6	93.4	32.56	0.10
5587-02	13.43	1.47E-02	2.73E-03	6.1E-15	34.8	94.0	32.58	0.09
5587-27	13.41	1.47E-02	2.65E-03	3.4E-15	34.8	94.2	32.58	0.10
5587-35	14.45	1.63E-02	6.14E-03	5.6E-15	31.3	87.5	32.59	0.11
5587-31	13.72	1.39E-02	3.66E-03	4.2E-15	36.6	92.1	32.60	0.11
5587-34	14.19	1.56E-02	5.24E-03	3.9E-15	32.7	89.1	32.62	0.12
5587-38	13.21	1.55E-02	1.92E-03	6.9E-15	32.8	95.7	32.63	0.09
5587-06	13.33	1.39E-02	2.30E-03	5.3E-15	36.8	94.9	32.64	0.10
5587-09	14.27	1.52E-02	5.44E-03	6.0E-15	33.5	88.7	32.66	0.11
5587-01	14.72	1.57E-02	6.94E-03	6.3E-15	32.6	86.1	32.68	0.11
5587-08	17.40	1.65E-02	1.60E-02	5.8E-15	30.9	72.8	32.70	0.15
5587-21	13.01	1.29E-02	1.10E-03	8.0E-15	39.5	97.5	32.71	0.09
5587-26	13.74	1.50E-02	3.58E-03	4.1E-15	34.0	92.3	32.73	0.12
5587-05	13.96	1.56E-02	4.23E-03	2.8E-15	32.8	91.1	32.79	0.13
5587-29	13.05	1.64E-02	1.08E-03	2.8E-15	31.0	97.6	32.84	0.10
5587-24	13.73	1.56E-02	3.38E-03	2.0E-15	32.7	92.7	32.85	0.13
5587-23	13.47	1.84E-02	2.26E-03	4.2E-15	27.7	95.1	33.04	0.11

Mean values: $n=30$; $\text{K}/\text{Ca}=33.0\pm 3.5$; $\text{age}=32.58\pm 0.13$

Analytical parameters: Mass discrimination= 1.005 ± 0.002 ; $^{39}\text{Ar}_{\text{Ca}}/^{37}\text{Ar}_{\text{Ca}}=0.0007\pm 0.0005$; $^{36}\text{Ar}_{\text{Ca}}/^{37}\text{Ar}_{\text{Ca}}=0.00026\pm 0.00002$;

$^{38}\text{Ar}_{\text{K}}/^{39}\text{Ar}_{\text{K}}=0.0119$; $^{40}\text{Ar}_{\text{K}}/^{39}\text{Ar}_{\text{K}}=0.0002\pm 0.0003$; $J\text{-value}=0.001442918\pm 0.000002$. Decay constants from Steiger and Jager (1977).

published analysis (Brent Turrin, written communication to Manchester, 1989).

The new age of 32.58 ± 0.13 Ma is consistent with those obtained for rocks associated with the classic locality of the Bridge Creek flora at the Painted Hills Unit of John Day Fossil Beds National Monument. Evernden and others (1964) published K-Ar ages of 31.8 and 32.3 Ma (corrected to decay constants of Steiger and Jager, 1977) based upon sanidine crystals from tuffs and whole-rock analysis of basalt, respectively. More recently, $^{40}\text{Ar}/^{39}\text{Ar}$ ages of 32.99 ± 0.11 Ma and 32.66 ± 0.03 Ma were obtained from a biotite tuff 3–5 m stratigraphically below the leaf-bearing tuffs at Painted Hills and from a tuff situated well above the leaf beds, respectively (C. Swisher *in* Bestland and Retallack, 1994); Bestland and others, 1994; Retallack and others, 1996).

The new radiometric data indicate that the Bridge Creek flora, represented by temperate forest assemblages at Fossil, Painted Hills, and various other sites in north-central Oregon (Meyer and Manchester, *in press*), are early Oligocene

in age. Swisher has obtained a radiometric age of 33.62 ± 0.19 for the “slanting leaf beds” on Iron Mountain (Retallack and others, 1996). With the Eocene/Oligocene boundary now placed at about 34.0 million years (Swisher and Prothero, 1990; Berggren and others, 1992), these ages show that the Bridge Creek flora, as known at Fossil, Painted Hills, and Iron Mountain, is representative of the forest that had developed within 0.3–1.5 million years following the Eocene-Oligocene transition.

ACKNOWLEDGMENTS

This research was funded in part by grant EAR 9506727 from the National Science Foundation to S.R. Manchester. Thanks are owed to the citizens of Fossil, Oregon, for keeping the Wheeler High School locality open for public fossil collecting. Critical comments on the original paper were kindly provided by Jeff A. Myers and Wesley Wehr.

(Continued on page 20)

Guidelines for site-specific seismic hazard reports for essential and hazardous facilities and major and special-occupancy structures in Oregon

by the Oregon Board of Geologist Examiners and the Oregon Board of Examiners for Engineering and Land Surveying. Printed with permission and assistance of these Boards. Adopted by the Oregon State Board of Geologist Examiners on September 6, 1996. Adopted by the Oregon State Board of Examiners for Engineering and Land Surveying on September 17, 1996, for distribution and comment.

For over a year, the Board of Geologist Examiners has fostered the development of this document. It was drafted by members of this Board, with input from the practice community through several professional societies. Local chapters of the Association of Engineering Geologists and the Geotechnical Engineering Technical Group of the American Society of Civil Engineers, Oregon Section, were major contributors. The Boards intend to keep the guidelines current and flexible through continuous input from the practice community. Comments and suggestions for improvement of the guidelines are welcomed and encouraged and should be directed to either Board. Both agencies are located at 750 Front Street NE, Salem, OR 97310.

I. INTRODUCTION

These guidelines were prepared by the State of Oregon Boards of Geologist Examiners and Examiners for Engineering and Land Surveying to assist those who prepare reports for site-specific seismic hazard reports for essential facilities, hazardous facilities, major structures and special occupancy structures as provided in Oregon Revised Statutes 455.447(2)(a) and Oregon Administrative Rules 918-460-015. The guidelines describe the general content of these reports and are not intended to be a complete listing of all the elements of a site-specific seismic hazard report as outlined in Section 2905 of the Oregon Structural Specialty code.

These guidelines are intended to be used as a checklist for projects of varying size and complexity including hospitals, schools, and emergency-response facilities. The preparer and the reviewer of site-specific seismic hazard reports are expected to tailor the scope of work and interpretations to the size, occupancy, and critical use of the proposed structure. It is recognized that the techniques used to evaluate a site for a larger and more critical facility will be more complete and detailed than for a smaller and less critical building or other structures. The site-specific investigations vary according to the local geologic conditions that may affect the performance of the proposed or existing structure and to the proximity to faults that are expected to be seismogenic. The investigator(s) is (are) expected to be knowledgeable about the current practice of seismic geology and earthquake engineering and should be aware of the need to provide designers of buildings and other structures with information that can be readily utilized in construction or remodeling projects to reduce seismic risk.

The professional who is performing, signing, and stamping the site-specific investigation is responsible for the adequacy of investigative procedures and reporting that will adequately characterize seismic risk for the proposed use of the subject site. The report should clearly state the techniques used in the investigation, the data acquired, and the findings and recommendations, so that peer reviewers and users of the resulting reports will have a basis for judging the adequacy of the investigation.

In Oregon, the complexity of local geology, limited geologic exposure, variety of earthquake types, and the potential for multiple seismic hazards, including ground shaking, fault rupture, amplification, landsliding, liquefaction, uplift and subsidence, seiche, and tsunami generation, necessitate a choice of investigative techniques that will vary from site to site and that must be chosen based on the geologic hazards and subsurface conditions and on the intended use of the structure.

The following guidelines are intended to be applicable for projects with a wide range in size, cost, and utility. Flexibility in the use of the guidelines is expected, and professional judgment is needed in the selection of work elements for the investigation and in the thoroughness of the resulting report. The preparer and the reviewer of site-specific seismic hazard reports are expected to be familiar with the use of such reports by engineers engaged in the geotechnical and structural design of buildings, so that the reports are designed to be routinely used by designers to maximize the reduction in seismic risk, as structures are constructed or retrofitted.

State law, related administrative rules, and state and local building codes are evolving in an effort to mitigate seismic risk. The preparers, supervisors, and reviewers of site-specific seismic hazard reports are expected to be knowledgeable about relevant laws, rules, and codes.

Some cities and counties in Oregon have ordinances requiring geologic hazard reports. The content of these reports may overlap with the guidelines for the site-specific seismic hazard reports. The geologic hazard reports typically are required for areas mapped by the Oregon Department of Geology and Mineral Industries as landslide or potential landslide areas or as tsunami inundation areas. The geologic hazard reports required by local government ordinance may cover a broader range of facility uses, sizes, and occupancy levels than the site-specific seismic hazard reports that are the focus of these guidelines. The geologic hazard reports range in scope from reconnaissance level investigations to more intensive site-specific seismic hazard studies.

These guidelines are intended to be informal and not regulations. The guidelines are expected to evolve, as the relevant seismic hazards are better defined and as building codes and engineering practices change.

II. CONTENT OF SITE-SPECIFIC SEISMIC HAZARD REPORTS

The following information should be considered in preparing site-specific seismic hazard reports in Oregon.

- A. Purpose and scope of the investigation**, including a brief description of the proposed site use, size of the proposed building or other structure, occupancy, and current seismic zonation (UBC).
- B. Regional geologic and tectonic setting**, including a complete list of all seismogenic faults that could impact the site and a description of the crustal, intraplate, and subduction-zone earthquake hazards.

- C. Site conditions**, including elevation, subsurface conditions, landforms, site grading, vegetation, existing structures, and other features that may influence the investigation.

D. Description of the investigation

1. Regional seismic history and tectonic setting

- a. Significant historic earthquakes and tsunamis in the region and locations and magnitudes of seismic events in the vicinity of the site. Crustal earthquakes, intraplate, and interface subduction zone events should be included.
- b. Evidence of prehistoric earthquakes and tsunamis that may have affected the site.
- c. Map showing the location of seismic features relative to the proposed project and an estimate of the amount of disturbance relative to bedrock and surficial materials.
- d. Selection for appropriate strong-motion attenuation relationships for the site.
- e. Published probabilistic estimate of earthquake occurrence.
- f. Geodetic and strain measurement, microseismicity monitoring, or other monitoring.

2. Interpretation of aerial photography and other available remotely sensed images relative to the geology and earthquake history of the site, including vegetation patterns, soil contrasts, and lineaments of possible fault origin.

3. Site investigation

- a. Detailed field mapping of soils, geologic units and structures, and topographic features indicative of faulting, such as sag ponds, spring alignments, disrupted drainage systems, offset topographic and geologic features, faceted spurs, vegetation patterns, and deformation of buildings or other structures.
- b. Review of local groundwater conditions including wa-

ter depth and elevation.

- c. Trenching and other excavating to permit the detailed and direct observation and logging of continuously exposed geologic units, including soils and features that are relevant to seismic hazards. Trenching should cross known or suspected active faults in order to determine the location, timing, and recurrence rate of past movements, the area disturbed, the physical condition of fault zone materials, and the geometry of faulting.
- d. Exploratory drilling and/or test pits designed to permit the collection of data needed to evaluate the depth, thickness, and types of earth materials and groundwater conditions that may identify past seismicity or could contribute to damage potential at the site. Drill holes and/or pits should be located and spaced sufficiently to allow valid interpretations of the resulting data. Subsurface testing could include Standard Penetration Tests (SPT), Cone Penetrometer Tests (CPT), undisturbed tube samples, and collection of bulk samples for laboratory testing.
- e. Surface and subsurface geophysical surveys as appropriate to determine the dynamic properties of the subsurface materials, including shear-wave velocity, shear modulus, and damping.

4. Subsurface investigation

- a. Laboratory testing of samples for moisture content, grain size, density, dynamic properties, and other pertinent parameters.
- b. Radiometric analysis of geologic units, study of fossils, mineralogy, soil-profile development, paleomagnetism, or other age-determinating techniques to characterize the age of geologic units.
- c. Estimates of expected magnitude, acceleration, and duration of strong motion for the design earthquakes for crustal and intraplate and interface subduction-zone sources and for other defined earthquakes if required by statute or regulation of the proposed project. The rationale for earthquake-source selection for the relevant types of events should be provided. The design basis earthquakes and ground acceleration maps available from the State of Oregon should be consulted and described.
- d. Determination of appropriate UBC site-specific soil-profile coefficients.
- e. Analytic dynamic soil response analyses to evaluate potential amplification or attenuation of subsurface soil deposits to the underlying bedrock motions.
- f. Evaluation of the liquefaction potential of the subsurface deposits at the site and, if applicable, estimation of liquefaction-induced settlement and liquefaction-induced lateral spreading.
- g. Evaluation of other seismic hazards, including earthquake-induced landslides, generation of tsunamis or seiches, regional subsidence, and fault displacement.

E. Conclusions and recommendation

1. Summarize the results of the seismic study, including the review of regional seismicity, site investigations, selection of the design earthquakes, and office analysis, including the evaluation of ground response, liquefaction, landsliding, and tsunamis on the proposed structure and use of the site. The report should be stamped and signed by a certified engineering geologist or by a registered professional engineer experienced in seismic hazard design or by both, when the work of each can be clearly identified.
2. Recommendations for site development to mitigate seismic hazards. The recommendations could include: ground modification to reduce amplification of ground shaking or liquefaction-induced settlement and lateral spreading potential, remedial treatment options for slope stability, and foundation alternatives to minimize seismic impact to structure.

F. References and appendices

1. Literature and records reviewed.
2. Aerial photographs or other images used, including the type, scale, source, date, and index numbers.
3. Maps, photographs, plates, and compiled data utilized in the investigation.
4. Description of geophysical equipment and techniques used in the investigation.
5. Personal communications or other data sources.

G. Illustrations

1. Location map to identify the site locality, significant faults, geographic features, seismic epicenters, and other pertinent data.
2. Site development map at a scale appropriate to show the site boundaries, existing and proposed structures, graded and filled areas, streets, and proposed and completed exploratory trenches, geophysical traverses, drill holes, pits, and other relevant data.
3. Geologic map and sections showing the distribution of soils, geologic units, topographic features, faults and other geologic structures, landslides, lineaments, and springs.
4. Logs of exploratory trenches, borings, and pits to show the details of observed features and conditions. Ground-water data should be included.

III. ACKNOWLEDGMENTS

The Boards of Geologist and Engineering Examiners would like to thank the individuals who have reviewed and contributed to the preparation of these guidelines, including the local chapters of the Association of Engineering Geologists and the Geotechnical Engineering Technical Group of the American Society of Civil Engineering-Oregon Section. The Oregon guidelines represent a modification of guidelines that have been prepared by the Association of Engineering Geologists; the California Division of Mines and Geology, Department of Conservation; and the Utah Geological and Mineral Survey. □

DOGAMI PUBLICATIONS

Released November 27, 1996:

Relative Earthquake Hazard Map of the Linnton Quadrangle, Multnomah and Washington Counties, Oregon, by M.A. Mabey, I.P. Madin, G.L. Black, and D.B. Meier. Geological Map Series map GMS-104, 6 p. text., \$10.

The new map covers portions of northwest Portland, Saint Johns, Linnton, Beaverton, Hillsboro, and West Slope.

The relative hazard map indicates areas that will be most severely affected by earthquakes. Included on the map sheet are smaller maps showing relative liquefaction, ground motion amplification, and slope instability hazards that depend on the way the ground responds to earthquake shaking. These were combined to develop the large relative hazard map. The scale of the relative hazard map is 1:24,000; the smaller maps are at a scale of 1:55,000.

The map is a continuation of a joint DOGAMI-Metro earthquake hazard mitigation study partly funded by the Federal Emergency Management Agency. Earlier released publications from this study include relative earthquake hazard maps of the Portland, Mount Tabor, Lake Oswego, Beaverton, and Gladstone quadrangles, as well as areas in Vancouver, Washington.

Released November 26, 1996:

Oil and Gas Potential of the Southern Tyee Basin, Southern Oregon Coast Range, by I.-C. Ryu, A.R. Niem, and W.A. Niem. Oil and Gas Investigation Series report OGI-19. 141 p., 9 plates, \$20.

This report is the result of a five-year study funded by a consortium of corporations and agencies from private industry and federal, state, and county government. The study area is located in the southern Oregon Coast Range and is bounded by the northern margin of the Klamath Mountains.

The authors propose several revisions to the stratigraphy and have created several fence diagrams that correlate logs from numerous exploration wells and measured sections.

Although the authors believe that overall hydrocarbon potential of the area is relatively low, they suggest that the Spencer Formation and members of the White Tail Ridge Formation could serve as reservoir rock for hydrocarbons and that four structures have the potential for natural gas. They indicate that on the basis of their findings, further exploration drilling in the area is warranted.

These DOGAMI publications are now available over the counter, by mail, FAX, or phone from the Nature of the Northwest Information Center and the DOGAMI field offices in Baker City and Grants Pass. Addresses are on page 2 of this issue. Orders may be charged to Visa or Mastercard. Orders under \$50 require prepayment. □

Field trip guide to the eastern margin of the Oregon-Idaho graben and the middle Miocene calderas of the Lake Owyhee volcanic field

by Mark L. Ferns, Oregon Department of Geology and Mineral Industries

INTRODUCTION

This field trip guide is for a one-day trip along the eastern flank of the Oregon-Idaho graben (Ferns and others, 1993a,b) in Malheur County, beginning in Jordan Valley and ending in Ontario. The focus is on the early volcanic evolution of the Oregon-Idaho graben, primarily the middle Miocene calderas formed during initial subsidence within the graben. En route commentary and specific stops have been compiled from guidebooks printed for the 1990 joint meeting of the Geological Society of Nevada and the U.S. Geological Survey (Rytuba and others, 1990) and for the 1994 Annual Meeting of the Geological Society of America (Cummings and others, 1994). Emphasis is on the more easily accessible portions of both field trips along segments of the Oregon Scenic Byway system that can be reached by ordinary motor vehicles under most weather conditions. A cautionary note: Although the route is generally suitable for passenger-car travel, wet road surfaces during the spring thaw and sudden summer rainstorms make travel along the unpaved Succor Creek Road between Highway 95 and Highway 201 hazardous. In the summer, the casual traveler is also advised to take along plenty of water. Private property should not be entered without previous permission from the owner. This pertains particularly to the Teague zeolite mine discussed at Stop 5.

The Oregon-Idaho graben is a 30-mi-wide, north-trending volcano-tectonic depression that lies midway between the McDermitt volcanic field (Rytuba and McKee, 1994) and the northeastern Oregon feeder dikes for the Columbia River basalt (Figure 1). Defined by recent geologic mapping of approximately 3,000 mi² of extreme eastern Oregon (Ferns and others, 1993a,b), the central part of the graben is filled by over 6,000 ft of middle Miocene volcanic and volcanoclastic rocks.

The Oregon-Idaho graben is one of a number of middle Miocene depressions that began developing during the later

stages of Columbia River basalt volcanism, when significant volumes of silicic volcanic lavas were erupted from a north-south belt of vents extending from the south end of the Baker graben southward through the Lake Owyhee volcanic field (Rytuba and others, 1990) in the Oregon-Idaho graben to the McDermitt volcanic field (Rytuba and McKee, 1984) at the north terminus of the northern Nevada rift (Zoback and others, 1994). These features evolved as part of a north-northwest-trending, 560-mi-long middle Miocene synvolcanic rift system (Zoback and others, 1994) that links the northern Nevada rift with the Columbia River

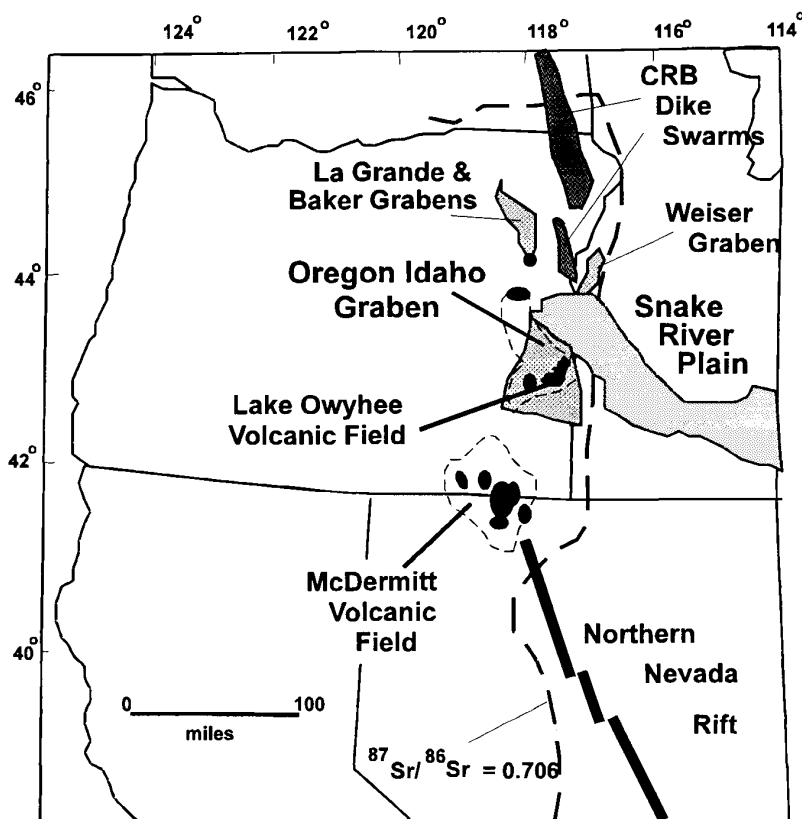


Figure 1. Tectonic setting of the Oregon-Idaho Graben, showing location between the northern Nevada rift, La Grande-Baker grabens, and the main feeder dike swarms of the Columbia River basalt (CRB). These features lie just to the west of the $^{87}\text{Sr}/^{86}\text{Sr} = 0.706$ line and define a major middle Miocene rift system. The western Snake River Plain is a younger structure that crosses the earlier middle Miocene structures. Current thinking (see Zoback and others, 1994) is that the extensional basins, dike swarms, and caldera fields are all related to emergence of the Yellowstone Hot Spot in this region at about 16 Ma.

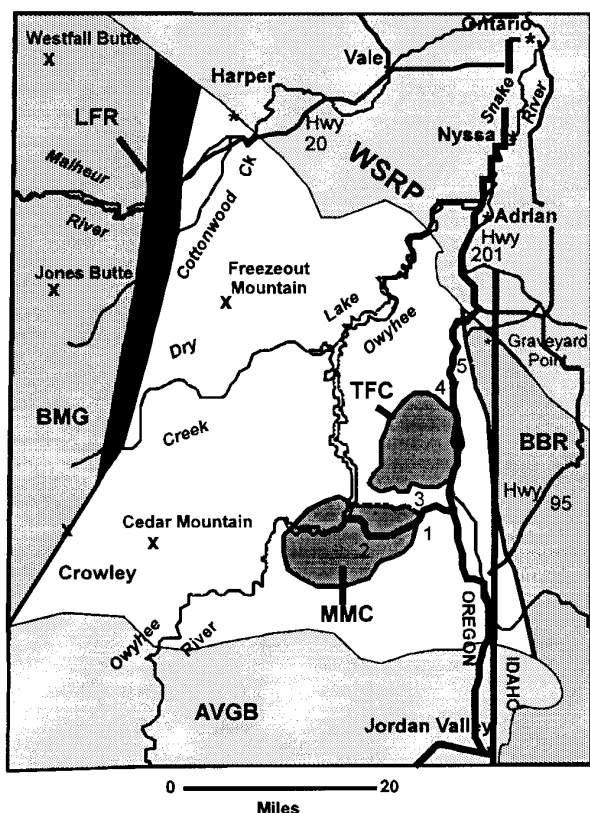


Figure 2. Sketch map of the Oregon-Idaho graben showing field trip route, stops, and major geologic features. AVGB=Antelope Valley graben, WSRP=western Snake River Plain; intragaben rhyolites include Littlefield Rhyolite (LFR), Mahogany Mountain caldera (MMC), and Three Fingers caldera (TFC). Margins of the graben are defined by middle Miocene tholeiitic basalts: the basalt of Bishop's Ranch (BBR) and the basalt of Malheur Gorge (BMG).

basalt dike swarms. Purpose of this field trip is to examine early calderas whose collapse coincided with initial subsidence within the graben.

Although the sedimentary, volcanic, and structural features that define the later stages of graben evolution are best developed in the central part of the Oregon-Idaho graben, which lies to the west of the field trip route, the reader should be aware of the overall structural, sedimentary, and volcanic history within the graben. Cummings and others (1994) noted three subsequent stages of structural evolution following caldera collapse:

Stage 1 was marked by incursion of fluvial arkoses in a basin where topographic highs, rhyolite domes, and coalescing fields of silicic tuff cones were constructional features related to the caldera-forming eruptions. This was the period in which the lower units of the Sucker Creek Formation (Corcoran and others, 1962; Kittleman and others, 1965) were deposited.

Stage 2 was marked by the breakup of the graben floor into subsiding intragaben subbasins during initial eruption of the calc-alkaline lava flows that make up the Owyhee Basalt (Bryan, 1929). Topographic highs at this time were mainly constructional features formed by mafic volcanoes, such as Spring Mountain, and hydrovolcanic vents, all of which are situated along north-trending intragaben fault zones. Reducing rates of magmatism resulted in local erosion along fault scarps. Large geothermal systems active at this time fed hot springs that discharged into arkose-laden streams, forming epithermal gold systems such as the Katey and Mahogany prospects. The Deer Butte Formation (Corcoran and others, 1962; Kittleman and others, 1965) and upper units in the Sucker Creek Formation were deposited throughout Stage 2.

Fluvial and lacustrine sediments of the Grassy Mountain Formation (Kittleman and others, 1965) were deposited in Stage 3 and mark a return to aggrading, basin-wide sedimentation accompanied by reduced rates of subsidence and waning volcanic and geothermal activity. Stage 3 units along the field trip route have been largely removed by erosion and are preserved only as arkose conglomerates in the uppermost part of the Sucker Creek Formation that crop out at the base of the Jump Creek Rhyolite (Kittleman and others, 1965).

The Oregon-Idaho graben ceased to be an important syn-volcanic feature at about 11 Ma, when the Jump Creek and Star Mountain rhyolites were erupted on the east and west graben flanks, respectively. Renewed eruption of large-volume rhyolites coincided with cessation of calc-alkaline volcanism within the graben and marked the start of the westward-younging rhyolite track across central Oregon (MacLeod and others, 1976; Walker and MacLeod, 1991). Later subsidence, volcanism, and hydrothermal activity were related to regional forces accompanying development of the northwest-trending western Snake River Plain and the east-west trending Antelope Valley graben (Rytuba and others, 1990; Ferns and others, 1993a,b). Lavas erupted at this time are mainly olivine basalts, ranging in composition from high-alumina olivine tholeiites to alkalic basalts (Hart and Mertzman, 1983; Cummings and others, 1994). Much of the modern topographic relief now apparent within the graben formed as many of the north-trending faults were reactivated.

FIELD TRIP GUIDE

Mile point 0.0 Field trip begins at Jordan Valley (Figure 2), on the Oregon-Idaho state line at intersection of Yturri Road and U.S. Highway 95.

The town of Jordan Valley lies on the northeast edge of the Antelope Valley graben (Rytuba and others, 1990), a Pliocene to Holocene, east-west trending graben that truncates the south end of the Oregon-Idaho graben. Bold cliffs on the skyline to the south mark the major, down-to-the-north fault that defines the south margin of the Antelope

Valley graben (Rytuba and others, 1990). The northern margin of the Antelope Valley graben is not well expressed topographically and consists of a series of small-displacement, short-strike-length, down-to-the-south faults that have been largely buried by Pliocene to Holocene lava flows erupted from vents within and along the northern flank of the Antelope Valley graben.

En route to the Mahogany Mountain caldera

Mile point 1.0 Near hills to northeast and northwest are silicified siltstone and sandstone beds in the Sucker Creek Formation (Kittleman and others, 1965, 1967). The low hill immediately to the west is underlain by a basalt sill that is mined for road metal. Silicified mudstones mark the surface expression of a paleo-hot spring at the top of the hill. Ridge line 3 mi to the east is part of the eastern margin of the Oregon-Idaho graben and is underlain by 16-Ma rhyolite lava flows and tholeiitic basalts. The basalts were erupted at about the same time as the Imnaha and Grande Ronde Basalts of the Columbia River Basalt Group to the north and the Steens Basalt to the west and together make up an extensive middle Miocene flood-basalt province that extends from the northern Nevada rift northward through eastern Oregon to southeast Washington (Figure 1).

Workings of the DeLamar Mine are visible on the skyline to the southeast. The modern open-pit mine has been in operation since 1977. About 160,000 oz of silver and 26,000 oz of gold a year (Rytuba and others, 1990) are mined from mineralized fault zones in a rhyolite-dome complex here on the east flank of the Oregon-Idaho graben.

Mile point 6.0 Low hills on the right (east) of the highway and the low sinuous east-west trending ridge immediately to the left (west) are capped by unconsolidated gravels and are examples of inverted topography. Flat-topped mountain farther to the west is Table Mountain, capped by a Pliocene basalt flow. Even though unconsolidated, the gravels are more resistant to erosion than the adjacent soft tuffaceous lake sediments. Elevation of the channels suggest that they formed when the Pliocene basalt flows on Table Mountain were erupted. Opaline sinter exposed under the gravels on the low ridge to the west marks another ancient hot spring.

Mile point 9.0 The Table Mountain basalt is one of the older and northernmost flows erupted from vents within the Antelope Valley graben. Here, the northern margin of the Antelope Valley graben is not well expressed topographically. Road to the left leads to Jordan Craters, the youngest (2,000–4,000 yr B.P.) basalt flow in this region. The Jordan Crater flow blocked Cow Creek and formed Cow Lakes (Kittleman, 1973; Hart and Mertzman, 1983).

Mile point 10.0 The old town site of Sheaville was located just north of where Highway 95 crosses Cow Creek. The mountain that forms the skyline to the northwest is Spring Mountain, a large Stage 2 calc-alkaline shield volcano

(MacLeod, 1990b). Silicified conglomerates exposed to the west overlie Spring Mountain basalt flows. Ridge to the east is made up of rhyolite lava flows similar to those at DeLamar that are overlain by the basalt flows. Bold cliff-formers on the ridges to the southeast are the tuff of Swisher Mountain (Ekren and others, 1982), an enormous ash flow that entered into the southern end of the Oregon-Idaho graben from the south at about 14.7 Ma (Minor and others, 1987; Evans and others, 1987; Rytuba and others, 1990). The stratigraphic position of the ash flow atop distal basalt flows from Spring Mountain indicates that the Spring Mountain volcano erupted between 15.5 and 14.7 Ma, at roughly the same time as the better studied Owyhee Basalt to the north. Eruption of these calc-alkaline flows heralded the Stage 2 breakup of the floor of the Oregon-Idaho graben into distinct subbasins.

The tuff of Swisher Mountain is one of the largest rhyolitic units identified in Oregon, covering an area of about 3,300 mi² with as much as 1,000 ft of rheomorphic ash-flow tuffs. It was emplaced at very high temperatures, hot enough to liquefy and flow for short distances following its initial emplacement as an ash flow. Volume of material emplaced in Oregon, Nevada, and Idaho during this eruption is estimated to be on the order of 300 mi³ (Ekren and others, 1984).

Mile point 12.5 White beds exposed on both sides of the highway as it drops down to the valley of Succor Creek are zeolitized airfall tuffs that crop out in the lower part of the Sucker Creek Formation. At least five massive beds of clinoptilolite-rich zeolite are exposed. Holmes (1990) noted that zeolitization here is at least in part a hydrothermal process, as the most intensely altered rocks are associated with large breccia pipes. Although the rhyolite vents that produced these massive airfall deposits have not yet been identified, their stratigraphic position beneath the basalt flows at Spring Mountain suggests that the Mahogany Mountain and Three Fingers calderas might have been sources for the ashes.

Mile point 16.6 Disrupted rock layer to the east is part of a large landslide (MacLeod, 1990a). White ridges farther to the east are within Coal Mine Basin, a noted plant fossil locality within the Sucker Creek Formation (Walden, 1986).

The Sucker Creek and Deer Butte Formations are stratigraphic units well entrenched in the literature. The Sucker Creek Formation, as originally defined by Corcoran and others (1962), Kittleman and others (1965, 1967), and Kittleman (1973), includes all clastic rocks, including ash-flow and air-fall tuffs, hydrovolcanic deposits, and fluvial and lacustrine sediments that lie either below the Jump Creek Rhyolite or the Owyhee Basalt, while the Deer Butte Formation (Corcoran and others, 1962; Kittleman and others, 1965, 1967) includes all middle Miocene units that lie above the Owyhee Basalt (Bryan, 1929). Thus, in the area encompassed by this field trip, the Sucker Creek Formation

as originally defined includes all outflow and intracaldera tuffs and sedimentary units deposited between 15.5 and 10.6 Ma. Early workers (Corcoran and others, 1962; Kittleman and others, 1965, 1967; Kittleman, 1973), lacking radiometric dates, geochemical analyses, and high-resolution faunal dates, concluded that the Owyhee Basalt was a regionally extensive stratigraphic marker whose position determined whether a sedimentary unit was Sucker Creek Formation (stratigraphically below the Owyhee Basalt) or Deer Butte Formation (stratigraphically above the Owyhee Basalt). More recent workers, (Ferns and others, 1993a,b) have concluded that the Owyhee Basalt is confined to the central part of the Oregon-Idaho graben and, together with hydrovolcanic centers in both the Sucker Creek and Deer Butte Formations, was produced by an areally restricted pulse of early Stage 2 calc-alkaline volcanism (Cummings and others, 1994). Walden (1986) and Ferns (1988a,b) noted an angular unconformity within the Sucker Creek Formation that separates predominantly tuffaceous lacustrine units, such as the lowermost exposures in Coal Mine Basin, from overlying, predominantly fluvial arkosic units.

Mile point 18.9 Turn left (west) off Highway 95 onto Succor Creek Road; marked by the Oregon Scenic Byway sign. Exposures at the intersection are distal hyaloclastite deposits erupted from a large mafic hydrovolcanic vent to the northeast. Picture rock (varicolored silicified tuff) and zeolite are being mined from parts of the large hydrothermal-alteration zone that encompasses the vent. A classic hydrothermal-eruption breccia within late Stage 2 arkose sandstones is exposed at the Mahogany gold prospect, located about 1.5 mi to the northeast (Rytuba and others, 1990).

Mile point 23.0 Succor Creek Road heads north along Deadman Gulch. The ridge to the east is made up of altered hydrovolcanic deposits. The large hydrovolcanic center lies to the east and forms Chrisman Hill.

CALDERAS OF THE LAKE OWYHEE VOLCANIC FIELD

Although Kittleman (1973) recognized the Leslie Gulch Ash-Flow Tuff as the product of a large volcanic eruption, Rytuba and others (1985) were the first to identify large rhyolite calderas in the Lake Owyhee region. Rytuba and others (1990) include all middle Miocene silicic vents that formed following eruption of the Steens Basalt in the Lake Owyhee volcanic field, the eastern margin of which coincides with the Oregon-Idaho state line. The western margin is roughly coincident with the course of the South Fork of the Malheur River, the southern margin is marked by the Antelope Valley graben, and the northern margin is marked by the pre-Tertiary exposures of the southern Blue Mountains province (Rytuba and others, 1990). Even though seven ash-flow sheets and five calderas are reported by Rytuba and others (1990) within the Lake Owyhee volcanic

field, only two, the Mahogany Mountain and Three Fingers calderas (Figure 3), are recognizable middle Miocene silicic centers that predate Stage 1 subsidence of the Oregon-Idaho graben. Of the other calderas reported by Rytuba and others (1990), his "Castle Peak" lies west of the graben; his "Saddle Butte" is undefined; and his "Star Peak," presumably coincident with the 10- to 12-Ma Star Mountain center identified by Ferns and others (1993b), is a late Miocene center that formed after the Oregon-Idaho graben became quiescent. Another possible caldera, defined by a pronounced, arcuate gravity low to the southwest of the Mahogany Mountain caldera, has been suggested as the source for either the tuff of Birch Creek (Vander Meulen and others, 1990) or the tuff of Iron Point (Evans and others, 1990).

Of the two calderas—Mahogany Mountain and Three Fingers (Rytuba and others, 1990)—exposed well enough to show internal stratigraphy, only the Mahogany Mountain caldera has been studied in any detail (Vander Meulen, 1989). The Mahogany Mountain caldera is marked by thick sections of intracaldera pyroclastic surge, ash-flow tuff, and air-fall tuff deposits as well as ring-fracture and central-vent rhyolite domes, dikes, and autobreccias. Abrupt changes in ash-flow thickness over caldera margins mark the transition between outflow and intracaldera facies. Although the northern and western margins of the Mahogany Mountain caldera are poorly defined topographically and the eastern margin is truncated by the Devil's Gate fault zone, the near-coincident occurrence of an arcuate mass of thick ash-flow and air-fall deposits with a prominent, arcuate gravity low (Brown and others, 1980; Rytuba and others, 1990) provides evidence of a classic rhyolite caldera.

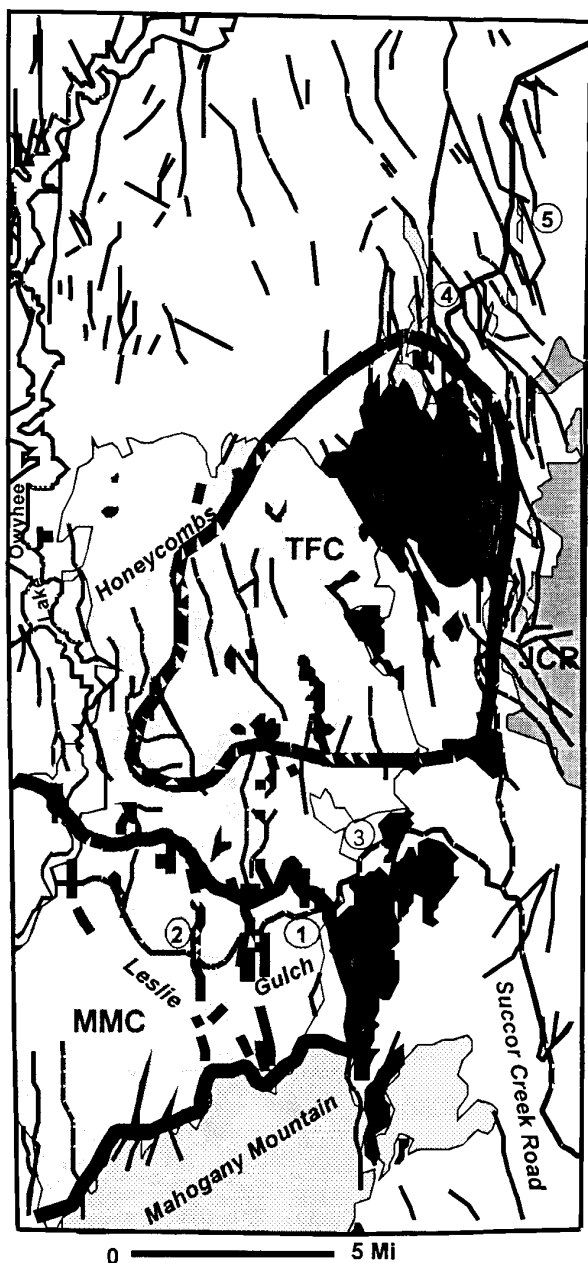
En route

Mile point 27.1 Turn west (left) at Rockville School; the road to the north leads back to Highway 95. Major cliff former to the northeast is the Jump Creek Rhyolite (Kittleman and others, 1965, 1967), a 10.6-Ma, large-volume rhyolite lava flow that was erupted near the east graben margin, near the end of synvolcanic subsidence within the graben. Prominent knob to northwest is Smith Butte, an older 15.5 Ma rhyolite dome that was emplaced along the southern ring fracture of the Three Fingers caldera.

Mile point 27.4 Cross small bridge and bear right, heading to north.

Mile point 27.9 The main massif formed by the Jump Creek Rhyolite lies to the north. Hummocky topography at the base of the cliffs is made up of landslide blocks of Jump Creek Rhyolite on underlying, less competent Sucker Creek Formation units. Brown and white units exposed just west of the are part of the younger Sucker Creek Formation units, here dominantly bentonite clays, that lie unconformably across older Sucker Creek tuffs.

Mile point 29.0 Turn left onto the well-maintained BLM gravel road leading to Leslie Gulch. Hills that form skyline



← Figure 3. Geologic sketch map along the east side of the Oregon-Idaho graben showing locations of Stops 1–5. Margins for the Mahogany Mountain (MMC) and Three Fingers (TFC) calderas are from Vander Meulen (1989) and Rytuba and Vander Meulen (1991). Large, precaldere rhyolite lava flows on Mahogany Mountain (Stop 1) and at Devils Gate (Stop 4) mark caldera margins. Curvilinear faults on the southwest margin of the Three Fingers caldera suggest multiple stages of collapse (Vander Meulen and others, 1989). North-trending rhyolite dikes near the center of the Mahogany Mountain caldera (Stop 2) mark the central vent complex (Vander Meulen, 1989). Postcollapse domes at Bannock Ridge (Stop 3) that were erupted along the Devils Gate fault zone at about 12.8 Ma host hot-spring-type mineralization. Rheomorphic ash-flows at Stop 5 are outflow sheets that lie atop older middle Miocene tholeiitic basalt basement rocks (basalt of Bishop's Ranch). JCR = Jump Creek Rhyolite.

as the fault zones exerted control on volcanism, displacement on individual fault segments was small (<3 ft) with cumulate displacement in tens of feet across the fault zone. As an individual fault zone evolved, the greatest displacements (>150 ft) were localized along a few, longer strike-length faults. Displacements of this magnitude produced topographic scarps that deflected drainages along the sub-basin boundaries. Cumulative displacements of at least 500 ft typically occur along long strike-length master faults late in the evolution of the intragaben fault zones. Sense of movement along the Devils Gate zone is down to the east, with postcaldera units downdropped to the east.

Mile point 32.7 The southern topographic wall of the Mahogany Mountain caldera is visible on the skyline south of the road (Rytuba and others, 1985; Vander Meulen and others, 1987b). The Mahogany Mountain caldera was the vent from which the Leslie Gulch Ash-Flow Tuff (Kittleman and others, 1965, 1967) was erupted. The ash-flow is the lowest exposed unit of the Sucker Creek Formation and was first described by Kittleman and others (1965) as a sillar, an ash-flow indurated by escaping gases rather than by welding.

Prominent ridges to the north are made up of resistant rhyolite dikes and faulted rhyolite domes. Intervening areas of low relief are underlain by less resistant ash flows. The pale pink area to the northeast is part of the Bannock gold prospect. Alteration zones in the rhyolites are commonly marked by such bleached, lighter colored zones.

Mile point 35.7 Stop 1

Stop at view point for overlook of upper Leslie Gulch. Steep escarpment to the south marks where the south wall of the Mahogany Mountain caldera cuts a precaldere rhyolite-flow dome on Mahogany Mountain (Rytuba and others, 1985). Tall spires and pinnacles to the west are part of the intracaldere facies of the Leslie Gulch Ash-Flow Tuff, which was erupted at about 15.5 Ma (Rytuba and Vander Meulen, 1991). Section here dips to the west, toward

in distance (west) are rhyolite flows and domes of Bannock Ridge, a rhyolite complex emplaced at 12.8 Ma (Rytuba and others, 1990; Zimmerman, 1991) along the north-trending Devils Gate fault zone (Ferns and others, 1993a). Major intragaben fault zones (shown on Figure 4) include the Wall Rock Ridge (WRZ), Dry Creek Buttes (DCZ) (Cummings, 1991; Cummings and others, 1993), and Devils Gate (DGZ) zones. The fault zones form prominent, north-striking structures that served as magmatic and hydrothermal conduits. Each fault zone typically consists of a 2- to 3-km-wide zone of closely spaced, short-strike-length, steeply dipping normal faults. During their early evolution,

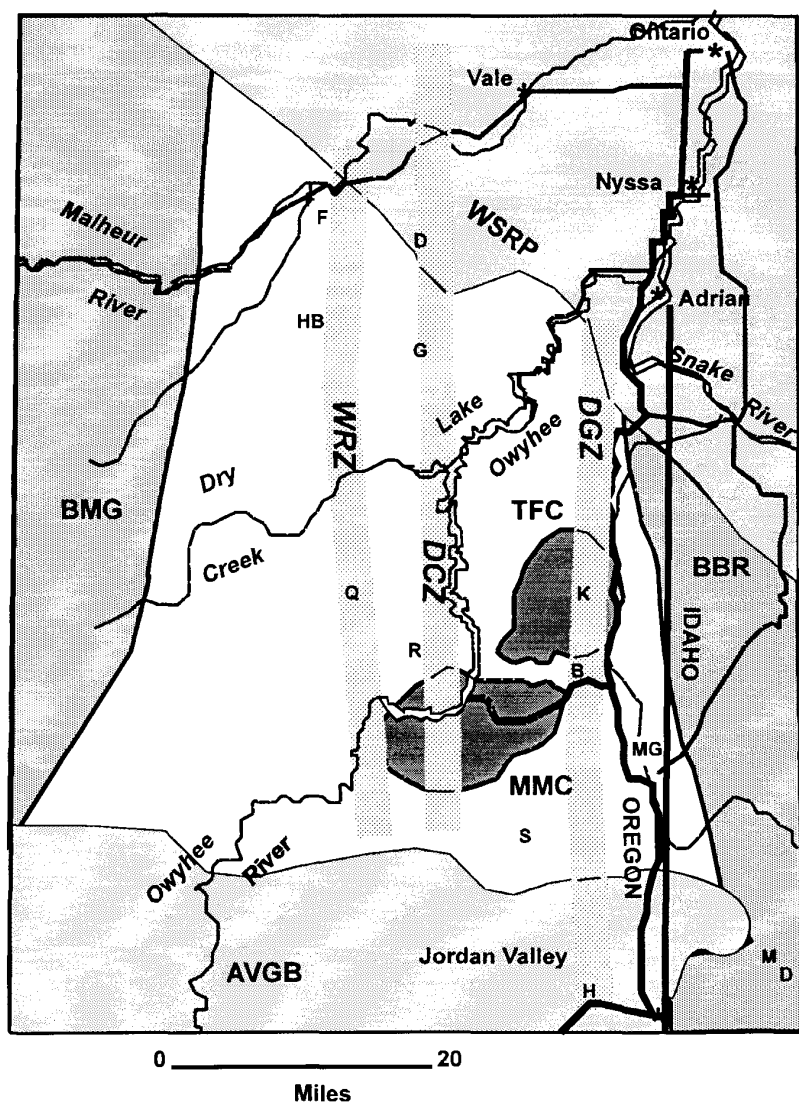


Figure 4. Sketch map showing major intragaben fault zones, major gold prospects, and the DeLamar Mine. DCZ=Dry Creek fault zone; WRZ=Wall Rock Ridge fault zone; DGZ=Devils Gate fault zone; D=DeLamar Mine, MI=Milestone; HI=Hillside; M=Mahogany; S=Storm; B=Bannock; K=Katey; R=Red Butte, Q=Quartz Mountain; G=Grassy Mountain, FZ=Freezeout, DM=Double Mountain; HB=Harper Basin; F=Fenceline. Other symbols are the same as in Figure 2.

the Oregon-Idaho graben axis. The interior of the caldera is well exposed along the road as it descends down Leslie Gulch.

En route

Mile point 37.2 Intracaldera-facies ash flows typically weather to form colorful cliffs and spires such as those to the left. During a climactic eruption, walls of the caldera commonly collapse inward, as multiple ash-flow sheets issue from ring-fracture and axial vents, surging across the subsiding cauldron. Calderas such as Mahogany Mountain

evidently collapsed at such a rapid rate that most of the surge and ash-flow deposits are trapped within the caldera, producing relatively small outflow sheets.

Mile point 39.0 Prominent columnar-jointed rhyolite dikes are exposed on both sides of the road. Rhyolite dikes such as these generally trend north-south and can be traced for as much as 3 mi. The pronounced north-south trend of the dikes runs parallel to the graben axis.

Mile point 39.2 Please note that, although most of Leslie Gulch is managed by the U.S. Bureau of Land Management (BLM), the cabin here is on private property. Massive reddish-orange outcrops to the west are intracaldera surge and air-fall deposits of the Leslie Gulch Ash-Flow Tuff. More rounded, green exposures are interpreted by Vander Meulen and others (1987a) and Rytuba and others (1990) to be outflow sheets of the tuff of Spring Creek that entered into an axial graben formed during collapse and resurgence within the central core of the Mahogany Mountain caldera. Massive orange outcrops farther to the west make up part of the central vent complex, one of the main feeder vents for the Leslie Gulch Ash-Flow Tuff (Vander Meulen, 1989).

Details pertaining to the number of caldera eruptions as well as the magmatic and temporal evolution of the Lake Owyhee volcanic field are unclear. Rytuba and others (1990) favor a two-caldera model, initiated by eruptions of the Leslie Gulch Ash-Flow Tuff during collapse of the Mahogany Mountain caldera, followed by resurgence doming and block faulting at the center of the caldera along the eruptive axis, and later followed by eruption of the tuff of Spring Creek from the nearby Three Fingers caldera. Rhyolite dikes were then emplaced along north-trending fissures.

This model is based in part on the outcrops straight ahead. The orange spires form the eastern margin of a feature interpreted by Rytuba and others (1990) as the central apical graben formed during resurgence doming following eruption of the Leslie Gulch Ash-Flow Tuff and preceding the eruption of the tuff of Spring Creek, the green-colored outcrops to the east.

Mile point 40.7 Stop 2

Contact between green and orange tuffs. Pull off into the parking area with restroom to the left of the road to exam-

ine outcrops on the north side of Leslie Gulch. Green outcrops to the north are considered by Rytuba and others (1990) to be younger Spring Creek outflow sheets that entered into central apical graben. Detailed examination of the outcrops to the north suggests that individual ash beds can be traced laterally from the green unit to the orange unit, which indicates that here the color contrast between rock units is an alteration front related to rhyolite dike intrusions into the central vent complex rather than two separate eruptions.

The orange pinnacles and spires form part of the central vent complex (Vander Meulen, 1989) for the Mahogany Mountain caldera. The complex consists of an irregularly shaped, matrix-supported autobreccia that is cut by dikes and irregularly shaped plugs of flow-foliated rhyolite.

En route

Mile point 43.0 The BLM road ends on the shores of the Owyhee Reservoir. Leslie Gulch ash flows exposed west of the reservoir are cut by the Rooster Comb, a rhyolite dike that has yielded a K-Ar age of 14.9 ± 0.4 Ma (Rytuba and others, 1990). Green outcrops at the turnaround are interpreted as moat-filling Spring Creek units (Rytuba and others, 1990). Note iron staining of the tuff of Spring Creek where the tuff is intruded by dikes. Rounded hills to the west are made up of Stage 1 sediments that were deposited onto the caldera-fill. Turn around and retrace route to the east, back up Leslie Gulch

Mile point 53.3 Stop 3

Overview of the northern part of the Lake Owyhee volcanic field. The thick intracaldera facies of the Leslie Gulch Ash-Flow Tuff documents eruption, collapse, and fill of the Mahogany Mountain caldera. Although the exact margins of the caldera are in places unclear, the extraordinarily thick pyroclastic deposits visible along Leslie Gulch and a nearly coincident gravity low (Brown and others, 1980; Rytuba and others, 1990) are evidence of the Mahogany Mountain caldera. Pyroclastic eruptions to the north produced a second subsidence structure, the Three Fingers caldera (Rytuba and others, 1989, 1990), whose intracaldera facies, the tuff of Spring Creek, appears chemically distinct from the Leslie Gulch Ash-Flow Tuff (Rytuba and others, 1990). The northwest wall of the Three Fingers caldera is visible in the distance to the north as the rugged outcrops that comprise part of the Honeycombs volcanic center, a series of coalescing silicic tuff cones (Vander Meulen and others, 1987c). The east margin of the caldera is marked by ring-fracture domes such as Round Mountain to the northeast. Rugged topography just this side of the Honeycombs is made up of rhyolite intrusions that were emplaced along three arcuate intracaldera ring fractures (Vander Meulen and others, 1989) on the southwest edge of the Three Fingers caldera. While the Three Fingers caldera has not been studied in detail, it is certain that the caldera's geologic evolution was complex, involving multiple dome

and pyroclastic eruptions, coincident with successive stages of collapse along the intracaldera ring fractures.

Rugged outcrops in the immediate foreground are part of the rhyolite of Bannock Ridge, a 12.8-Ma rhyolite (Zimmerman, 1991), which was erupted along the Devils Gate fault zone several million years after the Mahogany Mountain caldera collapsed. The Devils Gate, Dry Creek Butte, and Wall Rock Ridge fault zones have served as magmatic and hydrothermal conduits throughout the subsequent evolution of the Oregon-Idaho graben. While ancient hot springs along the faults occasionally deposited variable amounts of gold, the most important mineral resource mined in this area has been the renowned Owyhee picture rock, a silicified and variably colored fine-grained tuff. Most of the picture rock deposits occur just to the north.

En route to the northeast margin of the Three Fingers caldera

Mile point 53.7 Intersection of Leslie Gulch road with Succor Creek Road. Turn left (north) toward Succor Creek State Park.

Mile point 61.1 Smith Butte, the rhyolite dome exposed to the left (west) side of Succor Creek Road, is located near the southern margin of the Three Fingers caldera.

Mile point 66.6 Round Mountain to the north is another rhyolite dome. The domes are believed to have intruded along the southeast margin of the Three Fingers caldera following its collapse (Rytuba and others, 1990). Rhyolite flows and domes of McIntyre Ridge visible along the horizon farther to the north are also believed to have been emplaced along the caldera margin and overlie a thick section of caldera-fill ash-flow and air-fall tuffs (tuff of Spring Creek).

Mile point 69.1 Continue on main Succor Creek Road. The dirt road to the left leads to Three Fingers Rock and the Katey gold prospects. Gold mineralization at Katey is spatially associated with small high-silica rhyolite domes. Part of the prospect is hosted by late Stage 2 arkose sandstones.

Mile point 70.2 Negro Rock, immediately to the west of the road, is a small rhyolite porphyry dome. McIntyre Ridge to the north is made up of faulted segments of rhyolite domes and lava flows that extruded along the east margin of the Three Fingers caldera. K-Ar dates indicate that McIntyre Ridge flows are 15.8 ± 0.6 Ma old (Rytuba and others, 1990).

Mile point 70.6 Here, Succor Creek Road crosses a landslide that can be tricky to negotiate during wet weather conditions. The landslide is formed on bentonitic clays in the upper part of the Sucker Creek Formation.

Mile point 72.2 The dirt road to the right leads to an overview of upper Sucker Creek Formation units. High cliffs in the background to the east are part of the Jump Creek Rhyolite.

Mile point 73.0 Cliffs to the west are formed of McIntyre

Ridge domes and flows, part of the 15.4-Ma Three Fingers caldera. Massive outcrops to the east are much younger (10.6 Ma) Jump Creek Rhyolite. A number of north- to northwest-trending, down-to-the-east faults cut diagonally across Succor Creek, dropping down the Jump Creek and underlying upper Sucker Creek units adjacent to the older caldera units.

Mile point 73.7 Campground at Succor Creek State Park. The road here follows Succor Creek as it cuts through faulted slices of McIntyre Ridge rhyolite lava flows. Note the steeply dipping vertical and complexly folded flow foliation in the rhyolite lava flows along the west side of the road.

Mile point 75.2 The Succor Creek area is renowned among rockhounds for thundereggs, silica-filled lithophysae, and large gas cavities commonly found in rhyolite. The talus slope to the west contains some thundereggs. While the role of mineralizing fluids in forming thundereggs is not well understood, it is certain that thundereggs here are located in alteration zones along mineralized faults.

Mile point 76.2 Green outcrops to the northwest below the McIntyre Ridge Rhyolite are a section at least 600 ft thick of multiple, caldera-fill ash-flow and air-fall units of the tuff of Spring Creek (Vander Meulen and others, 1987a). Darker outcrops include intermediate-composition dikes and sills that have intruded into these intracaldera tuffs and detached lenses of vitrophyre associated with individual ash flows. Old mine openings low on both sides of Succor Creek date back to an unsuccessful turn-of-the-century effort to mine nitrates. Nitrates were reportedly discovered in 1914, when the young sons of George Huntley started a fire in a cave and were surprised when the white material in rock crevices took fire and burnt vigorously (Mansfield, 1915).

Mile point 79.1 The road crosses Board Corral Creek and leaves Succor Creek canyon, which opens to the north into a broad valley. Dark exposures in the foreground to the northeast are vitrophyre lenses in an outflow sheet of the tuff of Spring Creek. Here, the buried caldera margin is marked by the dramatic thinning of tuff of Spring Creek, from >600 ft in Succor Creek canyon (base not exposed) to <100 ft north of Succor Creek, where the tuff of Spring Creek lies on older tholeiite basalt flows. Prominent cliffs to the northwest are made up of the Devils Gate rhyolite lava flow that issued from a vent along the northeast margin of the Three Fingers caldera. Dirt road to the left leads to an overview of the caldera margin. This is one of the few places where a pronounced lithologic break between caldera-fill tuffs and precaldern basalt can be identified along a caldera wall.

Mile point 80.0 Stop 4

Overview of the Three Fingers caldera margin. Stop at the turnout to the left at the summit of a small hill for an

overview of the northeast margin of the Three Fingers caldera. The poorly consolidated arkose conglomerates at the top of the hill are one member of the late Stage 2 upper Sucker Creek Formation. Climb to top of hill to the right (east) for a panoramic view of lower Succor Creek. Granite and rhyolite clasts on the hill are typical of late Stage 2 arkoses in both the Deer Butte and Sucker Creek Formations. Highlands to the southeast are capped by the Jump Creek Rhyolite. High cliffs in foreground are silicified upper Sucker Creek conglomerates exposed below the rhyolite. Other upper Sucker Creek units include bentonitic claystones and siltstones, which are prone to produce landslides where overlain by the Jump Creek Rhyolite. It is instructive to note that here, on the east flank of the Oregon-Idaho graben, only about 200 ft of sediments separate the 10.6- and 15.5-Ma rhyolites, while in the central part of the graben, over 6,000 ft of sedimentary and volcanic rocks were deposited over the same time interval.

Highlands south and west of the Succor Creek canyon, are capped by the older McIntyre Ridge rhyolite flow, which overlies the intracaldera facies of the Spring Creek tuff. North-trending ridges are part of the Devils Gate fault zone (DGZ). Prominent knob in the foreground is a high-silica rhyolite dome that intruded along the caldera margin (Ferns, 1988a). Black, slope-forming outcrops on the north side of the knob are early Stage 2 high-alumina olivine tholeiite basalt (HAOT) flows (Table 1). The HAOT flows are in turn overlain by lower Sucker Creek units.

The Three Fingers caldera margin runs parallel to Board Corral Creek (Figure 4) and is defined by the southernmost exposures of tholeiitic lavas and overlying Devils Gate rhyolite. Eruption of the Devils Gate rhyolite coincided with early ash eruptions and the initial collapse of the caldera. The caldera margin is best exposed about 2 mi up Board Corral Creek.

The Devils Gate fault zone, like other major intragraben fault zones described by Cummings (1991, Cummings and others, 1993), was important in controlling the location of magmatic and hydrothermal conduits. Individual faults exposed here are typical of faults formed late in the evolution of the fault zones, where displacements (>150 ft) are localized along a few, longer strike-length faults that developed following the main pulse of calc-alkaline volcanism. Here, along the east flank of Owyhee Ridge, the Devils Gate fault zone formed a topographic barrier that prevented late Stage 2 members of the upper Sucker Creek Formation from being deposited to the west. Ridge-capping basalt flows to the northwest, west of the fault zone are 13- to 14-Ma Blackjack Basalt flows (Bryan, 1929; Corcoran and others, 1962; Ferns, 1988b) erupted from vents along the fault zone farther to the north. The Blackjack flows include hypersthene-phyric calc-alkaline flows erupted following the main pulse of Stage 2 calc-alkaline volcanism that produced the Owyhee Basalt to the west.

Late Stage 2 upper Sucker Creek Formation units are exposed in the low hills to the north, where arkose con-

Table 1. Major- and trace-element analyses of tholeiitic and calc-alkaline mafic rocks along the east edge of the Oregon-Idaho graben. Blackjack, HAOT (high-alumina olivine tholeiite), and Spring Mountain samples are representative of post-caldera, calc-alkaline lavas. Hooker Creek and Graveyard samples are representative of the precaldern, tholeiitic basalt of Bishop's Ranch. The Hunter Creek sample is typical of precaldern tholeiites on the west flank of the graben. CRB-GR is a representative sample of the Grande Ronde Basalt, Columbia River Basalt Group, from Hooper and Swanson (1990). The alkali-olivine basalt flow (87-BO-54) lies immediately above outflow facies of the tuff of Spring Creek (Stop 5). Major- and selected trace-element analyses performed by XRAL Laboratories, who used X-ray fluorescence techniques. Major-element analyses were recalculated and normalized on a volatile-free basis. Trace elements marked by * were determined with wet chemical methods by the Oregon Department of Geology and Mineral Industries Analytical Laboratory. Major-element values in percent; trace-element values in ppm

	Postcaldera calc-alkaline lavas					Columbia River basalt		Precaldern tholeiites			
Sample no.	87-BO-121	87-BO-88a	87-BO-54	AXB-511	AZB-144	I-68	AXB-707	BAB-312	BAB-328	87-BO-26	TLB-1
Unit	Blackjack	HAOT	Alkali	Spring Mtn	Spring Mtn	CRB-GR	Hunter Cr	Hooker Cr	Graveyard	Graveyard	Graveyard
SiO ₂	52.98	48.67	50.85	56.11	48.52	54.86	54.31	52.40	53.13	56.22	52.48
Al ₂ O ₃	16.70	18.05	15.12	16.49	16.65	13.71	13.25	13.78	16.15	15.41	14.50
TiO ₂	1.36	1.15	1.94	1.08	1.43	2.02	2.33	1.73	1.48	1.91	2.60
FeO ^f	10.20	11.61	14.71	8.42	12.34	13.11	14.26	13.38	11.99	10.82	12.95
MnO	0.17	0.15	0.24	0.16	0.24	0.23	0.22	0.22	0.26	0.24	0.19
CaO	8.70	10.43	7.35	7.10	10.59	7.51	6.90	9.26	7.18	6.37	7.92
MgO	5.14	7.19	3.87	4.50	6.79	4.02	3.17	5.08	3.62	2.36	4.10
K ₂ O	1.18	0.22	1.69	2.31	0.40	1.36	2.03	1.02	1.86	1.66	1.81
Na ₂ O	3.08	2.26	3.54	3.27	2.71	2.70	3.11	2.72	3.73	3.97	2.98
P ₂ O ₅	0.49	0.26	0.68	0.56	0.33	0.30	0.42	0.42	0.60	1.05	0.47
	100.00	100.00	100.00	100.00	100.00	99.82	100.00	100.00	100.00	100.00	100.00
Cr	139	92	<10	87	57	16	25	58	29	<10	34
Co*	27	50	31	23	45	n.d.	25	n.d.	n.d.	19	33
Ni*	72	165	26	51	100	3	13	n.d.	n.d.	15	25
Cu*	44	138	61	46	90	33	18	n.d.	n.d.	17	34
Zn*	94	82	144	108	104	123	151	n.d.	n.d.	126	144
Rb	40	19	28	48	27	32	73	22	37	63	57
Sr	513	244	397	642	448	368	318	366	514	447	432
Y	14	29	46	35	38	36	27	30	31	34	18
Zr	128	39	149	203	101	185	229	159	137	201	275
Nb	20	10	23	26	<10	11	12	35	17	20	<10
Ba	553	89	696	720	222	620	690	528	846	978	668
Li*	11	33	13	7	8	n.d.	14	n.d.	n.d.	10	n.d.

glomerates and underlying bentonite claystone and tuffaceous siltstone were deposited onto a tilted surface of lower Sucker Creek tuffs and hyaloclastite deposits. The upper Sucker Creek is an important source of bentonite clay, which is mined by Teague Mineral Products of Adrian, Oregon, from shallow pits to the north. Drillhole data indicate that the clay resource was deposited in a shallow lake (Leppert, 1990), the western margin of which was marked by the Devils Gate fault zone.

En route to rheomorphic ash-flow tuffs, typical of outflow facies

Mile point 82.5 Turn off to right to proceed to Teague Mineral Products SC zeolite mine. Permission should be obtained from Teague (Adrian, Oregon) before entering the site.

Mile point 83.1 Stop 5

Succor Creek Zeolite Mine. Teague produces here a heulandite zeolite from a massive ash bed associated with a peralkaline ash-flow tuff considered by Ferns and others

(1993a) to be an outflow sheet of Leslie Gulch Ash-Flow Tuff. The correlation is based on stratigraphic position and on petrographic and geochemical similarities to analyses reported by Vander Meulen (1989). The Leslie Gulch here is a prominently flow-banded rheomorphic ash-flow tuff that physically resembles a rhyolite lava flow. As is common with many rheomorphic tuffs, it is difficult to find clear field or petrographic evidence of an ash-flow origin. Flattened pumice lapilli and broken crystals are considered to be the best evidence for a rheomorphic ash-flow. Outcrop patterns are often the most diagnostic tool in determining origin: the ash-flows are generally planar sheets, commonly underlain by airfall pumice or tuff, whereas the rhyolite lava flows are considerably more irregular in thickness and possess basal flow breccias that lie on variably baked and deformed tuffaceous sediments (Bonnichsen, 1982). The Leslie Gulch Ash-Flow Tuff can be traced to the southwest, where it is overlain by an outflow sheet of the tuff of Spring Creek (Ferns, 1988b).

The zeolite deposit is a massive ash bed underlain by tholeiite lavas of the basalt of Bishop's Ranch (Kittleman and others, 1965, 1967; Lawrence, 1988). The basalts include ferroandesites and tholeiitic basalts (Ferns, 1988b) that are among the westernmost exposures of an extensive, >1,000-ft-thick section of interbedded middle Miocene mafic and intermediate flows that was erupted at about 17 Ma (Pansze, 1975) onto pre-Tertiary basement rocks to the east (Ekren and others, 1982). Although these flows were erupted at about the same time as Columbia River Basalt Group-type lavas in the Malheur Gorge area on the west side of the Oregon-Idaho graben (15.78 ± 0.59 to 16.49 ± 1.2 Ma, Lees and Hawkesworth, 1993), they typically have more alumina than the Malheur Gorge lavas.

An unusual alkali olivine basalt flow overlies the ash flow south of the mine pit. Well-developed pillows with hyaloclastite rinds are locally developed at the base of the flow, indicating flowage into water (Lawrence, 1988). Although correlation with Blackjack Basalt flows on the top of Owyhee Ridge may be warranted, based on a $^{39}\text{Ar}/^{40}\text{Ar}$ age of 13.08 ± 0.56 Ma (Lees and Hawkesworth, 1993), no other Miocene alkalic olivine basalts have been identified within the Oregon-Idaho graben.

Faulted blocks of the basalt of Bishop's Ranch on the ridgeline and in the foreground to the east extend into Idaho, where they are unconformably overlain by the Jump Creek Rhyolite (Ferns, 1998a) along the eastern margin of the Oregon-Idaho graben. Ridges to the north include faulted segments of basalt of Bishop's Ranch and Leslie Gulch Ash-flow Tuff.

The prominent bluff in the foreground to the southeast is the Graveyard Point sill, a late Miocene (6.7 ± 0.4 -Ma) (Ferns, 1988b) tholeiitic gabbro intrusion that was emplaced near the juncture of the east and south margins of the younger western Snake River Plain. The intrusion was emplaced during tholeiitic magmatism associated with early subsidence along the plain. The 360-ft-thick intrusion is capped by a cordierite-bearing, porcelanite hornfels and is a classic example of a fractionated mafic intrusion, ranging in composition from high-alumina olivine tholeiite along the chilled margins to ferrodiorite occurring as lenses 270 ft from the base (Long and White, 1992).

En route to Ontario, across the south margin of the western Snake River Plain

Mile point 83.7 Return along mine road west to Succor Creek Road, turn right, and proceed north. High ridge to the east is Owyhee Ridge, here capped by Blackjack Basalt flows. One of the vent areas for the Blackjack lies along the Devils Gate fault zone in the lower hills to the northeast. Note the pronounced northward tilt of Owyhee Ridge toward the western Snake River Plain, visible to the northeast. Much of the modern relief along Owyhee Ridge can be partially attributed to renewed, differential movement along older faults during downwarping of the western Snake River Plain.

Mile point 87.3 Here, the road crosses an unconformable contact between late Miocene sediments of the Idaho Group in the western Snake River Plain. Light-colored sediments are well exposed to the north along the truncated northern margin of the Oregon-Idaho graben. The contact follows and is, in places, marked by a series of northwest-trending, down-to-the-north faults that juxtapose western Snake River Plain and Oregon-Idaho graben units. Fault intersections have localized conduits for geothermal fluids that in places continue to vent to the surface as hot springs. These younger geothermal systems are characterized by high levels of arsenic and molybdenum (Ferns and others, 1993c). Varicolored chalcedonic quartz stringers are the source of the prized Graveyard Point plume agate, mined from small open pits to the southeast.

Mile point 87.5 Late Miocene lacustrine sediments are locally mantled by Pliocene-Pleistocene terrace and alluvial-fan gravels. The late Miocene lacustrine deposits are the lower part of the Chalk Butte Formation (Corcoran and others, 1962) and have been correlated with the late Miocene Chalk Hills Formation of Malde and Powers (1962) by Kimmel (1982). Most workers today agree that the lacustrine units were deposited in a single large lake system generally known as Lake Idaho that filled much of the plain from the late Miocene to the early Pliocene (Jenks and Bonnicksen, 1989). The terrace and alluvial fan gravels were deposited as tributary drainages incised through the lacustrine sediments following emptying of the lake to the north through Hells Canyon.

Mile point 90.3 Turn left (west) onto Highway 201.

Mile point 95.0 Late Miocene and Pliocene lacustrine units are exposed along the ridge line to the west. White layers include an air-fall tuff correlated by Swirydczuk and others (1982) with a Chalk Hills air-fall tuff. The ridge is capped by chert-pebble conglomerate that lies on a slight angular unconformity on the older tuffs. Smith and others (1982) and Kimmel (1982) reported fish fossils above the unconformity that indicate a correlation with the younger Glens Ferry Formation (Malde and Powers, 1962) of western Idaho. The underlying angular unconformity marks a period of erosion and nondeposition coincident with lowering of the lake in the late Miocene (Smith and others, 1982; Kimmel, 1982). The chert-pebble conglomerate may mark incursion of fluvial sediments from the north, as the lake began to refill in the Pliocene.

The north end of the ridge line is broken by small, down-to-the-north faults of the northwest-trending Adrian fault zone (Ferns, 1989; Ferns and others 1993a). Conglomerates near the fault zone have been silicified and contain elevated levels of trace metals such as arsenic and molybdenum.

Mile point 96.5 To the left is the Teague Mineral Products zeolite and montmorillonite clay processing plant. The Big Bend of the Snake River is to the right. Here, the Oregon-Idaho state line runs north-south, with part of Oregon lying

to the east of the river. In the 1890s, very fine grained "flour" gold was mined from sand bars on the Snake River at Midas Bar along the inside curve of the Big Bend. The particles of gold mined were very small, each weighing less than $\frac{1}{2,000,000}$ of an ounce (Lindgren, 1901).

Mile point 99.0 Highway passes through Adrian, a small farming community. Browns Butte to the west is made up of silicified sandstones in Glens Ferry Formation.

Mile point 103.0 Continue north on Highway 201 through crossroads community of Owyhee. Road to left leads up the Owyhee River to the Owyhee Dam. Fertile fields along the highway are in a thick flood deposit of overbank silt and mud left from the Bonneville flood (Malde, 1968) at about 14,000 yr B.P. (Scott and others, 1982). Low hills to the northwest are capped by terrace gravels deposited during the final draining of Lake Idaho between about 1.5 million and 2 million yr. B.P. The terrace gravels are locally displaced by faults.

Mile point 111.0 Nyssa city limits. Turn left (north) at stop light onto Highway 30.

Mile point 118.3 Cairo Junction, where U.S. 30 joins with U.S. 20. Highway 20 leads west to Vale and Burns. Continue north to Ontario.

Mile point 124.0 Ontario city limits. End of field trip.

ACKNOWLEDGMENTS

The author gratefully acknowledges the assistance of his fellow workers in the Owyhee region. Special thanks go Jim Evans, U.S. Geological Survey, Spokane, Washington, and Mike Cummings, Portland State University, Portland, Oregon, for providing a detailed review.

REFERENCES CITED

- Bonnichsen, B., 1982, Rhyolite lava flows in the Bruneau-Jarbridge eruptive center, southwestern Idaho, in Bonnichsen, B., and Breckenridge, R.M., eds., *Cenozoic geology of Idaho*: Idaho Geological Survey Bulletin 26, p. 283-319.
- Brown, D.E., McLean, G.D., and Black, G.L., 1980, Preliminary geology and geothermal-resource potential of the western Snake River Plain, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-80-5, 114 p.
- Bryan, K., 1929, Geology of reservoir and dam sites with a report on Owyhee irrigation project, Oregon: U.S. Geological Survey Water Supply Paper 597-A, 89 p.
- Corcoran, R.E., Doak, R.A., Porter, P.W., Pritchett, F.I., and Privrasky, N.C., 1962, Geology of the Mitchell Butte quadrangle: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-2, scale 1:96,000.
- Cummings, 1991, Geology of the Deer Butte Formation, Malheur County, Oregon: Faulting, sedimentation, and volcanism in a post-caldera setting: *Sedimentary Geology*, v. 74, p. 345-362.
- Cummings, M.L., Ebeling, C., and Johnson, A.G., 1993, North-striking fault zones and evolution of the central graben, Ore-Ida graben, Malheur County, Oregon [abs.]: *Geological Society of America Abstracts with Programs*, v. 25, no. 6, p. 26.
- Cummings, M.L., Evans, J.G., and Ferns, M.L., 1994, Stratigraphic and structural evolution of the middle Miocene Oregon-Idaho graben, Malheur County, Oregon: in Swanson, D.A., and Haugerud, R.A., eds., *Geologic field trips in the Pacific Northwest*: Seattle, Wash., University of Washington, v. 1, p. IG1-IG20.
- Ekren, E.B., McIntyre, D.H., and Bennett, E.H., 1984, High-temperature, large-volume, lava-like ash-flow tuffs without calderas in southwestern Idaho: U.S. Geological Survey Professional Paper 1272, 76 p.
- Ekren, E.B., McIntyre, D.H., Bennett, E.H., and Marvin, R.F., 1982, Cenozoic stratigraphy of western Owyhee County, Idaho: in Bonnichsen, B., and Breckenridge, R.M., eds., *Cenozoic geology of Idaho*: Idaho Geological Survey Bulletin 26, p. 215-235.
- Evans, J.G., Hoffman, J.D., Kulik, D.M., and Linne, J.M., 1987, Mineral resources of the Owyhee Canyon Wilderness Study Area, Malheur County, Oregon: U.S. Geological Survey Bulletin 1719, 18 p.
- Evans, J.G., Turner, R.L., Griscom, A., Sawatzky, D.L., and Causey, J.D., 1990, Mineral resources of the Lower Owyhee Canyon Wilderness Study Area, Malheur County, Oregon: U.S. Geological Survey Bulletin 1741-F, 18 p.
- Ferns, M.L., 1988a, Geology and mineral resources map of the Owyhee Ridge quadrangle, Malheur County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-53, scale 1:24,000.
- Ferns, M.L., 1988b, Geology and mineral resources map of the Graveyard Point quadrangle, Malheur County, Oregon, and Owyhee County, Idaho: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-54, scale 1:24,000.
- Ferns, M.L., 1989, Geology and mineral resources map of the Adrian quadrangle, Malheur County, Oregon, and Canyon County, Idaho: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-56, scale 1:24,000.
- Ferns, M.L., Brooks, H.C., Evans, J.G., and Cummings, M.L., 1993a, Geologic map of the Vale 30x60 minute quadrangle, Malheur County, Oregon, and Owyhee County, Idaho: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-77, scale 1:100,000.
- Ferns, M.L., Evans, J.G., and Cummings, M.L., 1993b, Geologic map of the Mahogany Mountain 30x60 minute quadrangle, Malheur County, Oregon, and Owyhee County, Idaho: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-78, scale 1:100,000.
- Ferns, M.L., Cummings, M.L., and Evans, J.G., 1993c, Spatial and temporal relationships between calc-alkaline volcanism and late Miocene mineralization in the Ore-Ida graben [abs.]: *Geological Society of America Abstracts with Programs*, v. 25, no. 5, p. 37.
- Hart, W.L., and Mertzman, S.A., 1983, Late Cenozoic volcanic stratigraphy of the Jordan Valley area, southeastern Oregon: *Oregon Geology*, v. 45, no. 2, p. 15-19.
- Holmes, D.A., 1990, Pacific Northwest zeolite update, in Geitgey, R.P., and Vogt, B.F., eds., *Industrial rocks and minerals of the Pacific Northwest*: Oregon Department of Geology and Mineral Industries Special Paper 23, p. 79-88.
- Hooper, P.R., and Swanson, D.A., 1990, The Columbia River Basalt Group and associated volcanic rocks of the Blue Mountains Province, in Walker, G.W., ed., *Geology of the Blue Mountains region of Oregon, Idaho, and Washington: Cenozoic geology of the Blue Mountains region*: U.S. Geological Survey Professional Paper 1437, p. 63-99.
- Jenks, M.D., and Bonnichsen, B., 1989, Subaqueous basalt eruptions into Pliocene Lake Idaho, Snake River Plain, Idaho, in Chamberlain, V.E., Breckenridge, R.M., and Bonnichsen, B., eds., *Guidebook to the geology of northern and western Idaho and surrounding area*: Idaho Geological Survey Bulletin 28, p. 17-34.
- Kimmel, P.G., 1982, Stratigraphy, age, and tectonic setting of the Miocene-Pliocene lacustrine sediments of the western Snake River Plain, in Bonnichsen, B., and Breckenridge, R.M., eds., *Cenozoic geology of Idaho*: Idaho Geological Survey Bulletin 26, p. 559-578.
- Kittleman, L.R., 1973, Guide to the geology of the Owyhee region of Oregon: Eugene, Oreg., University of Oregon Museum of Natural History Bulletin 21, 61 p.
- Kittleman, L.R., Green, A.R., Hagood, A.R., Johnson, A.M., McMurray, J.M., Russell, R.G., and Weeden, D.A., 1965, Cenozoic stratigraphy of the Owyhee region, southeastern Oregon: Eugene, Oreg., University of Oregon Museum of Natural History Bulletin 1, 45 p.
- Kittleman, L.R., Green, A.R., Haddock, G.H., Hagood, A.R., Johnson, A.M., McMurray, J.M., Russell, R.G., and Weeden, D.A., 1967, Geologic map of the Owyhee region, Malheur County, Oregon: Eugene, Oreg., University of Oregon Museum of Natural History Bulletin 8, scale 1:125,000.
- Lawrence, D.C., 1988, Geologic field trip guide to the northern Succor Creek area, Malheur County, Oregon: *Oregon Geology*, v. 50, no. 2, p. 15-21.
- Lees, K.R., and Hawkesworth, C.J., 1993, Patterns of geochemical change in north Basin and Range volcanic rocks [abs.]: *Geological Society of America Abstracts with Programs*, v. 25, no. 5, p. 69.
- Leppert, D., 1990, Developments in applications for southeast Oregon bentonites and natural zeolites, in Geitgey, R.P., and Vogt, B.F., eds., *Indus-*

- trial rocks and minerals of the Pacific Northwest: Oregon Department of Geology and Mineral Industries Special Paper 23, p. 19–23.
- Lindgren, W., 1901, Gold belt of the Blue Mountains of Oregon: U.S. Geological Survey Annual Reports, no. 22, p. 551–776.
- Long, M.F., and White, C.M., 1992, Petrographic and geochemical reconnaissance of the Graveyard Point sill, Malheur County, Oregon [abs.]: Geological Society of America Abstracts with Programs, v. 24, no. 5, p. 65.
- MacLeod, N.S., 1990a, Geology and mineral resources map of the Sheaville quadrangle, Malheur County, Oregon, and Owyhee County, Idaho: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-64, scale 1:24,000.
- MacLeod, N.S., 1990b, Geology and mineral resources map of the Mahogany Gap quadrangle, Malheur County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-65, scale 1:24,000.
- MacLeod, N.S., Walker, G.W., and McKee, E.H., 1976, Geothermal significances of eastward increase in age of upper Cenozoic rhyolitic domes in southeast Oregon: Second United Nations Symposium on the development and use of geothermal resources, Proceedings, v. 1, p. 465–474.
- Malde, H.E., 1968, The catastrophic late Pleistocene Bonneville Flood in the Snake River Plain, Idaho: U.S. Geological Survey Professional Paper 596, 52 p.
- Malde, H.E., and Powers, H.A., 1962, Upper Cenozoic stratigraphy of western Snake River Plain, Idaho: Geological Society of America Bulletin, v. 73, p. 1197–1220.
- Mansfield, G.R., 1915, Nitrate deposits in southern Idaho and eastern Oregon: U.S. Geological Survey Bulletin 620, p. 19–44.
- Minor, S.A., King, H.D., Kulik, D.M., and Sawatzky, 1987, Mineral resources of the Upper Deep Creek Wilderness Study Area, Owyhee County, Idaho: U.S. Geological Survey Bulletin 1719-G, 14 p.
- Pansze, A.J., Jr., 1975, Geology and ore deposits of the Silver City-DeLamar-Flint region, Owyhee County, Idaho: Idaho Geological Survey Pamphlet 161, 79 p.
- Rytuba, J.J., and McKee, E.H., 1984, Peralkaline ash-flow tuffs and calderas of the McDermitt volcanic field, southeast Oregon and north-central Nevada: Journal of Geophysical Research, v. 89, p. 8616–8628.
- Rytuba, J.J., and Vander Meulen, D.B., 1991, Hot-spring precious-metal systems in the Lake Owyhee volcanic field, Oregon-Idaho, in Raines, G., Lisle, R.E., Schafer, R.W., and Wilkinson, W.H., eds., Geology and ore deposits of the Great Basin: Geological Society of Nevada, Symposium Proceedings, v. 2, p. 1985–1096.
- Rytuba, J.J., Vander Meulen, D.B., Plouff, D., and Minor, S.A., 1985, Geology of the Mahogany Mountains caldera, Oregon [abs.]: Geological Society of America Abstracts with Programs, v. 17, no. 4, p. 263.
- Rytuba, J.J., Vander Meulen, D.B., and Minor, S.A., 1989, Geologic evolution of the Three Fingers caldera, Malheur Co., Oregon [abs.]: Geological Society of America Abstracts with Programs, v. 21, no. 5, p. 138.
- Rytuba, J.J., Vander Meulen, D.B., Barlock, V.E., and Ferns, M.L., 1990, Field guide to hot-spring gold deposits in the Lake Owyhee volcanic field, eastern Oregon: Geology and ore deposits of the Great Basin: Geological Society of Nevada Field Trip Guide 10, 119 p.
- Scott, W.E., Pierce, K.L., Bradbury, J.P., and Forrester, R.M., 1982, Revised Quaternary stratigraphy and chronology in the American Falls area, southeastern Idaho, in Bonnicksen, B., and Breckenridge, R.M., Cenozoic geology of Idaho: Idaho Geological Survey Bulletin 26, p. 581–596.
- Smith, G.R., Swirydzuk, K., Kimmel, P.G., and Wilkinson, B.H., 1982, Fish biostratigraphy of late Miocene to Pleistocene sediments of the western Snake River Plain, Idaho, in Bonnicksen, B., and Breckenridge, R.M., Cenozoic geology of Idaho: Idaho Geological Survey Bulletin 26, p. 519–542.
- Swirydzuk, K., Larson, G.P., and Smith, G.R., 1982, Volcanic ash beds as stratigraphic markers in the Glens Ferry and Chalk Hills Formations from Adrian, Oregon, to Bruneau, Idaho, in Bonnicksen, B., and Breckenridge, R.M., eds., Cenozoic geology of Idaho: Idaho Geological Survey Bulletin 26, p. 543–558.
- Vander Meulen, D.B., 1989, Intracaldera tuffs and central-vent intrusion of the Mahogany Mountain caldera, eastern Oregon: U.S. Geological Survey Open-File Report 89–77, 58 p., 2 plates, scale 1:72,750.
- Vander Meulen, D.B., Rytuba, J.J., Grubensky, M.J., and Goeldner, C.A., 1987a, Geologic map of the Bannock Ridge 7.5' quadrangle, Malheur County, Oregon: U.S. Geological Survey Miscellaneous Field Studies Map MF-1903-A, scale 1:24,000.
- Vander Meulen, D.B., Rytuba, J.J., Grubensky, M.J., Vercoutere, T.L., and Minor, S.A., 1987b, Geologic map of the Pelican Point quadrangle, Malheur County, Oregon: U.S. Geological Survey Miscellaneous Field Studies Map MF-1904, scale 1:24,000.
- Vander Meulen, D.B., Rytuba, J.J., Vercoutere, T.L., and Minor, S.A., 1987c, Geologic map of the Rooster Comb 7.5' quadrangle, Malheur County, Oregon: U.S. Geological Survey Miscellaneous Field Studies Map MF-1902-C, scale 1:24,000.
- Vander Meulen, D.B., Rytuba, J.J., Minor, S.A., and Harwood, C.S., 1989, Preliminary geologic map of the Three Fingers Rock 7.5' quadrangle, Malheur County, Oregon: U.S. Geological Survey Open-File Report 89–344, scale 1:24,000.
- Vander Meulen, D.B., Barlock, V.E., Plumley, P.S., Frisken, J.G., Griscom, A., and Causey, J.D., 1990, Mineral resources of the Blue Canyon and Owyhee Breaks Wilderness Study Areas, Malheur County, Oregon: U.S. Geological Survey Bulletin 1741-G, 28 p.
- Walden, K.D., A stratigraphic and structural study of Coal Mine Basin, Idaho-Oregon: East Lansing, Mich., Michigan State University master's thesis, 70 p.
- Walker, G.W., and MacLeod, N.S., 1991, Geologic map of Oregon: U.S. Geological Survey Special Map, scale 1:500,000.
- Zimmerman, B.S., 1991, Geology and geochemistry of epithermal gold mineralization in the Lake Owyhee volcanic field—western Snake River Plain region of eastern Oregon and western Idaho: Pullman, Wash., Washington State University doctoral dissertation, 262 p.
- Zoback, M.L., McKee, E.H., Blakely, R.J., and Thompson, G.A., 1994, The northern Nevada rift: Regional tectono-magmatic relations and middle Miocene stress direction: Geological Society of America Bulletin, v. 106, no. 3, p. 371–382. □

(Continued from page 5)

REFERENCES CITED

- Berggren, W.A., Kent, D.V., Obradovich, J.D., and Swisher, C.C., III, 1992, Toward a revised Paleogene geochronology, in Prothero, D.R., and Berggren, W.A., eds., Eocene-Oligocene climatic and biotic evolution: Princeton, N.J., Princeton University Press, p. 29–45.
- Bestland, E.A., and Retallack, G.J., 1994, Geology and paleoenvironments of the Painted Hills unit, John Day Fossil Beds National Monument, Oregon: Unpublished final report to the USDI National Park Service for contract CX-9000-1-0009, 211 p.
- Bestland, E.A., Retallack, G.J., and Fremd, T., 1994, Sequence stratigraphy of the Eocene-Oligocene transition: Examples from the nonmarine volcanically influenced John Day basin, in Swanson, D.A., and Haugerud, R.A., eds., Geologic field trips in the Pacific Northwest: Seattle, Wash., University of Washington, v. 1, p. A1–A19.
- Brown, R.W., 1959, A bat and some plants from the upper Oligocene of Oregon: Journal of Paleontology, v. 33, p. 135–139.
- Evernden, J.F., Savage, D.E., Curtis, G.H., and James, G.T., 1964, Potassium argon dates and the Cenozoic mammalian chronology of North America: American Journal of Science, v. 262, p. 145–198.
- Maluski, H., 1989, ³⁹Ar/⁴⁰Ar dating. Principles and applications to minerals from terrestrial rocks, in Roth, E., and Poty, B., eds., Nuclear methods of dating: Dordrecht, The Netherlands, Kluwer Academic Publishers, p. 325–351.
- Manchester, S.R., and Meyer, H.W., 1987, Oligocene fossil plants of the John Day Formation, Fossil, Oregon: Oregon Geology, v. 49, p. 115–127.
- Meyer, H.W., and Manchester, S.R., in press, The Oligocene Bridge Creek flora of the John Day Formation, Oregon: University of California Publications in Geological Sciences.
- Naylor, B.G., 1979, A new species of *Taricha* (Caudata, salamandridae) from the Oligocene John Day Formation of Oregon: Canadian Journal of Earth Sciences, v. 16, p. 970–973.
- Retallack, G.J., Bestland, E.A., and Fremd, T.J., 1996, Reconstructions of Eocene and Oligocene plants and animals of central Oregon: Oregon Geology, v. 58, p. 51–70.
- Riseley, P.W., 1989, Geology in the vicinity of Fossil, Wheeler County, north-central Oregon: Loma Linda, Calif., Loma Linda University master's thesis, p. 29–30.
- Samson, S.D., and Alexander, E.C., 1987, Calibration of the interlaboratory ⁴⁰Ar/³⁹Ar dating standard, Mmhb-1: Chemical Geology, v. 66, p. 27–34.
- Steiger, R.H., and Jager, E., 1977, Subcommittee on geochronology: Convention on the use of decay constants in geo- and cosmochronology: Earth and Planetary Science Letters, v. 36, p. 359–362.
- Swisher, C.C., III, and Prothero, D.R., 1990, Single-crystal ⁴⁰Ar/³⁹Ar dating of the Eocene-Oligocene transition in North America: Science, v. 249, p. 760–762. □

BOOK REVIEWS

New book introduces hikers to Oregon's geology

Hiking Oregon's Geology, by Ellen Morris Bishop and John Eliot Allen. Seattle, Wash., The Mountaineers. Soft cover, 221 pages, 51 hikes, 80 black-and-white photos, 10 page-size maps. Price \$16.95.

This new book, *Hiking Oregon's Geology*, was designed for the hiker who is interested in learning about geology. The authors are Ellen Morris Bishop, Lewis and Clark College Graduate School of Professional Development, and the late John Eliot Allen, Portland State University. Both authors are or were professional geologists, but they are also known to the general public for their numerous books, articles, and newspaper columns popularizing the geology of the state.

The book begins with a short nontechnical explanation of rocks and minerals, general geology, Oregon's geology, and general geologic terminology. The main part of the book is devoted to geologic information related to popular trails found in Oregon's various geologic provinces: the Klamath Mountains, the Coast Range, the Willamette Valley, the Columbia River Gorge, the Cascades, the Deschutes Basin, the High Lava Plains, the Basin and Range, the Owyhees, and the Blue Mountains. Some of the sections are further divided—the Blue Mountains sections, for example, is divided into the eastern, central, and western Blue Mountains, each of which covers geologically distinct areas. Trails are rated for difficulty, and information is included about the distance, elevation covered by the trail, relevant topographic and geologic maps, sources of information, geology of the general area, and geology of the trail.

The book contains a geologic time chart, a glossary of geologic terms, a list of recommended books, a list of geologic maps for geologic province, and the addresses of the Federal Forest Service and Bureau of Land Management offices. The book is also indexed.

The readers will be introduced to such interesting places as the seldom seen Coffeepot Crater at Jordan Craters near the Oregon-Idaho border, Spencers Butte near Eugene, the trail between Mariel and Illahee along the Rogue River, Latourell Falls in the Columbia River Gorge, and Sunset Bay to South Cove near Cape Arago on the southern coast. Not only will the readers learn about these places—they will also learn about the geology that makes each place unique and interesting.

This book does not present a mile-by-mile description of each trail. The serious hiker will still want the appropriate maps and trail guides for each trail. But this book complements the existing literature about trails. With this book serving as an introduction to the geology of the area, any hiker will have not only the pleasure of a good hike but also the fun of learning something new about the area. Now the hiker can find out why the trail is steep or slippery or

beautiful, why it has rocks and cliffs that look the way they do, and what geologic forces shaped the area.

USGS Prof. Paper addresses earthquake hazards

Assessing Earthquake Hazards and Reducing Risk in The Pacific Northwest, volume 1, edited by A.M. Rogers, T.J. Walsh, W.J. Kockelman, and G.R. Priest. U.S. Geological Survey Professional Paper 1560, 306 pages, 5 map sheets. Price \$25.

The book is a good technical compilation of knowledge about earthquake hazards through 1991, primarily for engineers, planners, decisionmakers, and land and building owners. The editors assure us that "Although many of the research reports address specialists having some familiarity with the geologic and geophysical sciences and earthquake-hazard mitigation, the overview chapter and reports on implementation of hazard-reduction techniques [to be published in volume 2] are intended to inform both technical and nontechnical readers." They hope to help policy makers promote the awareness of seismic hazards and reduce the risk of those hazards.

The overview chapter of this volume takes up more than 60 pages and includes introductions to the various aspects of earthquake hazards as well as special advisory sections for different types of users, from government agencies to "private, corporate, and quasi-public users." It also includes an extensive bibliography and a 12-page glossary of technical terms.

The following 10 chapters discuss the tectonic setting of the Pacific Northwest with regard to past earthquakes, the potential for great earthquakes, and other aspects of paleoseismicity, tectonics and geophysics. ("Paleoseismic" and "tectonic" are explained in the glossary!)

The Willamette Valley appears to have received the most detailed attention. Of the five accompanying maps, one shows faults in the entire Pacific Northwest. The other four present the geologic units, cross sections, and the bedrock topography (below the sediments) of the Willamette Valley.

Both publications are now available from the Nature of the Northwest Information Center (see address in order form on back cover of this issue) or from the usual USGS publication outlets. Volume 2 is to be released in the near future. □

John Nielsen retires

John Nielsen, long-time institution with the Portland office of the Department of Geology and Mineral Industries (DOGAMI), has retired at the end of December 1996 from his position as fiscal manager of the agency.

Nielsen began to work for the State of Oregon in 1973 and served at Southern Oregon State College and the University of Oregon Health Sciences Center before he joined DOGAMI in 1978 as business manager.

He is succeeded by his former assistant Charles Kirby. □

This question will be debated in the 1997 Legislature:

Seismic rehabilitation—what price are we willing to pay?

by Donald A. Hull, Oregon State Geologist

Oregon is known for its natural resources—a heritage we are proud to help protect. Now that Oregon also is known as an "earthquake state," another heritage needs our protection: older buildings.

In the event of a large earthquake, unreinforced older structures pose a catastrophic threat to public safety. Those built before 1993, when western Oregon's seismic zone was upgraded, could be vulnerable. Oregon has about 97,000 nonresidential buildings, about 11 percent of which are unreinforced masonry buildings (URMs). They pose the biggest hazard. In the words of California's emergency manager Richard Eisner, "I'd rather be in L.A. when the big one hits than in Portland because, relatively speaking, they are not prepared at all."

sands if we do not reinforce URMs. Property loss would be in the billions of dollars.

The costs of reinforcing all URMs in Oregon is estimated at roughly \$5 billion, according to the Task Force report. Who should pay these costs, how, and by when? These will be among HB2139's most debated issues. Recent quakes in Klamath Falls and Scotts Mills alone are strong evidence of the need for seismic rehabilitation. Further, much of the high cost of California's Northridge earthquake was caused by improper construction and inadequate inspection. The 1995 Kobe, Japan, earthquake took 5,400 lives, principally due to building damage.

Understanding this, the Task Force included a variety of tax incentives in HB2139 for building owners, along with a



Typical damage to a parapet made of unreinforced masonry (URM), caused by the Klamath Falls earthquakes of 1993.

House Bill 2139 will be introduced in the 1997 Legislature to address this need. The bill grew out of a balanced, comprehensive, year-long study by the Oregon Seismic Rehabilitation Task Force appointed by Governor Kitzhaber in 1995. Members represented views and expertise ranging from insurance, finance, and government to science, and engineering. Property owners and the general public were also represented. The Task Force findings balance public safety concerns against equity and economic reality.

According to studies performed for the City of Portland, the benefits of rehabilitating URMs could far outweigh the costs. For example, using values provided by FEMA, the firm of Goettel and Horner determined that URMs require only about one occupant per 1,000 square feet for life safety benefits to equal typical rehabilitation costs.

In his recent doctoral dissertation in civil engineering at Portland State University, Thomas McCormack developed a model to determine earthquake losses in terms of building damage and loss of life. He writes that deaths from an earthquake in the Portland area alone would be in the thou-

system of passive triggers to gradually and affordably help Oregon strengthen all public buildings over the next few decades. A critical first step in the bill is to conduct a statewide inventory.

The good news is that seismic rehabilitation is becoming a standard part of many renovation and remodeling projects. It has also become a national priority through FEMA and the President's orders to rehabilitate federal buildings. Examples of reinforcing projects include the Multnomah County Library, Portland City Hall, the Madeleine Parish School (completed), and the Multnomah Hotel, which is being renovated into an Embassy Suites Hotel. Several public schools are being strengthened throughout Oregon as money becomes available through local bonds and levies.

Regardless of HB2139's fate, the need for action is inescapable. Whether we see a major earthquake in our lifetime is uncertain—but it will happen. We do have a choice, however. We can begin to prepare now—or pay in catastrophic consequences later. □

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

Price ☑

GMS-75 Portland 7½' quadrangle, Multn., Wash., Clark Counties. 1991	7.00
GMS-76 Camas Valley 7½' quadrangle, Douglas and Coos Counties. 1993	6.00
GMS-77 Vale 30×60 minute quadrangle, Malheur County. 1993	10.00
GMS-78 Mahogany Mountain 30×60 minute quadrangle, Malheur C. 1993	10.00
GMS-79* Earthquake hazards, Portland 7½' quad., Multnomah C. 1993	20.00
GMS-80* McLeod 7½' quadrangle, Jackson County. 1993	5.00
GMS-81* Tumalo Dam 7½' quadrangle, Deschutes County. 1994	6.00
GMS-82* Limber Jim Creek 7½' quadrangle, Union County. 1994	5.00
GMS-83* Kenyon Mountain 7½' quadrangle, Douglas/Coos Counties. 1994	6.00
GMS-84* Remote 7½' quadrangle, Coos County. 1994	6.00
GMS-85* Mount Gurney 7½' quadrangle, Douglas/Coos Counties. 1994	6.00
GMS-86* Tenmile 7½' quadrangle, Douglas County. 1994	6.00
GMS-87* Three Creek Butte 7½' quadrangle, Deschutes County. 1996	6.00
GMS-88* Lakecreek 7½' quadrangle, Jackson County. 1995	8.00
GMS-89* Earthquake hazards, Mt. Tabor 7½' quad., Multnomah C. 1995	10.00
GMS-90* Earthquake hazards, Beaverton 7½' quad., 1995	10.00
GMS-91* Earthquake hazards, Lake Oswego 7½' quad., 1995	10.00
GMS-92* Earthquake hazards, Gladstone 7½' quad., 1995	10.00
GMS-93* Earthquake hazards, Siletz Bay area, Lincoln County. 1995	20.00
GMS-94* Charleston 7½' quadrangle, Coos County. 1995	8.00
GMS-97* Coos Bay 7½' quadrangle, Coos County. 1995	6.00
GMS-98* Dora and Sitkum 7½' quadrangles, Coos County. 1995	6.00
GMS-99* Tsunami hazard map, Siletz Bay area, Lincoln County. 1996	6.00
GMS-100* Earthquake hazard maps for Oregon. 1996	8.00
GMS-101* Steelhead Falls 7½' quad., Deschutes/Jefferson Co. 1996	7.00
GMS-104* Earthquake hazards, Linnton 7½' quad., Multn./Wash. Co. 1996	10.00
GMS-105* Earthquake hazards, Salem East/West 7½' quads. 1996	12.00

SPECIAL PAPERS

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

OIL AND GAS INVESTIGATIONS

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

AVAILABLE DEPARTMENT PUBLICATIONS (continued)

BULLETINS

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

MISCELLANEOUS PAPERS

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

SHORT PAPERS

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

MISCELLANEOUS PUBLICATIONS

Hiking Oregon's geology, E.M. Bishop and J.E. Allen, 1996	16.95
Assessing earthquake hazards in the Pac. NW (USGS Prof. Paper 1560)	25.00
Relative earthquake hazard map, Portland quadrangle (DOGAMI/Metro), 1993, with scenario report (add \$3.00 for mailing)	10.00
Geology of Oregon, 4th ed., E.L. and W.N. Orr and E.M. Baldwin, 1991, published by Kendall/Hunt (add \$3.00 for mailing)	29.95
Geologic map of Oregon, G.W. Walker and N.S. MacLeod, 1991, published by USGS (add \$3.00 for mailing)	11.50
Geological highway map, Pacific Northwest region, Oregon, Washington, and part of Idaho (published by AAPG). 1973	8.00
Oregon Landsat mosaic map (published by ERSAL, OSU). 1983	11.00
Mist Gas Field map, rev. 1995, with 1993-94 production figs. (OFR O-95-1)	8.00
Digital form of map (CAD formats .DGN, .DWG, .DXF), 3 1/4-in. diskette	25.00
Mist Gas Field production figures 1979 through 1992 (OFR O-94-6)	5.00
Northwest Oregon, Correlation Sec. 24. Bruer & others, 1984 (AAPG)	6.00
Oregon rocks and minerals, a description. 1988 (OFR O-88-6)	6.00
Mineral information layer for Oregon by county (MILOC), 1993 update (OFR O-93-8), 2 diskettes (5 1/4-in., high-density, MS-DOS)	25.00
Directory of mineral producers, 1993 update, 56 p. (OFR O-93-9)	8.00
Geothermal resources of Oregon (published by NOAA). 1982	4.00
Mining claims (State laws governing quartz and placer claims)	Free
Back issues of <i>Oregon Geology</i>	3.00
Color postcard with Oregon State Rock and State Gemstone	1.00

NEW

Separate price lists for open-file reports, tour guides, recreational gold mining information, and non-Departmental maps and reports will be mailed upon request. GMS maps marked with an asterisk (*) are available in digital form on diskette (geological information only).

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

ORDER AND RENEWAL FORM

Check desired publications in list above or indicate how many copies and enter total amount below. Send order to **The Nature of the Northwest Information Center, Suite 177, 800 NE Oregon Street, Portland, OR 97232-2162**, or to FAX (503) 731-4066. If you wish to order by phone, have your credit card ready and call (503) 872-2750. Payment must accompany orders of less than \$50. Payment in U.S. dollars only. Publications are sent postpaid. All sales are final. Subscription price for *Oregon Geology*: \$10 for 1 year, \$22 for 3 years.

Renewal ___ / new subscription ___ to *Oregon Geology*: 1 year (\$10) or 3 years (\$22) \$
 Total amount for publications marked above: \$
 Total payment enclosed or to be charged to credit card as indicated below: \$

Name _____
 Address _____
 City/State/Zip _____

Please charge to Visa ___ / Mastercard ___, account number: _____

Expiration date: _____

Cardholder's signature _____

OREGON GEOLOGY

published by the
Oregon Department of Geology and Mineral Industries



VOLUME 59, NUMBER 2

MARCH/APRIL 1997

March to September in Portland at OMSI: *Nurosaurus qaganensis*



IN THIS ISSUE:

PREPARING FOR EARTHQUAKES IN OREGON

OIL AND GAS EXPLORATION AND DEVELOPMENT IN OREGON, 1996

OMSI OPENS "GIANT" EXHIBIT

OREGON GEOLOGY

(ISSN 0164-3304)

VOLUME 59, NUMBER 2 MAR./APR. 1997

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

Governing Board

Jacqueline G. Haggerty, Chair Enterprise
Donald W. Christensen Depoe Bay
John W. Stephens Portland

State Geologist Donald A. Hull
Deputy State Geologist John D. Beaulieu
Publications Manager/Editor Beverly F. Vogt
Production Editor Klaus K.E. Neuendorf
Production Assistants Geneva Beck
Kate Halstead

Main Office: Suite 965, 800 NE Oregon Street # 28, Portland 97232, phone (503) 731-4100, FAX (503) 731-4066.

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

Mark L. Ferns, Regional Geologist.

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

Thomas J. Wiley, Regional Geologist.

Mined Land Reclamation Program: 1536 Queen Ave. SE, Albany 97321, phone (541) 967-2039, FAX (541) 967-2075.

Gary W. Lynch, Supervisor.

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

Periodicals postage paid at Portland, Oregon. Subscription rates: 1 year, \$10; 3 years, \$22. Single issues, \$3. Address subscription orders, renewals, and changes of address to *Oregon Geology*, Suite 965, 800 NE Oregon Street # 28, Portland 97232. **POSTMASTER: Send address changes to *Oregon Geology*, Suite 965, 800 NE Oregon Street # 28, Portland 97232-2162.**

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

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

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

Permission is granted to reprint information contained herein. Credit given to the Oregon Department of Geology and Mineral Industries for compiling this information will be appreciated. Conclusions and opinions presented in articles are those of the authors and are not necessarily endorsed by the Oregon Department of Geology and Mineral Industries.

Cover photo

This giant sauropod is the largest complete fossil dinosaur currently on exhibit at the Oregon Museum of Science and Industry in Portland. It is the most impressive specimen of a collection on loan from the Inner Mongolian Museum of Natural History, China. On display are fossils collected in the Gobi desert mostly during the 1980s. See description of the exhibit on page 41 of this issue.

April is National Earthquake Awareness Month

April is again being observed as National Earthquake Awareness Month in Oregon through a partnership including the Oregon Department of Geology and Mineral Industries (DOGAMI), the Office of Emergency Management, and local American Red Cross chapters. The following major events are planned:

- Oregon Governor John Kitzhaber will proclaim April as Earthquake Awareness Month.
- DOGAMI will set up an earthquake display on seismic rehabilitation on April 1 and 2 at the State Capitol in Salem.
- Free information materials will be provided through the Nature of the Northwest Information Center in Portland and DOGAMI field offices in Grants Pass and Baker City. Materials will provide resources to homeowners on how to protect their homes and families from earthquake damage.
- DOGAMI Earthquake hazard maps and related materials will be sold at a 20-percent discount at the Nature of the Northwest Information Center during April. That includes relative hazard maps of the Portland, Mount Tabor, Beaverton, Lake Oswego, Gladstone, Linnton, and Salem East/Salem West quadrangles and of the Siletz Bay area and a statewide probabilistic map. (A list is available from the Center and can also be found on the DOGAMI homepage under <http://sarvis.dogami.state.or.us/eq/eqpblst5.htm-ed>.)
- The free booklet, "Before Disaster Strikes" is offered through the Oregon Trail Chapter of the American Red Cross. This complete guide highlights preparedness measures for most emergencies, with heavy emphasis on earthquakes.
- In the Portland area, the Oregon Trail Chapter of the American Red Cross and local emergency managers will distribute earthquake education kits to elementary schools.

Last year's biennial "QuakeEx" earthquake simulation was cancelled because emergency responders were busy with the floods. The exercise is planned for April 1998. □

Corrections

With apologies to authors and readers, we have to correct two errors that slipped into the last two issues: In the November 1996 issue, volume 58, number 6, on page 148, the right-hand column in Table 3 lists "Average expected value of losses" in **thousands** (not millions) of dollars—as is apparent from other places in Bob Whelan's article. And in the January 1997 issue, volume 59, number 1, page 2, the "In memoriam" column for John Eliot Allen should have said that Allen died **December** (not November) 17, 1996. □

Preparing for earthquakes in Oregon

by Yumei Wang, Oregon Department of Geology and Mineral Industries

This article is a slightly modified version of a paper by Yumei Wang, Geotechnical Engineer and Director of Earthquake Programs of the Oregon Department of Geology and Mineral Industries. The paper will be included in *Engineering and Environmental Geology of Oregon: Case Histories*, an upcoming publication sponsored by the Oregon Section of the Association of Engineering Geologists. The paper is presented here because April is Earthquake Awareness Month—an appropriate time to examine what has been and is being done in the State of Oregon to prepare for earthquakes and to consider what other steps need to be taken to protect Oregonians and their property from earthquakes. —ed.

ABSTRACT

This paper traces the changes in the understanding of Oregon's earthquake hazards and provides an overview of how Oregon addresses reducing earthquake risks. The threat of a great Cascadia subduction zone earthquake identified during the last decade and the occurrence of two relatively minor yet damaging "wake-up calls" with the Scotts Mills and Klamath Falls earthquakes of 1993 have underscored the reality of earthquake hazards in Oregon. While periodic earthquake shaking has been reported in Oregon for over the last century and a half, modern earthquake monitoring has been possible only for the past few decades. Most of the earthquake hazard assessment and mitigation efforts made to date have been accomplished within the last decade, and public awareness has risen remarkably during that same period. Major federal, state, and local government agencies and private organizations support earthquake risk reduction and have made significant contributions. Despite the progress, Oregon still remains underprepared. Many structures and lifelines, such as buildings, bridges, and water systems, need to be strengthened, and land use planning needs to be improved.

INTRODUCTION

Some people who used to live in Oregon believed so strongly that earthquakes pose a tremendous threat that they have packed their belongings and moved out of the state. Others have sought refuge from earthquake hazards by moving to Oregon after the 1989 Loma Prieta earthquake in California. These extreme cases illustrate the range of problems that people are having in understanding and responding to earthquake hazards in Oregon.

Earth scientists now believe that all parts of Oregon can be shaken by earthquakes. Oregon lies where two tectonic plates, the North American plate and the Juan de Fuca plate, are colliding, and the Juan de Fuca plate is being forced to dive under the North American plate along a large active fault called the Cascadia subduction zone. Earthquakes can occur within the Juan de Fuca plate (such earthquakes are called intraplate earthquakes), in the overriding North American plate (called crustal earthquakes), or along the Cascadia subduction zone, which is the interface between the two plates (called subduction zone earthquakes). All three possible earthquake types (intraplate, crustal, and

subduction zone) (Figure 1) can severely impact the state. Active volcanoes in the Cascade Range present another earthquake source.

Although the number of earthquakes in Oregon's recorded history is limited compared to that of California or Washington, earthquakes have occurred in every Oregon county. Surface expressions of faults capable of producing earthquakes are sparse, but young faults (defined here as active within the Quaternary Period, the last 1.6 million years) have been mapped in almost every county in Oregon (Figure 2). These facts show Oregon's earthquake potential despite its moderate level of seismicity and suggest the existence of a significant seismic threat to the inhabitants.

EARTHQUAKE SOURCES AND THEIR SIGNIFICANCE

The western part of the Pacific Northwest lies in an actively converging plate-tectonic setting. The scenic topography along the coast, throughout the Willamette Valley, and in the Cascades, was essentially created by plate tectonic activity related to the Cascadia subduction zone, the active fault zone separating the Juan de Fuca and North American plates. The Juan de Fuca plate extends from northern California to British Columbia and lies just off Oregon's coastline. This plate is continually being "subducted" or forced under the North American plate (Figure 1). As a result, the highly publicized Cascadia subduction zone "megathrust" earthquake is expected to occur sometime in the future along the boundaries of these plates. Although no significant Cascadia subduction zone earthquake has occurred in historic times, several large-magnitude subduction zone earthquakes are thought to have occurred during the past few thousand years, with the last event about 300 years before the present (Atwater and others, 1995). The maximum magnitude of Cascadia subduction zone earthquakes, for both past and future events, is estimated to be about 8.5–9.0.

Intraplate earthquakes occur within the subducting Juan de Fuca plate at depths of 40–60 km. The maximum magnitude of an intraplate earthquake is estimated to be about 7.5. Although numerous microearthquakes have been identified as intraplate events in Oregon, none has been of significant magnitude. The Puget Sound region in Washington has experienced two significant intraplate events in modern

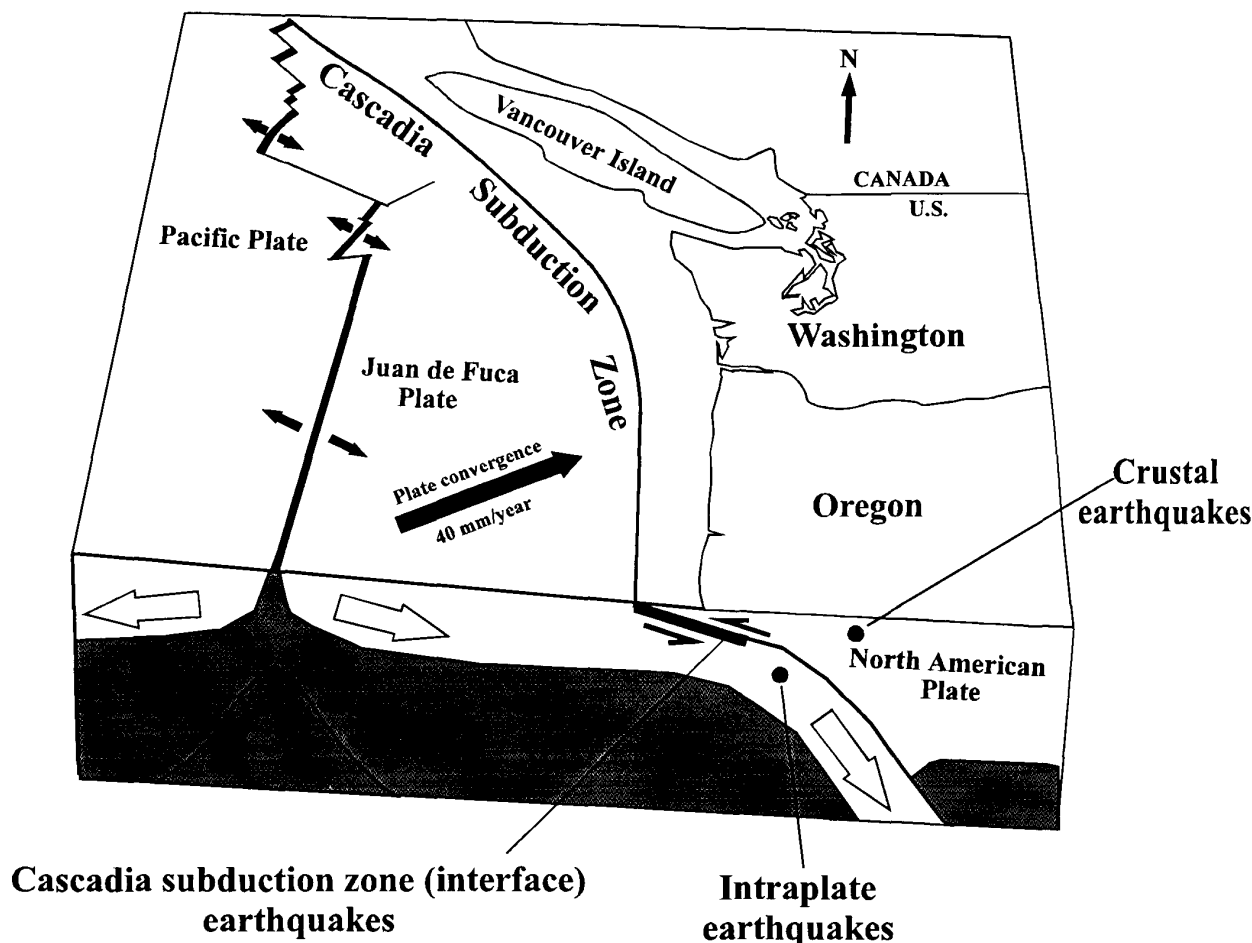


Figure 1. Map and cross section showing the North American plate, the Juan de Fuca plate, the Cascadia subduction zone, and typical locations for the three earthquake types discussed in the text. Figure modified from Anthony Qamar, University of Washington (written communication, 1996).

times, in 1949 and 1965, with magnitudes of 7.1 and 6.5, respectively. Both events caused serious local damage and were felt in Portland and as far away as Montana.

Shallow crustal earthquakes typically occur within the overriding North American plate at depths of 10–25 km. The 1993 M 5.6 Scotts Mills earthquake (Figure 3) centered northeast of Salem was a crustal event, as were the 1993 Klamath Falls earthquakes (M 5.9 and M 6.0). The maximum estimated magnitude of a crustal earthquake ranges from 6.5 to over 7.0. In 1962, a M 5.5 event with a maximum intensity of MM VII (Bott and Wong, 1993) that occurred in the Portland area was felt a distance of 150 mi away (Dehlinger and Berg, 1962; Dehlinger and others, 1963).

Volcanic earthquake sources, such as at the Mount St. Helens seismic zone in Washington and the less active Mount Hood area in Oregon, generally pose a lesser threat than the other types of earthquake sources. Seismic volcanologists limit the maximum magnitude of volcanic earthquakes to about 5¼. Two volcanic earthquakes of M 4.9 and

M 5.1 occurred in May 1980 at the time of the Mount St. Helens volcanic eruption (Steve Malone, University of Washington, personal communication, 1996).

A recent statewide seismic study commissioned by the Oregon Department of Transportation (ODOT) includes a map onto which the locations of all known Quaternary-active faults and earthquake epicenters since 1827 were compiled. The report, which also includes probabilistic ground motion maps, provides the most current and comprehensive data available for the state (Geomatrix Consultants, Inc., 1995). This information is being used by ODOT to provide ground motion parameters necessary for design, construction, and earthquake mitigation of the state-owned road system.

A recent study of historic earthquakes in the greater Portland area indicates that several earthquakes larger than M 5 have occurred in the Willamette basin over the last 150 years and gives descriptive accounts of each earthquake (Bott and Wong, 1993).

THE GROWING UNDERSTANDING

Earthquakes were felt in Oregon as early as 1877 (Algermissen, 1983). Human recollections of earthquakes tend to fade quickly, however, and the general sentiment has been that "Oregon is not earthquake country." As early as 1912, geologists recognized and documented the fact that Oregon was seismically active (Smith, 1919). Despite early scientific recognition, the public failed to understand and appreciate the seismic risk for many decades. During the past decade, however, there has been increasing acknowledgment that earthquakes pose a real threat to the state's inhabitants.

In reality, the seismic risk is getting more severe, not because the level of seismicity is increasing, but because the population is increasing. With more people, more buildings, more infrastructure, and more businesses and industries in the state, more is at stake. It is fortunate that the awareness of Oregon's seismic threat has grown from "almost nil by most" to "well recognized by many." Furthermore, awareness of Oregon's vulnerability to earthquakes has even reached the national level, and several significant Portland-based seismic projects that will be discussed later in this paper were federally supported.

The first major earthquake risk studies in the Pacific Northwest, however, were related to siting of nuclear power plants. In 1970, when the siting of the Trojan nuclear power plant near Rainier in Columbia County was under consideration, the realization of the need for considering earthquake risk for the siting of this facility led to an investigation of earthquake potential and risk within the state (see appendix of Oregon Department of Geology and Mineral Industries, 1978).

The question of seismic hazards at Trojan was later revisited. In 1978, the Oregon Department of Geology and Mineral Industries (DOGAMI) conducted an independent geologic hazard review of the site, including earthquake hazards (Oregon Department of Geology and Mineral Industries, 1978). In 1981, following the May 1980 Mount St. Helens volcanic eruption, DOGAMI geologists conducted a seismic and volcanic hazard evaluation of the Trojan site (Beaulieu and Peterson, 1981). The 1981 study indicated that the maximum possible earthquake in the source region was in the range of M 5.2 to M 6.2. This report also described the plate tectonic setting off the coast of Oregon and presented the seismic potential associated with the Cascadia subduction zone as an unresolved question.

The first notable regional seismic study was performed in 1972. It was conducted to assess ground motion characteristics in the federal Bonneville Power Administration service area (Shannon and Wilson, Inc., 1972), which includes Oregon, Washington, Idaho, and western Montana. At that time, the still relatively new theory of plate tectonics, which helped to explain the nature of earthquakes, was gaining broad acceptance. The report's findings alluded to the existence of the Cascadia subduction zone and stated that "it is generally recognized . . . that the Pacific North-

west is not the site of major tectonic thrusting, nor is it as inactive as the central area of a tectonic plate." The study surveyed historic earthquakes and considered an earthquake of "magnitude $m_b = 6.5$ as the likely maximum for Portland and vicinity" (Shannon and Wilson, Inc., 1972).

Among many important studies on the Cascadia subduction zone, the following three played a key role in leading toward the current mainstream understanding that the Cascadia subduction zone is an active subduction zone: First, in 1981, findings from a study on geodetic strain measurements in Washington indicated that, in the vicinity of the Olympic Peninsula, measurable horizontal strain parallel to the direction of plate-convergence had accumulated over a 10-year observation period (Savage and others, 1981). This manifestation of crustal shortening indicated that active convergence was taking place on the Cascadia subduction zone and supported a history of subduction zone earthquakes. Second, in 1984, a study that compared the Cascadia subduction zone with many other subduction zones around the world was published (Heaton and Kanamori, 1984). The authors noted the low level of seismicity associated with the Cascadia subduction zone and provided three possible explanations: "(1) The North American and Juan de Fuca plates are no longer converging; (2) the plates are converging, but slip is accommodated aseismically; or (3) the northwestern United States is a major seismic gap that is locked and presently seismically quiescent but that will fail in great earthquakes in the future." The authors concluded that the plate convergence rate appeared to be 3–4 cm/yr and "that there was sufficient evidence to warrant further study of the possibility of a great subduction zone earthquake in the Pacific Northwest." Finally, a 1987 paper by B.F. Atwater (1987) presented paleoseismic evidence (buried peat soils) for great Holocene earthquakes along the outer coast of Washington. These three studies have fundamentally shaped the way earth scientists currently view the Cascadia subduction zone and its potential impact on Oregon.

In 1987, the Oregon State University Geology Department and DOGAMI hosted a landmark professional gathering at the Oregon Academy of Science in Monmouth, Oregon. For the first time, earth scientists gathered together to discuss the potential of a Cascadia subduction zone earthquake. Later that same year, DOGAMI hosted a "cluster" meeting of regional state surveys with U.S. Geological Survey (USGS) scientists to discuss earthquake hazards in the Pacific Northwest. With the added momentum generated by these scientific enthusiasts, the USGS was convinced that the Portland, Oregon, area was vulnerable to major earthquakes. This led to a Cooperative Agreement between the USGS and DOGAMI that involved collecting earthquake-related geologic data in the greater Portland area and educating the public on earthquake hazards. These initial meetings directed DOGAMI to assist in leading many of the present-day statewide earthquake efforts.

CURRENT STATE OF UNDERSTANDING

Since 1987, voluminous research findings support the fact that the Cascadia subduction zone is active and a threat. These research data are from three primary sources: (1) prehistoric earthquakes, (2) instrument-recorded earthquakes, and (3) geologic records from old earthquakes. More specifically, data on prehistoric earthquakes include Native American legends and Japanese historic documents. Instrument-recorded earthquake data include geophysical and seismicity analyses, geodetic (including global positioning system [GPS]) analyses, and heat-flow analyses. The geologic evidence of old earthquakes (paleoseismic data) comprises the most compelling evidence and includes earthquake-induced landslides (in Washington State), marsh soils buried and forests drowned by coseismic subsidence, tsunami sand deposits, liquefaction features, turbidites, and offshore submarine landslide features possibly related to past Cascadia subduction zone events.

By the early 1990s, the idea of the threat of a Cascadia subduction zone earthquake in the Pacific Northwest was

accepted by many in the scientific community; by the mid-1990s, the idea was much more widely accepted. In April 1996, at the Geological Society of American Cordilleran Section conference in Portland, a straw poll of some 150 earth scientists attending a session on Cascadia subduction zone earthquake issues indicated they all believed that the Cascadia subduction zone could experience a M 8 or larger earthquake.

The most pressing unresolved problem that remains for most scientists is not whether a Cascadia subduction zone event will occur but rather how big it can be and how often it will occur. Some scientists believe that M 8 is the upper magnitude limit, while others believe that an event even greater than M 9 is possible. One can assert, based on presumed rupture zone, paleoseismic evidence, and historic Japanese tsunami records, that it is possible for the Cascadia subduction zone to generate an earthquake greater than M 9. One counterargument is that major offshore strike-slip faults, such as the offshore Wecoma fault located west of Siletz Bay in Lincoln County (Goldfinger

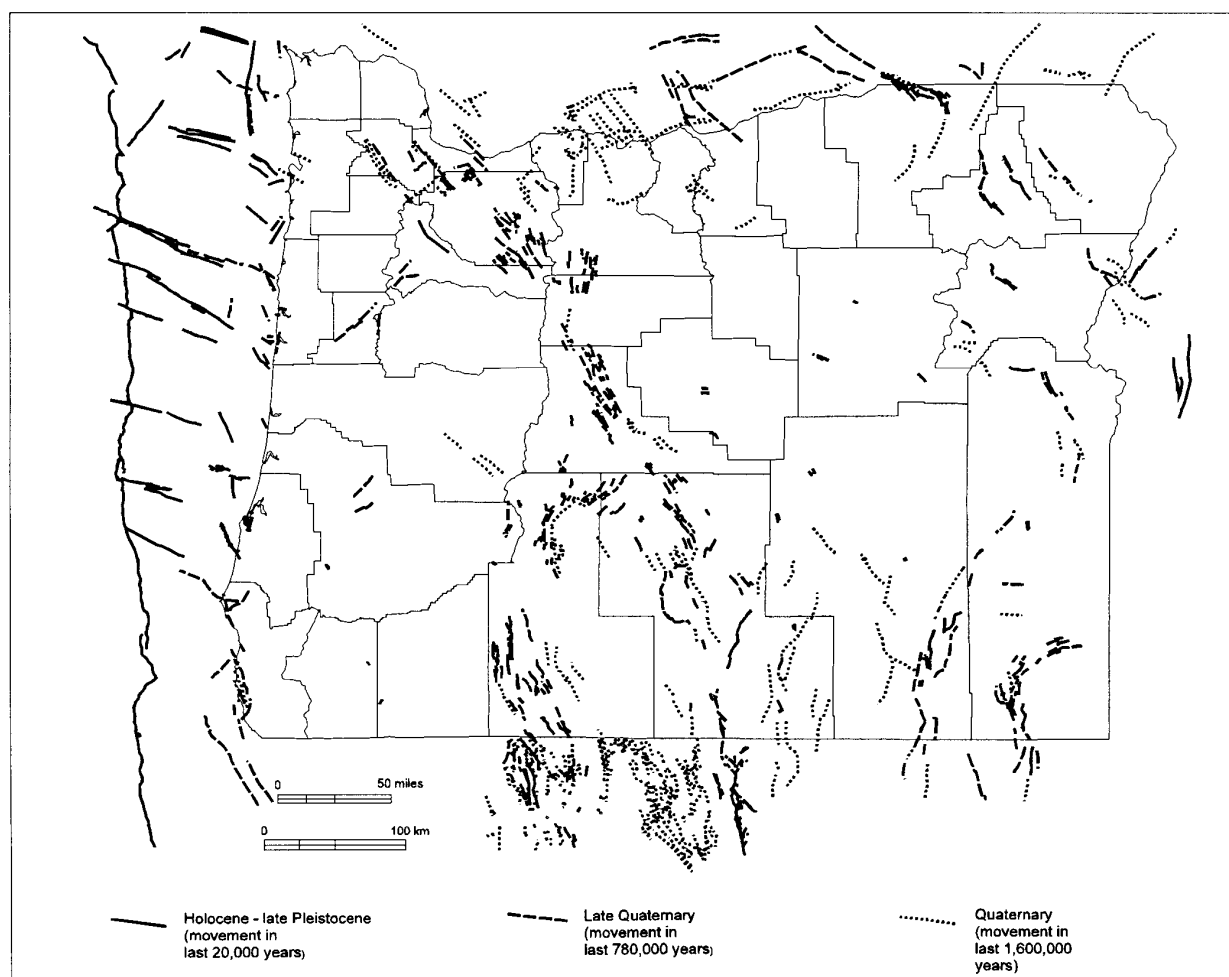


Figure 2. Map showing young faults in Oregon. Map from Geomatrix Consultants, Inc. (1995).

and others, 1992), may divide the Cascadia subduction zone into "segments" and limit the size of the maximum possible earthquake to M 8 or so. Although the possible maximum magnitude question needs to be pursued, clearly, even a M 8 event would be ominously large and would impact a widespread region.

How often do these great subduction zone earthquakes occur? Current thinking limits the range for the average recurrence interval (the time between earthquakes) to between 400 and 600 years (Atwater and others, 1995). The recent Geomatrix Consultants, Inc. (1995) study narrows the estimate of the recurrence interval to 450 ± 150 years. Japanese historic documents describing a tsunami not preceded by a local earthquake suggest that the most recent Cascadia subduction zone event occurred on January 26, 1700 (Satake and others, 1996).

Although these questions of magnitude and frequency of a Cascadia subduction zone earthquake cannot be definitively answered at this time, our understanding of earthquake hazards is at the level where we can say, "There is consensus in the scientific community that in Oregon strong ground shaking from earthquakes is inevitable and poses a significant threat."

NEED FOR ACTION

Giving society a better chance to function in personal and economic safety and with minimal disruption after an earthquake involves a concentrated effort among many people. It is no easy task to convey to the community at large the importance of being well prepared and the necessity of taking concrete steps to get prepared. For instance, many who purchase earthquake insurance do not realize that being insured does not equate with being adequately prepared. Having insurance does not prevent fatalities, strengthen facilities, or stave off damage in any way—being prepared does.

Therefore, the next fundamental steps are to define the "hazards" associated with ground shaking and to identify the "risks" associated with the hazards. "Hazards" are important only when there are "risks," and the level of risk depends not only on the hazards present but also the amount of exposure (population and buildings). Therefore, the higher the hazard and the greater the exposure (such as vulnerable populations or weak buildings), the higher the risk. Risk includes not only fatalities, injuries, and property damage, which are immediate impacts, but also lifeline interruption, business interruption, worker displacement, homelessness, and other effects that can have a serious long-term impact on recovery from an earthquake.

The next steps are to identify ways to reduce these risks, mitigate the unacceptable risks to acceptable levels, and develop policies to reduce risk. The following discussion reviews how reduction of earthquake risks has been addressed through state legislation and organized efforts in Oregon.

STATE LEGISLATION

A broad array of earthquake-related state legislation has been introduced over the last decade, and many laws have been passed to help improve earthquake preparedness in Oregon. Listed below are the more important items of legislation that have been passed and written into the Oregon Revised Statutes (ORS).

In mid-1989, the Oregon legislature expanded the scope of DOGAMI's responsibilities, thereby requiring the agency not only to develop an understanding of hazards, including earthquakes, landslides, tsunamis, and floods, but also to mitigate the loss of life and property these hazards can cause (ORS 516.030[3]).

Following the October 1989 Loma Prieta earthquake, then Governor Goldschmidt created a task force to evaluate Oregon's seismic vulnerability. In response to the task force findings that indicated the general vulnerability of the state, the Governor issued an Executive Order (EO-90-02) to form a eight-member commission. In 1991 legislation, this commission was formally established as the Oregon Seismic Safety Policy Advisory Commission (OSSPAC) (ORS 401.337 to 401.353). OSSPAC's mission is to reduce exposure to earthquake hazards through education, research, mitigation, and response preparation. In 1995, four more members were added to OSSPAC.

Also in 1991, DOGAMI introduced State Senate Bill 96, which involved several seismic issues and became law. It required site-specific seismic hazard investigations for essential facilities, major structures, hazardous facilities, and special-occupancy structures (e.g., schools and hospitals); the filing of the hazard investigation reports with DOGAMI; and a program for the installation of strong-motion accelerographs in or near selected major buildings (ORS 455.447). It also required "duck, cover, and hold" drills to be conducted for grades K-8 in public schools (ORS 336.071).

By 1992, there was substantial support of seismic mitigation by State Legislators and executive leaders. The Oregon Legislative Emergency Board increased DOGAMI's base budget to cover the salary of an earthquake geologist (initially funded by the previously mentioned USGS Cooperative Agreement).

In 1993, the Building Codes Division (BCD) of the Department of Consumer and Business Services adopted a zone change from Seismic Zone 2B to Seismic Zone 3 in western Oregon (Figure 4). This change meant that new buildings were required to meet a higher standard of seismic strength. That same year, the State Senate adopted Senate Joint Memorial (SJM) 12, which asked Congress to retain existing earthquake funding levels and encouraged federal agencies to assist Oregon, California, Alaska, and Washington in earthquake hazard mitigation efforts.

In 1993, Senate Bill 81 designated \$4.3 million in lottery funds for reinforcing the poorly constructed State Capitol dome, which was damaged from low levels of shaking during the 1993 Scotts Mills earthquake. The Legislative Administrative Committee oversaw this retrofit work and is

pursuing additional seismic strengthening of the remainder of the State Capitol Building.

Most recently, in 1995, 14 earthquake-related bills were introduced into the legislature. Passage of several of them resulted in new or changed Oregon Revised Statutes (ORS). Included among the new statutes were a requirement for tsunami drills and education in schools (ORS 336.071), a requirement that essential and special occupancy structures be built outside the tsunami zone (ORS 455.446), the creation of a Seismic Rehabilitation Task Force to make recommendations to the legislature for the seismic rehabilitation of existing buildings (ORS 455.395[4]), provisions for entering and inspecting earthquake-damaged buildings (ORS 455.448), and provisions for the abatement of unsafe buildings (ORS 455.449).

The Seismic Rehabilitation Task Force was created in 1995 by the legislature and appointed by the Governor in consultation with the State Geologist. This 13-member Task Force convened to examine the safety of buildings that were built under prior building code criteria and to make recommendations to the 1997 Legislature for any seismic rehabilitation that should be required in those existing buildings to protect the public from seismic risk. The identification of existing buildings that require mitigation and the implementation of mitigation measures are highly complex and controversial issues. A report containing the recommendations of the Task Force was submitted to the legislature in September 1996 and developed into 1997 House Bill 2139.

House Bill 2139 proposes a survey over the next six years that will determine the type of construction and degree of safety of each building in the state, except for one- and two-family homes and other exempt structures. House Bill 2139 also proposes that seismic rehabilitation be performed in a three-stage time frame, dating from notification that results from the survey: (1) within 15 years, for unreinforced masonry (URM) buildings with parapets, signs, and other appendages, except for cornices and nonstructural cladding, that may constitute a falling hazard during an earthquake; (2) within 30 years, for the remainder of the URM buildings; and (3) within 70 years, for all other unsafe buildings. The upgrading may be stimulated by tax credits, property tax abatements, and public education.

LEADING ORGANIZATIONS

Experience has shown that public expenditures for mitigation (e.g., risk reduction of loss of life and property) are dramatically less than the costs of reconstruction following a disaster. The potential billions of dollars that will be spent in Oregon on reconstruction and business interruption losses by governments, private insurers, and the public can be minimized by mitigation expenditures to an amount on the order of only millions. The benefit-to-cost ratio is generally estimated to be somewhere between 10:1 and 100:1. More importantly, many needless fatalities can be avoided.

Several organizations have led the effort on reducing

earthquake risks. These organizations included DOGAMI, Metro (Metropolitan Portland area regional government), Oregon Seismic Safety Policy Advisory Commission, Building Codes Division, Seismic Rehabilitation Task Force, Oregon Department of Transportation, and Oregon Emergency Management. Their most significant contributions are described below.

Oregon Department of Geology and Mineral Industries

In addition to its other responsibilities, DOGAMI has the legislature's mandate to better understand and mitigate earthquake hazards. Part of the agency's mission is to "reduce the future loss of life and property due to potentially devastating earthquakes." Realizing that the state is currently underprepared to suffer a destructive earthquake, the agency applies its earthquake efforts in three broad areas: (1) earthquake hazard identification, (2) mitigation of earthquake hazards, and (3) increasing earthquake hazard awareness. Although the agency provides technical information, it also encourages policy applications associated with its efforts.

Earthquake hazard identification: Since the year 1987, DOGAMI has incorporated earthquake hazard identification into the agency's scope of work. DOGAMI concluded that hazard identification was best approached by evaluating ground response from source-independent earthquakes, rather than by attempting to determine the locations of all active faults. The agency further concluded that the geology-related hazards that contribute to most of the damage are strong ground shaking (including amplification of peak ground accelerations), landsliding, and liquefaction.

DOGAMI has focused on earthquake hazard identification by developing geology-based earthquake hazard maps that indicate susceptibility to ground shaking amplification of peak ground accelerations, landsliding, and liquefaction susceptibility. Also, a general hazard composite map was produced by combining these three hazards with geographic information system (GIS) tools. Information on expected ground response from these regional maps can be used for a variety of purposes and applications. For example, in the case of new buildings, consideration of the siting of facilities may be based on expected ground response, and the level of the geotechnical investigation, design, and construction may be scaled according to the expected hazards. For existing buildings, the maps can be used to conduct a systematic risk assessment, so that property owners have the information needed to prioritize retrofit of their structures. The maps can also help facilitate prudent regional land use planning and emergency response planning both before and during an earthquake disaster.

Hazard mapping is under way in several urban areas, including the outer reaches of the greater Portland area and the greater Eugene and Springfield area. Mapping has been completed for most of Portland, for Salem, and for the Siletz Bay area in coastal Lincoln County. Continued mapping efforts are projected for Klamath Falls and 24 small-



Figure 3. Damage to Molalla High School, Molalla, Oregon, from the Scotts Mills earthquake of 1993. Bricks from the unreinforced masonry gable over the doorway fell to the steps and sidewalk (left photo) during the earthquake, illustrating the need for seismic rehabilitation. The damage to the steps (right photo) that was revealed when the debris was removed can serve as a vivid reminder of an important rule for response during an earthquake: Do not run out of a building! Rather, "duck, cover, and hold!"

to moderate-sized cities in western Oregon (including communities such as Albany, Corvallis, Newberg, Medford, Coos Bay, and Newport).

The Oregon coast is the focus of substantial risk from Cascadia subduction zone earthquakes and accompanying tsunamis, which have estimated first-wave arrival times of about 5 to 30 minutes after the onset of ground shaking. Regional tsunami-inundation zone maps have been completed for the entire Oregon coast. Also, detailed mapping has been completed for the greater Siletz Bay area; mapping is being conducted in Seaside and Newport; and future mapping in other areas (including Gold Beach and Coos Bay) is in preparation. In addition, large historical markers describing tsunamis have been erected at Seaside, Newport, and Reedsport; tsunami hazard zone and evacuation route signs have been installed in several coastal towns and communities; and informational tsunami brochures and book-marks have been distributed all along the coast.

Mitigation of earthquake hazards: In 1989, DOGAMI was charged with the additional duties of mitigating earthquake hazards, that is, reducing the loss of life and property from earthquakes. Four main areas are targeted: new buildings, existing buildings, uses of the DOGAMI hazard maps, and earthquake damage and loss studies.

Since 1993, the Building Codes Division has required construction of safer new buildings (discussed below under "Building Codes Division"). For existing buildings, efforts are underway to develop a prioritized strategy for reduction of future losses by identifying steps that can provide for greatly enhanced safety at reasonable and justifiable expense. The goal is to establish policies that will help identify and strengthen vulnerable existing buildings (discussed below in "Seismic Rehabilitation Task Force").

DOGAMI collaborates with Metro on the Portland earthquake hazard mapping project, with DOGAMI developing the maps and Metro focusing on the application of the maps in its jurisdiction over the greater Portland area (see discussion below under "Metro"). DOGAMI's and Metro's efforts can help guide the use of hazard maps in other areas of the state as well as other parts of the country.

Another element of mitigation is conducting damage and loss assessments to estimate the loss of life and property from expected future earthquakes. With this information, strategic retrofit programs can be developed. DOGAMI has been involved in several earthquake damage and loss assessments. In 1993, a hazard map of the Portland 7½-minute quadrangle was accompanied by an earthquake damage and loss estimate for an area of 60 city blocks (Metro/Oregon Department of Geology and Mineral Industries, 1993). Initiated in 1995, a federally funded National Institute of Building Sciences (NIBS) damage and loss study of the greater Portland area is under way. Results are projected to be available to the public in early 1997 (discussed below in "National Institute of Building Sciences"). In 1996, DOGAMI completed an economic impact

evaluation from a design earthquake for each county. The study led to the result that over the next 55 years, the estimated average annual loss in Oregon would total over \$100 million (Whelan and Mabey, 1996).

The agency encourages local partnerships and cooperation with communities, so that a systematic evaluation of risk can be better understood and mitigation efforts can be prioritized. An additional element is cooperation with local officials, such as land use and emergency planners and building officials, to incorporate the understanding of the mapped hazards and risks into everyday practices, plans, and policies.

Increasing earthquake hazard awareness: Earthquake risk can be reduced by increasing hazard awareness in the public. DOGAMI engages in technology transfer and public education by leading and participating in committees, conferences, workshops, and applied sessions with targeted audiences, including planners and building officials, and by developing and distributing fact sheets and brochures. Some outreach includes disseminating information through media, schools, and universities and supporting continuing education and studies for organizations such as the Oregon Building Officials Association, Oregon Planning Institute, American Society of Safety Engineers, Oregon Occupational Safety and Health Division of the Department of Consumer and Business Services, Oregon League of Women Voters, Northwest Power Pool (lifeline managers), and insurers. DOGAMI also assists with preparedness efforts of the American Red Cross.

Metro

Metro is authorized through its charter to address natural-disaster planning and response coordination in the greater Portland area. The agency's focus to date is on collection and dissemination of seismic risk information and on interaction with federal, state, and local governments, businesses, utilities, and special-interest groups in developing a regional earthquake preparedness program.

Metro was a key player in the Regional Planning Group that created the Regional Emergency Management Workplan, with the stated goal "to determine the emergency management issues and needs of the region and propose methods of coordinating, improving, and maintaining the emergency services system in the region." A geographic information system (GIS) database with regional infrastructure and building inventory is about half completed and has been shared with those who are conducting the National Institute of Building Sciences (NIBS) damage and loss assessment of the greater Portland area.

In early 1994, Metro formed the Metro Advisory Committee for Mitigating Earthquake Damage (MACMED) to support cooperative efforts among community members and to address regional policy issues regarding uses of the DOGAMI earthquake hazard maps. In May 1996, MACMED completed its efforts to tie earthquake hazard maps to land use planning and building practices and issued a report titled "Using Earthquake Hazard Maps for Land Use Plan-

ning and Building Permit Application." Metro plans to present the recommendations in the report to the Metro Policy Advisory Committee and Metro Council for future action.

Since 1993, Metro has sponsored several regional conferences that addressed earthquake hazards and emergency response. Metro is involved in several ongoing projects, including the NIBS-funded damage and loss study for the Metro area.

Oregon Seismic Safety Policy Advisory Commission (OSSPAC)

OSSPAC serves to reduce earthquake exposure and advises the legislature and government agencies on earthquake policy issues. OSSPAC includes representatives from the Building Codes Division, DOGAMI, the Department of Human Resources, Department of Land Conservation and Development, Department of Transportation, Oregon Emergency Management, Department of Water Resources, legislature, school districts, structural engineers, city governments, and county governments.

While OSSPAC functions as a forum and is still in developmental stages, it has identified the potential risk from existing buildings and bridges as the greatest earthquake-related risk the state now faces. OSSPAC played a vital role in presenting legislation that upgraded Oregon's building requirements from Zone 2B to Zone 3 for western Oregon. Currently, OSSPAC is evaluating the policy issues surrounding a possible change of seismic zone ratings along the Oregon coast for the Building Codes Division.

Department of Consumer and Business Services, Building Codes Division (BCD)

BCD sets state requirements of the minimum design and construction standards for new buildings. In 1993, BCD upgraded the Oregon Structural Specialty Code (OSSC) seismic zonation rating for western Oregon and Hood River and Klamath Counties from Zone 2B to Zone 3, which requires that new buildings be built to higher seismic standards.

Also since 1993, BCD requires that site-specific seismic hazard investigations be performed for new essential facilities, major structures, hazardous facilities, and special-occupancy structures such as hospitals, schools, and emergency response facilities. BCD is currently evaluating the merits of changing the requirements of coastal Oregon, such as possibly upgrading to a Uniform Building Code Zone 4 rating, and is active on several earthquake committees and continuing education programs.

Oregon Department of Transportation (ODOT)

ODOT has focused on reducing seismic risks by placing an emphasis on strengthening future construction and by developing a priority list for retrofitting existing structures. Starting in 1991, ODOT began seismic retrofit of high-priority bridges, a screening of all state-owned bridges for seismic retrofit prioritization, and installation of a statewide seismic strong-motion instrumentation network. By 1995, ODOT had concluded its seismic hazard mapping project

for the state. The agency is continuing its aggressive search for funding alternatives for seismic strengthening of bridges and is moving forward as well on other mitigation efforts.

Department of State Police, Oregon Emergency Management (OEM)

OEM is charged with applying for and administering disaster and other grants related to emergency program management and emergency services for the state. OEM coordinates the activities of all public and private organizations providing emergency services within the state. Most of the coordination efforts are related to planning for and conducting emergency response. OEM coordinates the response to an earthquake, which includes providing inspectors to assess damage. OEM led its first biannual statewide emergency response exercise for a Cascadia subduction zone earthquake scenario (QuakEx) in 1994 and continues scheduling the exercise on a biannual basis, involving many public and private organizations and sponsoring conferences and education focused on mitigation.

OTHER GOVERNMENT ORGANIZATIONS

Other organized efforts by agencies on the federal, state, and local government levels, some of which some are partnerships among various governmental agencies and private groups, are listed below. For the purposes of this paper, information about partnership efforts is generally provided under the section of the leading organization.

Federal Emergency Management Administration (FEMA)

FEMA is charged with mitigating the effects of natural disasters and responding to needs that develop after a disaster. FEMA provides disaster relief funds following an emergency and works most closely with OEM (for example, in response to the 1993 Scotts Mills and Klamath Falls earthquakes). FEMA has helped elevate the awareness of Oregon's seismic risk to the national level and has been a strong financial supporter of earthquake mitigation projects in the Portland area, including the Portland area earthquake hazard mapping project.

U.S. Geological Survey (USGS)

The USGS actively engages in earthquake research and also strongly supports research by others by providing funds and professional involvement through a variety of means.

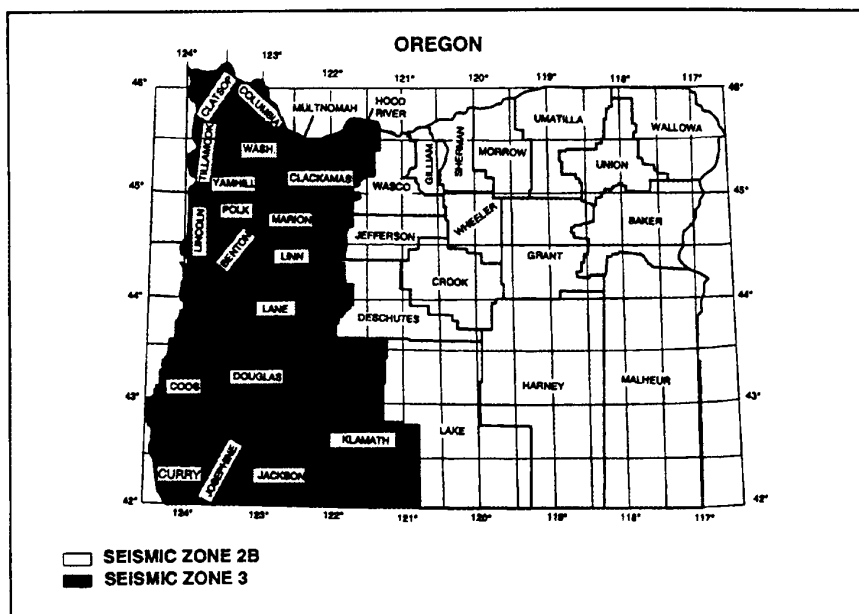


Figure 4. Seismic zone map of Oregon. Prior to the 1993 change of the Oregon Structural Specialty Code, all of Oregon was Seismic Zone 2B.

Recent USGS research includes paleoseismic investigations along the Columbia River, aeromagnetic surveys of the Portland area and the northern Willamette Valley, recordings of the 1993 Scotts Mills and Klamath Falls earthquake aftershocks by deployment of temporary seismometers, evaluation of landslides induced by the 1993 Klamath Falls earthquake and of slopes in the greater Eugene and Springfield area that are prone to fail in earthquakes, and evaluation of crustal strain related to the Juan de Fuca plate subduction zone through a global positioning system (GPS) network.

In addition, the USGS funds the Pacific Northwest Regional Network, with headquarters at the University of Washington (UW), which provides earthquake recording coverage of much of Oregon. Other parts of Oregon are covered by Boise State University. The USGS, UW, and DOGAMI are currently initiating a system that allows for real-time monitoring of earthquakes. The USGS participates in partnership efforts (FEMA, DOGAMI, and California Division of Mines and Geology) to develop standardized methods of making earthquake hazard maps.

National Earthquake Hazards Reduction Program (NEHRP)

NEHRP was established by act of Congress in 1977 and is charged with providing long-term, nationwide earthquake risk reduction. NEHRP consists of federal agencies-FEMA, USGS, National Science Foundation (NSF), and National Institute of Standards and Technology (NIST) and awards grants on a competitive basis. NEHRP has funded such studies in Oregon as the evaluation of the 1993 Scotts Mills and 1993 Klamath Falls earthquakes, publication of

liquefaction maps in the greater Portland area, Portland area basin studies, Portland area probabilistic ground motion studies, and Coos Bay area fault maps.

National Earthquake Loss Reduction Program (NEP)

NEP, which was formed in 1996 to focus on earthquake loss reduction by complementing NEHRP activities, is led by FEMA and involves many agencies in addition to those that make up NEHRP. The stated goals are to provide leadership and coordination for federal earthquake research, improve technology transfer and outreach, improve engineering of the built environment, improve data for construction standards and codes, continue the development of assessment tools for seismic hazards and risks, analyze seismic hazard mitigation incentives, develop understanding of societal impacts and responses to earthquake hazard mitigation, and continue documentation of earthquakes and their effects.

National Institute of Building Sciences (NIBS)

FEMA has sponsored NIBS to develop for NEHRP a risk assessment tool that estimates earthquake losses and that should be available in early 1997. Ultimately, local officials responsible for planning and stimulating mitigation efforts can utilize this methodology to reduce losses and better prepare for emergency responses and recovery following and earthquake. With results thus obtained by a consistent method, NEHRP can better determine the level of resources needed on a nationwide basis and more accurately allocate those resources to appropriate regions.

At this time, three pilot studies to test the developmental software (HAZUS) produced by NIBS are being conducted. The greater Portland area was selected as the western U.S. site.

Cascadia Region Earthquake Workgroup (CREW)

CREW is a private-public coalition formed in 1995 that works to reduce the risk of Cascadia-region earthquake hazards by linking regional mitigation resources and encouraging regional mitigation projects. CREW consists of a broad spectrum of Northwest-based members, including representatives of government, corporate, medical, financial, manufacturing, utility, and transportation groups. CREW plans to develop earthquake scenarios of Cascadia subduction zone and Portland earthquakes to identify areas of high risk.

Western States Seismic Policy Council (WSSPC)

WSSPC is a policy consortium of 18 governmental bodies from 13 western states represented by their emergency managers and State Geologists, whose mission includes the sharing of information among the states for earthquake mitigation purposes.

Oregon Department of Land Conservation and Development (DLCD)

DLCD supports earthquake hazard planning relating to its Comprehensive Plan Goal 7 on natural hazards and en-

courages prudent land use planning according to the MACMED report recommendations (see "Metro," above). DLCD participates in earthquake efforts together with OSSPAC and MACMED.

Oregon State System of Higher Education

All three of the state's major public universities, University of Oregon, Oregon State University, and Portland State University, are involved with earthquakes and earthquake hazards in some capacity. At these institutions, the federally funded work conducted tends to be oriented towards basic research, whereas the state-funded work typically has more practical application.

Some of this work has included the analysis of the Scotts Mills and Klamath Falls earthquakes, studies of offshore faults and geology, studies of paleoseismic evidence along the coast and the Columbia River, installation and operation of a limited seismic network in cooperation with the Pacific Northwest Regional Network, geologic modeling and geophysical studies for supporting DOWAMI earthquake hazard mapping, and course offerings and seminar lectures on earthquake engineering issues.

Oregon Department of Education

The Department of Education is generally concerned with seismic safety in schools. It supports the required monthly earthquake drills mandated in the Oregon Revised Statutes (ORS 336.072). The Department does not have authorization to mandate seismic safety efforts in schools but can make recommendations to local school districts on such issues. For example, it encourages use of a curriculum produced by FEMA that focuses on mitigating nonstructural hazards in schools and assists schools in obtaining funds for these purposes.

Oregon Department of Administrative Services (DAS)

DAS is responsible for all state government buildings and has taken a leading role in applying the new earthquake awareness to the safety of structures. The new state office building in Portland was built to Zone 3 standards in 1991/1992—before Zone 3 was adopted by BCD. Existing structures, such as the Public Service building and the Public Utility Commission building in Salem, have been rehabilitated for increased seismic resistance.

Oregon Department of Water Resources (DWR)

DWR safeguards many of the existing dams in the state. The agency has recently begun to consider earthquake safety of dams, for instance, as part of the dam relicensing process and has recommended installing seismic instrumentation on dam sites.

Oregon Boards of Geologist Examiners and Engineering Examiners

In late 1996, the Boards jointly adopted guidelines for the preparation of reports on seismic hazard investigations

required for new essential facilities, major structures, hazardous facilities, and special-occupancy structures.

Local governments

Implementation of earthquake preparedness policy often takes place at the local government level, in cities, counties, water districts, and on school boards. For example, many decisions regarding planning, building, strengthening of structures, and post-disaster response are made at the local level.

In August 1993, the City of Portland formed the Portland Seismic Task Force to address the City of Portland Dangerous Building Code, which was substantially affected by the 1993 state building code changes. In order to determine which existing Portland buildings need to undergo seismic rehabilitation, the task force initiated a risk study to determine acceptable levels of risk within its jurisdiction. The ultimate goal of the task force is to develop public policies encompassing acceptable seismic practices involving the Portland Dangerous Building code and existing vulnerable structures. The history of the building codes for Portland can be found in Kennedy (1996).

PRIVATE ORGANIZATIONS

Various branches of the professional engineering, earthquake, and earth science communities have been actively involved in Oregon's earthquake issues. The Structural Engineers Association of Oregon (SEAO) has recommended requiring continuing education for structural engineers to better address the increasing level of competence needed to design seismically resistant structures. The Oregon Chapters of the American Society of Civil Engineers (ASCE) and the Association of Engineering Geologists (AEG) have provided input on various proposed earthquake-related items of legislation and have offered numerous lectures on seismic issues. National conferences of ASCE and AEG covering Pacific Northwest earthquake issues are planned in 1997. The Earthquake Engineering Research Institute (EERI) and the Geological Society of America (GSA) have sponsored conferences centered on earthquake issues in the Pacific Northwest.

The growing earthquake awareness and concern over earthquake preparedness and mitigation is reflected in the activities of many more organizations, institutions, media, and individuals. Coverage of earthquake-related issues has increased considerably in the region's public media. Educational facilities have developed instructional programs such as the FEMA-funded "Seismic Sleuths" and "Tremor Troops" teacher workshops presented throughout the Pacific Northwest by the Oregon Museum of Science and Industry. Nonprofit organizations have been active in earthquake awareness activities. For example, the League of Women Voters of Oregon conducted a statewide earthquake hazard and awareness study partially funded by DOGAMI that also raised awareness of earthquake issues at the community level. The American Red Cross focuses on public

education, preparedness, and emergency response aimed at families and businesses.

DISCUSSION

The understanding of Oregon's earthquake hazards and the way the state addresses earthquake risks have changed over the years. Periodic earthquake shaking has been felt in Oregon for over a century and a half. The great Cascadia subduction zone earthquake threat was identified in the past decade. The 1993 Scotts Mills and 1993 Klamath Falls "wake-up call" earthquakes confirmed to most people that earthquake hazards are present in Oregon. These recent events have dispelled the notion that Oregon was not earthquake country.

Because earthquakes are low-probability catastrophic events, it is not easy to gain political support and the necessary resources to reduce earthquake risks. However, enough Oregonians have come to realize that the huge costs to society associated with damaging earthquakes can easily exceed the cost of reasonable efforts of preparedness, and attempts are being made to bring the state into a better position before next big earthquake hits.

Progress in identifying hazards and risks, estimating the damage and loss potential, reducing risks, and planning for emergency response has been made mainly in the last decade. In view of the fact that no major earthquakes that would raise public awareness have occurred yet, Oregon has made great strides. Many, in fact, consider Oregon to have created an exemplary framework of proactive steps that may be applied elsewhere in the nation to regions that can benefit from guidance in earthquake preparedness. National and regional awards have been granted to the DOGAMI/Metro hazard-mapping project for the Portland area. The surprising thing about Oregon's remarkable progress is that the earthquake mitigation efforts have been performed in fragments by various organizations without comprehensive oversight, whereas addressing the region as a whole would probably have been more efficient. Perhaps the most noteworthy aspect of the accomplishments is that the professional disciplines, including those within government agencies, have managed to overcome the common communication barriers between each other to the advantage of society and have taken decisive initial steps in the right direction. Still, Oregon remains largely underprepared for a significant earthquake, and much more effort is needed to lower the earthquake risk.

History shows that every earthquake has been a "surprise." The exact timing of an earthquake always contains the element of surprise, because true prediction is not possible at this time, nor does it seem likely to be possible for decades to come. Also, earthquakes are all different in respect to their type, the environment in which they occur, and the built environment they affect. In seismically active regions, the earthquake "surprises" and the associated damages and losses should not really be surprises. For that reason, inhabitants of seismically active regions have the opportunity of being prepared for the next "surprise" earth-

quake. It is possible to understand reasonable bounds of potential earthquakes and earthquake hazards, to approximate them through earthquake scenarios, and to reduce the risks to a reasonable level to the benefit of current populations and future generations.

Many earthquakes around the world have had disastrous consequences. Preliminary estimates from earthquake damage-and-loss studies of the densely populated greater Portland area indicate that many hundreds of lives could be lost and that property loss could be on the order of tens of billions of dollars in such an event. Quantifying potential losses is one step in getting closer to the difficult question: "How much can we invest prudently in safer living?"

Since 1993, a higher standard for the seismic safety of new buildings and seismic investigations of building sites for certain new structures, such as hospitals, schools, or emergency response facilities, have been mandated in Oregon. To achieve safer conditions for the entire community, however, more than just the safety of its new buildings must be assured. All buildings and the vulnerability of lifelines such as roads and water, waste-water, electricity, gas, and communication systems need to be addressed. Many need seismic strengthening. Realistic measures to prioritize seismic strengthening must be taken quickly and prudent land use measures established promptly. In addition, a higher degree of preparedness needs to be attained at many levels, from emergency response at the government level to disaster preparedness at the personal level.

ACKNOWLEDGMENTS AND REMARKS

Special thanks to John Beaulieu, Klaus Neuendorf, and Beverly Vogt at the Oregon Department of Geology and Mineral Industries for their generous support. I also thank my coworkers Don Hull, Ian Madin, Dan Wermiel, Angie Karel, Paul Staub, Neva Beck, and Kate Halstead, for helping me acquire the necessary background to write this paper. Thanks to Robert J. Deacon for his insightful comments.

Although it is not the author's intention, this paper may be biased with general viewpoints of the Oregon Department of Geology and Mineral Industries due to the fact that much of the background was gathered from the agency's staff and files. Significant earthquake research and mitigation efforts by those not mentioned in this paper can be brought to the author's attention for future clarification.

REFERENCES CITED

Algermissen, S.T., 1983, An introduction to the seismicity of the United States: Berkeley, Calif., Earthquake Engineering Research Institute Monograph, 148 p.

Atwater, B.F., 1987, Evidence for great Holocene earthquakes along the outer coast of Washington State: *Science*, v. 236, p. 942-944.

Atwater, B.F., Nelson, A.R., Clague, J.J., Carver, G.A., Yamaguchi, D.K., Bobrowsky, P.T., Bourgeois, J., Darienzo, M.E., Grant, W.C., Hemphill-Haley, E., Kelsey, H.M., Jacoby, G.C., Nishenko, S.P., Palmer, S.P., Peterson, C.D., and Reinhart, M.A., 1995, Summary of coastal geologic evidence for past great earthquakes at the Cascadia subduction zone: *Earthquake*

Spectra, v. 11, no. 1, p. 1-18.

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

Beaulieu, J.D., and Peterson, N.V., 1981, Seismic and volcanic hazard evaluation of the Mount St. Helens area, Washington, relative to the Trojan nuclear site, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-81-9, 80 p.

Bott, J.D.J., and Wong, I.G., 1993, Historical earthquakes in and around Portland, Oregon: *Oregon Geology*, v. 55, no. 5, p. 116-22.

Dehlinger, P., and Berg, J.W., Jr., 1962, The Portland earthquake of November 5, 1962: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 24, no. 11, p. 185-188.

Dehlinger, P., Bowen, R.G., Chiburis, E.F., and Westphal, W.H., 1963, Investigations of the earthquake of November 5, 1962, north of Portland: Oregon Department of Geology and Mineral Industries, the Department of Geology and Mineral Industries, Ore Bin, v. 25, no. 4, p. 53-68.

Geomatrix Consultants, Inc., 1995, Seismic design mapping, State of Oregon: Final report to Oregon Department of Transportation, Project no. 2442, var. pag.

Goldfinger, C., Kulm, L., Yeats, R., Mitchell, C., Weldon, R., Peterson, C., Darienzo, M., Grant, W., and Priest, G.R., 1992, Neotectonic map of the Oregon continental margin and adjacent abyssal plain: Oregon Department of Geology and Mineral Industries Open-File Report O-92-4.

Heaton, T.H., and Kanamori, H., 1984, Seismic potential associated with subduction in the northwestern United States: *Seismological Society of America Bulletin*, v. 74, no. 3, p. 933-941.

Kennedy, R.E., 1996, The development of the Portland, Oregon, Building Code—50 years of evolution, 1945-1995. A comparison of seismic events and structural aspects: *Oregon Geology*, v. 58, no. 1, p. 10-14.

Metro/Oregon Department of Geology and Mineral Industries, 1993, Earthquake scenario pilot project: Assessment of damage and losses: Oregon Department of Geology and Mineral Industries Open-File Report O-93-6, 19 p., 16-p. appendix.

Oregon Department of Geology and Mineral Industries, 1978, Geologic hazards review, Trojan nuclear power plant site, Columbia County, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-78-1, 42 p.

Satake, K., Shemazaki, K., Yoshinobu, T., and Ueda, K., 1996, Time and size of a giant earthquake in Cascadia inferred from Japanese tsunami records of January 1700, 1996: *Nature*, v. 379, no. 6562, p. 246-249.

Savage, J.C., Lisowski, M., and Prescott, W.H., 1981, Geodetic strain measurements in Washington: *Journal of Geophysical Research*, v. 86, no. B6, p. 4929-4940.

Shannon and Wilson, Inc., 1972, Seismic regionalization studies, Bonneville Power Administration service area, Washington, Oregon, Idaho, and western Montana: Portland, Ore., Report to Agabian Associates, El Segundo, Calif. (Job no. 0-653); R.W. Couch and R.J. Deacon, investigators, 43 p.

Smith, W.D., 1919, Earthquakes in Oregon: *Seismological Society of America Bulletin*, v. 9, no. 3, p. 58-71 (Reprint: University of Oregon Publications, v. 1, no. 3).

Whelan, R.M., and Mabey, M.A., 1996, The expected financial losses due to building damage caused by severe earthquakes in Oregon: *Oregon Geology*, v. 58, no. 6, p. 146-149. □



Oil and gas exploration and development in Oregon, 1996

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

ABSTRACT

Oil and gas leasing activity was about the same during 1996 as it was in 1995. Four U.S. Bureau of Land Management (BLM) lease sales were held during the year, and no offers were received. Federal applications were filed and leases issued on 25,335 acres in Jefferson County. A total of 39,571 federal acres were under lease at year's end. The State of Oregon conducted no lease sales during the year. There were 12 State of Oregon tracts under lease at year's end, comprising 941 acres. Columbia County held no lease sales during the year.

During 1996, Enerfin Resources Company drilled two exploratory wells at the Mist Gas Field, Columbia County. These were the first exploratory wells drilled in Oregon since 1993, when thirteen exploratory wells and three redrills were drilled. Both wells have been temporarily abandoned pending further evaluation. Enerfin Resources plugged two depleted former gas producers at Mist Gas Field during the year.

At Mist Gas Field, 21 wells were productive during 1996. A total of 1.7 Bcf of gas was produced, less than the 2.3 Bcf of gas produced during 1995. The total value of the gas for the year was about \$3.4 million, which is higher than the \$1.8 million for 1995, because of changes in gas price.

Northwest Natural Gas Company did natural gas injection and withdrawal testing and conducted an extensive 3-D seismic program. Results will be used to develop additional underground natural gas storage at Mist Gas Field.

The final report on DOGAMI's five-year study of the oil, natural gas, and coal resource potential of the Tyee Basin was released during 1996 as Oil and Gas Investigation OGI-19.

One rule change to DOGAMI administrative rules during 1996 provided DOGAMI with the authority to permit temporary underground natural gas storage testing without use of a packer.

LEASING ACTIVITY

Oil and gas leasing activity was low in Oregon during 1996. This is a continuation of a trend of generally inactive leasing activity that began during the early 1990s. Activity included four public sales by the U.S. Bureau of Land Management (BLM) at which no bids were received for any leases on federal lands. Aside from those public sales, applications were filed and leases issued to Robert F. Harrison, Seattle, Washington, for 25,335 federal acres located in Jefferson County, Oregon. Harrison and other individuals have held leases on a block of federal lands comprising about 39,500 acres in this general area since 1977.

At year's end, 39,571 federal acres were under lease, which is an increase over the 11,760 acres at the end of 1995. Total rental income to BLM was \$35,313 for 1996.

The State of Oregon held no lease sales during 1996, and no new leases were issued. At year's end, 12 State of Oregon tracts were under lease, comprising 941 acres, which is a decline from the 25,240 acres of State of Oregon tracts under lease during 1995. Total rental income to the State of Oregon was about \$950.

Columbia County held no lease sales during the year.

DRILLING

Two exploratory gas wells were drilled in Oregon during 1996. These were the first two exploratory wells drilled since 1993, when thirteen exploratory wells and three redrills were drilled. The wells were drilled by Enerfin Resources Company of Houston, Texas. Both wells, the John Hancock 31-20-54, located in NE¼ sec. 20, T. 5 N., R. 4 W., and drilled to a total depth of 2,436 ft, and the



Shallow seismic shot hole drilled as part of the Northwest Natural Gas Company 3-D seismic program at the Mist Gas Field during 1996. The seismic data will be used to develop more underground storage for natural gas.

Table 1. Oil and gas permit activity in Oregon, 1996

Permit number	Operator, well, API number	Location	Permit activity (TD=total depth)
500	Enerfin Resources Co. Columbia Co. 22-26-65 36-009-00320	NW¼ sec. 26 T. 6 N., R. 5 W. Columbia County	Permit issued; Proposed TD 1,730 ft.
501	Enerfin Resources Co. John Hancock 31-20-54 36-009-00321	NE¼ sec. 20 T. 5 N., R. 4 W. Columbia County	Temporarily suspended; TD 2,436 ft.
502	Enerfin Resources Co. Columbia Co. 32-27-65 36-009-00322	NE¼ sec. 27 T. 6 N., R. 5 W. Columbia County	Temporarily suspended; TD 2,084 ft.

Columbia County 32-27-65, located in NE¼ sec. 27, T. 6 N., R. 5 W., and drilled to total depth of 2,084 ft, are located at the Mist Gas Field, Columbia County, and are temporarily abandoned pending further evaluation.

Enerfin Resources abandoned two depleted former producing gas wells at Mist Gas Field during 1996. These are the Columbia County 34-28-65, located in the SE¼ sec. 28, T. 6 N., R. 5 W., and the Columbia County 12-19-65, located in the NW¼ sec. 19, T. 6 N., R. 5 W.

During 1996, DOGAMI issued three permits to drill, while no permits were withdrawn or canceled during the year. Permit activity is listed in Table 1.

PRODUCTION

The Mist Gas Field was operated by Enerfin Resources and Northwest Natural Gas during 1996. During the year, 21 natural gas wells were productive at Mist Gas Field, 14 operated by Enerfin Resources and 7 by Northwest Natural Gas. This is about the same number of wells productive during 1995. Gas production for the year totaled 1.7 Bcf, which is lower than the production during 1995, when the Mist Gas Field produced 2.5 Bcf of gas.

Most of the decrease in production can be attributed to normal decline in the production from the existing wells with no new wells brought on to production during the year. The gas price during 1996 was about 20 cents per therm, an increase over the 1995 price that ranged from between four cents to eleven cents per therm until December, when the price rose to 22 cents per therm. The total value of the gas produced at Mist Gas Field was about \$3.4 million, which is higher than the \$1.8 million during 1995 because of the higher gas price. Cumulatively, the Mist Gas Field has produced about 60.0 Bcf of gas with a total value of \$116.2 million since it was discovered in 1979.

GAS STORAGE

The Mist Gas Storage Project remained fully operational during 1996. The gas storage project has nine injection-withdrawal service wells, five in the Bruer Pool and four in the Flora Pool, and 13 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 of gas 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 1996, about 4,813,386 cubic feet of gas was injected and 5,188,835 cubic feet of gas was withdrawn at the Mist Storage Project.

Northwest Natural Gas Company began work during 1996 to develop additional underground natural gas storage at the Mist Gas Field. This included natural gas injection and withdrawal testing of three former producing wells. The three wells were evaluated for injection and withdrawal rates from which data will be used to design and develop the additional underground natural gas storage. The wells that were evaluated were the Busch 14-15, located in the SW¼ sec. 15, T. 6 N., R. 5 W.; the Columbia County 14-23, located in SW¼ sec. 23, T. 6 N., R. 5 W.; and the Columbia County 23-22, located in NW¼ sec. 22, T. 6 N., R. 5 W. In addition, Northwest Natural Gas conducted an extensive 3-D seismic program whose results will be used to develop the underground storage project. The seismic program was primarily located in four sections at Mist Gas Field: secs. 22, 23, 26, and 27, T. 6 N., R. 5 W.

OTHER ACTIVITIES

DOGAMI has 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. DOGAMI Oil and Gas Investigation OGI-19, *Oil and Gas Potential of the Southern Tyee Basin, Southern Oregon Coast Range*, includes a 141-page report plus maps and support data. The study was funded by landowners in the study area and by county, state, and federal agencies in a public-private partnership. OGI-19 is the final report of an investigation of the source rock, stratigraphy, and structural framework of the Tyee Basin for those characteristics that are needed to generate and trap oil and gas. A series of maps and preliminary reports that presented a revised understanding of the geologic framework of the area had been published previously. The final report now concludes that the area has natural gas potential and presents plays for future exploration. Contact DOGAMI for a complete publication list including those for the Tyee Basin study.

The Northwest Energy Association remained active for the year and has over 100 members. At its regular monthly meetings, speakers give talks that are generally related to energy matters in the Pacific Northwest. The 1996 fall symposium was held at LaConner, Washington, and the 1997 fall symposium will be held in Portland, Oregon. For information, contact the NWEA, P.O. Box 6679, Portland, Oregon 97228.

During 1996, one change was made to DOGAMI administrative rules pertaining to oil and gas operations. The change concerns temporary testing for underground natural gas storage. It gives DOGAMI the authority to permit temporary gas storage testing into an existing well without the use of a packer, a device for separating vertical zones in a well. Copies of current statutes and administrative rules can be obtained from DOGAMI. □

OMSI opens "giant" exhibit

The Oregon Museum of Science and Industry (OMSI) has brought a west coast exclusive blockbuster to Portland. AT&T will be the title sponsor of the exhibit entitled "Giants of the Gobi," which can be seen at OMSI from March 1 through September 1, 1997. The exhibit showcases a rare and important collection of dinosaur and mammal fossils from the Gobi desert of Inner Mongolia. The collection, which contains 75 fossil specimens, including 16 complete creatures, is on loan from the Inner Mongolian Museum in Hohhot, China, and has never been seen before in the western United States.

AT&T's "Giants of the Gobi" is the largest exhibit ever staged by OMSI. The centerpiece of the exhibit, a giant sauropod, measures 25 ft tall and 85 ft long and is considered to be one of the largest assembled dinosaur fossils in the world (see cover photo). Among the other giants are a 17-ft-tall mammoth, woolly rhinoceros, *Protoceratops*, *Bactrosaurus*, *Psittacosaurus*, and *Archaeornithomimus*. Other highlights include nests, eggs, dinosaur tracks, turtles, and plants. Several specimens are shown still in matrix.

With fossils dating back from 100 million years ago to 30,000 years ago (mid-Cretaceous to late Pleistocene), the exhibit is designed to take the visitor on a journey through geologic time as well as to an authentic modern "dig" experience, both in the field and at the research laboratory. The setting created by OMSI is that of Gobi desert scenery in which the fossil site was located. The free audio tape guide leads the visitor through the experience as a member of a dig team.

As an additional experience, a working paleontology laboratory project of the Northwest Museum of Natural History Association can be seen in OMSI's Earth Science Laboratory. As Dave Taylor, director of the Association, describes it, the project shows how work on a dinosaur proceeds once it is brought in from the field. In this case, the object is a *Triceratops* skeleton, which members of the Association recovered from eastern Wyoming.

Admission to "Giants of the Gobi" is \$9.50 for adults and \$8.00 for seniors (63+) and youths (4-13). It includes an audio tape tour, admission to the museum as well as a planetarium show. Members receive their first visit free; thereafter, they pay \$3.50 for the audio tour headset. Members always have free access to all other exhibit halls.

Opening times March 1 to May 23 are 9:30 a.m. to 5:30 p.m., except on Thursdays, when closing time is 8:00 p.m. From May 24 through September 1, times will be 9:30 a.m. to 7:00 p.m. (8:00 p.m. on Thursdays). Tickets to the exhibit will be sold until 1½ hours before closing time; they are also available at Fastixx locations and at phone numbers 1-800-992-8499 or (503) 224-8499. Information on special rates for groups is available at 1-800-955-OMSI or (503) 797-4629.

OMSI can be reached by phone at (503) 797-4000. The World Wide Web address is www.omsiedu. □

December fireball lights up NW skies

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

At 6:14 a.m., December 17, 1997, the sky was clear for the first time in many weeks, and thousands of people were going to work, when a brilliant fireball appeared in the morning sky. It was seen in Oregon as far south as Salem, as far west as Clatskanie, and as far east as The Dalles. The northernmost sighting was Port Townsend in northwestern Washington.

The fireball appeared to have formed above the Chehalis/Centralia (Washington) area. It descended toward the west at an angle of about 45°. The observed duration was from three to five seconds. Most observers reported the object to be brighter than a full moon and about the size of a full moon. The head of the fireball had a fairly long tail. Many colors were reported, with most people seeing a white to green object with a yellow tail. Many reports mentioned sparks and flames in the tail. Some observers reported a bright flash as the fireball disappeared.

No sonic booms or rumbling were reported. There is no evidence that this object produced meteorites. Although events like this happen several times a month, our frequent occurrence of cloud cover lets most of them go unnoticed. Perhaps only once or twice a year will a fireball produce meteorites in the Pacific Northwest. □

DOGAMI volunteers honored

Since the Oregon Department of Geology and Mineral Industries (DOGAMI) first began to receive help through its volunteer program in 1991, volunteers have donated 7,577 hours, or 947 days, to the Department, including 1,605 hours, or 202 days, during the past year 1996.

The volunteers were honored at a recent dinner and are listed below with the hours they had donated through 1996:

Sonya Bruce (46), Esther Kennedy (132), Dorothy Blattner (138), Joan Konner (407), Phyllis Thorne (409), Phil Johnson (417), Charlene Holzwarth (459), Jan Murphy (609), Rosemary Kenney (1,120), and Archie Strong (1,246). □

MineQuest 97 announced

The Columbia Section of the Society of Mining, Metallurgy, and Exploration, Inc. (SME) will host the 1997 Pacific Northwest Metals and Minerals Conference in Spokane, Washington. The conference will be held April 23-25, 1997, at the WestCoast Ridpath Hotel. The conference theme is "MineQuest 97—Technology Updates."

The program will emphasize technology updates in the exploration, mining, processing, and reclamation aspects of the mining industry. Also included are field trips to area mines and processing plants. Get information from Andrew Berg at (509) 747-3659, e-mail: aberg@on-ramp.ior.com. □

BOOK REVIEW

by Beverly F. Vogt

Bin Rock and Dump Rock, by John Eliot Allen. Hells Canyon Publishing, 1997, soft cover, 282 pages, \$12.95

John Eliot Allen, Emeritus Professor of Geology at Portland State University, writer, one-time geologist for the Oregon Department of Geology and Mineral Industries (DOGAMI), and frequent contributor to *Oregon Geology*, died last December. Before his death, he had made arrangements to have Hells Canyon Publishing Company print his autobiography, *Bin Rock and Dump Rock*. Unfortunately he died before he saw the final printed version. Had he had seen it, he would have been delighted with it, because it is an attractive and thoroughly enjoyable book. To browse through it is to take a trip back in time to a different world where someone like John, who was willing to put heart and soul into his exciting chosen profession, was able to have a wonderful life. John Allen's love of life, family, and chosen career shines through every line of this delightful book. Reading it will be a pleasure to anyone who knew John Allen, who wants to know more about geology, who wants to learn how old-time geologists thought and acted, or who likes to read about the days when life was simpler and a field geologist could have a great time pursuing fascinating geologic questions.

The title of this autobiography came from an old miner Allen encountered in his early days with DOGAMI. Allen was doing a survey of mines in Baker County. He started to tell an old miner the technical names of all the rocks in his mine but was interrupted by the miner who said, "Confound it, sonny, this here mine has only two kinds of rock—bin rock and dump rock." Allen took the words to heart. He ignored the dump rock of his life and polished the bin rock into the "concentrates" he presents in this autobiography.

John Allen writes directly and honestly about what matters to him—scouting, his family and friends, geology, what he saw, what he did, and what he thought about it all. An inveterate list maker, he lists such details as what he bought, what he ate, what he wrote, where he lived, and what he read. These are not just Allen's lists, however, they are lists that describe the time in which he lived. In the classic diarist's tradition, he has noted the details of his experiences and thereby recreated a world.

A good geologist observes and records many details but keeps enough perspective to perceive the broad picture the details are presenting. And so it is with John Allen—he provides lots of details but also an understanding of what they are telling him about geology, his life, and the world around him. He describes the details of his geologic field adventures, the vehicles that took him out into the field and got him home again, the instruments and other equipment, including maps he used, the routes he took, the characters he met, and the people who accompanied him along the way.

He loves to find universal truths in his experiences. Take for example, some of his laws of field geology:

- "The more you know, the more you see.
- "You see only what you are looking for.
- "You can't see something you are not looking for.
- "When investigating the unknown, you do not know what you will find.
- "The geology of any area is more complex than you think it is going to be. The key outcrops and fossil localities are usually found at dusk in the most inaccessible part of the area, on the last day of the field season.
- "The weight of a hand specimen is directly proportional to the square of the distance from the car."

He writes like a master musician delighted with the capability of his instrument. No matter what aspect of his life he approaches, he has much to say about it—with flourishes. When he writes about the academic world, he takes time to describe the hierarchy and language of academe. When he describes his first car, a Model T, he lists the 10 steps to follow to get it started. In talking about professional ethics for geologists, he lists the five attributes he believes all professions have in common (a systematic body of knowledge that is consistent, professional authority recognized by clients and based on education and competence, community sanction granted by an authority beyond the client or employer, a professional culture that has common standards, and an ethical code).

The dominant theme presented in his autobiography is optimism and general belief in the essential goodness of humanity. As he says, "My lifelong policy of accepting everyone as honest and reliable *until they prove themselves otherwise* has been especially valuable. This way you don't spend your time and energy doubting and worrying about people." Instead, John took off, studied geology, explored the remote corners of the West, traveled the world, established a family that he loved as dearly as life, made numerous valued friends, started the Portland State University Department of Geology, kept records of everything, and wrote and published books and articles almost until the moment of his death. Although geology was his profession and passion, he had many other interests as well, many of which he discusses in this autobiography.

Sunny and outgoing by nature, Allen was also well disciplined. Until shortly before his death, he went each day to his office at Portland State University to write something on his beloved computer. Unlike so many geologists who love to go out and collect data and resent taking time to write up their conclusions, Allen knew that the only way to share what he had learned and keep it alive long after he had died was to "write it up." When his health was failing, he could no longer go out and observe the external world as a geologist. So he turned his geologist's observational skills inward and observed what was happening to himself. He observed the process, took good notes, described it in clinical

(Continued on page 45, Book review)

Regional Geologist looks at Newport

The letter below was written in answer to the information request of a student. The writer, George Priest, is the Regional Geologist in the Portland office of the Oregon Department of Geology and Mineral Industries. We believe it deserves sharing with our readers.

Dear Mark:

You asked for information on the geology of the Newport area for your eighth-grade paper. A short summary follows:

The rocks of the area are composed mainly of the Nye Mudstone and overlying sandstones and siltstones of the Astoria Formation. In local areas these 20- to 16-million-year-old sedimentary rocks are overlain by the 16- to 15-million-year-old lava flows of the Columbia River Basalt Group. The hard lavas resist erosion, thus forming most of the headlands (for example, Yaquina Head) and offshore sea stacks (rocks that form little islands like Otter Rock). The lavas were erupted from big fissures near the Idaho border and were of such great volume that they formed vast sheets of lava covering the plateaus of eastern Washington and northern Oregon and even traveled all the way to the ocean. The entire sequence of rocks is tilted westward, which causes some west-facing slopes underlain by weak rocks like mudstones to slide. Big landslides like the Jumpoff Joe landslide at the end of 11th Street in Newport have carried away whole neighborhoods that were built close to the edge of the west-facing cliffs.

During the Pleistocene Ice Age (1.6 million years ago to 10,000 years ago), the sea retreated and advanced as continental glaciers grew or melted during the glacial and interglacial times (we are currently in an interglacial time). Interglacial high sea stands at about 120,000 and 83,000 years ago have left prominent wave-cut platforms that are covered with partially consolidated beach and dune sands called Pleistocene marine terrace deposits. These "almost rocks" crop out at the top of most of the sea cliffs and underlie the flat topography in the main City of Newport. The porous and permeable sand deposits store ground water for water wells in the area. The deposits also erode easily, especially if not vegetated, so one should be careful not to climb on them or carve into them when visiting the beach. Homeowners with houses next to these sea cliffs will not appreciate it!

During the last 16,000 years, the continental ice sheets up in Canada and in the Arctic and Antarctic have been melting off as the climate warmed. Sea level has risen over 400 feet during that time! Just imagine the shoreline being many miles west of where it is today. Yaquina Bay was a river valley with its bottom probably 200 feet below where it is today. By about 10,000 years ago, much of the continental ice sheets had melted, and sea water had returned to the bottom of the old river valley at Newport. Over the last 10,000 years, the river has brought in sediment as sea level continued to rise, filling in the old valley and forming

Yaquina Bay. Yaquina Bay is therefore an example of drowned river valley.

The Cascadia subduction zone, a big active fault at the base of the continental slope offshore from British Columbia, Washington, Oregon, and northern California, causes earthquakes of magnitude 8–9 every 200–600 years. These earthquakes deform the sea bottom, causing the sea itself to be deformed so that great tsunamis (tidal waves) roll into the bay 15–20 minutes after these earthquakes. The tsunamis have left behind sandy layers in the marsh deposits around the edges of the Bay. These tsunami sands generally lie on buried black soils called "peat layers," which are the remains of marsh grasses that were killed when the whole area subsided a few feet during the great earthquakes. Buried peats and overlying tsunami sands are some of the main pieces of evidence that make scientists believe that the Oregon coast has experienced these very large earthquakes. The last great earthquake sent a tsunami all the way to Japan, where harbor masters recorded a 6- to 10-ft wave on January 27, A.D. 1700. Scientists hypothesize that the Cascadia subduction zone had a great earthquake at 9 p.m., January 26, A.D. 1700, that probably affected the whole Northwest coast with an earthquake approaching magnitude 9! Indian legends tell of great destruction and loss of life from the tsunami that struck the coast.

The Oregon Department of Geology and Mineral Industries warns people to head to high ground or inland if they feel an earthquake on the coast. The earthquake could mean that a big tsunami will hit within 20–30 minutes on the north coast, 15–20 minutes on the central coast, and 5–10 minutes on the south coast. Waves will continue to strike for several hours after the first one hits; sometimes these waves are nearly as big as the first one, so don't go back to the beach until an official gives you the "all clear."

Best regards,
Dr. George R. Priest
Regional Geologist

Nevada offers symposium in 2000

A symposium entitled "Geology and Ore Deposits 2000—The Great Basin and Beyond" will be held at John Ascuaga's Nugget in Reno/Sparks, Nevada, May 15–18, 2000. It is sponsored by the Geological Society of Nevada, the Nevada Bureau of Mines and Geology, and the U.S. Geological Survey.

The symposium will feature oral and poster presentations, field trips, workshops and short courses, trade exhibits, and social events. The metallogeny and ore deposits of the Great Basin will be the focus of this symposium with contributions from other areas of the American Cordillera.

More information is available from the Geological Society of Nevada at P.O. Box 12021, Reno, NV, 89510-2021, phone (702) 323-3500, FAX (702) 323-3599.

—Geological Society of Nevada news release

DOGAMI library now holds over 100 seismic site hazard reports

On May 1, 1994, an amendment took effect that changed the Oregon Structural Specialty Code, a part of the Oregon Administrative Rules, by ordering that a copy of each legally required "seismic site hazard report" should be "submitted by the applicant to the Department of Geology and Mineral Industries." The Department is thus building a collection of site-specific seismic hazard reports that are on file and accessible to the public for inspection.

This collection has now accumulated over 100 reports. The following abbreviated list is derived from the records in the library's bibliographic database and includes the authors of the reports, the sites investigated, and the 7½-minute quadrangle (Q.) in which the site is located:

- AGI Technologies: Grande Ronde Hospital, La Grande. La Grande Q.
- Proposed Sumitomo Sitix site, Newberg. Newberg Q.
- Proposed new fire station, 6600 SE Lake Road, Milwaukie. Gladstone Q.
- AGRA Earth & Environmental: Liberty Northwest Insurance Building, Portland. Portland Q.
- Metropolitan Exposition Center expansion, Portland. Portland Q.
- Proposed Siltec silicon facility, Fairview Industrial Park, Salem. Salem West Q.
- Bechtel Power Corporation: Hermiston Generating project. Hermiston Q.
- Revised SHAKE analysis report, Umatilla Generating project, Hermiston. Hermiston Q.
- Braun Intertec Corporation: Proposed Jesuit High School addition, SW Beaverton-Hillsdale Hwy. and SW Apple Way, Portland. Beaverton Q.
- Proposed new fire station, Tomahawk Island Drive, Hayden Island, Portland. Portland Q.
- Carlson Testing: Butte Creek Scout Ranch, 13462 South Butte Creek Road, Clackamas County. Willhoit Q.
- Crater Schools site, Yamhill County. Newberg Q.
- Far South Middle School site, Liberty and Davis Roads, Marion County. Salem West Q.
- Tigard United Methodist Church, 9845 SW Walnut Place, Tigard. Beaverton Q.
- CH2M Hill: Hewlett-Packard Building 9, Corvallis. Riverside Q.
- Dames & Moore: Bank parking structure, Eugene. Eugene East Q.
- Central utilities plant expansion, Portland International Airport. Mount Tabor Q.
- City Garage parking structure, Eugene. Eugene East Q.
- Groundwater pump station/interstate facility, Portland. Camas/Portland Qs.
- Hospital addition, Providence Milwaukie Hospital. Lake Oswego Q.
- New police and fire station, Cornelius. Forest Grove Q.
- Pine Grove fire station addition, Hood River. White Salmon Q.
- Planned centers for the humanities and visual arts, Lewis and Clark College, Portland. Lake Oswego Q.
- Proposed Firwood Road fire station, Sandy. Sandy Q.
- Proposed parking structure and helipad, Providence Portland Medical Center. Mount Tabor Q.
- Dames & Moore; Fujitani Hiltz & Associates: New fueling facilities, Portland International Airport. Mount Tabor Q.
- David J. Newton Associates: Impact site for proposed new elementary school, N.E.C. of Monroe and Spruce Street, Cannon Beach. Tillamook Head Q.
- New elementary school, SE 129th Avenue and Masa Lane, Clackamas County. Gladstone Q.
- New Taft High School, High School Drive at SE Spyglass Ridge Drive, Lincoln City. Lincoln City Q.
- Oregon City United Methodist Church, 18955 South End Road, Oregon City. Oregon City Q.
- Proposed Emmanuel Temple Church, North Missouri Avenue at North Sumner Street, Portland. Portland Q.
- Proposed expansion, Terpenning Recreation Center, NW 158th Ave. and SW Walker Road, Beaverton. Linnton Q.
- Proposed Hillsboro Union High School, SW Johnson Street and SW 234th Avenue, Hillsboro. Hillsboro Q.
- Proposed new Newport Middle School. Newport North Q.
- Proposed recreation/aquatic center, Southwest 125th Avenue at Southwest Conestoga Road, Beaverton. Beaverton Q.
- Proposed Waldport Elementary School, Crestline Drive. Waldport Q.
- RV site for proposed new elementary school, 345 Elk Creek Road, Cannon Beach. Tillamook Head Q.
- Silverton Main Fire Station, 819 Railway Drive, Silverton. Silverton Q.
- Springfield High School additions, 7th Street at "G" Street, Springfield. Eugene East Q.
- Springfield Middle School, South 32d Street and Jasper Road, Springfield. Springfield Q.
- Student services building, Portland Community College, Cascade Campus. Portland Q.
- Thurston High School additions, 58th Street at "A" Street, Springfield. Springfield Q.
- Toledo High School additions, 1800 NE Sturdevant Road, Toledo. Toledo North Q.
- Waldport High School Gymnasium, Waldport Q.
- Ebasco: Seismic hazards evaluation, Coyote Springs power generation project, Boardman. Boardman Q.
- Site densification report, Coyote Springs cogeneration facility, Boardman. Boardman Q.
- Foundation Engineering: Dallas ambulance facility. Dallas Q.
- Fujitani Hiltz and Associates, Inc.: Ambulance Service Building, NW 6th and Coast Streets, Newport. Newport North Q.
- New East Precinct, Portland. Mount Tabor Q.
- Proposed Inverness Jail expansion, Portland. Mount Tabor Q.
- GeoEngineers: Geotechnical and seismic services, Proposed Asahi [Glass] and Tokai [Carbon] developments, Hillsboro. Hillsboro Q.
- Milwaukie, Oregon, Stake Center, Cason Road, Gladstone, Oregon. Gladstone Q.
- Proposed John's Landing office building, Portland. Lake Oswego Q.
- Seismic hazard report, Asahi [Glass] and Tokai [Carbon] sites, Hillsboro. Hillsboro Q.
- Geotechnical Resources, Inc.: Act III theaters, Division Street Cinema, Portland. Camas Q.
- Fujitsu facility additions, Gresham. Camas Q.
- Horton Reservoir No. 2, S Day Road, West Linn. Canby Q.
- IDT facility, Hillsboro. Hillsboro Q.
- Intel D1B-Site X, Hillsboro. Hillsboro Q.
- Proposed BOC industrial gas facility, Hillsboro. Hillsboro Q.
- Proposed Dawson Creek Development electronics manufacturing facility, Hillsboro. Hillsboro Q.
- Proposed DYNIC USA Corp. facility, Hillsboro. Hillsboro Q.
- Reed College Auditorium, Portland. Lake Oswego Q.
- Revised report, Broadway and Washington parking structure and hotel, Portland. Portland Q.
- Golder Associates, Inc.: Klamath Cogeneration Project, Klamath Falls. Klamath Falls Q.
- HongWest & Associates: Molalla United Methodist Church. Molalla Q.
- Kleinfelder, Inc.: Phase I geotechnical study, Oregon Department of Corrections, BLM site, Mitchell. Mitchell Q.
- Boeing site, Boardman. Crow Butte Q.
- Bootsma site, Baker City. Baker City Q.
- Collins site, Lakeview. Lakeview NW Q.
- Dammash site #CK-WS-1, Wilsonville. Sherwood Q.
- Dammash site #CK-WS-2, Wilsonville. Sherwood Q.
- Dover Lane site, Madras. Culver Q.
- Hay Field site, Salem. Salem East Q.
- Klamath Hills site, Klamath Falls. Lost River Q.
- Martin Dairy site, Cave Junction. Cave Junction Q.
- Meadow View site, Eugene. Junction City Q.
- Orchard site, Medford. Gold Hill Q.
- Pasture (Kunze Road) site, Boardman. Boardman Q.
- Port of Tillamook site. Tillamook Q.
- Port of Umatilla site. Umatilla Q.
- Rigdon site, Oakridge. Oakridge Q.
- Roseburg Resources site, Medford. Sams Valley Q.
- Steel Bridge site, Willamina. Grand Ronde Q.
- Wilsonville Tract, Wilsonville. Sherwood Q.
- Zemke site, Madras. Buck Butte Q.
- Mark V. Herbert and Associates, Inc.: Deschutes County Public Safety Center, N. Hwy 97 adjacent to existing Criminal Justice Center, Bend. Bend Q.
- New Gymnasium, Dufur School, Wasco County. Dufur East Q.
- Marquess and Associates, Inc.: Additions to Hedrick and McLoughlin Middle Schools, Medford 549C School District. Medford East/Medford West Qs.

(Continued on page 45, Library)

Books featured at the Nature of the Northwest Information Center

by Center Manager Don Haines

Introduction to Earthquake Retrofitting—Tools and Techniques, by Building Education Center, 77 pages, \$9.95. Many wood frame houses may not be strong enough to withstand a major earthquake. This step-by-step manual illustrates tools and techniques needed to do strengthening projects. The manual is designed for the beginners and do-it-yourselfers. Each step is illustrated with photographs.

Bin Rock and Dump Rock—Recollections of a Geologist, by John Eliot Allen, 282 pages, \$12.95, Hells Canyon Publishing (reviewed in this issue). Founder of Portland State University's Geology Department and former geologist for DOGAMI, Allen offers a view of a geologist's life and mind. The book contains poetry and anecdotes, along with some excerpts from his "Time Travel" series in *The Oregonian*.

Northwest Exposures—A Geologic Story of the Northwest, by David Alt and Donald W. Hyndman, 443 pages, \$24, Mountain Press. This new book by the authors of *Roadside Geology of Oregon* is not written as a road log the way many of their previous publications were but presents a nontechnical overview of Pacific Northwest geology.

Gold Mining in Oregon, by Bert Weber, 332 pages, \$29.95, Webb Research Group. This book reprints most of the text from DOGAMI's *Gold and Silver in Oregon* (Bulletin 61), which is now out of print. The separate maps from Bulletin 61 are not included. *Gold Mining in Oregon* describes the mining activity and many of the historic mines in Oregon.

Hiking Oregon's Geology, By Ellen Morris Bishop and John Eliot Allen, 221 pages, \$16.95, The Mountaineers. A new hiking guide that contains 51 hikes to some of the most scenic and geologically interesting places in Oregon.

All publications are available from the Center. VISA and Mastercard orders are accepted. For shipping, include \$3.00 per destination. □

AEG calls for technical papers

The Oregon Section of the Association of Engineering Geologists (AEG) will host the national 40th Annual Meeting of the organization September 30 to October 4, 1997, at the Portland Hilton Hotel. For this meeting, which has been titled "Converging at Cascadia," AEG invites submittals for paper and poster presentations.

The list of suggested topics includes seismic hazards, landslides and slope stability, coastal engineering, environmental investigations, field and laboratory testing, groundwater investigations/modeling, water-supply studies, landfill technology, stream restoration, fluvial geomorphology, transportation geology, and general engineering geology topics. Topics other than those suggested will be considered, and presentations based on case histories are encouraged. Presentations will be limited to 20 minutes each.

Abstracts should be no longer than 250 words and must be submitted by May 15, 1997. Submittals via e-mail are preferred and should be addressed to aegjuliek@aol.com; mailed abstracts are to be sent to AEG'97 c/o Julie Keaton, 130 Yucca Drive, Sedona, AZ 86336-3222, whose phone number is (520) 204-1553, FAX (520) 204-5597.

For further information, contact

- Gary Peterson, Chairman, Annual Meeting, inquiries and general information, phone (503) 635-4419, e-mail: garyp@squier.com;
- Ed Stearns, Chairman, Technical Sessions, (503) 661-0462, e-mail: 73564.3251@compuserve.com;
- Dave Michael, Chairman, Exhibitors and Sponsors, (503) 359-7448, e-mail: dave.l.michael@state.or.us.

DOGAMI geotechnical engineer Yumei Wang will chair the theme symposium on October 2 and focus on Pacific Northwest earthquake issues, including earthquake risk, seismicity, earthquake sources, current research on hazards, and an overview of attenuation relationships. Speakers will include Bruce Bolt (University of California at Berkeley), Ivan Wong (Woodward-Clyde Federal Services), and Dave Keefer, Steve Obermeier, Silvio Pezzopane, Kaye Shedlock, and Ray Wells of the U.S. Geological Survey. □

(Book review—continued from page 42)

detail, including the frustration and methods he used to fight to keep himself functioning. He was not one to give up easily.

To John Allen, life was to be experienced fully. He did his best to do that, and he kept good records along the way, many of which became part of this book. It may be purchased from the Nature of the Northwest Information Center and most other local booksellers. □

(Library—continued from page 44)

- Ashland Community Hospital additions. Ashland Q.
- PacRim Geotechnical, Inc.: Proposed Ronler Acres fire station, 229th Street and Evergreen Road, Hillsboro. Hillsboro Q.
- Patrick B. Kelly: Proposed new fire station, NE corner of Sunset and Spruce Streets, Cannon Beach. Tillamook Head Q.
- Redmond & Associates: Proposed North Harbor site, NE Marine Drive, Portland. Portland Q.
- Proposed Opengate Church of the Nazarene, Keizer (Marion County). Mission Bottom Q.
- Schlicker & Associates: Proposed theater site, West 7th and Snipes, The Dalles. The Dalles South Q.
- Siemens & Associates: La Pine Fire Station, La Pine. La Pine Q.
- Spray water tanks, Spray (Wheeler County). Spray Q.
- Squier Associates: Airport Embassy Suites Hotel, Portland. Mount Tabor Q.
- Exhibit G in Hermiston power project, application for site certificate. Hermiston Q.
- West Coast Geotech: New Parkrose community center/high school, Portland. Mount Tabor Q.
- Wright/Deacon & Associates: The Blazers Boys and Girls Club, NE MLK Blvd. and Roselawn St., Portland. Portland Q.

The library also contains some site-specific seismic reports dated before the 1994 rule change and other site-specific reports related to landslides and mined land reclamation projects. Part of the library's mission is an increased attention to reports usually referred to as "gray literature"—collecting them and making them accessible to a wider audience. □

DOGAMI PUBLICATIONS AND RELEASES

Released January 22, 1997

Description of economic models that forecast the demand for construction aggregates in Oregon, by Robert M. Whelan. Open-File Report O-96-03, 1 CD-ROM disk, \$30.

Former DOGAMI Mineral Economist Whelan, now with ECONorthwest in Portland, has developed an aggregate demand model for each of Oregon's counties with a forecast that extends through the year 2050.

The aggregate model includes forecasts of population, income, and construction of roads, housing, and 23 other categories such as schools, bridges, and airports. Included on the CD-ROM are a text describing use of the model and forecasts of aggregate consumption for 45 end uses such as maintenance of asphalt roads, building of low-rise office buildings, and maintenance of railways. Population data that extend from 1960 to 2050 include population projections broken into age categories and number of households in each county and are based on census data from the U.S. Bureau of the Census, the Portland State University Center for Population Research and Census, and forecasts by the author. Construction statistics came from F.W. Dodge.

Oregon is the first state to use econometric analysis and sophisticated modeling techniques to project aggregate demand. The report is the only source in Oregon of population and construction forecast to 2050 that is available at the county level. It will be useful for planners who need to know future demand for aggregate, for mining companies seeking long-term projections of sales, and for people who need information on outlook for construction in counties. This model can also be used as a template to build a model for aggregate demand in other parts of the United States and other countries.

The model now released as Open-File Report O-96-03 was used earlier by Whelan to prepare DOGAMI Special Paper 27, *An Economic Analysis of Construction Aggregate Markets and the Results of a Long-Term Forecasting Model for Oregon*.

Released March 7, 1997

Mist Gas Field Map, 1997 edition. Open-File Report O-97-01, 1 map sheet, 40 p. text, \$8.

The map of the Mist Gas Field in Columbia and Clatsop Counties that has been published since 1981 has been updated over its 1996 edition. The release includes the map and a production summary for 1993 through 1996.

The map shows the field divided into quarter sections. It displays location, status, and depth of all existing wells and serves as a basis for locating any new ones. It also shows the areas and wells that are used for storage of natural gas. The production summary includes well names, revenue generated, pressures, production, and other data. The map and accompanying data are useful tools for administrators and planners, as well as explorers and producers of natural gas.

The Mist Gas Field Map is also available, on request, in digital form (price \$25). It is offered in three different CAD formats (.DGN, .DWG, and .DXF), all on one 3½-inch high-density diskette formatted for DOS, for use by different software systems.

A cumulative report of past production at the Mist Gas Field between 1979 and 1992 is available in a separate release under the title *Mist Gas Field Production Figures* as DOGAMI Open-File Report O-94-6 (price \$5).

The following releases are available for inspection in the library of the DOGAMI Portland office. They are not published in multiple copies and are not for sale but limited to library access only. Photocopies may be obtained at cost:

Released January 27, 1997

Tsunami Hazard Map of the Siletz Bay Area, Lincoln County, by George R. Priest. Open-File Report O-95-06, scale 1:4,800.

The tsunami hazard map for the Siletz Bay area consists of three map sheets covering the coastal area from D River in the north to Gleneden Beach in the south. On an orthophoto map base, different lines mark four levels of inundation hazard, from negligible/low to low/moderate, to moderate/high to high/extreme.

The hazard map was prepared in a cooperative effort by scientists from DOGAMI, the Oregon Graduate Institute of Science and Technology, and Portland State University. It represents a pilot study of detailed tsunami inundation hazard and aided the work that produced the tsunami hazard zone maps DOGAMI Open-File Reports O-95-09 through O-95-67 for the implementation of Senate Bill 379 of the 1995 Oregon Legislative Session.

Released January 31, 1997

Geologic Map of the Malheur Butte Quadrangle, Malheur County, Oregon, by Ian P. Madin and Mark L. Ferns in cooperation with the Oregon Department of Corrections. Open-File Report O-97-02, scale 1:24,000, 13 p. text.

The new map includes the geologic map and two geologic cross sections as well as a separate, 13-page text. The Malheur Butte quadrangle covers an area near the Idaho border just west of the City of Ontario and includes a portion of the Malheur River at its southern end and Jacobsen Gulch at its northern end. The text contains explanations of the rock units presented on the map, the geologic history of the area, geologic structure and seismic hazards, and geologic resources. Sand and gravel, used for aggregate in the local construction industry, are the main mineral resources mined in the quadrangle. Potential energy resources include natural gas and geothermal energy.

The map was prepared specifically to evaluate possible earthquake hazards in the quadrangle. The Malheur fault zone, the major complex of faults in the quadrangle, has probably not been active since the middle Pleistocene and is not currently active. □

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

Price☑

GMS-75 Portland 7½' quadrangle, Multn., Wash., Clark Counties. 1991	7.00
GMS-76 Camas Valley 7½' quadrangle, Douglas and Coos Counties. 1993	6.00
GMS-77 Vale 30×60 minute quadrangle, Malheur County. 1993	10.00
GMS-78 Mahogany Mountain 30×60 minute quadrangle, Malheur C. 1993	10.00
GMS-79* Earthquake hazards, Portland 7½' quad., Multnomah C. 1993	20.00
GMS-80* McLeod 7½' quadrangle, Jackson County. 1993	5.00
GMS-81* Tumalo Dam 7½' quadrangle, Deschutes County. 1994	6.00
GMS-82* Limber Jim Creek 7½' quadrangle, Union County. 1994	5.00
GMS-83* Kenyon Mountain 7½' quadrangle, Douglas/Coos Counties. 1994	6.00
GMS-84* Remote 7½' quadrangle, Coos County. 1994	6.00
GMS-85* Mount Gurney 7½' quadrangle, Douglas/Coos Counties. 1994	6.00
GMS-86* Tenmile 7½' quadrangle, Douglas County. 1994	6.00
GMS-87* Three Creek Butte 7½' quadrangle, Deschutes County. 1996	6.00
GMS-88* Lakecreek 7½' quadrangle, Jackson County. 1995	8.00
GMS-89* Earthquake hazards, Mt. Tabor 7½' quad., Multnomah C. 1995	10.00
GMS-90* Earthquake hazards, Beaverton 7½' quad., 1995	10.00
GMS-91* Earthquake hazards, Lake Oswego 7½' quad., 1995	10.00
GMS-92* Earthquake hazards, Gladstone 7½' quad., 1995	10.00
GMS-93* Earthquake hazards, Siletz Bay area, Lincoln County, 1995	20.00
GMS-94* Charleston 7½' quadrangle, Coos County. 1995	8.00
GMS-97* Coos Bay 7½' quadrangle, Coos County. 1995	6.00
GMS-98* Dora and Sitkum 7½' quadrangles, Coos County. 1995	6.00
GMS-99* Tsunami hazard map, Siletz Bay area, Lincoln County. 1996	6.00
GMS-100* Earthquake hazard maps for Oregon. 1996	8.00
GMS-101* Steelhead Falls 7½' quad., Deschutes/Jefferson Co. 1996	7.00
GMS-104* Earthquake hazards, Linnton 7½' quad., Multn./Wash. Co. 1996	10.00
GMS-105* Earthquake hazards, Salem East/West 7½' quads. 1996	12.00

SPECIAL PAPERS

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

OIL AND GAS INVESTIGATIONS

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

OREGON GEOLOGY

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

Periodicals postage
paid at Portland, OR

AVAILABLE DEPARTMENT PUBLICATIONS (continued)

BULLETINS

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

MISCELLANEOUS PAPERS

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

SHORT PAPERS

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

MISCELLANEOUS PUBLICATIONS

Hiking Oregon's geology, E.M. Bishop and J.E. Allen, 1996	16.95
Assessing earthquake hazards in the Pac. NW (USGS Prof. Paper 1560)	25.00
Relative earthquake hazard map, Portland quadrangle (DOGAMI/Metro), 1993, with scenario report (add \$3.00 for mailing)	10.00
Geology of Oregon, 4th ed., E.L. and W.N. Orr and E.M. Baldwin, 1991, published by Kendall/Hunt (add \$3.00 for mailing)	29.95
Geologic map of Oregon, G.W. Walker and N.S. MacLeod, 1991, published by USGS (add \$3.00 for mailing)	11.50
Geological highway map, Pacific Northwest region, Oregon, Washington, and part of Idaho (published by AAPG). 1973	8.00
Oregon Landsat mosaic map (published by ERSAL, OSU). 1983	11.00
Mist Gas Field map, rev. 1996, with 1993-95 production figs. (OFR O-96-1)	8.00
Digital form of map (CAD formats .DGN, .DWG, .DXF), 3 1/4-in. diskette	25.00
Mist Gas Field production figures 1979 through 1992 (OFR O-94-6)	5.00
Northwest Oregon, Correlation Sec. 24. Bruer & others, 1984 (AAPG)	6.00
Oregon rocks and minerals, a description. 1988 (OFR O-88-6)	6.00
Mineral information layer for Oregon by county (MILOC), 1993 update (OFR O-93-8), 2 diskettes (5 1/4-in., high-density, MS-DOS)	25.00
Directory of mineral producers, 1993 update, 56 p. (OFR O-93-9)	8.00
Geothermal resources of Oregon (published by NOAA). 1982	4.00
Mining claims (State laws governing quartz and placer claims)	Free
Back issues of <i>Oregon Geology</i>	3.00

Separate price lists for open-file reports, tour guides, recreational gold mining information, and non-Departmental maps and reports will be mailed upon request. GMS maps marked with an asterisk (*) are available in digital form on diskette (geological information only).

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

ORDER AND RENEWAL FORM

Check desired publications in list above or indicate how many copies and enter total amount below. Send order to **The Nature of the Northwest Information Center, Suite 177, 800 NE Oregon Street, Portland, OR 97232-2162**, or to FAX (503) 731-4066. If you wish to order by phone, have your credit card ready and call (503) 872-2750. Payment must accompany orders of less than \$50. Payment in U.S. dollars only. Publications are sent postpaid. All sales are final. Subscription price for *Oregon Geology*: \$10 for 1 year, \$22 for 3 years.

Renewal ___ / new subscription ___ to *Oregon Geology*: 1 year (\$10) or 3 years (\$22) \$ _____
Total amount for publications marked above: \$ _____
Total payment enclosed or to be charged to credit card as indicated below: \$ _____

Name _____
Address _____
City/State/Zip _____

Please charge to Visa ___ / Mastercard ___, account number: _____

Expiration date: _____

Cardholder's signature _____

OREGON GEOLOGY

published by the
Oregon Department of Geology and Mineral Industries



VOLUME 59, NUMBER 3

MAY/JUNE 1997



IN THIS ISSUE:

COSEISMIC PALEOLIQUEFACTION EVIDENCE IN THE CENTRAL CASCADIA MARGIN

OREGON GEOLOGY

(ISSN 0164-3304)

VOLUME 59, NUMBER 3 MAY/JUNE 1997

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

Governing Board

Jacqueline G. Haggerty, Chair Enterprise
Donald W. Christensen Depoe Bay
John W. Stephens Portland

State Geologist Donald A. Hull
Deputy State Geologist John D. Beaulieu
Publications Manager/Editor Beverly F. Vogt
Production Editor Klaus K.E. Neuendorf
Production Assistants Geneva Beck
Kate Halstead

Main Office: Suite 965, 800 NE Oregon Street # 28, Portland 97232, phone (503) 731-4100, FAX (503) 731-4066.

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

Mark L. Ferns, Regional Geologist.

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

Thomas J. Wiley, Regional Geologist.

Mined Land Reclamation Program: 1536 Queen Ave. SE, Albany 97321, phone (541) 967-2039, FAX (541) 967-2075.

Gary W. Lynch, Supervisor.

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

Periodicals postage paid at Portland, Oregon. Subscription rates: 1 year, \$10; 3 years, \$22. Single issues, \$3. Address subscription orders, renewals, and changes of address to *Oregon Geology*, Suite 965, 800 NE Oregon Street # 28, Portland 97232. **POSTMASTER: Send address changes to *Oregon Geology*, Suite 965, 800 NE Oregon Street # 28, Portland 97232-2162.**

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

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

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

Permission is granted to reprint information contained herein. Credit given to the Oregon Department of Geology and Mineral Industries for compiling this information will be appreciated. Conclusions and opinions presented in articles are those of the authors and are not necessarily endorsed by the Oregon Department of Geology and Mineral Industries.

Cover photo

Oregon coast south of Coquille Point and the city of Bandon in Coos County. This Oregon Department of Transportation photo from about 1970 shows one example of some 25 mi of marine terrace exposures that were examined for evidence of liquefaction related to earthquakes in the past. Some sites mentioned in the article beginning on the next page are located north and south of this particular terrace.

Oregon tsunami hazard signs officially adopted by California, Washington, Alaska, and Hawaii

Undersea earthquakes can cause tsunamis. These seismic sea waves have hit the coast of the Pacific Northwest in the past and will again in the future. Coastal residents and visitors have to be alerted to the hazard so they know what to do to protect themselves.

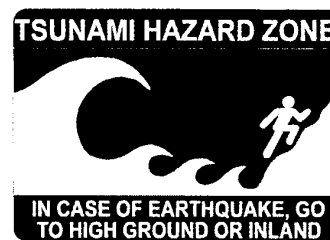
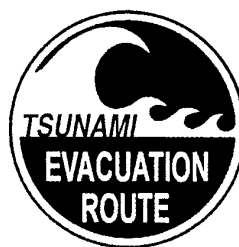
In 1994, representatives from the Oregon Department of Geology and Mineral Industries, Department of Transportation, Land Conservation and Development, Parks and Recreation, and Oregon State University Extension Sea Grant searched for an international warning symbol for tsunamis and could not find one.

So they asked Oregon State University Extension and Experiment Station Communications artist Tom Weeks to make one, and he created the bright blue tsunami hazard zone and tsunami evacuation route signs that are now showing up all along the Oregon coast.

At its March 4, 1997, meeting in Seattle, the Tsunami Hazard Mitigation Federal/State Steering Group voted unanimously to adopt the Oregon signs as official tsunami hazard zone and evacuation route signs for California, Washington, Alaska, and Hawaii. This means that anyone visiting the beaches in any of those states will see the same signs warning them of this hazard.

The blue-and-white reflective signs are manufactured by the Oregon Department of Transportation and come in several sizes. The round evacuation route sign features a tsunami wave and is available in 12-, 18-, and 24-inch diameter sizes. A second sign with a white arrow on a blue background is placed below the evacuation route sign to show which way to go to safely escape a tsunami.

The rectangular tsunami hazard zone sign shows a person running up a hill to escape the tsunami wave and says, "In case of earthquake, go to high ground or inland." The hazard zone sign, which is to be placed in low-lying areas that are vulnerable to tsunamis, also comes in three sizes: 15×12, 22½×18, and 30×24 inches. Signs may be placed only in locations agreed upon by local and/or state governmental authorities and may be purchased by calling Orville Gaylor, Oregon Department of Transportation, 503-986-3603. □



Coseismic paleoliquefaction evidence in the central Cascadia margin, USA

by Curt D. Peterson, Portland State University, Portland, Oregon 97207-0751; and Ian P. Madin, Oregon Department of Geology and Mineral Industries

ABSTRACT

Approximately 40 km of late Pleistocene marine terrace exposures on the coasts of Oregon and Washington were surveyed for evidence of coseismic paleoliquefaction. Clastic dikes and sills and other fluidization features are reported from 25 localities that are screened for likely seismic origins of fluidization. At least 11 of the localities demonstrate erosional truncation and burial of the fluidization features, implying that corresponding paleoliquefaction was syndepositional with the marine highstands. Features interpreted to reflect strong shaking include cobble plumes (2 sites), lateral spreads (2 sites), and large clastic dikes at least 20 cm wide (10 sites).

Inland from the coast, late Holocene deposits of the upper Columbia River valley (Portland to Bonneville) were surveyed for paleoliquefaction evidence that might correspond to the proposed A.D. 1700 Cascadia earthquake records reported for the lower Columbia River valley. About 1 km of cutbank exposures from eight islands was examined for evidence of late prehistoric and/or historic liquefaction in the upper Columbia River valley. All but one island locality showed evidence of small clastic dikes (generally 3–6 cm maximum width) in late prehistoric deposits but no apparent fluidization in surficial “historic” deposits.

The age of the fluidization event(s) in the upper river valley is bounded by upper radiocarbon dates from two islands (250 ± 70 and 260 ± 50 RCYBP [radiocarbon years before present]) and by lower, dike-intruded “tephra” layers (410 ± 70 RCYBP). These fluidization features are tentatively correlated to paleoliquefaction in the lower Columbia River that has been attributed to the last Cascadia earthquake, circa A.D. 1700. If verified, these correlations would extend the known liquefaction from a Cascadia subduction-zone earthquake to a distance of at least 150 km due east from the coast, along the Columbia River.

INTRODUCTION

The potential for strong ground motion associated with interplate earthquakes in the Cascadia margin (Figure 1) has been widely debated. A lack of consensus on this issue has led planners to rely on probabilistic models based on a range of earthquake scenarios (Geomatrix Consultants, Inc., 1995). Another approach to estimating the potential strength of shaking is provided by the geologic record of paleoliquefaction. Local ground accelerations and duration of sufficient magnitude to damage unreinforced structures should also produce clastic dikes and other similar features

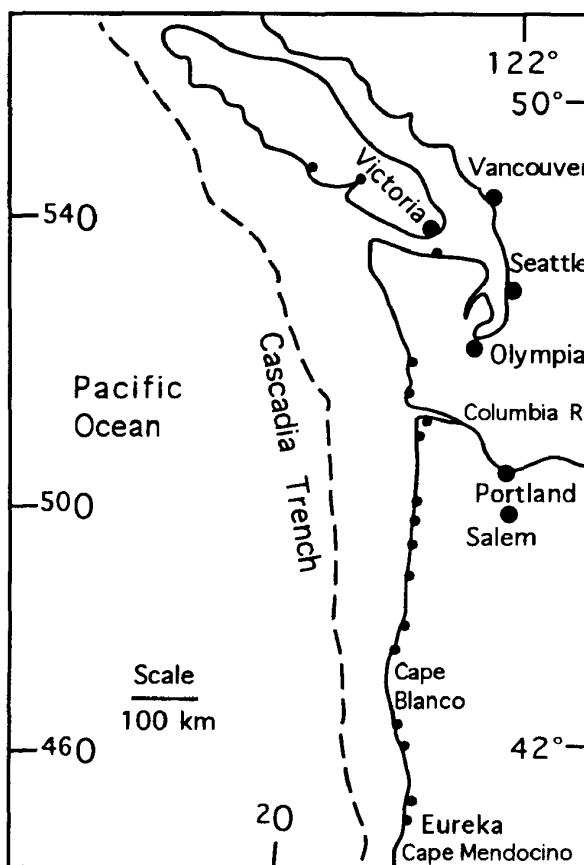


Figure 1. Map showing the Cascadia margin from Vancouver Island to Cape Mendocino, including the trench (dashed line), shoreline (solid line), Columbia River (solid line), major cities (large solid circles), and smaller coastal cities (small solid circles).

in susceptible deposits (Youd, 1991). A lack of such features would argue against, but not rule out, strong shaking during the period of record. In this regard, paleoliquefaction evidence serves as an indicator of the strength of prehistoric ground motion.

It is possible, but more difficult, to use paleoliquefaction evidence to confirm the magnitude of earthquakes in early historic time (Saucier, 1989; Tuttle and Seeber, 1991; Obermeier, 1996). This requires discrimination between fluidization from coseismic and aseismic mechanisms. This is aided by (1) ruling out depositional environments that foster rapid autocompaction or hydraulic pumping, and (2) establishing spatial trends in the distribution of fluidization

features that correspond to historic seismic sources (Obermeier, 1996). Peak ground accelerations and corresponding soil liquefaction should diminish with increasing distance from the earthquake epicenter. Site-specific conditions of ground motion amplification and deposit susceptibility to fluidization can strongly influence the local development of coseismic liquefaction (National Research Council, 1985). Therefore, ground motion attenuation must be established over large distances to rule out local effects from wave focusing and site amplification.

Paleoliquefaction analysis of prehistoric earthquakes can be a difficult undertaking in settings that contain multiple earthquake sources. For example, subduction zones, such as the Cascadia subduction zone (CSZ) can include interplate (megathrust) sources, deep intraplate (Benioff-Wadati zone) sources, and shallow upper plate (crustal) sources (Geomatrix Consultants, Inc., 1995). These factors limit the use of paleoliquefaction evidence to independently establish the magnitude of prehistoric earthquakes in subduction zones. On the other hand, a lack of substantial fluidization evidence in susceptible deposits would provide a strong argument against large-magnitude earthquakes from any source within the subduction zone.

In this paper, we report on the nature, scale, and distribution of paleoliquefaction features in late Quaternary coastal and fluvial-tidal deposits of the central Cascadia margin (Figure 1). These features are observed in late Pleistocene marine terraces of the Oregon and southern Washington coasts (Peterson and Madin, 1992) and in latest Holocene deposits that are exposed in island cutbanks of the Columbia River (Obermeier and others, 1993; Atwater, 1994; Siskowic and others, 1994; Obermeier, 1995). The Pleistocene marine terraces range from 60 to 130 km in distance from the deformation front (base of the continental slope), as a function of their position on the coast. The Columbia River paleoliquefaction sites range from 30 to 150 km inland from the coast or about 150–260 km landward of the deformation front.

The fluidization features observed in the late Pleistocene coastal terraces have been analyzed for size, nature of source beds, and site-specific criteria to help discriminate between coseismic and aseismic origins. The late Holocene liquefaction sites in the Columbia River deposits have been analyzed for potential correlation to the last Cascadia dislocation event at about A.D. 1700. The results of these analyses are used to test whether strong shaking associated with large-magnitude earthquakes (M_W 8 range) can be discounted in the Cascadia subduction zone on the basis of the existing paleoliquefaction evidence.

BACKGROUND

Sediment fluidization and seismic liquefaction

Fluidization of saturated sediments occurs when unconsolidated grains in source beds are compacted into denser packing structures. The escaping pore fluid raises hydrostatic pressure, thereby locally fluidizing the unconsoli-

dated deposits. Particle resettlement in source beds can occur from overburden pressure or strong gradients in pore pressure (aseismic liquefaction) or from cyclic shear stress through shaking (coseismic liquefaction). Sand deposits are generally more susceptible to fluidization than either gravel or cohesive mud (Seed and Idriss, 1982; Seed and others, 1985; Stokoe and others, 1988). Finally, the effects of fluidization are often most apparent directly under low-permeability capping layers (e.g., mud), where ascending pore-pressure fronts are locally enhanced (Figure 2; Fiegel and Kutter, 1994).

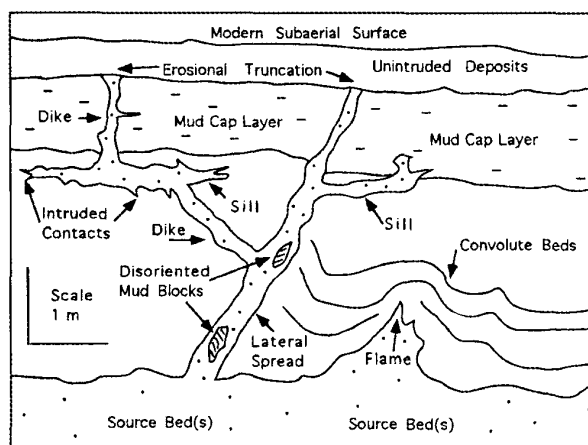


Figure 2. Drawing of subsurface fluidization features including clastic dikes and sills and flames. Internal structures include intruded contacts with host deposit and disoriented mud blocks in sandy matrix. Fluidization features such as clastic sills are often enhanced under thin capping deposits of mud overlying thick source beds of sand.

The factors that favor the development of fluidization features include (1) shallow overburden, (2) thin capping layers of impermeable deposits, and (3) thick source beds of well-sorted sand below groundwater level. On the other hand, the development of fluidization discharge features is inhibited by high lithologic pressure, containment of elevated pore pressure, and small volumes of available pore fluids. Even under "favorable" conditions the development of clastic dikes and sills can vary substantially, to the point of local absence within an outcrop. This variability in fluidization response might reflect small changes in grain packing, permeability, or bed shear strength.

As previously noted, the discrimination between coseismic and aseismic mechanisms of fluidization can be inconclusive, based on a single feature or even a single locality. For this reason, depositional environments that are associated with episodic autocompaction and/or hydraulic pumping should be ruled out for paleoseismic analysis. More specifically, aseismic fluidization can occur from rapid sedimentation rates, slope failures, artesian springs, rapid changes in groundwater saturation, and/or surf pounding, among others (Kolb, 1976; Nataraja and Gill, 1983; Holzer and Clark, 1993).

Stratigraphic evidence is very useful in constraining interpretations of the mechanisms of fluidization. Fluidization features that cut vertically through overlying strata of different depositional environments suggest coseismic origins. The strongest arguments for coseismic liquefaction come from large-scale spatial trends in the abundance and scale of fluidization features. Regional trends or continuities of paleoliquefaction sites that cross through different depositional environments imply a regional response to seismic shaking (Obermeier, 1996). In rare cases, the timing of fluidization can be tied directly to other paleoseismic indicators, such as abrupt regional subsidence, as shown later in this paper.

Post-earthquake field surveys usually rely on ground surface observations of deposits vented from sand volcanoes, i.e., sand blows and boils or sand-filled fissures, to demonstrate coseismic liquefaction. However, subsurface fluidization features are more likely to be preserved in the geologic record (Walsh and others, 1995). These features typically include clastic dikes, sills, pipes, or cones with widths of a few centimeters to several decimeters (Figure 2). The widest dikes (greater than 50 cm in width) are probably associated with lateral spreads from slope failures.

Fluidized injection features are commonly bounded by intruded (irregular) contacts with their host deposits. These contacts are sharply defined when sands are intruded into mud. The internal structures of fluidization features can include pseudo-shear bedding or laminae, grading, or particle orientation parallel to injection flow (Peterson, 1968). Inclined mud clasts or pebbles that are supported by structureless matrix are also good clues to the recognition of sediment remobilization by fluidization (Figure 2). Although not necessarily of fluidization origin, the presence of convolute beds and/or the absence of primary bedding are common indicators of potential paleoliquefaction.

A note to the reader: We use the terms "fluidization" and "liquefaction" to represent liquefaction from either aseismic or coseismic mechanisms, i.e., undifferentiated. Where abundance, regional continuity, and/or stratigraphic evidence of fluidization imply probable earthquake origins, we use the term "coseismic liquefaction."

Prehistoric liquefaction sites

An early argument against coseismic subduction in the central Cascadia subduction zone was the lack of reported fluidization features in coastal deposits. However, a preliminary search of late Pleistocene marine terraces in 1989 and 1990 showed evidence of possible coseismic fluidization in the central Cascadia margin (Peterson and others, 1991b; Peterson and Madin, 1992). Paleoliquefaction sites were found in beach, dune, and estuarine deposits from exposed sea cliffs near Gold Beach, Coos Bay, Newport, Willapa Bay, and Kalaloch (Figure 3). These paleoliquefaction sites and others in the late Pleistocene marine terraces are further described in this paper.

Evidence of fluidization in late Holocene deposits of the

central Cascadia coast was first reported from the Copalis River estuary (Figure 3) (Atwater, 1992). Large-scale dikes and sills (20-cm thickness) at this site vented sand onto a paleomarine surface, dated at 900–1,300 radiocarbon years before present (RCYBP). Unlike the bays to the south, the Copalis estuary did not experience coastal subsidence during the interval from 900 to 1,300 yr B.P., leaving some doubt as to the mechanism of fluidization at this site (Atwater, 1992). Additional late Holocene paleoliquefaction sites have been reported from the Cape Blanco area (Kelsey, and others, 1993) and the Umpqua and Siuslaw Bays of south-central Oregon (Briggs, 1994) and in small tributaries to Grays Harbor in Washington (Obermeier,

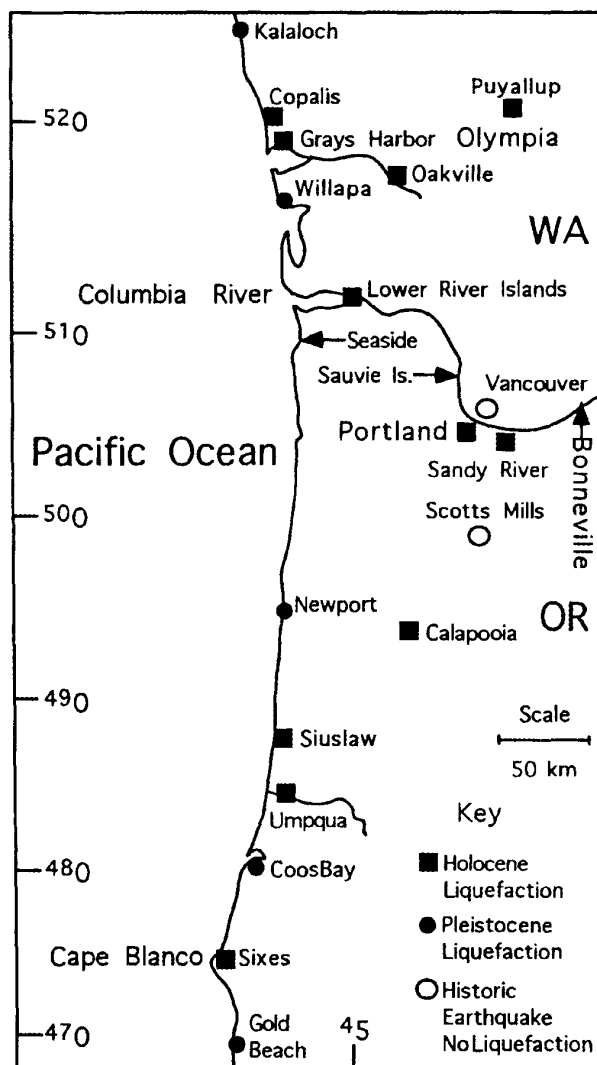


Figure 3. Map of reported liquefaction sites on the coast and at inland sites of the Cascadia margin. Solid squares represent reported Holocene coseismic-liquefaction sites. Solid circles represent reported late Pleistocene liquefaction sites. Open circles represent historic earthquakes (M_w 5) with no reported liquefaction.

1995). However, these late Holocene sites are located in small bays or creeks, and the evidence of paleoliquefaction is limited to short outcrops or subsurface cores. The potential earthquake sources responsible for these late Holocene coastal sites have yet to be rigorously established.

The most conclusive evidence of paleoliquefaction produced by a prehistoric CSZ earthquake is that observed in the lower Columbia River (Obermeier and others, 1993). Clastic dikes now exposed in river banks of small islands in the lower Columbia River estuary (Figure 3) vented sand onto wetland surfaces (Obermeier, 1995) that subsided (contemporaneously) with the last Cascadia earthquake, circa A.D. 1700 (Atwater, 1987; Darienzo, 1991). Paleoliquefaction evidence in exposed cutbanks has been traced up the Columbia River to the Sandy River delta, east of Portland (Siskowic and others, 1994; Vockler and others, 1994). Preliminary findings that tie these records of paleoliquefaction in the upper river valley to the last CSZ earthquake are discussed in this paper.

The discovery of late Holocene liquefaction sites in the upper Columbia River valley has led to reconnaissance searches of other localities in the forearc basins for evidence of paleoliquefaction (Figure 3). Small clastic dikes have been observed in shallow late Holocene deposits exposed in river banks of the Chehalis River near Oakville, Washington, and most recently in the Calapooia River of the southern Willamette Valley, Oregon (Obermeier, 1995; Obermeier, unpublished data, 1995). By comparison, larger clastic dikes cut Missoula flood deposits (12–13 Ka) in several Portland basin localities (I.P. Madin, unpublished data, 1995). Additional work is needed to discriminate between potential local sources and regional sources of seismicity for the paleoliquefaction events recorded in forearc basin localities.

Historic liquefaction in coastal sites

Liquefaction was induced by a small (M_w 7.1) coastal earthquake that occurred in the CSZ in April 1992 at Cape Mendocino (Figure 1). Although the origin of this thrust earthquake is controversial, its focus is reported to have occurred at a depth of 10 km within the Cape Mendocino triple junction (Michael and others, 1992). Two strong aftershocks (M_w 6.6 and 6.7) occurred on separate faults about 20 km offshore. The small rupture plane (about 300 km²) of the main shock produced local peak accelerations of at least 0.5 g for several seconds (Oppenheimer and others, 1993). The aftershocks produced comparable accelerations. Small sand blows from the main shock and/or aftershocks were found within a radius of about 30 km from the epicenter (Prentice and others, 1992).

Other surface expressions of the 1992 Cape Mendocino earthquake include small landslides on steep slopes and localized coastal uplift (1–1.5 m) near the epicenter (Jayko and others, 1992). With the exception of one lateral spread (0.5-m width), no extensive dike fields, fissures, or large-scale sand geysers were reported in the area. The liquefaction features observed within the epicentral region (20-km

radius) of this M_w 7 subduction-zone earthquake can be generally characterized as relatively small in scale and sparse in distribution.

By comparison, an inland earthquake in the Puget Sound area of southern Washington did result in substantial liquefaction in susceptible soils, such as those in the Puyallup valley (Figure 3) (Shulene, 1990). Two earthquakes, one each in 1949 (M 7.0) and 1965 (M 6.5) originated from deep intraplate (Benioff-Wadati zone) sources. Whereas sand blows in the City of Puyallup were widely reported for the 1949 earthquake, they were less common for the 1965 event. Geotechnical site analyses (Palmer, 1990) suggest that critical accelerations of the local source beds fall between the peak ground accelerations (PGA) estimated for the 1949 event (0.17 g) and the 1965 event (0.11 g) in the Puyallup valley. The Puyallup valley is located roughly 65 km from the two different epicenters, so the unequal liquefaction response is attributed to the differences in event magnitudes (Palmer, 1990).

The Portland basin (Figure 3) has experienced several historic earthquakes in the range of M 4–5, including the largest recorded earthquake (1962) with a magnitude estimate of up to 5.5 (Bott and Wong, 1993). The 1962 earthquake produced peak ground accelerations of 0.08–0.10 g in downtown Portland, located about 15 km to the southwest of the proposed epicenter in Vancouver, Washington (Yelin and Patton, 1991). Sand blows were not reported for any of the historic earthquakes in the Portland area (I.G. Wong, oral communication, 1995). However, thorough searches for such features were probably not undertaken at the time of the events. Preliminary results of our ongoing searches for historic coseismic liquefaction in river cutbanks of the Portland basin are reported in this paper.

The most recent earthquake in the Portland-Willamette Valley area (Scotts Mills, M 5.6) occurred in 1993 (Figure 3). This short-duration earthquake (main shock about two seconds) was located at about 13–15 km depth (Nabelek and Xia, 1995) and probably reached peak ground accelerations of 0.11–0.12 g near the epicenter (Madin and others, 1993). A search of roadsides, river banks, and pond margins did not yield any surface evidence of slumps, sand blows, or fissures near the earthquake epicenter. Trenches cut into small sand bars of the Pudding River near Scotts Mills showed no evidence of liquefaction. These observations are consistent with the relatively small magnitude of this most recent event, which did cause local damage to some unreinforced structures (Black, 1996).

METHODS OF RECONNAISSANCE SURVEYS

Late Pleistocene coastal terrace outcrops

Reconnaissance surveys of paleoliquefaction evidence in late Pleistocene coastal deposits of Oregon and Washington were conducted for several weeks of each summer from 1989 to 1992. The uplifted late Pleistocene deposits are well exposed in sea cliffs, bay cliffs, and/or road cuts. In this reconnaissance survey, the youngest (lowest) locally ex-

posed terrace was generally examined for possible evidence of coseismic liquefaction. The age of the lowest terrace varies along the central Cascadia margin due to differential uplift but probably ranges between 80 and 125 Ka in age (Florer, 1972; Kennedy and others, 1982; Kelsey, 1990; McInelly and Kelsey, 1990; Muhs and others, 1990; Mulder, 1992; Ticknor, 1993; Clifton, 1994).

Three areas of the central Cascadia margin were chosen for marine terrace surveys, including (1) Kalaloch and Willapa Bay in southern Washington, (2) Netarts to Alsea Bay in central Oregon, and (3) Coos Bay to Cape Blanco in southern Oregon (sites T1–T25, Figure 4; data summary in Table 1). These areas represent different distances from the trench (Figure 1) and possibly different distances from the megathrust locked zone (Geomatrix Consultants, Inc., 1995). Multikilometer reaches within the study areas were selected for beach- and bay-cliff surveys largely on the basis of ease of accessibility. A total of about 32 km of terrace deposit exposures was examined for possible evidence of fluidization features. This total corresponds to about 10 km,

14 km, and 8 km, respectively, for the the north, central, and south study areas. The distance of road-cut exposures examined in the Coos Bay area was not logged but probably exceeds 5 km. Terrace localities with apparent clastic dikes and/or sills at least 10 cm wide were noted for subsequent examinations. No attempt was made to normalize the frequency of fluidization features by outcrop length, height, or lithology. Liquefaction localities that showed evidence of (1) landsliding, (2) loading by colluvium overburden, and/or (3) extensive groundwater leaching were abandoned. Such localities could be influenced by aseismic mechanisms of fluidization (see "Background" section above).

About two dozen coastal localities were measured and photographed for the form, size, and stratigraphic development of fluidization features. These representative localities were selected on the basis of (1) observed dikes or sills of at least 10-cm width or (2) proximity to mapped Quaternary structures (upper plate faults or folds) in the southern study area. Field logs from the localities include estimates of outcrop length, depositional environment, and the lithologies

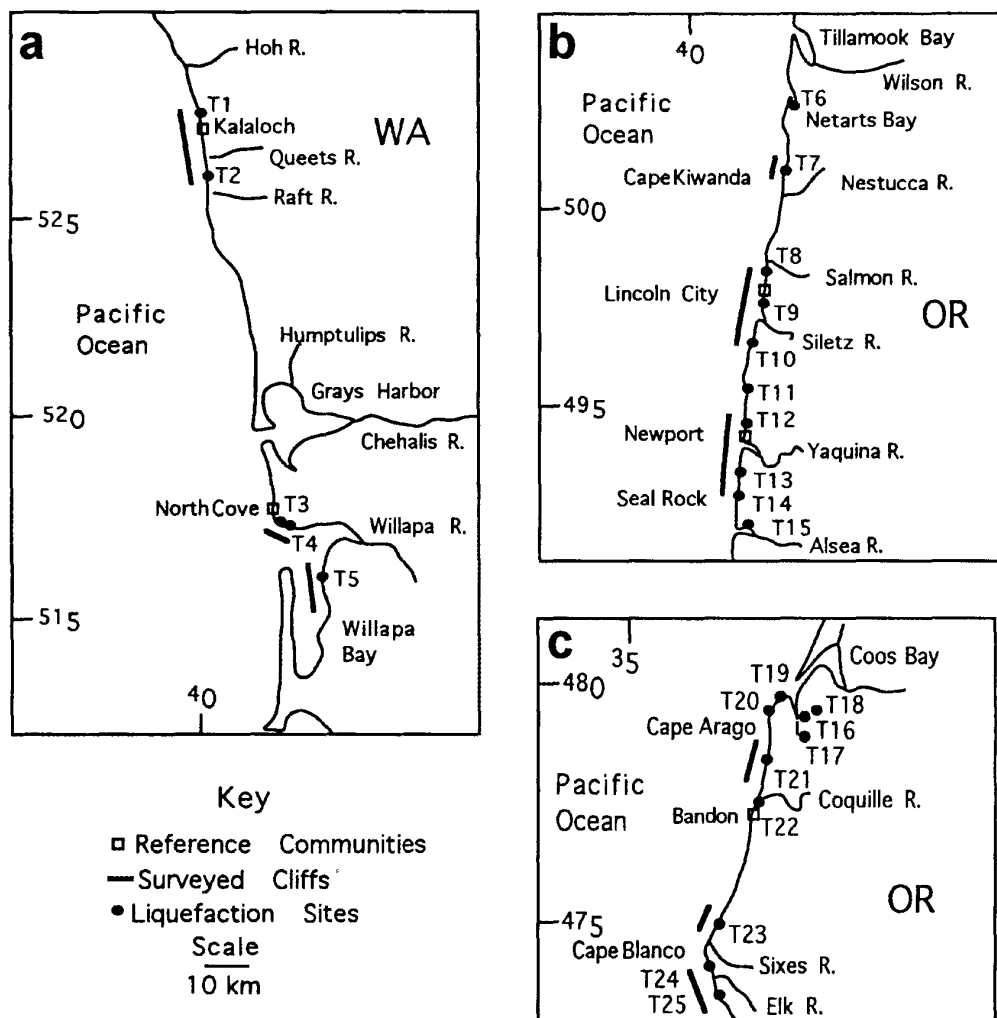


Figure 4. Maps of late Pleistocene paleoliquefaction sites (T1–T25, solid circles) in coastal marine terraces: a—north study area, b—central study area, c—south study area in the central Cascadia margin.

These areas were picked on the basis of representative distances from the trench. Specific beach-cliff traverses within the study areas were picked on the basis of known exposure of marine terrace deposits and ease of accessibility.

of the source beds, host deposits, and capping deposits. Particular attention was paid to localities that showed erosional truncation and subsequent burial of clastic dikes and sills or convolute beds. The burial of these truncated features constrains the timing of fluidization to the general period of deposition during the corresponding marine highstand (see "Discussion" section below).

For the purposes of this study only the largest fluidization features, i.e., plumes, lateral spreads, dikes, and sills, were measured at each locality. Clastic dikes were defined here as injection-conduit features, i.e., tabular bodies of sandy material, with apparent dips of at least 45° from horizontal in the plane of the outcrop. Some dikes were observed to widen at their base, so maximum dike width was taken from about the middle of the largest dike observed in the outcrop. Maximum sill width was taken from the largest sill that was not associated with a sill-dike juncture in the plane of the outcrop. Measurements of the widths of the largest features, i.e., cobble plumes and lateral spreads, were arbitrarily limited to 100 cm. Some of the largest features, those wider than 1 m, appear to contain multiple shear boundaries, which made it difficult to establish the width of a single feature or event. Due to the limited vertical exposures of most outcrops, typically less than 5 m in sea cliffs and less than 3 m in road cuts, the maximum lengths of clastic dikes are rarely exposed. Therefore the measurements of dike lengths reported here are minimum lengths, as exposed in the outcrop.

Late Holocene cutbanks of Columbia River islands

In 1991, initial observations of possible paleoliquefaction features were made in late Holocene deposits of the lower Columbia River area. Convolute bedding was found in cutbanks of a drainage ditch in Sauvie Island, near Portland, and fluidized sands were found beneath the youngest buried marsh deposit exposed in cutbanks of Neawanna River, north of the S Avenue bridge in Seaside, Oregon (Figure 3). A regional survey of the lower Columbia River islands in 1992 resulted in the discovery of widespread paleoliquefaction features (Obermeier and others, 1993). It was followed up in 1993 with a more thorough search for fluidization features and some subsurface geotechnical testing (Atwater, 1994; Obermeier, 1995).

Exposed cutbanks of these islands in the lower Columbia River valley were surveyed at low tides for evidence of vertical dikes cutting through capping layers of mud. In the westernmost islands, some dikes vented sand onto a paleowetland surface (peaty mud) that had abruptly subsided and had been buried by lower intertidal muds. Several of the island sites also show dikes cutting a thin tephra layer, located about half a meter below the paleosurfaces of sand venting. Samples for radiocarbon dating and tephrochronology were collected from these outcrops to establish the relative ages of the fluidization associated with the wetland subsidence. Subsurface deposits from islands in the lower reaches of the Columbia River have been examined for pa-

leoliquefaction evidence by vibracoring (Craig and others, 1993; Peterson and others, 1994).

Cutbanks in islands and floodplains of the Columbia River east of Portland were surveyed for liquefaction evidence during the summers of 1993–1995. Upriver from Portland, the cutbanks were selected on the basis of active channel erosion into deposits that are rooted by old cottonwood trees with trunk diameters greater than 1 m. Tree-ring counts on sawn stumps indicate that these old trees are approximately 50–100 yr in age. Thus, the underlying deposit surfaces should predate most dredge-and-fill operations on the river.

Convolute bedding and small dikes and sills were traced upriver along cutbanks from Government Island, just east of Portland, to Pierce Island, just downstream from the Bonneville Dam (Figure 3). Wood fragments from horizons immediately above intruded dikes or sills were collected from the Sandy River delta and Pierce Island for radiocarbon dating. Apparent "tephra" horizons cut by the fluidization features were collected at the Sandy River delta and at Reed Island for petrographic and geochemical analysis. A preliminary report on liquefaction susceptibility in the Sandy River delta has been presented by Anderson and others (1994).

RESULTS

Late Pleistocene paleoliquefaction

Kalaloch to Willapa Bay (Figure 4a)

Sea cliffs north and south of Kalaloch, Washington, contain multiple liquefaction sites in a low marine terrace. This terrace is thought to be correlative with the 80-Ka marine highstand (Florer, 1972). This part of the coast is deformed by faults and folds (Rau, 1973), apparently representing an onshore expression of the accretionary wedge. Just north of Point Brown (site T1), beach cobble imbrication demonstrates multiple convection plumes (Figure 5a). Convection structures are known from cyclic stress loading of dry granular materials (Jaeger and others, 1996) but have not been reported previously for coseismic disturbance sites. Small clastic sand dikes and sills are intruded into lagoonal muds that are located stratigraphically above the disturbed beach cobble deposits at this site. The presence of the small clastic dikes (5 cm wide) in lagoonal mud layers above the cobble plumes at site T1 argues against fluidization from surf pounding. However, additional work to test the interpreted coseismic origin of the imbricate cobble convection structures is warranted.

Larger dikes (20 cm wide) occur near Whale Creek (site T2). They are erosionally truncated, indicating that paleoliquefaction events at these sites were syndepositional with the period of marine highstand deposition. Relatively minor liquefaction features, e.g., small sand dikes and sills, were found in coarse-grained glacial outwash deposits between Whale Creek and the Queets River.

The accretionary wedge is assumed to be well offshore off Willapa Bay in southernmost Washington. Lateral

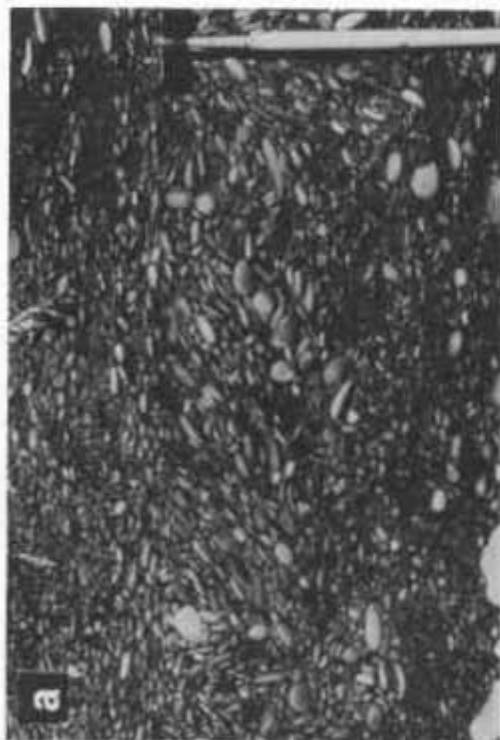


Figure 5. Photographs of (a) cobble plumes at Point Brown, Wash. (site T1) (hoe handle is 40 cm long); (b) 10-m vertical section of tidal inlet deposits dismembered by lateral spreads, sills, dikes, and convolute bedding at the North Cove quarry (site T3); (c) 40-cm-wide dike feeding a flame structure intruded into overlying host deposits (also site T3); note that two episodes of syndepositional paleoliquefaction are separated by the erosional truncation of fluidization features in the underlying source beds; (d) a clastic sill (0.5 m wide) intruded into estuarine mud deposits in a young (80 Ka) terrace inset in Willapa Bay (site T5).

spreads and large dikes (40 cm wide) occur at the North Cove quarry (site T3) in late Pleistocene terrace deposits (at least 125 Ka) at the north end of Willapa Bay (Figure 5b). These deposits of tidal-inlet sand (10–20 m thick) over gravel (10 m thick) show multiple episodes of liquefaction. At least two liquefaction events are separated by erosional truncation of fluidization features and subsequent flame injection through the erosional contact (Figure 5c). The flame is intruded into overlying beds that are undisturbed, which implies that the paleoliquefaction did not arise from channel-bank slumping. This paleoliquefaction locality appears to extend at least 0.5–1 km southwest to site T4, where rare clastic dikes (up to 20 cm wide) in tidal-flat facies are fed by convolute source beds of sand at several meters depth below the rare dikes (Table 1). Sills are more abundant than dikes (ratio greater than 10:1) in these layered tidal-flat deposits.

Clastic sills and rare dikes are found in the lower (80–120 Ka) terraces surrounding Willapa Bay, such as at site T5 (Figure 5d). The scale and abundance of paleolique-

faction features in the Willapa Bay terraces diminish to the south, where the late Pleistocene deposits are dominated by mud or muddy sand facies (Clifton, 1994). Muddy flowage structures (as described below for Netarts Bay) were observed in about a dozen sites in a 5-km traverse of bay terraces along the eastern shore of Willapa Bay.

Netarts to Alsea Bay (Figure 4b)

Late Pleistocene marine terraces along the eastern shore of Netarts Bay are dominated by thin-bedded mud and buried peats (Mulder, 1992). Thin layers of channel sand feed clastic dikes (up to 20 cm thick) that cut through capping layers of mud and peat. However, the dominant forms of liquefaction at the Netarts locality (site T6) are muddy flowage structures. The fluidization of these viscous mud deposits is demonstrated by flow banding (shear orientation) of organic fragments in the convolute mud layers. The injected mud is sometimes confined between deformed, but intact, peaty layers.

Eight paleoliquefaction sites exposed in sea cliffs were

Table 1. Paleoliquefaction localities in late Pleistocene marine terraces. For locations, see Figure 4

Site name (number T-)	UTM coordinates	Exposure length (m)	Depositional setting	Maximum fluidization	Feature width (cm)	Feature length (m)	Source bed lithology	Host deposit lithology	Capping bed lithology	Accessory features [†]	Erosional truncation events
North											
Kalaloch (1)	5277650N395860E	150	Platform/beach	Cobble plume	100	1	Sandy cobble	Sandy cobble	—	CS	2
Whale Creek (2)	5259800N398890E	30	Beach/lagoon	Clastic dike	20	2	Gravelly sand	Sand	Peat	CB	1
North Cove (3) ²	5175870N419450E	100	Tidal inlet	Lateral spread	50	5	Sand	Sand	Muddy sand	CD,CS,CB	2
Shoal Water (4) ²	5175500N419910E	100	Estuarine	Clastic dike	20	2	Sand	Muddy sand	—	CB	—
Ramsey Pt. (5)	5168200N429200E	20	Estuarine	Clastic dike	15	2	Sand	Sand	Muddy sand	CS,MF,CB	—
Central											
Netarts Bay (6)	5027420N426800E	50	Estuarine	Clastic dike	20	2	Gravelly sand	Mud	Mud	CS, MF	—
Cape Kiwanda (7)	5008510N423810E	30	Beach/lagoon	Clastic dike	15	1	Sand	Muddy peat	Peat	CS,MF,CB	—
Roads End (8)	4984110N420420E	50	Beach/dune	Clastic dike	10	2	Sand	Sand	—	CS, CB	3
Nelscott Beach (9)	4977010N419300E	20	Dune/pond	Clastic dike	5	1	Sand	Sand	Mud	CS, CB	3
Sea and Sand (10)	4968170N417640E	50	Beach/lagoon	Clastic dike	30	2	Sand	Mud	Peat	CS, CB	1
Otter Rock (11)	4954650N416500E	50	Beach/dune	Clastic dike	20	2	Sand	Sand	—	CS	2
Agate Beach (12)	4946840N416040E	20	Beach/dune	Clastic dike	30	2	Sand	Sand	—	CB	—
Deer Creek (13) ³	4928650N413180E	30	Platform/lagoon	Flame	30	1	Sandy cobble	Mud	—	BS, MF	—
Seal Rock (14)	4926800N413900E	20	Beach/dune	Clastic sill	25	2	Sand	Sand	—	CB	1
Alsea Bay (15)	4922100N416000E	20	Estuarine	Clastic dike	30	3	Silty sand	Sandy mud	Mud	CS	—
South											
Crown Point (16) ²	4797810N394870E	10	Beach/?	Dike	30	—	Sand	Sand	—	CB	—
Winchester (17) ²	4790200N393400E	20	Beach/?	Dike	15	1	Muddy sand	Sand	—	CS	—
Pony Ridge (18) ²	4799010N397770E	90	Estuarine	Lateral spread	100	6	Sand	Sand	—	CD,CS,CB	—
Boat House (19)	4800320N392000E	10	Beach/dune	No fluidization	—	—	Sand	Muddy sand	Mud	—	—
Sunset Bay (20)	4798650N388900E	50	Beach/dune	Convolute beds	—	—	Sand	Sand	—	—	—
Merchants (21)	4786580N387000E	100	Dune/pond	Clastic dike	5	1	Sand	Sand	Mud	CB	—
Bandon (22)	4776000N386850E	100	Fluvial/tidal	Clastic sill	10	2	Sand	Gravelly sand	—	CB	1
Floras Lake (23)	4750130N376400E	100	Beach/dune	Clastic dike	25	3	Sand	Gravelly sand	—	CS, CB	2
Cape Blanco (24)	4742350N373780E	50	—	Cobble plume	100	2	Sandy cobble	Sandy cobble	—	CS	—
Paradise (25)	4736410N375760E	100	Beach/dune	Clastic sill	35	2	Gravelly sand	Sand	—	CD, CB	2

¹ CP=cobble plume; LS=lateral spread; CD=clastic dike; CS=clastic sill; BS=basal shear; MF=mud flowage; CB=convolute beds

² Older terrace, presumed to equal or exceed 125 ka.

³ Deposit fill in valley cut of late Pleistocene terrace. Age is younger than terrace.

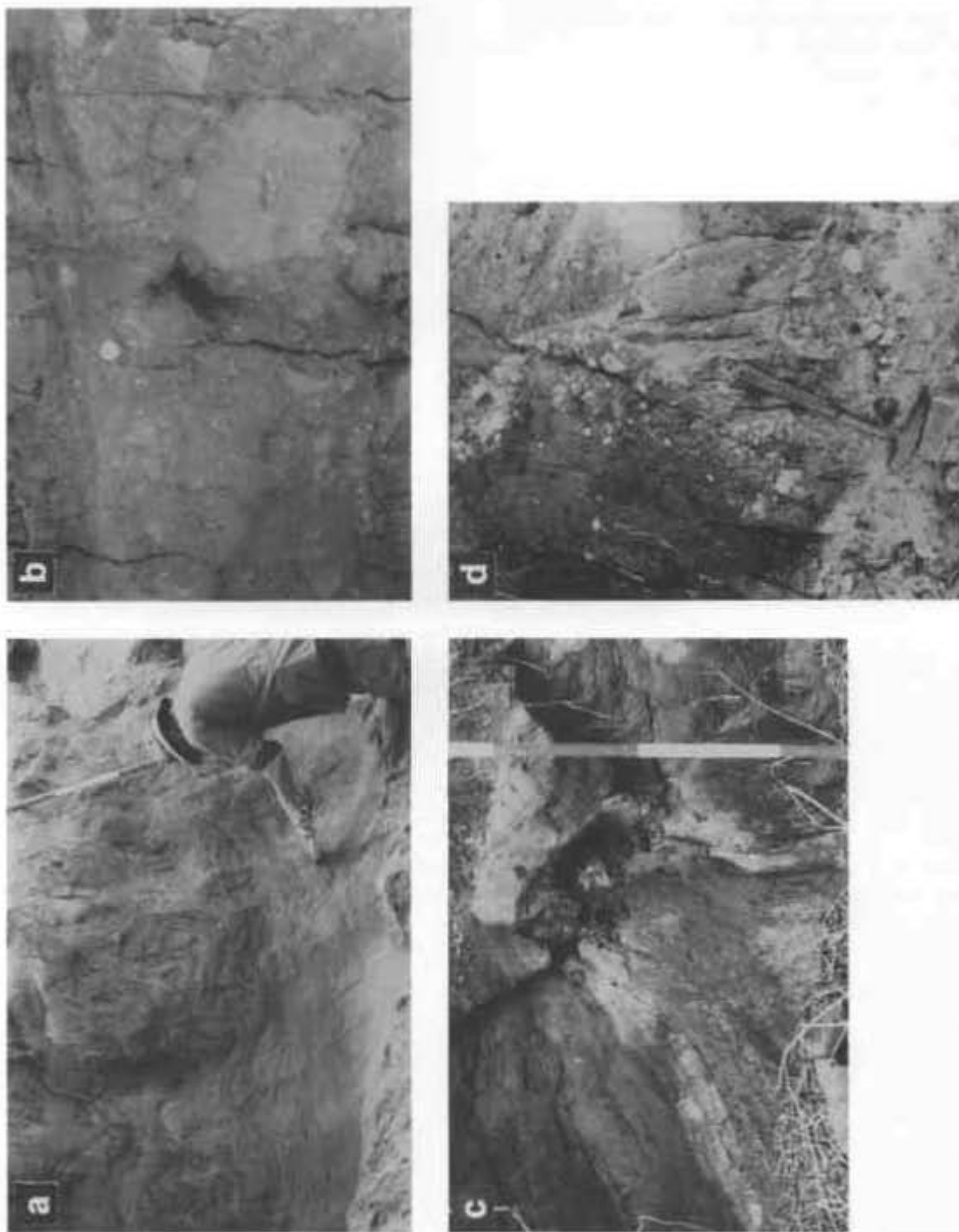


Figure 6. Photographs of (a) highly convoluted beds of beach laminae (originally planar) feeding clastic dikes that terminate in backshore collan dune deposits, north of Lincoln City (site T8); (b) outcrop exposure showing clastic sills and entrained/disembled sand blocks developed under a deformed peat, south of Lincoln City (site T10) (U.S. quarter-dollar coin in upper center for scale); (c) large clastic dike deforming originally horizontal beach laminations, north of Newport (site T12) (staff divisions are 30 cm long); (d) basal shear of wave-cut platform developing mudstone breccia and associated breccia/cobble flame structure in overlying lagoonal mud, south of Newport (site T13).

examined from Cape Kiwanda to Seal Rocks. The source beds are well-sorted beach sand (Figure 6a) or mixed sand and gravel (Figure 6b). However, the extension of fluidization features upwards into eolian dunes or lagoonal peats argues against aseismic liquefaction from surf pounding. Two of the localities (sites T8 and T9) might demonstrate three events each of paleoliquefaction: Each disturbed layer displays erosional truncation of fluidization features, such as small dikes, flames, and/or convolute beds (Figure 7). Large clastic sills (greater than 20 cm wide) are locally developed under capping layers of peat (sites T7 and T10) or mud (interdune pond deposits at site T9). Whereas large dikes are observed under a deformed peat layer in a lagoonal setting at site T10 (Figure 6b), only small dikes (5–10 cm in width) cut through the deformed peaty capping layer there.

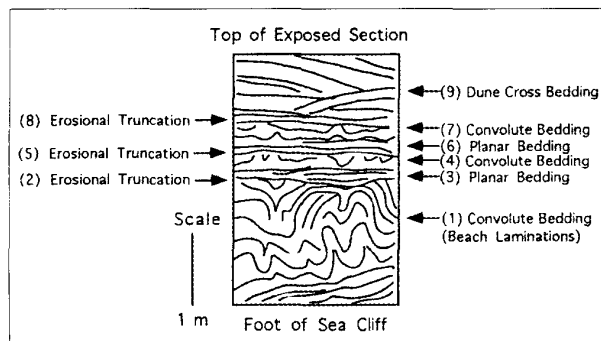


Figure 7. Drawing of episodic paleoliquefaction and erosional truncation sequences at Roads End (site T8). See photograph of lower convolute beds in Figure 6a. The truncation of several convolute beds implies syndepositional paleoliquefaction. Possibly three events of liquefaction and erosional truncation are represented at this site. The youngest flame and convolute beds extend upwards from beach backshore to eolian dune deposits.

Paleoliquefaction sites are also common in the marine terraces north and south of Newport. Liquefaction features include clastic dikes at sites T11 and T12 (Figure 6c) and basal shear structures, such as at site T13 (Figure 6d). In the Newport area, the late Pleistocene wave-cut platform is cut into Tertiary mudstones. Where exposed by local uplift, the weathered platform surface shows unusual evidence of brecciation by mud injection and shear flow. Pieces of the weathered platform (Tertiary mudstones) are entrained into convoluted beds and/or flames. The flames and the convolute bedding are restricted to a couple of meters above the platform (bedrock) contact. Vertical orientations of flames indicate that basal shears are probably not the products of postdepositional landsliding. Clastic dikes are absent from the several observed basal shear sites, but sills are common in adjacent sandy facies. The combination of platform-surface brecciation and fluidization of adjacent sandy facies argues for a cyclic stress mechanism of disturbance at these sites.

A brief survey of marine terraces on the north side of

Alsea Bay located a paleoliquefaction site (20-m road-cut exposure) that is dominated by a large clastic sill and dike complex (site T15). Measured sections at this site show an abundance of clastic sills feeding rare dikes (Figure 8). The

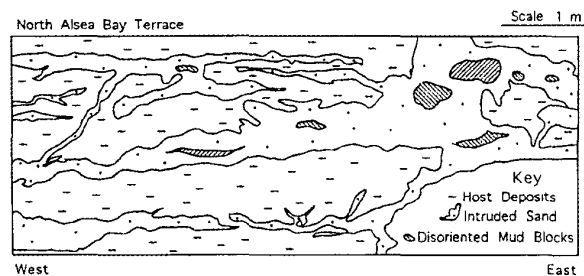


Figure 8. Drawing of large clastic sill and dike complex in tidal-flat deposits from late Pleistocene terrace at Alsea Bay (site T15).

sand-filled sills display sharp (eroded) upper and lower contacts with muddy sand host deposits. The sharp upper contacts were apparently produced by shear-flow erosion of the host deposits during sill injection. The clastic sills also display intruded contacts at their lateral terminations and disoriented (inclined) mud blocks surrounded by structureless matrix or horizontal shear bedding within the sill interiors. Whereas some of these clastic sills might represent minor fluidization of preexisting beds, other sills show evidence of substantial shear flow including eroded contacts, internal flow banding and transport of exotic mud blocks. The extensive fluidization of these shallow tidal-flat deposits is interpreted to represent (1) long duration of coseismic liquefaction and/or (2) multiple liquefaction events.

Coos Bay to Cape Blanco (Figure 4c)

The southern study area contains highly deformed marine terraces, an indication of its proximity to the accretionary wedge fold and thrust belt (Peterson and others, 1991a). Marine terrace outcrops were examined along an east-west traverse from the south end of Coos Bay to the coast. Sites T16 and T17 are from the Metcalf terrace (>125 Ka) that was disrupted by late Quaternary faulting (Madin and others, 1995). These two localities include clastic dikes, 30–50 cm in width at Crown Point (site T16) and 15 cm in width at Winchester (site T17). Large convolute beds and flames are associated with the fluidized beds at the Crown Point site (Figure 9a). The host deposits at sites T16 and T17 are thought to be beach sand, but the terrace deposit thickness (20–40 m) implies more complex shoreface settings. Very large dikes and lateral spreads are also found in a road-cut exposure of an older deposit at the top of Pony Ridge (site T18 and Figure 9b). The age of this unit has not been established, but the relatively minor amount of interstratal weathering implies a Quaternary age. Little primary structure is left at the Pony Ridge locality, where the host deposits are intruded by numerous dikes, sills, and convolute bedding along a 90-m road-cut exposure.



Figure 9. Photographs of (a) convolute beds of deformed beach laminations in Metcalf terrace near Crown Point (site T16) (a large elastic dike at least 30 cm wide was found nearby in the Crown Point road-cut exposure); (b) lateral spread, dikes, and sills at Pony Ridge (site T18); (c) elastic dike and sills cutting sand and gravel layers in beach backshore deposit at Floras Lake (site T23), with diatomaceous mudstone (white elongate feature at lower right) lodged in silt-dike juncture (staff divisions are 30 cm long); (d) large cobble plumes at Cape Blanco (site T24).

Several other localities (sites T19–T22) were examined between Coos Bay and Bandon due to their proximity to reported Quaternary faults or folds along this coast. For example, Merchants Beach (site T21) sits on the west flank of the uplifting Cape Arago (Pioneer) anticline. Quaternary faults are reported for the Boat House (site T19), Sunset Bay (site T20), and Bandon (site T22) localities (Madin and others, 1995; Goldfinger and others, 1992; Geomatrix Consultants, Inc., 1995). The well-exposed deposits of the Whisky Run and Pioneer terraces, 80 and 105 Ka respectively, at these localities (McInelly and Kelsey, 1990) show only weak to moderate evidence of fluidization. Thin source beds (site T20), eolian dune host deposits (site T21), and gravelly sand host deposits (site T22) might account for the weak fluidization at these localities. However, similar depositional settings in the central study area (sites T6–T15) yield equivalent or better paleoliquefaction evidence.

A young terrace locality that does include large fluidization features in a beach-dune setting occurs just south of Floras Lake on the north side of Cape Blanco (site T23). Clastic dikes and sills up to 25 cm and 50 cm wide, respectively, are abundant in this 100-m sea-cliff exposure (Figure 9c). Two sets of erosionally truncated convolute beds indicate that, at this locality, multiple liquefaction events occurred syndepositionally, i.e., within the period of marine highstand.

At Cape Blanco (site T24), a terrace deposit exposed in ravine and beach cliffs contains poorly organized cobble plumes (Figure 9d). Though not as well imbricated as those at Point Brown, Washington (site T1), the apparent convection plumes at Cape Blanco are larger, reaching 2 m in width. Another cobble liquefaction site (not included in Figure 4 or Table 1) exists in a terrace deposit located about 1 km northwest of the Elk River mouth (UTM 4739300N–375600E). Fluidization of underlying sand deposits might have disrupted the overlying cobble beds at this site. South of the Elk River mouth, several paleoliquefaction localities are exposed in the beach cliff. At one locality (T25), large clastic sills (35 cm wide) and small dikes entrain pea gravel into hosting dune deposits. The fluidization features abruptly decrease in abundance and scale several meters above the transition between beach backshore and eolian dune facies. Erosional truncations of convolute beds at this locality indicate that the paleoliquefaction events were syndepositional with the marine highstand deposition.

LATE HOLOCENE PALEOLIQUEFACTION IN THE COLUMBIA RIVER

Lower river valley

Clastic dikes are exposed in shallow cutbanks and wave-cut benches of many islands in the lower reaches of the

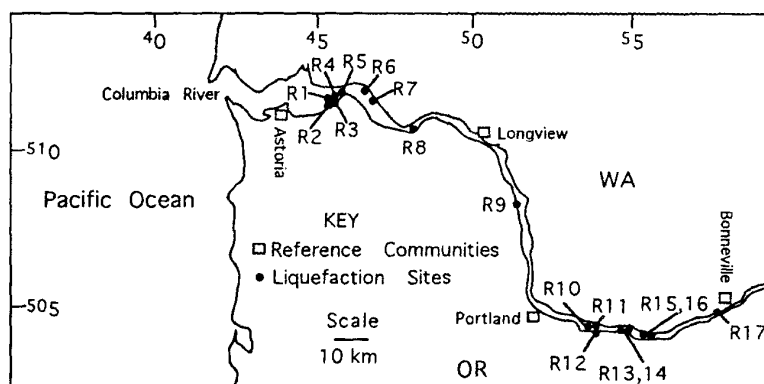


Figure 10. Map of late Holocene paleoliquefaction sites (R1–R17) in the Columbia River islands between Astoria and Bonneville.

Columbia River. Island outcrops surveyed in 1992 and 1993 include Marsh, Karlson, Brush, Woody, Price, Hunting, Wallace, and Deer Islands, among others (sites R1–R17, Figure 10; data summary in Table 2). The observed clastic dikes range in width from 30 cm at site R1 (Figure 11a) to only 3 cm at adjacent locality R2. The sand-filled dikes cut capping mud layers about 1 m thick but generally terminate in peaty deposits or erosional surfaces 0.5–1 m below the modern floodplain (see “Paleoliquefaction chronostratigraphy” below). Accretionary-bank sand deposits under the capping mud layers (Peterson and others, 1994) are the likely source beds for the clastic dikes. Cementation along the dike walls produces erosionally resistant selvages that stand out from the wave-cut benches, observable at low tides at site R8 (Figure 11b).

Vibracores driven to subsurface depths of 5–6 m at several positions at sites R1, R6, R7 (Figure 11c), and R8 demonstrate abundant subsurface evidence of clastic dikes and other intruded structures. The 30-cm-wide dike at Marsh Island (site R1) was followed to a depth of 2.5 m before it angled away from paired vibracores. Fluidization features recovered in vibracores (Figure 11d) occur to depths of at least 6 m below corresponding venting surfaces at sites R1, R7, and R8 (Craig and others, 1993). Anomalous core sections (20–100 cm thick) that lack any primary bedding occur at various depths in most of the recovered vibracores (see, e.g., Figure 12). These sections might represent fluidized source beds or clastic sills, as evidenced by (1) intruded contacts, (2) entrained (disoriented) mud clasts, and/or (3) zones of disturbed or absent cross-bedding that are seen in the vibracores. Undisturbed cross-bedding seen in adjacent core sections implies that the vibracoring itself was not the cause of fluidization. More importantly, iron oxide stains along deep intruded contacts (4–6 m depth) indicate that the (possibly several) fluidization events clearly predate the vibracoring.

Summaries of vibracore logs and supporting geotechnical data from the lower Columbia River islands are in preparation (B. Atwater, personal communication, 1995).

Figure 11. Photographs of (a) large sand-filled clastic dike (30 cm wide) cutting mud-cap layer at Marsh Island (site R1); (b) elastic dike cutting mud-cap layer in wave-cut bench at Wallace Island (site R8) (pocket knife for scale at left of dike is 10 cm long); (c) vibracore rig at Hunting Island (site R7); (d) elastic dike in vibracore (V15) at site R7, taken 1 m west of north-south striking dike (20° dip west), section showing breached mud layer, intruded contacts, disoriented mud blocks in sand matrix, and lack of primary cross-bedding in sand.

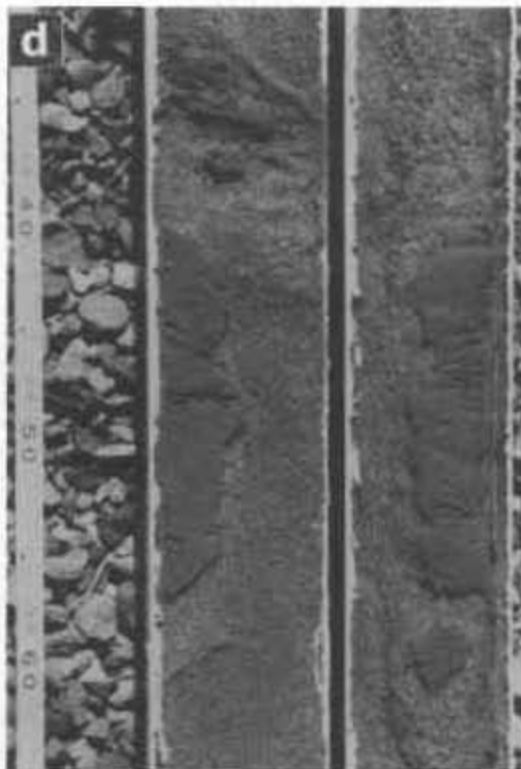


Table 2. Paleoliquefaction localities in exposed cutbanks of Columbia River islands (shown in Figure 10)

Site name (number R-)	UTM coordinates	Exposure length (m)	Dike width (cm)	Sill width (cm)	Source bed lithology	Source bed depth (m)	Host deposit lithology	Capping bed lithology	Capping bed thickness (m)
Western islands									
Marsh Is. (1)	5119080N454000E	100	30	20 ¹	Sand	>2.5	Mud	Mud	1
Karlson Is. (2)	5116410N454600E	30	3	—	Sand	>1	Mud	Mud	2
Blind Slough (3)	5116440N456210E	50	0	0	—	—	—	Mud	>3
Brush Is. (4)	5119710N454370E	50	15	—	Sand	>1	Mud	Mud	1
Woody Island (5)	5121450N457650E	50	15	—	Sand	>1	Mud	Mud	1
Price Is. (6)	5122490N465660E	100	7	—	Sand	>1.5	Mud	Mud	1.5
Hunting Is. (7)	5119120N467670E	200	15	20 ¹	Sand	>1.5	Mud	Mud	1.5
Wallace Is. (8)	5109700N479100E	100	8	—	Sand	>1.5	Mud	Mud	1.5
Deer Is. (9) ²	5092100N511900E	1,000	10	—	Sand	1.0–3.0	Mud	Mud	1.0–3.0
Eastern islands									
Government Is. (10)	5045900N540550E	50	0	5	—	—	—	Mud	>3
N. McGuire Is. (11)	5045650N540920E	50	1	3	Sand	>1.5	Sandy mud	Mud	>2
S. McGuire Is. (12)	5045350N541300E	50	6	20	Sand	>1	Sandy mud	Mud	2
W. Sandy Delta (13)	5045600N547000E	30	5	15	Sand	>1.5	Sandy mud	Mud	2
E. Sandy Delta (14)	5046000N547600E	30	3	15	Gravelly sand	2	Muddy sand	Mud	3
W. Reed Is. (15)	5044150N553350E	50	6	10	Sand	>1.5	Muddy sand	Mud	2
E. Reed Is. (16)	5044100N555470E	30	3	5	Sand	1	Mud	Mud	2
Pierce Is. (17)	5052100N577000E	30	5	13	Sand	1	Muddy sand	—	1

¹ Sill width data from vibracore.

² Deer Island dike width data from L. Palmer (pers. comm., 1996), limiting radiocarbon age <690±70 RCYBP (Obermeier, 1995).

Upper river valley

Cutbanks in McGuire, Reed, and Pierce Islands and the Sandy River delta of the upper Columbia River valley (sites R11–R17, Figure 10 and Table 2) contain small clastic dikes and sills beneath thick capping mud layers. Maximum dike widths are on the order of 5–6 cm. The more abundant sills reach 15–20 cm in thickness. At the Sandy River delta (site R13), fluidized source beds (Figure 13a) feed thin clastic dikes (2–5 cm in thickness) that penetrate about 2 m into overlying sandy mud. Fluidization features terminate at least 0.5 m below the modern island surface. No dikes were found along the south side of Government Island (site R10), where only mud is exposed in a 3-m-high outcrop. However, clastic sills (5 cm wide) are observed low in the exposed section, presumably near the bottom of the mud cap. In 50 m of outcrop exposed along the south side of Reed Island (site R15), clastic sills outnumbered dikes by more than 20:1 (Figure 13b). Coarse sand in the sills must have risen via clastic dikes from coarse channel deposits below the exposed host deposits of fine sand and overlying flood silts. Clastic sills also predominate in the exposed cutbank section at Pierce Island (site R17), although some short dikes interconnect sills between muddy sand layers there (Figures 13c,d).

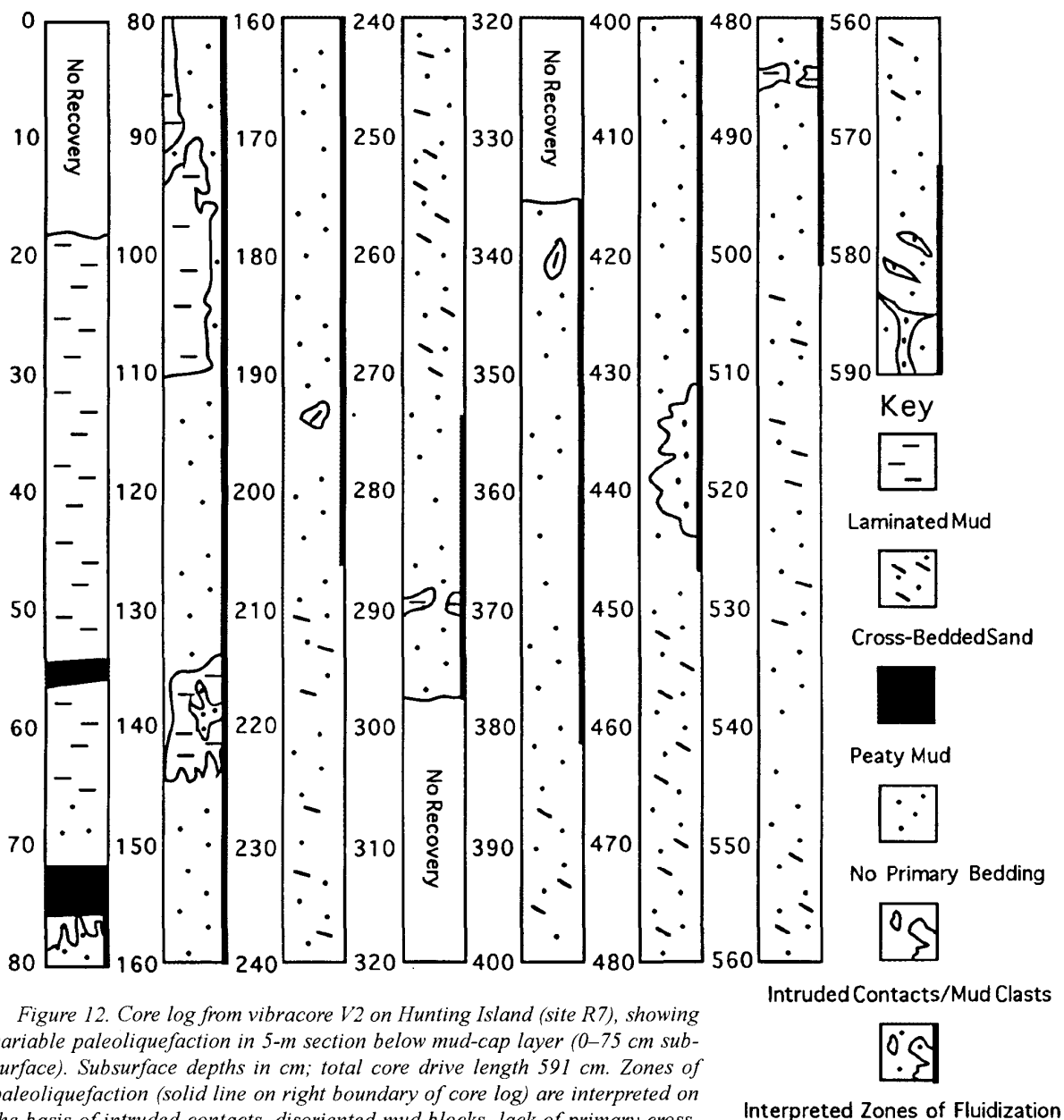
Some effort was made to establish whether more than one event of fluidization was apparent in the exposed cut-

banks of the islands in the upper river valley. These preliminary efforts were unsuccessful. Small dikes were observed to cut clastic sills at sites R13 and R15, but a lack of weathering or cementation precludes a determination of the age relations of the sills and dikes. No subsurface vibracoring has been performed in those islands, so the potential depth of paleoliquefaction evidence there is not known. Finally, some of the sills in these islands might have formed via in situ liquefaction of preexisting sand layers rather than by intrusion of clastic sills from feeder dikes. The thickness of these sills might not reflect intensity of liquefaction, but rather the incipient fluidization of layered source beds. For this reason, the thickness of the clastic sills is not used to compare potential strength of shaking between the Columbia River paleoliquefaction sites.

Paleoliquefaction chronostratigraphy

The timing and correlation of the most recent paleoliquefaction event(s) in the late Holocene deposits of the Columbia River were addressed by several independent methods. These methods include stratigraphic correlation with regional coseismic subsidence (lower river valley), radiocarbon dating and tephrochronology (lower and upper river valley), and observations of surficial “historic” deposits (upper river valley).

In the lower river valley localities (sites R1, R6, and R7),



thin sand layers (1–3 cm thick) are infrequently preserved immediately above buried wetlands. These features are interpreted to represent fluidized sand that was vented onto the preexisting wetland surfaces (Obermeier, 1995). However, the first correlation of paleoliquefaction and coseismic subsidence in the lower Columbia River was made at Karlson Island (site R2). At this site, muddy flowage disrupted a buried peat surface that was also intruded by small clastic dikes and sills (Figure 14a). The small sand dikes terminated at the top of the disrupted peat layer which was itself overlain by undisturbed (horizontal) mud laminations.

The disrupted peat layer at Karlson Island was traced across the channel to cutbank outcrops in Blind Slough (site R3). There, in situ spruce roots in the buried peaty horizon were sampled for radiocarbon dating. The spruce roots had a limiting (conservatively old) age of 700 ± 60 RCYBP $\pm 1\sigma$ (Beta Analytic, Inc., sample no. 56407). The last two regional events of coseismic subsidence in the lower Columbia River valley area occurred at about 300 and 1,100 yr B.P. (Atwater, 1987; Darienzo, 1991). Therefore, the paleoliquefaction was tentatively attributed to the last Cascadia earthquake about 300 yr ago. Subsequent radio-

carbon dating of buried soils and tree-ring counts from submergence-killed trees in the lower Columbia River islands (Atwater, 1994) confirm that the most recent event of paleosubsidence in the lower Columbia River does correlate to the A.D. 1700 Cascadia earthquake.

The amount of coseismic paleosubsidence diminishes upriver, until it becomes undetectable between Hunting and Wallace Islands. However, an independent time line (tephra layer) was found about 0.5 m below the buried wetland horizon at Marsh Island (Figure 14b). A gray silt layer (1–3 cm thick) is locally present some 5–20 cm below the tephra layer. The tan-colored tephra layer was subsequently traced to Hunting and Wallace Islands, where it is also cut by shallow clastic dikes. Petrographic analysis confirms an abundance of ash shards (30–90 percent of silt-sized grains) in the tephra layer. Instrumental neutron activation analysis (INAA) of pumice fragments from the Marsh Island tephra layer (Table 3) discriminates the volcanic source, i.e., Mount St. Helens, from other potential sources, e.g., Mount Mazama and Glacier Peak (Figure 15) (Gates, 1994). The relative age of this tephra layer (greater than 300 yr B.P.) and the extent of its distribution (volume) in the preserved deposits of the lower Columbia River indicate an origin from the Mount St. Helens set W eruptions at about A.D. 1480 (Yamaguchi, 1985; Mullineaux, 1986).

Table 3. INAA geochemical data for pumice fragments from Marsh Island tephra layer

Element	Pumice sample NG-10		Pumice sample NG-11	
	Concentration (ppm)	Uncertainty (percent)	Concentration (ppm)	Uncertainty (percent)
As	6	36.8	3	34.2
Rb	55	10.9	61	10.7
Cs	2.1	5.5	2.4	6.2
Sr	377	12.3	326	14.6
Ba	432	5.7	474	5.4
Sc	6.1	1	6	1.2
Cr	17	6.8	17	6.2
Fe (%)	2.1%	1.1	2.1%	0.9
Co	5	4.7	4.9	4.6
Zn	41	30.5	44	27.3
Ce	34	2.1	35	2
Nd	21	14	17	38.8
Sm	3.6	5.6	3.3	6.1
Eu	0.9	4.4	1	ND
Yb	2	11.7	2	12.9
Lu	0.2	9.7	0.2	9.5
Zr	127	39.1	139	31.7
Hf	4.4	4.2	4.3	5.5
Ta	1.1	17.4	1.5	17.2
Th	6.3	3.2	7.6	2.5
La	29	6	34	3.7

In the upper river valley, the apparent "tephra" layer(s) exposed in cutbanks of McGuire and Reed Islands and the Sandy River delta are locally cut by small clastic dikes. Petrographic analysis of the anomalous pink layers (1–3 in number) shows them to be enriched in altered rock fragments and hypersthene, but ash shards are rare. INAA geochemical analysis of the target layers at Reed Island shows the layers (3–10 cm thick) to be largely diluted by Columbia River sediments (Barnes, 1995). A charcoal sample in contact with the pink "tephra" layer from the west cutbank of the Sandy River delta (Figure 16a) has a radiocarbon age of 410 ± 70 RCYBP $\pm 1\sigma$ (Beta Analytic, Inc., sample no. 67448). On the basis of this radiocarbon date and the widespread occurrence of these anomalous "tephra" layers in the upper river islands, we ascribe their origin to the Mount St. Helens set W eruptions. Confirmation of this source awaits sampling and geochemical analysis of possible ash shards or pumice fragments from the target "tephra" layers.

Anomalous beds of coarse gray sand are also exposed in the Sandy River delta cutbanks, which are dominated by Columbia River sand. At several meters' depth, these coarse gray sands are cut by the clastic sills and dikes; however, similar gray sands in isolated scour fills near the top of the section are undisturbed. These coarse gray sands might represent Mount Hood lahars or reworked lithic-rich sand carried down the Sandy River during floods. One set of lahars apparently caused foundering of the local overburden and liquefaction in Columbia River flood silts immediately downriver from the Sandy River delta (Vöckler and others, 1994). However, no such evidence was observed in the Sandy River delta cutbanks (sites R13 and R14). In any case, the Sandy River lahars cannot account for the paleo-liquefaction at McGuire (sites R11, R12), Reed (sites R15, R16), and Pierce Islands (site R17), well away from the Sandy River confluence with the Columbia River.

Two age-limiting radiocarbon samples were collected at the uppermost reach of intruded sands at the Sandy River delta (R13) and Pierce Island (R17) sites. Wood fragments from these two localities (Figure 16) have radiocarbon ages of 250 ± 70 RCYBP $\pm 1\sigma$ (Beta Analytic, Inc., sample no. 67446) and 260 ± 50 RCYBP $\pm 1\sigma$ (USGS-WW540 Livermore-CAMS-22498), respectively. These radiocarbon ages confirm broader field observations (below) indicating that the paleo-liquefaction event(s) are of latest prehistoric age. A total of about 1 km of well-exposed outcrop was examined from the Government, McGuire, Sandy River, Reed, and Pierce Island cutbanks. None of the examined sections showed evidence of intruded sands reaching modern floodplain deposits, i.e., the upper 20–30 cm of exposed sections. Fluidization was also absent in cross-bedded sands filling shallow scours at the top of the exposed sections at several of these localities. Apparently, the Vanport flood of 1948, the Olympia earthquakes of 1949 and 1965, and the Portland-Vancouver earthquake of 1962 were insufficient to produce liquefaction at any of the observed cutbank localities (sites R10–R17) in the Columbia River islands east of Portland.

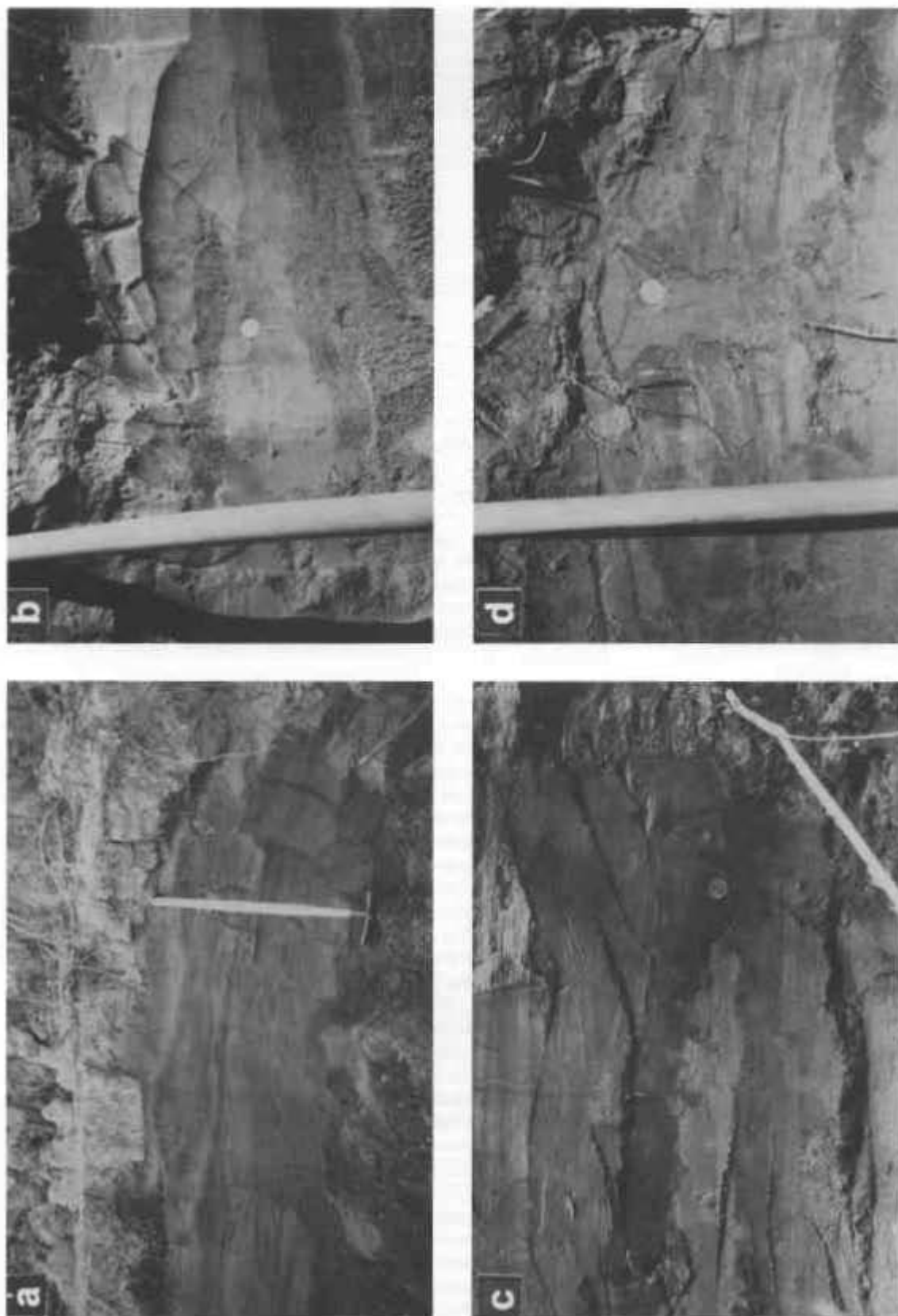


Figure 13. Photographs of (a) interfingering intruded sills in or near source beds (sand) at Sinky River delta (site R13) (hoe handle 40 cm long); (b) coarse sand in elastic sills injected into fine-sand host deposits at Reed Island (site R15); (c) elastic sills injected into muddy sand host deposits at Pierce Island (site R17); and (d) elastic dike, 5 cm wide, connecting elastic sills at Pierce Island (site R17). Quarter coins for scale in Photographs b, c, d.

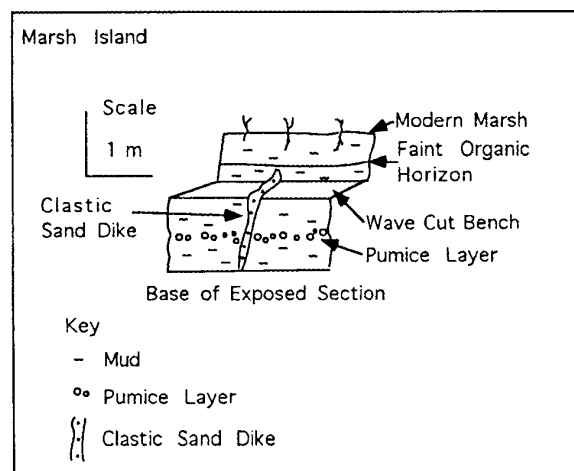
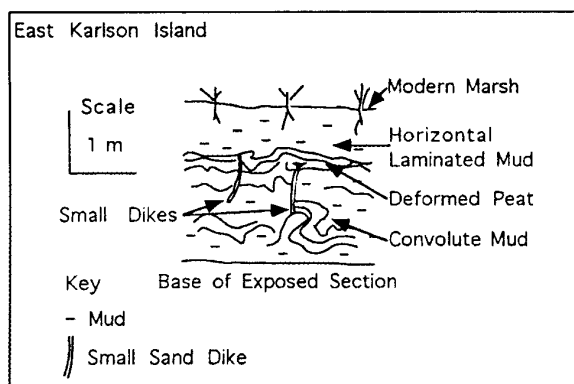


Figure 14. Drawings of exposed cutbank sections from (a) Karlson Island (site R2) and (b) Marsh Island (site R1) in the lower Columbia River valley. The Karlson Island section shows convolute mud beds and small clastic dikes associated with a deformed buried-wetland soil. Horizontally laminated mud above the deformed wetland soil is undisturbed, thereby linking the paleoliquefaction (sand intrusion) and paleosubside. The paleosubside is traced regionally to the last Cascadia earthquake about 300 yr ago (Atwater, 1987; Darienzo, 1991). The Marsh Island section shows a large clastic dike cutting a tephra layer that contains abundant ash shards and small pumice blocks.

DISCUSSION

Distribution of late Pleistocene evidence of paleoliquefaction

We assume that cobble plumes, basal shears, and lateral spreads are evidence for probable strong shaking in settings where aseismic paleoliquefaction is unlikely. A regional plot of these features (Figure 17) shows them to be uncommon (present at 5 out of 25 reported sites) but widespread across the Washington, central Oregon, and southern Oregon study areas. Clastic dikes of at least 5-cm width are

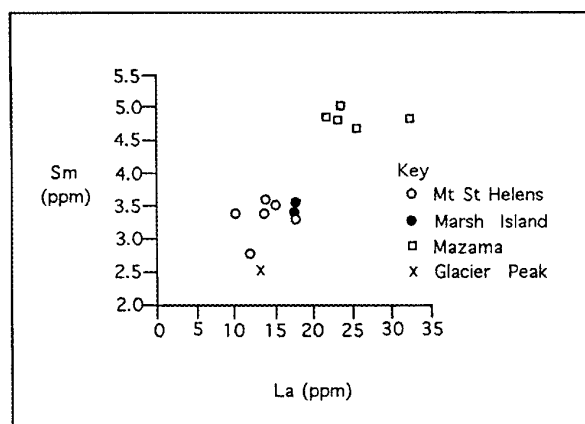


Figure 15. Plot of INAA rare-earth concentrations (Sm=samarium, La=lanthanum) for Marsh Island tephra pumice blocks (solid circles) and other potential tephra sources, including Mazama eruption (open squares), Mount St. Helens eruptions (open circles), and Glacier Peak eruption (x). The Marsh Island tephra geochemistry (Table 3) correlates with the Mount St. Helens source. It is also distinguished from the Mazama and Glacier Peak sources on the basis of Sm/Ce ratios and La/Ce ratios, among others. The data for the Mazama, Mount St. Helens, and Glacier Peak eruptions are taken from a compilation by Gates (1994).

more common (observed in 15 of 25 reported sites). They provide a different indicator for comparing probable response to coseismic liquefaction between the three study areas. Specifically, maximum dike width is assumed to reflect strength of shaking, assuming all other variables to be constant (Obermeier, 1996). Large lateral spreads (i.e., vertical fissures at least 50 cm wide) are possibly related to slope failures and thus are not included in this semiquantitative analysis of moderate-size dikes (5–49 cm wide). Regional plots of maximum dike width in the Pleistocene coastal terraces show a relatively uniform distribution of maximum dike widths along the margin (Figure 17). Within the limit of the coastal terrace positions, there is no apparent correlation between dike size and distance from the trench.

The presumed active structures, i.e., mapped Quaternary surface faults and folds in the southern Oregon study area, yield conflicting evidence of paleoliquefaction. For example, sites T16 and T18 near Coos Bay contain large-scale fluidization features, whereas sites T19–22 in the Cape Arago area do not (Table 1). Long recurrence intervals between ruptures of these upper plate structures might account for the weak paleoliquefaction evidence observed in their immediate vicinities. If that is true, then regional subduction-zone seismicity might dominate the geologic record of coseismic liquefaction. Unfortunately, the question of local versus regional coastal seismicity is left unresolved for the late Pleistocene marine terraces. However, the preliminary evidence of probable coseismic fluidization

Figure 16. Drawings of exposed cut-bank sections from west Sandy River delta (site R13) and Pierce Island (site R17) in the Columbia River valley east of Portland. The south end of the Sandy River delta section contains a pink "tephra" layer that is cut by small clastic dikes. A charcoal sample in contact with the pink layer has a radiocarbon age of 410 ± 70 RCYBP. At the north end of the Sandy River delta section, a wood fragment was collected from the maximum height of dike intrusion. The wood fragment has a radiocarbon age of 250 ± 70 RCYBP. The clastic sills at the bottom of the Sandy River delta north section are shown in Figure 13a. The Pierce Island section includes a radiocarbon age (260 ± 50 RCYBP) on a detrital wood fragment from the top of the intruded sands. Small clastic sills and dikes at the lower left and right, respectively, of the Pierce Island section are shown in Figures 13c and 13d.

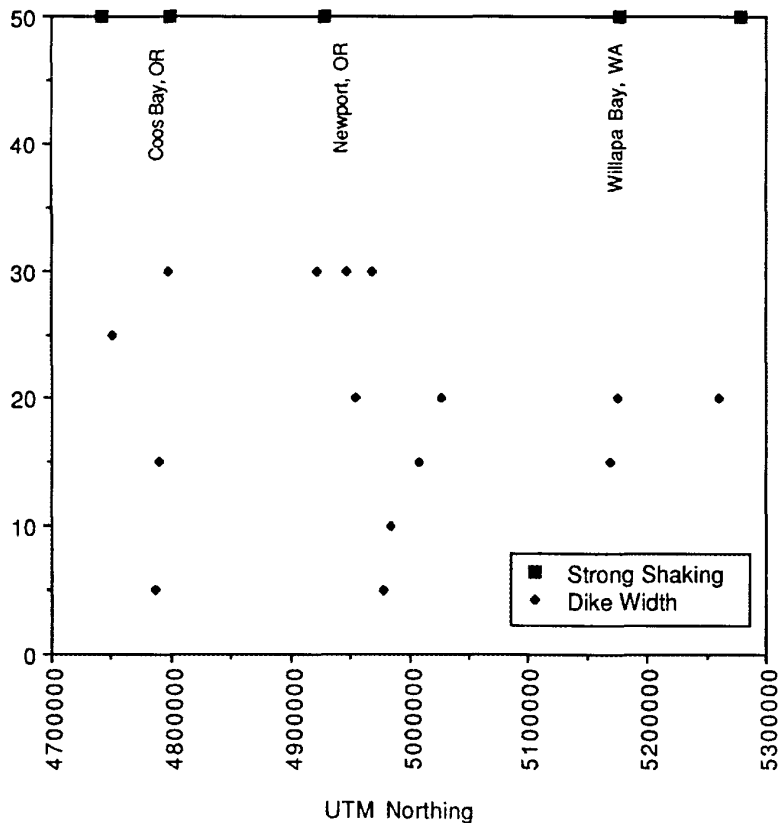
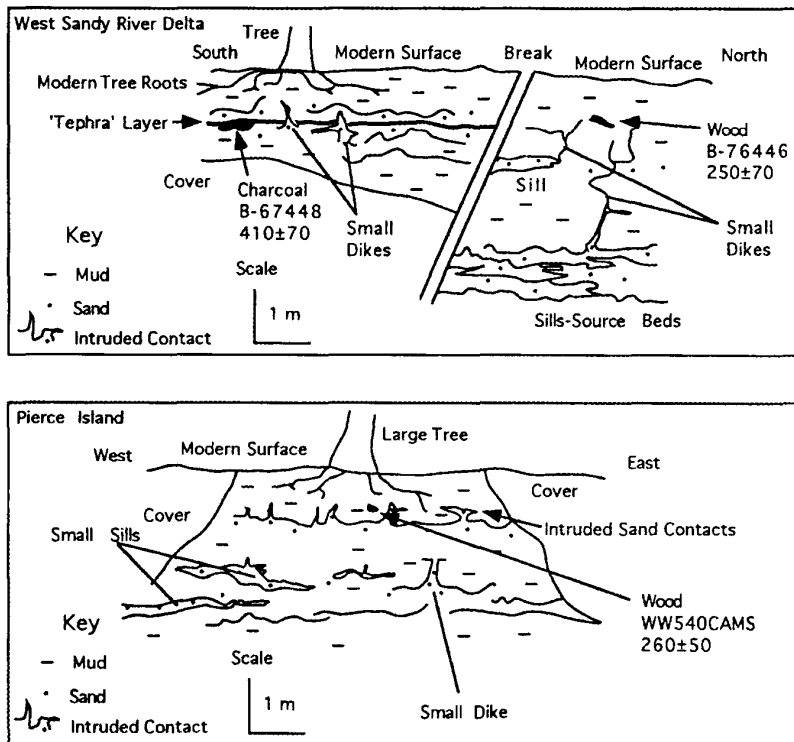


Figure 17. Plot of probable coseismic-fluidization features in late Pleistocene marine terrace deposits (represented as maximum dike widths) as a function of north-south position (UTM coordinates) along the coast. Features interpreted to indicate strong shaking, such as disrupted cobble beds, sheared wave-cut platform surfaces, and lateral spreads, are shown by solid squares for five sites (top of plot). Maximum clastic dike widths between 5 and 30 cm (solid diamonds) are shown for 15 terrace sites.

in the marine terraces of the central Cascadia margin (Peterson and Madin, 1992) is now verified in at least two dozen localities. That is to say that paleoliquefaction evidence of probable seismic origin is widespread in late Pleistocene terrace deposits of coastal Oregon and Washington.

Depositional settings of fluidization features

The largest dikes and lateral spreads in the late Pleistocene deposits are generally found in bay, lagoonal, or thick shoreface settings (sites T3, T10, T15, T16, and T18; Table 1). These settings contain substantial subaqueous sand deposits (5–10 m in thickness), which likely serve as source beds for the larger fluidization features. By comparison, dikes and sills originating in beach backshore settings (sites T8, T9, T11, T21, T23, and T25) rapidly decrease in size and abundance with penetration into overlying eolian dune sand. These relations might reflect dissipation of fluid pore pressure in unsaturated dune deposits. Within the eolian dune facies, the fluidization evidence is often concentrated under low-permeability mud layers, where pore pressures might be locally enhanced. Boundary effects are also apparent in deposits above wave-cut platforms (sites T1 and T14), where cobble plumes, basal shears, and flames are locally concentrated near the platform contacts. Different ground-motion responses between the platform “bedrock” and the overlying unconsolidated deposits might amplify shear stresses near these platform contacts.

In summary, the distribution of observed paleoliquefaction sites within the three study areas of the central Cascadia margin appears to be largely dependent on the presence of exposed deposits that were conducive to cyclic-stress fluidization. The apparent distribution of such deposits is limited by (1) local depositional settings, e.g., facies and groundwater saturation conditions, (2) postdepositional preservation, and (3) modern exposure in cliffs and road cuts. Although liquefaction-susceptible settings are not abundant in the study areas surveyed, they can be found by focused searches of the remnant marine terraces.

Timing of late Pleistocene paleoliquefaction

The relative timing of late Pleistocene paleoliquefaction is constrained at 11 localities by evidence of erosional truncation and subsequent burial of fluidization features. These localities include sites T1–T3, T8–T11, T14, T22–T23, and T25 (Table 1). The probable coseismic liquefaction at these sites was syndepositional with the development of the sedimentary packages above the wave-cut platforms. Vertical upward successions of estuarine, beach, dune, and interdune-pond facies demonstrate that these marine terrace deposits represent transgressive system tracts (TST) or high-stand tracts (HST). At least seven of the late Pleistocene sites possibly record multiple events (two or three) of paleoliquefaction, i.e., vertical successions of erosionally truncated and buried fluidization features. The interpretation of multiple liquefaction events is tentative, and further field work to test this hypothesis is warranted.

On the basis of eustatic sea-level records (Pirazzoli, 1993) and the thickness of the late Pleistocene TST-HST sections (typically 3–8 m in height), the periods of depositional record are probably limited to several thousand years each for the 80-, 105-, and 120-Ka terraces. The multiple events of paleoliquefaction possibly recorded at some of the late Pleistocene sites could indicate two or more earthquakes during the several thousand years of record for each locality. Other evidence of multiple earthquakes during the late Pleistocene TST periods is recorded in northern Oregon marine terraces by vertical sequences of episodic peat burial (Mulder, 1992). These episodes of abrupt wetland subsidence in late Pleistocene time have yet to be directly tied to evidence of sand venting. However, muddy flow features and small dikes are associated with disrupted peaty horizons at two sites (T6 and T7) in the northern Oregon study area (Table 1). Better exposures of the disrupted buried peaty units in the late Pleistocene terraces might reveal sand-vented deposits at the buried peat contacts, thus constraining interpretations of seismic source, as discussed below.

Paleoliquefaction evidence of the A.D. 1700 Cascadia earthquake

The most recent episode of paleoliquefaction in the lower Columbia River valley is directly tied to the last CSZ earthquake through correlation of sand venting with regional coastal subsidence (Obermeier, 1995). The buried-wetland evidence of regional subsidence has not been found upriver (east) of Hunting Island. By comparison, evidence of late prehistoric liquefaction is traced up the Columbia River valley through a series of cutbank localities including sites R10–R17 (Figure 10). Paleoliquefaction at these localities is tentatively correlated to the A.D. 1700 event through (1) generally decreasing maximum size and abundance of fluidization features with increasing distance inland, (2) upper bounding radiocarbon dates at two localities (sites R13 and R17), and (3) lower bounding “tephra” layers cut by clastic dikes and sills at four localities (sites R7, R8, R13, and R15).

Maximum dike widths generally decrease from the lower to the upper river valley (Figure 18). However, strong trends in dike abundance and width also occur over much smaller traverses, i.e., normal to the river valley axis. For example, the maximum dike width in the lower river valley decreases from 30 cm (site R1) to 3 cm (site R2) to zero (no dikes) at Blind Slough (site R3), a distance of only 2.5 km. In the upper river valley, the small dikes at McGuire Island (sites R11 and R12) were not observed at nearby Government Island (site R10). The decreases in dike abundance and maximum width at these two traverses might correspond to increases in thickness of the capping mud layer (Table 2). Other factors not addressed here must account for the observed dike variability within individual outcrops of constant capping-layer thickness (B. Atwater, personal communication, 1995).

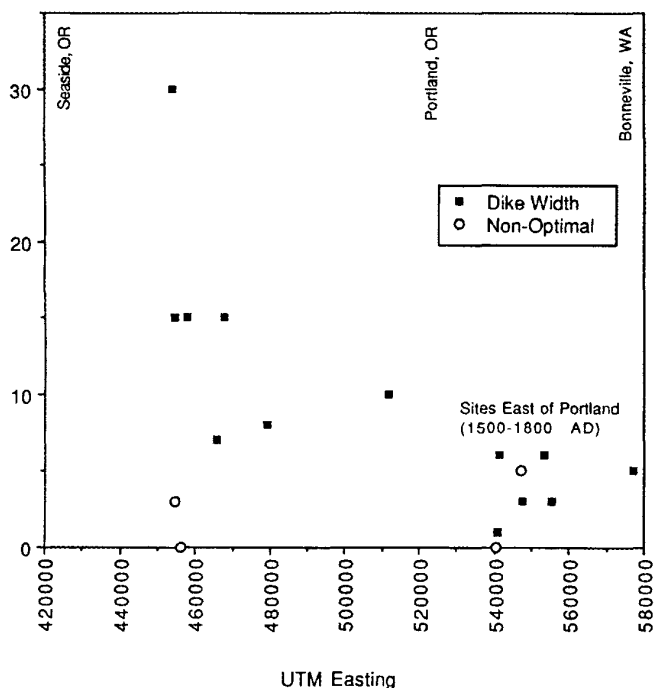


Figure 18. Plot of maximum dike widths in Columbia River island cutbanks as function of position west-east (UTM coordinates) along the Columbia River valley. Cutbanks from optimal sites (shorelines presently adjacent to major river channels) are shown by solid squares. Non-optimal cutbank sites from island interiors that are distal to major river channels are shown by open circles. Measured dikes from the lower Columbia River islands west of Portland are attributed to the last Cascadia earthquake, circa A.D. 1700. Measured dikes from the cutbank sites east of Portland are tentatively correlated with the A.D. 1700 paleoliquefaction event in the western islands but are presently constrained to a broader interval: between A.D. 1500 and 1800.

For this reconnaissance survey we identify optimal fluidization sites in the Columbia River valley on the basis of thin mud caps over thick sand deposits, i.e., islands with cutbanks adjacent to main river channels. These optimal sites (R1, R4, R6, R7, R9, R12, R13, R14, R15, R17) confirm a regional decline of both dike abundance and maximum width over a west-east distance of about 120 km. Simple extrapolation from Figure 18 implies that small sills and rare dikes might have been produced in susceptible deposits further upstream beyond Pierce Island. Unfortunately, the river valley east of Pierce Island, i.e., the Columbia River gorge, is flooded by a series of impoundments.

Radiocarbon ages of wood fragments collected at or immediately above intruded dikes from sites R13 (250 ± 70 RCYBP) and R17 (260 ± 50 RCYBP) place the fluidization at these localities in latest prehistoric time. However, clear evidence of sand venting onto subaerial surfaces has not been established at any of the islands in the upper river valley. The apparent lack of such evidence might be attributed

to poorer preservation potential, thicker mud caps, or less intense shaking relative to the islands of the lower river valley.

The "tephra" layers cut by dikes and sills in islands of the upper river valley are assumed to provide a maximum event age of 500 yr B.P., based on reported Mount St. Helens set W eruptions at about A.D. 1480 (Yamaguchi, 1985). Additional work is needed to verify the eruptive source of the apparent "tephra" layers in islands of the upper river valley. However, a radiocarbon date from charcoal in contact with a cut "tephra" layer exposed in the Sandy River delta (site R13) does yield an age (410 ± 70 RCYBP) that is consistent with a Mount St. Helens set W eruptive source. If verified, these widespread "tephra" layers could provide important key beds for environmental and archaeological investigations in the islands of the Columbia River valley.

Sill-to-dike ratios

One of the general observations of this reconnaissance survey is the high proportion of clastic sills relative to clastic dikes in the central Cascadia margin. At several late Pleistocene sites (T4, T9, T10, T15, and T25), clastic sills are on the order of 10 times more abundant than clastic dike contacts in exposed outcrops. Clastic sills are interpreted to be more abundant than dikes in vibracores of the lower Columbia River islands (Peterson and others, 1994). The abundance of clastic sills increases to about 90 percent of the fluidization features exposed in cutbanks at localities of the upper Columbia River valley (sites R10–R17). The dominance of sills over dikes suggests that fluidization pore pressures were insufficient to penetrate capping layers and/or were laterally dissipated in permeable beds. We hypothesize that the large ratios of sills to dikes might reflect long duration of shaking at modest accelerations, which resulted in long duration of fluidization with moderately elevated pore pressures. Additional work is needed to evaluate the cyclic stress conditions that apparently favor clastic sill development at many localities in the central Cascadia margin.

Null-hypothesis test of M_w 8 subduction zone earthquakes

From the existing evidence of paleoliquefaction in the late Pleistocene marine terraces of Oregon and Washington, we find that the occurrence of subduction zone earthquakes in the M_w 8 range can not be ruled out for the central Cascadia margin. Specifically, the large size and abundance of fluidization features in the late Pleistocene marine terraces argue for strong coastal shaking in late Quaternary time. By comparison, the Cape Mendocino subduction-zone earthquake (M_w 7) is not reported to have produced cobble plumes, basal shears, or extensive lateral spreads (Prentice, Keefer, and Sims, 1992) as they were observed at some of the late Pleistocene paleoliquefaction sites. Such features could arise from shallow upper plate faults and/or from

deeper interplate earthquakes of larger magnitude. The results from this study do not discriminate between local and regional seismic sources for the paleoliquefaction localities in the late Pleistocene terrace deposits.

More diagnostic of potential earthquake magnitude in the central Cascadia margin is the inland extent of paleoliquefaction evidence in the Columbia River valley. Coseismic fluidization that is attributed to the A.D. 1700 Cascadia earthquake is traced up the lower river valley to Deer Island (Obermeier, 1995), a distance of about 85 km from the coast (Figure 10). Fluidization features that fall within a conservative time bracket of 150–500 yr B.P. are traced in the upper river valley to Pierce Island (site R17), a distance of about 150 km from the coast. Based on the 1992 Cape Mendocino earthquake (M_w 7), the possible 150-km extent of coseismic paleoliquefaction in the Columbia River exceeds that to be expected from a M_w 7 interplate rupture. However, this distance should be within reach of an interplate earthquake in the M_w 8 range, assuming local accelerations of 0.1 *g* (Anderson and others, 1994) and attenuation curves predicted for this margin (Geomatrix Consultants, Inc., 1995). Given these preliminary results, we cannot discount a M_w 8.5±0.5 earthquake for the last Cascadia dislocation event about 300 years ago.

A study of paleoliquefaction features produced by the 1964 great Alaskan earthquake (M_w 9) was recently performed, in part, for purposes of comparison to the Cascadia margin (Walsh and others, 1995). The study by Walsh and others concentrated on the preservation of dikes from reported liquefaction sites in fluvial-tidal settings. The forms and scales of fluidization features from the 1964 Alaskan earthquake are not substantially different from those of similar settings in the Cascadia marine terraces or the lower Columbia estuary. The larger fluidization features, i.e., wide dikes and lateral spreads, might be more abundant in the inland Alaska study areas (some 100 km from the coast) than at similar distances from the coast in this Cascadia reconnaissance survey.

Three points raised by Walsh and others (1995) are relevant to the geologic preservation potential of large dikes in fluvial-tidal settings. These points are that (1) large dikes mapped after the 1964 Alaskan earthquake were concentrated near channel margins, sites most susceptible to post-seismic channel erosion; (2) sand fillings in large dikes were selectively eroded by bottom currents following coseismic subsidence; and (3) dike occurrence was widely variable between liquefaction-susceptible areas of similar distance from the epicenter. These factors could diminish the apparent abundance of large clastic dikes in remnant marine terraces and eroded island outcrops of the Columbia River.

Regardless of earthquake magnitude or source, the scale and abundance of paleoliquefaction features along the Oregon coast and up the Columbia River are substantially greater than those produced by historic earthquakes in corresponding settings. For example, the coastal Cape Mendocino earthquake (1992) produced brief peak accelerations of

0.5 *g*, but liquefaction of susceptible deposits was limited to a 30-km radius of the main-shock epicenter. Paleoliquefaction produced by the Cascadia A.D. 1700 earthquake reached at least twice—and possibly five times—that distance inland from the coast. Historic earthquakes in the Portland basin area (Vancouver in 1962 and Scotts Mills in 1993) produced very brief peak accelerations of 0.1 *g*. Although they were locally damaging, these two earthquakes did not result in any reported evidence of liquefaction in susceptible deposits. By comparison, late prehistoric fluidization is widespread in susceptible deposits of the Columbia River islands for distances of at least 50 km both west and east of Portland. In summary, the use of historic earthquakes alone to establish regional or local seismic hazards in western Oregon understates the potential hazard of future earthquakes in the central Cascadia margin.

CONCLUSION

Evidence of strong shaking from cobble plumes, basal shears, lateral spreads, and clastic dikes and abundant sills is widely distributed in late Pleistocene marine terraces of the central Cascadia margin. The patchy distribution of large-scale fluidization features in the marine terraces appears to be related to the preservation and exposure of liquefaction-susceptible deposits. By comparison, no apparent correlations were found between the abundance of large clastic dikes, possible indicators of strong shaking, and relative position along the margin or proximity to mapped upper plate structures. Unfortunately, the late Pleistocene paleoliquefaction evidence from this reconnaissance survey does not discriminate between local or regional seismic sources along the coast.

Late Holocene paleoliquefaction sites in islands of the upper river valley of the Columbia River are tentatively correlated to the last Cascadia earthquake, circa A.D. 1700. This tentative correlation is based on (1) landward attenuation of dike abundance and width, (2) upper bounding radiocarbon dates, and (3) lower bounding “tephra” layers cut by the dikes. If the fluidization features in the upper river valley were produced by the A.D. 1700 Cascadia earthquake, then their distance from the coast (at least 150 km) would argue for a large subduction-zone earthquake (M_w 8.5±0.5).

Historic earthquakes (M_w 7.1 at Cape Mendocino and about M_w 5.5 near Portland) have not produced fluidization features that match the abundance, size, or extent of fluidization features from prehistoric events in corresponding settings of western Oregon. The recent historic earthquakes on the coast or in the Portland-Willamette Valley region do not provide adequate analogs for the local ground motions that could be expected from future earthquakes in the central Cascadia margin.

ACKNOWLEDGMENTS

Much of the paleoliquefaction mapping and vibracoring reported here was performed by undergraduate students in

the Geology Department at Portland State University. We particularly thank Doug Anderson, Scott Craig, Tara Karnes, Brian Peterson, John Siskowic, and Kristi Vockler for their assistance. Roger Hart, Tom Horning, Jim Phipps, Paul See, and other coastal geologists provided us with suggestions about paleoliquefaction sites on the coast. The Instrumental Neutron Activation Analysis (INAA) of tephra layers in the lower Columbia River was performed by Edward Gates. Marvin Beeson assisted with interpretation of the INAA data. This reconnaissance survey of paleoliquefaction evidence in the Cascadia margin was funded by the Oregon Department of Geology and Mineral Industries. Additional support for mapping cross sections in the late Pleistocene localities and for vibrocoring in the lower Columbia River was provided under U.S. Geological Survey service contracts administered by Steve Obermeier and Brian Atwater, respectively. We thank Steve Obermeier for preliminary reviews of this manuscript.

REFERENCES CITED

- Anderson, D.A., Soar, M., Peterson, C.D., and Mabey, M.A., 1994, Amplification modeling of possible coseismic liquefaction at the Sandy River delta, Troutdale, Oregon [abs.]: Oregon Academy of Science, Proceedings, v. 30, p. 39.
- Atwater, B.F., 1987, Evidence for great Holocene earthquakes along the outer coast of Washington State: *Science*, v. 236, p. 942–944.
- , 1992, Geologic evidence for earthquakes during the past 2,000 years along the Copalis River, southern coastal Washington: *Journal of Geophysical Research*, v. 97, p. 1901–1919.
- , 1994, Geology of Holocene liquefaction features along the lower Columbia River at Marsh, Brush, Price, Hunting, and Wallace Islands, Oregon and Washington: U.S. Geological Survey Open-File Report 94–209, 64 p.
- Barnes, M.L., 1995, Geochemistry of the Boring Lava along the west side of the Tualatin Mountains and of sediments from drill holes in the Portland and Tualatin basins, Portland, Oregon: Portland, Ore., Portland State University master's thesis, 182 p.
- Black, G.L., 1996, Earthquake intensity maps for the March 25, 1993, Scotts Mills, Oregon, earthquake: *Oregon Geology*, v. 58, no. 2, p. 35–41.
- Bott, J.D.J., and Wong, I.G., 1993, Historical earthquakes in and around Portland, Oregon: *Oregon Geology*, v. 55, no. 5, p. 116–122.
- Briggs, G.G., 1994, Coastal crossing of the elastic strain zero-isobase, Cascadia margin, south-central Oregon coast: Portland, Ore., Portland State University master's thesis, 251 p.
- Clifton, H.E., 1994, Transgressive and early highstand systems tracts: Pleistocene terrace deposits, Willapa Bay, Washington: Field Trip Guide SEPM Research Conference, Clastic Deposits of the Transgressive Systems Tract, Long Beach, Wash., 1994.
- Craig, W.S., Peterson, C.D., Travis, P., Meek, M., Wieneke, D., Soar, M., and Bertelling, J., 1993, Shallow subsurface stratigraphy of late Holocene coseismic liquefaction sites in the Columbia River, Central Cascadia margin, USA [abs.]: *EOS*, v. 74, no. 43 suppl., p. 199.
- Darlenzo, M.E., 1991, Late Holocene paleoseismicity along the northern Oregon coast: Portland, Ore., Portland State University doctoral dissertation, 167 p.
- Darlenzo, M.E., and Peterson, C.D., 1995, Magnitude and frequency of subduction-zone earthquakes along the northern Oregon coast in the past 3,000 years: *Oregon Geology*, v. 57, no. 1, p. 3–12.
- Fiegel, G.L., and Kutter, B.L., 1994, Liquefaction mechanism for layered soils: *Journal of Geotechnical Engineering*, ASCE, v. 120, p. 737–755.
- Florer, L.E., 1972, Quaternary paleoecology and stratigraphy of the sea cliffs, western Olympic Peninsula, Washington: *Quaternary Research*, v. 2, p. 202–216.
- Gates, E.B., 1994, The Holocene sedimentary framework of the lower Columbia River basin: Portland, Ore., Portland State University master's thesis, 210 p.
- Geomatrix Consultants, Inc., 1995, Seismic design mapping, State of Oregon: Final report to Oregon Department of Transportation, Project no. 2442, var. pag.
- Goldfinger, C., Kulm, L.D., Yeats, R.S., Mitchell, C., Weldon, R., II, Peterson, C., Darienzo, M., Grant, W., and Priest, G.R., 1992, Neotectonic map of the Oregon continental margin and adjacent abyssal plain: Oregon Department of Geology and Mineral Industries Open-File Report O-92-4, 17 p., 2 plates.
- Holzer, T.L., and Clark, M.M., 1993, Sand boils without earthquakes: *Geology*, v. 21, p. 873–876.
- Jaeger, H.M., Nagel, S.R., and Behringer, R.P., 1996, The physics of granular materials: *Physics Today*, v. 49, no. 4, p. 32–38.
- Jayko, A.S., Marshall, G.A., and Carver, G.A., 1992, Elevation changes [Cape Mendocino earthquakes of April 25–26, 1992]: *Earthquakes and Volcanoes*, v. 23, no. 3, p. 139–143.
- Kelsey, H.M., 1990, Late Quaternary deformation of marine terraces on the Cascadia subduction zone near Cape Blanco, Oregon: *Tectonics*, v. 9, p. 983–1014.
- Kelsey, H.M., Witter, R.C., and Polenz, M., 1993, Cascadia paleoseismic record derived from late Holocene fluvial and lake sediments, Sixes River Valley, Cape Blanco, south coastal Oregon [abs.]: *EOS*, v. 74, no. 43 suppl., p. 199.
- Kennedy, G.L., Lajoie, K.R., and Wehmiller, J.F., 1982, Aminostratigraphy and faunal correlations of late Quaternary marine terraces, Pacific coast, USA: *Nature*, v. 299, p. 545–547.
- Kolb, C.R., 1976, Geologic control of sand boils along Mississippi River levees, in Coats, D.R., ed., *Geomorphology and engineering*: Halstead Press, p. 99–114.
- Madin, I.P., McInelly, G.W., and Kelsey, H.M., 1995, Geologic map of the Charleston quadrangle, Coos County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-94, scale 1:24,000.
- Madin, I.P., Priest, G.R., Mabey, M.A., Malone, S., Yelin, T.S., and Meier, D., 1993, March 25, 1993, Scotts Mills earthquake—western Oregon's wake-up call: *Oregon Geology*, v. 55, no. 3, p. 51–57.
- McInelly, G.W., and Kelsey, H.M., 1990, Late Quaternary tectonic deformation in the Cape Arago-Bandon region of coastal Oregon as deduced from wave-cut platforms: *Journal of Geophysical Research*, v. 95, no. B5, p. 6699–6713.
- Michael, A., Oppenheimer, D., and Reasenber, P., 1992, Preliminary seismological results [Cape Mendocino earthquakes of April 25–26, 1992]: *Earthquakes and Volcanoes*, v. 23, no. 3, p. 110–115.
- Mulder, R.A., 1992, Regional tectonic deformation of the northern Oregon coast as recorded by Pleistocene marine terraces: Portland, Ore., Portland State University master's thesis, 96 p.
- Muhs, D.R., Kelsey, H.M., Miller, G.H., Kennedy, G.L., Whelan, J.F., and McInelly, G.W., 1990, Age estimates and uplift rates for late Pleistocene marine terraces: Southern Oregon portion of the Cascadia forearc: *Journal of Geophysical Research*, v. 95, no. B5, p. 6685–6698.
- Mullineaux, D.R., 1986, Summary of pre-1980 tephra-fall deposits erupted from Mount St. Helens, Washington State, USA: *Bulletin of Volcanology*, v. 48, no. 1, p. 17–26.
- Nabelek, J., and Xia, G., 1995, Moment-tensor analysis using regional data: Application to the 25 March, 1993, Scotts Mills, Oregon earthquake: *Geophysical Research Letters*, v. 22, p. 13–16.
- Nataraja, M.S., and Gill, H.S., 1983, Ocean-wave-induced liquefaction analysis: *Journal of Geotechnical Engineering*, ASCE, v. 109, p. 573–590.
- National Research Council, 1985, Liquefaction of soils during earthquakes: Washington D.C., National Academy Press, 240 p.
- Obermeier, S.F., 1995, Preliminary estimates of the strength of prehistoric shaking in the Columbia River valley and the southern half of coastal Washington, with emphasis for a Cascadia subduction zone earthquake about 300 years ago: U.S. Geological Survey Open-File Report 94–589, 46 p.
- , 1996, Use of liquefaction-induced features for paleoseismic analysis. An overview of how seismic liquefaction features can be distinguished from other features and how regional distribution and properties of source sediment can be used to infer the location and strength of Holocene paleoearthquakes: *Engineering Geology*, v. 44, p. 1–76.
- Obermeier, S.F., Atwater, B.F., Benson, B.E., Peterson, C.D., Moses, L.J., Pringle, P.T., and Palmer, S.P., 1993, Liquefaction about 300 years ago along tidal reaches of the Columbia River, Oregon and Washington [abs.]: *EOS*, v. 74, no. 43 suppl., p. 198.
- Oppenheimer, D., Beroza, G., Carver, G., Dengler, L., Eaton, J., Gee, L., Gonzalez, F., Jayko, A., Li, W.H., Lisowski, M., Magee, M., Marshall, G., Murray, M., McPherson, R., Romanowicz, B., Satake, K., Simpson, R., Somerville, P., Stein, R., and Valentine, D., 1993, The Cape Mendocino, California, earthquakes of April 1992: Subduction at the Triple Junction: *Science*, v. 261, p. 433–438.

DOGAMI PUBLICATIONS AND RELEASES

- Palmer, S.P., 1990, Geotechnical analysis of liquefaction in Puyallup during the 1949 and 1965 Puget Sound earthquakes: Washington Geologic Newsletter, v. 18, no. 3, p. 3-7.
- Peterson, B., Peterson, C.D., Vockler, K., Wyatt, J., Marsh, M., Rose, G., and Horning, T., 1994, Vibracore subsurface investigation of a late Holocene liquefaction site in the central Cascadia margin: Hunting Island, Columbia River, Washington: Unpublished field study report to U.S. Geological Survey, 12 p.
- Peterson, C.D., Darienzo, M.E., Pettit, D.J., Jackson, P., and Rosenfeld, C., 1991, Littoral cell development in the convergent Cascadia margin of the Pacific Northwest, USA, in Osborne, R.H., ed., From shoreline to abyss: Contributions to marine geology in honor of Francis Parker Shepard: Society for Sedimentary Geology (SEPM) Special Publication 46, p. 17-34.
- Peterson, C.D., Hansen, M., and Jones, D., 1991, Widespread evidence of paleoliquefaction in late Pleistocene marine terraces from the Oregon and Washington margins of the Cascadia subduction zone [abs.]: EOS, v. 72, no. 44 suppl., p. 313.
- Peterson, C.D., and Madin, I.P., 1992, Variation in form and scale of paleoliquefaction structures in late Pleistocene deposits of the central Cascadia margin [abs.]: Geological Society of America Abstracts with Programs, v. 24, no. 5, p. 74.
- Peterson, G.L., 1968, Flow structures in sandstone dikes: Sedimentary Geology, v. 2, p. 177-190.
- Pirazzoli, P.A., 1993, Global sea-level changes and their measurement: Global and Planetary Change, v. 8, p. 135-148.
- Prentice, C.S., Keefer, D.K., and Sims, J.D., 1992, Surface effects of the earthquakes [Cape Mendocino earthquakes of April 25-26, 1992]: Earthquakes and Volcanoes, v. 23, no. 3, p. 127-134.
- Rau, W.W., 1973, Geology of the Washington coast between Point Grenville and the Hoh River: Washington Division of Geology and Earth Resources Bulletin 66, 58 p.
- Saucier, R.T., 1989, Evidence for episodic sand-blow activity during the 1811-1812 New Madrid (Missouri) earthquake series: Geology, v. 17, no. 2, p. 103-106.
- Seed, H.B., and Idriss, I.M., 1982, Ground motions and soil liquefaction during earthquakes: Earthquake Engineering Research Institute Monograph, 134 p.
- Seed, H.B., Tokimatsu, K., Harder, L.F., and Chung, R.M., 1985, Influence of SPT procedures in soil liquefaction resistance evaluations: Journal of Geotechnical Engineering, ASCE, v. 111, p. 1425-1445.
- Shulene, J.A., 1990, Evidence of liquefaction in the Puyallup Valley: Washington Geologic Newsletter, v. 18, no. 2, p. 15-16.
- Stokoe, K.H., Andrus, R.D., Rix, G.J., Sanchez-Salinero, I., Sheu, J.C., and Mok, Y.J., 1988, Field investigation of gravelly soils which did and did not liquefy during the 1983 Borah Peak, Idaho, earthquake: Austin, Tex., University of Texas Geotechnical Engineering Center, Geotechnical Engineering Report GR87-1, 206 p.
- Siskowic, J.D., Anderson, D.A., Peterson, B., Peterson, C.D., Soar, M., Travis, P., and Vockler, K., 1994, Possible coseismic liquefaction evidence at the Sandy River delta, Portland, Oregon: Tentative correlation with the last great Cascadia rupture [abs.]: Geological Society of America Abstracts with Programs, v. 26, no. 2, p. 92.
- Ticknor, R., 1993, Late Quaternary crustal deformation on the central Oregon coast as deduced from uplifted wave-cut platforms: Bellingham, Wash., Western Washington University master's thesis, 70 p.
- Tuttle, M., and Seeber, L., 1991, Historic and prehistoric earthquake-induced liquefaction in Newbury, Massachusetts: Geology, v. 19, p. 594-597.
- Vockler, K., Anderson, D., Peterson, B., Peterson, C., Siskowic, J., Soar, M., and Travis, P., 1994, Discrimination of liquefaction-inducing events (lahar, flood, and seismic) at the Sandy River delta, Troutdale, Oregon [abs.]: Geological Society of America Abstracts with Programs, v. 26, no. 2, p. 101.
- Walsh, T.J., Combellick, R.A., and Black, G.L., 1995, Liquefaction features from a subduction zone earthquake: Preserved examples from the 1964 Alaska earthquake: Washington Division of Geology and Earth Resources Report of Investigations 32, 80 p.
- Yamaguchi, D.K., 1985, Tree-ring evidence for a two-year interval between recent prehistoric explosive eruptions of Mount St. Helens: Geology, v. 13, no. 8, p. 554-557.
- Yelin, T.S., and Patton, H.J., 1991, Seismotectonics of the Portland, Oregon, region: Seismological Society of America Bulletin, v. 81, no. 1, p. 109-130.
- Youd, T.L., 1991, Mapping of earthquake-induced liquefaction for seismic zonation, in International Conference on Seismic Zonation, 4th, August 1991, Stanford, Calif., Proceedings: Oakland, Calif., Earthquake Engineering Research Institute, p. 111-147. □

Released April 24, 1997

Estimates of Coastal Subsidence from Great Earthquakes in the Cascadia Subduction Zone, Vancouver Island, B.C., Washington, Oregon, and Northernmost California, by a team of scientists from Portland State University, Humboldt State University, and the Geological Survey of Canada. Open-File Report O-97-05, 19 p. text and illustrations, 25 p. tabular data, \$6.

The report presents estimates of drops in ground level (subsidence) that can be caused by great earthquakes along the Pacific Northwest coast. The results can aid in the evaluation of shoreline erosion and coastal flooding that might result from earthquake-related subsidence.

Great subduction-zone earthquakes can result in coastal subsidence of up to a few meters and cause coastal flooding and beach erosion that may persist for decades. It has been estimated that an earthquake-related subsidence of 75 cm (about 30 inches) at Siletz Bay would cause 50 m (about 55 yards) of beach retreat. Such catastrophic beach erosion would lead to faster undercutting of bluffs and failures of sea cliffs.

Estimates of subsidence were derived from the study of various indicators of past changes in tide levels, such as buried peat and certain fossils. Data in the report were obtained from more than a dozen different studies supported by U.S., State, and Canadian Provincial grants and contracts during the last ten years. The final compilation was supported by the National Oceanic and Atmospheric Administration (NOAA) and by appropriations made by the Oregon State Legislature.

The following release is available for inspection in the libraries of the DOGAMI offices in Portland and Grants Pass. It is not published in multiple copies and is not for sale but limited to library access only. Photocopies may be obtained at cost.

Released April 21, 1997

Preliminary Geologic Map of the Southwest Part of the Medford 30 x 60 Minute Quadrangle, Oregon and California, by Jad D'Allura, Southern Oregon State College, in cooperation with DOGAMI. Open-File Report O-97-03, 1 map sheet (scale 1:100,000), 23 p. text. Library access only.

The area covered extends approximately from Ashland toward the southwest to the Siskiyou Mountains and the California border and includes eight 7½-minute quadrangles: Sterling Creek, Talent, Ashland, Emigrant Lake, Siskiyou Pass, Mount Ashland, Siskiyou Peak, and Dutchman Peak. The text contains explanations of the rock units presented on the map, the geologic history, composition, and structure, and radiometric age determinations of 15 samples collected in the area. □

About predicting earthquakes

Earthquakes cannot be predicted. This is the considered conviction of scientists Robert J. Geller of Tokyo University, David D. Jackson and Yan Y. Kagan of the University of California at Los Angeles, and F. Mulargia of the University of Bologna. In the March 14, 1997, issue of *Science* they discuss the consensus of a meeting on the subject that was held in London in late 1996.

- Faults, the places where earthquakes originate, are "notoriously intractable," i.e., they are generally inaccessible to direct measurements.
- It would be, of course, most valuable to be able to predict large earthquakes. However, the current assessment is that the Earth is "in a state of self-organized criticality," which means that any small earthquake could develop into a large one. The uncountable details that make up the initial conditions for a given earthquake in a given place and time may come from an area much broader than just the immediate vicinity of the fault. Being able to know all the relevant details is so highly unlikely as to be inherently impossible—aside from the fact that we have no theory that can analyze such data and arrive at a prediction.
- The various "anomalous" phenomena that have been offered as precursors to earthquakes cannot reasonably be claimed as such. Their significance was "seen" only after the event; they do not show consistent patterns; and there are no definitions, physical mechanisms, or statistics that would allow a correlation between the alleged precursors and earthquakes.
- Claims that, in China, one earthquake in 1975 was successfully predicted are questionable, because the claim that "very few people were killed" conflicts with official reports of over 1,300 deaths and almost 17,000 injuries. Reports on that earthquake may have been distorted under political pressure. A swarm of microearthquakes beginning over 24 hours before the main shock may have done enough to motivate people to evacuate spontaneously.
- A scientific theory linking geoelectric observations with earthquakes in Greece has been found to be without scientific merit.
- The question that remains is whether prediction of earthquakes is "inherently impossible or just fiendishly difficult." But in practice, the difference does not matter. In view of the unsuccessful attempts over more than 100 years, continued thorough scientific research would require so much effort that it "seems unwise to invest heavily in monitoring possible precursors."

However, while prediction does not seem to be a worthwhile goal to pursue, hazard mitigation does profit from scientific efforts. Statistical estimates of expected seismicity and expected strong ground motion can be developed as data for earthquake preparedness, such as the designing of earthquake-resistant structures. The ability to quickly deter-

mine sources and magnitudes of earthquakes will help with disaster relief efforts. Being able to warn coastal areas of tsunamis from undersea earthquakes will save many lives. Such efforts are indeed "where earthquake research can greatly benefit the public." □

Geologic-hazard slide sets available

The National Geophysical Data Center of the National Oceanic and Atmospheric Administration (NOAA) offers a variety of educational slide sets depicting the effects of earthquakes, tsunamis, landslides, and volcanic eruptions. Each of the sets costs \$30 and consists of 20 slides in color or black-and-white, documentation that provides background material, dates, locations, and descriptions of effects for the depicted hazards. The slides are suitable for both technical and nontechnical audiences. We are reprinting a partial list of what is available.

Landslides

Depicts diverse types of landslides and mass wasting. Photos were taken at various locations in the United States, Canada, Australia, Peru, and Switzerland. Of particular interest are views of the famous 1903 rock slide at Frank, Alberta, Canada, that covered the town of Frank in less than two minutes, and the 1970 earthquake-induced rock and snow slide that buried the towns of Yungay and Ranrahirca in Peru. (Color; 647-A11-006)

Earthquake damage—general

Illustrates several kinds of effects caused by 11 earthquakes in seven countries and four states in the United States. Pictures show surface faulting, landslides, soil liquefaction, and structural damage. This set is designed to give an overview and summary of earthquake effects. (Color; 647-A11-001)

Earthquake damage, San Francisco, California, April 18, 1906

Includes a panoramic view of San Francisco in flames a few hours after the earthquake, damage scenes from the area, and other unique photographs. (B&W; 647-A11-002)

Earthquake damage, Mexico City, September 1985

Shows different types of damaged buildings and major kinds of structural failure including collapse of top, middle, and bottom floors and total building failure. The effect of the subsoils on the earth's shaking and on building damage is emphasized. (Color; 647-A11-003)

Earthquake damage, Loma Prieta, October 1989, Set 1—Loma Prieta vicinity

Includes damage in Boulder Creek, Aptos, Los Gatos, San Jose, Santa Cruz, Scott's Valley, and Watsonville. The slides also depict earth cracks and structural damage to

homes in the Santa Cruz mountains. (Color; 641-A11-012)

Set 2—San Francisco and Oakland

Highlights the damage in the Marina area of San Francisco. The set also includes photographs of the damaged building in the area south of Market Street where five deaths occurred, the now famous damage to the San Francisco-Oakland Bay Bridge, and the Cypress Section of the Nimitz Freeway (I-880) where 41 deaths occurred. (Color; 647-A11-013)

Earthquake damage, Northridge, January 17, 1994

Set 1—Community of Northridge

This set of slides depicts the damage in the immediate area of the epicenter of this destructive earthquake. Photos showing damage to shopping centers, parking garages, and the interior and exterior of apartment buildings are included. (Color; 647-A11-018)

Set 2—Communities other than Northridge

This set of slides depicts some of the severely damaged structures in Sylmar, Fillmore, Granada Hills, Reseda, Van Nuys, Sherman Oaks, Chatsworth, Santa Monica, and Los Angeles. (Color; 641-A11-019)

Earthquake damage to transportation systems

Depicts earthquake damage to streets, highways, bridges, overpasses, and railroads caused by 12 earthquakes in Guatemala, Japan, Mexico, Armenia, and five states in the United States. Views of structural damage to the San Francisco-Oakland Bay bridge and the Nimitz Freeway (I-880) sustained in the October 1989 earthquake are included. (B&W/color; 641-A11-004)

Earthquake damage to schools

Nine destructive earthquakes that occurred in the United States and eight earthquakes that occurred in foreign countries from 1886 to 1988 are depicted. The set graphically illustrates the potential danger that major earthquakes pose to school structures. The photograph taken in 1886 of the damage at Charleston College, Charleston, South Carolina, is of special interest since it is an illustration of earthquake damage possible on the east coast of the United States. (B&W/color; 647-A11-005)

Earthquake damage, great Alaska earthquake, March 1964

Shows geologic changes; damage to structures, transportation systems, and utilities; and tsunami damage. Features the effects of four major landslides in Anchorage, including the Fourth Avenue and Turnagain Heights landslides. (Color; 641-A11-007)

Earthquake damage, southern California, 1979–1989

Shows earthquake damage from the following events: Imperial Valley, 1979; Westmorland, 1981; Palm Springs, 1986; and Whittier, 1987. Partially and totally collapsed

buildings resulting from the Whittier Narrows earthquake are shown. (Color; 647-A11-008)

Earthquake damage, central California, 1980–1984

Shows earthquake damage from the following events: Livermore, 1980; Coalinga, 1983; and Morgan Hill, 1984. Several totally and partially collapsed buildings in the downtown area of Coalinga are shown. (Color; 641-A11-009)

Earthquake damage, Armenian SSR, December 1988

Includes damage photographs taken in and around the devastated cities of Spitak and Leninakan, where 25,000 deaths occurred. Illustrates the structural types that were vulnerable to failure. This set shows that inadequate building construction combined with shaking from a moderate earthquake can result in high death tolls and tremendous economic loss. (Color; 647-A11-011)

Earthquake damage, northern Iran, June 21, 1990, engineering aspects

This set depicts damage resulting from intensive ground motion and soil liquefaction. It shows damage to buildings of various types, including unreinforced masonry, steel structures, and concrete buildings. Damage to infrastructure is also shown. (Color; 647-A11-014)

Earthquake damage, the Cape Mendocino earthquakes, April 25 and 26, 1992

Illustrates effects of a moderately large earthquake and moderate aftershocks in a sparsely settled area. Includes damage in Rio Dell, Scotia, Honeydew, Petrolia, and Ferndale, California. (Color; 647-A11-016)

Earthquake damage, the Landers and Big Bear earthquakes, June 28, 1992

Damage photos from a magnitude 7.6 earthquake in southern California and a magnitude 6.7 earthquake occurring 17 miles away about three hours later. Examples of structural damage, liquefaction, surface faulting, and landslides. (Color; 641-A11-011)

Earthquake damage, the San Fernando Valley earthquakes, February 9, 1971, and January 17, 1994

This set of slides compares and contrasts these two earthquakes that were separated by ten miles and about 23 years. Disproving the notion that once an earthquake has occurred, an area is "safe" from future earthquakes, these two events affected much of the same area and even some of the same structures. (Color; 647-A11-020)

Tsunamis—general

Depicts advancing waves, harbor damage, and structural damage from seven tsunami events that have occurred since 1946 in the Pacific region. The set includes before-and-after views of Scotch Cap Lighthouse (the Aleutian Islands), which was completely washed away by a wave of

more than 30 meters. A somewhat out-of-focus, but nevertheless unique photograph of a man about to be inundated by a huge wave that destroyed the Hilo, Hawaii, waterfront is also included. (B&W/Color; 648-A11-001)

The major tsunamis of 1992—Nicaragua and Indonesia

The slide set shows damage from the two major tsunami events of 1992—the September tsunami along Nicaragua's Pacific coast (6 slides), and the December tsunami in the Flores region of Indonesia (14 slides). The slides illustrate how a tsunami may affect an area economically and ecologically. (Color; 64S-A11-002)

The Hokkaido Nansei-Okai tsunami, July 12, 1993

The slides show the result of one of the largest tsunamis in Japan's history. It caused spectacular localized damage, especially on the southwestern shores of Hokkaido, and on Okushiri Island. The set includes views of damage to ships, dwellings, and businesses and unique views of clocks stopped in time by the tsunami. (Color; 648-A11-003)

Most of the slide sets, except for the more recent ones, have been digitally scanned and replicated on a two-volume CD-ROM set (1115-A27-001) that sells for \$71.

Images on the CDs are in both a 24-bit TIF image and a compressed 8-bit PCX image. Included with each image is the caption. These images can be imported into many standard software packages. Windows-based access software, for PCX images only, is provided. Please note that the display quality of these images is strongly influenced by the resolution of your computer's graphics card.

These slide sets and similar ones on volcanic hazards can be ordered from

National Geophysical Data Center
NOAA, E/GC1, Dept 953
325 Broadway
Boulder, CO 80303, U.S.A.
Phone: 303-497-6607
Fax: 303-497-6513
Voice/TDD: 303-497-6958
Telex: 592811 NOAA MASC BDR
Internet: info@ngdc.noaa.gov

U.S. Department of Commerce regulations require prepayment on all orders, with the exception of orders from U.S. agencies. Also, due to recent legislation, prices are subject to change without notice. Call for price verification. Please refer to the product number when ordering.

Make checks and money orders payable to COMMERCE/NOAA/NGDC. Do not send cash. All non-U.S.A. orders must be in U.S. Dollars drawn on a U.S.A. bank. A ten-dollar (\$10) handling fee is required for delivery outside the U.S.A. Orders may be charged to American Express, MasterCard, or VISA by phone, letter, or fax. Please include a credit card account number, expiration date, telephone number, and your signature with your order. □

THESIS ABSTRACTS

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

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 leveling surveys. Both methods detect only relative motion, but the two entirely independent data sets produce comparable profiles along the coast. The leveling 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.

Numerical modeling of tsunamis with applications to the Sea of Japan and the Pacific Northwest, by Edward P. Myers, III (M.S., Oregon Graduate Institute of Science and Technology, 1994), 161 p.

Recent evidence along the Oregon and Washington coastlines suggests that the Pacific Northwest experiences great subduction earthquakes every 200 to 600 years. Such events appear to occur as the Juan de Fuca tectonic plate subducts beneath the North American plate in what is termed the Cascadia Subduction Zone. These earthquakes are estimated to range between 8 and 9 on the magnitude scale and cause sufficient displacement in the sea floor to generate large tsunamis.

This evidence provides the incentive for numerical modeling of tsunamis. Two test cases are used as the framework for evaluating the ability of a numerical model to represent tsunami wave activity. A finite element approach is used that shows that a wave continuity formulation is capable of handling such tsunami simulations. Details of initial and boundary conditions are provided, taking into account a moving sea floor and allowing waves to travel undisturbed through transmissive boundaries.

Principles of mass conservation and energy conservation are used as benchmarks for how well the physics is represented in the systems. Such results have historically not been presented in numerical studies of tsunamis. A detailed evaluation of them here shows that mass is generally well conserved while energy is not. Some of the energy loss can

be taken into account by energy leaving the domain through transmissive boundaries, yet problems still occur during the early time steps, when initial conditions have been imposed and when the waves interact with land boundaries. My interpretation is that both of these situations are ones in which vertical accelerations are important. However, the shallow-water equations assume a hydrostatic approximation that neglects pressure gradients due to vertical accelerations. It is therefore possible that the shallow-water equations do not inherently conserve energy.

The July 7, 1993, Hokkaido Nansei-Oki tsunami is used to test the ability of the model to reproduce observed wave forms at tidal gauge stations. This involves calibration with respect to seismic source scenarios, friction, and diffusion. Wave forms are reasonably reproduced at near-field stations, yet far-field stations show differences in amplitude and wavelength. If the width and length of the fault plane are correctly specified, the numerical results at near-field stations suggest that fault plane models are able to generate initial conditions quite well.

Two seismic source scenarios are then considered for the Pacific Northwest. Wave forms are computed for various coastal locations, and patterns of energy distribution are displayed. Such information should be useful for coastal communities in terms of what types of waves would be arriving near their portion of the coastline and what regions may be more susceptible to energy focusing. Uncertainty remains, in particular regarding the source mechanism, because computed subsidence from fault plane models for both scenarios is less than what field evidence from past subduction events suggests. □

History of mapping can be a puzzle

Some time not too long ago, we tried to determine the location of a 1960 master's thesis in the DOGAMI library collection. The title said, "northwest quarter Alvord Lake Three quadrangle," but we could not find any record of a quadrangle by that name. Finally, Peter Stark of the University of Oregon map library responded to our call for help with the following explanation:

"We have a 1946 U.S. Army Corps of Engineers topo map index/progress sheet for Oregon/Washington/Idaho/western Montana. In places where no mapping was completed or even started or projected, the Corps went ahead and named all the possible 30-minute quadrangles. The Alvord Lake 30-minute quadrangle was named at that time.

"In keeping with the military way of numbering quadrangles even further to describe larger scale mapping, the numbers 1, 2, 3, or 4 were added to the 30-minute name to designate 15-minute maps (Alvord Lake 1 = NE 15-minute segment, 2 = NW, 3 = SW, 4 = SE). Even though Alvord Lake and many other quadrangle maps numbered in this way were never published, the name/number system served as a locating convention for many years.

"Our student used this convention to describe the area he

BOOK REVIEW

by Beverly F. Vogt

Fire, Faults and Floods: A Road and Trail Guide Exploring the Origins of the Columbia River Basin, by Marge and Ted Mueller, 1997, University of Idaho Press, paperback, 288 p., \$19.95

This wonderful little book tells two geologic stories—the story of the Columbia River Basalt Group and the story of the catastrophic floods from Glacial Lake Missoula. It covers the Columbia River country from Montana to the Pacific Ocean. The introductory section introduces the reader to plate tectonics, the Glacial Lake Missoula Floods, some general concepts of the regional geology, and the Columbia River Basalt Group. Each of the ten chapters that follow introduces the geology of a specific area, along with descriptions of interesting roads or trails to follow. Included are 95 photos and 80 maps and illustrations.

If you were ever curious about the geology of the area covered by the book, this is the way to find out about it. If you already have a nodding acquaintance with the geology but have ever wondered such things as the story of the Blue Lake Rhino, which Columbia River basalt flows reached the coast, how Grand Coulee was formed, where the ancestral Columbia River flowed, or where to find ring dikes or giant ripple marks from the Missoula floods, this is the book for you. It has maps and directions on how to reach these and many other interesting features—and as a bonus provides diagrams explaining how they formed.

The authors have written ten other books on the Pacific Northwest. The geology in this book is presented in non-technical terms and is accompanied with other information about such topics as history, plant life, wild life, petroglyphs, and recreational opportunities. One of the authors confesses that before he was bitten by the geology bug, he thought the scenery of area was "unendingly boring." Luckily for us, he and his wife learned about geology and chose to share what they learned—because if you travel through the Columbia River Basin with this book in hand, you will be introduced to a variety of wonders that you never suspected existed. *Fire, Faults and Floods* may be purchased from the Nature of the Northwest Information Center or your neighborhood book seller. □

mapped, even though there was no topographic mapping for this area. [He used a base map by the Oregon State Highway Department—ed.]

"Applying this scheme to the northwest quarter of the Alvord Lake Three quadrangle, I come up with the modern USGS quadrangle name 'Robbers Roost' . . ."

Indeed, this area was not mapped until production of the familiar USGS topographic maps had progressed to 7½-minute coverage. Only at the 7½-minute level do we have complete topographic coverage of the state of Oregon. The historic event of finishing this work came 1991, after a 42-year effort (see *Oregon Geology* of May 1990). □

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

Price☑

GMS-75	Portland 7½' quadrangle, Multn., Wash., Clark Counties. 1991	7.00
GMS-76	Camas Valley 7½' quadrangle, Douglas and Coos Counties. 1993	6.00
GMS-77	Vale 30×60 minute quadrangle, Malheur County. 1993	10.00
GMS-78	Mahogany Mountain 30×60 minute quadrangle, Malheur C. 1993	10.00
GMS-79*	Earthquake hazards, Portland 7½' quad., Multnomah C. 1993	20.00
GMS-80*	McLeod 7½' quadrangle, Jackson County. 1993	5.00
GMS-81*	Tumalo Dam 7½' quadrangle, Deschutes County. 1994	6.00
GMS-82*	Limber Jim Creek 7½' quadrangle, Union County. 1994	5.00
GMS-83*	Kenyon Mountain 7½' quadrangle, Douglas/Coos Counties. 1994	6.00
GMS-84*	Remote 7½' quadrangle, Coos County. 1994	6.00
GMS-85*	Mount Gurney 7½' quadrangle, Douglas/Coos Counties. 1994	6.00
GMS-86*	Tenmile 7½' quadrangle, Douglas County. 1994	6.00
GMS-87*	Three Creek Butte 7½' quadrangle, Deschutes County. 1996	6.00
GMS-88*	Lakecreek 7½' quadrangle, Jackson County. 1995	8.00
GMS-89*	Earthquake hazards, Mt. Tabor 7½' quad., Multnomah C. 1995	10.00
GMS-90*	Earthquake hazards, Beaverton 7½' quad., 1995	10.00
GMS-91*	Earthquake hazards, Lake Oswego 7½' quad., 1995	10.00
GMS-92*	Earthquake hazards, Gladstone 7½' quad., 1995	10.00
GMS-93*	Earthquake hazards, Siletz Bay area, Lincoln County. 1995	20.00
GMS-94*	Charleston 7½' quadrangle, Coos County. 1995	8.00
GMS-97*	Coos Bay 7½' quadrangle, Coos County. 1995	6.00
GMS-98*	Dora and Sitkum 7½' quadrangles, Coos County. 1995	6.00
GMS-99*	Tsunami hazard map, Siletz Bay area, Lincoln County. 1996	6.00
GMS-100*	Earthquake hazard maps for Oregon. 1996	8.00
GMS-101*	Steelhead Falls 7½' quad., Deschutes/Jefferson Co. 1996	7.00
GMS-104*	Earthquake hazards, Linnton 7½' quad., Multn./Wash. Co. 1996	10.00
GMS-105*	Earthquake hazards, Salem East/West 7½' quads. 1996	12.00

SPECIAL PAPERS

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

OIL AND GAS INVESTIGATIONS

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

OREGON GEOLOGY

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

Periodicals postage
paid at Portland, OR

AVAILABLE DEPARTMENT PUBLICATIONS (continued)

BULLETINS

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

MISCELLANEOUS PAPERS

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

SHORT PAPERS

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

MISCELLANEOUS PUBLICATIONS

Hiking Oregon's geology, E.M. Bishop and J.E. Allen, 1996	16.95
Assessing earthquake hazards in the Pac. NW (USGS Prof. Paper 1560)	25.00
Geology of Oregon, 4th ed., E.L. and W.N. Orr and E.M. Baldwin, 1991, published by Kendall/Hunt (add \$3.00 for mailing)	33.95
Geologic map of Oregon, G.W. Walker and N.S. MacLeod, 1991, published by USGS (add \$3.00 for mailing)	11.50
Geology of the Pacific Northwest, E.L. and W.N. Orr, 1996, published by McGraw-Hill (add \$3.00 for mailing)	43.00
Geological highway map, Pacific Northwest region, Oregon, Washington, and part of Idaho (published by AAPG). 1973	8.00
Oregon Landsat mosaic map (published by ERSAL, OSU). 1983	11.00
Mist Gas Field map, rev. 1997, with 1993-96 production figs. (OFR O-97-1)	8.00
Digital form of map (CAD formats .DGN, .DWG, .DXF), 3 1/4-in. diskette	25.00
Mist Gas Field production figures 1979 through 1992 (OFR O-94-6)	5.00
Northwest Oregon, Correlation Sec. 24. Bruer & others, 1984 (AAPG)	6.00
Oregon rocks and minerals, a description. 1988 (OFR O-88-6)	6.00
Mineral information layer for Oregon by county (MILOC), 1993 update (OFR O-93-8), 2 diskettes (5 1/4-in., high-density, MS-DOS)	25.00
Directory of mineral producers, 1993 update, 56 p. (OFR O-93-9)	8.00
Geothermal resources of Oregon (published by NOAA). 1982	4.00
Mining claims (State laws governing quartz and placer claims)	Free
Back issues of <i>Oregon Geology</i>	3.00

Separate price lists for open-file reports, tour guides, recreational gold mining
information, and non-Departmental maps and reports will be mailed upon request.
GMS maps marked with an asterisk (*) are available in digital form on diskette
(geological information only).

The Department also sells Oregon topographic maps published by the U.S. Geo-
logical Survey.

ORDER AND RENEWAL FORM

Check desired publications in list above or indicate how many copies and enter total amount below. Send order to **The Nature of the Northwest Information Center, Suite 177, 800 NE Oregon Street, Portland, OR 97232-2162**, or to FAX (503) 731-4066. If you wish to order by phone, have your credit card ready and call (503) 872-2750. Payment must accompany orders of less than \$50. Payment in U.S. dollars only. Publications are sent postpaid. All sales are final. Subscription price for *Oregon Geology*: \$10 for 1 year, \$22 for 3 years.

Renewal ___ / new subscription ___ to *Oregon Geology*: 1 year (\$10) or 3 years (\$22) \$ _____

Total amount for publications marked above: \$ _____

Total payment enclosed or to be charged to credit card as indicated below: \$ _____

Name _____

Address _____

City/State/Zip _____

Please charge to Visa ___ / Mastercard ___, account number: _____

Expiration date: _____

Cardholder's signature _____

OREGON GEOLOGY

published by the
Oregon Department of Geology and Mineral Industries



VOLUME 59, NUMBER 4

JULY/AUGUST 1997

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



IN THIS ISSUE:

- THE DANGER OF COLLAPSING LAVA DOMES: LESSONS FOR MOUNT HOOD •
 - MINED LAND RECLAMATION AWARD WINNERS OF 1996 •
 - TOPSOIL AND ITS ROLE IN SUCCESSFUL RECLAMATION •
 - TSUNAMI HAZARD MITIGATION EFFORTS IN OREGON •

OREGON GEOLOGY

(ISSN 0164-3304)

VOLUME 59, NUMBER 4 JULY/AUGUST 1997

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

Governing Board

Donald W. Christensen, Chair Depoe Bay
John W. Stephens Portland
Jacqueline G. Haggerty Enterprise

State Geologist Donald A. Hull

Deputy State Geologist John D. Beaulieu

Editor Klaus K.E. Neuendorf

Production Assistants Geneva Beck

Kate Halstead

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

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

Mark L. Ferns, Regional Geologist.

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

Thomas J. Wiley, Regional Geologist.

Mined Land Reclamation Program: 1536 Queen Ave. SE, Albany 97321, phone (541) 967-2039, FAX (541) 967-2075.

Gary W. Lynch, Supervisor.

Internet: <http://www.proaxis.com/~dogami/mlrweb.shtml>

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

Internet: <http://www.naturenw.org>

Periodicals postage paid at Portland, Oregon. Subscription rates: 1 year, \$10; 3 years, \$22. Single issues, \$3. Address subscription orders, renewals, and changes of address to *Oregon Geology*, Suite 965, 800 NE Oregon Street # 28, Portland 97232.

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

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

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

Permission is granted to reprint information contained herein. Credit given to the Oregon Department of Geology and Mineral Industries for compiling this information will be appreciated. Conclusions and opinions presented in articles are those of the authors and are not necessarily endorsed by the Oregon Department of Geology and Mineral Industries.

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

Cover photo

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

Oregon coastal communities install interpretive signs explaining tsunami hazards

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

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

Location

Astoria

Bandon, Port of

Brookings, Port of

Depoe Bay

Florence

Heceta Head State Park

Gold Beach

Lincoln City Outlet Mall

Lincoln City, D-River Park

Alsea Bay Interpr. Center

Garibaldi waterfront

Tillamook Bay

Local funding partners

City of Astoria

City of Bandon, Coos. Co.

Parks Dept., Port of Bandon

City of Brookings, Port of

Brookings

City of Depoe Bay

City of Florence, Florence

Fire Dept., Port of Siuslaw

Oregon State Parks, Sea

Lion Caves

City of Gold Beach, Port of

Gold Beach

Lincoln Factory Outlet Stores

Oregon State Parks, Travel

Information Council

Oregon State Parks, Oregon

Dept. of Transportation

U.S. Coast Guard

U.S. Coast Guard

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

The danger of collapsing lava domes: Lessons for Mount Hood, Oregon¹

by Steven R. Brantley and William E. Scott, U.S. Geological Survey, Cascades Volcano Observatory, 5400 MacArthur Boulevard, Vancouver, Washington 98661²

INTRODUCTION

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

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

During this century, scientists have documented py-

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

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



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

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

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

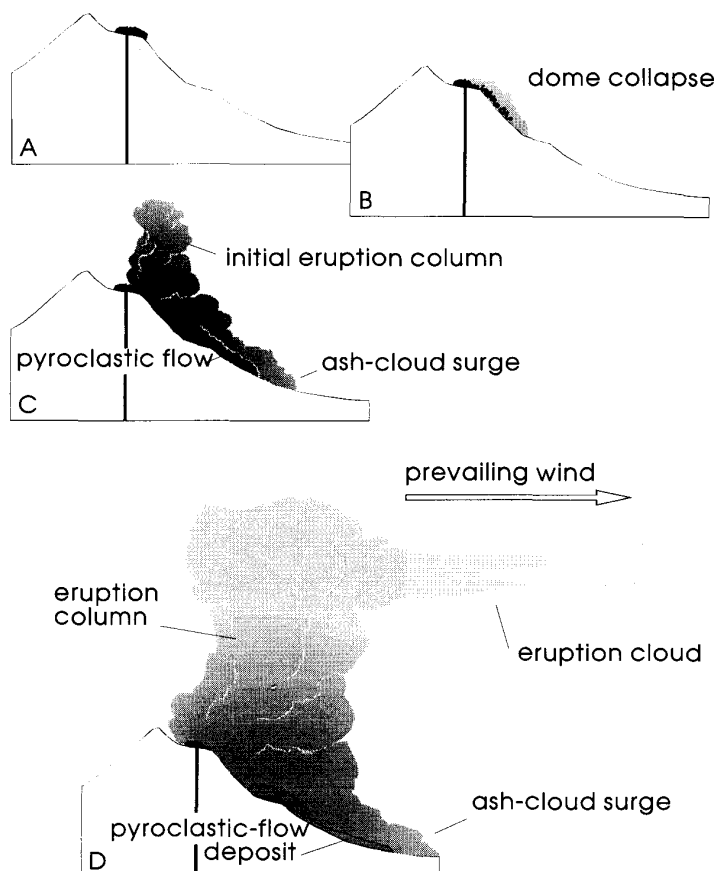
When compared to major eruptions, such as the eruption of Mount St. Helens in 1980, dome collapses are modest in size. Nonetheless, dome collapses can cause considerable destruction and interruption of human activity.

PYROCLASTIC FLOWS TRIGGERED BY DOME COLLAPSES OR EXPLOSIONS

A growing lava dome provides geologists with an exceptional occasion to study pyroclastic flows. One of the most lethal of volcanic phenomena, a pyroclastic flow is extremely dangerous to observe close up. When a dome grows high and steep sided or when it spreads onto a steep slope, the dome becomes unstable. Huge blocks or whole sections of the dome can suddenly break away to form an avalanche of mostly solidified, but still-hot lava fragments. With initial temperatures as high as 950°C, the fragments rapidly disintegrate, and the entire moving mass becomes a pyroclastic flow of shattered lava fragments and searing-hot gases. As a pyroclastic flow races across the ground at hurricane speed, a more dilute and highly turbu-

lent cloud of hot gas and mostly ash-sized lava fragments, called an "ash-cloud surge" by scientists, forms above the flow. Ash-cloud surges are more mobile than the denser, coarser pyroclastic flows and can travel from hundreds of meters to a few kilometers farther.

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



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

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

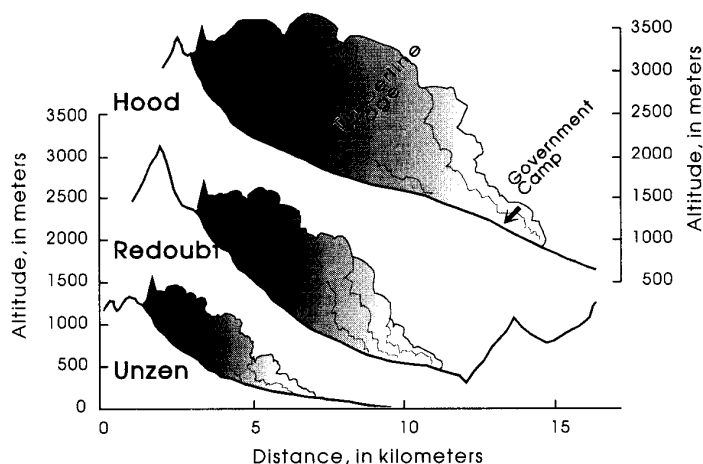
Pyroclastic flows can also be generated solely by the explosive release of volcanic gases that have accumulated inside a dome or the flashing to steam of super-hot groundwater within or beneath a dome. Such explosions can occur months or even years after a dome stops growing. For example, as magma within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

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

CAN COLLAPSES BE PREDICTED?

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

Volcano-monitoring techniques, however, help scientists assess a dome's instability and likelihood of collapse. For example, during growth of the Unzen and Redoubt domes, observations of the locations and character of earthquakes, the rate of volcanic gas release, and the rate of dome growth were useful in detecting changes in the rate of magma delivery to the dome or in pinpointing when a new episode of growth would



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

begin. However, even with this information, the best that scientists could do at both volcanoes was to advise officials that dome collapses were more likely, perhaps even imminent. In general, predictions of specific collapse events can not yet be made.

IDENTIFICATION OF HAZARDOUS AREAS

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

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



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

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

ERUPTION OF UNZEN VOLCANO, JAPAN, 1991–1993

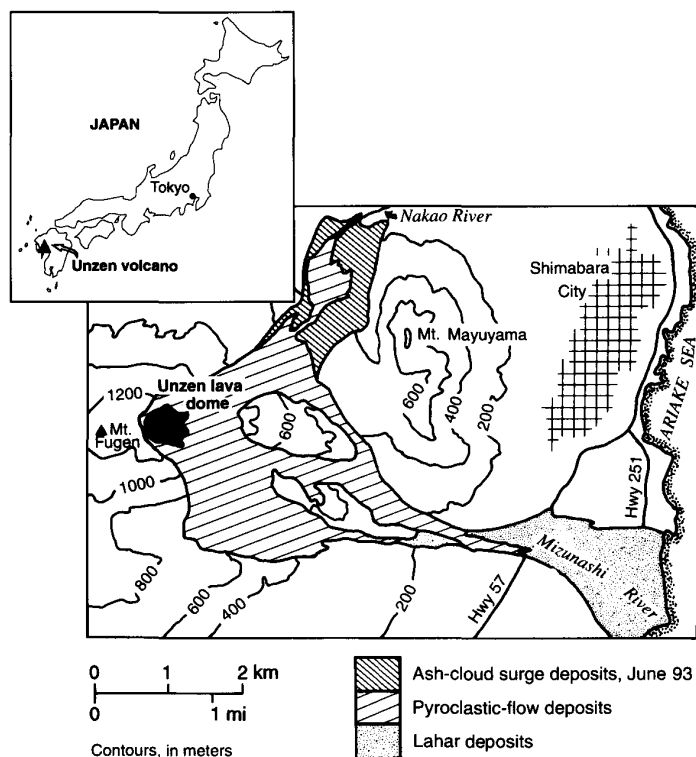
When pasty lava first breached the forested summit crater of Unzen in May 1991 after several months of small explosions, nearby residents may have breathed a sigh of relief. The slow extrusion of gas-poor lava quietly built a small dome that made the volcano seem less threatening and less likely to erupt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

Suddenly on June 3, a much larger dome collapse and explosion produced a pyroclastic flow and ash-cloud surge that raced 4.5 km from the crater, burning

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

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

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



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

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

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

sudden evacuation of several thousand residents along the Mizunashi and Nakao Rivers.

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

A similar long-term eruption scenario is possible at Mount Hood in Oregon. Dome collapses and lahars at Mount Hood would require public officials and residents to wrestle with similar issues regarding evacuations, even though the area around the volcano is much less developed than at Unzen. Complicating the hazard scenario at Mount Hood is the presence of snow and ice, which ensure that lahars would be triggered directly by some dome-collapse events. The collapse of several domes at Redoubt Volcano in 1990 provided insight

into the generation and effects of such lahars. This eruption also drew critical attention to hazards to aircraft posed by eruption clouds downwind from the volcano and to the danger from an ash-cloud surge that can move well beyond the edge of a pyroclastic flow.

ERUPTION OF REDOUBT VOLCANO, ALASKA, 1989—1990

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

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



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

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

One pyroclastic flow triggered by a dome collapse spawned an unusually energetic overriding ash-cloud surge that ultimately reached a distance of 12 km from the crater. When the surge encountered a steep, 700-m-high ridge about 8 km north of the vent, it had

sufficient momentum to climb the ridge and continue on for another 4 km. The hot mixture of gas and ash-sized and gravel-sized rock debris burned and abraded small willow trees on the ridge and drove the ends of broken branches at least 1 m into the snow.

We do not know why this ash-cloud surge traveled so much farther than the others. Clearly, some dome-collapse events can trigger pyroclastic flows with attendant ash-cloud surges that can travel several kilometers beyond

the average distance. Such rare, but large, collapse-triggered surges at both Unzen and Redoubt volcanoes emphasize the need for scientists and public officials to be conservative when outlining hazardous areas.

Redoubt lahars close oil terminal

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

Redoubt eruption clouds disrupt air traffic

During the largest explosive eruption on December 15, 1989, a Boeing 747 en route from Amsterdam to Anchorage with 231 passengers unknowingly flew into Redoubt's eruption cloud about 240 km downwind from the volcano. As the pilot attempted to climb out of

the cloud, tiny ash particles ingested by the engines melted to form a glassy deposit that impeded air flow and stalled all four engines. After gliding steeply for 8 min and losing 4,000 m of altitude—and with only 2,000 m of ground clearance remaining—the crew was able to restart the engines. The plane landed safely at Anchorage, but this near-tragic encounter galvanized action among commercial and military operators, aircraft manufacturers, and Federal agencies to prevent future volcanic-ash encounters. Aircraft successfully avoided direct contact with subsequent eruption clouds, but ash lingering in the atmosphere led to a higher than usual rate of window glazing and greater engine wear.

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

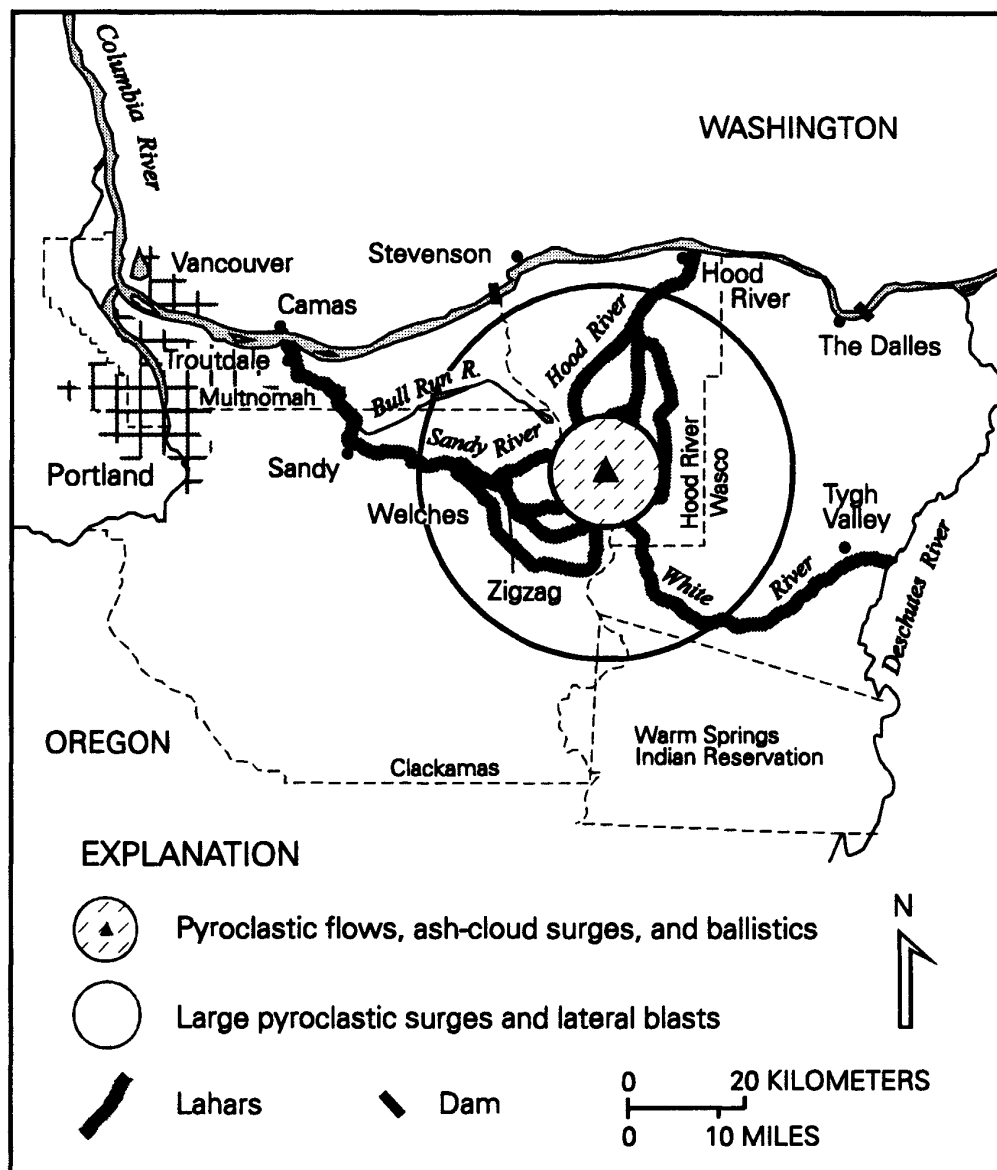
DOME ERUPTIONS AT MOUNT HOOD

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



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

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

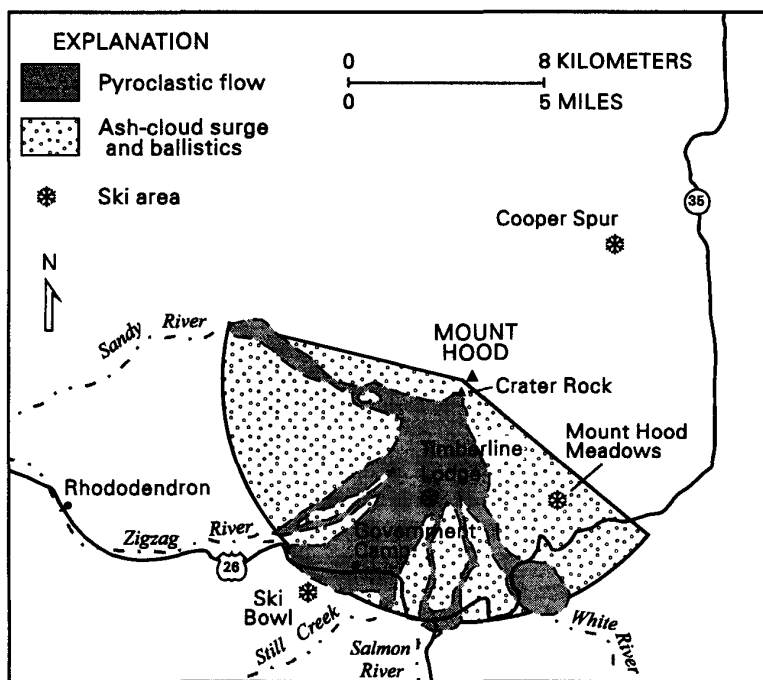


rock debris tapering upward to Crater Rock. Individual lava rocks in the apron are more than 5 m in diameter. Hikers on the Timberline Trail, which cuts across the debris apron and descends into several deep canyons, find the secret of the debris apron and Crater Rock. The debris apron is composed of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

At Mount Hood, the abundance of deposits related to dome collapse and the rarity of evidence for other types of volcanic activity indicate that the most likely

type of eruption in the future will be the growth and collapse of another dome, probably at or near the site of Crater Rock. As indicated by the debris apron, future dome collapses will produce pyroclastic flows and overriding ash-cloud surges, the largest of which could travel 10 km or more down the volcano's south and west flanks. When pyroclastic flows melt snow and ice, or when an intense rainstorm erodes newly emplaced deposits, lahars will race down one or more drainages, including Still Creek and the Sandy, Zigzag, Salmon, and White Rivers.

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



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

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

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

Anticipating an eruption at Mount Hood

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

At Redoubt Volcano, scientists of the Alaska Volcano Observatory identified a rapid increase in the number of earthquakes beginning only 24 hours before

the first explosive eruption on December 14, 1989. A lava dome appeared on December 22, and the first collapse event occurred 11 days later.

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

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

(Continued on page 92)

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

by Shannon Priem, Oregon Department of Geology and Mineral Industries

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

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

Other new awards were for voluntary reclamation efforts, reclamation planning, and salmon habitat enhancement. "These awards recognize the growing commitment in the mining industry to 'do the right thing' in not only reclaiming the land back to a natural habitat, but in many cases, going well beyond what is

required, through innovation and creativity in reclamation," said Gary Lynch, Supervisor of DOGAMI's Mining Reclamation Program. "This year, we also wanted to recognize the increased efforts to improve salmon habitat by creating more off-channel ponds and waterways to rivers for migration."

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

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

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

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

(Continued on next page)

(Continued from page 91)

discuss the hazards and appropriate levels of emergency response.

ACKNOWLEDGMENTS

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

ADDITIONAL READING

For a more complete description of the 1989–1990 eruption of Redoubt Volcano, of problems concerning volcanic ash and aviation safety, and of activity that

could accompany future eruptions of Mount Hood, the reader may consult the following publications:

- Brantley, S.R. (ed.), 1990, The eruption of Redoubt Volcano, Alaska, December 14, 1989–August 31, 1990: U.S. Geological Survey Circular 1061, 33 p.
- Casadevall, T.J., 1994, Volcanic ash and aviation safety. Proceedings of the First International Symposium on Volcanic Ash and Aviation Safety: U.S. Geological Survey Bulletin 2047, 450 p.
- Crandell, D.R., 1980, Recent eruptive history of Mount Hood, Oregon, and potential hazards from future eruptions: U.S. Geological Survey Bulletin 1492, 81 p.
- Till, A.B., Yount, M.E., and Riehle, J.R., 1993, Redoubt Volcano, southern Alaska: A hazard assessment based on eruptive activity through 1968: U.S. Geological Survey Bulletin 1996, 19 p. □

(Continued from page 92)

stages of development north of Central Point along the Rogue River.

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

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

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

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

Outstanding Small Operator—Paul Gallagher, Nyssa, Oregon

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

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

Paul Gallagher and partner Frank Lamb began developing a small-scale placer operation to mine for gold. Over 30,000 cubic yards of material was handled and regraded to get to the "pay zone." Gallagher stated that he "didn't get rich, but didn't go broke." They developed a pond to recycle process water used in gold

mining operations. In 1995, they filled the process-water pond and regraded the entire four acres, preserving several "islands" of existing vegetation. They "tracked" slopes, creating a good seed bed. A seed mix of native species was applied in addition to natural seeding by adjacent native plants such as rabbit brush and sage brush.

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

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

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

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

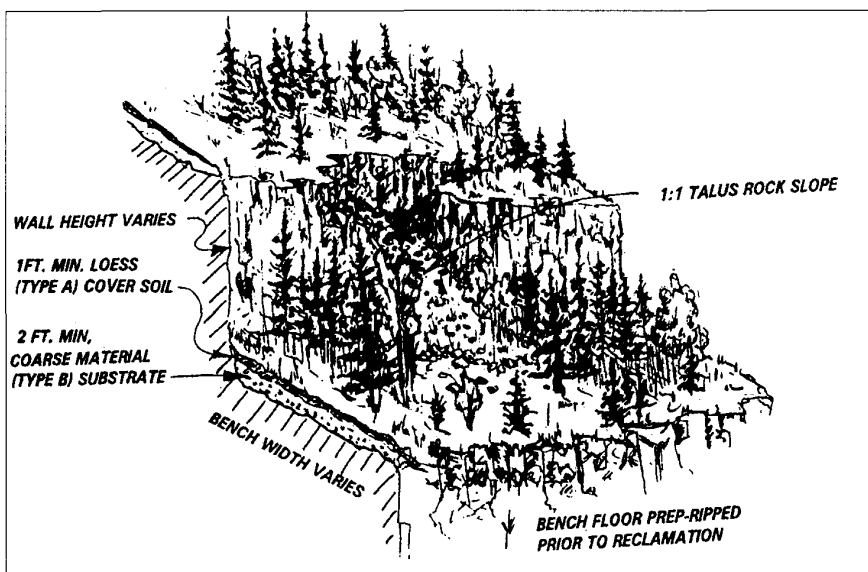
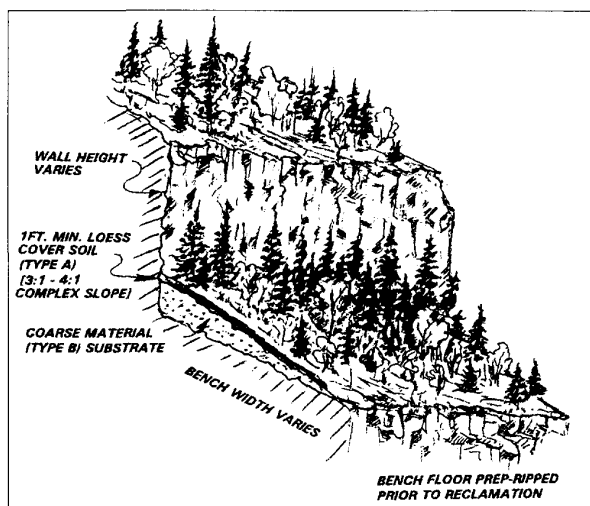
Beaver State had been mining sand and gravel since 1974 within the floodplain of the South Umpqua River, 6 mi south of Roseburg. Mining ended in 1993, and the land has been restored to agriculture and wetland use. Irregular shorelines and islands were created to provide a predator-free wildlife habitat;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

Outstanding Reclamation Planning—Angell Brothers, Inc., Portland

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

Agency Award—Baker County Road Department

Marble Creek quarry, a limestone mine located 8 mi west of Baker City on USDA Forest Service land, dates back to the 1960s. Mining ended in the early 1970s, with extensive stockpiles and waste rock left over. Impacts to Marble Creek from eroding lime spoils have been documented over the last 20 years. Baker County tested the rock and found it suitable for county roads. In 1995, the USDA Forest Service, Baker County, and the mine owner agreed to remove the waste rock, then bench and revegetate the land. Existing vegetation was preserved, and soil was salvaged from an old stockpile and spread along the creek. The original streambed was rebuilt with an erosion-control matting spread to hold



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

the soil in place and help revegetation. Roads that had crossed the creek were removed. The county virtually rebuilt Marble Creek Road by resurfacing it, widening narrow areas, and installing new culverts and erosion-control systems. The agency graded and watered the road throughout the project. Scrap metal was collected and placed in a secure area, where a salvage contractor cut up the metal and hauled it away.

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

Topsoil and its role in successful reclamation¹

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

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

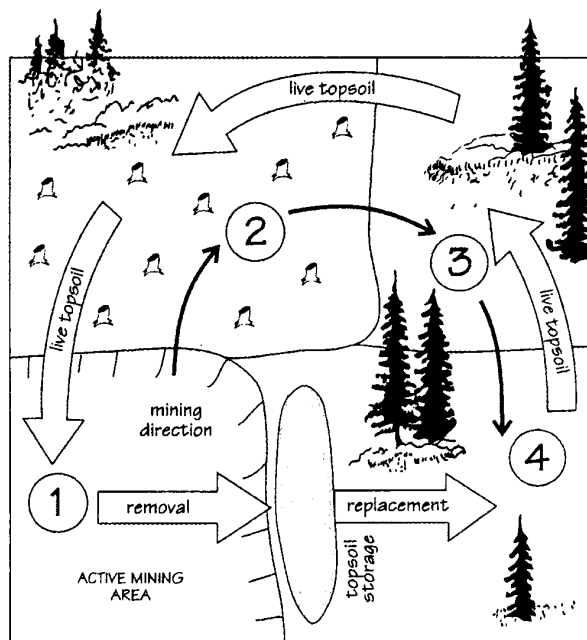
Soil systems continually produce and recycle organic matter. The presence of the organisms that live in a soil environment and their ability to decompose organic matter to a form usable by plants make soil a dynamic medium that is very much alive. Decomposition of organic matter also produces relatively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

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

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

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

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



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

quarry operations where long-term stockpiling cannot be avoided.

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

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

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

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

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

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

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

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

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

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

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



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

Tsunami Inundation Mapping Effort (TIME).

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

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

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

Update on tsunami mapping progress in Oregon

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

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

ministration (NOAA). The new funds will allow :

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

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

Table 1. Summary of detailed tsunami hazard mapping in Oregon

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

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

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

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

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

cases will be mapped, based on modeling results and interpretations of available data on prehistoric tsunamis and coseismic subsidence. Where possible, tsunami inundation from the 1964 Alaskan tsunami will be mapped as a proxy for a maximum teletsunami⁵ event.

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

ing catalogued historical observations of the runup from the 1964 Alaskan tsunami in Seaside.

Footnotes

¹ Moment magnitude assuming a rigidity of 4×10^{11} dyne/cm²

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

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

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

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

Yaquina Head Natural Area now has interpretive center

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

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

The \$4 million interpretive center was built in the

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

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

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

Johnston Ridge Observatory opens at Mount St. Helens

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



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

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

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

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

In the exhibit hall, state-of-the-art interpretive displays educate visitors about the sequence of

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

The JRO is open daily, including holidays, from 9 a.m. to 6 p.m. through September 28, 1997. Winter hours are yet to be determined. The observatory is one of the Monument's designated fee areas, and visitors

using the site must purchase and display a Monument Pass. Passes cost \$8 for each person between 16 and 61 years of age, \$4 for seniors from 62 years on. Children are free up to age 15. The Monument Pass is good for three days and for all designated fee areas around the Monument, which includes not only the visitor centers but also a number of interpretive sites, viewpoints, and picnic areas. Annual passes are available for \$24 and \$12 (seniors and Golden Access Passport discount). Monument Passes may be purchased at Monument visitor centers and information stations and at the Cascade Peaks Restaurant and Gift Shop on Forest

Road 99. Information may also be obtained from the Mount St. Helens National Volcanic Monument, 42218 NE Yale Bridge Road, Amboy, WA 98601, phone (360) 247-3900. □



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

DOGAMI PUBLICATIONS

Released April 3, 1997

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

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

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

Released May 12, 1997

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

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

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

Robert L. Bates Scholarship Endowment Fund

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

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

THESIS ABSTRACTS

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

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

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

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

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

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

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

Mixing during synextensional magmatism of a layered magma chamber, followed by prolonged fractionation during tectonic quiescence, is recorded in the stratigraphy, geochemistry, geochronology, and structural history of the Duck Creek Butte eruptive center (DBEC). The DBEC, located in the Basin and Range province of southeastern Oregon, is the easternmost center in a west-northwest-trending, northwest-younging sequence of silicic vents. DBEC was studied by a combination of detailed geologic mapping (400 km²), 37 chemical analyses, mineral chemistry, three new ⁴⁰Ar/³⁹Ar ages, and Sr and Nd isotope data.

The DBEC sequence is dominated by rhyodacite and rhyolite but includes andesite, basaltic andesite, and basalt. Effusive volume decreases with time, and the compositional range becomes more restricted and more mafic. The earliest volcanic activity is recorded in more than 6 km³ of pyroclastic and effusive lava flows of porphyritic rhyodacite (10.38±0.04 Ma; ⁴⁰Ar/³⁹Ar, biotite) during movement along the faults related to uplift of the Steens Mountain fault block. The lava flowed over existing fault escarpments and was later truncated by these same faults. Late flows of rhyodacite contain quenched andesite inclusions that were entrained during evacuation of the magma chamber. Eruption of dacite with up to 30 percent quenched basaltic andesite inclusions ensued, possibly as the result of synmagmatic faulting. Andesite with mixing textures, associated with basaltic andesite and basalt, marks the end of DBEC activity along the fault system. Silicic magmatism migrated 2–4 km northwest to Indian Creek Buttes, where high-silica rhyolitic magma fractionated during tectonic quiescence and then was erupted (10.32±0.01 Ma; ⁴⁰Ar/³⁹Ar, sanidine).

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

Post-DBEC rocks were deposited chiefly in drainages and west-northwest-trending, fault-bounded valleys. The 9.7-Ma Devine Canyon Ash-Flow Tuff and underlying tuffaceous sedimentary strata are found throughout southeastern Oregon. Following a protracted hiatus, a primitive high-alumina olivine tholeiite was erupted

adjacent to DBEC (1.38±0.01 Ma; ⁴⁰Ar/³⁹Ar, whole rock). No further volcanic activity is recorded. Quaternary sediment covers much of the area.

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

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

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

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

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

(Continued on page 102)

Beverly F. Vogt retires

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

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

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

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



From the front cover of *Oregon Geology*—South Falls at Silver Falls State Park.

(Continued from page 101)
The range of parameter input values for the Bruun model include: the depth of closure (h) range from 15-m to 20-m water depth; the cross-shore distance (L) range from 846 m to 5,975 m; and the estimated subsidence amount (S) range from 0 m to 1.5 m.

The minimum to maximum range of post-subsidence shoreline retreat is 142–531 m in the Columbia River cell, 56–128 m in the Cannon Beach cell, 38–149 m in

When in 1992 the Department offices were moved to the new location of the State Office Building, Bev organized the creation of the (then) Nature of Oregon

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

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

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

the Tillamook cell, 25–91 m in the Pacific City cell, 11–126 m in the Lincoln City cell, 30–147 m in the Otter Rock cell, 0–165 m in the Newport cell, 0–76 m in the Waldport cell, and 0 m in the Winchester cell.

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

AVAILABLE PUBLICATIONS

OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

GEOLOGICAL MAP SERIES

Price ☑

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

Price☑

GMS-76 Camas Valley 7½' quadrangle, Douglas/Coos Counties. 1993	6.00
GMS-77 Vale 30x60' quadrangle, Malheur County. 1993	10.00
GMS-78 Mahogany Mountain 30x60' quadrangle, Malheur Co. 1993	10.00
GMS-79* EQ hazards, Portland 7½' quad., Multn. Co. 1993	20.00
GMS-80* McLeod 7½' quadrangle, Jackson County. 1993	5.00
GMS-81* Tumalo Dam 7½' quadrangle, Deschutes County. 1994	6.00
GMS-82* Limber Jim Creek 7½' quadrangle, Union County. 1994	5.00
GMS-83* Kenyon Mountain 7½' quadrangle, Douglas/Coos Co. 1994	6.00
GMS-84* Remote 7½' quadrangle, Coos County. 1994	6.00
GMS-85* Mount Gurney 7½' quadrangle, Douglas/Coos Co. 1994	6.00
GMS-86* Tenmile 7½' quadrangle, Douglas County. 1994	6.00
GMS-87* Three Creek Butte 7½' quadrangle, Deschutes County. 1996	6.00
GMS-88* Lakecreek 7½' quadrangle, Jackson County. 1995	8.00
GMS-89* EQ hazards, Mt. Tabor 7½' quad., Multn. Co. 1995	10.00
GMS-90* EQ hazards, Beaverton 7½' quad., Wash. Co. 1995	10.00
GMS-91* EQ hazards, Lake Oswego 7½' quad., Tri-county. 1995	10.00
GMS-92* EQ hazards, Gladstone 7½' quad., Clack./Multn. Co. 1995	10.00
GMS-93* EQ hazards, Siletz Bay area, Lincoln County. 1995	20.00
GMS-94* Charleston 7½' quadrangle, Coos County. 1995	8.00
GMS-97* Coos Bay 7½' quadrangle, Coos County. 1995	6.00
GMS-98* Dora and Sitkum 7½' quadrangles, Coos County. 1995	6.00
GMS-99* Tsunami hazard map, Siletz Bay area, Lincoln County. 1996	6.00
GMS-100* EQ hazard maps for Oregon. 1996	8.00
GMS-101* Steelhead Falls 7½' quad., Deschutes/Jefferson Co. 1996	7.00
GMS-104* EQ hazards, Linnton 7½' quad., Multn./Wash. Co. 1996	10.00
GMS-105* EQ hazards, Salem East/West 7½' quads. 1996	12.00
GMS-106* Grizzly Peak 7½' quadrangle, Jackson County. 1997	6.00

SPECIAL PAPERS

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

OIL AND GAS INVESTIGATIONS

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

OREGON GEOLOGY

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

Periodicals postage
paid at Portland, OR

AVAILABLE DEPARTMENT PUBLICATIONS (continued)

BULLETINS

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

MISCELLANEOUS PAPERS

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

SHORT PAPERS

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

MISCELLANEOUS PUBLICATIONS

Hiking Oregon's geology, E.M. Bishop and J.E. Allen, 1996	16.95
Assessing earthquake hazards in the Pac. NW (USGS Prof. Paper 1560)	25.00
Geology of Oregon, 4th ed., E.L. and W.N. Orr and E.M. Baldwin, 1991, published by Kendall/Hunt (add \$3.00 for mailing)	33.95
Geologic map of Oregon, G.W. Walker and N.S. MacLeod, 1991, published by USGS (add \$3.00 for mailing)	11.50
Geology of the Pacific Northwest, E.L. and W.N. Orr, 1996, published by McGraw-Hill (add \$3.00 for mailing)	43.00
Geological highway map, Pacific Northwest region, Oregon, Washington, and part of Idaho (published by AAPG). 1973	8.00
Oregon Landsat mosaic map (published by ERSAL, OSU). 1983	11.00
Mist Gas Field map, rev. 1997, incl. 1993-96 production (OFR O-97-1)	8.00
Digital form of map (CAD formats .DGN, .DWG, .DXF), 3 1/2-in. disk	25.00
Mist Gas Field production figures 1979 through 1992 (OFR O-94-6)	5.00
Northwest Oregon, Correlation Sec. 24. Bruer & others, 1984 (AAPG)	6.00
Oregon rocks and minerals, a description. 1988 (OFR O-88-6)	6.00
Mineral information layer for Oregon by county (MILOC), 1993 update (OFR O-93-8), 2 diskettes (5 1/4-in., high-density, MS-DOS)	25.00
Directory of mineral producers, 1993 update, 56 p. (OFR O-93-9)	8.00
Geothermal resources of Oregon (published by NOAA). 1982	4.00
Mining claims (State laws governing quartz and placer claims)	Free
Back issues of <i>Oregon Geology</i>	3.00

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

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

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

ORDER AND RENEWAL FORM

Check desired publications in list above or indicate how many copies and enter total amount below. Send order to The Nature of the Northwest Information Center, Suite 177, 800 NE Oregon Street, Portland, OR 97232-2162, or to FAX (503) 731-4066. If you wish to order by phone, have your credit card ready and call (503) 872-2750. Payment must accompany orders of less than \$50. Payment in U.S. dollars only. Publications are sent postpaid. All sales are final. Subscription price for *Oregon Geology*: \$10 for 1 year, \$22 for 3 years.

Renewal ___ / new subscription ___ to *Oregon Geology*: 1 year (\$10) or 3 years (\$22) _____ \$

Total amount for publications marked above: \$ _____

Total payment enclosed or to be charged to credit card as indicated below: \$ _____

Name _____

Address _____

City/State/Zip _____

Please charge to Visa ___ / Mastercard ___, account number: _____

Expiration date: _____

OREGON GEOLOGY

published by the
Oregon Department of Geology and Mineral Industries



VOLUME 59, NUMBER 5

SEPTEMBER/OCTOBER 1997



IN THIS ISSUE:

ZEOLITES IN THE
CASCADE RANGE OF
NORTHERN OREGON

NATIONAL NATURAL
LANDMARKS PROGRAM
IN THE PACIFIC
NORTHWEST

"REAL-TIME"
EARTHQUAKE
INFORMATION HAS
COME TO DOGAMI



OREGON GEOLOGY

(ISSN 0164-3304)

VOLUME 59, NUMBER 5 SEPT./OCT. 1997

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

Governing Board

Donald W. Christensen, Chair.....Depoe Bay
John W. Stephens.....Portland
Jacqueline G. Haggerty.....Enterprise

State Geologist.....Donald A. Hull
Deputy State Geologist.....John D. Beaulieu
Editor.....Klaus K.E. Neuendorf
Production Assistants.....Geneva Beck
.....Kate Halstead

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

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

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

Mined Land Reclamation Program: 1536 Queen Ave. SE, Albany
97321, phone (541) 967-2039, FAX (541) 967-2075.

Gary W. Lynch, Supervisor.

Internet: <http://www.proaxis.com/~dogami/mlrweb.shtml>

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

Internet: <http://www.naturenw.org>

Periodicals postage paid at Portland, Oregon. Subscription rates: 1
year, \$10; 3 years, \$22. Single issues, \$3. Address subscription orders,
renewals, and changes of address to Oregon Geology, Suite 965, 800 NE
Oregon Street # 28, Portland 97232.

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

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

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

Permission is granted to reprint information contained herein. Credit
given to the Oregon Department of Geology and Mineral Industries for
compiling this information will be appreciated. Conclusions and opinions
presented in articles are those of the authors and are not necessarily
endorsed by the Oregon Department of Geology and Mineral Industries.

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

Cover photos

Fort Rock in south-central Oregon (upper photo)
and Newberry Crater (East Lake shown in lower photo)
in the Newberry National Volcanic Monument are two
examples of designated National Natural Landmarks in
Oregon. See article describing the National Natural
Landmarks Program on pages 123-124.

Portland light rail tunnel praised by Engineering Geologists

During its annual national meeting, September 30 to
October 4, 1997, in Portland, Oregon, the Association
of Engineering Geologists (AEG) will honor the city's
Westside Light Rail Tunnel as an "Outstanding Environ-
mental and Engineering Geologic Project." The Tri-
County Metropolitan Transportation District (Tri-Met) is
extending its light rail line to the west of the city center
and is completing twin rail tunnels under the West Hills
that border the city center on the west. The following is
excerpted from the association's proclamation.

"One hundred years ago, rail trolleys ran from Port-
land's city center to the residential neighborhoods of
the West Hills. This early rail system was severely
damaged by a massive landslide now called the Wash-
ington Park landslide, and also severely affected con-
struction of the city's water-supply reservoirs. Even
then, residents of Portland began to appreciate the
geologic hazards of the West Hills.

"The success of this project was achieved through
the understanding and management of the many geo-
logic hazards posed by the West Hills. Difficult and
widely variable rock types were penetrated; faults were
crossed and avoided; landslide forces were balanced—
and the result provides a safe, convenient transporta-
tion route for all.

"Host rocks for the Washington Park station and the
eastern two miles of the light rail tunnels originated as
enormous eruptions of lava that flowed from fissures in
northeastern Oregon and southeastern Washington.
Numerous lava floods occurred, and some extended
across the Pacific Northwest to the Pacific Ocean. They
cooled forming a layered basalt sequence. A tunnel-
boring machine named "Bore-Regard" carved a path
for the Metropolitan Area Express (MAX) light rail cars
through these basalt flows. The western mile of the twin
tunnels was dug and blasted through younger lavas that
are interlayered with windblown silt deposits. Two vol-
canoes are located within a mile of the alignment. The
tunnel was drilled through one feeder dike where lava
once welled up.

"This Westside Light Rail Tunnel Project has pre-
served for public enjoyment the unique cultural and
environmental resources that lie above it." □

NWMA meeting set for December

The 103d annual meeting of the Northwest Mining
Association (NWMA) is scheduled for December 1-5,
1997, at the Doubletree Hotel-Spokane City Center,
Spokane, Wash. Former Idaho Governor and Interior
Secretary Cecil D. Andrus will be the keynote speaker.
For information, contact NWMA at 10 N. Post Street,
Suite 414, Spokane, WA 99201, ph. (509) 624-7655. □

Zeolites in the Cascade Range of northern Oregon

by Keith E. Bargar and Robert L. Oscarson, U.S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025

ABSTRACT

Twenty-three zeolite minerals were identified during secondary mineralogy studies of late Tertiary volcanic rock outcrop samples and/or late Tertiary to Quaternary geothermal drill-hole specimens in three areas of the Oregon Cascade Range (near Mount Hood, the Breitenbush-Austin Hot Springs area, and Newberry volcano). The Neogene to Holocene volcanic rocks contain euhedral to subhedral zeolite crystals in open spaces of fractures and vesicles and between breccia fragments. The widespread occurrence of zeolite minerals indicates that a substantial portion of these volcanic rocks underwent low-temperature ($<200^{\circ}\text{C}$), zeolite-facies, hydrothermal alteration at some time following their emplacement. A few of the zeolites (wairakite, faujasite, ferrierite, harmotome, and yugawaralite) encountered during these studies had not previously been reported from Oregon.

Zeolite minerals occur in most geothermal exploration holes drilled on the flanks of Newberry volcano and in the upper part of drill holes completed within the volcano's caldera. Temperatures measured during drilling of these holes are compatible with zeolite-facies metamorphism. A temperature of 265°C was measured near the bottom (932-m depth) of one hole drilled within the caldera of the volcano, and secondary minerals recovered from this part of the drill hole are indicative of subgreenschist- to greenschist-facies metamorphism (temperatures up to $\sim 400^{\circ}\text{C}$).

The studied late Tertiary volcanic rocks from the Western Cascade Range of northern Oregon have primarily been subjected to low-temperature zeolite-facies metamorphism. Some low-temperature zeolite minerals are superimposed upon higher temperature alteration minerals that occur in narrow halos surrounding the intrusive remnants of late Miocene volcanoes in the Breitenbush-Austin Hot Springs area and near Mount Hood. These higher temperature secondary minerals are indicative of greenschist- to subgreenschist-facies metamorphism that locally preceded zeolite-facies metamorphism. Secondary mineral distribution in these areas appears to be

consistent with localized rather than widespread high heat-flow conditions.

INTRODUCTION

Quaternary volcanic activity, several hot springs, and a few fumaroles present in the Cascade Range of northern Oregon suggested the possibility that exploitable geothermal energy sources might occur within these mountains. During the 1970s and 1980s, numerous test drill holes were completed in several areas of

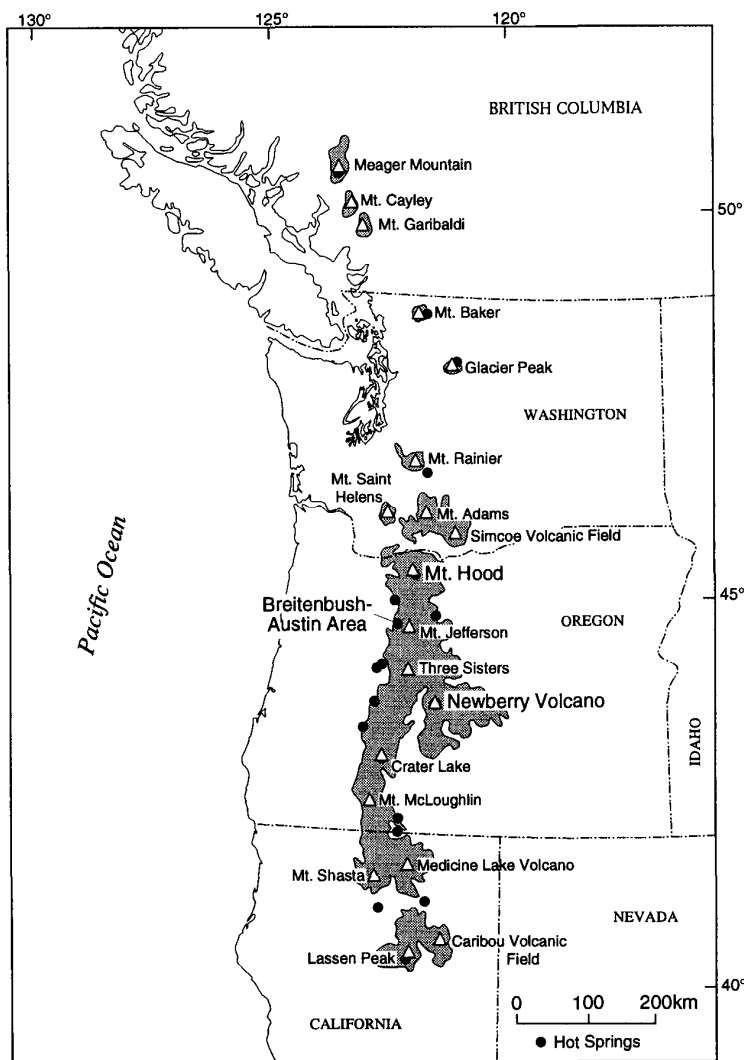


Figure 1. Map showing the location of the Pacific Northwest Cascade Range (shaded areas). The three areas included in this study are shown in larger type.

the Cascades to aid in the evaluation of some of the more favorable geothermal sites. Detailed studies of hydrothermal alteration mineralogy were made for core and cuttings from 24 of the drill holes at Newberry volcano (Bargar and Keith, 1984; Keith and Bargar, 1988; Bargar and Keith, in preparation), the Mount Hood area (Bargar and others, 1993), and the Breitenbush-Austin Hot Springs area (Keith, 1988; Bargar, 1990, 1994; Oscarson and Bargar, 1996) (Figure 1). During the investigations, twenty-three zeolite minerals were identified, along with many other hydrothermal minerals, in drill-hole specimens from these three areas or in nearby outcrops of late Tertiary volcanic rocks at Mount Hood and the Breitenbush-Austin Hot Springs area.

Zeolite minerals are a large group of hydrated aluminosilicates that contain one or more alkali or alkaline earth cations (Mumpton, 1977). Zeolites can function as catalysts to promote chemical reactions; they have the unique ability to gain or lose liquids (generally water) and gases (such as ammonia); and they can act as cation exchangers without significant alteration of their structures (Barrer, 1978). Consequently, there are numerous commercial uses for both natural and synthetic zeolites, ranging from additives for various types of pollution abatement, to agriculture and aquiculture, energy conservation, and metallurgy, and even to polishing agents in toothpaste (Mumpton, 1978). No ore-grade zeolite deposits occur in the Cascade Range. However, mining claims have been filed in several areas of eastern Oregon (Mumpton, 1983), and zeolite has been produced commercially from deposits near Adrian since 1983 (Leppert, 1990).

Zeolite minerals form in a variety of low-temperature (mostly <200°C), water-rich environments including alkaline lakes, deep-sea sediments, cooling lava flows, and hydrothermal systems (Tschernich, 1992). Drill-hole and rock-outcrop specimens of late Tertiary to Holocene volcanic rocks (intrusives, lava flows, pyroclastic flows, and volcanoclastic deposits) from the northern Oregon Cascade Range (including Newberry volcano) contain sparse to common, subhedral to euhedral zeolite crystals in open spaces of vesicles and fractures and between fragments of volcanic or tectonic breccias. Although zeolitization can occur with diagenetic or deuteric alteration, the large size of the numerous euhedral zeolite crystals is believed to be an indication that these minerals were precipitated from circulating hydrothermal fluids (Gottardi, 1989). Chemical composition of the zeolite minerals is somewhat variable and reflects the elements contained in the mineralizing solutions which in turn are influenced by the rocks through which the waters flow (Barrer, 1982).

Because of their unique properties, the large number of identified minerals, and their wide-spread abundance in the altered late Tertiary volcanic rocks, these zeolites

constitute a significant mineral group in Oregon's Cascade Range. Unfortunately, they have been largely ignored by previous workers. Some studies list identified zeolite minerals (Hammond and others, 1980), but many investigators just report that "zeolites" were present in their studies. In part, the subordination of zeolite minerals has resulted from the difficulty in identifying individual members of this large mineral group, which includes more than 40 species. In this report, we present information on the occurrence, morphology, and chemistry of zeolite minerals encountered in studies of low-temperature hydrothermally altered volcanic rocks from three geothermal areas in the Oregon Cascade Range. A few of the zeolites (wairakite, faujasite, ferrierite, harmotome, and yugawaralite) discussed in this report do not appear to have been reported previously in Oregon.

ANALYTICAL METHODS

A few zeolite minerals have distinctive morphologies or optical properties, and individual mineral identifications can be made by routine binocular or petrographic microscope methods. However, most zeolites can best be identified by X-ray diffraction (XRD) for which in this study, a Norelco¹ X-ray unit and Cu-K α radiation were used. Qualitative chemical analyses were obtained for several zeolites during scanning electron microscope (SEM) studies that used a Cambridge Stereoscan 250 scanning electron microscope equipped with an energy dispersive spectrometer (EDS). The SEM studies also provided much information on the paragenesis and morphology of the zeolites and associated secondary minerals. Quantitative chemical analyses for several zeolites and other minerals were obtained by use of either an ARL-SEMQ electron microprobe or JEOL JXA-8900L electron probe microanalyzer. The microprobe data for zeolites from the Mount Hood area, Breitenbush-Austin Hot Springs area, and Newberry volcano are reported in Bargar and others (1993), Oscarson and Bargar (1996), and Bargar and Keith (in preparation), respectively. Both natural and synthetic mineral standards were used. Instrument conditions employed for the carbon-coated, polished thin sections or mounts containing zeolite (and other) minerals were quite variable and included: a sample current of 7.5 or 15.0 nA, a beam diameter of 15–25 μ , count times of 10 or 20 seconds, and an accelerating voltage of 15 kV.

GEOHERMAL AREAS

Breitenbush-Austin Hot Springs area

In the Breitenbush-Austin Hot Springs area, chemical geothermometers for three groups of hot springs, dis-

¹Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

charging dilute NaCl or Na-Ca-Cl (minor K and traces of Mg) water, indicate that reservoir temperatures may be as high as 186°C (Ingebritsen and others, 1989, 1994). These workers also indicate that high heat flow ($>100 \text{ mW/m}^2$) throughout the area emanates from the Quaternary volcanic arc ~10–15 km to the east. Boden (1985) reported epistilbite, stilbite, laumontite, mesolite, analcime, mordenite, and clinoptilolite(?) from three shallow (150-m) drill holes (bottom temperatures 18°–55°C) in Miocene microdiorite and extrusive andesitic rocks near Austin Hot Springs. Two deep drill holes in the area, designated as CTGH-1 (1,463 m) and SUNEDCO 58–28 (2,457 m), encountered temperatures of only about 96°C and 141°C, respectively (A.F. Waibel, unpublished data, 1982; Blackwell and Steele, 1987). In drill hole CTGH-1, dominantly basaltic late Tertiary to Quaternary drill core samples yielded abundant heulandite, clinoptilolite, and mordenite below about 900-m depth. At depths of about 600–900 m, some chabazite, analcime, and thomsonite, and minor erionite, mesolite (misidentified as scolecite), phillipsite, and wellsite were recognized (Bargar, 1990). Seven zeolites were identified in late Tertiary, mostly basaltic to andesitic lava flows and tuffaceous drill cuttings from drill hole SUNEDCO 58–28. Many drill-hole specimens contain laumontite and heulandite. A few specimens contain stilbite/stellerite, or analcime, and traces of mordenite, epistilbite, and scolecite (Bargar, 1994). Several zeolite minerals (analcime, chabazite, heulandite, epistilbite, gismondine, laumontite, levyne, mesolite, mordenite, phillipsite, scolecite, stilbite/stellerite, thomsonite, and yugawaralite) were collected from scattered outcrops of late Tertiary volcanic rocks in the Breitenbush-Austin Hot Springs area.

Zeolites in late Tertiary rock outcrops must have formed sometime between extrusion of the volcanic rocks and their subsequent erosion to present-day levels. However, zeolite minerals in the CTGH-1 and SUNEDCO 58–28 drill holes might have formed from the present-day geothermal system, because their formation temperatures are compatible with measured temperatures in the drill holes (Kristmannsdóttir and Tómasson, 1978).

Mount Hood area

In the Mount Hood area, a few thermal springs occur near the southern base of the mountain. The dominant cation in the dilute, tepid Swim Warm Springs is Na, although substantial Mg, Ca, and K are present in the samples (Mariner and others, 1980). Most of the 30 geothermal test drill holes in the Mount Hood area encountered only low-temperature, marginally thermal fluids ($<23^\circ\text{C}$). However, in four of the drill holes, bottom temperatures were between 60° and 113°C. Present-day zeolite-facies metamorphism could occur at these temperatures. However, all of the zeolite minerals

(wairakite, chabazite, ferrierite, heulandite, laumontite, mordenite, scolecite, stilbite/stellerite, and harmotome) identified in fractures and vugs and between breccia fragments of late Tertiary basaltic to dacitic volcanic rocks and quartz diorite or quartz monzonite intrusives from outcrops and 13 geothermal drill holes are believed to have formed during earlier periods of hydrothermal metamorphism (Bargar and others, 1993).

Newberry volcano

At Newberry volcano, temperatures as high as 265°C were measured in one of two holes spudded in the Holocene caldera deposits. Temperatures as high as 170°C were recorded in drill holes on the western flank of the volcano (Arestad and others, 1988). Zeolite minerals (chabazite, dachiardite, heulandite, laumontite, mordenite, and phillipsite) are sparsely distributed in four of the seven flank drill holes studied (Bargar and Keith, in preparation). Within the caldera, analcime, chabazite, erionite, faujasite, clinoptilolite, dachiardite, and mordenite occur in fractures, vugs, and spaces between breccia fragments and as alteration products of glass in drill-hole specimens of Pleistocene to Holocene rhyolitic tuffaceous rocks and basaltic sediments (Keith and Bargar, 1988). Present-day temperatures (presumably the formation temperatures) at which the Newberry volcano zeolites occur are about 30°–160°C (Bargar and Keith, in preparation). Dilute hot springs within the caldera contain varying proportions of Na, Ca, Mg, and K (Mariner and others, 1980).

ZEOLITE MINERALS

Many of the zeolite minerals included in this study occur rarely and are not well known. Accordingly, chemical formulas from definitive zeolite references (Gottardi and Galli, 1985; Tschernich, 1992) are given for each of the zeolites identified in this investigation.

Analcime— $\text{Na}_{16}(\text{Al}_{16}\text{Si}_{32}\text{O}_{96}) \cdot 16\text{H}_2\text{O}$

Wairakite— $\text{Ca}_8(\text{Al}_{16}\text{Si}_{32}\text{O}_{96}) \cdot 16\text{H}_2\text{O}$

Analcime and wairakite in the Oregon Cascade Range usually occur as colorless, subhedral to euhedral, trapezohedral crystals that formed in open spaces of fractures and vugs or between breccia fragments (Figure 2). Analcime appears to be more common than wairakite, but this study suggests that neither mineral is especially plentiful in the northern Oregon Cascades. A continuous solid-solution series exists between the analcime and wairakite end members (Gottardi and Galli, 1985). In this report, the nomenclature of Tschernich (1992), which defines analcime as containing more than 50 percent Na and wairakite as containing more than 50 percent Ca, is used to distinguish between the two minerals. Distinction between the two end-member minerals also has been reported by Coombs (1955), based on minor differences in their XRD patterns. How-

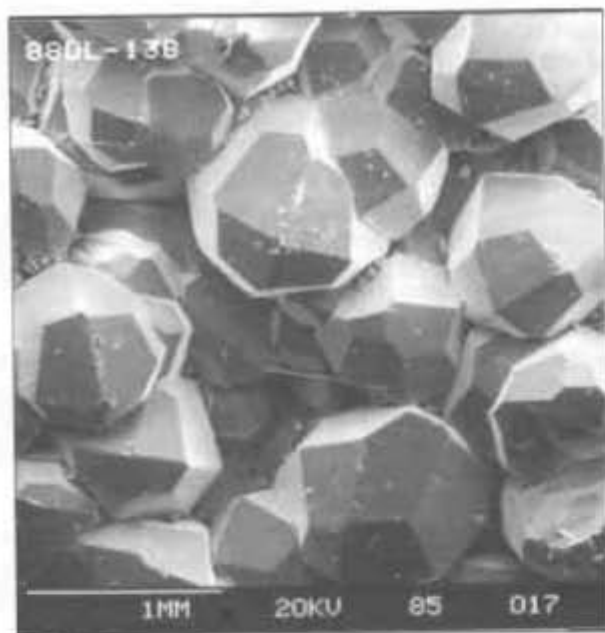


Figure 2. Scanning electron micrograph of colorless, euhedral, trapezohedral analcime crystals that cement early Miocene volcanic breccia fragments in the Breitenbush Hot Springs area. Tiny fibrous crystals are mordenite.

ever, Tschernich (1992) indicates that analcime and wairakite cannot be distinguished by XRD. In this report, we utilized both methods to distinguish between the two minerals. Microprobe analyses of two Mount Hood wairakites (Bargar and others, 1993) show that one specimen is very near the stoichiometric composition for the mineral (Figure 3A), whereas the second specimen contains substantially more potassium than previously has been reported for wairakite (Gottardi and Galli, 1985; Tschernich, 1992).

A "sodian" wairakite was identified by microprobe in core from the CTGH-1 drill hole near Breitenbush Hot Springs. The microprobe analyses also show the presence of significant potassium (Figure 3A). Analcime specimens collected from the SUNEDCO 58-28 drill hole and outcrops near Breitenbush Hot Springs mostly are a nearly pure analcime end member (Bargar, 1994). One analysis shows the presence of a "calcian" analcime (Figure 3A).

The intracaldera drill holes (USGS-N2 and RDO-1) at Newberry volcano both contain analcime (Keith and others, 1986; Keith and Bargar, 1988). Microprobe analyses for two specimens from depths of 314.6-315.1 m and 318.5 m in USGS-N2 show a pure end-member analcime and a "calcian" analcime containing significant potassium (Bargar and Keith, in preparation) (Figure 3A).

Analcime is a fairly common zeolite mineral that is found in many different environments; this includes

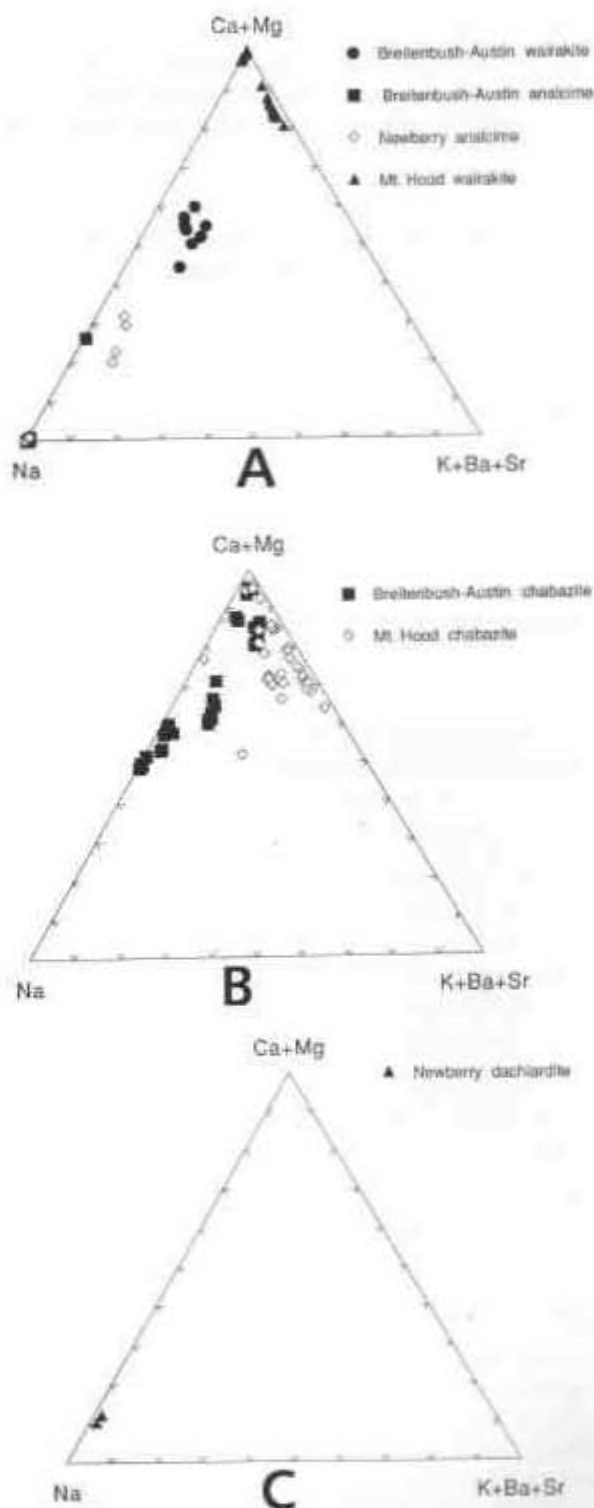


Figure 3. Ca+Mg-Na-K+Ba+Sr ternary diagrams for microprobe analyses of (A) analcime and wairakite, (B) chabazite, and (C) dachiardite from outcrops and geothermal drill holes in the Oregon Cascades.

geothermal areas throughout the world where it formed at temperatures ranging from about 60°–300°C (Kristmannsdóttir and Tómasson, 1978). Tschernich (1992) lists many localities in Oregon where analcime previously has been found. Wairakite also has been reported from geothermal areas in many parts of the world at about the same temperatures as analcime, but the mineral does not appear to have been located previously anywhere in Oregon (Tschernich, 1992).

Chabazite— $\text{Ca}_2(\text{Al}_4\text{Si}_6\text{O}_{24}) \cdot 12\text{H}_2\text{O}$

Colorless to white, euhedral, pseudocubic rhombohedral, chabazite crystals (Figure 4A) were identified in open-space deposits of specimens from several drill holes and outcrops at Mount Hood and the Breitenbush-Austin Hot Springs area. Trace amounts of chabazite with the same morphology also coat fractures in core from one drill hole on the southern flank of Newberry volcano. The USGS-N2 drill hole, within the caldera of Newberry volcano, contains colorless, intergrown, twinned, hexagonal, lens-shaped, phacolitic chabazite crystals between depths of 308.9 and 318.5 m. This phacolitic habit (Figure 4B) apparently is uncommon in the Cascade Range; leastwise it was not observed elsewhere during this study.

The composition of chabazite is characteristically quite variable (Gottardi and Galli, 1985). Semiquantitative EDS analysis of chabazite from the Newberry volcano USGS-N2 drill hole shows the presence of (in order of abundance) Ca, K, and Na in addition to Si and Al (Bargar and Keith, in preparation). Numerous micro-

probe analyses of chabazite from near Mount Hood and the Breitenbush-Austin Hot-Springs area (Figure 3B) show that calcium is the dominant cation in both areas; however, the Mount Hood chabazite contains substantial potassium (Bargar and others, 1993) while, in some chabazite from the Breitenbush-Austin area, sodium comprises as much as 50 percent of the exchangeable cations (Oscarson and Bargar, 1996).

Chabazite is a characteristic hydrothermal mineral in low-temperature (<75°C) alteration zones of Icelandic geothermal areas (Kristmannsdóttir and Tómasson, 1978). Chabazite deposits in geothermal drill holes of the Cascade Range occur at similar low temperatures.

Dachiardite— $(\text{Na,K,Ca}_{0.5})_4(\text{Al}_4\text{Si}_{10}\text{O}_{40}) \cdot 18\text{H}_2\text{O}$

Dachiardite is a fairly rare zeolite mineral, but previously it has been identified from two locations in Oregon (Tschernich, 1992). At Newberry volcano, clusters of fibrous, acicular, or lath-shaped dachiardite crystals were found in a single specimen of rhyolitic tuff from 443.2-m depth (temperature –98°C) in drill hole USGS-N2, where the mineral, along with smectite, was formed by hydrothermal alteration of pumice fragments. A volcanic breccia specimen in drill hole GEO-N5 (southwest flank of Newberry volcano) contains tiny, colorless dachiardite crystals along with mordenite and smectite in open spaces between breccia fragments at 886.7-m depth (temperature –65°C).

Electron microprobe analyses of dachiardite from USGS-N2 (Bargar and Keith, in preparation) show that the mineral is rich in sodium (Figure 3C) and probably

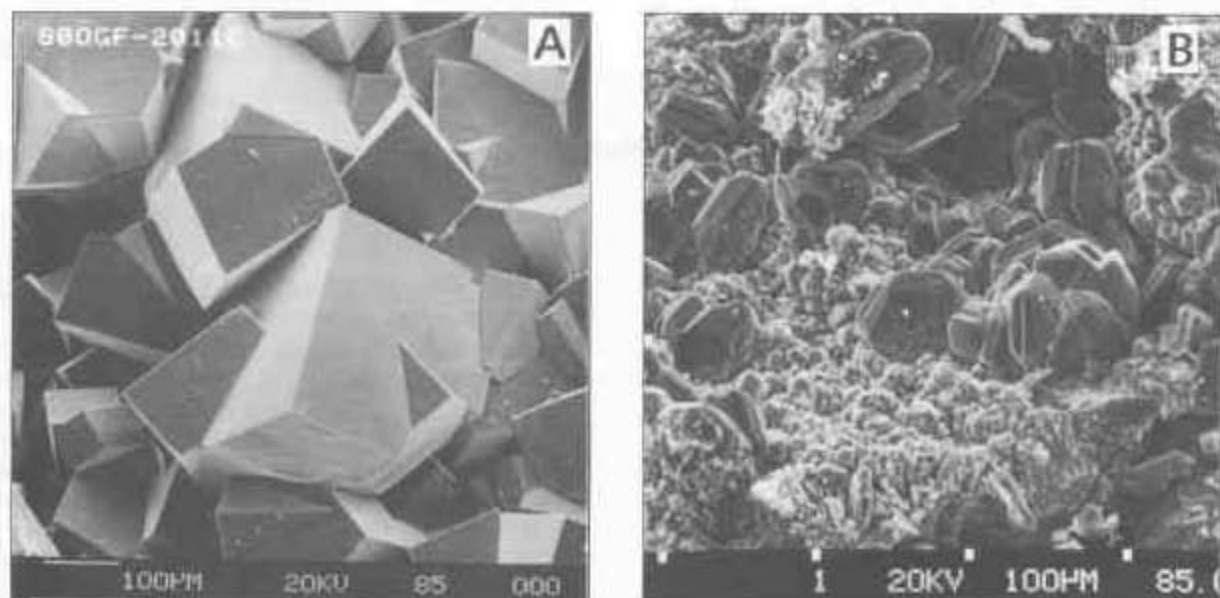


Figure 4. Scanning electron micrographs showing (A) colorless, euhedral, pseudocubic chabazite crystals, coating vesicles in Pliocene(?) andesite from an outcrop near Austin Hot Springs; (B) colorless, lens-shaped (phacolitic) chabazite crystals deposited on faujasite, coating a veinlet in basaltic sandstone from 308.9-m depth in USGS-N2 Newberry drill hole. Distance between white tick marks at bottom of micrograph is 100 μ .

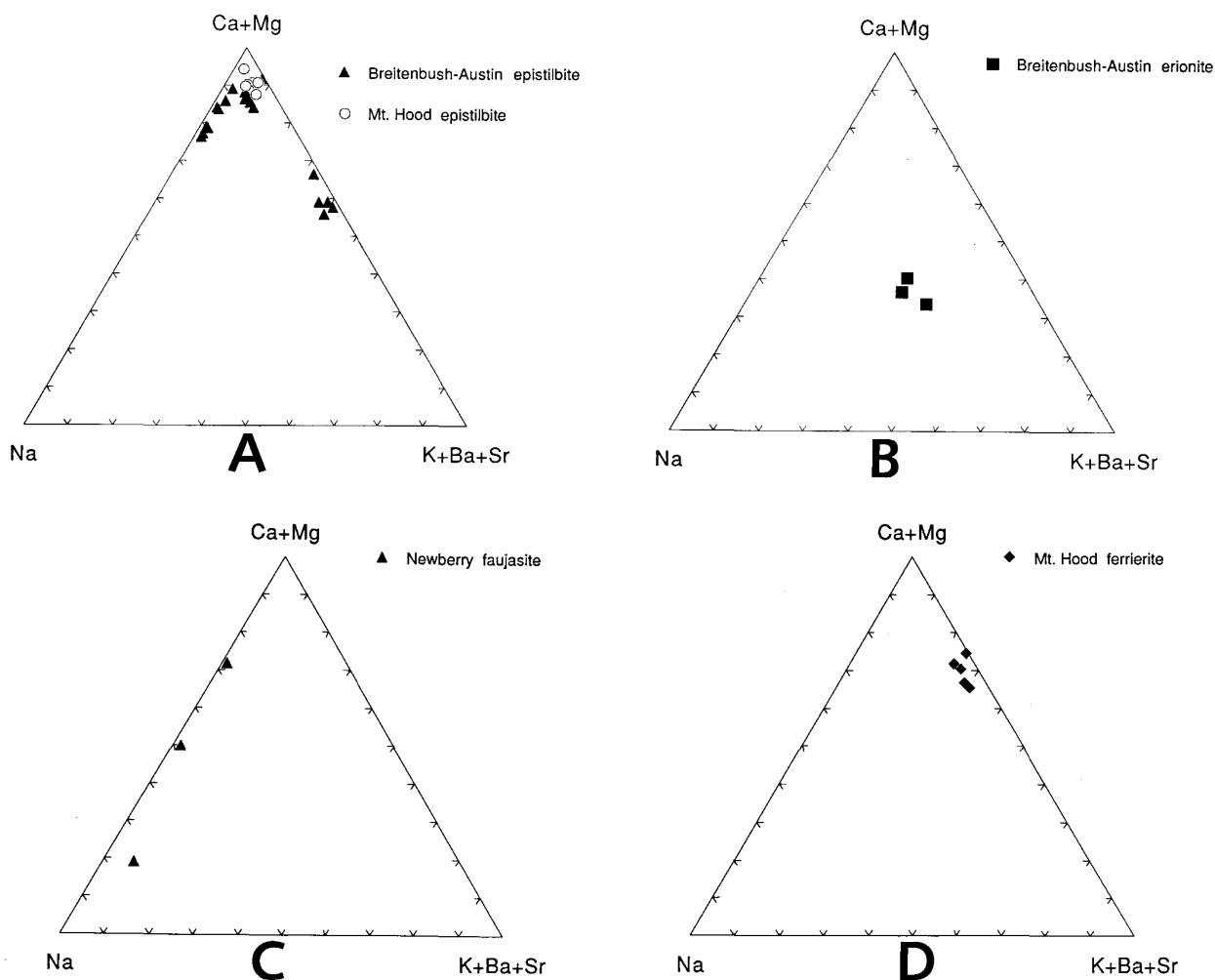


Figure 5. Ca+Mg–Na–K+Ba+Sr ternary diagrams for microprobe analyses of (A) epistilbite, (B) erionite, (C) faujasite, and (D) ferrierite from the Oregon Cascades.

should be referred to as “sodium dachiardite” rather than just “dachiardite” as recommended by Bargar and others (1987), who reported several optical, crystallographic, and chemical differences between dachiardite and sodium dachiardite.

Epistilbite— $\text{Ca}_3(\text{Al}_6\text{Si}_{18}\text{O}_{48}) \cdot 16\text{H}_2\text{O}$

Epistilbite was identified in four geothermal drill holes and one late Tertiary volcanic rock outcrop in the Mount Hood area (Bargar and others, 1993). Epistilbite occurs in drill cuttings of a basaltic intrusive specimen from 1,411-m depth in the SUNEDCO 58–28 hole (Bargar, 1994). This study also located minor epistilbite in seven outcrops of late Tertiary volcanic rocks in the Breitenbush-Austin Hot Springs area. Epistilbite has only

been reported from two other areas in Oregon (Tschernich, 1992).

Electron microprobe analyses of the Mount Hood Ca-rich epistilbite indicate that it is lower in Si and higher in Al and Ca than the stoichiometric formula (Bargar and others, 1993). Analyzed specimens from the Breitenbush-Austin Hot Springs area plot into two groups, with one group containing slightly more Na and the second group having substantially more K than the Mount Hood epistilbite (Oscarson and Bargar, 1996) (Figure 5A).

Erionite— $\text{NaK}_2\text{MgCa}_{1.5}(\text{Al}_8\text{Si}_{28}\text{O}_{72}) \cdot 28\text{H}_2\text{O}$

Three specimens between 886- and 888-m depth in the CTGH-1 hole contain columnar bundles of acicular

erionite crystals that formed later than smectite. SEM studies show that the erionite columns occasionally have hexagonal cross sections (Figure 6). Bundles of tiny prismatic erionite crystals occur in three basaltic sediment samples between depths of 315 and 318.5 m in the USGS-N2 hole. Temperatures at the depths where erionite occurs in the two geothermal holes were about 50°C. Electron microprobe analyses for erionite from the CTGH-1 hole show that the mineral contains nearly equal parts of Ca, Na, and K (Oscarson and Bargar, 1996) (Figure 5B).

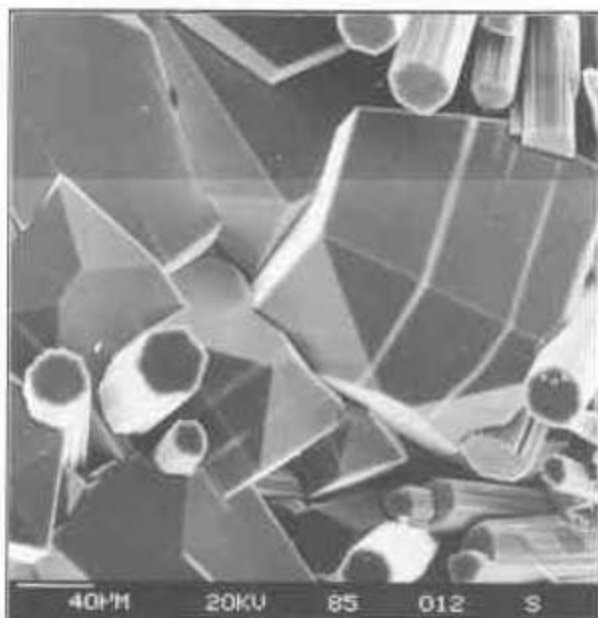


Figure 6. Scanning electron micrograph showing hexagonal bundles of fibrous erionite and later blocky heulandite crystals, filling vesicles in basaltic andesite breccia fragments from 887-m depth in the CTGH-1 drill hole.

Faujasite— $\text{Na}_{20}\text{Ca}_{12}\text{Mg}_8(\text{Al}_{60}\text{Si}_{132}\text{O}_{384})\cdot 235\text{H}_2\text{O}$

Faujasite is a rare zeolite mineral that was identified in colorless to white vein fillings and intergranular open-space fillings of eleven porous basalt sediment specimens between 308.9- and 320-m depth in the USGS-N2 geothermal hole (temperature about 40° to 50°C) (Bargar and Keith, in preparation). SEM studies of the faujasite show extensive deterioration with cracking and flaking of the crystal surfaces (Figure 7) that is perhaps caused by dehydration. Electron microprobe analyses of three faujasite crystals from 314.4-m depth show considerable variability in the Na and Ca contents (Figure 5C) (Bargar and Keith, in preparation), which is reported as typical for faujasite (Gottardi and Galli, 1985). To the best of our knowledge, this is the only faujasite ever found in Oregon.

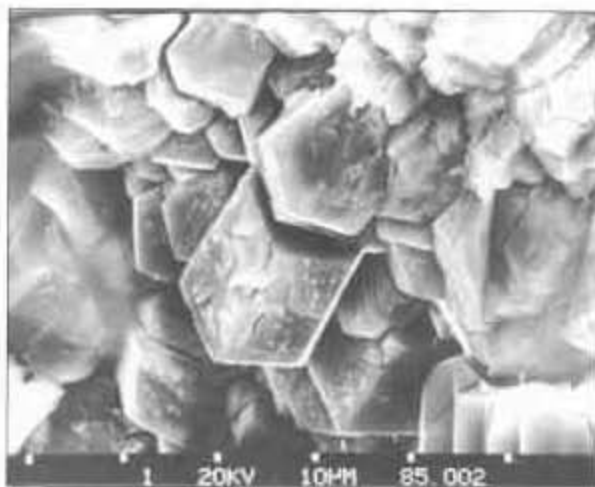


Figure 7. Scanning electron micrograph of fractured and flaking faujasite crystals filling a veinlet in basaltic sandstone from 308.9-m depth in the USGS-N2 drill hole at Newberry volcano. Distance between white tick marks at bottom of micrograph is 10 µ.

Ferrierite— $(\text{Na,K})\text{Mg}_2\text{Ca}_{0.5}(\text{Al}_8\text{Si}_{30}\text{O}_{72})\cdot 20\text{H}_2\text{O}$

Another rare zeolite mineral that previously has not been reported from Oregon is ferrierite. One fault gouge sample from a late Miocene andesite flow at the southern base of Mount Hood contained colorless, acicular to lamellar crystals of ferrierite in association with smectite (Figure 8) (Bargar and others, 1993). Electron microprobe analyses (Oscarson and Bargar, 1996) show the presence of significant Mg (Figure 5D) (Mg:Ca ranges from 3:1 to 6:1). Ferrierite is one of the few zeolite minerals that may contain an appreciable amount of magnesium (Gottardi and Galli, 1985).

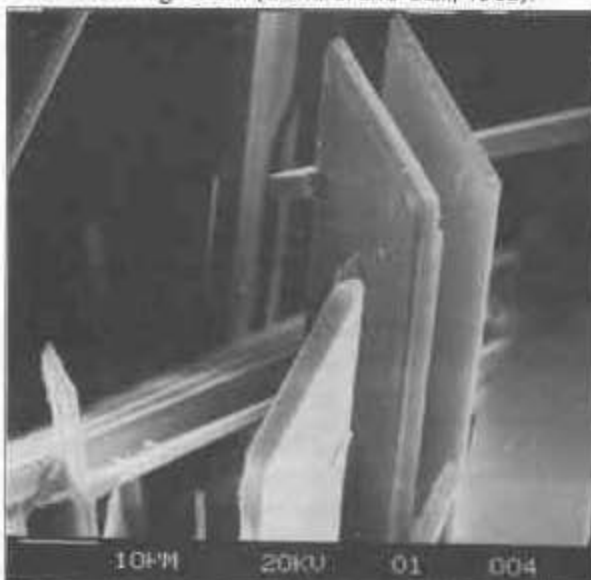


Figure 8. Scanning electron micrograph showing bladed ferrierite crystals from an outcrop near Mount Hood.

Gismondine— $\text{Ca}_4(\text{Al}_3\text{Si}_5\text{O}_{32}) \cdot 16\text{H}_2\text{O}$

Tschernich and Howard (1988) described gismondine as filling vesicles, in association with chabazite, calcite, levyne, smectite, and thomsonite, in an outcrop of light-colored volcanic rocks along the Oak Grove Fork Clackamas River in the Breitenbush-Austin Hot Springs area. A vesicular basaltic lava flow specimen was collected from the same general area for the present study. Vesicles in this specimen are filled by pseudotetragonal gismondine crystals and later chabazite (Figure 9). A scanning electron microscope EDS analysis of the gismondine shows only Ca, Al, and Si (Oscarson and Bargar, 1996). According to Tschernich (1992), the Oak Grove Fork area is the only location in the Pacific Northwest where gismondine has been found.

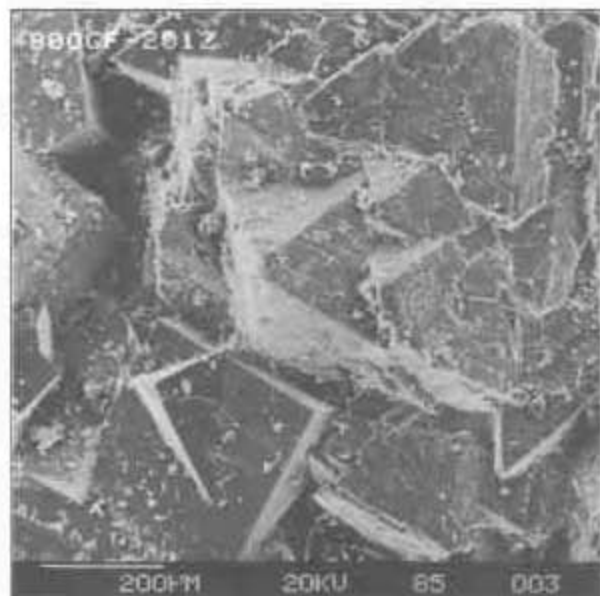


Figure 9. Scanning electron micrograph of pseudotetragonal gismondine crystals in association with penetration twinned chabazite crystals (lower left), filling vesicles in basaltic rock from the Oak Grove Fork Clackamas River.

Harmotome— $\text{Ba}_2(\text{Ca}_{0.5}\text{Na})(\text{Al}_8\text{Si}_{11}\text{O}_{32}) \cdot 12\text{H}_2\text{O}$

Phillipsite— $\text{K}_2(\text{Ca}_{0.5}\text{Na})_4(\text{Al}_6\text{Si}_{10}\text{O}_{32}) \cdot 12\text{H}_2\text{O}$

Wellsite— $(\text{Ba,Ca,K})_2\text{Al}_2\text{Si}_6\text{O}_{16} \cdot 6\text{H}_2\text{O}$

The three zeolite minerals, harmotome, phillipsite, and wellsite, are generally classified as belonging to the phillipsite-harmotome group of zeolite minerals (Gottardi and Galli, 1985). A single specimen of harmotome was collected from a tailings pile in an old mining area southwest of Mount Hood (Bargar and others, 1993); the colorless, blocky, hydrothermal harmotome crystals (Figure 10A) formed in association with earlier stilbite/stellerite (chlorite, pyrite, and calcite also present) on the fracture surface of a late Tertiary andesite lava flow (Bargar and others, 1993). Electron micro-

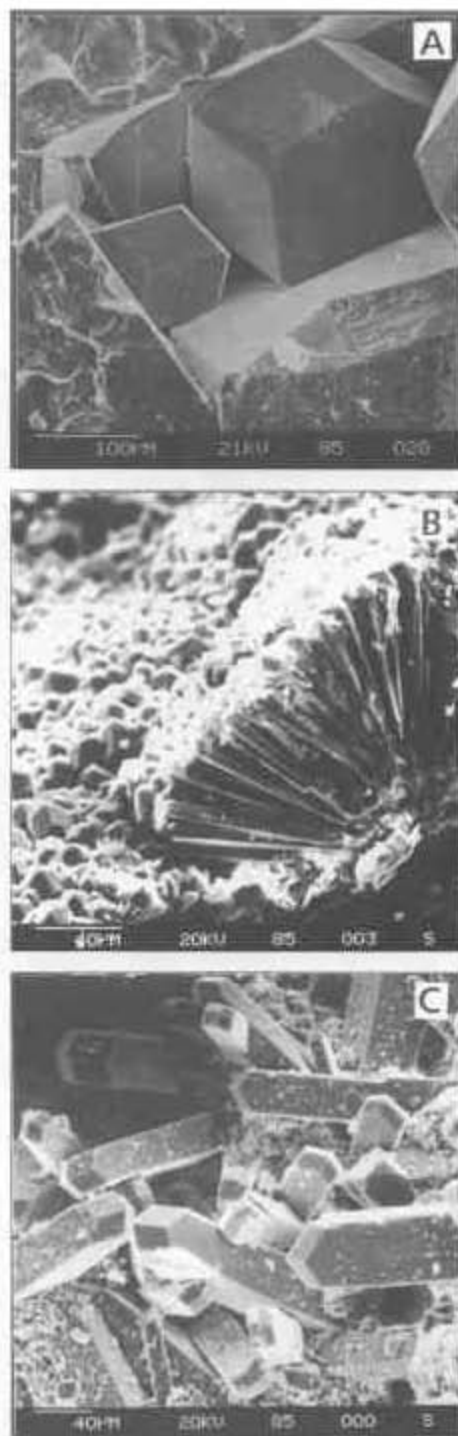


Figure 10. Scanning electron micrographs of (A) euhedral harmotome crystals from near Mount Hood, (B) radiating prisms of phillipsite crystals that fill open spaces between breccia fragments in core from 812-m depth in the CTGH-1 drill hole, and (C) prismatic wellsite crystals and later smectite that coat vesicles in basaltic andesite at 564-m depth in CTGH-1.

probe analyses (Bargar and others, 1993) show that the euhedral, pseudo-orthorhombic harmotome crystals have a very high Ba content (only minor Ca, Na, and K) (Figure 11A), which is characteristic of harmotome (Gottardi and Galli, 1985). Harmotome is a fairly uncommon mineral, and it does not appear to have been reported elsewhere in Oregon (Tschernich, 1992). Although harmotome has not been identified in modern geothermal areas, some harmotome is known to have a hydrothermal origin (Tschernich, 1992).

Phillipsite occurs at several localities in Oregon (Tschernich, 1992). However, in the present study, phillipsite was identified only in two Breitenbush-Austin Hot Springs area outcrop samples and three core specimens from the CTGH-1 hole (Bargar, 1990). Phillipsite, an early formed mineral in this drill core, occurs at depths of 811, 812, and 821 m (measured temperature ~40°C) as fillings in basalt vesicles or between fragments in volcanic breccia. Phillipsite from Icelandic geothermal areas occurs at temperatures between 60° and 85°C; however, Gottardi and Galli (1985), indicate that it can form at temperatures up to 200°C. The blocky to prismatic crystals occur in very closely spaced clusters (Figure 10B). At 812-m depth, the phillipsite crystals have a skeletal appearance and are partly dissolved. The dominant cation in one CTGH-1 specimen is K (Figure 11A); Na and Ca (uncombined) are less abundant and Ba is absent.

Wellsite was identified only in vesicles of basaltic core from 564-m depth in the CTGH-1 hole (measured temperature is ~32°C). The mineral formed as randomly oriented, elongate prismatic crystals (Figure 10C); clusters of radiating crystals; or closely spaced elongate crystals deposited as overlapping, radiating, hemispherical crystal clusters. The latter deposits produce a botryoidal-appearing vesicle coating similar to phillipsite in Figure 10B. Electron microprobe analyses of the CTGH-1 wellsite (Oscarson and Bargar, 1996) show that the mineral is composed of nearly equal amounts of Na and K+Ba, and contains relatively little Ca (Figure 11B). Tschernich (1992) indicates that "barian phillipsite (= wellsite)" occurs in at least two other locations in Oregon, both of which are only a few tens of kilometers from the CTGH-1 drill-hole site.

Heulandite— $(\text{Na}, \text{K})\text{Ca}_4(\text{Al}_5\text{Si}_{27}\text{O}_{72}) \cdot 24\text{H}_2\text{O}$

Clinoptilolite— $(\text{Na}, \text{K})_6(\text{Al}_6\text{Si}_{30}\text{O}_{72}) \cdot 20\text{H}_2\text{O}$

Heulandite group minerals—heulandite, clinoptilolite, and intermediate heulandite(?)—occur in drill holes and/or outcrops of all three areas studied. Past researchers have distinguished between heulandite and clinoptilolite by either XRD (Mumpton, 1960) or chemical differences (Mason and Sand, 1960). Later studies (Alietti, 1972; Boles, 1972) even indicated the presence of a third or intermediate heulandite mineral phase. Reliance upon the definitions presented in the above

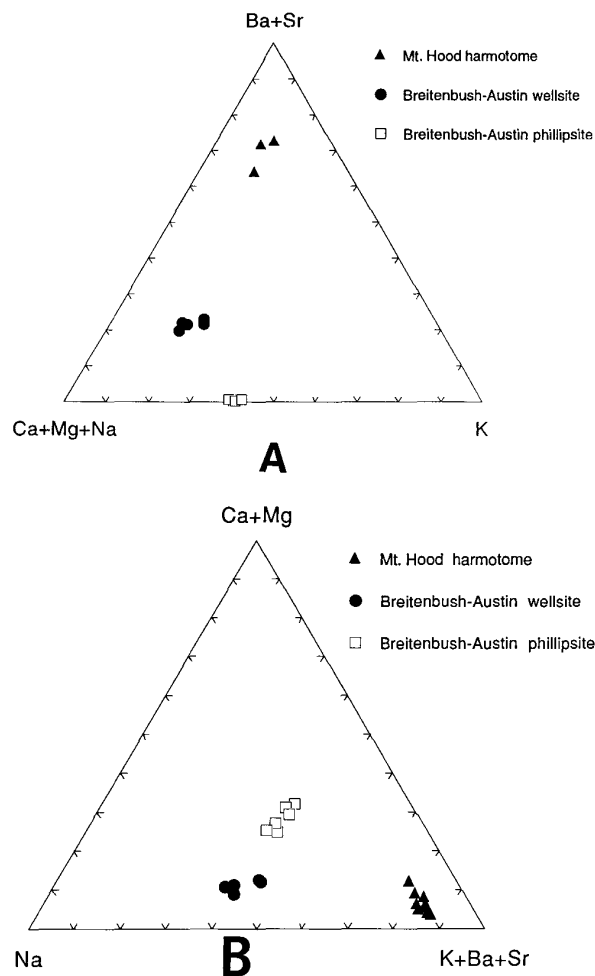


Figure 11. (A) Ba+Sr–Ca+Mg+Na–K and (B) Ca+Mg–Na–K+Ba+Sr ternary diagrams for electron microprobe analyses of harmotome, phillipsite, and wellsite from the Oregon Cascades.

references indicates that all three phases of the heulandite group of minerals are present in the Oregon Cascade Range.

Heulandite was identified from fractures and open spaces between rock fragments in a few outcrops of late Tertiary volcanogenic deposits near Mount Hood; also, late Tertiary to Quaternary volcanic drill chips from five nearby geothermal holes contain tiny, colorless, tabular or blocky, heulandite crystals (Bargar and others, 1993).

Both heulandite and clinoptilolite are present in the lower part of the CTGH-1 drill hole near Breitenbush Hot Springs (Bargar, 1990). These heulandite group minerals were deposited in vesicles and fractures and between breccia fragments of late Tertiary andesitic to basaltic lava flows, tuffs, and breccias. The tabular

zeolite minerals formed later than hematite, most smectite, celadonite, and erionite but are earlier than cristobalite (Figure 12), mordenite, or minor late smectite.



Figure 12. Vesicle fillings in a very vesicular basaltic rock outcrop from the Oak Grove Fork Clackamas River that contain colorless, euhedral, tabular heulandite crystals and later hemispherical cristobalite.

Heulandite and intermediate heulandite are fairly common minerals in open spaces of late Tertiary volcanic rocks throughout the Breitenbush-Austin Hot Springs area. Drill cutting specimens from several depths in the SUNEDCO 58-28 geothermal hole near Breitenbush Hot Springs also contain heulandite (Bargar, 1994).

Minor clinoptilolite occurs in rhyolitic tuff breccia core from near the middle of the USGS-N2 geothermal hole within the crater of Newberry volcano (Keith and Bargar, 1988). The only other heulandite group mineral identified from this volcano is a small amount of heulandite which occurs in fractures and vesicles of basaltic to andesitic drill core recovered from near the bottom of the western flank GEO-N5 hole (Bargar and Keith, in preparation).

Heulandite group minerals typically are found in modern geothermal areas at low to moderate temperatures. Measured temperatures at the depths where heulandite occurs in the SUNEDCO 58-28 drill hole range from about 80° to 130°C. These temperatures are within the apparent temperature limits (about 70° to 170°C) for heulandite in Icelandic geothermal drill holes (Kristmansdóttir and Tómasson, 1978). However, some heulandite and clinoptilolite minerals occur at temperatures as low as 30°C (range is about 30° to

96°C) in the CTGH-1 hole (Bargar, 1990). A bottom-hole temperature of about 60°C was measured for the only Mount Hood geothermal hole containing substantial heulandite (Bargar and others, 1993). At Newberry volcano, clinoptilolite was located in the USGS-N2 drill hole at a depth where the measured temperature was about 99°C (Keith and Bargar, 1988). The present temperature at the core depth where heulandite was identified in the Newberry GEO-N5 hole is about 80°C (Bargar and Keith, in preparation).

Figure 13 shows a ternary diagram of the exchangeable cations commonly present in heulandite-group minerals of the northern Oregon Cascade Range. The Newberry and Breitenbush-Austin clinoptilolites are Na- or K-rich minerals that show no structural changes following heating at 450°C for 24 hours (Mumpton, 1960). One clinoptilolite specimen contains 8.34 weight percent K_2O (Bargar and Keith, in preparation). Clinoptilolites with such high K_2O contents usually are produced by sedimentary (Stonecipher, 1978) or diagenetic (Ogihara and Iijima, 1990) processes rather than hydrothermal alteration. However, Keith and others (1978) and Bargar and Beeson (1985) reported K_2O contents of 5.73 and 4.99 weight percent, respectively, for clinoptilolite in rhyolitic drill core specimens from thermal areas of Yellowstone National Park.

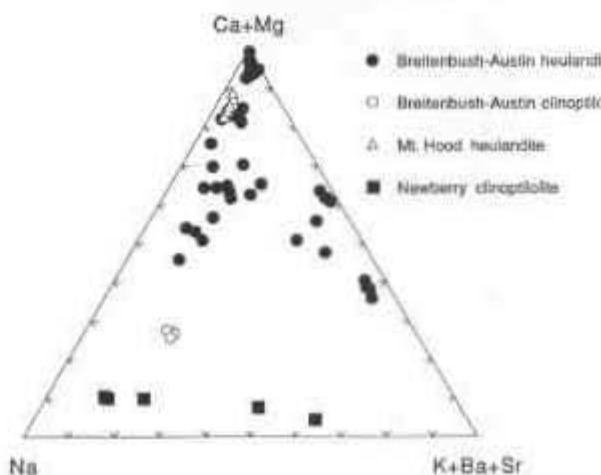


Figure 13. Ca+Mg-Na-K+Ba+Sr ternary diagram for electron microprobe analyses of heulandite-group minerals from the Oregon Cascades.

The remaining Breitenbush-Austin and Mount Hood heulandite-group minerals show weak to substantial changes in intensity or spacing of XRD patterns following heating, which corresponds to results reported for heulandite or intermediate heulandite (Alietti, 1972; Boles, 1972). The microprobe analyses of these mineral specimens (Oscarson and Bargar, 1996) are all Ca-rich, but many of the analyses exhibit considerable scatter (Figure 13), owing to the presence of substantial Na or K.

Laumontite— $\text{Ca}_4(\text{Al}_8\text{Si}_6\text{O}_{48}) \cdot 16\text{H}_2\text{O}$

Laumontite is a common zeolite mineral in the Oregon Cascade Range. White, euhedral, prismatic laumontite crystals, up to about 3 cm in length, were found during this study, filling open spaces between volcanic breccia fragments and lining vugs and fractures. Frequently, laumontite can be readily identified from its distinctive habit in which the terminal sloping {201} crystal face is prominent (Figure 14).

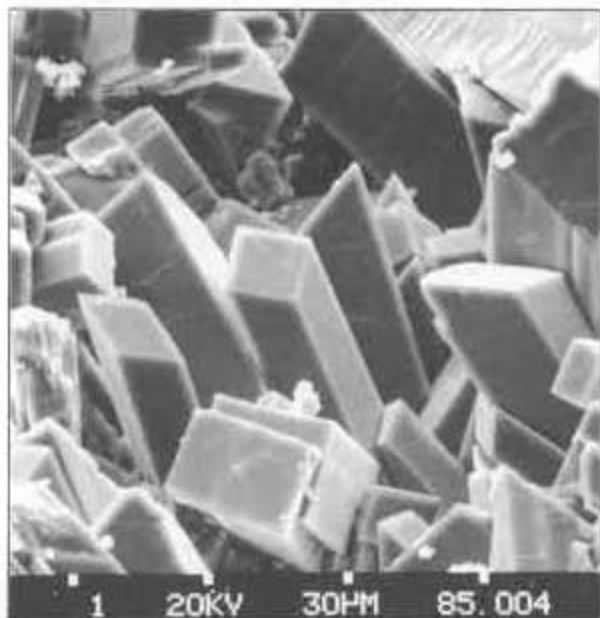


Figure 14. Scanning electron micrograph showing euhedral laumontite crystals that coat a rock fragment in drill cuttings from 1,125-m depth in the Pucci geothermal drill hole located on the southern slopes of Mount Hood. Distance between white tick marks at bottom of micrograph is 30 μ .

In the Mount Hood and Breitenbush-Austin Hot Springs areas, laumontite occurs in several geothermal drill holes and numerous outcrops of late Tertiary volcanic rocks (Bargar and others, 1993; Bargar, 1994). The temperature range at which laumontite was identified in the SUNEDCO 58-28 hole is about 110°–130°C. Conversely, at Newberry volcano, traces of laumontite were identified in only two drill holes (temperatures about 150° and 160°C) (Bargar and Keith, in preparation). These temperatures fall within the wide temperature range (43° to 230°C) at which laumontite previously has been reported (Kristmannsdóttir and Tómasson, 1978; McCulloh and others, 1981).

Electron microprobe analyses of laumontite from both the Mount Hood and Breitenbush-Austin areas (Oscarson and Bargar, 1996) are Ca-rich with only minor amounts of other exchangeable cations (Figure 15A).

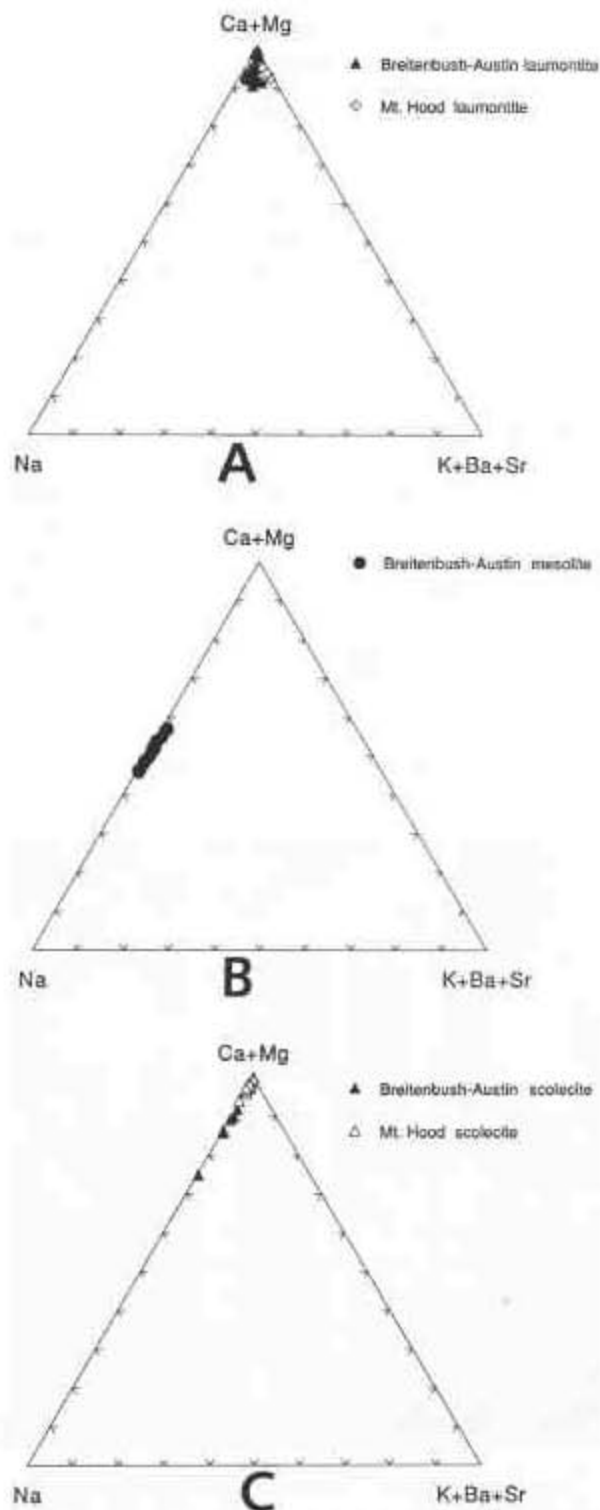


Figure 15. Ca+Mg–Na–K+Ba+Sr ternary diagrams for electron microprobe analyses of (A) laumontite, (B) meso-lite, and (C) scolecite specimens collected from near Mount Hood and Breitenbush-Austin Hot Springs areas.

Levyne— $\text{NaCa}_{2.5}(\text{Al}_6\text{Si}_{12}\text{O}_{36}) \cdot 18\text{H}_2\text{O}$

Levyne was found in association with smectite, filling vesicles in a basalt outcrop located ~3–4 km southeast of Breitenbush Hot Springs. A fracture surface in the collected specimen was filled by thomsonite and chabazite. Levyne is not a rare mineral in Oregon, but it was not found elsewhere during the present study. According to studies of Kristmannsdóttir and Tómasson, (1978), levyne occurs in Icelandic geothermal areas at temperatures below 70°C; chabazite forms over the same temperature range; however, thomsonite occurs at temperatures as high as 110°C.

Mesolite— $\text{Na}_{16}\text{Ca}_{16}(\text{Al}_{48}\text{Si}_{72}\text{O}_{240}) \cdot 64\text{H}_2\text{O}$

Scolecite— $\text{Ca}_6(\text{Al}_{12}\text{Si}_{24}\text{O}_{80}) \cdot 24\text{H}_2\text{O}$

Mesolite and scolecite are classified in the same group of fibrous zeolites (Figure 16) (Gottardi and Galli, 1985). Morphologically, the two minerals are indistinguishable; however, they can be differentiated by optical characteristics, and they have different chemical compositions. Mesolite contains nearly equal proportions of Na and Ca, while Ca is the dominant cation in scolecite. Other cations mostly are absent in both minerals (Figures 15B,C) (Tschernich, 1992). Analysis of trace elements for one scolecite specimen from the Mount Hood area shows the presence of minor Ba, Cu, Mn, Zn, and some Sr (Bargar and others, 1993).

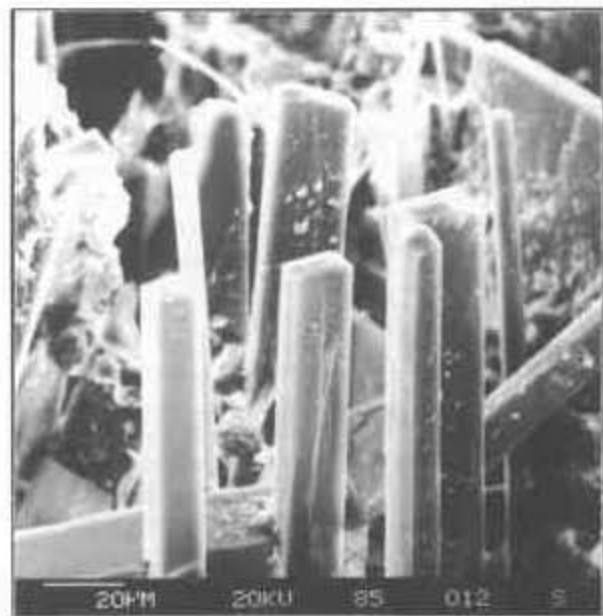


Figure 16. Scanning electron micrograph showing acicular mesolite crystals that coat fractures at 767-m depth in the CTGH-1 drill hole located near Breitenbush Hot Springs. Tabular mineral in the upper right and lower left corners of the figure is thomsonite. Both of these minerals are slightly coated by late smectite.

Mesolite has been reported from several locations in Oregon, including some areas within the Cascade Range. Scolecite, on the other hand, has been reported only from three areas in Oregon (Tschernich, 1992). Mesolite and scolecite occur in only a few specimens collected for this study.

Mordenite— $\text{Na}_2\text{KCa}_2(\text{Al}_2\text{Si}_{40}\text{O}_{96}) \cdot 28\text{H}_2\text{O}$

Mordenite occurs in outcrop specimens and/or drill-hole samples in all three study areas, but it is not very abundant in any of them (Keith and Bargar, 1988; Bargar, 1990; Bargar and others, 1993; Bargar, 1994). Individual white, fibrous to acicular mordenite crystals or mats of fibrous crystals (Figure 17) have a qualitative EDS chemistry consisting of Ca, Al, and Si (Oscarson and Bargar, 1996) and, occasionally, trace amounts of Na or K. Mordenite usually formed later than associated hydrothermal minerals. In the Cascade Range, measured drill-hole temperatures at depths where mordenite was located range from about 50°C to more than 160°C. In Icelandic geothermal areas, mordenite occurs over a somewhat wider temperature range (~75° to 230°C) (Kristmannsdóttir and Tómasson, 1978).

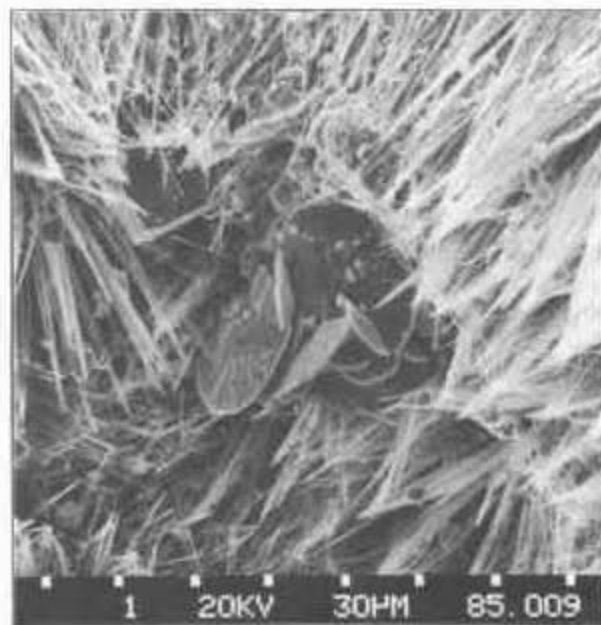


Figure 17. Scanning electron micrograph showing fibrous mordenite and earlier disk-shaped clusters of siderite, coating open spaces between breccia fragments in core from 496-m depth in the USGS-N2 drill hole. Distance between white tick marks at bottom of micrograph is 30 µ.

Stilbite/Stellerite



Next to laumontite, white to colorless, tabular (Figures 18A,B) stilbite and stellerite are the most common zeolite minerals found in the Mount Hood and Breitenbush-Austin Hot Springs areas. These minerals

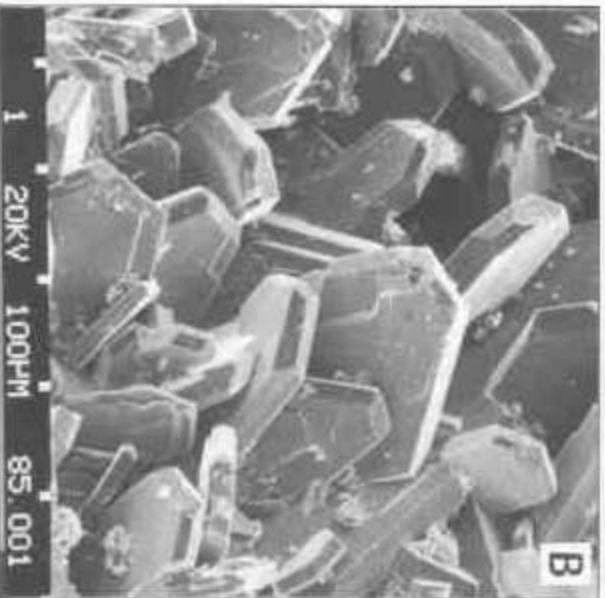
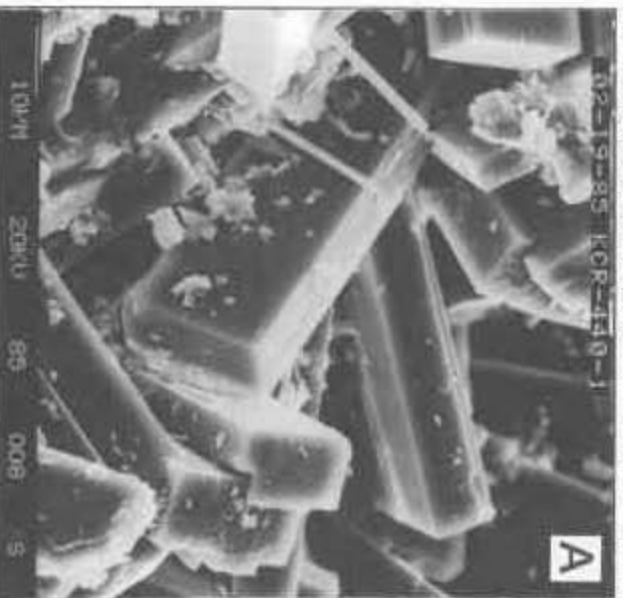


Figure 18. Scanning electron micrographs showing different morphologies for stilbite/stellerite that coats rock fragments in drill cuttings from (A) 134-m depth in the Zigzag River geothermal drill hole and (B) 1,161-m depth in the Pucci drill hole. Both drill holes are located near Mount Hood (Bargar and others, 1993). Distance between white tick marks at bottom of micrograph is 100 μ .

were not identified in the Newberry volcano drill holes. The two solid-solution series minerals are combined here because they are distinguishable with confidence only by single-crystal XRD analysis (R.C. Erd, written communication, 1992), which was not attempted for this report. Electron microprobe analyses of stilbite/stellerite from the two study areas (Oscarson and Bargar, 1996) may show a separation of the two minerals (Figure 19A), with Na-rich analyses corresponding to stilbite; however, the possibility was not investigated for this report. Trace element analyses for two stilbite/stellerite specimens from the Mount Hood area show the presence of significant Pb (Bargar and others, 1993, Table 5). Drill-hole temperatures at depths where stilbite/stellerite was identified in drill hole SUNE DCO 58-28 were between 100° and 120°C (Bargar, 1994). Stilbite from Icelandic geothermal drill holes occurs over a temperature range of 70° to about 170°C (Kristmannsdóttir and Tómasson, 1978). Tschernich (1992) lists several Oregon localities where stilbite previously has been reported.

Thomsonite— $\text{Na}_4\text{Ca}_6(\text{Al}_{20}\text{Si}_{20}\text{O}_{60})\cdot 24\text{H}_2\text{O}$

Thomsonite was located in fracture and vesicle fillings between about 648- and 866-m depth in the CTGH-1 drill hole (temperatures between 30° and 50°C) (Bargar, 1990); bladed thomsonite (Figure 20) also was located, filling vesicles and fractures of three outcrops in the Breitenbush-Austin Hot Springs area. While thomsonite is fairly rare in the three study areas of this report, it is not uncommon elsewhere in Oregon (Tschernich, 1992). Electron microprobe analyses (Oscarson and Bargar, 1996) for three thomsonite specimens appear to be fairly typical for thomsonite (Cottardi and Galli, 1985) (Figure 19B).

Yugawaralite— $\text{Ca}_2\text{Al}_4\text{Si}_4\text{O}_{22}\cdot 8\text{H}_2\text{O}$

Rare specimens of yugawaralite are reported from a few geothermal areas where the temperatures range between 110° and 200°C (Cottardi and Galli, 1985; Tschernich, 1992). One sample, collected on the north shore of Detroit Reservoir, contains stacked, colorless, tabular yugawaralite crystals, along with laumontite, stilbite/stellerite, scolecite, and mixed-layer chlorite-smectite in an extremely altered outcrop of early Neogene (Hammond and others, 1982) volcanic rocks. This occurrence appears to be the only specimen of yugawaralite that has ever been found in Oregon (Tschernich, 1992). Electron microprobe analyses of the mineral are given in Oscarson and Bargar (1996); calcium is the dominant cation; only minor sodium and potassium was detected in these analyses (Figure 19C).

FINAL REMARKS

Twenty-three zeolite minerals were identified from rock-outcrop and geothermal drill-hole specimens ob-

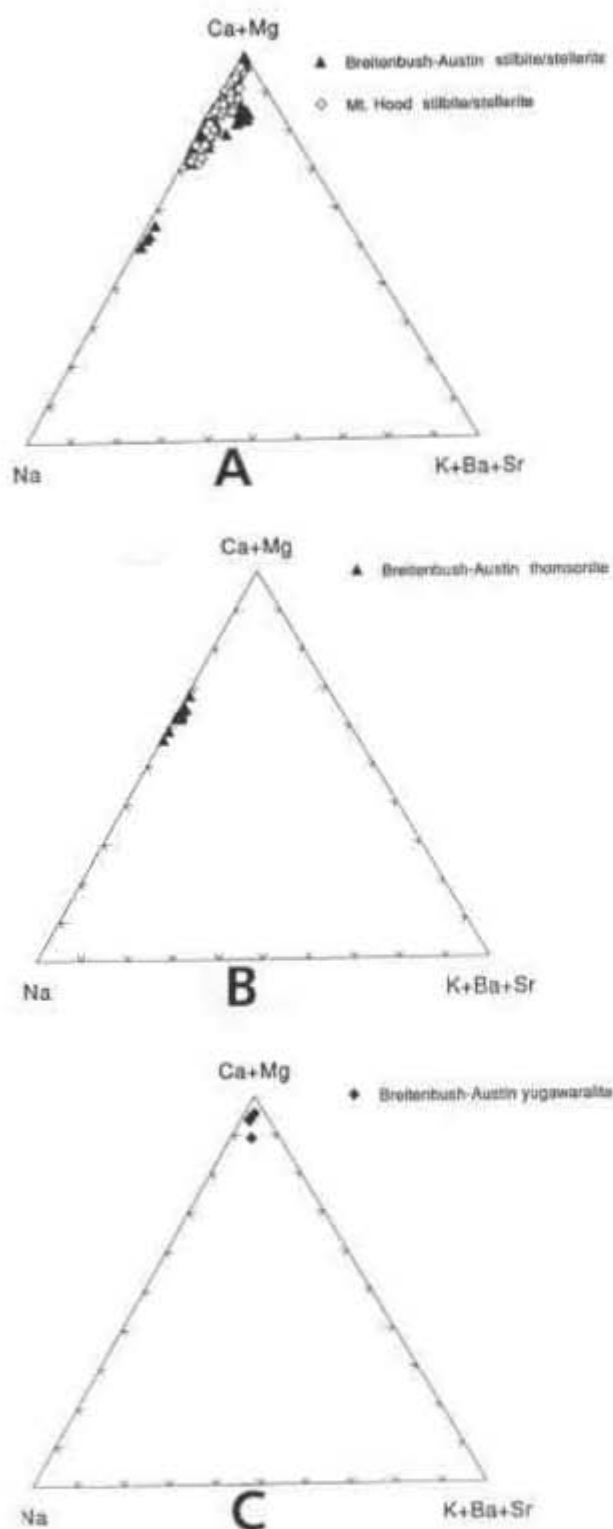


Figure 19. Ca+Mg-Na-K+Ba+Sr ternary diagrams for electron microprobe analyses of (A) stilbite/stellerite, (B) thomsonite, and (C) yugawaralite from the Breitenbush-Austin Hot Springs and Mount Hood areas.

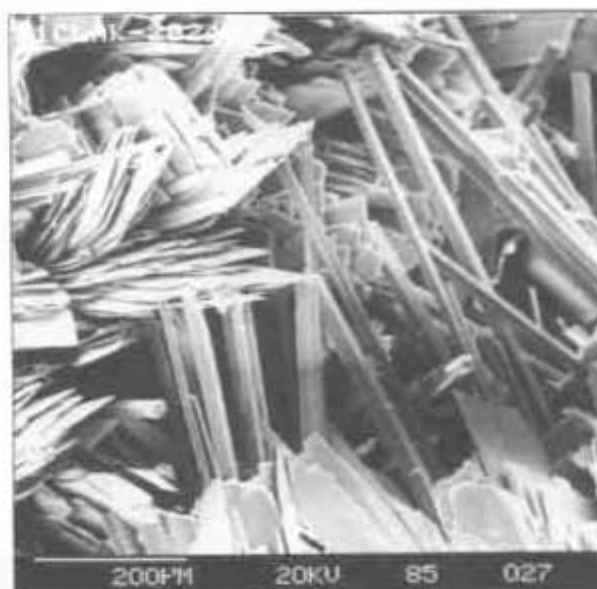


Figure 20. Scanning electron micrograph showing bladed thomsonite and acicular scolecite that fill fractures in a basalt outcrop in the Breitenbush-Austin Hot Springs area.

tained from the three study areas (near Mount Hood, Newberry volcano, and the Breitenbush-Austin Hot Springs area). Of these zeolites, five (wairakite, faujasite, ferrierite, harmotome, and yugawaralite) are significant because they apparently have not been found elsewhere in Oregon. The widespread occurrence of zeolite minerals throughout the Western Cascade Range of northern Oregon (especially in the Breitenbush-Austin Hot Springs area) attests to the significance of zeolite metamorphism in altering the late Tertiary volcanic rocks.

The most intense (greenschist facies) hydrothermal alteration of volcanic rocks in the Mount Hood and Breitenbush-Austin Hot Springs areas was observed in surface-exposed or drill-hole-penetrated, small, scattered, late Tertiary intrusions. A few kilometers away from these intrusions, zeolites and other low-temperature minerals are the dominant hydrothermal alteration products. The low-temperature minerals frequently are superimposed upon the higher temperature minerals formed during late stages of hydrothermal alteration. Fluid inclusion data obtained for the two areas (Bargar, 1993, 1994; Bargar and others, 1993; Bargar and Oscarson, 1997) support and serve to quantify these conclusions.

Within the caldera of the active Newberry volcano, fluid inclusion and hydrothermal mineralogy studies of the Quaternary volcanic drill-hole specimens indicate that the rocks have been altered by thermal fluids compatible with zeolite (at shallower levels) to greenschist (at depth) metamorphism. Drill holes located a

few kilometers outside the caldera on the north, east, and south flanks of the volcano contain evidence of only very low temperature alteration. On the west flank of Newberry, the available measured temperature and fluid-inclusion homogenization temperature data suggest that the fluids become hotter nearer the rim of the caldera.

Preliminary hydrothermal alteration and fluid inclusion studies of geothermal drill holes at Medicine Lake volcano in northern California (Bargar and Keith, 1993) also indicate that temperatures capable of producing greenschist-facies minerals appear to be confined to the area within the caldera. As at Newberry volcano, current available data for drill holes outside the caldera do not show evidence of high temperature alteration.

Two very different models have been proposed to explain the high heat flow observed throughout much of the Oregon Cascade Range. One model indicates that the source of the heat is widespread and that the geothermal energy potential of the area is very significant (Blackwell and others, 1990). The second model suggests that the heat source is more localized and the heat is spread by fluid movement, which results in a substantially smaller geothermal potential (Ingebritsen and others, 1994). The hydrothermal alteration studies conducted for this report appear to support the second model, inasmuch as hydrothermal mineralogical evidence of past or present high temperatures in the Cascade Range of northern Oregon (and at Medicine Lake volcano, northern California) was found only in close proximity to small, late Tertiary intrusions or within or very near the calderas of active volcanoes.

ACKNOWLEDGMENTS

We thank the Oregon Department of Geology and Mineral Industries and A.F. Waibel for making drill-hole samples available for this study. Reviews by M.A. Clynne and R.H. Mariner improved the manuscript and are gratefully acknowledged.

REFERENCES CITED

- Alietti, A., 1972, Polymorphism and crystal-chemistry of heulandites and clinoptilolites: *American Mineralogist*, v. 57, p. 1448-1462.
- Arestad, J.F., Potter, R.W., II, and Stewart, G.E., 1988, Stratigraphic test drilling in the Newberry crater KGRA, Oregon: *Geothermal Resources Council Bulletin*, v. 17, no. 10, p. 3-8.
- Bargar, K.E., 1990, Hydrothermal alteration in geothermal drill hole CTGH-1, High Cascade Range, Oregon: *Oregon Geology*, v. 52, no. 4, p. 75-81.
- , 1993, Fluid-inclusion evidence for previous higher temperatures in the SUNEDCO 58-28 drill hole near Breitenbush Hot Springs, Oregon: *Geothermal Resources Council Transactions*, v. 17, p. 83-89.
- , 1994, Hydrothermal alteration in the SUNEDCO 58-28 geothermal drill hole near Breitenbush Hot Springs, Oregon: *Oregon Geology*, v. 56, no. 4, p. 75-87.
- Bargar, K.E., and Beeson, M.H., 1985, Hydrothermal alteration in research drill hole Y-3, Lower Geyser Basin, Yellowstone National Park, Wyoming: *U.S. Geological Survey Professional Paper* 1054-C, 23 p.
- Bargar, K.E., Erd, R.C., Keith, T.E.C., and Beeson, M.H., 1987, Dachiardite from Yellowstone National Park, Wyoming: *Canadian Mineralogist*, v. 25, p. 475-483.
- Bargar, K.E., and Keith, T.E.C., 1984, Hydrothermal alteration mineralogy in Newberry 2 drill core, Newberry volcano, Oregon: *U.S. Geological Survey Open-File Report* 84-92, 66 p.
- , 1993, Hydrothermal alteration in cores from geothermal drill holes at Medicine Lake volcano, northeastern California [abs.]: *EOS*, v. 74, no. 43 suppl., p. 688.
- , in preparation, Hydrothermal mineralogy of core from geothermal drill holes at Newberry volcano, Oregon: *U.S. Geological Survey Bulletin*.
- Bargar, K.E., Keith, T.E.C., and Beeson, M.H., 1993, Hydrothermal alteration in the Mount Hood area, Oregon: *U.S. Geological Survey Bulletin* 2054, 70 p.
- Bargar, K.E., and Oscarson, R.L., 1997, Zeolites and selected other hydrothermal minerals in the Cascade Mountains of northern Oregon: *U.S. Geological Survey Open-File Report* 97-100, 64 p.
- Barrer, R.M., 1978, Zeolites and clay minerals as sorbents and molecular sieves: London, Academic Press, 497 p.
- , 1982, Hydrothermal chemistry of zeolites: London, Academic Press, 360 p.
- Blackwell, D.D., and Steele, J.L., 1987, Geothermal data from deep holes in the Oregon Cascade Range: *Geothermal Resources Council Transactions*, v. 11, p. 317-322.
- Blackwell, D.D., Steele, J.L., Frohme, M.K., Murphey, C.F., Priest, G.R., and Black, G.L., 1990, Heat flow in the Oregon Cascade Range and its correlation with regional gravity, Curie point depths, and geology: *Journal of Geophysical Research*, v. 95, no. B12, p. 19,475-19,493.
- Boden, J.R., 1985, Lithology, hydrothermal petrology, and stable isotope geochemistry of three geothermal exploration drill holes, upper Clackamas River area, Cascade Range, Oregon: Riverside, Calif., University of California master's thesis, 137 p.
- Boles, J.R., 1972, Composition, optical properties, cell dimensions, and thermal stability of some heulandite group zeolites: *American Mineralogist*, v. 57, p. 1463-1493.
- Coombs, D.S., 1955, X-ray observations on wairakite and non-cubic analcime: *Mineralogical Magazine*, v. 30, no. 230, p. 699-708.
- Gottardi, G., 1989, The genesis of zeolites: *European Journal of Mineralogy*, v. 1, p. 479-487.
- Gottardi, G., and Galli, E., 1985, Natural zeolites: Berlin, Springer-Verlag, 409 p.
- Hammond, P.E., Anderson, J.L., and Manning, K.J., 1980, Guide to the geology of the upper Clackamas and North Santiam Rivers area, northern Oregon Cascade Range, in Oles, K.F., Johnson, J.G., Niem, A.R., and Niem, W.A., eds., *Geologic field trips in western Oregon and southwestern Washington*: Oregon Department of Geology and Mineral Industries Bulletin 101, p. 133-167.
- Hammond, P.E., Geyer, K.M., and Anderson, J.L., 1982, Preliminary geologic map and cross sections of the upper Clackamas and North Santiam Rivers area, northern Oregon: Portland, Ore., Portland State University Department of Geology, scale 1:62,500.
- Ingebritsen, S.E., Mariner, R.H., and Sherrod, D.R., 1994, Hydrothermal systems of the Cascade Range, north-central Oregon: *U.S. Geological Survey Professional Paper* 1044-L, 86 p.
- Ingebritsen, S.E., Sherrod, D.R., and Mariner, R.H., 1989, Heat flow and hydrothermal circulation in the Cascade

- Range, north-central Oregon: *Science*, v. 243, p. 1458–1462.
- Keith, T.E.C., 1988, Regional patterns of hydrothermal alteration, Breitenbush-Austin Hot Springs area, Cascade Range, Oregon, in Sherrod, D.R., ed., *Geology and geothermal resources of the Breitenbush-Austin Hot Springs area, Clackamas and Marion Counties, Oregon*: Oregon Department of Geology and Mineral Industries Open-File Report O-88-5, p. 31–37.
- Keith, T.E.C., and Bargar, K.E., 1988, Petrology and hydrothermal mineralogy of U.S. Geological Survey Newberry 2 drill core from Newberry caldera, Oregon: *Journal of Geophysical Research*, v. 93, no. B9, p. 10,174–10,190.
- Keith, T.E.C., White, D.E., and Beeson, M.H., 1978, Hydrothermal alteration and self-sealing in Y-7 and Y-8 drill holes in northern part of Upper Geyser Basin, Yellowstone National Park, Wyoming: U.S. Geological Survey Professional Paper 1054-A, 26 p.
- Keith, T.E.C., Gannett, M.W., Eichelberger, J.C., and Waibel, A.F., 1986, Lithology and hydrothermal alteration of drill hole RDO-1, Newberry caldera, Oregon: *Oregon Geology*, v. 48, no. 9, p. 103–107, 110.
- Kristmannsdóttir, H., and Tómasson, J., 1978, Zeolite zones in geothermal areas in Iceland, in Sand, L.B., and Mump-ton, F.A., eds., *Natural zeolites: occurrence, properties, use*: Oxford, Pergamon Press, p. 277–284.
- Leppert, D., 1990, Developments in applications for south-east Oregon bentonites and natural zeolites, in Geitgey, R.P., and Vogt, B.F., eds., *Industrial rocks and minerals of the Pacific Northwest. Proceedings of the 25th Forum on the Geology of Industrial Minerals, Portland, Oreg., 1989*: Oregon Department of Geology and Mineral Industries Special Paper 23, p. 19–23.
- Mariner, R.H., Swanson, J.R., Orris, G.J., Presser, T.S., and Evans, W.C., 1980, Chemical and isotopic data for water from thermal springs and wells of Oregon: U.S. Geological Survey Open-File Report 80-737, 50 p.
- Mason, Brian, and Sand, L.B., 1960, Clinoptilolite from Patagonia. The relationship between clinoptilolite and heulandite: *American Mineralogist*, v. 45, p. 341–350.
- McCulloh, T.H., Frizzell, V.A., Jr., Stewart, R.J., and Barnes, Ivan, 1981, Precipitation of laumontite with quartz, thenardite, and gypsum at Sespe Hot Springs, Western Transverse Ranges, California: *Clays and Clay Minerals*, v. 29, no. 5, p. 353–364.
- Mumpton, F.A., 1960, Clinoptilolite redefined: *American Mineralogist*, v. 45, p. 351–369.
- , 1977, Natural zeolites, in Mumpton, F.A., ed., *Mineralogy and geology of natural zeolites*: Mineralogical Society of America Reviews in Mineralogy, v. 4, chp. 1, p. 1–17.
- , 1978, Natural zeolites: a new industrial mineral commodity, in Sand, L.B., and Mumpton, F.A., eds., *Natural zeolites: occurrence, properties, use*: Oxford, Pergamon Press, p. 3–27.
- , 1983, Discovery and commercial interest in zeolite deposits examined during Zeo-Trip '83, in Mumpton, F.A., ed., *Zeo-Trip '83: An excursion to selected zeolite deposits in eastern Oregon, southwestern Idaho, and northwestern Nevada, and to the Tahoe-Truckee water reclamation plant, Truckee, California, July 7–10, 1983*: International Committee on Natural Zeolites, c/o Dept. of Earth Sciences, State University College, Brockport, N.Y., 14420, p. 66–72.
- Oscarson, R.L., and Bargar, K.E., 1996, Electron microprobe analyses of zeolite minerals from Neogene volcanic rocks in the Breitenbush-Austin Hot Springs area, Oregon: U.S. Geological Survey Open-File Report 96-41, 61 p.
- Ogihara, S., and Iijima, A., 1990, Exceptionally K-rich clinoptilolite—heulandite group zeolites from three offshore boreholes off northern Japan: *European Journal of Mineralogy*, v. 2, p. 819–826.
- Stonecipher, S.A., 1978, Chemistry of deep-sea phillipsite, clinoptilolite, and host sediments, in Sand, L.B., and Mumpton, F.A., eds., *Natural zeolites: occurrence, properties, use*: Oxford, Pergamon Press, p. 221–234.
- Tschernich, R.W., 1992, *Zeolites of the world*: Phoenix, Ariz., Geoscience Press, 563 p.
- Tschernich, R.W., and Howard, D., 1988, Gismondine from the Oak Grove Fork of the Clackamas River, Clackamas County, Oregon: *Micro Probe*, v. 6, no. 6, p. 1–3. □

AEG meeting in Portland has many features

The 40th annual meeting of the Association of Engineering Geologists will be held September 30 through October 4, 1997, at the Hilton Hotel in downtown Portland, Oregon, and is hosted by the organization's Oregon Section. In conjunction with the meeting theme, "Converging at Cascadia" (with its allusion to the Cascadia subduction zone), the technical program will focus on a variety of earthquake-related issues as well as classic topics of engineering geology, landslides, and environmental and groundwater concerns.

The meeting will offer 25 technical sessions with over 200 presentations. This includes six special symposia: "Building the Westside Light Rail Tunnel," "Earthquakes—Converging at Cascadia," "Probabilistic vs. Deterministic Seismic Hazard Analysis," "Characterization of Weak and Weathered Rock Masses," "Landslide Mechanisms and Failure Modes," and "Pros and Cons of ASTM Standard Guides."

Field trips before and after the meeting will lead to south and north Oregon coast landslides; the Columbia River Gorge; Ochoco and Bowman Dams in central Oregon; Mount St. Helens; and prehistoric earthquake evidence in Willapa Bay, Washington. Two "quick trips" of four hours during the meeting, on October 2 and 3, will offer a visit to the Westside Light Rail Transit tunnel.

Nine short courses, on September 29 and 30 and October 2, will offer a wide variety of educational opportunities. The courses are accredited for CEUs (Continuing Education Units).

A whole-day teachers' workshop, "Earth Science on the Edge," on October 1, offers sessions on volcanic, earthquake, and tsunami hazards; groundwater flow, wells, pollution, and cleanup; hydrothermal vents on the ocean floor at the Juan de Fuca Ridge; a plate tectonics curriculum for elementary schools; and the use of multimedia in the Earth Sciences. The workshop also includes a field trip to view bioengineering techniques for stream restoration and habitat improvement.

The 176-page book "Program with Abstracts" and further information are available from Julie Keaton, AEG '97, 130 Yucca Drive, Sedona, AZ 86336-3222, phone 520-204-1553, FAX 520-204-5597. □

National Natural Landmarks Program in the Pacific Northwest

by Stephen T. Gibbons, National Park Service, Columbia Cascades Support Office, 909 First Avenue, Seattle, WA 98104

The National Natural Landmarks Program was established in 1962 by Secretary of the Interior Stewart Udall under the authority of the Historic Sites, Buildings, and Antiquities Act of 1935. National Natural Landmarks (NNL) are nationally significant areas that have been so designated by the Secretary of the Interior. To be nationally significant, a site must be one of the best examples of a type of biotic community or geologic feature in its physiographic province. Examples include terrestrial and aquatic ecosystems, as well as features, exposures, and landforms that record active geologic processes and fossil evidence of biological evolution.

The goal of the NNL Program is to identify, recognize, and encourage the protection of sites containing outstanding examples of geological and ecological components of the nation's landscape. The landmarks have been designated on both public and private land; the program is designed to obtain concurrence of the owner or administrator for the landmark's status.

SELECTION CRITERIA

The determination that a site is one of the best examples of a particular feature in a natural region or physiographic province is based primarily on how well it illustrates the feature and the condition of the specific feature; secondary criteria are its rarity, diversity, and values for science and education.

Studies of the thirty-three physiographic provinces of the United States and its territories have produced an inventory of potential sites for further evaluation. These sites have a variety of ecological and geological themes. Sites can be added to this inventory through an initial recommendation by outside groups or private citizens. Recommendations quite often come from state natural heritage program inventories or other groups, including The Nature Conservancy.

DESIGNATION PROCESS

The National Park Service must receive prior approval from the landowner to conduct an on-site evaluation of areas that are highly ranked either in the theme studies or by outside recommendations. The National Park Service contracts with scientists to conduct on-site evaluations. The evaluations gather additional information and compare the site with other similar sites, guided by the national significance criteria.

Completed on-site evaluations are peer-reviewed by other scientists and then by the National Park Service. If a site is deemed to fulfill the requirements for NNL status, and if landowners have indicated their consent

for designation, the Director of the National Park Service then nominates the site to the Secretary of the Interior for designation. During the designation process, the National Park Service solicits comments from landowners, from local, State, and Federal government officials, and from other interested groups and individuals. Once designated, the area is listed on the National Registry of Natural Landmarks.

The NNL Program recognizes and encourages voluntary, long-term commitment of public and private owners to protect an area's outstanding values. Owners who voluntarily agree to help protect their landmark property are eligible to receive a certificate and plaque for display at the site.

As of July 1997, 587 NNL sites have been designated. Thirty-four of these sites are in the Pacific Northwest Region: 6 in Oregon, 11 in Idaho and 17 in Washington. The general location of the Oregon sites is indicated in the map on the next page.

To date, 16 of the 587 sites originally designated as NNLs have become part of the National Park system. The three landmarks in the Pacific Northwest Region are Cassia Silent City of Rocks (City of Rocks National Reserve) and Hagerman Fauna Sites (Hagerman Fossil Beds National Monument) in Idaho and Point of Arches (Olympic National Park) in Washington.

NATIONAL NATURAL LANDMARK MORATORIUM

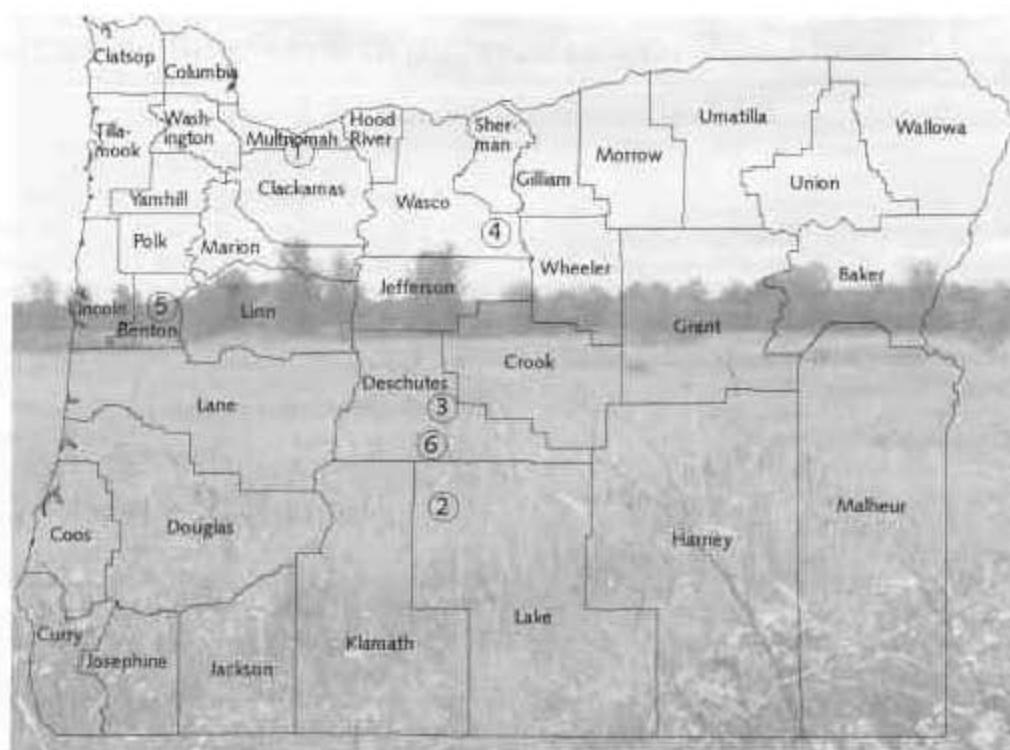
On November 28, 1989, the Director of the National Park Service placed a moratorium on the NNL Program, specifically postponing activities related to the evaluation, nomination, and designation of new sites for NNL status. The purpose of the moratorium was to allow sufficient time to conduct a thorough review of the program, including regulations and procedures. Attention was also focused on ensuring adequate provisions for landowner notification, rights, and consent. The moratorium is still in effect at this time.

STATUS OF THE NNL PROGRAM

The Washington, D.C., office of the NNL Program has promulgated five initiatives as a result of recent audits:

1. A proposed rule revising the regulations (36 CFR Part 62) for the NNL Program was published in November 1991. Provisions require landowner consent before conducting an evaluation of property as part of the landmark designation process. Publication of the final rule is pending.

2. A program handbook is being developed to ensure



Map showing approximate locations of National Natural Landmarks in Oregon. Numbers are keyed to text. Background shows Willamette Floodplain Landmark (no. 5) that is part of the William L. Finley National Wildlife Refuge in Benton County.

that applicable standards and quality-control procedures for all aspects of the landmark evaluation, nomination, designation, and monitoring process are complete.

3. A contract to identify and corroborate the names and addresses of all private NNL landowners has been completed.

4. A user needs analysis of the Natural Landmarks System database was completed, and an update of the database was completed in December 1993.

5. A management control system will be operational within six months after adoption of the NNL regulations.

OREGON LANDMARK SITES

Locations of sites described below are shown on the map above; numbers in the list are keyed to these locations on the map.

1. Crown Point—The Crown Point section of the Columbia Gorge illustrates more gradual stream valley formation as downcutting kept pace with the rise of the Cascade Range. The Columbia River Gorge at Crown Point passes from the steeper, more rugged terrain of the western slopes of the Cascade Range to rolling cultivated plains. The promontory provides a strategic vantage point for observing this classic illustration of riverine processes.

2. Fort Rock State Monument—The site is a striking example of a circular, fortlike outcrop. Although other

volcanic outcrops may exhibit many of the same features, few are as well-shaped and distinct.

3. Horse Ridge Natural Area—The site is of national significance in providing a characteristic and high-quality example of Sandy Western Juniper (*Juniperus occidentalis*) Steppe. Its biota represent a distinctive climax community. It is an ecological community that typifies geographically the fringe of the Great Basin Desert and biologically the transitional area between the ponderosa pine (*Pinus ponderosa*) forest and the sagebrush (*Artemisia tridentata*) desert.

4. Lawrence Memorial Grassland Preserve—The site constitutes an excellent example of biscuit and scabland topography. Moreover, it is the patterned landscape superimposed upon the basaltic bedrock that is especially illustrative, as well as an associated matrix of minimally disturbed grassland and shrub-steppe ecosystems.

5. Willamette Floodplain—The site represents the largest remaining native and unplowed example of bottomland interior valley grasslands in the North Pacific Border natural region.

6. Newberry Crater—The crater is a young volcano formed within the last million years during the Pleistocene and is the largest Pleistocene volcano east of the Cascade Range. It stands isolated and conspicuous on a broad plateau of lava. □

"Real-time" earthquake information

DOGAMI has been chosen as test site for a new, quick earthquake alert system

by Shannon Priem, Oregon Department of Geology and Mineral Industries

When the Seattle and Bremerton-area earthquakes occurred on June 23 and 24 this year, geologists of the Oregon Department of Geology and Mineral Industries (DOGAMI) in Portland knew—almost instantly—the size, time, and location of the earthquakes and were able to relay this information without delay to the public and the news media.

They had just installed a prototype alert system that is linked to the Pacific Northwest Seismograph Network (PNSN) operated by the University of Washington Geophysics Department.

Within minutes of an earthquake, a computer alarm is triggered at DOGAMI, displaying a map with details of the event. The PNSN includes about 130 seismograph stations that record earthquake ground shaking from several thousand earthquakes a year in Oregon and Washington (of which one or two dozen are strong enough to be felt by local residents). PNSN's "nerve center" is the University of Washington's Seismology Lab.

DOGAMI's new system is one of only three pager-based earthquake alert systems in the United States. It is still considered a prototype, according to Mei Mei Wang, DOGAMI Earthquake Program Coordinator. It is part of a larger PNSN effort to provide more and better information about earthquakes and earthquake hazards to scientists, engineers, emergency managers, critical-facility operators, the media, and the general public. Improvements in pager technology now allow PNSN staff to broadcast basic earthquake information using a commercial paging system and personal computers as receivers. Eventually, any who choose to become subscribers to this system could benefit as well. PNSN chose DOGAMI to help develop the prototype because of the agency's increased efforts in earthquake hazard mapping, public education, and risk reduction.

The predecessor of the system was the Caltech/USGS Broadcast of Earthquakes (CUBE), developed in 1991 in southern California and operated by the U.S. Geological Survey and the California Institute of Technology. For a quick assessment of earthquake ground shaking levels and associated damage, knowing the location, size, and magnitude of an earthquake is essential. CUBE reports earthquakes recorded by the 350-station southern California seismograph network. A companion seismograph network and broadcast system reports earthquakes in northern California.

An example will show how CUBE helped in the 1994 Northridge, California, earthquake: Ten seconds of strong ground shaking on the north edge of Los Angeles left more than 40,000 people homeless. While police

and fire departments and medical emergency teams rescued people and fought fires, emergency managers were faced with deciding what resources would be needed to shelter people and help them recover from the disaster. Scientists and engineers quickly prepared a shaking-intensity map for all parts of the greater Los Angeles area. This map showed estimated severity of shaking and the level of damage likely associated with such shaking. It was available long before a complete picture of the damage could be assembled and enabled emergency managers to promptly locate the hardest hit areas and to send appropriate help. Victims whose homes were destroyed or severely damaged could be directed to shelter before a predicted storm added to their misery. Teams of relief workers were sent where they were most needed, and the time for delivery of relief money to individuals was reduced from weeks to hours.

Preparation and use of the shaking-intensity map after the Northridge earthquake was the first instance in which this technology helped focus relief efforts during a disaster.

The new alert system in Oregon and Washington, although it is still in its development stage, will offer similar benefits as well as added advantages. For example, in the case of Cascadia tsunamis (giant damaging waves caused by offshore earthquakes), the ability to pinpoint the fact that an earthquake occurred offshore will help coastal communities to evacuate more quickly—or, in contrast, reduce the incidences of "false alarms." □

Rare tsunami photos on the Internet

An earthquake of magnitude 8 shook the Pacific coast of central Mexico on October 9, 1995, and produced a moderate tsunami along about 200 km (125 mi) of coastline with runup heights up to 5 m (16 ft). Because much of the affected area is sparsely populated, only one person was reported killed, while damage was considerable in some places.

Remarkably, some people were able to take photographs of the tsunami in action, specifically at Tenacatita Bay and the small town of La Manzanilla. These photos have been made available for viewing on the University of Southern California website at

<http://www.usc.edu/dept/tsunamis/>.

This information is taken from a report by Jose Borrero and others in EOS, v. 78, no. 8 of February 25, 1997, which also mentions a reference to J. Ramirez and R. Pugliesi in *EERI Earthquake Report* 29(12), 6, 1995, describing the tsunami event. □

THESIS ABSTRACTS

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

The Olympic-Wallowa Lineament, Hite fault system, and Columbia River Basalt Group stratigraphy in northeast Umatilla County, Oregon, by Stephen Christopher Kuehn (M.S., Washington State University, 1995), 170 p.

The significance of strike-slip faulting on the Columbia Plateau, including displacement along the structural zone coincident with the Olympic-Wallowa Lineament (OWL zone) and along the Hite fault System (HFS), has long been controversial, in part because of difficulty in determining strike-slip displacements in horizontal flows of the Columbia River Basalt Group (CRBG). Even the significance of apparent strike-slip displacement of vertical feeder dikes has been questioned because of the possibility of an echelon dike emplacement. This investigation was undertaken to clarify the type and timing of displacements on faults of the OWL zone and HFS. The area immediately southeast of Walla Walla, Washington, and Milton-Freewater in northeast Oregon was chosen for study because it is located at the intersection of the OWL and HFS and contains many important exposures.

Numerous faults in this area, both those mapped by earlier workers and those observed for the first time in this study, were examined to determine striae, associated minor structures, and displacements. To determine displacements, which occur entirely within horizontal flows of the CRBG, it was necessary to distinguish the numerous basalt flows. This was done by building a local stratigraphic framework through the sampling of a series of sections on opposite sides of major faults and correlating the flows by their petrologic and paleomagnetic character and chemical composition. To accomplish this, 347 samples of basalts were analyzed for 27 major and trace elements by XRF.

The main conclusions are (1) that there is significant, albeit still somewhat circumstantial, evidence that the structures acted as right-lateral (OWL zone) and left-lateral (HFS) fault zones prior to the eruption of the Columbia River basalts, (2) that there has been 300 m of exposed syn- and post-CRBG vertical displacement of flows on the Hite fault, (3) that virtually all of the fault zones studied are dominated by horizontal striae, and (4) that the OWL zone and HFS probably represent conjugate fault systems with real, but limited, post-CRBG strike-slip displacements.

Rock magnetic and paleomagnetic characteristics of the late Miocene Rattlesnake and Devine Canyon Ashflow Tuffs, eastern Oregon, by John Paul Stimac (Ph.D., University of Oregon, 1996), 183 p.

Thirty-seven sites from the Rattlesnake Ash-Flow Tuff (7.05 Ma) and twenty-one sites from the Devine Canyon Ash-Flow Tuff (9.7 Ma) of eastern Oregon were analyzed to study the application of rock magnetic and paleomagnetic techniques for emplacement and deformation studies in ash-flow tuffs (AFT). Rock magnetic analysis of the tuffs reveals that the main carrier of magnetic remanence in both units is fine-grained ($\sim 10 \mu\text{m}$), pseudo-single domain titanomagnetite. Although both alternating field (AF) and thermal (TT) demagnetization reveal primary and secondary remanences, a comparison of the AF and TT techniques shows that TT demagnetization removes all overprints, whereas AF demagnetization does not; thus thermal demagnetization results in smaller site uncertainties. Emplacement temperatures for both tuffs are in excess of the Curie temperature of magnetite ($\sim 575^\circ\text{C}$), since rip-up clasts of basalt and pumice clasts have had their directions reset to that of the encompassing tuff.

Vertical and horizontal traverses show that paleomagnetic variations are similar to site uncertainties for the tuff. These data indicate that natural variations within a tuff are such that sampling from any appropriate microfacies within a well-oriented structural block will produce reliable paleomagnetic results. Structural corrections based on eutaxitic foliation, defined by the fiamme, increased dispersion of the entire data set and therefore are not reliable indicators of paleohorizontal; underlying sedimentary units or a trend surface fit of the outcrop base are more reliable indicators of paleohorizontal, and these corrections greatly reduce dispersion.

The Devine Canyon AFT records systematic vertical axis rotations that average 5° , relative to the mean, and become more clockwise to the northeast. The younger Rattlesnake AFT shows no systematic rotation (average $<1^\circ$). Both contain a few small blocks that record larger variable rotations or errors.

Anisotropy of magnetic susceptibility (AMS) measurements show an approximately radial outflow pattern from the postulated source caldera near Lake on the Trail in the U.S. Geological Survey 7.5-minute quadrangle by the same name. The AMS vectors due to individual sites show deviations from radial that are interpreted to be from paleotopography. The most striking paleotopographic feature is the John Day Valley. □



AVAILABLE PUBLICATIONS

OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

GEOLOGICAL MAP SERIES

Price ☑

Price☑

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

GMS-76 Camas Valley 7½ quadrangle, Douglas/Coos Counties. 1993	6.00
GMS-77 Vale 30x60' quadrangle, Malheur County. 1993	10.00
GMS-78 Mahogany Mountain 30x60' quadrangle, Malheur Co. 1993	10.00
GMS-79* EQ hazards, Portland 7½ quad., Multn. Co. 1993	20.00
GMS-80* McLeod 7½ quadrangle, Jackson County. 1993	5.00
GMS-81* Tumalo Dam 7½ quadrangle, Deschutes County. 1994	6.00
GMS-82* Limber Jim Creek 7½ quadrangle, Union County. 1994	5.00
GMS-83* Kenyon Mountain 7½ quadrangle, Douglas/Coos Co. 1994	6.00
GMS-84* Remote 7½ quadrangle, Coos County. 1994	6.00
GMS-85* Mount Gurney 7½ quadrangle, Douglas/Coos Co. 1994	6.00
GMS-86* Tenmile 7½ quadrangle, Douglas County. 1994	6.00
GMS-87* Three Creek Butte 7½ quadrangle, Deschutes County. 1996	6.00
GMS-88* Lakecreek 7½ quadrangle, Jackson County. 1995	8.00
GMS-89* EQ hazards, Mt. Tabor 7½ quad., Multn. Co. 1995	10.00
GMS-90* EQ hazards, Beaverton 7½ quad., Wash. Co. 1995	10.00
GMS-91* EQ hazards, Lake Oswego 7½ quad., Tri-county. 1995	10.00
GMS-92* EQ hazards, Gladstone 7½ quad., Clack./Multn. Co. 1995	10.00
GMS-93* EQ hazards, Siletz Bay area, Lincoln County. 1995	20.00
GMS-94* Charleston 7½ quadrangle, Coos County. 1995	8.00
GMS-97* Coos Bay 7½ quadrangle, Coos County. 1995	6.00
GMS-98* Dora and Sitkum 7½ quadrangles, Coos County. 1995	6.00
GMS-99* Tsunami hazard map, Siletz Bay area, Lincoln County. 1996	6.00
GMS-100* EQ hazard maps for Oregon. 1996	8.00
GMS-101* Steelhead Falls 7½ quad., Deschutes/Jefferson Co. 1996	7.00
GMS-104* EQ hazards, Linnton 7½ quad., Multn./Wash. Co. 1996	10.00
GMS-105* EQ hazards, Salem East/West 7½ quads. 1996	12.00
GMS-106* Grizzly Peak 7½ quadrangle, Jackson County. 1997	6.00

SPECIAL PAPERS

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

OIL AND GAS INVESTIGATIONS

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

OREGON GEOLOGY

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

Periodicals postage
paid at Portland, OR

AVAILABLE DEPARTMENT PUBLICATIONS (continued)

BULLETINS

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

MISCELLANEOUS PAPERS

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

SHORT PAPERS

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

MISCELLANEOUS PUBLICATIONS

Hiking Oregon's geology, E.M. Bishop and J.E. Allen, 1996	16.95
Assessing earthquake hazards in the Pac. NW (USGS Prof. Paper 1560)	25.00
Geology of Oregon, 4th ed., E.L. and W.N. Orr and E.M. Baldwin, 1991, published by Kendall/Hunt (add \$3.00 for mailing)	33.95
Geologic map of Oregon, G.W. Walker and N.S. MacLeod, 1991, published by USGS (add \$3.00 for mailing)	11.50
Geology of the Pacific Northwest, E.L. and W.N. Orr, 1996, published by McGraw-Hill (add \$3.00 for mailing)	43.00
Geological highway map, Pacific Northwest region, Oregon, Washington, and part of Idaho (published by AAPG). 1973	8.00
Oregon Landsat mosaic map (published by ERSAL, OSU). 1983	11.00
Mist Gas Field map, rev. 1997, incl. 1993-96 production (OFR O-97-1)	8.00
Digital form of map (CAD formats .DGN, .DWG, .DXF), 3 1/2-in. disk	25.00
Mist Gas Field production figures 1979 through 1992 (OFR O-94-6)	5.00
Northwest Oregon, Correlation Sec. 24. Bruer & others, 1984 (AAPG)	6.00
Oregon rocks and minerals, a description. 1988 (OFR O-88-6)	6.00
Mineral information layer for Oregon by county (MILOC), 1993 update (OFR O-93-8), 2 diskettes (5 1/4-in., high-density, MS-DOS)	25.00
Directory of mineral producers, 1993 update, 56 p. (OFR O-93-9)	8.00
Geothermal resources of Oregon (published by NOAA). 1982	4.00
Mining claims (State laws governing quartz and placer claims)	Free
Back issues of <i>Oregon Geology</i>	3.00

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

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

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

ORDER AND RENEWAL FORM

Check desired publications in list above or indicate how many copies and enter total amount below. Send order to The Nature of the Northwest Information Center, Suite 177, 800 NE Oregon Street, Portland, OR 97232-2162, or to FAX (503) 731-4066. If you wish to order by phone, have your credit card ready and call (503) 872-2750. Payment must accompany orders of less than \$50. Payment in U.S. dollars only. Publications are sent postpaid. All sales are final. Subscription price for *Oregon Geology*: \$10 for 1 year, \$22 for 3 years.

Renewal ___ / new subscription ___ to *Oregon Geology*: 1 yr (\$10) or 3 yrs (\$22) \$ _____
Total amount for publications marked above: \$ _____
Total payment enclosed or to be charged to credit card as indicated below: \$ _____

Name/Address/City/State/Zip _____

Please charge to Visa ___ / Mastercard ___, account number: _____

Expiration date: _____ Cardholder's signature _____

OREGON GEOLOGY

published by the
Oregon Department of Geology and Mineral Industries



VOLUME 59, NUMBER 6

NOVEMBER/DECEMBER 1997



IN THIS ISSUE:

EPISODICALLY
BURIED FORESTS
IN THE OREGON
SURF ZONE

NATIONAL
OUTSTANDING
RECLAMATIONIST
OF THE YEAR:
E. FRANK SCHNITZER

OREGON GEOLOGY

(ISSN 0164-3304)

VOLUME 59, NUMBER 6 NOV./DEC. 1997

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

Governing Board

Donald W. Christensen, Chair..... Depoe Bay
John W. Stephens..... Portland
Jacqueline G. Haggerty.....Enterprise

State Geologist..... Donald A. Hull
Deputy State Geologist..... John D. Beaulieu
Editor..... Klaus K.E. Neuendorf
Production Assistants..... Geneva Beck
..... Kate Halstead

Main Office: Suite 965, 800 NE Oregon Street # 28, Portland 97232,
phone (503) 731-4100, FAX (503) 731-4066.

Internet: <http://sarvis.dogami.state.or.us>

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

Mark L. Ferns, Regional Geologist.

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

Thomas J. Wiley, Regional Geologist.

Mined Land Reclamation Program: 1536 Queen Ave. SE, Albany
97321, phone (541) 967-2039, FAX (541) 967-2075.

Gary W. Lynch, Supervisor.

Internet: <http://www.proaxis.com/~dogami/mlrweb.shtml>

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

Internet: <http://www.naturenw.org>

Periodicals postage paid at Portland, Oregon. Subscription rates: 1
year, \$10; 3 years, \$22. Single issues, \$3. Address subscription orders,
renewals, and changes of address to Oregon Geology, Suite 965, 800 NE
Oregon Street # 28, Portland 97232.

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

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

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

Permission is granted to reprint information contained herein. Credit
given to the Oregon Department of Geology and Mineral Industries for
compiling this information will be appreciated. Conclusions and opinions
presented in articles are those of the authors and are not necessarily
endorsed by the Oregon Department of Geology and Mineral Industries.

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

Cover photo

Rooted stump on the wave-cut platform near Moore Creek
south of Newport. The stump was exposed in February 1996.
Based on the size of the roots, the trunk is estimated to have
been at least 2 m in diameter. Related article on episodically
buried forests along the Oregon coast begins on next page.

DOGAMI revises map production

The Oregon Department of Geology and Mineral Industries (DOGAMI) has added to its publications two new map series that represent different types of mapping detail and mapping subjects. The first product of a new series, map IMS-1, is expected to be released before the end of this year. The following is an excerpt from the revised section on geologic maps in the Department's policy manual:

"DOGAMI produces three separate map series, all are subject to multiple external peer review.

"1. **GMS** (Geologic Map Series) maps are complete and detailed and prepared (though not necessarily published) at 1:24,000 or smaller scale. These maps include, where appropriate, chemical data, age data, paleontological data, petrography, geophysics, water-well data, and other types of specific geologic information.

"2. **RMS** (Reconnaissance Map Series) maps are lower resolution maps aimed at rural areas with scant existing information, which do not justify GMS-level effort. These will normally be compiled at 1:24,000 but generally published at 1:100,000. Individual 1:24,000 sheets may be released as separate RMS maps. RMS maps will require compilation of existing mapping, resolution of nomenclature, correlation of units, driving all major roads, and complete air-photo and imagery interpretation. The goal of these maps is to unify and clean up existing mapping, and to ensure that most major units or structures have been identified, if not mapped accurately. It is likely that future more detailed mapping in these areas would identify significant new features. Each sheet should be anchored by GMS-level mapping of at least one 1:24,000 quadrangle.

"3. **IMS** (Interpretive Map Series) maps are geology based but depict an interpretation of some characteristic based on geology. Examples would be maps showing hazard zones, aggregate resources, engineering properties, groundwater-related data, geophysical interpretations, etc. These maps would be published at a variety of scales, depending on the issue covered." □

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

Publication title: OREGON GEOLOGY, no. 600040; filing date 9-19-97. Published bimonthly, 6 issues per year, annual subscription price \$10. Address of publication office, publisher's business office, editor, and owner: State Office Building, 800 NE Oregon St., #28, Portland, OR 97232-2162. Publisher and owner: Oregon Department of Geology and Mineral Industries; editor: Klaus K.E. Neuendorf. There are no bondholders. Circulation during last 12 months of single issue, respectively: Net press run 2,500/2,500; paid circulation est. 50/50; mail subscriptions 1,255/1,228; total paid circulation 1,305/1,278; free distribution 123/167; free distribution outside the mail 279/292; total free distribution 402/459; total distribution 1,707/1,737; not distributed 793/763; return 0/0; total 2,500/2,500; percent paid and/or requested circulation 86.4/84.1. I certify that the statements made by me above are correct and complete.

Klaus K. Neuendorf, Editor

Episodically buried forests in the Oregon surf zone

by Roger Hart, *College of Oceanic and Atmospheric Sciences, Oregon State University, Hatfield Marine Science Center, Newport, Oregon 97365*; and Curt Peterson, *Department of Geology, Portland State University, Portland, Oregon 97207*

ABSTRACT

Severe winter storms, especially in ENSO¹ years, expose rooted tree stumps in the surf zone of the central Oregon coast. Root mats up to 6 m in diameter are anchored in the Tertiary rocks of the late Holocene wave-cut platform. We studied more than 275 stumps at 14 localities between Neskowin and Coos Bay. Forest soil preserved beneath some roots can be traced landward, where it overlies creek mouth marsh and paleo-sand dune deposits. The stump fields and the forest soil are remnants of a continuous forest or series of forests that extended farther seaward than present-day temperate coniferous rain forest. Litter in the soil indicates that the forest soil was rapidly buried. Ages of the rooted stumps range from $1,970 \pm 50$ to $4,340 \pm 70$ radiocarbon years before the present (RCYBP).

Eustatic change of sea level and migration of sand barriers are considered as explanations for preservation of rooted stumps at some sites. However, large-diameter stumps rooted on continuously active late Holocene wave-cut platforms depleted of littoral sand are indicators of tectonic movements on the central Oregon coast. A necessary history requires six stages: (1) wave cutting of platform at sea level, (2) tectonic uplift of the platform, (3) growth of the forest on the wave-cut platform, (4) rapid burial and preservation of the forest, (5) inundation of the forest at sea level, and (6) renewed erosion of the beach platform. These results corroborate salt-marsh evidence of late Holocene vertical tectonic displacements associated with local or regional earthquake sources along the Oregon coast. Further radiocarbon dating of annular rings in the rooted stumps and preserved litter in the soil can potentially constrain the nature, age, and extent of the tectonic displacements.

INTRODUCTION

For several decades, scientists have reported tree stumps rooted on the wave-cut platforms of the surf zone along Oregon beaches (Kelley and others, 1978; Peterson and others, 1993; oral communications from R. Bayer, Yaquina Birders and Naturalists, 1985; E. Zoebel, Department of Botany, Oregon State University,

1995; and R. Loeffel, Fisheries Manager, retired, 1996). However, no systematic study of these rooted stumps has been published. The stumps stand upright, with broad root mats spread parallel to the wave-cut platform (cover photo). They have been observed in place for over ten years, even during periods when the surrounding sand has been stripped from the beach. Although some stumps may be rooted in submerged late Pleistocene stream channels, most are rooted in the Tertiary bedrock of the late Holocene wave-cut platforms. Similar roots associated with currently living trees are found only inland from the surf zone. The live trees that left the stumps on the beach must have grown on the wave-cut platform after regression of the surf zone. Following at least several hundred years of growth, transgression of the surf zone must have invaded the tree growing zone. These observations led to early concepts of late Holocene seismic activity along the central Oregon coast (Darienzo and Peterson, 1990).

We report on a study of 1.9- to 4.4-ka (kilo-annum = 10^3 years) trees rooted on the wave-cut platforms of the central Oregon coast, lat 43.23° – 45.00° N. (Figure 1). We document the association of forest soils, debris flows, and liquefaction features with the buried stumps. In the discussion, we evaluate three mechanisms for regression and transgression of the surf zone: (1) growth and removal of sand barriers, (2) eustatic change of sea level, and (3) vertical tectonic displacement of the Cascadia margin. We use observed stratigraphic relations to rule out mechanisms 1 and 2 at most localities.

BACKGROUND

The beaches of the central Oregon coast occupy late Holocene wave-cut platforms, at least several hundred meters in width, that are carved in late Pleistocene marine terrace deposits or in Tertiary sedimentary rocks. South of Newport, the surf zone may have reoccupied late Pleistocene platforms (Ticknor, 1993). North of Newport the youngest apparent Pleistocene platform is elevated as much as 30 m above present sea level.

In general, elevated wave-cut platforms underlie a series of inland marine terraces composed mainly of Pleistocene beach and dune sand (Kelsey and others, 1994; Ticknor, 1993).

Ticknor (1993) used the uplifted platforms to calculate average vertical displacement rates for the past 105 ka and found 0.85 ± 0.06 mm/year north of Newport and -0.01 ± 0.03 /year for the area around Yachats.

¹ El Niño Southern Oscillation. El Niño refers to the equatorial Pacific warm water anomaly. The Southern Oscillation traditionally refers to associated variations in atmospheric circulation in the south Pacific. Recently, teleconnection links to enhancement of the Aleutian low-pressure system off the Oregon coast have been documented and are thought to cause an increase in storminess and associated coastal erosion.

Rooted Stumps on Beaches of the Central Oregon Coast

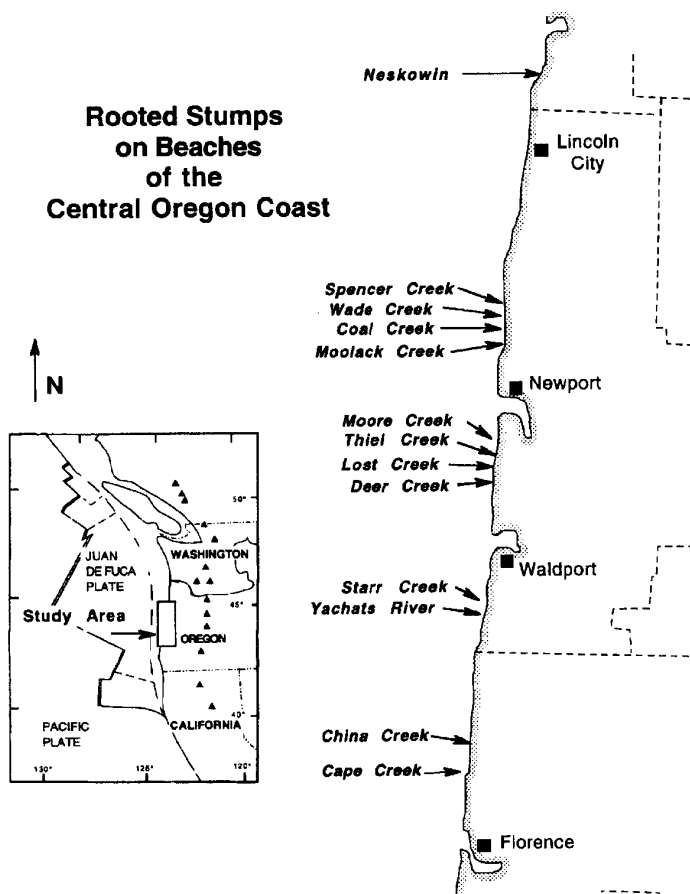


Figure 1. Location of the study area where rooted stumps have been mapped. The stump field at Sunset Bay discussed in the text and referred to in Table 1 is south of the enlarged area.

Mitchell and others (1994) calculated present-day vertical displacement rates from repeated leveling surveys and tide gauge records. Their results indicate that, at the present time, the area around Newport is stationary or subsiding, whereas the area around Yachats is being up-lifted.

The wave-cut platforms in the vicinity of Newport terminate landward in wave-cut cliffs; whereas, the wave-cut platforms north and south of Yachats most frequently terminate landward in Holocene foredunes.

RESULTS

More than 288 rooted stumps were mapped at 14 localities between Coos Bay and Neskowin, a distance of 206 km (Figure 1). Additional rooted stumps and soil profiles were studied and sampled at seven localities in creek mouths and backshore deposits. We collected 26 wood samples and 59 soil samples from beaches, creek mouths, and soil run-ups and examined them under the microscope. Over 60 km of beaches, marine cliffs, and creek mouths were photographed and mapped on either U.S. Geological Survey 1:24,000-scale (7½-minute series) topographic maps or on 1:4,800-scale aerial orthophoto maps used by Priest and others (1994). Details of the mapping and sampling are given in Table 1.

Rooted stumps

Normally, 1–5 m of beach sand covers the stumps in the surf zone (Figure 2), but they are exposed during periods of extreme beach sand erosion, most commonly during the winters of

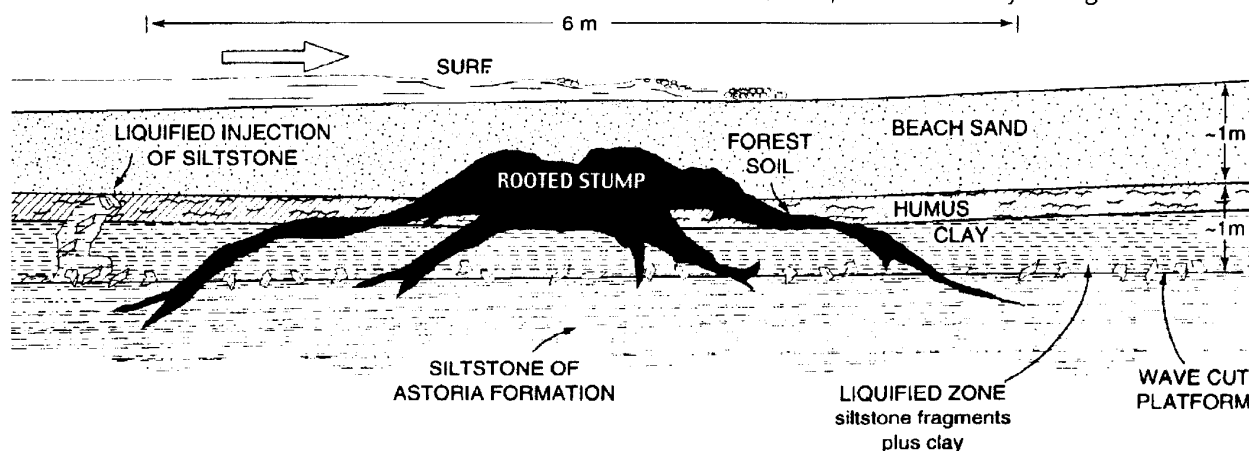


Figure 2. Diagrammatic figure of the principal features of the buried stumps beneath beach sand. The roots extend into the Tertiary siltstone on which the platform was cut. Some of the stumps have erosional remnants of forest soil with fresh litter, humus, and gray clay directly on the wave-cut platform. The inferred liquefied injection of siltstone fragments into the soil was probably coseismic but not necessarily synchronous with burial of the rooted stump.

strong ENSO events such as 1973/74, 1982/83, and 1994/95 (Peterson and others, 1990; Komar, 1986). Rooted stumps in the surf zone at Deer Creek, Moolack Creek, Coal Creek, Wade Creek, and Spencer Creek, first noted during the 1982/83 ENSO, have since been episodically exposed (R. Bayer, oral communication, 1995). New exposures occurred at nine localities during the 1994/95 ENSO.

The rooted stumps in the surf zone were exposed for variable lengths of time. Those at Wade Creek and Yachats River were exposed for less than a month. The stumps at Thiel Creek were exposed for more than ten months. Two photographs of the Thiel Creek stump field are shown in Figure 3; the first one was taken January 24, 1995, just after initial exposure, the second one on May 17, 1995. Shortly after exposure in 1995, the logs and stumps at Thiel Creek were colonized by algae (*Enteromorpha*) and a species of the bay barnacle (*Balanus*) (Figure 3). There was no evidence of prior colonization, which suggests that the rooted stumps were not previously exposed during an epifaunal growing season. The Thiel Creek stump field was completely covered by sand by October 1995 but reappeared briefly in February and December of 1996 and January of 1997. Relics of the previous algae and barnacle colonization were apparent upon re-emergence. Stumps exposed during the 1982/83 ENSO at Neskowin had substantially decayed by 1995 (Figure 4).

The rooted stumps are in clusters of from 3 to 200. The roots spread parallel to the beach platform and extend radially outward up to 6 m (Figure 4). In places, bark with the general appearance of present-day western hemlock (*Picea sitchensis*) is intact. Complete annular-ring records are intact in some stumps and roots (Figure 4). The trunks are generally not preserved, but trunk diameters estimated by reconstruction of remnants range up to 2 m in diameter (Figure 4).

The absence of trunks may be either because they were broken off or because they decomposed faster than the roots. Wind, storms, tsunamis, or debris flows could have broken off the trunks. However, most of the stumps exposed in the surf zone do not show evidence of breakage, i.e., no splintered ends have been observed. Yet, rooted stumps exposed landward of the backshore in creek mouths and dune fields do have splintered ends (Figure 4). The absence of splintered ends on the surf zone stumps may be due to abrasion by waves and moving sand.

Alternatively, the trunks may have decomposed, and the roots were preserved by partial sterilization and/or mineralization in wet, salty, anaerobic sand. Indeed, the outer portions of the surf zone roots in contact with wet sand are better preserved than the cores (Figure 4).

The following radiocarbon ages were derived from rooted stumps: $1,970 \pm 50$ RYBP at Neskowin, $3,920 \pm 60$ RYBP at Deer Creek, and $4,340 \pm 70$ RYBP at

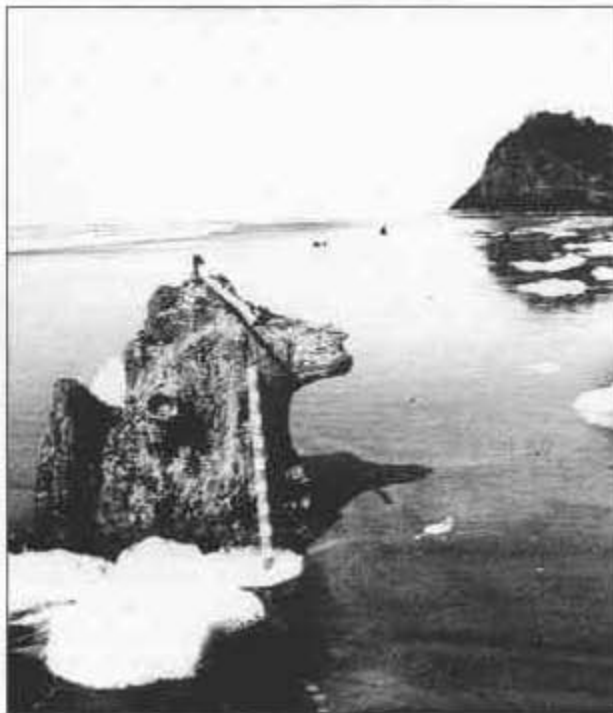


Figure 3. Comparison photographs of the stump field at Thiel Creek. The stump in the foreground of the top photograph, taken January 24, 1995 is rooted and the same as the one in the middle of the bottom photograph, taken May 17, 1995. The freshly exposed stump in the top panel is devoid of barnacles and algae. The same stump in the bottom panel is more fully exposed and has been colonized by barnacles of the genus *Balanus* and marine algae of genus *Enteromorpha*. The other logs in the photograph, tilted by folding, are unrooted, embedded in soil and clay, and were similarly colonized by barnacles and algae.

Wade Creek. The uncertainties in the relationship between tree death and forest subsidence and/or inundation prohibits correlation of these dates with other tectonic events.

Some trees may have died but may have been preserved before a given event. Snags, dated by forest fire scars, stand up to 150 years after death of the tree. Roots persist even longer, especially if buried by a debris flow or in a peat bog. On the other hand, trees that are only partially buried during inundation on the backshore beach, such as Deer Creek DC-3, may have continued to grow after trees that were submerged in the surf

(Continued on page 136)



← Figure 4. Photographs of rooted stumps: Upper left is a photograph taken on the wave-cut platform near Wade Creek and shows a root 6 m in diameter. Radiocarbon age derived on a wood sample from this stump is $4,340 \pm 70$ RCYBP. Upper right is a photograph of a surf zone rooted stump at Deer Creek. The root core is intact and greater than 1 m in diameter. Middle left is a photograph of a rooted stump at China Creek, located on the backshore beach. Two layers of forest soil underlying late Holocene foredunes are apparent in the small wave-cut cliff behind the stump. This soil is a continuation of the surf zone forest soil shown in Figure 5. Forest soil with litter underlies the beach sand and cobbles in the foreground. The stump is 5 m in diameter and displays a splintered top. Middle right is a photograph of a rooted stump at Sunset Bay. The cores of the root have decayed, which suggests that the outer layers are more resistant to decomposition. Lower left is stump embedded in the marine cliff at Deer Creek. Diameter of root branch is > 1 m, suggesting trunk was at least 2 m in diameter. Lower right is a stump on the wave-cut platform at Neskowin. In the background is Proposal Rock.

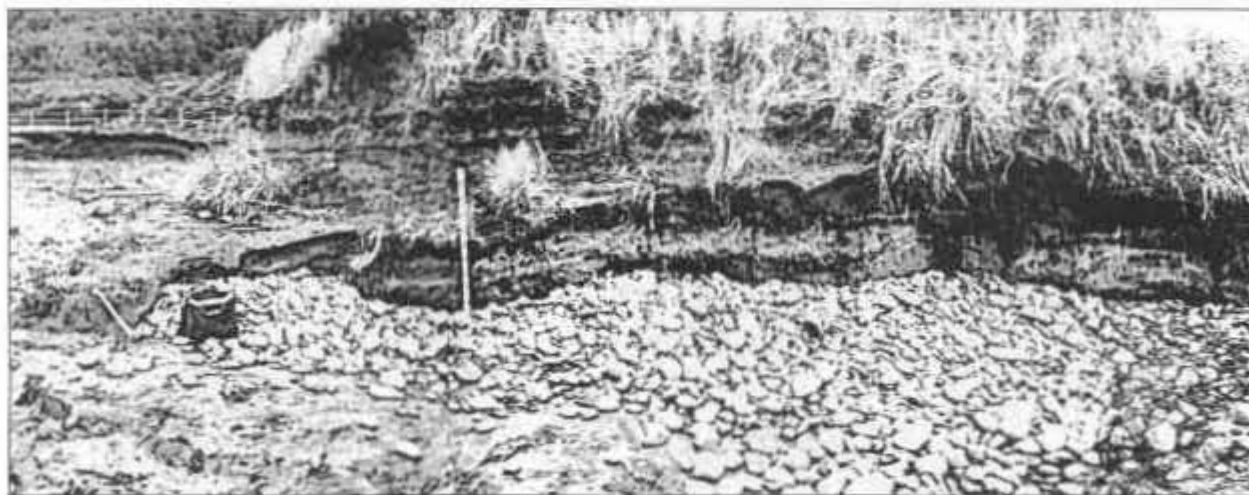
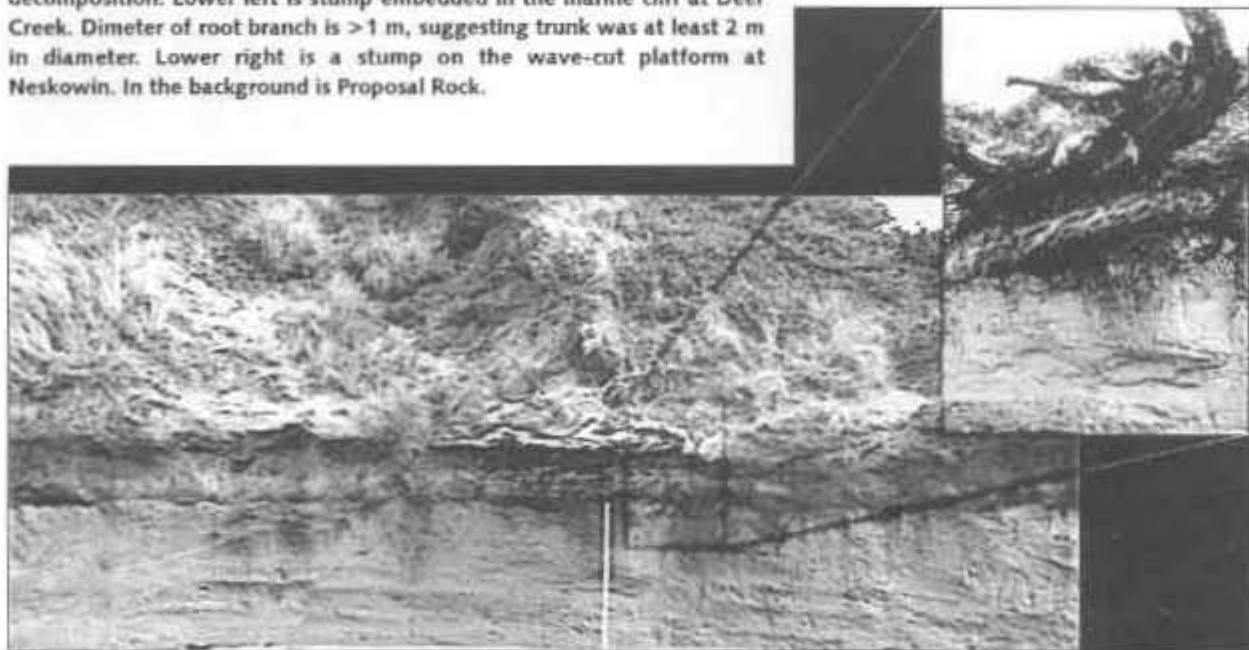


Figure 5. Podzol horizons: Top photograph shows forest soil with podzol profile exposed in the marine cliffs near Blowout Creek. Insert shows a rooted stump in place. Elevation of the soil above the beach is about 2.6 m. The soil can be traced continuously southward to the ascending soil horizon shown in Figure 7. Bottom panel is a photograph taken at China Creek. Forest soil is exposed on the beach in the left foreground. The soil can be traced continuously from the beach, up the ramp behind the ax (left middle ground) to the small wave-cut cliff at the top of the beach. Five rooted stumps are present on the beach and in the cliffs just to the south (right) of this location (see Figure 4). Cones of the western hemlock, *Tsuga heterophylla*, and Sitka spruce, *Picea sitchensis*, were sampled from the beach in the foreground (see Figure 8).

(Continued from page 133)

zone died. The radiocarbon ages do constrain the forest growth to late Holocene times and suggest that undecomposed litter fragments and individual tree rings may contain sufficient radiocarbon for more detailed studies.

Forest soil

A 5- to 30-cm-thick layer of organic rich soil is preserved under and around the rooted stumps on the beaches at Neskowin, Thiel Creek, China Creek, and Sunset Bay. The soil can be traced landward into creek mouths, beneath Holocene foredunes, and upslope to dune deposits that cap the top of marine cliffs (Figures 5, 6, 7). Forest soil horizons are identified by litter and well-developed Podzol profiles. The litter includes cones, needles, moss fragments, and shredded bark (Figure 8). The Podzol profiles, with a pronounced leached zone typical of temperate rain forests, are best developed on ascending soil horizons that stratigraphically the surf zone forests to deposits on top of the marine cliffs (Figures 5, 7).

The soil layer on the beach at China Creek is less than 0.5 m thick and underlies the Holocene foredunes as shown in Figure 5. Since the rooted stumps are

anchored in their growing position, the soil must be in situ. At China Creek, the soil is compact, plastic, and rich in organic matter and gray clay. It is typified by three zones: (1) an upper litter-rich zone, (2) a humus-rich layer, and (3) a clay layer with matrix-supported clasts of underlying rock that have been injected into the clay (Figure 2).

The litter-rich zone at China Creek includes cones, fragments of moss, needles, diatoms, twigs, branches, and woody debris (Figure 8). The cones are similar to that of Sitka spruce (*Picea sitchensis*) and western hemlock (*Tsuga heterophylla*). The moss stems and leaves belong to a bryophyte similar to present-day *Scouleria aquatica*. The conifer needles are similar to those of *Picea sitchensis* and show intact stoma structures. The dark-brown humus underlying the litter is dense and compact with matrix-supported clasts of the underlying Tertiary siltstone.

The soil, where exposed in the lower low-water zone, was colonized and degraded by burrowing clams similar to the rough piddock (*Zirfaea pilosus*).

The paleo-soil profiles at the creek mouth, exposed at eight localities (Table 1), are stratified, with a layer of

(Continued on page 139)

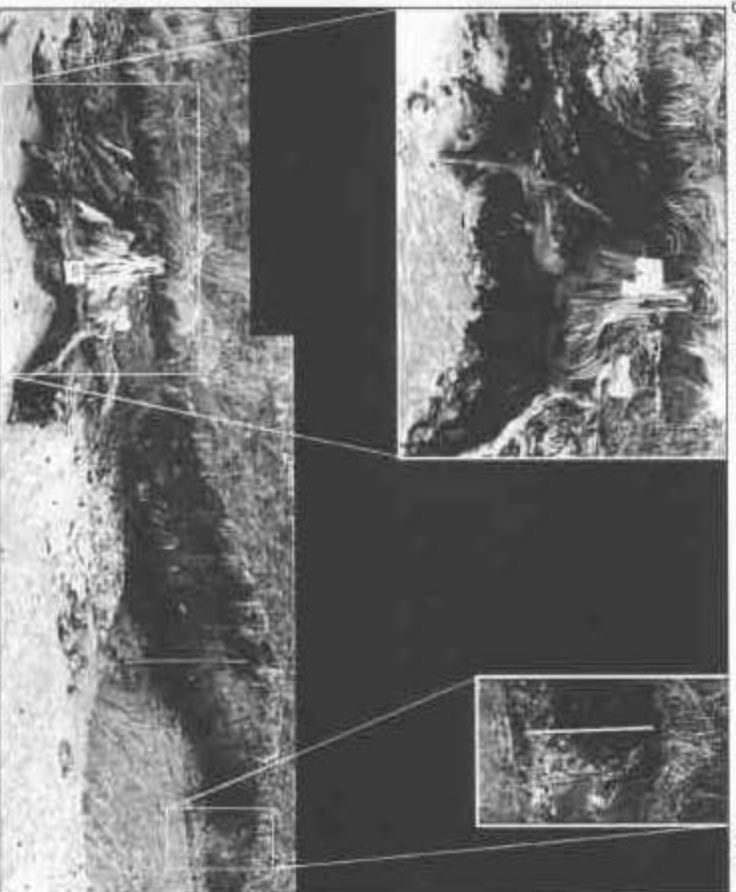


Figure 6. Orthophoto panorama taken at Deer Creek of rooted stump DC-3. Forest soil ascends onto the uplifted wave-cut platform. Insets depict closeup of the stump and a coseismic liquefaction feature. Radiocarbon age of the stump is $3,920 \pm 60$ RCYBP. Forest soil is exposed under stump, and runup is continuously exposed to top of marine cliffs. It is inferred that the soil is the same age as the stump. It is also inferred that the liquefaction feature is coseismic because of the lack of overburden capable of inducing load structure, but it could be younger than the rooted stump and soil.

Table 1. *Rooted stumps and forest soil localities*

Locality	Access	Stump field	Soil	Samples
1 Neskowin	Cross Neskowin Creek south to Prospect Rock. Upright stumps in the surf zone south to basalt cliffs.	Over 200 upright stumps exposed in winter of 1983. In winter of 1995, about 20 stumps exposed but degraded by shipworms and boring clams (Figure 4).	Some soil remnants in surf zone, but mostly eroded away.	Carbon-14 age on one sample by C. Peterson 1983: $1,970 \pm 50$ RCYBP, Beta Analytical No. 26128. Sample NS-1 collected 3/95 by RH. An age of $1,730 \pm 160$ RCYBP reported by Kelley and others, 1978.
2 Logan Creek	Forest soil and debris flow underlie parking lot at Road's End Beach State Wayside. Debris flow also exposed in bank at base of access path.	None observed.	Soil runs up from creek mouth to top of marine cliff under parking lot (Figure 9).	Soil profile measured and sampled on marine cliff SW of parking lot. Soil samples, LC-1 debris flow; LC-2, forest litter (L-zone); LC-3, forest humus (H-zone); LC-4, leached dune sand (E-zone), sesquioxide-enriched dune sand (B-zone); LC-5, clay layer of uncertain origin.
3 Lincoln Beach	Access beach for 900–1,800 m N. from Fishing Rock. Rooted stumps and forest soil buried in driftwood line.	7 stumps reported 5/97 by Don Christensen (DOGAMI Governing Board member from Depoe Bay).	Soil ascending from beach to top of low marine cliffs. Observed 5/97. Fire-scorched horizons noted.	1 stump sample with intact core, LB-1, sampled by Don Christensen 5/97.
4 Spencer Creek	Access from Beverly Beach State Park; 2 stumps 100 m S. of creek on beach backshore.	2 rooted stumps exposed 3/95.	Debris flow on bank of creek under Hwy 101 bridge and on E. side of highway.	No samples.
5 Wade Creek	Descend gravel road to beach from Hwy 101 turnout, 1 mi S. of Beverly Beach. Largest stump is visible from the highway.	3 rooted stumps exposed 3/10/95 to 3/25/95 S. of creek runout. Largest stump re-exposed for one week in 2/96 (Figure 4). 7 additional stumps first exposed 4/97.	Creek mouth forest soil and blue clay exposed in bank at top of beach next to marine cliffs. Debris flows exposed W. of highway on top of marine cliffs.	Wood sample WC-1, carbon-14 dated at $4,340 \pm 70$ RCYBP, Beta Analytical No-89166. Bark sample WC-2 similar to <i>Picea sitchensis</i> .
6 Coal Creek	Descend marine cliff from abandoned Hwy 101 turnout just S. of Carmel Knoll. Stump field and soil profile are located 150 m N. of creek mouth.	5 rooted stumps exposed in roughly E.-W. line from bank at backshore of beach to lower low-water zone. First reported intermittent exposures 1985–1992 by R. Bayer. Re-exposed 3/95–6/95.	Debris flow deposit covers stump in bank at top of the beach. Forest soil covered with debris flow at top of marine cliff extends 375 m to N.	Wood sample CCS-3 taken from rooted stump at high-water line. Soil section measured in the marine cliff.
7 Moolack Creek	Descend on path from parking lot at Moolack Beach State Park. Soil and debris flow exposed 1 m below present day soil. Rooted stump 100 m directly W. on beach.	1 rooted stump exposed 3/96 in high-water zone.	Forest soil covered by debris flow exposed in marine cliff.	Soil profile measured. Wood sample MC-1 collected 3/96.
8 Schooner Creek	W. down gravel road 170 m N. of Schooner's Landing. Debris flow, forest soil, and creek mouth marsh underlie parking area at end of road.	None observed on beach. 5–6 present in creek mouth soil profile beneath parking area.	Layered forest soil covered by debris flow covers blue clay with marsh grass. Complex stratigraphy because of liquefaction and debris infall.	4 soil profiles measured. Sample SC-1 of debris flow. Samples SC-1, SC-2, and SC-3 of cones similar to <i>Picea sitchensis</i> from litter in forest soil.
9 Nye Creek	Marine cliffs N. of Nye Beach turnaround exhibit forest soil and creek marsh horizons with cross-cutting relations.	None observed.	Forest soil on top of marine cliffs with dense mats of litter and bark is overlain by debris flow.	Forest soil sample NB-1. Mat of compact forest litter.
10 Grant Creek	Enter beach access through Pacific Shores residential area or walk 2 km S. from South Beach State Park. Soil profile and rooted stump exposed in bank in creek mouth.	One rooted stump in creek mouth marsh deposit.	Debris flow overlying layered forest soil and creek mouth marsh deposit.	Sample GC-1, debris flow; GC-2, forest soil; GC-3, scorched forest soil; and GC-4, marsh clay. Wood sample GC-1.

Table 1. *Rooted stumps and forest soil localities, continued*

Locality	Access	Stump field	Soil	Samples
11 Moore Creek	Walk 1.2 km N. on Holiday Beach from Thiel Creek to mouth of Moore Creek.	1 rooted stump on beach 200 m directly W. of creek mouth exposed 3/96 (cover photo). 1 rooted stump in creek mouth marsh deposit in bank at top of beach.	Creek mouth marsh and overlying forest soil.	Wood sample MC-1 taken from stump on beach.
12 Thiel Creek	Turnout on Hwy 101, 300 m S. of Thiel Creek motel. Follow path to beach.	2 extensive stump fields. The one S. of creek mouth arches 151 m from high-water zone (139 m W. of marine cliffs) to lower low-water zone. Photograph by P. Komar taken 1/74 shows soil about 6 in. higher than 3/96, with over 100 forest logs and small woody debris embedded in the soil with a preferred E.-W. orientation. 2 rooted stumps exposed 1/94-12/96 (Figure 3). Stump field N. of creek with 3 rooted stumps and about 50 unoriented logs. From 1/24/95 to 10/20/95, possible rooted stump at top of marine cliffs 520 m S. of Thiel Creek.	Extensive forest soil under rooted stumps and around logs in surf zone (Figures 8 and 10). Soil in creek mouth runs up onto marine cliffs and extends 3 km south. Possible debris flow in creek mouth.	Wood samples STC-1 and STC-2 from S. stump field. Wood samples NTC-1 to -3 from N. stump field, collected 3/24/95. Soil samples TCA-0 to -9 from S. stump field, TCS-1 to -11 from soil horizon in lower low-water zone, TCM-1 to -5 from soil horizon in marine cliff. Cone samples TCC-1 to -4 from S. stump field, collected 8/5/95.
13 Lost Creek	Descend path from Lost Creek State Park. Stump field exposed 500 m due W. on beach.	Woody debris, oriented and injected logs observed in low low-water 5/95; no confirmed rooted stumps. Possible washout of rooted stump observed by R. Loeffel in 1982.	Creek mouth marsh and forest soil exposed in elevated creek cut 225 m N. of State Park. Forest soil ascends to top of marine cliffs and continues 200 m N. and S. Woody debris and possible stump present at top of elevated wave-cut terrace.	No samples.
14 Deer Creek	Turnout 2.2 km S. of Ona Beach State Park on W. side of Hwy 101. Rooted stumps on beach 100 m W. of beach access. Rooted stumps, forest soil, and coseismic liquefaction feature in bank at top of beach 300 m S. to creek mouth (Figure 6).	Good access and continuous exposure. 2 rooted stumps exposed on beach intermittently since 1982. 2 rooted stumps in bank at top of beach (Figure 6), 1 stump in marine cliff just S. of creek cut.	Layered forest soil in bank at top of beach. 2 layers separated by beach sand. Top layer is fire scorched and contains charcoal. Soil ascends to top of marine cliff, unconformably overlies Pleistocene dunes, and continues for 1.2 km S. to Seal Rock State Park, where it crops out around warning signs at beach access.	Wood samples DCS-1 to -5. Sample DC-3 from backshore beach dated at $3,920 \pm 60$ RCYBP. Soil samples DC-1 to -6. 4 soil sections measured.
15 Starr Creek	Stump field exposed in surf zone 50 m N. and S. of Starr Creek.	10-20 roots exposed 1983-1985. Stumps mostly eroded away.	Not observed.	No samples.
16 Yachats River	Access from S. side mouth of Yachats River, Yachats Ocean Road State Wayside picnic area. Stump field 120 m N. of stairway to beach.	5 rooted stumps exposed for 3 weeks, 3/95.	None observed.	Wood samples from rooted stumps, YR-1 and YR-3, collected 3/3/95.
17 Cook's Chasm	Access on paved path from turnout N. of Cook's Chasm. Rooted stumps, forest soil, and debris flows in cliff face at top of basalt platform.	1 rooted stump at base of cliff.	Three layers of forest soil capped by debris flows.	2 sections measured.
18 Cummin's Creek	Forest soil and creek mouth marsh soil in cliffs below parking lot at picnic area at Neptune State Park and extend S. 540 m.	1 rooted stump at top of beach. 1 rooted stump exposed at top of cliff 500 m S. of picnic area.	Forest soil runs up marine cliffs and continues 500 m S. Paleosoil separated from present soil by shell midden, 370 m S. of picnic area.	4 sections measured.

Table 1. *Rooted stumps and forest soil localities, continued*

Locality	Access	Stump field	Soil	Samples
19 Ten Mile Creek	Rooted stump, forest soil, and marsh soil at top of beach 75 m S. of beach access from Stonefield Beach State Wayside.	1 rooted stump at the top of the beach.	Creek mouth marsh soil and forest soil at top of beach. Forest soil runs up marine cliffs S. Separated from modern soil by dune sands and shell midden 390 m S. of beach access.	3 sections measured. Wood sample TMC-1.
20 China Creek	Access beach from Muriel O. Ponsler Memorial Wayside. 3 rooted stumps on beach 50 m N. of access. Extensive stump field and forest soil horizon on beach S. across China Creek continues 1.2 km S.	3 rooted stumps in beach high-water zone exposed 6/96, 50 m N. of wayside. First noted 1982/83 by E. Zoebel. 5 rooted stumps exposed in higher high-water zone of beach S. of China Creek. 1 stump continuously exposed in bank at top of beach 500 m S. of Creek (Figure 4).	Forest soil on beach with litter S. of China Creek runs up to bank at top of beach and underlies dune field continuously 0.9 km to S. (Figures 5 and 8). Exposed 3/25/95–8/4/95. Extensive fire-scorched layers.	Wood samples from rooted stumps CCs-1, to -5. Cones of <i>Tsuga heterophylla</i> from beach S. of China Creek. Soil samples CC-1, CC-2, and CC-5. 3 sections measured.
21 Blowout Creek	Forest soil in bed of Blowout Creek 200 m S. of picnic area beach access at Carl G. Washburne Memorial State Park.	1 rooted stump in marine cliff 12 m S. of Blowout Creek.	Forest soil runs up from Blowout Creek and continues 2.1 km to Heceta Head. Runs up 12 m over large dune form (Figure 7). Litter exposed south of dune form.	Litter sample BC-1. Wood sample BC-1 from stump rooted in soil runup.
22 Cape Creek	1 rooted stump on top of beach near picnic area of Devil's Elbow State Park.	1 rooted stump.	None observed.	Wood sample CaC-1.
23 Sunset Bay	18 rooted stumps and buried soil horizons on beach and in bed of Big Creek at Sunset Bay State Park.	18 stumps from Big Creek to fault line on N. end of beach. Intermittently exposed since 1983 ENSO.	Laminated soil of uncertain origin underlies beach sand.	Wood samples SSB-1 to -6; soil samples SSB-1 to -17.

(Continued from page 136)

clay underlying a horizon of forest soil. The clay layer, 1–3 m thick, is characterized by rooted stumps, layers of peat, marsh grass fragments, and clasts of siltstone. The forest soil, 0.5–2 m thick, is characterized by humus, litter, and rooted stumps. At some sites, two or more forest soil layers are divided by layers of beach sand and/or cobbles. The bottom forest layer is thickest and contains cones, bark, and needles. The top forest layer is sandy and contains a zone of fire-scorched material with red iron oxide minerals and possible charcoal.

Soil horizons stratigraphically equivalent to the surf zone soil ascend creek mouth valley walls and cross-cut Pleistocene sand-dune deposits of the marine terraces at seven localities (Figures 5, 6, 7; Table 1). The ascending forest horizons are characterized by Podzol profiles similar to the present day profile formed on top of Holocene dune deposits (Corliss, 1973). The top layer of undecomposed forest litter, shredded bark, cones, and twigs in a matrix of sandy loam varies in thickness from 2 in. to 20 in. This layer grades down into the humus layer which is 10–54 in. thick. The humus is friable with a few firm aggregates, slightly sticky, and nonplastic. Woody debris is locally abundant, and in places 10-cm-thick mats of bark and shredded bark are present. The gray leached zone, which varies from 0.1 to 1 m in thickness, is underlain by an orange-red B horizon 0.5–2 m thick and with well-developed laminae of sesquiox-

ides. The forest soil horizons terminate abruptly upward and are capped by Holocene debris flows, backshore beach sands, or dune sands that separate them from the present-day soil horizon.

Debris flows up to 5 m thick cover creek mouth and ascending forest horizons at nine sites (Table 1). The debris flows contain fragments of the underlying forest soil, angular dune-paleosol fragments, semicircular siltstone fragments, and woody debris mixed in with gravel and mud. The high abundance of angular and unconsolidated fragments suggests that the flows did not travel long distances. At Coal Creek, a debris flow covers a rooted stump at the backshore edge of the beach, which suggests a possible coincidence between platform subsidence and the debris flow. The debris flows probably extended onto the wave-cut platform.

DISCUSSION

The location and abundance of the tree stumps and associated soil indicate that they are erosion remnants of extensive forests that grew on Holocene wave-cut platforms. Several questions are raised by the data: (1) what caused regression of the surf zone off the late-Holocene wave-cut platform? (2) what caused inundation and burial of the established forests? and (3) what was the extent and timing of the burial events? In this section, we discuss each of these questions in turn.

(Continued on page 141)

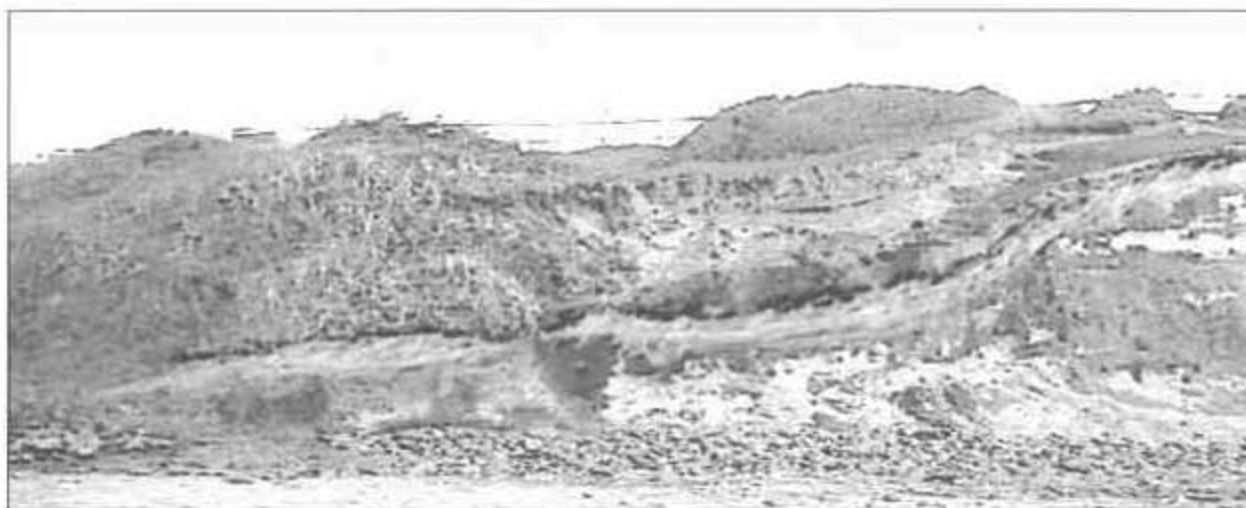


Figure 7. Ascending soil horizons cross-cut older beach and dune sands. Top panel shows well-developed podzol horizon in the ascending forest soil horizon at Blowout Creek. Soil in this photo attains elevation of 8 m and is overlain by Holocene dune deposits. Middle panel shows ascending forest soil horizon below the Road's End parking lot at Logan Creek. Bottom panel shows the ascending forest soil horizon near Wakonda Beach north of Starr Creek.



Figure 8. Buried forest litter. Top panel shows cones and shredded bark from the soil horizon in the marine cliffs at Blowout Creek. Bottom panel shows cones and moss fragments from the litter zone in the soil in the surf zone near China Creek.

(Continued from page 139)

Regression of the surf zone

The surf zone must have receded offshore after the cutting of the platform and before the forest grew on it. Three possible mechanisms of surf zone regression are (1) eustatic drop of sea level, (2) transient sand barrier formation, or (3) tectonic uplift of the coast.

If the wave-cut platforms on which the stumps are now rooted were cut during the previous interglacial high stand at 80 ka, the forest could have transgressed seaward as the sea-level receded. The forest could have grown continuously until return of sea level. However, north of Newport, the wave-cut platform identified with the last interglacial high stand (80 ka) now lies inland and at higher elevations than the platform on which stumps are rooted. The rooted stumps must have grown on a platform cut more recently than the last glacial high stand. Furthermore, surf zone regression by

eustatic drop of sea level seems unlikely for the stumps in the range of 1.9–4.4 ka, because that is the period of late Holocene marine transgression (Berger, 1983).

Regression of the surf zone due to prograding sand features or other barriers cannot be ruled out for all sites studied; however, the Spencer Creek, Wade Creek, Coal Creek, and Moolack Creek stump fields are all in a sand-starved cell that is cut off from longshore sand supply by two major headlands (Peterson and others, 1991). Between Deer Creek and Grant Creek, the sites are on straight, broad, well-developed wave-cut platforms with wave-cut cliffs up to 10 m in height. Thus wave attack has been dominant at these sites in late Holocene time. China Creek and Blowout Creek lack well-developed wave-cut cliffs and uplifted wave-cut platforms, so sand barriers cannot be ruled out. Sunset Bay and Yachats River, because of their enclosed topography, are the most likely sites to have been isolated by sand bars.

There is abundant evidence that the Oregon coast is influenced by the tectonically active convergent margin of the Cascadia subduction zone (CSZ). Regional and/or local faults have vertically displaced the shoreline during strain buildup and coseismic release in late Holocene times (Darienzo and Peterson, 1990). Uplifted wave-cut platforms indicate the coastline has emerged at rates fast enough to cause regression of the surf zone (Ticknor, 1993; Mitchell and others, 1994).

The scarcity of surf zone forests discovered so far precludes a test of whether uplift of the forested wave-cut platforms was gradual or rapid.

Burial and preservation of the rooted stumps and forest soil

The presence of fresh forest litter in the surf zone and the abrupt upward termination of podzol profiles on ascending soil horizons implies rapid burial of the forest soil. Under normal forest soil conditions, aerobic fungi and bacteria decompose litter to form humus. The rate of decomposition is variable and depends on temperature, moisture, drainage, and the resin content of the litter. Typical residence time for deciduous leaves is 1–2 years (Waring and Schlesinger, 1985). Data are not available for rates of decomposition in temperate coniferous rain forests, but the presence of moss, leaves, and conifer needles with intact fine structure indicates that little decomposition occurred in the forest soil now preserved on the beaches. We propose that the forest soil must have been protected from agents of decomposition and fermentation within several years of deposition. Some stumps in the creek mouths are preserved in peat, but peat is absent from the wave-cut platforms. Conditions suitable for preservation of forest soil on the wave-cut platform can be produced by burial under (1) wet, salty beach sand; (2) arid dune sand; or (3) debris-flow deposits.

(Continued on page 143)

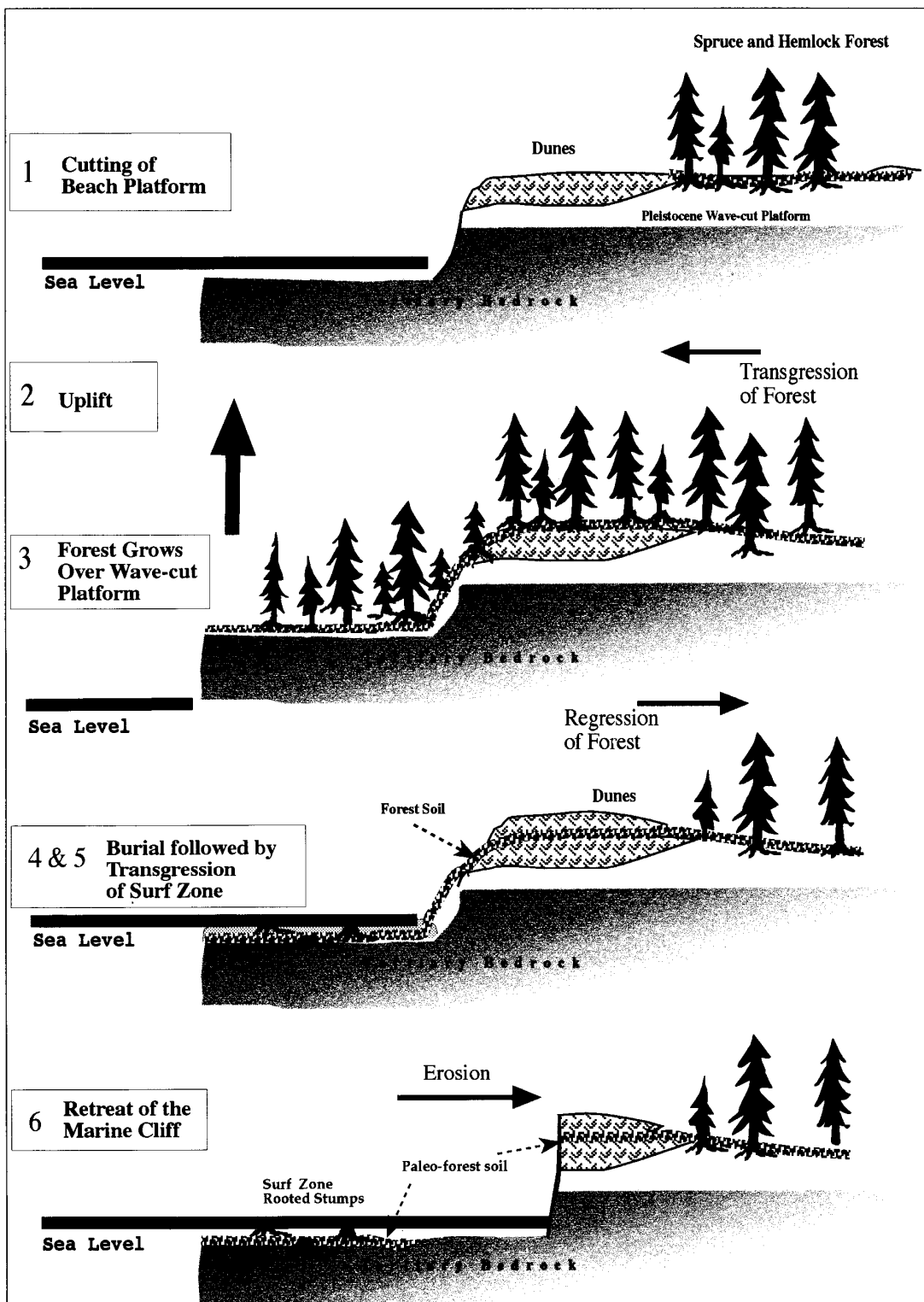


Figure 9. The six stages necessary to explain the occurrence of rooted stumps in the Oregon surf zone. Regression of the surf zone off the platform was probably the result of vertical tectonic displacement. Burial is inferred from the presence of nondecomposed forest litter. Transgression of the surf zone was not necessarily synchronous with burial and could have been the result of eustatic sea level rise, removal of sand barriers, or vertical tectonic displacement or any combination of the three.

(Continued from page 141)

Forest soil at Deer Creek appears buried in beach sand. Trees growing near beaches can be buried in wet, salty sand if there is a rapid seaward growth of the beach. Growth of the beach can be caused by an abrupt increase of littoral sand supply induced by shifting nearshore currents or by an increase in sediment supply to the littoral cell (Peterson and others, 1990). Sudden vertical tectonic displacement could also induce burial of trees in beach sand if the displacement is great enough.

The ascending forest soil horizons are covered by dune sand at China Creek and Blowout Creek. Rapid migration of dunes over the trees as a result of an abrupt increase in littoral sand supply is a possible agent for burial and protection of the forest. Vertical tectonic displacement could also induce migration of dunes over forests by introducing the forest to areas of active dune formation at lower elevations.

Debris flows cover forest soil at nine localities north of Thiel Creek. A nearly continuous apron 15 mi wide may have covered the beaches between Spencer Creek and Lost Creek and could have buried the forest on the beach platform. Although it is nearly impossible to determine whether or not debris flows are coseismic, debris flows are commonly associated with earthquakes. For example, over 10,000 debris flows occurred during the 1976 Guatemalan earthquake (M_s 7.5) (Harp and others, 1981).

Additional work is needed to verify whether deposits currently covering the forest soils reflect the initial burial of the forests.

Inundation of the forest

Inundation of the forest in the surf zone was not necessarily synchronous with burial. Preservation of litter by burial in beach sand or in a peat bog would have required a synchronous drop to sea level. However, burial by debris flows or eolian dunes could have taken place above sea level before inundation. At any rate, the forest was inundated by a transgressing surf zone that could have been the result of eustatic rise of sea level and/or removal of sand barriers and/or tectonic subsidence.

In this paper we do not attempt to discriminate between the possible mechanism of inundation. Possibly all are involved. For example, even though eustatic rise of sea level was a factor, it was less than 1 mm per year at 1.9–4.4 ka (Berger, 1983). Some parts of the coastline were tectonically uplifted faster than this. Others were probably tectonically submerging.

Sequence of events

Although we cannot assume the same sequence of events for all sites, we propose a six-step sequence (Figure 9) as the most likely one for the majority of sites of rooted stumps and associated forest soil. First, the

wave-cut platform was cut at sea level prior to growth of the trees. Second, sea level regressed off the platform due to tectonic uplift. In the third stage, the forest grew over the platform. In the fourth stage, the forest was rapidly buried and the litter preserved. In the fifth stage, the forest was inundated by the surf zone. In the sixth and final stage, the forest soils and overlying deposits were eroded during the retreat of the marine cliffs.

CONCLUSIONS

The rooted stumps and forest soils on Oregon's beaches are remnants of forests similar to present-day coastal temperate rain forest that grew on the Holocene wave-cut platform and adjacent creeks, dune fields, and marine terraces. The paleo-forest soils exposed in the surf zone, in creek mouths, and on valley walls are probably contemporaneous with rooted stumps in the surf zone, but this cannot be established without further mapping, coring, and radiocarbon dating. The abrupt upward termination of the forest soil and the preservation of undecomposed litter indicates rapid burial by debris flows, dunes, or beach sands. The burial may have been coseismic and synchronous with inundation, but this cannot be established with the data set on hand. The preliminary ages of the stumps, 1.9–4.4 ka, show that the growth and burial of some of the trees took place after the time of major eustatic sea level rise in early mid-Holocene time. The rapid colonization and deterioration of the stumps and exposed soils in the surf zone indicate that these forest remnants were exposed only during short-lived erosion events or have not been previously exposed. The full cycle of platform cutting, uplift, forest growth, burial, inundation, and renewed platform cutting may have taken place over a period upward of 1,000 years. Additional platform-forest site coring/mapping and radiocarbon dating are necessary to test the extent, duration, and possible cyclicity of these processes. For example, do other forest remnants exist landward under Holocene dune fields or offshore on the inner shelf?

ACKNOWLEDGMENTS

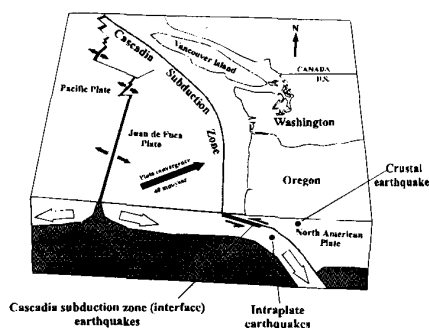
Radiocarbon dating was supported by the Portland State University Department of Geology. This work was partially supported by grant No. NA36RG0451 from the National Oceanic and Atmospheric Administration to the Oregon State University Sea Grant College and by appropriations made by the Oregon State Legislature. The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA or any of its subagencies. Author Hart is grateful to Ian Hart, Cathy Heflin, and Bob Shivers for their assistance in the field and to Cathy Heflin for her assistance in preparation of the manuscript and figures. The field work and manuscript benefited from discussions with Alan Niem and Paul Komar.

REFERENCES CITED

- Berger, R., 1983, Sea levels and tree-ring calibrated radiocarbon dates, in Masters, P.M., and Fleming, N.C., eds., *Quaternary coastlines and marine archaeology*: New York, N.Y., Academic Press, p. 51-61.
- Corliss, J.F., 1973, Soil survey of Alsea area, Oregon: USDA Soil Conservation Service and Forest Service, U.S. Bureau of Land Management, in cooperation with Oregon Board of Natural Resources and Oregon Agricultural Experiment Station, 82 p., 43 map sheets.
- Dariento, M.E., Peterson, C.D., 1990, Episodic tectonic subsidence of late Holocene salt marshes, northern Oregon, central Cascadia margin: *Tectonics*, v. 9, p. 1-22.
- Harp, E.L., Wilson, R.C., and Wiecek, G.F., 1981, Landslides from the February 4, 1976, Guatemala earthquake: U.S. Geological Survey Professional Paper 1204-A, 35 p.
- Kelley, L., Spiker, E., and Rubin, M., 1978, U.S. Geological Survey, Virginia, radiocarbon dates XIV: Radiocarbon (*American Journal of Science*) v. 20, no. 2, p. 283-312.
- Kelsey, H.M., Engebretson, D.C., Mitchell, C.E., and Ticknor, R.L., 1994, Topographic form of the Coast Ranges of the Cascadia margin in relation to coastal uplift rates and plate subduction: *Journal of Geophysical Research*, v. B99, p. 12,245-12,255.
- Komar, P.D., 1986, The 1982-83 El Niño and erosion on the coast of Oregon: *Shore and Beach*, v. 54, p. 3-12.
- Mitchell, C.E., Vincent, P., and Weldon, R.J., II, 1994, Present-day vertical deformation of the Cascadia margin, Pacific Northwest, United States: *Journal of Geophysical Research*, v. B99, p. 12,257-12,277.
- Peterson, C.D., Dariento, M.E., Burns, S.F., and Burris, W.K., 1993, Field trip guide to Cascadia paleoseismic evidence along the northern Oregon coast: Evidence of subduction zone seismicity in the central Cascadia margin: *Oregon Geology*, v. 55, no. 5, p. 99-114.
- Peterson, C.D., Dariento, M.E., Pettit, D.J., Jackson, P., Rosenfeld, C., 1991, Littoral cell development in the convergent Cascadia margin of the Pacific Northwest, U.S.A., in Osborne, R.H., ed., *From shoreline to abyss: Contributions to marine geology in honor of Francis Parker Shepard*: Society for Sedimentary Geology (SEPM) Special Publication 46, p. 17-34.
- Peterson, C.D., Jackson, P.L., O'Neil, D.J., Rosenfeld, C.L., and Kimerling, A. J., 1990, Littoral cell response to inter-annual climatic forcing 1983-1987 on the central Oregon coast, USA: *Journal of Coastal Research*, v. 6, no. 1, p. 87-110.
- Priest, G.R., Saul, I., and Diebenow, J., 1994, Chronic geologic hazard maps of coastal Lincoln County, Oregon: Oregon Department of Geology and Mineral Industries Open-File Reports O-94-12 through O-94-30, scale 1:4,800.
- Ticknor, R., 1993, Late Quaternary crustal deformation on the central Oregon coast as deduced from uplifted wave-cut platforms: Bellingham, Wash., Western Washington University master's thesis, 70 p.
- Waring, R.H., and Schlesinger, W.H., 1985, *Forest ecosystems concepts and management*: New York, N.Y., Academic Press, Inc. □

Winter term earthquake course offered by OSU on educational TV

A general-interest course entitled "Earthquakes of the Pacific Northwest" will be offered at Oregon State University on educational television during winter term, January-March 1998. The three-hour course will review the earthquake hazards from the Cascadia subduction zone (interface earthquakes), the overriding North American plate (crustal earthquakes), and the subducted Juan de Fuca plate (intraplate earthquakes). This



is followed by discussions of earthquake forecasting, earthquake insurance, stability of buildings (including the effects of recent upgrading of the building code for seismic

protection), and role of government agencies, including the Department of Geology and Mineral Industries. Included are also sections on retrofitting a typical Northwest residence and on preparing for the next earthquake. Speakers will include local experts from government and private industry.

The three-hour course is GEO 380, offered by educational television (EDNET) through Oregon State University. The course will be taught live in room ECE 102 on the OSU campus and on local Cable Channel 18 Monday evenings from 7 to 10 pm, starting January 5. Live satellite transmission will make the course available at the same time to students in Astoria (Clatsop Community College), Bend (Central Oregon Community College), Coos Bay (Southwestern Oregon Community College), Newport (Hatfield Marine Science Center), and Hood River (Memorial Hospital). The televised course will begin in the Portland area via tape delay on Monday, January 12, from 10 a.m. to 1 p.m. on Cable Channel 11. In southern Oregon, the course begins on Thursday, January 15, 7-10 p.m., and ends March 19, carried on Cable Channel 32.

The course satisfies the baccalaureate core curriculum requirement for a course relating science, technology, and society. The text will be the manuscript of a forthcoming book by the instructor, Dr. Robert Yeats. The book will be entitled *Earthquakes of the Pacific Northwest* and is to be published in 1988.

Interested persons can register for the three-credit course by phone at 1-800-235-6559. Additional information can be obtained from the instructor, Dr. Yeats, at 541-737-1226. □

Schnitzer named national Outstanding Reclamationist of the Year for environmental work

E. Frank Schnitzer of the Oregon Department of Geology and Mineral Industries (DOGAMI) has been named 1997 Outstanding Reclamationist of the Year by the National Association of State Land Reclamationists (NASLR).

Schnitzer, 45, a lead scientist for the DOGAMI Mined Land Reclamation (MLR) Program in Albany, received the award on September 16 during the NASLR joint annual meeting with the Interstate Mining Compact Commission in Lake Placid, New York.



E. Frank Schnitzer

NASLR, the nationally recognized authority on the reclamation of mined land, advocates research, innovative technology, and training in restoring lands and waters affected by mining. Oregon's reclamation program ensures that mined land is "reclaimed" for subsequent agricultural, forestry and other beneficial uses.

NASLR President Bruce Ragon recognized Schnitzer's years of work and dedication to the science of reclamation. "This award is not given every year, but Frank's ability to find technical solutions to complex issues is outstanding," said Ragon, also noting his role in creating guidelines for floodplain operations to protect fish-

eries and his quick response to the Oregon floods of 1996 and 1997, when Schnitzer organized an interagency team of experts to help mining operators with flood control.

"I'm always pleased when outstanding Oregon public servants are recognized for their talent and hard work," said Governor John Kitzhaber. "I congratulate Frank Schnitzer on this award and thank him for his dedication to his job and the state as a whole."

In addition to inspecting and permitting aggregate mines in Oregon's northwest region, Schnitzer has statewide responsibilities for trouble-shooting and inspecting the most complex and controversial of the 800 permitted mines in Oregon.

"Frank's field savvy and technical knowledge have earned him much respect in the aggregate industry," said MLR Supervisor Gary Lynch. "His negotiation skills have saved the industry—and the State of Oregon—a lot of time and money in turning rock quarries back to a natural environment, while helping operators find cost-effective ways to meet or exceed Oregon's mining standards."

Schnitzer also led DOGAMI field efforts to help implement the Oregon Coastal Salmon Restoration Initiative (later named "The Oregon Plan"). Last year, he and other MLR reclamationists inspected all aggregate mines near the coast, with operators given "fish report cards" on the water quality of their operations. With flood issues emerging as a priority after the 1996 and 1997 storms, Schnitzer is helping DOGAMI and other state and federal agencies create the first agreement among major aggregate producers near the Willamette and McKenzie Rivers to coordinate reclamation efforts.

"Frank has been a big help to our industry over the years he has been with DOGAMI," said Rich Angstrom, managing director of the Oregon Concrete and Aggregate Producers Association. "Some of the strides we have made in meeting regulatory requirements would not have been possible without him."

Schnitzer, with DOGAMI since 1983, received his bachelor's degree in soil science in 1978 from California Polytechnic State University and his master's degree in soil science and biometeorology in 1980 from Utah State University. He lives in Lacombe near Lebanon, Oregon.

"This award belongs to the whole Albany office because we work as a team," Schnitzer said. "We're in this profession because we care about Oregon's environment and about doing the right thing. So recognition like this becomes important—like cash for the psyche." □

Zhenming Wang joins DOGAMI earthquake team

The Oregon Department of Geology and Mineral Industries (DOGAMI) has acquired the services of Zhenming Wang, who joined the Department's earthquake staff as a Geotechnical Specialist.



Zhenming Wang

Wang comes to DOGAMI from the University of Kentucky, where he was research assistant, student, and consultant, mostly in the Department of Geological Sciences but also with other branches of the university.

Wang began his training and his professional career in China, where he earned his first bachelor's degree in geology at Peking University in Beijing and worked as a geologist, geophysicist, and geotechnical engineer in Fujian Province.

At the University of Kentucky he acquired, in order, a master of science degree in geophysics, a bachelor's degree in civil engineering, and his doctorate in geophysics and is about to receive a master of science degree in environmental engineering. Since 1987, he has been making numerous published contributions to research in geology, geophysics, and engineering, particularly in the area of earthquake hazards.

As a member of the DOGAMI earthquake team, Wang participates in all aspects of earthquake hazard mitigation. "His broad technical experience," says team leader Mei Mei Wang, "is most welcome for the many tasks the Department is undertaking to reduce the risks for Oregonians of living in earthquake country." □

DOGAMI PUBLICATIONS

Released September 30, 1997

Earthquakes—Converging on Cascadia, Symposium Proceedings, Association of Engineering Geologists 40th annual meeting, September 30 to October 4, 1997, Portland, Oregon, edited by Yumei Wang and Klaus K.E. Neuendorf, Special Paper 28, 96 p., \$12.

The Oregon Department of Geology and Mineral Industries (DOGAMI) and the Association of Engineering Geologists (AEG) have jointly released the proceedings of a symposium on earthquakes in the Pacific Northwest, one of several special events of the AEG annual meeting 1997. The proceedings have also been published as AEG Special Publication 10.

Focus of the symposium was to broaden the understanding of earthquake research issues centering on the Cascadia region earthquake setting and to apply them to hazard risk reduction. Keynote speaker for the symposium was Bruce A. Bolt of the University of California at Berkeley, who presented an "Assessment of seismic hazard assessments." Other contributors included researchers from the U.S. Geological Survey, DOGAMI, Oregon State University, and the firm of Woodward-Clyde Federal Services and a private earthquake engineering consultant. □

Entertaining mug teaches about tsunami hazard

In conjunction with World Disaster Reduction Day on October 8, 1997, a cooperative federal/state partnership has created a special gift that carries the tsunami safety message in a non-alarmist, playful manner. It is a heat-sensitive mug that, when cold, depicts a person splashing in the ocean and the heading "Tsunami?" When the mug is hot, the picture changes to the tsunami logo, the official tsunami hazard symbol for Oregon, Washington, California, Alaska, and Hawaii, and the heading changes to "TSUNAMI!" The other side of the mug shows—hot or cold—a permanent checklist of the essential steps to escape a tsunami. It also includes the web-site address for the National Tsunami Hazard Mitigation Program so that those interested can use their computer to find further information about this natural hazard.

The mugs are now available at the Hatfield Marine Science Center in Newport, the Alsea Bay Bridge Interpretive Center in Waldport, and the Nature of the Northwest Information Center in Portland. Additional coastal retail facilities (gift shops) will also be carrying the tsunami mug in the near future. Suggested retail price of the mug is \$12.00. Further information is available from Jessica Waddell at 541-867-0274 or the Nature of the Northwest Information Center at 503-872-2750. □

THESIS ABSTRACTS

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

Geology and Petrologic Evolution of the Silicic to Intermediate Volcanic Rocks underneath Steens Mountain Basalt; SE Oregon, by Vera W. Langer (M.S., Oregon State University, 1991), 109 p.

Steens Mountain in southeast Oregon is part of the northern Basin and Range province, and represents a horst tilted about 10° to the west that is bounded to the east by a high-angle, north-northeast-trending normal fault. The minimum displacement is about 1,200 m. Volcanic rocks, exposed along the eastern escarpment, range from basalt to high-silica rhyolite. By establishing a stratigraphy and determining chemical variations in the volcanic rock sequence underlying the Steens Mountain Basalt, it was possible to evaluate the origin of this volcanism and the role of crustal contamination, explain its chemical variation with time, and relate the chemical evolution to extensional processes. The necessary chemical data were obtained by X-ray fluorescence, electron microprobe, and instrumental neutron activation analyses; field mapping provided information about stratigraphy and structure.

The oldest units are lake sediments, which are overlain by a volcanic rock sequence that proceeded from early rhyolitic tuffs to rhyolitic lava flows, dacites, and andesites, and culminated with the eruption of Steens Mountain Basalt (SMB). All stratigraphic units are tilted to the northwest or southwest to various degrees. Early sediments and rhyolitic tuffs are tilted as much as 25°; whereas younger andesites (15° tilt), and SMB (5–10° tilt) overlie the older units unconformably. The stratigraphy and mapped unconformities indicate that active, volcanic episodes alternated with episodes of erosion and block tilting. Tilting events are thought to be connected to extensional tectonics, and the maximum extension for the Steens Mountain area is estimated to be 30 percent.

Relationships between basalt, andesites, dacites, and rhyolites of the Steens Mountain volcanic suite are complex. Crystal fractionation alone cannot relate the different rocks to each other. Trace-element chemistry of intermediate compositions requires fractional crystallization plus large degrees of assimilation and magma mixing. Magma mixing is also suggested by different plagioclase populations and zoning patterns in plagioclase and clinopyroxene phenocrysts from intermediate rock compositions. The role of assimilation is greater in the andesites and that of mixing in the dacites. The silicic mixing partner has to be extremely low in rare-

earth elements. Rhyolites are not directly related to the rest of the suite, but are related to each other by crystal fractionation. They most likely evolved from a partial melt of depleted crust (probably lower crust) by fractionation.

Assimilation coupled with fractionation and simple magma mixing are typical magma processes for major metaluminous volcanic suites in the Basin and Range and elsewhere. These processes decrease the density of stagnated basaltic melts and subsequently increase their buoyancy. Extension triggers the ascent of mafic magma, but small amounts of extension alone do not increase the mean crustal density enough for basalts to rise to the surface. Increasing the crustal density by injection of mafic plutons and extension is able to produce a shift in volcanism from intermediate to more basaltic compositions as seen at Steens Mountain, where the influence of crustal material decreases upwards in the volcanic sequence.

Potential for coastal flooding due to coseismic subsidence in the central Cascadia margin, by Elson T. Barnett (M.S., Portland State University, 1997), 144 p.

Interpretations made from compilation of existing core and cutbank data for Oregon and Washington are used to evaluate the potential flooding impact from regional coseismic subsidence.

Estimates of regional subsidence are based on tidal level indicators including plant macrofossils, peat development, and diatoms. A compilation of existing late Holocene stratigraphic records shows multiple burial events in all bays of Oregon, however some coastal sites in central Oregon show continuous submergence. Tests of tidal level indicators using modern Cascadia wetlands indicate that paleosubsidence can be estimated to 0.0 ± 0.5 m, 1.0 ± 0.5 m, and 2 ± 0.5 m. An AMS date from a cone atop a buried wetland deposit (250 ± 40 RCYBP) in Tillamook Bay, Oregon, is consistent with the interpretation of the most recent buried wetland deposit correlated to a regional coseismic subsidence event occurring at ~A.D. 1700. Estimates of paleosubsidence produced by the most recent regional seismic event are 1 to 2 m ± 0.5 m for Grays Harbor, 1 ± 0.5 m Necanicum Estuary, 1 ± 0.5 m Tillamook Bay, and 0 to 1 m ± 0.5 m Siletz Bay. A database using the most recently buried wetland is produced from published and unpublished core and cutbank data collected throughout the central Cascadia margin. A regional trend of decreasing subsidence is found from north to south and locally from east to west. These trends yield an apparent correlation between the amount of subsidence and distance (east-west) from the subsidence site to the Cascadia trench.

Paleosubsidence estimates for sites at Elliot Slough (2.0 m) and Neawanna Creek (1.0 m) are used for analysis of flooding in Aberdeen, Washington, and

Seaside, Oregon, respectively. Paleosubsidence estimates added to the 10- and 100-yr. flood elevations are compared to current 10-, 100-, and 500-yr. flood elevations (pre-subsidence). Emergency access roads, dikes, tidegates, and city drainage outfalls are susceptible to seasonal flooding at 1- to 10-yr. flooding frequencies following coseismic subsidence of 1–2 m.

Volcanology and petrology of the Rattlesnake Ash-Flow Tuff, eastern Oregon, by Martin J. Streck (Ph.D., Oregon State University, 1994), 185 p., 1 data diskette.

The dissertation consists of three chapters of which each is designed as a separate publication. The author of the thesis is the first author of the first two papers (chapters I and II) and is the only author of the last paper (chapter III).

Chapter I. Facies variations in a thin, widespread ignimbrite sheet: The Rattlesnake Tuff, eastern Oregon, by Martin J. Streck and Anita L. Grunder.

Today's outcrops of the Rattlesnake Ash Flow Tuff, emplaced 7.05 m.y. ago, cover ca. 9,000 km², but reconstructed original coverage was between 30,000 and 40,000 km². Thicknesses are remarkably uniform, ranging between 15 and 30 m for the most complete sections. Only 13 percent of the outcrop area is covered with tuff thicker than 30 m, up to a maximum of 70 m. Present-day estimated tuff volume is 130 km³, and reconstructed erupted magma volume is 280 km³ dense rock equivalent (DRE). An exponential decrease in average pumice size implies a source area in the western Harney basin, centered on the main outcrop areas. Distance from inferred source to most distal outcrops is 150 km. A large number of welding and crystallization zones formed during post-emplacement processes. The zone of partial welding, the vapor phase zone, and the lithophysal zone are divided into macroscopically distinguishable subzones. Rheomorphic vitric to devitrified tuff is found up to a radius of 40–60 km around the inferred source. In non-rheomorphic tuff, lithological zoning of individual sections, at constant outcrop thickness of 17–23 m, varies from vitric, non- to incipiently welded tuff throughout to highly zoned sections consisting of a basal non- to densely welded vitric tuff overlain by a zone of crystallized tuff which grades internally from spherulite to lithophysae-dominated, to a zone of devitrification, and finally to a zone of vapor-phase crystallization and is capped by upper partially welded vitric tuff. The two facies zonation extremes occur within 1–3 km of one another at several places. Welding and crystallization decrease with distance from the inferred source, but the regional pattern becomes apparent only by integrating many sections within a given area. Strong local variations are interpreted to be the result of threshold-governed welding and crystallization near the critical welding temperature, due to slight original thickness differences influ-

encing the thermal insulation. A three-dimensional welding and crystallization facies model has been developed based on 85 measured sections incorporating local and regional variations.

Chapter II. The Rattlesnake Tuff, part I: Relationships between high-silica rhyolites, dacites and mafic inclusions, by Martin J. Streck and Anita L. Grunder.

The Rattlesnake Ash Flow Tuff from eastern Oregon represents ca. 280 km³ of high-silica rhyolite magma erupted as pumices and glass shards. Dacite pumices make up less than 1 percent of the total volume, and quenched basalt and basaltic andesite inclusions inside dacite pumices constitute <<0.1 volume percent.

Trace and major element variations among high-silica rhyolite pumices indicate a series of progressively more evolved compositions. Derivation of least evolved high-silica rhyolites through dehydration melting events is the process that is most compatible with the chemical record. Major element composition of least evolved Rattlesnake Tuff high-silica rhyolites and melts obtained from dehydration experiments are similar. Ba/Rb ratios of 30±5 and La_N/Yb_N of 4.5±0.2 for the group of least evolved high-silica rhyolites (group E pumices) constrain potential protolith compositions to some amphibolites, high-Ba greywackes or granulite facies intermediate to mafic rocks.

At least three types of mafic inclusions, ranging in size from cm to mm, are recognized which are mainly found inside dacite or dacite/rhyolite banded pumices. Ubiquitous glomerocrysts of plagioclase and chrysolite characterize the inclusion type which is similar to regional high-alumina olivine tholeiite (HOAT) lava flows typical of the Oregon Plateau. Phenocrysts and groundmass show strong quenching features. Phenocryst-poor, basaltic andesite inclusions with a micro-quenched groundmass is the second type. Such inclusions have round to streaky forms, often with mingled textures with the host pumice. Phenocryst-poor inclusions acquired their enriched trace element signatures mainly through fractionation and recharge processes. The third inclusion type is also basaltic but consists of clinopyroxene which poikilitically encloses plagioclase phenocrysts or of granular olivine with plagioclase.

Dacite pumices (62–68 weight percent SiO₂) are phenocryst poor with 1–4 percent crystals. Mineral assemblages are strongly bimodal with euhedral, resorbed, or reacted phenocrysts from high-silica rhyolites or from basaltic magmas. Dacite magmas are likely to have been generated through mixing of least evolved high-silica rhyolites with enriched basaltic andesite magma represented in phenocryst-poor basaltic andesite inclusions. A silica gap of ca. 6 weight percent exists between dacites and high-silica rhyolites. Only pumices with strong banding fall in the gap.

The reconstructed magma chamber was stratified from high-silica rhyolites at the top to mafic magmas

with dacites at the interface. The compositional range of the pre-eruption magma chamber is based on banded pumices containing all compositions. The stratification is inferred from vertical and lateral distribution of erupted compositions within the Rattlesnake Tuff. This stratification is likely to have been stable over some time, based on a petrologic model, which explains the relationships between high-silica rhyolites, dacites, and basaltic compositions. After formation, a silicic magma chamber impeded the ascent of mafic magmas (HAOT), therefore causing the mafic magma to fractionate (enriched mafic inclusions), which in turn thermally stabilizes the silicic magma, causing it to fractionate (zoned high-silica rhyolites). Mafic and silicic melts interact and form dacites along their interface.

Chapter III. The Rattlesnake Tuff, part II: Differentiation of the high-silica rhyolites, by Martin J. Streck.

More than 99 percent of the 280 km³ of magma erupted as Rattlesnake Ash-Flow Tuff, eastern Oregon, is composed of high-silica rhyolite in form of glass shards and pumices. Glassy, high-silica rhyolite pumices cluster in five chemical groups, three consisting of white pumices and two consisting of dark-gray pumices. Key elements for defining these five high-silica rhyolite compositions are Fe, Ti, La (LREE), Ba, Eu, Rb, Cs, Zr(Hf), Ta(Nb), and Th. On element-element diagrams, the high-silica rhyolite pumice clusters define linear or curvilinear arrays sometimes with gaps between groups. Heavy liquid separation on one representative pumice from each group indicates crystal contents around 1 weight percent for the least evolved composition decreasing to 0.09 weight percent and to virtually aphyric at the most evolved composition. Progressive changes with higher degree of evolution of the magma occur in mineral modality, mineral chemistry, and partition coefficients. Data on physical parameters indicate that conditions became more oxidizing with differentiation.

Models of crystal fractionation in non-modal proportions of observed phases with empirical partition coefficients agree generally with enrichment trends and yield compositions of removed solids ranging from syenitic to granitic. On the other hand, crystal fractionation of observed phases in modal proportions is incompatible with observed zonation patterns. Fractionation combined with assimilation (AFC) could have occurred during the first 20 percent (of 60 percent) fractionation but is thought to be of minor importance for observed chemical gradients among high-silica rhyolites. Accumulation of liquids in a single stratified chamber generated by successive partial melting is inconsistent with extremely low Ba (25 ppm) in most evolved and highest Ba (1900 ppm) in least evolved rhyolite. Derivation of the intermediate high-silica rhyolite compositions through mixing of end members is excluded because variable mixing degrees are necessary to explain element abundances of individual pumices.

The likeliest process responsible for the generation of the progressively more evolved high-silica rhyolite compositions is a differentiation process through which each composition is derived from the previous, less evolved liquid. Assuming a slablike chamber geometry, the fractionation process might occur primarily along the roof of the chamber, which is the coolest and largest surface. Each successive more evolved and lighter liquid is generated at the roof and stays as the top layer, generating a composition- and density-stratified magma chamber.

Geologic evidence of historic and prehistoric tsunami inundation at Seaside, Oregon, by Brooke K. Fiedorowicz (M.S., Portland State University, 1997), 197 p.

Over the past decade research conducted along the Cascadia subduction zone coast established evidence for coseismic subsidence, liquefaction, and nearfield tsunami deposition. Seaside is a low-lying northern Oregon coastal city, potentially at risk for nearfield tsunami inundation from a Cascadia earthquake. The 1964 Alaskan farfield tsunami impacted Seaside, and deposits from that event serve as a model for interpreting prehistoric tsunami deposits in the Seaside area.

A reconnaissance subsurface study of potential tsunami inundation sites was performed by trenching and gouge coring in the coastal wetlands along the Necanicum River, Neacoxie Creek, drainage to the east of Neacoxie Creek, Stanley Lake, and Neawanna Creek. A total of 278 core sites were logged for shallow lithologic stratigraphy and contact relations.

To establish tsunami depositional trends from the 1964 farfield event, 71 observation sites, 62 core logs, two grids, and 8 trenches were evaluated. Wave amplification occurred in the Necanicum River/estuary mouth and north of 12th Avenue, south of the G Street bridge crossing Neacoxie Creek, and south of the Hwy 101 bridge crossing Neawanna Creek. These areas contain anomalously thick sand deposits compared to the deposits along the Necanicum River and Neawanna Creek where the wave attenuated, depositing a sand layer thinning upstream.

Neawanna Creek wetlands contain most of the preserved A.D. 1700 earthquake subsidence horizons and sand layers. Within the Seaside wetlands, 90 core sites contain the A.D. 1700 subsidence horizon. No subsided peaty horizons were observed west of Neawanna Creek. At the Mill Creek/Stanley lake area, the A.D. 1700 tsunami deposition is minimal to nonexistent. In the southernmost Neawanna wetlands, A.D. 1700 tsunami deposits are restricted to a narrow zone southeast of the Mill Ponds and north of the S Avenue bridge.

Overland inundation of the A.D. 1700 tsunami, interpreted from core records, did not reach the central Neawanna wetlands (<1.5 km east of the present coastline) and crossed a narrow cobble ridge entering the Neawanna wetlands from a southern Necanicum channel. □

Index to OREGON GEOLOGY, volume 59, 1997

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

Abstracts of theses	3:77; 4:100; 5:126; 6:147
Allen, J.E., In memoriam	1:2
Bargar, K.E., and Oscarson, R.L., Zeolites in the Cascade Range of northern Oregon	5:107
Barnett, E.T., Potential for coastal flooding due to coseismic subsidence in the central Cascadia margin (thesis abs.)	6:147
Brantley, S.R., and Scott, W.E., The danger of collapsing lava domes: Lessons for Mount Hood, Oregon	4:83
Cascadia subduction zone: Beach response to subsidence (Doyle) ..	4:101
—Potential for coastal flooding due to subsidence (Barnett)	6:147
—Coseismic paleoliquefaction evidence (Peterson and Madin)	3:51
Columbia River Basalt Gp.: Stratigraphy, Umatilla Co. (Kuehn)	5:126
Cornucopia stock: Petrogenesis of tonalite (Johnson, K.S.)	4:100
Devine Canyon Ash-Flow Tuff: Magnetic characteristics (Stimac) ..	5:126
DOGAMI news. 1:21; 2:41, 44; 3:50; 4:92, 97, 102; 5:125; 6:130, 145, 146	
Doyle, D.L., Beach response to subsidence following a Cascadia subduction zone earthquake, Wash.-Oreg. coast (thesis abs.)	4:101
Earthquakes: About predicting earthquakes	3:75
—Assessing earthquake hazards and reducing risks in the Pacific Northwest, v. 1 (USGS Professional Paper 1560)	1:21
—Beach response to subsidence (Doyle)	4:101
—Buried forests in the Oregon surf zone (Hart and Peterson)	6:131
—Evidence of tsunami inundation at Seaside (Fiedorowicz)	6:149
—Flooding due to coseismic subsidence (Barnett)	6:147
—Guidelines for site-specific seismic hazard reports	1:6
—Paleoliquefaction evidence (Peterson and Madin)	3:51
—Preparing for earthquakes in Oregon (Y. Wang)	2:27
—“Real-time” earthquake information (Priem)	5:125
—Seismic rehabilitation (Hull)	1:22
—Seismic site hazard reports in DOGAMI library	2:44
Ferns, M.L., Field trip guide to the eastern margin of the Oregon-Idaho graben and the middle Miocene calderas of the Lake Owyhee volcanic field	1:9
Fiedorowicz, B.K., Geologic evidence of historic and prehistoric tsunami inundation at Seaside, Oregon (thesis abs.)	6:149
Field trip guides: Fire, faults, and floods: A road and trail guide exploring the origins of the Columbia River basin (rev. by Vogt)	1:9
—Oregon-Idaho graben, Lake Owyhee volcanic field (Ferns)	3:78
Geologic hazards: Collapsing lava domes (Brantley and Scott)	4:83
—Slide sets from National Geophysical Data Center	3:75
Gibbons, S.T., National Natural Landmarks Program	5:123
Haines, D., Books at the Nature of the Northwest Information Ctr. ...	2:45
Hart, R., and Peterson, C.D., Episodically buried forests in the Oregon surf zone	6:131
Hull, D.A., Seismic rehabilitation—what price are we willing to pay? ..	1:22
John Day Formation: Age of flora at Fossil (McIntosh and others)	1:3
Johnson, J.A., Geologic evolution of the Duck Creek Butte eruptive center, High Lava Plains, southeastern Oregon (thesis abs.)	4:101
Johnson, K.S., Petrogenesis of high-alumina tonalite and trondhjemites of the Cornucopia stock, Blue Mountains (thesis abs.)	4:100
Johnston Ridge Observatory opens at Mount St. Helens	4:99
Kuehn, S.C., The Olympia-Wallowa lineament, Hite fault system, and Columbia River Basalt Group stratigraphy in northeast Umatilla County, Oregon (thesis abs.)	5:126
Langer, V.W., Geology & petrologic evolution, silic to intermed. volcanic rocks under Steens Mountain Basalt (thesis abs.)	6:147
Madin, I.P., coauthor, Peterson and Madin	3:51
Manchester, S.R., coauthor, McIntosh and others	1:3
Mapping: History of quadrangle names can be a puzzle	3:78
McIntosh, W.C., Manchester, S.R., and Meyer, H.W., Age of the plant-bearing tuffs of the John Day Formation at Fossil, Oregon, based upon ⁴⁰ Ar/ ³⁹ Ar single-crystal dating	1:3
Meteorites and fireballs: December [1996] fireball (Pugh)	2:41
Meyer, H.W., coauthor, McIntosh and others	1:3
Mined land reclamation: MLR honors outstanding reclamation	4:95
—Schnitzer named national Outstanding Reclamationist	6:145
—Topsoil in reclamation (Schnitzer)	4:92
Mitchell, C.E., Vertical component of present-day deformation in the western Pacific Northwest (thesis abs.)	3:77
Mount Hood: Danger of collapsing lava domes (Brantley and Scott) ..	4:83
Mount St. Helens: Johnston Ridge Observatory opens	4:99
Myers, E.P., III, Numerical modeling of tsunamis with applications to the Sea of Japan and the Pacific Northwest (thesis abs.)	3:77
National Natural Landmarks Program (Gibbons)	5:123
Newport: Regional Geologist looks at Newport (Priest)	2:43
Nielsen, John: Retires	1:21
Oil & gas exploration & development, 1996 (Wermiel)	2:39
OMSI opens “giant” exhibit [Gobi desert fossils]	2:41
Oregon Boards of Geologist Examiners/Examiners for Engineering and Land Surveying, Guidelines for site-specific seismic hazard reports for essential and hazardous facilities and major and special-occupancy structures in Oregon	1:6
Oregon-Idaho graben (Ferns)	1:9
Oscarson, R.L., coauthor, Bargar and Oscarson	5:107
Paleontology: Age of John Day Fm. flora (McIntosh and others)	1:3
—OMSI opens “giant” exhibit [Gobi desert fossils]	2:41
Peterson, C.D., coauthor, Hart and Peterson	6:131
Peterson, C.D., and Madin, I.P., Coseismic paleoliquefaction evidence in the central Cascadia margin, USA	3:51
Portland light rail tunnel praised by Engineering Geologists	5:106
Priem, S., “Real-time” earthquake information [system]	5:125
Priest, G.R., Regional Geologist looks at Newport	2:43
—Update on tsunami mapping progress in Oregon	4:97
Publications by DOGAMI, announced:	
GMS-104, Relative earthquake hazard map, Linnton quad	1:8
GMS-106, Geology & mineral resources, Grizzly Peak quad	4:100
OGI-19, Oil & gas potential, Tyee Basin, S. Coast Range	1:8
Special Paper 28, AEG earthquake symposium proceedings	6:146
O-95-06, Tsunami hazard map, Siletz Bay area, Lincoln Co.	2:46
O-96-03, Economic models forecasting aggregate demand	2:46
O-97-01, Mist Gas Field map, 1997 edition	2:46
O-97-02, Geologic map, Malheur Butte quad., Malheur Co.	2:46
O-97-03, Prelim. geol. map, SW part Medford 30x60 quad	3:74
O-97-05, Coastal subsidence from great earthquakes	3:74
O-97-31, Tsunami hazard map, Winchester Bay quad. (update) ..	4:100
O-97-32, Tsunami hazard map, Reedsport quad. (update)	4:100
Publications by others, announced and reviewed:	
Assessing earthquake hazards and reducing risks in the Pacific Northwest, v. 1 (USGS Prof. Paper 1560)	1:21
Bin rock and dump rock (rev. by Vogt)	2:42
Books at Nature of the Northwest Information Center (Haines) ..	2:45
Fire, faults, and floods: A road and trail guide exploring the origins of the Columbia River basin (rev. by Vogt)	3:78
Geol. hazard slide sets from National Geophysical Data Center ..	3:75
Gold mining in Oregon (Haines)	2:45
Hiking Oregon's geology	review 1:21; (Haines) 2:45
Introduction to earthquake retrofitting (Haines)	2:45
Northwest exposures—A geologic story (Haines)	2:45
Pugh, R.N., December fireball lights up NW skies	2:41
Rattlesnake Ash-Flow Tuff: Magnetic characteristics (Stimac)	5:126
—Volcanology and petrology (Streck)	6:148
Schnitzer, E.F., Named national Outstanding Reclamationist	6:145
—Topsoil and its role in successful reclamation	4:95
Scott, W.E., coauthor, Brantley and Scott	4:83
Steens Mountain Basalt: Evolution of rocks underneath (Langer) ..	6:147
Stimac, J.P., Rock magnetic and paleomagnetic characteristics of the late Miocene Rattlesnake and Devine Canyon Ash-Flow Tuffs, eastern Oregon (thesis abs.)	5:126
Streck, M.J., Volcanology and petrology of the Rattlesnake Ash-Flow Tuff, eastern Oregon (thesis abs.)	6:148
Tsunamis: Center for Tsunami Inundation Mapping Effort, Newport. ...	3:50
—Coastal communities install interpretive signs	4:82
—Entertaining mug teaches about tsunami hazard	6:146
—Evidence of tsunami inundation at Seaside (Fiedorowicz)	6:149
—Hazard signs adopted by West Coast states	4:96
—Numeric modeling (Myers)	3:77
—Rare photos on the Internet	5:125
—Update on tsunami mapping progress in Oregon (Priest)	4:97
Vogt, B.F., Bin rock and dump rock (review)	2:42
—Fire, faults, and floods: A road and trail guide (review)	3:78
—Retires	4:102
Wang, Y., Preparing for earthquakes in Oregon	2:27
Wang, Z., Joins DOGAMI staff	6:146
Wermiel, D.E., Oil & gas exploration & development, 1996	2:39
Yaquina Head Natural Area: Interpretive center opened	4:98
Zeolites: In the Cascade Range (Bargar & Oscarson)	5:107

AVAILABLE PUBLICATIONS **OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES**

GEOLOGICAL MAP SERIES

Price ☒

Price ☒

GMS-5 Powers 15' quadrangle, Coos and Curry Counties. 1971	4.00
GMS-6 Part of Snake River canyon. 1974	8.00
GMS-8 Compl. Bouguer gravity anomaly map, central Cascades. 1978	4.00
GMS-9 Total-field aeromagnetic anomaly map, central Cascades. 1978	4.00
GMS-10 Low- to intermediate-temp. thermal springs & wells. 1978	4.00
GMS-12 Oregon part, Mineral 15' quadrangle, Baker County. 1978	4.00
GMS-13 Huntington/Olds Ferry 15' quads., Baker/Malheur Co. 1979	4.00
GMS-14 Index to published geol. mapping, 1898-1979. 1981	8.00
GMS-15 Gravity anomaly maps, north Cascades. 1981	4.00
GMS-16 Gravity anomaly maps, south Cascades. 1981	4.00
GMS-17 Total-field aeromagnetic anomaly map, south Cascades. 1981	4.00
GMS-18 Rickreall, Salem West, Monmouth, Sidney 7 1/2' quads., Marion and Polk Counties. 1981	6.00
GMS-19 Bourne 7 1/2' quadrangle, Baker County. 1982	6.00
GMS-20 S 1/2 Burns 15' quadrangle, Harney County. 1982	6.00
GMS-21 Vale East 7 1/2' quadrangle, Malheur County. 1982	6.00
GMS-22 Mount Ireland 7 1/2' quadrangle, Baker/Grant Counties. 1982	6.00
GMS-23 Sheridan 7 1/2' quadrangle, Polk and Yamhill Counties. 1982	6.00
GMS-24 Grand Ronde 7 1/2' quadrangle, Polk/Yamhill Counties. 1982	6.00
GMS-25 Granite 7 1/2' quadrangle, Grant County. 1982	6.00
GMS-26 Residual gravity, north/central/south Cascades. 1982	6.00
GMS-27 The Dalles 1° x 2° quadrangle. 1982	7.00
GMS-28 Greenhorn 7 1/2' quadrangle, Baker/Grant Counties. 1983	6.00
GMS-29 NE 1/4 Bates 15' quadrangle, Baker/Grant Counties. 1983	6.00
GMS-30 SE 1/4 Pearsoll Peak 15' quad., Curry/Josephine Counties. 1984	7.00
GMS-31 NW 1/4 Bates 15' quadrangle, Grant County. 1984	6.00
GMS-32 Wilhoit 7 1/2' quadrangle, Clackamas/Marion Counties. 1984	5.00
GMS-33 Scotts Mills 7 1/2' quad., Clackamas/Marion Counties. 1984	5.00
GMS-34 Stayton NE 7 1/2' quadrangle, Marion County. 1984	5.00
GMS-35 SW 1/4 Bates 15' quadrangle, Grant County. 1984	6.00
GMS-36 Mineral resources of Oregon. 1984	9.00
GMS-37 Mineral resources, offshore Oregon. 1985	7.00
GMS-38 NW 1/4 Cave Junction 15' quadrangle, Josephine County. 1986	7.00
GMS-39 Bibliography and index: ocean floor, continental margin. 1986	6.00
GMS-40 Total-field aeromagnetic anomaly maps, north Cascades. 1985	5.00
GMS-41 Elkhorn Peak 7 1/2' quadrangle, Baker County. 1987	7.00
GMS-42 Ocean floor off Oregon & adjacent continental margin. 1986	9.00
GMS-43 Eagle Butte/Gateway 7 1/2' quads., Jefferson/Wasco Co. 1987	5.00
as set with GMS-44 and GMS-45	11.00
GMS-44 Seekseequa Junc./Metolius B. 7 1/2' quads., Jefferson Co. 1987	5.00
as set with GMS-43 and GMS-45	11.00
GMS-45 Madras West/East 7 1/2' quads., Jefferson County. 1987	5.00
as set with GMS-43 and GMS-44	11.00
GMS-46 Breitenbush River area, Linn and Marion Counties. 1987	7.00
GMS-47 Crescent Mountain area, Linn County. 1987	7.00
GMS-48 McKenzie Bridge 15' quadrangle, Lane County. 1988	9.00
GMS-49 Map of Oregon seismicity, 1841-1986. 1987	4.00
GMS-50 Drake Crossing 7 1/2' quadrangle, Marion County. 1986	5.00
GMS-51 Elk Prairie 7 1/2' quadrangle, Marion/Clackamas Counties 1986	5.00
GMS-52 Shady Cove 7 1/2' quadrangle, Jackson County. 1992	6.00
GMS-53 Owyhee Ridge 7 1/2' quadrangle, Malheur County. 1988	5.00
GMS-54 Graveyard Point 7 1/2' quad., Malheur/Owyhee Counties. 1988	5.00
GMS-55 Owyhee Dam 7 1/2' quadrangle, Malheur County. 1989	5.00
GMS-56 Adrian 7 1/2' quadrangle, Malheur County. 1989	5.00
GMS-57 Grassy Mountain 7 1/2' quadrangle, Malheur County. 1989	5.00
GMS-58 Double Mountain 7 1/2' quadrangle, Malheur County. 1989	5.00
GMS-59 Lake Oswego 7 1/2' quad., Clackam./Multn./Wash. Co. 1989	7.00
GMS-60* Damascus 7 1/2' quad., Clackam./Multn. Counties. 1994	8.00
GMS-61 Mitchell Butte 7 1/2' quadrangle, Malheur County. 1990	5.00
GMS-62* The Elbow 7 1/2' quadrangle, Malheur County. 1993	8.00
GMS-63 Vines Hill 7 1/2' quadrangle, Malheur County. 1991	5.00
GMS-64 Sheaville 7 1/2' quadrangle, Malheur County. 1990	5.00
GMS-65 Mahogany Gap 7 1/2' quadrangle, Malheur County. 1990	5.00
GMS-66 Jonesboro 7 1/2' quadrangle, Malheur County. 1992	6.00
GMS-67 South Mountain 7 1/2' quadrangle, Malheur County. 1990	6.00
GMS-68 Reston 7 1/2' quadrangle, Douglas County. 1990	6.00
GMS-69 Harper 7 1/2' quadrangle, Malheur County. 1992	5.00
GMS-70 Boswell Mountain 7 1/2' quadrangle, Jackson County. 1992	7.00
GMS-71 Westfall 7 1/2' quadrangle, Malheur County. 1992	5.00
GMS-72 Little Valley 7 1/2' quadrangle, Malheur County. 1992	5.00
GMS-73* Cleveland Ridge 7 1/2' quadrangle, Jackson County. 1993	5.00
GMS-74 Namorf 7 1/2' quadrangle, Malheur County. 1992	5.00
GMS-75 Portland 7 1/2' quadrangle, Multn., Wash., Clark Counties. 1991	7.00

GMS-76 Camas Valley 7 1/2' quadrangle, Douglas/Coos Counties. 1993	6.00
GMS-77 Vale 30x60' quadrangle, Malheur County. 1993	10.00
GMS-78 Mahogany Mountain 30x60' quadrangle, Malheur Co. 1993	10.00
GMS-79* EQ hazards, Portland 7 1/2' quad., Multn. Co. 1993	20.00
GMS-80* McLeod 7 1/2' quadrangle, Jackson County. 1993	5.00
GMS-81* Tumalo Dam 7 1/2' quadrangle, Deschutes County. 1994	6.00
GMS-82* Limber Jim Creek 7 1/2' quadrangle, Union County. 1994	5.00
GMS-83* Kenyon Mountain 7 1/2' quadrangle, Douglas/Coos Co. 1994	6.00
GMS-84* Remote 7 1/2' quadrangle, Coos County. 1994	6.00
GMS-85* Mount Gurney 7 1/2' quadrangle, Douglas/Coos Co. 1994	6.00
GMS-86* Tenmile 7 1/2' quadrangle, Douglas County. 1994	6.00
GMS-87* Three Creek Butte 7 1/2' quadrangle, Deschutes County. 1996	6.00
GMS-88* Lakecreek 7 1/2' quadrangle, Jackson County. 1995	8.00
GMS-89* EQ hazards, Mt. Tabor 7 1/2' quad., Multn. Co. 1995	10.00
GMS-90* EQ hazards, Beaverton 7 1/2' quad., Wash. Co. 1995	10.00
GMS-91* EQ hazards, Lake Oswego 7 1/2' quad., Tri-county. 1995	10.00
GMS-92* EQ hazards, Gladstone 7 1/2' quad., Clack./Multn. Co. 1995	10.00
GMS-93* EQ hazards, Siletz Bay area, Lincoln County. 1995	20.00
GMS-94* Charleston 7 1/2' quadrangle, Coos County. 1995	8.00
GMS-97* Coos Bay 7 1/2' quadrangle, Coos County. 1995	6.00
GMS-98* Dora and Sitkum 7 1/2' quadrangles, Coos County. 1995	6.00
GMS-99* Tsunami hazard map, Siletz Bay area, Lincoln County. 1996	6.00
GMS-100* EQ hazard maps for Oregon. 1996	8.00
GMS-101* Steelhead Falls 7 1/2' quad., Deschutes/Jefferson Co. 1996	7.00
GMS-104* EQ hazards, Linnton 7 1/2' quad., Multn./Wash. Co. 1996	10.00
GMS-105* EQ hazards, Salem East/West 7 1/2' quads. 1996	12.00
GMS-106* Grizzly Peak 7 1/2' quadrangle, Jackson County. 1997	6.00

SPECIAL PAPERS

2 Field geology, SW Broken Top quadrangle. 1978	5.00
3 Rock material resources, Clackam./Columb./Multn./Wash. Co. 1978	8.00
4 Heat flow of Oregon. 1978	4.00
5 Analysis and forecasts of demand for rock materials. 1979	4.00
6 Geology of the La Grande area. 1980	6.00
7 Pluvial Fort Rock Lake, Lake County. 1979	5.00
8 Geology and geochemistry of the Mount Hood volcano. 1980	4.00
9 Geology of the Breitenbush Hot Springs quadrangle. 1980	5.00
10 Tectonic rotation of the Oregon Western Cascades. 1980	4.00
11 Bibliography/index of theses and dissertations, 1899-1982. 1982	7.00
12 Geologic linears, northern part of Cascade Range, Oregon. 1980	4.00
13 Faults and lineaments of southern Cascades, Oregon. 1981	5.00
14 Geology and geothermal resources, Mount Hood area. 1982	8.00
15 Geology and geothermal resources, central Cascades. 1983	13.00
16 Index to <i>Ore Bin</i> (1939-78) and <i>Oregon Geology</i> (1979-82). 1983	5.00
17 Bibliography of Oregon paleontology, 1792-1983. 1984	7.00
18 Investigations of talc in Oregon. 1988	8.00
19 Limestone deposits in Oregon. 1989	9.00
20 Bentonite in Oregon. 1989	7.00
21 Field geology, NW 1/4 Broken Top 15' quad., Deschutes Co. 1987	6.00
22 Silica in Oregon. 1990	8.00
23 Forum on Geol. of Industrial Minerals, 25th, 1989, Proceeds. 1990	10.00
24 Index to Forums on Geol. of Industrial Minerals, 1965-1989. 1990	7.00
25 Pumice in Oregon. 1992	9.00
26 On-/offshore cross section, N. Coast Range to cont. slope. 1992	11.00
27 Econ. analysis, construction aggregate markets and forecast. 1995	15.00
28 AEG meeting, earthquake symposium proceedings. 1997	12.00

OIL AND GAS INVESTIGATIONS

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

OREGON GEOLOGY

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

Periodicals postage
paid at Portland, OR

AVAILABLE DEPARTMENT PUBLICATIONS (continued)

BULLETINS

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

MISCELLANEOUS PAPERS

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

SHORT PAPERS

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

MISCELLANEOUS PUBLICATIONS

Hiking Oregon's geology, E.M. Bishop and J.E. Allen, 1996	16.95
Assessing earthquake hazards in the Pac. NW (USGS Prof. Paper 1560)	25.00
Geology of Oregon, 4th ed., E.L. and W.N. Orr and E.M. Baldwin, 1991, published by Kendall/Hunt (add \$3.00 for mailing)	33.95
Geologic map of Oregon, G.W. Walker and N.S. MacLeod, 1991, published by USGS (add \$3.00 for mailing)	11.50
Geology of the Pacific Northwest, E.L. and W.N. Orr, 1996, published by McGraw-Hill (add \$3.00 for mailing)	43.00
Geological highway map, Pacific Northwest region, Oregon, Washington, and part of Idaho (published by AAPG). 1973	8.00
Oregon Landsat mosaic map (published by ERSAL, OSU). 1983	11.00
Mist Gas Field map, rev. 1997, incl. 1993-96 production (OFR O-97-1)	8.00
Digital form of map (CAD formats .DGN, .DWG, .DXF), 3 1/2-in. disk	25.00
Mist Gas Field production figures 1979 through 1992 (OFR O-94-6)	5.00
Northwest Oregon, Correlation Sec. 24. Bruer & others, 1984 (AAPG)	6.00
Oregon rocks and minerals, a description. 1988 (OFR O-88-6)	6.00
Mineral information layer for Oregon by county (MILOC), 1993 update (OFR O-93-8), 2 diskettes (5 1/4-in., high-density, MS-DOS)	25.00
Directory of mineral producers, 1993 update, 56 p. (OFR O-93-9)	8.00
Geothermal resources of Oregon (published by NOAA). 1982	4.00
Mining claims (State laws governing quartz and placer claims)	Free
Back issues of <i>Oregon Geology</i>	3.00

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

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

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

ORDER AND RENEWAL FORM

Check desired publications in list above or indicate how many copies and enter total amount below. Send order to The Nature of the Northwest Information Center, Suite 177, 800 NE Oregon Street, Portland, OR 97232-2162, or to FAX (503) 731-4066. If you wish to order by phone, have your credit card ready and call (503) 872-2750. Payment must accompany orders of less than \$50. Payment in U.S. dollars only. Publications are sent postpaid. All sales are final. Subscription price for *Oregon Geology*: \$10 for 1 year, \$22 for 3 years.

Renewal ___ / new subscription ___ to *Oregon Geology*: 1 yr (\$10) or 3 yrs (\$22) \$ _____
Total amount for publications marked above: \$ _____
Total payment enclosed or to be charged to credit card as indicated below: \$ _____

Name/Address/City/State/Zip _____

Please charge to Visa ___ / Mastercard ___, account number: _____

Expiration date: _____ Cardholder's signature _____