OREGON GEOLOGY

Oregon Department of Geology and Mineral Industries
Volume 63, Number 1, Winter 2001

IN THIS ISSUE:

The HAZUS-RVS form: A new HAZUS-compatible rapid visual screening form for buildings

Where the Rockies meet the Columbia Plateau: Geologic field trip from the Walla Walla Valley to the Wallowa Mountains, Oregon

DOGAMI PUBLICATIONS

Publications are available from: Nature of the Northwest, 800 NE Oregon St. #5, Portland, OR 97232, info@naturenw.org or www.naturenw.org, (503) 872-2750; or from the DOGAMI field offices in Baker City, 1510 Campbell Street, (541) 523-3133, and Grants Pass, 5375 Monument Drive, (541) 476-2496. See also the gray pages at the center of this issue.

Released November 2, 2000:
Relative earthquake hazard map of the Klamath Falls metropolitan area, Oregon, by G.L. Black, Z. Wang, T.J. Wiley, and G.R. Priest. Interpretive Map Series IMS-19; 17 p. text, 1 CD-ROM with map and text data in easily accessible digital form; map scales 1:24,000 for composite relative hazard map, 1:96,000 for three individual hazard maps. $10.

The relative hazard map assigns each map area to one of four relative hazard zones, ranked from the highest hazard (Zone A) to the lowest hazard (Zone D). An advisory committee composed of representatives from local business and the general public provided input and direction for the project.

The assessment of soil behavior (and hence the relative earthquake hazard) is based on geologic mapping and specialized geophysical and geotechnical measurements. These measurements are combined with state-of-practice geotechnical analysis and Geographic Information System (GIS) methodology and tools to produce the final maps.

Released December 8, 2000:
Guidelines for engineering geologic reports and site-specific seismic hazard reports, developed and adopted by the Oregon Board of Geologist Examiners. Open File Report O–00–04, 8 p., $5.

As a service to the technical community, DOGAMI has collaborated with the Oregon Board of Geologist Examiners in publishing these two sets of guidelines.

They are intended to be used as checklists for reports in projects of varying size and complexity. The essential aspects of reports are included, but every project will need a unique set of information. The guidelines for site-specific seismic hazard reports are meant for 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. They 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. ☐

OREGON GEOLOGY

(ISSN 0164-3304)

VOLUME 63, NUMBER 1 **WINTER 2001**

Published quarterly in Winter, Spring, Summer, and Fall by the Oregon Department of Geology and Mineral Industries. (Volumes 1 through 40 were entitled *The Ore Bin*.)

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

Baker City Field Office: 1510 Campbell Street, Baker City 97814, phone (541) 523-3133, FAX (541) 523-5992.
Mark L. Ferns, Regional Geologist.

Coastal Field Office: 313 SW Second Street, Suite D, Newport 97365, phone (541) 574-6642, FAX (541) 265-5241.
George R. Priest, Coastal Team Leader.

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

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

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

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

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

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

Cover photo

Ice Lake and Craig Mountain, just south of Wallowa Lake in the Wallowa Mountains, Oregon's "Switzerland" and geologically one of the most fascinating areas in the state. An August snowfall has blanketed the tarn and horn carved from the Mesozoic granitic rocks of the Wallowa batholith.

In the article beginning on page 13, Robert Carson describes a six-part geologic field trip into the Wallowa Mountains.

The HAZUS-RVS form: A new HAZUS-compatible rapid visual screening form for buildings

by Christine Theodoropoulos, University of Oregon, Eugene, OR 97403-1206, and Yumei Wang, Oregon Department of Geology and Mineral Industries, Portland, OR 97232-2162

ABSTRACT

This paper presents a HAZUS-compatible version of the data collection forms in Federal Emergency Management Agency (FEMA) Publication 154, *Rapid Visual Screening of Buildings for Potential Seismic Hazards*. This adaptation of FEMA 154 was designed to facilitate building-inventory data collection in a sidewalk survey of 955 buildings within Klamath County for input into HAZUS risk studies. The new HAZUS-RVS form, which is double sided, has been designed to complement FEMA 154 and can be photocopied for field use. It retains most of the information gathered in the field when FEMA 154 is used and deletes information that is not a necessary part of the field-observation phase of the screening process. In addition, information required by HAZUS, the FEMA software for estimating earthquake losses, has been included. The collected data can be used in comparison studies with existing FEMA 154 data and include additional seismic vulnerability parameters.

INTRODUCTION

This paper provides a modified building-data collection form taken from Federal Emergency Management Agency (FEMA) Publication 154, *Rapid Visual Screening of Buildings for Potential Seismic Hazards* (ATC, 1988). The new form, referred to as the HAZUS-RVS (i.e., rapid visual screening) form, is intended to complement FEMA Publication 154. The paper provides a background on the purpose of collecting building-specific information for use in earthquake risk assessments, describes studies that were conducted during the development of this new HAZUS-RVS form, reviews the contents of the form, provides guidelines that augment the HAZUS-RVS form, and compares a completed FEMA 154 form to a completed HAZUS-RVS form.

The new HAZUS-RVS form, which is double sided and can be photocopied for field use, was developed to facilitate building-inventory data collection for input into HAZUS risk studies. The form retains most of the information gathered in the field on the basis of FEMA 154 and deletes information that is not a necessary part of the field-observation phase of the screening process. In addition, information required by the software HAZUS, the FEMA tool for estimating earthquake losses, has been included (National Institute of Building Sciences, 1997a,b). This adaptation of FEMA 154 was designed to facilitate building-inventory data collection in the State of Oregon for input into HAZUS risk studies as well as for inventory use by others. The data on the new form can be used in comparison studies with FEMA 154 data and include several additional seismic-vulnerability parameters that may be used for mitigation and planning purposes.

BACKGROUND

Why building-data collection is important

Building damage and failure cause the majority of economic and social losses resulting from earthquakes. This is because buildings are the predominant feature of our civilization's environment. In addition to providing for the basic needs of human habitation, buildings house the social institutions and businesses that constitute a functioning society. Some buildings, however, are particularly vulnerable in earthquakes. In order to prepare for future earthquakes and understand how Oregon's building stock is likely to contribute to future earthquake losses, it is necessary to estimate the seismic vulnerability of existing buildings.

HAZUS and its use in Oregon

In 1998, the Oregon Department of Geology and Mineral Industries (DOGAMI) completed preliminary estimates of earthquake-related damage and loss for the State of Oregon. The estimates were obtained with HAZUS97, an earthquake loss estimation software developed by the National Institute of Buildings Sciences (NIBS) and produced by FEMA for use by public agencies (National Institute of Building Sciences, 1997a,b). Earthquake loss estimation tools like HAZUS combine information about geologic hazards with information about buildings and other structures to predict the extent of damage likely to occur in seismic regions. The predicted damage to buildings forms the basis for estimates of numbers of casualties and losses of shelter, of emergency services, and of economic resources.

The results of the preliminary Oregon statewide study indicate that buildings pose serious levels not only of economic risk but of social losses as well. Estimates of total direct economic losses to buildings range from $12 billion for a magnitude 8.5 Cascadia (subduction zone) earthquake up to $32 billion for ground shaking levels assumed by Oregon's "Building Code" (based on a probabilistic earthquake event with a 500-yr return interval). The damage to these buildings was grouped into three state-of-practice damage categories defined by the Applied Technology Council (ATC) (ATC, 1989). As shown in Figure 1 for the Cascadia model, an estimated 885,000 buildings are either not damaged or green-tagged (as defined by ATC), which indicates that a post-earthquake inspection concluded the buildings may be damaged but safe to enter. An estimated 55,000 are yellow-tagged, which allows limited entry but requires permission to enter. An estimated 37,000 are red-tagged, i.e., unsafe to enter (Wang, 1998; Wang and Clark, 1999).

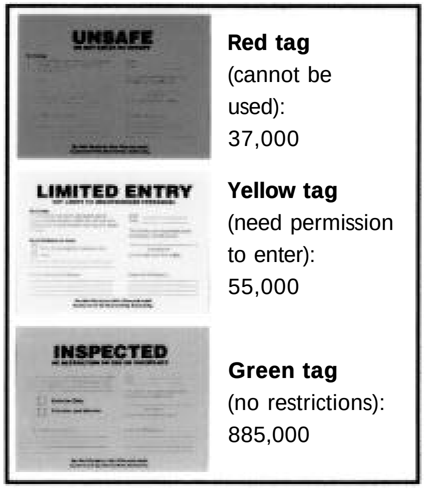


Figure 1. Building damage for Cascadia subduction zone model.

Social losses for the Cascadia and Building Code models include, respectively, about 12,700/29,600 casualties. In addition, estimates include, respectively, about 17,300/47,400 displaced households and 12,400/32,700 short-term shelters needed (Wang, 1998, 1999; Wang and Clark, 1999).

The need for more accurate building data

The above-mentioned estimates of state losses were based on the default building data in HAZUS97. Due to the differences between the default building characteristics in HAZUS and the actual building stock characteristics, this preliminary study underestimates potential damage to buildings and the economic and social losses derived from building performance.

Table 1 illustrates the differences between default values and observed regional construction practices by contrasting data from the default building inventory for government buildings generated by HAZUS97 and the inventory of government buildings from a survey of buildings in the early 1990s in Portland.

Approximately one-fifth of Portland's government buildings included in Table 1 are constructed of wood, considered the safest structural material due to its light weight and inherent flexibility; the remaining four fifths are constructed of other materials. Variations in dates of construction and structural systems affect HAZUS loss estimates, since different damage states are projected for different structural systems of different ages. HAZUS divides building stocks into three age categories; those constructed prior to 1950, between 1950 and 1970, and after 1970. HAZUS also divides building heights into low-, mid-, and high-rise categories. The default values generated by HAZUS97 for the preliminary Oregon loss estimates were based on the assumption that all buildings were low-rise and constructed after 1970. Therefore, the statewide preliminary loss estimate did not include the higher levels of damage expected for Oregon's older buildings. These losses can be particularly significant for communities with unreinforced masonry (URM) buildings, a structural type prone to severe damage and collapse in moderate-level earthquakes. To obtain more realistic projections, future studies for Oregon should be based on a more accurate building inventory informed by actual building data.

Developing a HAZUS-compatible building-data collection form

The HAZUS-RVS form was developed to improve the HAZUS risk evaluation being conducted in the Klamath County Pilot Study (described below). A combination of examining the Portland database and identifying some of the difficulties of using it to generate HAZUS inputs guided the development of the HAZUS building data collection form (Theodoropoulos and Perry, 2000).

The quality of building-inventory data is one of the most critical factors affecting loss estimates, yet comprehensive building inventories containing earthquake vulnerability information about buildings are rarely available. Although many of Oregon's government agencies compile inventory data such as building age, size, value, and others, these inventories do not include many of the parameters

Table 1. Percentages of floor area of low-rise, nonessential government buildings (GOV1) by structural material: Portland survey data versus HAZUS defaults (National Institute of Building Sciences, 1997a,b; Perry and Theodoropoulos, 2000)

	Wood	Steel	Concrete	Precast concrete	Reinforced masonry	Unreinforced masonry
Built before 1950						
Portland Survey	23	8	47	3	11	8
HAZUS default	9	28	46	0	6	11
Built 1950 to 1970						
Portland Survey	20	19	32	9	18	1
HAZUS default	21	13	31	6	29	0
Built after 1970						
Portland Survey	20	22	18	24	17	0
HAZUS default	8	29	34	4	25	0

known to contribute to potential earthquake hazards. An ideal building inventory would include information about the location, size, use, number of occupants, configuration, structural type, and nonstructural earthquake hazards for every building in the study region.

Much of this information can be estimated in the field by trained screeners using FEMA 154, *Rapid Visual Screening of Buildings for Potential Seismic Hazards*, also known as ATC–21 (or Applied Technology Council Project 21) (ATC, 1988). This quick and relatively affordable sidewalk survey can be conducted by building design professionals and intermediate to advanced university students enrolled in engineering and architecture programs. The FEMA 154 methodology was designed to be used for preliminary identification of potential seismic hazards and cannot be relied upon to produce accurate structural assessments for individual buildings. However, when used to generate data for large numbers of buildings, the method is sufficiently accurate to generate data for loss estimation purposes.

Although it is possible to use FEMA 154 data to prepare building-inventory information for input into HAZUS software, FEMA 154 data differ from HAZUS requirements in three respects:

Occupancy: The 35 occupancy classes used by HAZUS require more detailed information than the eight broad occupancy types asked for by FEMA 154. Although FEMA 154 provides a space for screeners to indicate building use, an examination of databases including this feature shows that screeners’ remarks in this field are frequently inconsistent and incomplete, making only a small portion of these databases convertible to HAZUS occupancy format. Translation from FEMA 154 occupancies to general HAZUS occupancy categories is possible, but this will not take full advantage of the HAZUS modeling method (Theodoropoulos and Perry, 2000).

Table 2 illustrates the differences between the FEMA 154 and HAZUS occupancies and illustrates some of the difficulties that can occur in translation when the individual items under general HAZUS groups fall into different FEMA 154 occupancies. The categories of government, public assembly, and emergency services are most problematic because they do not consistently map to general HAZUS classifications.

Structure type: Although most of the structural type designations used by HAZUS match those in FEMA 154, HAZUS structural types include a few variations. FEMA 154 has only one designation for wood structures, whereas HAZUS distinguishes between light wood frame buildings less that 5,000 ft^2 and larger commercial and industrial wood frame buildings. HAZUS also has two categories for reinforced-masonry bearing-wall systems that are more specific about diaphragm materials. In addition, HAZUS identifies mobile homes as a separate structural type.

Number of persons: Studies of a modified version of FEMA 154 data collected for the city of Portland show that screener estimates of numbers of occupants using the “No. Persons” options tend to generate unrealistically high numbers of occupants for a collection of buildings (McCormack and Rad, 1997). A more reliable method of estimating the numbers of people in buildings likely to be affected by earthquakes is needed.

DEVELOPMENTAL STUDIES

Three building inventories were conducted in Oregon with the express purpose for use in seismic vulnerability assessments and loss estimations. Two of these surveys, one in Portland and the other in Eugene and Springfield, incorporated FEMA 154 forms for field data collection. The third survey, in Klamath County, was used as a pilot project for the HAZUS-RVS building data collection form.

Table 2. Occupancy translations from FEMA 154 to HAZUS classification system

FEMA 154 occupancies	HAZUS occupancies
Residential	RES1: Single family house
	RES2: Mobile home
	RES3: Multi-family
	RES4: Hotel/motel
	RES5: Dormitory
	RES6: Nursing home
Commercial	COM1: Retail store
	COM2: Wholesale/warehouse
	COM3: Personal and repair services
	COM5: Bank
	COM8: Entertainment/restaurant
	COM10: Parking garage
Industrial	IND1: Heavy industry
	IND2: Light industry
	IND3: Food/drug/chem. factory
	IND4: Metal/mineral processing
	IND5: High tech factory
	IND6: Construction
Office	COM4: Prof. service office
	COM7: Medical offices
Government	GOV1: Govt. office
Emergency services	COM6: Hospital
	GOV2/EFFS Fire station
	GOV2/EFPS Police station
	GOV2/EFEO Emergency operations
School	EDU1/EFS1 Primary/high school
	EDU2/EFS2 College/University
Public assembly	COM9: Theater
	REL1: Church
Historic building	No equivalent occupancy
No equivalent occupancy	AGR1: Agricultural uses

Lessons learned from the Portland survey

In the early 1990s, FEMA 154 surveys on almost 50,000 buildings were conducted by the City of Portland, the Metro regional government, and Portland State University. The result is the only complete data set of its kind for a metropolitan area in the United States. This exceptional achievement that offers a wealth of information about the seismic vulnerability of a U.S. city represents an important contribution to hazard mitigation research. The Portland building survey includes FEMA 154 data for all buildings within the greater Portland metropolitan plan boundary, with the exception of single-family and duplex residences.

As discussed earlier, the greatest translation problem for HAZUS risk studies lies with the occupancy classes that are much more precisely defined in HAZUS than in FEMA 154. This is important because HAZUS generates tables describing building stock attributes that are organized by occupancy type. Although it is possible to identify some of the HAZUS occupancies in the Portland database from screener comments and building identifiers, the entries in these data columns can be hard to decipher accurately. It is not possible to fully convert the Portland database into a HAZUS format without conducting additional area surveys or making inferences with limited accuracy.

The Klamath County pilot project

In the spring of 1999, faculty and students in the Department of Civil Engineering and Land Surveying at the Oregon Institute of Technology (OIT) completed a sidewalk survey of 955 buildings within Klamath County. DOGAMI sponsored this survey for the purpose of obtaining data about the buildings with highest risk and highest importance in the region for input into HAZUS. Because the purpose of the data collection project was specifically geared toward developing HAZUS input, student screeners recorded field observations on a draft version of the HAZUS-RVS form developed at the University of Oregon and DOGAMI. The resulting database can serve as a model for future field data collection projects. The new form succeeded in facilitating data entry into HAZUS, while it remained comparable with FEMA 154 surveys. Student screeners reported that the form was easy to use, and data entry into HAZUS format from the forms could be completed efficiently. An examination of the OIT data shows a much higher level of consistency and completeness than that found in data compiled for Portland, where FEMA 154 was used. This is due in part to the smaller scale and shorter time frame of the Klamath Falls project. However, the simplification of the sidewalk screening process made possible by the elimination of all FEMA 154 items not directly observable on site may also be a factor.

Results from FEMA field tests

A second test of the new HAZUS-RVS form was conducted at the FEMA-sponsored 1999 National All-Hazards Mitigation Workshop, held in Mount Weather, Virginia. Kenneth Taylor, State Hazard Mitigation Officer and Earthquake Program Manager of the North Carolina Division of Emergency Management led 16 persons in a short course that utilized both the new HAZUS-RVS form and the original FEMA 154 form on four structures. Taylor reported that the participants found the HAZUS-RVS form to be more user friendly than the original form. In addition, the information on the HAZUS-RVS form is more easily integrated into HAZUS than the original form. Following this short course and a review, Taylor recommended that the authors incorporate two additional fields: geo code and site elevation. These new fields were added and are described in the following section.

NEW HAZUS-RVS FORM

Like FEMA 154, this HAZUS-compatible screening procedure can be used to collect information about buildings that are potentially hazardous and may contribute to damage and losses in an earthquake. The HAZUS-RVS form uses the same nontechnical approach found in FEMA 154 that enables trained building design professionals and students to conduct surveys of individual buildings from the sidewalk. The primary purpose of the HAZUS-RVS form is to gather pertinent information about buildings as quickly and accurately as possible. It assists with the evaluation of ordinary residential, commercial, and institutional buildings and is not recommended for structures that are part of military installations, airports, utilities, transportation, communications, bridges, and other infrastructure building components. It is not a substitute for professional evaluations but can provide useful preliminary information about the overall picture of which buildings may be at risk. The data gathered can also be used for loss estimation purposes and are compatible with HAZUS.

The HAZUS-RVS form was created to simplify the process of transferring field information from screening forms into databases in HAZUS format. This eliminates problems caused by differences between HAZUS and FEMA 154 parameters that are time consuming to adjust and compromise data accuracy. Another goal of this project was to streamline the screening process by eliminating all data from FEMA 154 that cannot be collected from the sidewalk. If needed, this additional information can be provided by experts and added to databases more rapidly and more accurately. Tools such as Geographic Information Systems (GIS) and database software can also eliminate the need to manually correlate geologic and building code information for individual buildings or compute the structural scores used to rank buildings according to how hazardous they may be.

The elimination of information not collected in the field made it possible to develop a form that includes a complete listing of all significant parameters by HAZUS label while maintaining a standard-letter sheet size. Explanations of occupancy and structure types appear on the form, making screening faster and more consistent, because screeners do not have to refer to separate sheets for descriptions of uncommon features. It was also possible to add several building attributes not collected by FEMA 154. On the reverse side, a user reference sheet provides guidelines on how to complete the form. These summary guidelines are not all-inclusive and should be augmented by an effective training program for screeners.

Information included on the HAZUS-RVS form

Occupancy classes and occupant numbers: Thirty-seven occupancy classes are listed using the HAZUS four character designations. Brief written definitions enable screeners to interpret each class.

In the Portland study, the FEMA 154 occupant load options were modified to obtain slightly more accurate maximum occupant numbers; but the total number of persons projected by that study far exceeded census estimates for the city and had to be adjusted for loss estimation purposes (McCormack and Rad, 1997). The occupant load tables published in FEMA 154 direct screeners to identify the maximum occupancy rates for buildings using occupant loads derived from building codes. The HAZUS-RVS form takes a different approach. Rather than having screeners estimate maximum occupant rates, screeners indicate the average number of occupants during peak use hours (i.e., evenings for housing, Saturdays for public libraries). In the event that numbers of occupants are difficult to discern from a sidewalk survey, screeners can indicate whether the occupancy rates are likely to be high, average, or low, compared to other buildings in the same occupancy class. This assessment can then be translated, on the basis of building square footage and typical occupancy patterns, into estimates of the number of people likely to be affected in an earthquake.

Structural types: HAZUS combines structural systems and materials with the number of stories to create 26 structure types. To simplify the screeners' task, the form lists the sixteen parameters that designate structure material and adds brief written explanations. Screeners also record the number of stories, so that the data can be entered according to the HAZUS format.

Building configuration: The same five building configuration parameters used in FEMA 154 are listed to identify building geometries known to contribute to earthquake hazards. They include vertical irregularities such as setbacks or the elimination of columns on lower floors, plan irregularities such as re-entrant corners or uncommonly large areas, torsion conditions such as asymmetrically placed cores, soft stories, and short columns. More detail about the nature of the irregularity cited can be provided using sketches and the comment section.

Additional seismic vulnerability parameters: Screeners using FEMA 154 note the presence of large heavy cladding and nonstructural falling hazards. In addition to these, the HAZUS-RVS form includes the following additional seismic vulnerability parameters:

•*Bias:* This is the term used by HAZUS to denote likely design levels by indicating whether structures are built to code, are superior to code, or inferior to code. In the HAZUS-RVS form, screeners respond to two questions to indicate their assessment of the building design level in relation to the codes in force at the time the building was constructed.

•*Condition:* Building maintenance levels can also impact building performance in earthquakes. In the HAZUS-RVS form screeners are asked to indicate whether the building appears to be in poor condition and at greater risk than other well-maintained buildings of its type and age.

•*Visible structural damage:* The purpose of this parameter is to identify building structures that have sustained observable damage from past earthquakes. It was included after an initial rapid visual screening exercise in downtown Klamath Falls (part of the Klamath County Pilot Study) revealed the presence of several buildings damaged in the 1993 Klamath Falls earthquake. Damaged buildings often have less reserve strength and damping capability than undamaged buildings and are more vulnerable to damage in future earthquakes.

•*Retrofitted building:* Retrofitted buildings are less hazardous than unretrofitted buildings of the same construction type and age. Although screeners may not always be able to detect whether a building has been retrofitted, there are several retrofit construction methods such as the introduction of braced frames or wall-to-floor diaphragm anchors that can be observed.

•*Vacant building:* This parameter has an effect on the person number count and occupancy class designation.

•*Sloped site or fill slope:* Buildings constructed on sloping sites can be more vulnerable than buildings on flat sites. This is also true for buildings constructed on flat surfaces formed by cut-and-fill regrading. The supporting soil can become unstable during an earthquake. In addition, buildings on sloping sides often have vertical irregularities in the zone where the building meets the ground. Although topographic maps can be used to obtain general slope of grade conditions for an area, they are generally available at a regional scale only and cannot be relied upon to provide accurate information about actual slope conditions at the foundations of a particular building. On large lots with variable slope, field observation is needed to determine where the building is sited with respect to topographical features. The HAZUS-RVS form requires screeners to indicate if the building is on a sloped site or fill slope.

- *Geo code:* This describes the coordinates (e.g., latitude and longitude) of the building location. This can be determined with hand-held field GPS units or from topographic or other maps. These data can be integrated into GIS systems and GIS-based software, including HAZUS.
- *Site elevation:* This is the lowest elevation of the site and vertical datum. These data can be used for flood, storm, and tsunami hazards.
- *Building height:* FEMA 154 requires the number of stories. The HAZUS-RVS form requires the number of stories and the building height. Building height is a significant seismic response parameter but cannot be accurately determined from the number of stories due to variations in story height.
- *Building footprint area:* In addition to the total floor area of the building, the HAZUS-RVS form prompts screeners to estimate the size of the building footprint. This gives some indication of the building massing and the size of building diaphragms.
- *Building orientation:* By including a north arrow on plan sketches, screeners can record the orientation of buildings. Although building orientation is not commonly considered in the seismic design of buildings, estimation of damage states for loss estimates, or post-earthquake damage assessments, predictive models based on scenario earthquakes may evaluate the directional effects of anticipated ground motion on buildings in the near future.

Information deleted from the FEMA 154 form

Several items in the FEMA 154 form have been removed from the HAZUS-RVS form. Information that can be obtained in the pre- and post-screening phases of compiling building inventories has been deleted. This includes parameters such as building code benchmark years and Uniform Building Code (UBC) soil types that are likely to apply to all of the buildings in a survey.

In addition, the structural scoring matrix used to rank the relative risk of buildings based on their structural type has been deleted. In addition to the fact that scoring is an activity not directly related to field observation, the authors suspect that the relative risk of different structural types may change as more data about building performance are obtained. Furthermore, regional construction practices, codes, and procedures may affect the relative risks. Lastly, many persons, in particular nontechnical persons, view the scoring system with concern because they believe a building's score could cause potential political and economic repercussions to owners, tenants, and communities. By eliminating the scoring system and focusing on descriptive data only, inventory collection projects may experience less resistance from building owners.

Samples of completed data collection forms

Figures 2 and 3 compare the use of the FEMA 154 form to the HAZUS-RVS form. The building illustrated in the examples is the City of Eugene Public Library.

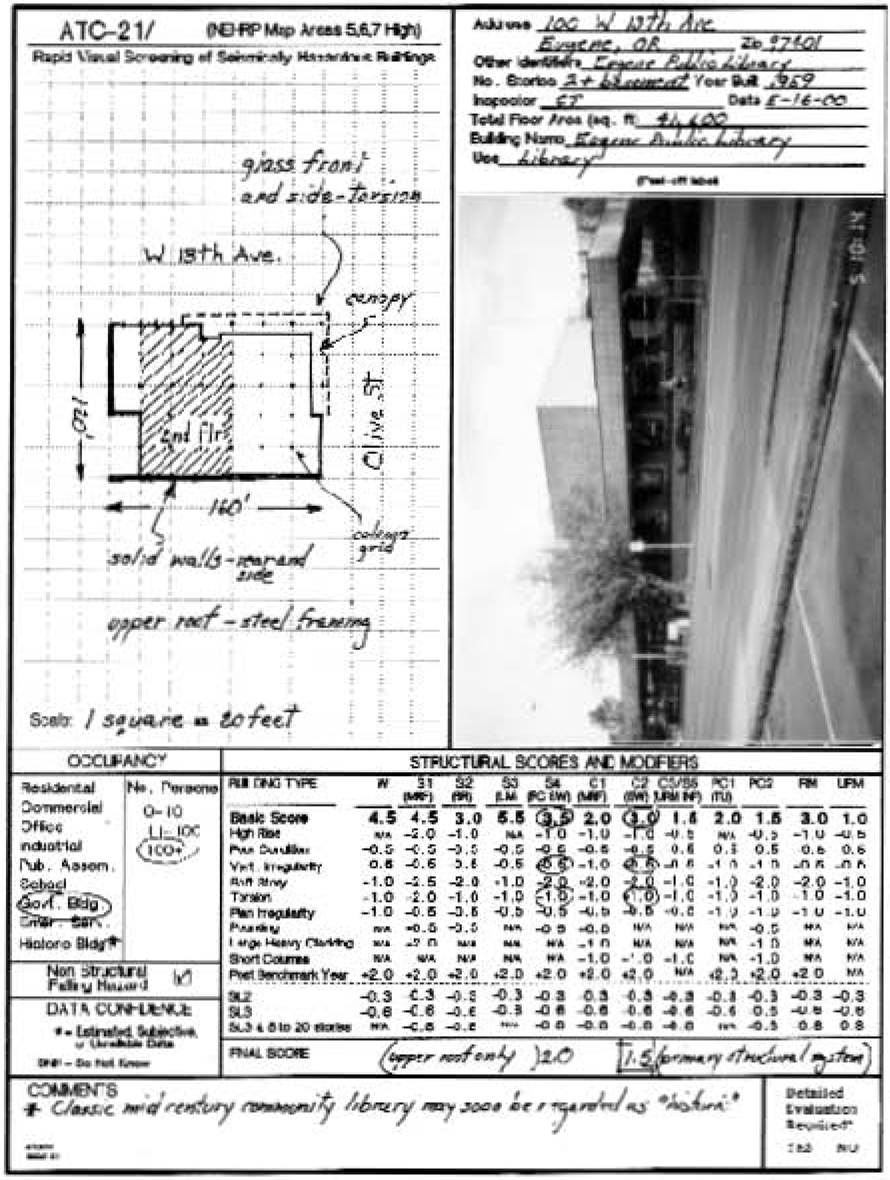
The Public Library in Eugene, Oregon, was constructed in 1959 on the corner of 13th Avenue and Olive Street in the downtown area. It is a two-story building with a basement. All three levels contain library spaces accessible to the public. It is constructed of reinforced concrete and uses shear walls for lateral resistance. The second story is smaller than the ground floor and set back from the building perimeter, creating a vertical irregularity in the building massing. Although classified as a concrete structure for the purpose of loss estimation, this is actually a building of mixed construction: the upper roof is framed in steel. The two walls fronting the streets have windows, which creates a configuration that can make a building susceptible to torsion forces during an earthquake. The cantilevered canopy may present a falling hazard. The Eugene Public Library has outgrown this present building, and a new building is planned to replace it. In the meantime, the library is heavily used and has evening and Sunday hours. The building is a typical example of a mid-century modern community library and may be regarded as an historic structure in the near future.

Figures 4a and 4b are blank samples of the new HAZUS-RVS form that can be used for reproduction of the front and back pages of the form.

SCREENER TRAINING REQUIREMENTS

The qualifications of screeners and an effective screener training program are critical to ensuring that data collected in the field are as accurate as possible. Although FEMA 154 states that the rapid visual screening methodology can be conducted by trained laypersons, data collection projects in Oregon have been most effective when screeners had professional or educational experience in building design, construction, or assessment. The most challenging task for screeners with limited access to buildings is to determine the correct structural type. For important buildings, such as essential facilities housing emergency response functions, survey projects should budget additional time for screeners to consult facilities representatives or construction documents to accurately determine unknown structural types. A training program that focuses on local construction

(Continued on page 12)



ATC-21/ (NEHRP Map Areas 5,6,7 High)

Rapid Visual Screening of Seismically Hazardous Buildings

Address 100 W 13th Ave

Eugene, OR Zip 97401

Other Identifiers Eugene Public Library

No. Stories 2 + basement Year Built 1959

Inspector CT Date 5-16-00

Total Floor Area (sq. ft) 41,600

Building Name Eugene Public Library

Use Library

(Peel-off label)

Scale: 1 square = 20 feet

OCCUPANCY

Residential
Commercial
Office
Industrial
Pub. Assem.
School
[✓ Gov't. Bldg]
Emer. Serv.
Historic Bldg*

No. Persons
0-10
11-100
[✓ 100+]

Non Structural Falling Hazard ✓

DATA CONFIDENCE

* = Estimated, Subjective, or Unreliable Data

DNK = Do Not Know

STRUCTURAL SCORES AND MODIFIERS

BUILDING TYPE	W	S1 (MRF)	S2 (BR)	S3 (LM)	S4 (RC SW)	C1 (MRF)	C2 (SW)	C3/S5 (URM INF)	PC1 (TU)	PC2	RM	URM
Basic Score	4.5	4.5	3.0	5.5	3.5	2.0	3.0	1.5	2.0	1.5	3.0	1.0
High Rise	N/A	-2.0	-1.0	N/A	-1.0	-1.0	-1.0	-0.5	N/A	-0.5	-1.0	-0.5
Poor Condition	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Vert. Irregularity	-0.5	-0.5	-0.5	-0.5	-0.5	-1.0	-0.5	-0.5	-1.0	-1.0	-0.5	-0.5
Soft Story	-1.0	-2.0	-2.0	-1.0	-2.0	-2.0	-2.0	-1.0	-1.0	-2.0	-2.0	-1.0
Torsion	-1.0	-2.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
Plan Irregularity	-1.0	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-1.0	-1.0	-1.0	-1.0
Pounding	N/A	-0.5	-0.5	N/A	-0.5	-0.5	N/A	N/A	N/A	-0.5	N/A	N/A
Large Heavy Cladding	N/A	-2.0	N/A	N/A	N/A	-1.0	N/A	N/A	N/A	-1.0	N/A	N/A
Short Columns	N/A	N/A	N/A	N/A	N/A	-1.0	-1.0	-1.0	N/A	-1.0	N/A	N/A
Post Benchmark Year	+2.0	+2.0	+2.0	+2.0	+2.0	+2.0	+2.0	N/A	+2.0	+2.0	+2.0	N/A
SL2	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3
SL3	-0.6	-0.6	-0.6	-0.3	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
SL3 & 8 to 20 stories	N/A	-0.8	-0.8	N/A	-0.8	-0.8	-0.8	-0.8	N/A	-0.8	-0.8	-0.8
FINAL SCORE	(upper roof only) 2.0						1.5 (primary structural system)					

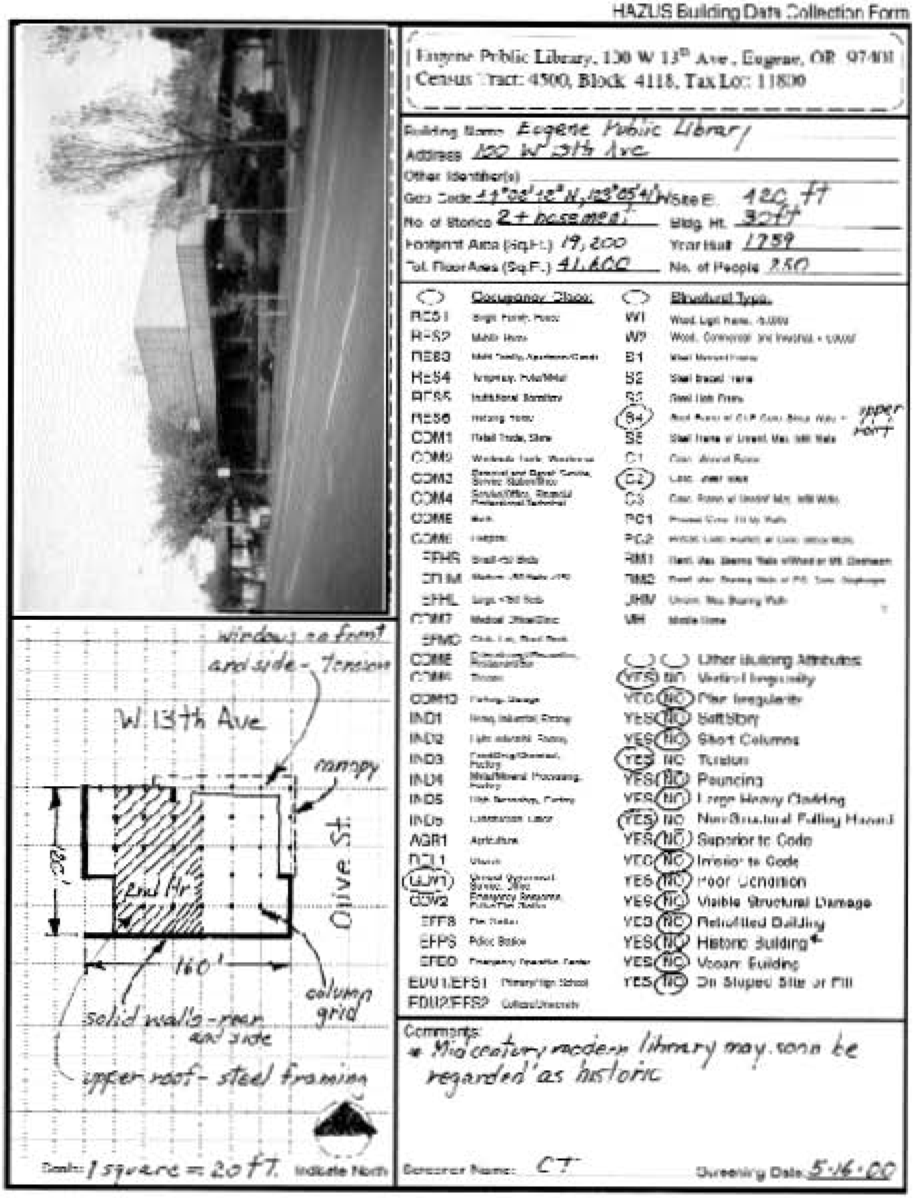
COMMENTS

* Classic mid-century community library may soon be regarded as "historic"

Detailed Evaluation Required?

YES NO

Figure 2. Completed FEMA 154 form for the Eugene Public Library.



HAZUS Building Data Collection Form

Eugene Public Library, 100 W 13th Ave., Eugene, OR 97401

Census Tract: 4500, Block 4118, Tax Lot: 11800

Building Name Eugene Public Library

Address 100 W 13th Ave

Other Identifier(s)

Geo Code 44°02'12" N, 123°05'41" W

Size E. 420 ft

No. of Stories 2 + basement

Bldg. Ht. 30 ft

Footprint Area (Sq.Ft.) 19,200

Year Built 1959

Tot. Floor Area (Sq.F.) 41,600

No. of People 250

Scale: 1 square = 20 ft.

Occupancy Class:

RES1
RES2
RES3
RES4
RES5
RES6
COM1
COM2
COM3
COM4
COM5
COM6
EFHS
EFHM
EFHL
COM7
EFMC
COM8
COM9
COM10
IND1
IND2
IND3
IND4
IND5
IND6
AGR1
REL1
[✓ GOV1]
GOV2
EFFS
EFPS
EFEO
EDU1/EFS1
EDU2/EFS2

Structural Type:

W1 Wood, Light Frame
W2 Wood, Commercial and Industrial
S1
S2
S3
[✓ S4] upper roof
S5
C1
[✓ C2]
C3
PC1
PC2
RM1
RM2
URM
MH

Other Building Attributes

[✓ YES] NO Vertical Irregularity

YES [✓ NO] Plan Irregularity

YES [✓ NO] Soft Story

YES [✓ NO] Short Columns

[✓ YES] NO Torsion

YES [✓ NO] Pounding

YES [✓ NO] Large Heavy Cladding

[✓ YES] NO Non-Structural Falling Hazard

YES [✓ NO] Superior to Code

YES [✓ NO] Inferior to Code

YES [✓ NO] Poor Condition

YES [✓ NO] Visible Structural Damage

YES [✓ NO] Retrofitted Building

YES [✓ NO] Historic Building*

YES [✓ NO] Vacant Building

YES [✓ NO] On Sloped Site or Fill

Comments:

* Mid-century modern library may soon be regarded as historic

Screener Name: CT

Screening Date: 5-16-00

Figure 3. Completed HAZUS-RVS form for the Eugene Public Library.

Following pages (10 and 11): Figures 4a and b. Blank new HAZUS-RVS form, front and back pages, for reproduction purposes.

PHOTO

Place Pre-printed Tracking Label Here
(Can include City, Census Tract, Tax Lot, Zip Code...)

Building Name ______________________

Address ______________________

Other Identifier(s) ______________________

Geo Code ______________ Site El. ______________

No. of Stories ______________ Bldg. Ht. ______________

Footprint Area (ft²) ______________ Year Built ______________

Total Floor Area (ft²) ______________ No. of People ______________

○ **OCCUPANCY CLASS**

RES1	Single Family, House
RES2	Mobile Home
RES3	Multi-Family, Apartment/Condo
RES4	Temporary, Hotel/Motel
RES5	Institutional Dormitory
RES6	Nursing Home
COM1	Retail Trade, Store
COM2	Wholesale Trade, Warehouse
COM3	Personal/Repair Service
COM4	Professional Service/Office
COM5	Bank
COM6	Hospital
EFHS	Small <50 Beds
EFHM	Medium >50 Beds <150
EFHL	Large >150 Beds
COM7	Medical Office/Clinic
EFMC	Clinic, Lab, Blood Bank
COM8	Entertainment/Restaurant/Rec
COM9	Theater
COM10	Parking, Garage
IND1	Heavy Industrial, Factory
IND2	Light Industrial, Factory
IND3	Food/Drug/Chemical Factory
IND4	Metal/Mineral Processing Factory
IND5	High Technology, Factory
IND6	Construction, Office
AGR1	Agriculture
REL1	Church
GOV1	Government Service/Office
GOV2	Emergency Response
EFFS	Fire Station
EFPS	Police Station
EFEO	Emergency Operation Center
EDU1 / EFS1	Primary or High School
EDU2 / EFS2	College or University

○ **STRUCTURAL TYPE**

W1	Wood, Light Frame, <5,000sf
W2	Wood, Commercial/Industrial, > 5,000sf
S1	Steel Moment Frame
S2	Steel Braced Frame
S3	Steel Light Frame
S4	Steel Frame w/ C.I.P. Conc. Shear Walls
S5	Steel Frame w/ Unreinf. Mas. Infill Walls
C1	Conc. Moment Frame
C2	Conc. Shear Walls
C3	Conc. Frame w/ Unreinf. Mas. Infill Walls
PC1	Precast Conc. Tilt-Up Walls
PC2	Precast Conc. Frames w/ Conc. Shear Walls
RM1	Reinf. Mas. Bearing Walls w/Wood or Mtl. Diaphragm
RM2	Reinf. Mas. Bearing Walls w/ P.C. Conc. Diaphragm
URM	Unreinf. Mas. Bearing Walls
MH	Mobile Home

○ ○ **OTHER BUILDING ATTRIBUTES**

YES	NO	Vertical Irregularity
YES	NO	Plan Irregularity
YES	NO	Soft Story
YES	NO	Short Columns
YES	NO	Torsion
YES	NO	Pounding
YES	NO	Large Heavy Cladding
YES	NO	Non-Structural Falling Hazard
YES	NO	Superior to Code
YES	NO	Inferior to Code
YES	NO	Poor Condition
YES	NO	Visible Structural Damage
YES	NO	Retrofitted Building
YES	NO	Historic Building
YES	NO	Vacant Building
YES	NO	On Sloped Site or Fill

SKETCH

Scale

Indicate North

COMMENTS:

Screener Name ______________________ Screening Date ______________

PHOTOGRAPHY TIPS

A wide angle lens is recommended.

Photograph from a sufficient distance to include the whole building if possible.

Select a view that will aid in building identification such as the front facade and one adjacent side.

The view selected can be used to clarify a building attribute. For complex buildings, additional photos are an option.

If the identification of building age or structural type is uncertain, select a view that will assist a consulting expert in making a determination.

Avoid obstructions by cars, trees, utility lines when possible.

The quality and durability of instant photos are often less than other photographic methods but they save time and can be attached to the screening form directly in the field. When taking photographs that must be developed or downloaded off-site it is important to maintain an accurate photo log keyed to screening forms.

When possible, the camera should be held level and parallel to the horizon. An adjustment may be necessary due to building height or accessibility.

Plan the times of your screening route to avoid pointing the camera in the direction of the sun or strong sunlit facades.

SKETCHING TIPS

Use sharpened # 2 pencils or a mechanical pencil and a good quality eraser.

Make clean, dark, reproducible lines. Use gridlines as guides to make straight, orthogonal lines.

Include a plan of the building footprint shown approximately to scale. Use gridlines to assist in representing approximate proportions and as a scaling tool. (i.e. one square = 30 feet)

Include approximate overall plan dimensions.

Show location of adjacent streets and buildings.

Place a north arrow in the circle provided.

Annotate the plan to identify building features such as the configuration of upper stories or location of visible structural damage.

Do not add other sketches such as elevations unless they are essential to record important information that will not be visible on the photograph.

Sketches can also be prepared from construction documents, aerial photographs or maps during the pre-field phase of the screening process and verified in the field.

GENERAL BUILDING INFORMATION

Address and Geo Code: Always include an address or exact location. Do not use geo code in lieu of address.

Year Built: If year built is unknown, estimate date or decade based on building style or context.

Year Built, No. of Stories, and Height: If more than one date, no. of stories or height, list from greatest to least according to size of building area affected (i.e. a 3 story building with a small 4th floor penthouse would be listed under No. of Stories as "3,4")

No. of People: Estimate the number of people likely to be in the building at typical peak-use times. The following maximum occupancy loads (in square feet per person) are provided for reference. Note that these loads will usually overestimate typical peak-use numbers of people.

residential	100-300	assembly	10+
commercial	50-200	school	50-100
office	100-200	government	100-200
industrial	200-500	emergency	100

BUILDING USE & SEISMIC PARAMETERS

Occupancy Class: For mixed use buildings circle all primary uses. Do not include secondary uses that occupy relatively small building areas such as a retail pharmacy within a hospital. Note that "EF" designations should be used for post-earthquake essential facilities only.

Structural Type: For definitions see HAZUS Users' Manual Appendix B. If the structural type cannot be determined, circle all likely types and note uncertainty in comments section. If more than one structural type is present circle all that apply. In comments or sketch explain the distribution of structural type in the building

Other Building Attributes:

VERTICAL IRREGULARITY - Includes story setbacks, vertical geometric irregularities of the lateral force resisting system such as discontinuous shear walls, mass irregularities, weak stories.

PLAN IRREGULARITY - Includes re-entrant corners, discontinuous diaphragms, non-parallel systems, out-of-plane offsets, & large footprints.

SOFT STORY - Can be caused by a tall first floor, a relatively open and flexible first floor or a floor with fewer or more flexible lateral load resisting elements.

SHORT COLUMNS - Columns that are shorter than the majority of columns carrying lateral loads often found at building perimeter and sloping sites.

TORSION - A plan irregularity in which the lateral load resisting system is not concentric with the building mass.

POUNDING - Caused when adjacent buildings "pound" against one another.

LARGE HEAVY CLADDING - Such as precast concrete panels.

NON-STRUCTURAL FALLING HAZARD Parapets, awnings, signage, etc.

SUPERIOR TO CODE - Likely to exceed code in force at time of construction.

INFERIOR TO CODE - Likely to not meet code in force at time of construction.

POOR CONDITION - Evidence of maintenance problems that may affect integrity of building structure.

VISIBLE STRUCTURAL DAMAGE Cracks, out-of-plumb columns and other signs of damage to structure in a post-earthquake area.

RETROFITTED BUILDING - Evidence of seismic retrofit installations such as braces.

HISTORIC BUILDING - buildings of historic significance at least 50 years of age.

VACANT BUILDING - Not occupied.

ON SLOPED SITE OR FILL - Slopes greater than 10 degrees.

SUGGESTED COMMENTS

Clarify any multiple entries for single data items. Screener uncertainty or evidence of mixed age, use or structure types?

Identify original building use if different from present use.

Note observable surface soils conditions such as: bedrock outcrops and topographical features, i.e. adjacency to a body of water.

Further explanations of building attributes, or other seismically significant information such as seismic design code used.

THESIS ABSTRACT

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

Effects of urbanization on streamflow in three basins in the Pacific Northwest, by Julie L. Clark (M.S., Portland State University, 1999), 136 p.

Three basins in the Puget Sound-Willamette Valley lowland area of western Washington and Oregon were analyzed to see if there were significant posturbanization differences in storm peak flows, storm volumes, and ratios of those variables to antecedent precipitation indices spanning 15 to 120 days.

Criteria for inclusion of basins included a flow record duration of at least 50 years and minimal disruption by impoundment or diversion. Basins selected included the Tualatin River (1,807 km^2) and Johnson Creek (68 km^2), both near Portland, Oregon; and the Newaukum River (397 km^2) near Centralia, Washington. A nonurbanized basin, the Luckiamute River (614 km^2) near McMinnville, Oregon, was used as a reference.

Peak flow rates higher than a one-year recurrence interval (RI) were used. The data set for each basin was broken into early and late periods. Linear regression, F and t tests, ANOVAs, and Spearman-Conley nonparametric tests were performed on the entire data set and on data subsets characterized by season (November-December and January-February) and by size (RI 1-1.9 years and RI 2–10 years).

Precipitation was unchanged between the early and late periods, suggesting changes in flows were due to urbanization, not climate.

The nonurbanized Luckiamute basin showed no changes in streamflow characteristics. Even after urbanization, the Tualatin showed no changes in streamflow characteristics. The Newaukum, however, had higher peaks (21 percent increase), storm volumes (10 percent increase), and (peak/volume) to antecedent precipitation ratios (18–22 percent increases). John-

(Continued on page 35)

(Continued from page 8)

practices is preferred over generic training. In addition, building professionals with long-term experience in the survey region can serve as consultants on survey projects. Their experience often enables them to make an accurate determination of a structural type from the field photographs attached to the forms.

ACKNOWLEDGMENTS

Special thanks to Carol Hasenberg of Portland State University for her work on the studies, her use of the forms in a draft state, and the helpful review of this paper. We thank Dawn Woods, a former University of Oregon (UO) Department of Architecture graduate student, who was instrumental in developing the layout and content of early versions of the HAZUS-RVS form; also Karen Chan, a UO undergraduate, who worked on the design of the document, reviewed drafts, and contributed to the development of the instructions to screeners. Thanks to Andrew Schmidt of DOGAMI for his thoughtful review comments on the paper.

REFERENCES CITED

ATC (Applied Technology Council), 1988, Rapid visual screening of buildings for potential seismic hazards: A handbook (ATC–21): Federal Emergency Management Agency publication FEMA 154 (Earthquake Hazards Reduction Series 41), 185 p.

———1989, Procedures for post-earthquake safety evaluation of buildings: Redwood City, Calif., Applied Technology Council publication ATC–20, 152 p.

McCormack, T.C., and Rad, F.N., 1997, An earthquake loss estimation methodology for buildings based on ATC–13 and ATC–21: Earthquake Spectra, v. 13, no. 4, p. 605–621.

National Institute of Building Sciences, 1997a, HAZUS technical manual, vols. 1–3: Federal Emergency Management Agency, NIBS Documents 5201–5203.

———1997b, HAZUS97 user's manual: Federal Emergency Management Agency, NIBS Document 5200.

Perry, S., and Theodoropoulos, C., 2000, Building inventory development: An assessment of current practices and a pragmatic new methodology to improve loss estimation, *in* Sixth International Conference on Seismic Zonation, Proceedings: Oakland, Calif., Earthquake Engineering Research Institute, in press.

Theodoropoulos, C., and Perry, S., 2000, State of Oregon building stock profile. Building inventory data development for earthquake loss estimation: Unpublished report to the Oregon Department of Geology and Mineral Industries, 63 p.

Wang, Y., 1998, Oregon earthquakes: Preliminary estimates of damage and loss: Oregon Geology, v. 60, no. 6, p. 123–131.

———1999, Risk assessment and risk management in Oregon, *in* Elliott, W.M., and McDonough, P., eds., Optimizing post-earthquake lifeline system reliability. Proceedings of the 5th U.S. Conference on Lifeline Earthquake Engineering: Reston, Va., American Society of Civil Engineers, Technical Council on Lifeline Earthquake Engineering Monograph 16, p. 197–206.

Wang, Y., and Clark, J.L., 1999, Earthquake damage in Oregon: Preliminary estimates of future earthquake losses: Oregon Department of Geology and Mineral Industries Special Paper 29, 59 p. ☐

Where the Rockies meet the Columbia Plateau: Geologic field trip from the Walla Walla Valley to the Wallowa Mountains, Oregon

by R.J. Carson, Department of Geology, Whitman College, Walla Walla, Washington 99362, carsonrj@whitman.edu

This field trip guide was prepared for the Keck Geology Consortium Symposium, supported by the W.M. Keck Foundation and held at Whitman College in April 2000. —*ed.*

INTRODUCTION

The magnificent scenery of northeastern Oregon is largely the result of an exciting geologic history with similarities to both the Rockies to the east and the Columbia Plateau to the west. Exotic volcanic and sedimentary rocks originating far away in the ancestral Pacific Ocean were accreted to North America late in the Mesozoic. Accretion-related intrusion, metamorphism, and uplift in places like the Wallowa Mountains are similar to those of the Idaho batholith to the east. Northeastern Oregon was then eroded to near sea level before widespread volcanism occurred throughout the Tertiary. The Miocene Columbia River basalts are the principal constituent of a diverse assortment of felsic and mafic volcanic (and volcaniclastic) rocks emplaced from the Eocene through the Pliocene. The whole package of rocks, from the accreted terranes to the young volcanic rocks, was folded and faulted in the late Cenozoic, creating many small mountain uplifts. These range from the glaciated Wallowa Mountains cored by granitic rocks to the larger Blue Mountains anticlinal ridge composed almost entirely of basalt flows. The rocks visible on this field trip are listed in the composite stratigraphic column shown in Figure 1.

The term "Blue Mountains" has two meanings. In the broad sense, it describes a mountainous section of the Columbia Plateau (Fenneman, 1931; Thornbury, 1965; Hunt, 1974), including the Strawberry, Elkhorn, Wallowa, and Blue Mountains in Oregon and Washington and the Seven Devils Mountains east of Hells Canyon in Idaho. It is also a geographically more restrictive term referring only to the anticlinal ridge which stretches from Clarkston, Washington, to north-central Oregon. In this guide, "Blue Mountains" refers to only the northeast-southwest-trending anticline of basalt flows, with Walla Walla and Milton-Freewater to the northwest and La Grande and Elgin to the southeast.

Our journey begins in the Walla Walla Valley which straddles the Washington-Oregon state line. With its tributaries, the Walla Walla River originates in the Blue Mountains at elevations over 5,000 ft and empties into the Columbia River (elevation 340 ft) just north of the Wallula Gap. The Walla Walla Valley's borders are as follows:

North: The Palouse Hills of Quaternary loess
East and southeast: The Blue Mountains
South: The Horse Heaven Hills, an anticlinal ridge of Miocene basalt (and the Olympic-Wallowa lineament)
West: "Nine-Mile Hill"—a basaltic high with the Pasco Basin to the west

The field trip stops are shown on the sketch map of northeastern Oregon (Figure 2). From Milton-Freewater (in the southeastern corner of the Walla Walla Valley) the route goes south across the Olympic-Wallowa lineament, the east end of the Horse Heaven Hills, and the narrow valley of the Umatilla River.

Note

Take this trip in good summer weather. Some roads will be closed in winter; some may be impassable just because of bad weather conditions. It is always a good idea to gather weather information before such a trip. Not all roads are paved, but all are negotiable with normal passenger vehicles in fair weather.

Be aware of traffic conditions. Some roads may be heavily used by log or gravel trucks, and since you are in tourist country, you will also find many recreational vehicles that could cause problems.

At many stops, no specific directions are given as to parking. You will have to judge from the given situation how to handle this safely. At all times, drive and stop with due caution!

Stop 15 requires a National Forest Service (NSF) trail head parking permit now called Northwest Forest Pass (day, $5; year, $30). This pass can be obtained online at www.naturenw.org (phone 1-800-270-7504), at any NSF office, or from any of over 300 independent vendors throughout Oregon and Washington.

Interstate Highway 84 takes us across the anticlinal uplift of the Blue Mountains. Soon after we reach the Grande Ronde River, flowing along the southeast flank of the Blue

Mountains, we can see a cutoff incised meander at Perry.

At La Grande, we enter the graben of the Grande Ronde Valley across which the Grande Ronde River wanders. This graben is bordered by the Blue Mountains to the northwest, the Wallowa Mountains to the east, and the Elkhorn Mountains to the south. We follow the Grande Ronde River downstream, leaving the main graben and entering a smaller one in which Elgin lies. At Elgin we turn eastward and cross an upland before descending to Minam, where the Minam River joins the Wallowa River.

From Milton-Freewater to Perry, all the rocks are middle Miocene basalt flows of the Columbia River Basalt Group. Exposures of rocks other than Miocene Columbia River basalts are rare in the Blue Mountains but include Mesozoic terrane rocks in the upper Tucannon River drainage at the Washington end of the uplift to the northeast, and granitic rocks at Battle Mountain Summit toward the southwest end.

From Perry to Minam, the volcanic rocks vary more in composition, texture, and age. For example, mapping by Carson and students of Whitman College in the late 1980s revealed felsic, pumiceous, and volcaniclastic rocks in addition to the basalt flows. Dating by Ferns and Madin of the Oregon Department of Geology and Mineral Industries in the late 1990s yielded ages as young as Pliocene for the volcanic rocks (Ferns and others, in preparation). These rocks lie on top of the Columbia River basalts and are much like the Powder River volcanic rocks (Hooper and Swanson, 1990).

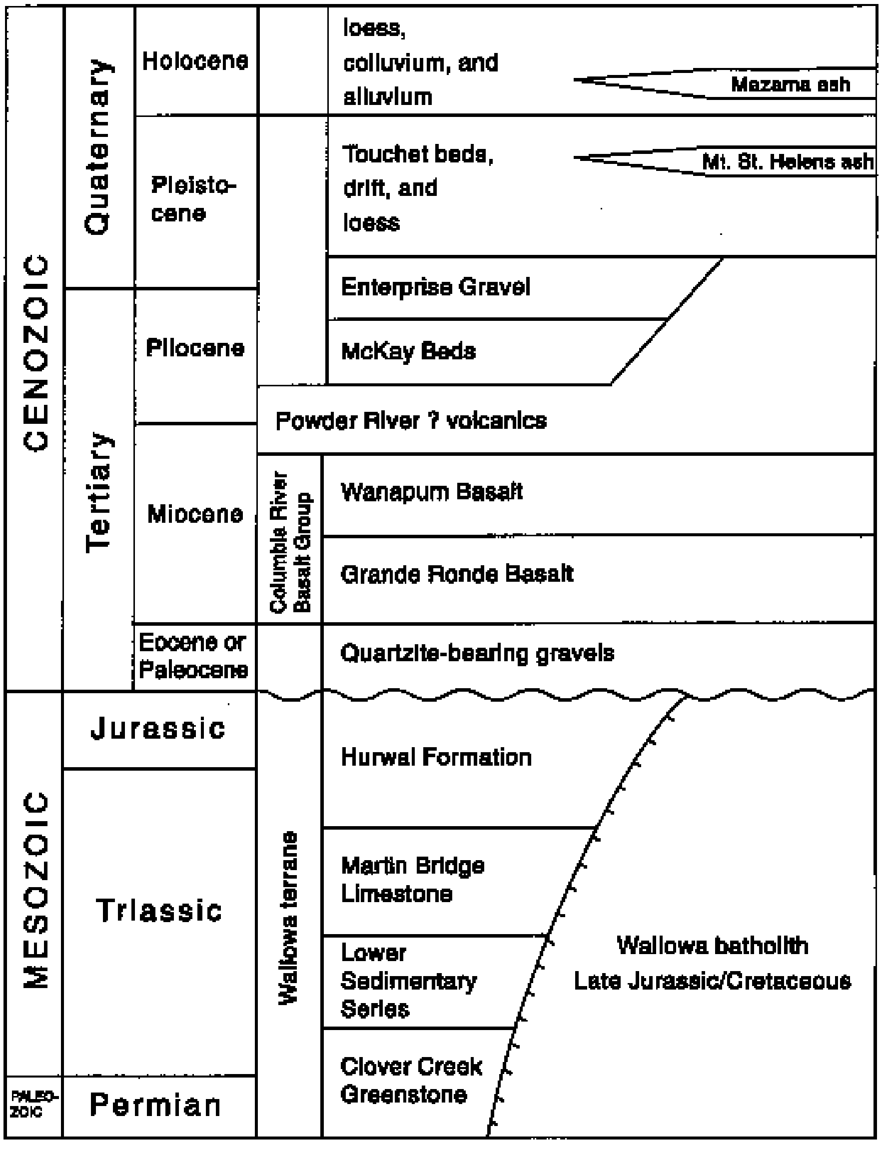


Figure 1. Composite stratigraphic column of the rocks visible on this field trip.

As we follow the Wallowa River upstream from Minam to Wallowa, the canyon ends as we cross the Olympic-Wallowa lineament again. We enter the ancient homeland of the Nez Perce Indians, a fertile valley at the north edge of the Wallowa Mountains. The borders of this highest range in northeastern Oregon are as follows:

Northeast: The Olympic-Wallowa lineament, and the Joseph Upland, a plateau of basalt that stretches north to the Grande Ronde River

East: Hells Canyon of the Snake River, with Idaho's Seven Devils Mountains on the other side

South: The Powder River

Southwest: Fault-bounded Baker Valley and, farther southwest, the Elkhorn Mountains, mostly Mesozoic accreted terrane and granitic intrusives

West: The Grande Ronde Valley

Northwest: The Grande Ronde River

The Olympic-Wallowa lineament, the Wallowa River, and Oregon Highway 82 lead southeast through the towns of Wallowa, Lostine, Enterprise, and Joseph to Wallowa Lake. The combination of two deep merging glacial troughs to the south and two huge merging lateral moraines to the north make Wallowa Lake one of the most scenic places in North America. Within a few kilometers of the lake a variety of Mesozoic igneous, metamorphic, and sedimentary rocks are found, in a landscape shaped by many late Cenozoic glacial, periglacial, fluvial, and mass-wasting processes.

The general geology of northeast-

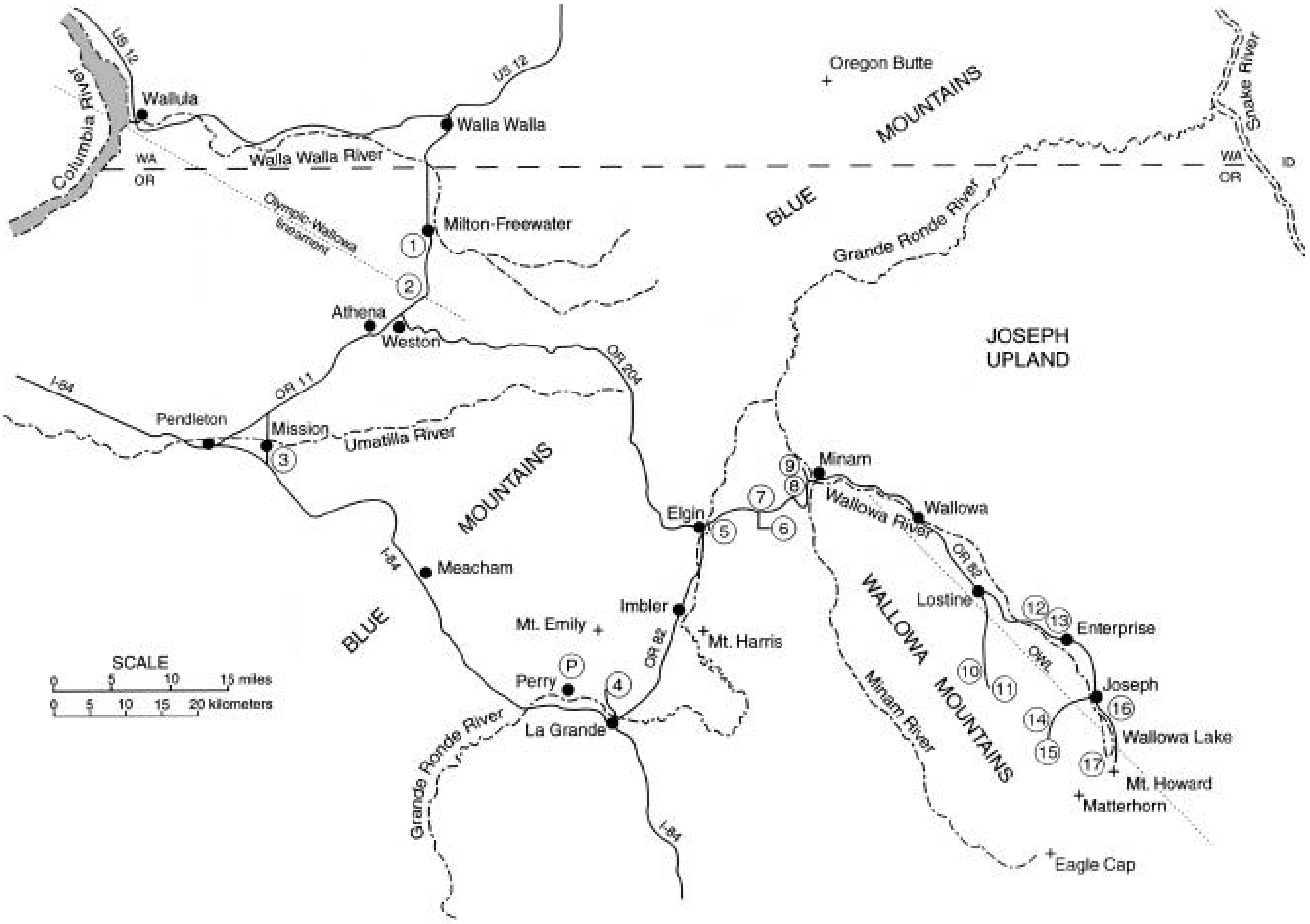


Figure 2. Sketch map of the field trip region, showing stops as circled numbers. Circled "P" = optional stop.

ern Oregon and adjacent areas is addressed in the following publications:

FURTHER READING

Less technical

Carson, R.J., and Pogue, K.R., 1996, Flood basalts and glacier floods: Roadside geology of parts of Walla Walla, Franklin, and Columbia Counties, Washington: Washington Division of Geology and Earth Resources Information Circular 90, 47 p.

McKee, B., 1972, Cascadia. The geologic evolution of the Pacific Northwest: New York, McGraw-Hill, 394 p.

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

Orr, E.L., Orr, W.N., and Baldwin, E.M., 1992, Geology of Oregon, 4th ed.: Dubuque, Iowa, Kendall/Hunt Publishing Company, 254 p.

Vallier, Tracy, 1998, Islands and rapids. A geologic story of Hells Canyon: Lewiston, Idaho, Confluence Press, 151 p.

More technical

Reidel, S.R., and Hooper, P.R., eds., 1989, Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, 386 p.

Vallier, T.L., and Brooks, H.C., eds., 1986, Geology of the Blue Mountains region of Oregon, Idaho, and Washington: Geologic implications of Paleozoic and Mesozoic paleontology and biostratigraphy, Blue Mountains province, Oregon and Idaho: U.S. Geological Survey Professional Paper 1435, 93 p.

———1987, Geology of the Blue Mountains region of Oregon, Idaho, and Washington. The Idaho batholith and its border zone: U.S. Geological Survey Professional Paper 1436, 196 p.

———1994, Geology of the Blue Mountains region of Oregon, Idaho, and Washington. Stratigraphy, physiography, and mineral resources of the Blue Mountains region: U.S. Geological Survey Professional Paper 1439, 198 p.

———1995, Geology of the Blue Mountains region of Oregon, Idaho, and Washington: Petrology and tectonic evolution of pre-Tertiary rocks of the Blue Mountains region: U.S. Geological Survey Professional Paper 1438, 540 p.

Walker, G.W., ed., 1990, 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, 135 p.

ACKNOWLEDGMENTS

This field trip guide was prepared for the Keck Geology Consortium Symposium, supported by the W.M. Keck Foundation and held at Whitman College in April 2000. I am indebted to Patti Moss for work on the manuscript and to Todd Shearer for help with the illustrations. Whitman College provided support for field work in connection with preparation of this guide. Molly Gerber and Matt Clausen, Whitman College students, and Jay Van Tassell, Professor of Geology at Eastern Oregon University, were enthusiastic companions during field work. I also thank John Winter, Pat Spencer, Kevin Pogue, and Carolyn Nielsen for editing the manuscript.

ROAD LOG

Part 1 — Milton-Freewater to La Grande

Miles

0.0 *Proceed south along Oregon Highway 11 from the Milton-Freewater City Hall (west side of South Main Street between SW 7th and SW 8th Streets).*

Elevation here is 1,033 ft. Had you lived here between about 15,300 and 12,700 years ago, you would have been inundated by at least one of 40 or more floods. British Columbia's Cordilleran ice sheet advanced south into Idaho, blocking the Clark Fork River. The ice dam created glacial Lake Missoula (Pardee, 1910), which covered western Montana with 2,500 km^3 (600 mi^3) of water (Waitt, 1985). The dam repeatedly failed, sending gigantic jökulhlaups (glacial outburst floods) west across northern Idaho, south across eastern Washington, and then west along the Columbia River (Waitt, 1980). The major bottleneck for these floods was Wallula Gap, which the Columbia River cut across the Horse Heaven Hills about 50 km (31 mi) west of Milton-Freewater. Wallula Gap formed a hydraulic dam to the jökulhlaups causing the water to rise to an elevation above 1,200 ft and back up into the Walla Walla Valley to the east of Walla Walla and the south of Milton-Freewater. Imagine being under 60 m of water here!

Had you been here on July 15, 1936, you would have felt Oregon's greatest historic earthquake. The quake, which occurred at 11:05 p.m., broke many chimneys; several houses were moved off their foundations; and many ground cracks appeared, aligned west-northwest (Brown, 1937), parallel to the Olympic-Wallowa lineament. The quake's intensity was VII+, its magnitude was about 6.1; and the total damage was $100,000 in 1936 dollars (Wong and Bott, 1995).

0.4 Stop 1 — Alluvium on Wanapum Basalt

Exposure on west side of South Main Street at the south end of Milton-Freewater (elevation 1,100 ft). The bedrock is the Miocene Wanapum Basalt of the Columbia River Basalt Group. Above the basalt lies alluvium of the old Walla Walla River—the modern Walla Walla River is less than 0.5 km (0.3 mi) to the east. Above these gravels you see fine-grained sediment of three possible origins: (1) Quaternary loess, (2) late Pleistocene Touchet Beds, and/or (3) overbank deposits of the ancient Walla Walla River. Touchet Beds (slackwater deposits of the Missoula floods) are possible here because flood height at Wallula Gap on the Columbia River (near the mouth of the Walla Walla River) was 1,200 ft (Waitt, 1994). The exposure is coincident with a northeast-facing scarp that is part of the Olympic-Wallowa lineament (OWL). Here the scarp is partly due to erosion by the Walla Walla River. The OWL (Raisz, 1945) is a northwest-trending feature that stretches from the Strait of Juan de Fuca (between Vancouver Island and the Olympic Peninsula) to the Wallowa Mountains. This is the southeastern end of a portion of the OWL called the Cle Elum-Wallula deformed zone (Reidel and Lindsey, 1991).

Continue south (uphill) on Oregon Highway 11.

Thin loess at the top of the hill is underlain by the Miocene Saddle Mountain Basalt of the Columbia River Basalt Group.

4.2 Begin series of road cuts, mostly in the Wanapum Basalt of the Columbia River Basalt Group.

5.4 Stop 2 — Fault through Wanapum Basalt

(Best exposed on northwest side of highway). This stop is between two intermittent streams (Dry Creek and Little Dry Creek) and before the intersection with Winn Road. The west-southwest-dipping "Dry Creek Fault" is associated with the OWL. The basalt has been ground to breccia and gouge.

Continue south on Highway 11.

6.9 *Continue straight (on Highway 11) at junction of Oregon Highways 11 and 204* (elevation 1,877 ft).

Highway 204 leads 42 mi over the Blue Mountains to Elgin. This is an alternate and shorter route of return from Wallowa Lake. The Horse Heaven Hills anticline stretches west-northwest from here; this anticline is the easternmost of the Yakima Fold Belt (Tolan and Reidel, 1989).

9.9 *Continue straight (on Highway 11) at junction with east-west road to Weston and Athena.*

15.1 *Continue straight (on Highway 11) at junction with road west to Adams.*

Oregon Highway 11 is following the valley of Wildhorse Creek, which flows southwest to the Umatilla River.

22.9 *Junction with Moens Road. Turn left (south) on Moens Road.*

To the south is the huge Blue Mountain anticline.

23.9 Going down the hill, you see an exposure of the Pliocene McKay beds (see Stop 3). The valley of the Umatilla River is cut in the Wanapum Basalt of the Columbia River Basalt Group.

24.9 *Cross Umatilla River.*

(Note osprey nest near southwest corner of the bridge). The Umatilla River flows west and joins the Columbia River in the Umatilla Basin.

25.4 *Mission* (elevation 1,215 ft) on the Umatilla Indian Reservation.

Continue south and up the hill.

26.0 Stop 3 — Gravels of the McKay beds

The type locality of the McKay beds is at McKay Reservoir just

(Continued on page 21)

PLEASE SEND US YOUR PHOTOS

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

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

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

If you have any photos that you would like to share with other readers of this magazine, please send them to us (Editor, *Oregon Geology*, 800 NE Oregon Street, Portland, OR 97232-2162) with information for a caption. If they are used, the printing and credit to you and a one-year free subscription to *Oregon Geology* is all the compensation we can offer. If you wish to have us return your materials, please include a self-addressed envelope.

Information for Contributors

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

Two copies of the manuscript should be submitted, one paper copy and one digital copy. All digital elements of the manuscript, such as text, figures, and tables should be submitted as separate files, not as incorporated, e.g., in a word processor product for a paper version. Hard-copy graphics should be camera ready; photographs should be glossies. All illustrations should be clearly marked. Captions should be placed together at the end of the text.

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

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

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

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

PUBLICATION ORDER AND *OREGON GEOLOGY* RENEWAL FORM

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

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

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

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

Name/Address/City/State/Zip ____

____

Please charge to Visa__ / Mastercard__, account number: ______________________________

Expiration date: _____________ Cardholder's signature ______________________________

AVAILABLE PUBLICATIONS
OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

NOTE

All publications require additional $3 for mailing.
Some maps may have to be plotted on demand. In that case, please allow two weeks for delivery.

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

GEOLOGICAL MAP SERIES	**Price**
GMS-113 Fly Valley 7½' quad., Union County. 1998	10.00
GMS-111 Summerville 7½' quad., Union County. 1997	10.00
GMS-110 Tucker Flat 7½' quad., Union/Baker C. 1997	6.00
GMS-109 Brownsboro 7½' quad., Jackson County. 1998	10.00
GMS-108 Rio Canyon 7½' quad., Jackson County. 1998	6.00
GMS-106 Grizzly Peak 7½' quad., Jackson County. 1997	6.00
GMS-105 EQ hazards, Salem East/West 7½' quads. 1996	12.00
GMS-104 EQ hazards, Linnton 7½' quad., Mult./Wash. C. 1996	10.00
GMS-101 Steelhead Falls 7½' quad., Desch./Jeffers. C., 1996	7.00
GMS-100 EQ hazard maps for Oregon. 1996	8.00
GMS-99 Tsunami hazard map, Siletz Bay, Lincoln C. 1996	6.00
GMS-98 Dora and Sitkum 7½' quad.s, Coos County. 1995	6.00
GMS-97 Coos Bay 7½' quad., Coos County. 1995	6.00
GMS-95 Henkle Butte 7½' quad., Deschutes County. 1998	10.00
GMS-94 Charleston 7½' quad., Coos County. 1995	8.00
GMS-93 EQ hazards, Siletz Bay area, Lincoln County. 1995	20.00
GMS-92 EQ hazards, Gladstone 7½' quad. 1995	10.00
GMS-91 EQ hazards, Lake Oswego 7½' quad. 1995	10.00
GMS-90 EQ hazards, Beaverton 7½' quad. 1995	10.00
GMS-89 EQ hazards, Mt. Tabor 7½' quad. 1995	10.00
GMS-88 Lakecreek 7½' quad., Jackson County. 1995	8.00
GMS-87 Three Creek Butte 7½' quad., Deschutes C. 1996	6.00
GMS-86 Tenmile 7½' quad., Douglas County. 1994	6.00
GMS-85 Mount Gurney 7½' quad., Douglas/Coos C. 1994	6.00
GMS-84 Remote 7½' quad., Coos County. 1994	6.00
GMS-83 Kenyon Mountain 7½' quad., Douglas/Coos C. 1994	6.00
GMS-82 Limber Jim Creek 7½' quad., Union County. 1994	5.00
GMS-81 Tumalo Dam 7½' quad., Deschutes County. 1994	6.00
GMS-80 McLeod 7½' quad., Jackson County. 1993	5.00
GMS-79 EQ hazards, Portland 7½' quad. 1993	20.00
GMS-78 Mahogany Mountain 30×60' quad., Malheur C. 1993	10.00
GMS-77 Vale 30×60' quad., Malheur County. 1993	10.00
GMS-76 Camas Valley 7½' quad., Douglas/Coos C. 1993	6.00
GMS-75 Portland 7½' quad. 1991	7.00
GMS-74 Namorf 7½' quad., Malheur County. 1992	5.00
GMS-73 Cleveland Ridge 7½' quad., Jackson County. 1993	5.00
GMS-72 Little Valley 7½' quad., Malheur County. 1992	5.00
GMS-71 Westfall 7½' quad., Malheur County. 1992	5.00
GMS-70 Boswell Mountain 7½' quad., Jackson County. 1992	7.00
GMS-69 Harper 7½' quad., Malheur County. 1992	5.00
GMS-68 Reston 7½' quad., Douglas County. 1990	6.00
GMS-67 South Mountain 7½' quad., Malheur County. 1990	6.00
GMS-66 Jonesboro 7½' quad., Malheur County. 1992	6.00
GMS-65 Mahogany Gap 7½' quad., Malheur County. 1990	5.00
GMS-64 Sheaville 7½' quad., Malheur County. 1990	5.00
GMS-63 Vines Hill 7½' quad., Malheur County. 1991	5.00
GMS-62 The Elbow 7½' quad., Malheur County. 1993	8.00
GMS-61 Mitchell Butte 7½' quad., Malheur County. 1990	5.00

	Price
GMS-60 Damascus 7½' quad., Clackamas/Multnomah C. 1994	8.00
GMS-59 Lake Oswego 7½' quad. 1989	7.00
GMS-58 Double Mountain 7½' quad., Malheur County. 1989	5.00
GMS-57 Grassy Mountain 7½' quad., Malheur County. 1989	5.00
GMS-56 Adrian 7½' quad., Malheur County. 1989	5.00
GMS-55 Owyhee Dam 7½' quad., Malheur County. 1989	5.00
GMS-54 Graveyard Point 7½' quad., Malheur/Owyhee C. 1988	5.00
GMS-53 Owyhee Ridge 7½' quad., Malheur County. 1988	5.00
GMS-52 Shady Cove 7½' quad., Jackson County. 1992	6.00
GMS-51 Elk Prairie 7½' quad., Marion/Clackamas C. 1986	5.00
GMS-50 Drake Crossing 7½' quad., Marion County. 1986	5.00
GMS-49 Map of Oregon seismicity, 1841-1986. 1987	4.00
GMS-48 McKenzie Bridge 15' quad., Lane County. 1988	9.00
GMS-47 Crescent Mountain area, Linn County. 1987	7.00
GMS-46 Breitenbush River area, Linn/Marion Counties. 1987	7.00
GMS-45 Madras West/East 7½' quads., Jefferson County. 1987	5.00
as set with GMS-43 and GMS-44	11.00
GMS-44 Seekseequa Junction/Metolius Bench 7½' quads. 1987	5.00
as set with GMS-43 and GMS-45	11.00
GMS-43 Eagle Butte/Gateway 7½' quads. 1987	5.00
as set with GMS-44 and GMS-45	11.00
GMS-42 Ocean floor off Oregon & adj. cont. margin. 1986	9.00
GMS-41 Elkhorn Peak 7½' quad., Baker County. 1987	7.00
GMS-40 Aeromagnetic anomaly maps, north Cascades. 1985	5.00
GMS-39 Bibliogr. & index: Ocean floor, cont. margin. 1986	6.00
GMS-38 NW¼ Cave Junction 15' quad., Josephine County. 1986	7.00
GMS-37 Mineral resources, offshore Oregon. 1985	7.00
GMS-36 Mineral resources of Oregon. 1984	9.00
GMS-35 SW¼ Bates 15' quad., Grant County. 1984	6.00
GMS-34 Stayton NE 7½' quad., Marion County. 1984	5.00
GMS-33 Scotts Mills 7½' quad., Clackamas/Marion C. 1984	5.00
GMS-32 Wilhoit 7½' quad., Clackamas/Marion Counties. 1984	5.00
GMS-31 NW¼ Bates 15' quad., Grant County. 1984	6.00
GMS-30 SE¼ Pearsoll Peak 15' qu., Curry/Josephine C. 1984	7.00
GMS-29 NE¼ Bates 15' quad., Baker/Grant Counties. 1983	6.00
GMS-28 Greenhorn 7½' quad., Baker/Grant Counties. 1983	6.00
GMS-27 The Dalles 1°×2° quadrangle. 1982	7.00
GMS-26 Residual gravity, north/ctr./south Cascades. 1982	6.00
GMS-25 Granite 7½' quad., Grant County. 1982	6.00
GMS-24 Grand Ronde 7½' quad., Polk/Yamhill Counties. 1982	6.00
GMS-23 Sheridan 7½' quad., Polk and Yamhill Counties. 1982	6.00
GMS-22 Mount Ireland 7½' quad., Baker/Grant C. 1982	6.00
GMS-21 Vale East 7½' quad., Malheur County. 1982	6.00
GMS-20 S½ Burns 15' quad., Harney County. 1982	6.00
GMS-19 Bourne 7½' quad., Baker County. 1982	6.00
GMS-18 Rickreall, Salem W., Monmouth, Sidney 7½' quads. 1981	6.00
GMS-17 Aeromagnetic anomaly map, south Cascades. 1981	4.00
GMS-16 Gravity anomaly maps, south Cascades. 1981	4.00
GMS-15 Gravity anomaly maps, north Cascades. 1981	4.00

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

	Price
GMS-14 Index to published geol. mapping, 1898–1979. 1981	8.00
GMS-13 Huntington/Olds Ferry 15' quads., Baker/Malheur C. 1979	4.00
GMS-12 Oregon part, Mineral 15' quad., Baker County. 1978	4.00
GMS-10 Low- to intermediate-temp. thermal springs/wells. 1978	4.00
GMS-9 Aeromagnetic anomaly map, central Cascades. 1978	4.00
GMS-8 Bouguer gravity anom. map, central Cascades. 1978	4.00
GMS-6 Part of Snake River canyon. 1974	8.00
GMS-5 Powers 15' quadrangle, Coos and Curry C. 1971	4.00

INTERPRETIVE MAP SERIES

IMS-19 Rel. EQ hazard map, Klamath Falls metropol. area. 2000	**10.00**
IMS-18 EQ-induced slope instability: Haz. map, Eola Hills. 2000	12.00
IMS-17 EQ-induced slope instab.: Haz. map, Salem Hills. 2000	12.00
IMS-16 EQ scenario and probabilistic maps, Portland. 2000	80.00
IMS-15 EQ scenario ground shaking map, Portland. 2000	10.00
IMS-14 Rel. EQ hazard map, Eugene-Springfield. 2000	12.00
IMS-13 Tsunami hazard map, Gold Beach area. 2000	10.00
IMS-12 Tsunami hazard map, Warrenton area. 1999	10.00
IMS-11 Tsunami hazard map, Astoria area. 1999	10.00
IMS-10 Rel. EQ hazard maps, coastal urban areas. 1999	20.00
IMS-9 Rel. EQ hazard maps, Cottage Grove to Ashland. 2000	20.00
IMS-8 Rel. EQ hazard maps, Canby to Sweet Home. 2000	20.00
IMS-7 Rel. EQ hazard maps, St. Helens to Monmouth. 2000	20.00
IMS-6 Water-induced landslide hazards, Salem Hills. 1998	10.00
IMS-5 Water-induced landslide hazards, Eola Hills. 2000	10.00
IMS-4 Geology/faults/sedim. thickness, Oregon City quad. 1997	10.00
IMS-3 Tsunami hazard map, Seaside area. 1998	6.00
IMS-2 Tsunami hazard map, Yaquina Bay area. 1997	6.00
IMS-1 Relative EQ hazards, Portland metro area. 1997	12.00

MINED LAND RECLAMATION PROGRAM STATUS MAPS

MLR-03 Clackamas County. 1998	10.00
MLR-10 Douglas County. 1998	10.00
MLR-17 Josephine County. 1998	10.00
MLR-24 Marion County. 1998	10.00

U.S. GEOLOGICAL SURVEY MAPS PLOTTED ON DEMAND

OFR 97-513 Volcano hazards at Newberry volcano	10.00
OFR 97-089 Volcano hazards in the Mount Hood region	10.00
OFR 94-021 Geologic map, Tillamook highlands (2 sheets)	20.00

BULLETINS

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

OIL AND GAS INVESTIGATIONS

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

SPECIAL PAPERS

33 Penrose Conference summary and abstracts. 2000	15.00
32 Geologic hazards: Reducing Oregon's losses. 2000	10.00
31 Mitigating geol. hazards:Technical reference manual. 2000	20.00
30 EQ-induced slope instability: Mapping methodology. 2000	15.00
29 Earthquake damage and loss estimates for Oregon. 1999	10.00
28 Earthquakes Symposium Proceedings, AEG Meeting. 1997	12.00
27 Construction aggregate markets and forecast. 1995	15.00
26 Cross section, N. Coast Range to continental slope. 1992	11.00
25 Pumice in Oregon. 1992	9.00
24 Index to Forums on Industrial Minerals, 1965-1989. 1990	7.00
23 Forum on Industrial Minerals, 1989, Proceedings. 1990	10.00
22 Silica in Oregon. 1990	8.00
21 Geology, NW¼ Broken Top 15' quad., Deschutes Co. 1987	6.00
20 Bentonite in Oregon. 1989	7.00
19 Limestone deposits in Oregon. 1989	9.00
18 Investigations of talc in Oregon. 1988	8.00
17 Bibliography of Oregon paleontology, 1792-1983. 1984	7.00
16 Index to Ore Bin and Oregon Geology (1939-82). 1983	5.00
15 Geology/geothermal resources, central Cascades. 1983	13.00
14 Geology/geothermal resources, Mount Hood area. 1982	8.00
13 Faults and lineaments of southern Cascades, Oregon. 1981	5.00

(Continued on next page)

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

	Price
12 Geologic linears, N. part of Cascade Range, Oregon. 1980	4.00
11 Bibliography/index, theses/dissertations, 1899-1982. 1982	7.00
10 Tectonic rotation of the Oregon Western Cascades. 1980	4.00
9 Geology of the Breitenbush Hot Springs quadrangle. 1980	5.00
8 Geology and geochemistry, Mount Hood volcano. 1980	4.00
7 Pluvial Fort Rock Lake, Lake County. 1979	5.00
6 Geology of the La Grande area. 1980	6.00
5 Analysis and forecasts of demand for rock materials. 1979	4.00
4 Heat flow of Oregon. 1978	4.00
3 Rock material, Clackam./Columb./Multn./Wash. Co. 1978	8.00
2 Field geology, SW Broken Top quadrangle. 1978	5.00

MISCELLANEOUS AND SHORT PAPERS (discontinued)

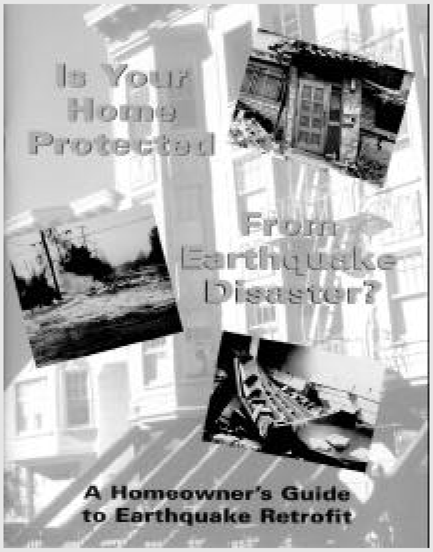
MP 20 Investigations of nickel in Oregon. 1978	6.00
MP 19 Geothermal exploration studies in Oregon, 1976. 1977	4.00
MP 15 Quicksilver deposits in Oregon. 1971	4.00
MP 11 Articles on meteorites (reprints from the Ore Bin). 1968	4.00
MP 5 Oregon's gold placers. 1954	2.00
SP 27 Rock material resources of Benton County. 1978	5.00
SP 25 Petrography of Rattlesnake Formation at type area. 1976	4.00

MISCELLANEOUS PUBLICATIONS

	Price
Oregon fossils.1999	40.95
Living with earthquakes in the Pacific Northwest. 1998	21.95
Islands & Rapids. Geologic story of Hells Canyon. 1998	25.00
The Pacific Northwest coast: Living with shores. 1998	18.50
Hiking Oregon's geology, E.M. Bishop and J.E. Allen, 1996	16.95
Assessing EQ hazards in the PNW (USGS Prof. Paper 1560)	25.00
Geology of Oregon, 5th ed. 1999	41.95
Geologic map of Oregon. 1991	11.50
Geologic highway map (AAPG), PNW region. 1973	8.00
Landsat mosaic map (published by ERSAL, OSU). 1983	11.00
Mist Gas Field map. 2000 (OFR O-00-1)	8.00
Digital disk (CAD formats .DGN, .DWG, .DXF)	25.00
Mist Gas Field production 1979-1992 (OFR O-94-6)	5.00
Oregon rocks and minerals, a description. 1988 (OFR O-88-6)	6.00
Mineral information by county (OFR O-93-8), 1 CD	25.00
Directory of mineral producers. 1993 (OFR O-93-9)	8.00
Geothermal resources of Oregon (DOGAMI/NOAA map). 1982	4.00
Mining claims (State laws on quartz and placer claims)	Free
Back issues of Oregon Geology	3.00

Highlighting Recent Publications

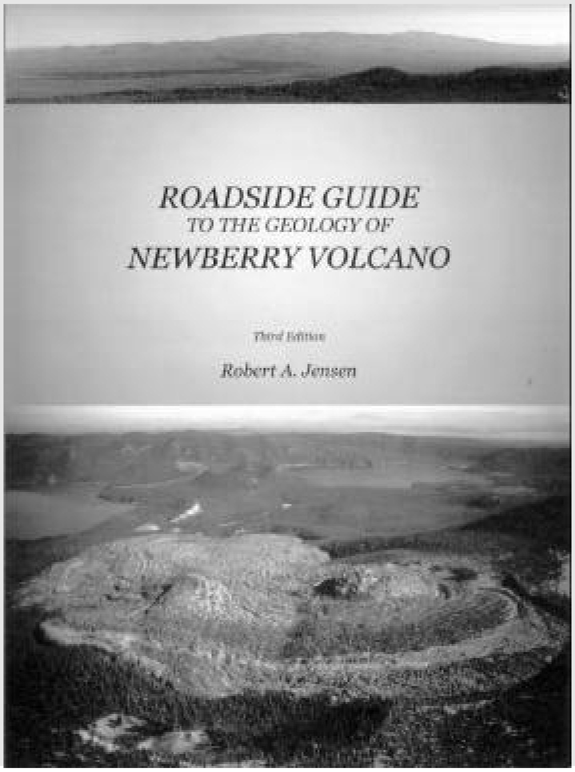
Now available from The Nature of the Northwest Information Center



A new, sensible, and practical contribution to earthquake preparedness: **Is Your home Protected from Earthquake Disaster? A Homeowner's Guide to Earthquake Retrofit.** It was published by the Institute for Business and Home Safety, a nonprofit initiative of the insurance industry. On 42 pages and with many colorful illustrations, earthquakes are explained, what they can do to your home, and what you can do to reduce the possible structural and nonstructural damage. Such advice is quite specific, down to technical drawings and lists of needed tools and materials. The book also helps to estimate the cost of retrofits, lists of useful books, and other sources of information with internet addresses. (Price $5)

* * *

Robert Jensen's **Roadside Guide to the Geology of Newberry Volcano** is now in its third, updated edition. The 168-page book is spiral bound for convenient use as a trip guide. It offers some history and extensive, solid geology, based on the latest scientific research—but written, presented, and illustrated for the nontechnical reader. It leads you on 19 (!) field trips between Bend and Fort Rock. (Price $15.95)



(Continued from page 16)

south of Pendleton; there the gravels include sand and silt lenses and are interpreted as a fanglomerate (Hogenson, 1964). The McKay beds are Pliocene, according to mammal fossils (Shotwell, 1956); they may correlate with the Dalles Formation to the west (Newcomb, 1966). Most of the cobbles are derived from erosion of the Columbia River basalt in the Blue Mountains.

27.5 *Turn left (southeast) after Wildhorse Casino* (elevation 1,400 ft)*, enter Interstate 84 (at unmarked Exit 216) and follow it toward La Grande.*

29.8 *Start up Blue Mountain anticline.* The elevation increases from less than 2,000 ft to more than 3,000 ft in a few miles and eventually reaches more than 4,000 ft at the top of the anticline. Most of the road cuts are in the Grande Ronde Basalt of the Columbia River Basalt Group, but on top of the Blue Mountains you can see some Wanapum Basalt.

40.4 *Rest area on Interstate 84 at Deadman Pass* (elevation 3,615 ft).

45.4 *Emigrant Spring State Park* (elevation 3,800 ft).

52.9 *"Summit" of Blue Mountains* (elevation 4,193 ft).
This is approximately the axis of the Blue Mountain anticline (Walker, 1973).

64.1 *Hilgard Junction State Park at exit 252 of Interstate 84.*
Here the Grande Ronde River at mile 170 (170 river miles above its confluence with the Snake River) is at an elevation of 3,000 ft. It is incised about 500 ft into the Grande Ronde Basalt. From here downstream to La Grande and upstream to Red Bridge Wayside, the Grande Ronde River lies close to the axis of the Grande Ronde syncline (Ferns and others, in preparation). The western part of the state park is on a terrace about 38 ft above the meandering river. The strath terrace has gravels over basalt.

66.5 Starting at milepost 255 on Interstate 84, you find exposures of Mazama ash on the south bank of the Grande Ronde River (see Stop 11). The ash is interpreted as filling gullies that existed during the huge eruption at Crater Lake about 6,845 years ago.

67.7 *Cross Grande Ronde River.*

67.8 Optional Stop P — Cutoff incised meander.
Take Exit 256 to Perry on Interstate 84. The stop is about 1 mi east at the Perry cutoff incised meander (Barrash and others, 1980) which is visible at mile 68.8 on this road log. From the exit ramp bear left and cross over Interstate 84. Bear left again and turn right at Frontage Road. Proceed southeast through the western portion of the community of Perry and cross the bridge to the north side of the Grande Ronde River. Turn left under the railroad tracks to the eastern portion of the community of Perry.
The core of the cutoff incised meander (Figure 3) is a hill of Grande Ronde basalt rising about 200 ft above the abandoned river course, which drops from 2,903 ft to below 2,880 ft. The elevation of the Grande Ronde River here is about 2,870 ft; the canyon rises to 4,650 ft (Mahoghany Mountain) on the north and to about 3,900 ft on the south. The canyon walls are mostly cut in Grande Ronde Basalt, but younger volcanic rocks (Powder River equivalents?) are present at the top of the canyon on both sides. A landslide occurred on the steep slope on the northeast side of the cutoff incised meander (Barrash and others, 1980). Three more cutoff incised meanders lie along the lower Grande Ronde River (Gerber and others, 2000).
Perry was the site of a sawmill and log-catch dam at the turn of the century. Each day, five "splash dams" along the upper Grande Ronde River were opened to flush logs downstream to the mill (Gildemeister, 1999).

Return to Interstate Highway 84. (Road-log mileage continues as if this optional stop was not visited.)

68.8 *Cross Grande Ronde River.*
View of Perry cutoff incised meander to north.

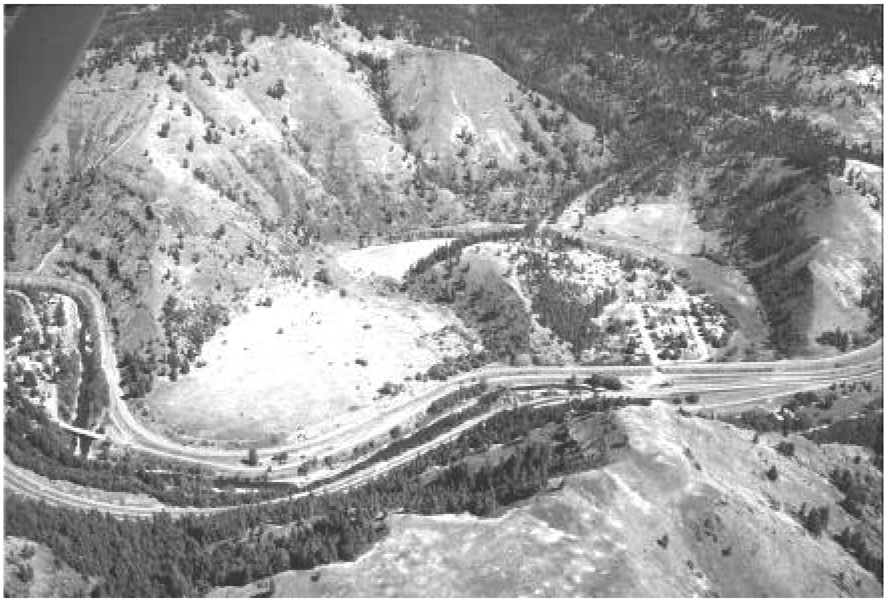


Figure 3. Cutoff incised meander of Grande Ronde River at Perry. To the left of the town of Perry lies the abandoned core of the meander. Behind Perry rises the toe of an ancient landslide. Grande Ronde River flows from left (west) to right.

70.8 Lateritic paleosol between flows of the Grande Ronde Basalt, between bridges over the Grande Ronde River.

Take exit 259 to La Grande on U.S. Highway 30 (sign to Elgin and Wallowa Lake via Oregon Highway 82).

71.0 *Cross Grande Ronde River.* Enter Grande Ronde Valley in La Grande Basin (see Stop 4).

71.5 *Enter La Grande.*

72.0 *Bear left onto Adams Avenue.*

72.3 *At the stoplight at Second Street* (elevation 2,790 ft)*, turn left (north) toward Fairgrounds.*

72.6 *Overpass at railroad tracks.*

73.2 *Overpass at Interstate Highway 84 and the Grande Ronde River; then bear left.*

73.4 *Bear right at Union County Fairgrounds.*

73.5 *Go straight at stop sign. Second Street becomes Black Hawk Trail Lane.*
The toe of a large landslide is straight ahead (see Stop 4).

73.6 *Black Hawk Trail Lane turns left (west)*
and then passes the toe of a smaller landslide on the right (north).

74.3 *At base of hill, Black Hawk Trail lane turns right (north) uphill and becomes Fox Hill Road.*
Note shallow road cuts of fine-grained sediments at base of hill. On the hillside are the Union County Landfill and quarries/gravel pits in the Grande Ronde Basalt. What are the potential problems of a landfill here?

75.3 Stop 4 — Overview of landslide and Grande Ronde Valley/ La Grande Basin

This stop is at a slight left turn in Fox Hill Road, at an elevation of 3,630 ft. Walk east 50 m (160 ft) to the top of the scarp.

The La Grande Basin (Figure 4) is surrounded mostly by Grande Ronde Basalt but partly by younger volcanic rocks (especially to the west) (Barrash and others, 1980). It is bordered by a few large down-to-the-west normal faults on the northeast and many smaller down-to-the-east normal faults on the southwest (Tolan and Reidel, 1989). Truncated spurs are particularly prominent along the northeastern side of the basin. The Grande Ronde River has a very low gradient across the basin; there are meanders, oxbows, and meander scars. A major shortcut was created in the 1870s with the excavation of the State Ditch, which is approximately 7.2 km (4.5 mi) long and bypasses about 63 km (39 mi) of the river, from river mile 154 to river mile 115. Fromwiller and Van Tassel (1999) summarized the development of the Grande Ronde Valley. It has been interpreted as an extensional graben (a northern extremity of the Basin and Range) or as a pull-apart basin related to motion along the Olympic-Wallowa lineament. The initial formation was

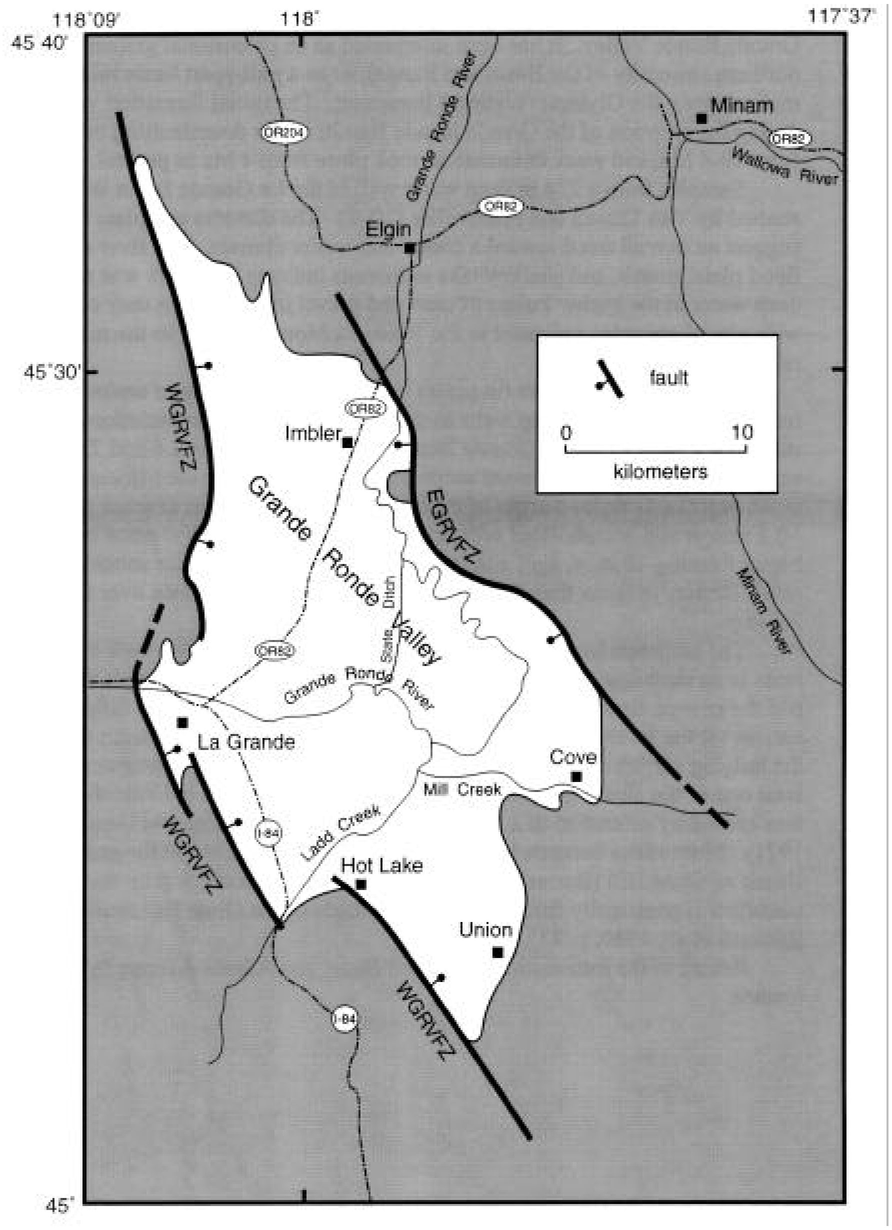


Figure 4. Map of Grande Ronde Valley/La Grande Basin, showing the graben bordered by the West Grand Ronde Valley fault zone (WGRVFZ) and the East Grand Ronde Valley fault zone (EGRVFZ). After Personius (1998).

during the eruption of the Grande Ronde Basalt; major downfaulting occurred from 10 to 4 Ma, and weak deformation took place from 4 Ma to the present.

Samples from a 224-m-deep (735 ft) water well in the La Grande Basin were studied by Fromwiller and Van Tassel (1999). The diatoms and plant fossils suggest an overall trend toward a cooler and wetter climate. River channel, flood plain, marsh, and shallow-lake sediments indicate that the basin was never filled with deep water. Pulses of sand and gravel into the basin may correlate with glacial episodes indicated in the Wallowa Mountains and in the marine record.

Van Tassell and others (2000) used ^{40}Ar/^{39}Ar dating of tephra samples recovered from several deep wells to determine sediment accumulation and subsidence rates of the La Grande Basin. Ash layers dated at 2.6 and 7.5 Ma suggest the following: (1) sediment accumulation began during the Miocene; (2) the southwest (La Grande) margin of the basin has subsided at an average rate of ~0.2 mm/yr and accumulated sediment at a rate of ~0.05 mm/yr since the basin began forming ~9 m.y. ago; and (3) over the past 2.6 m.y., the southwest basin margin has subsided at a rate 0.02 mm/yr faster than the northeast (Cove) side of the basin.

The landslide here may have originated as a slump, but the bulk of the mass is an earthflow (Figure 5). The top of the concave main scarp is at 4,020 ft, and the convex tip of the earthflow is at 2,860 ft. The top half of the failure is narrow: at the level of this stop it is about 200 m (650 ft) wide; the maximum width of the bulging earthflow toe is more than 900 m (3,000 ft). The earthflow is hummocky; at least one of the closed depressions contains a small pond. It is likely that failure was caused by saturation of a fine-grained interbed (Schlicker and Deacon, 1971). Most of the bedrock here is Grande Ronde Basalt, but at the scarp it is the Basalt of Glass Hill (Barrash and others, 1980). "Rock debris making up the earthflow is principally from flows and interbeds of the Glass Hill sequence" (Barrash and others, 1980, p. 23).

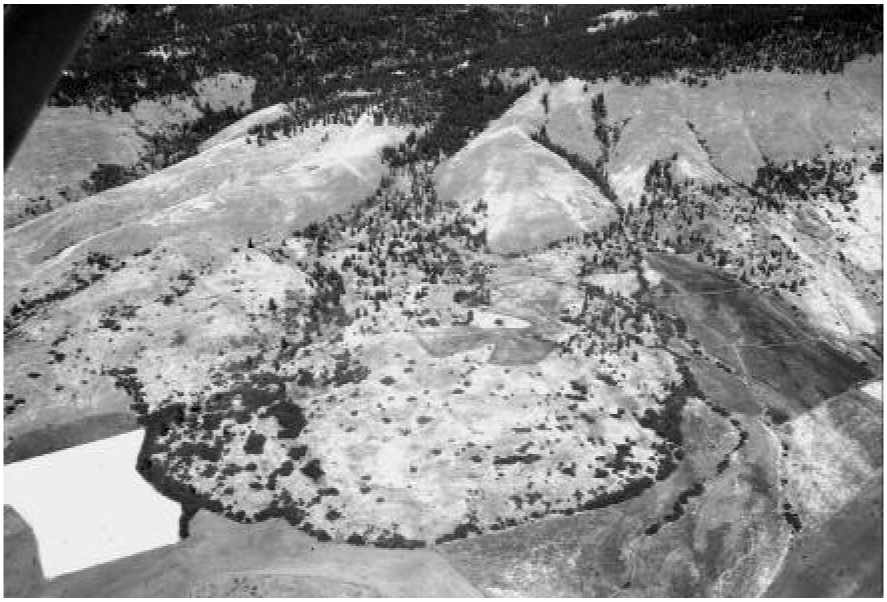


Figure 5. Landslide north of La Grande discussed at Stop 4. The mass-wasting event originated as a small slump at the top of the slope and spread out as an earthflow on the floor of the Grande Ronde Valley. The city landfill is along the road on the ridge to the left (west).

Return to the intersection of Second Street and Adams Avenue in La Grande.

Part 2 — La Grande to Cricket Flat

0.0 *Go east on Adams Avenue (U.S. Highway 30) from the intersection with Second Street.*

0.2 *At stoplight, bear right on Adams Avenue through downtown La Grande* (elevation 2,787 ft).

A block farther northeast are the Union Pacific Railroad yards. Underground fuel lines between underground storage tanks and the main line leaked diesel fuel from the mid-1950s until the early 1980s. The diesel fuel contaminated groundwater and soil. In the 1980s, monitoring and recovery operations were performed. Pumps recovered 44,680 gallons of diesel oil that was floating on the water table (The Observer, La Grande, Oregon, January 11, 1996). As of the mid-1990s, concerns still persisted about health and property values near the rail yards. Soil in and around the rail yards remained wet with diesel oil (Michael Anderson, Oregon Department of Environmental Quality, written communication, 1995). Downtown commercial properties had their market values lowered. The City of La Grande and downtown property owners sued the railroad in 1996 and agreed to a settlement in 1997. The lawsuit cited consequences from the contamination including diminished property values, loss of groundwater use for decades, health and safety claims, and blight and damage to surface water and potential drinking water (The Observer, La Grande, Oregon, January 11, 1996). The out-of-court settlement included payment by the Union Pacific Railroad to the City of La Grande and more than 40 private litigants of more than $13 million and the company's agreement to clean up property and wells (The Observer, La Grande, Oregon, November 26, 1997). A representative of the Union Pacific Railroad stated that the cleanup would take less than 15 years (The Observer, La Grande, Oregon, February 25, 1998). It was then discovered that the plume of contamination may be larger than earlier indicated, and 40 more property owners planned to sue the Union Pacific Railroad (The Observer, La Grande, Oregon, April 16, 1999).

0.7 *Turn left (northeast) on Oregon Highway 82 (Island Avenue) toward Elgin and Wallowa Lake.*
Just to the southwest, the campus of Eastern Oregon University sits on a terrace about 33 ft (10 m) above downtown La Grande. Jay Van Tassell obtained a radiocarbon age of 15,280 ± 180 years from a mammoth tooth in loess on top of the terrace gravels (Van Tassel, oral communication, 2000).

1.7 *Underpass beneath Interstate Highway 84.*

2.4 *Enter Island City.*
This town was an island prior to the 1964 flood, which also damaged La Grande (Van Tassell, oral communication, 1999).

3.2 *Turn left (north) at stop light (sign to Imbler, Elgin, and Enterprise).*

3.3 *Cross Grande Ronde River and bear right, continuing on Oregon Highway 82.*
Between here and Imbler are good views of the fault scarps and truncated spurs to the east. The high point, Mount Harris (elevation 5,357 ft) is a volcanic complex with a summit composed of rhyodacite; some of the lava flows of this volcano are dark andesites (Mark Ferns and Vicki McConnell, Oregon Department of Geology and Mineral Industries, oral communications, 1999).

12.8 *Enter Imbler* (elevation 2,718 ft), which is situated on top of Sand Ridge.

16.1 *Leave Grande Ronde Valley.*
For the next 3 mi or so, Oregon Highway 82 is just west of the Grande Ronde River. The river is confined between Pumpkin Ridge to the west and a ridge extending north from Mount Harris to the east.
An earthflow happened here in February 1996 during a rain-on-snow event that caused floods and landslides throughout the Pacific Northwest (Carson and others, 1998). The earthflow is part of an older landslide complex moving from Pumpkin Ridge toward the Grande Ronde River. The 1996 earthflow dropped the highway, and its toe covered the railroad below. The Oregon State Highway Department installed horizontal drains in the upper part of the slide and placed rocks at its base (Jay Van Tassell, oral communication, 2000). The total cost of cleanup and stabilization of the 1996 landslide was $147,668.

17.9 *Cross Grande Ronde River. Enter Indian Valley, the Elgin Basin.*
The Elgin Basin may be a small example of an extensional graben or pull-apart basin (see Stop 4).

19.3 *Cross Grande Ronde River (again!).*

19.6 *Enter Elgin.*

20.1 *Intersection of Oregon Highways 204 and 82.*
Oregon Highway 204 goes over the Blue Mountains and is a shorter route to Milton-Freewater than the one through La Grande.

20.2 *Oregon Highway 82 turns right (east) in downtown Elgin* (elevation 2,670 ft).

20.5 *Cross Grande Ronde River (last time!).*
The southern of two Twin Coves landslides straight ahead.

21.0 Stop 5 — Overview of Indian Valley/Elgin Basin.
Stop near Oregon Highway 82 milepost 21.
The *Geologic Map of Oregon* by Walker and MacLeod (1991) shows almost all Columbia River Basalt Group from here to Cricket Flat. However, pyroclastic units and at least one andesite flow have been found in the area (Swanson and others, 1981; Carson and others, 1989).
Several northwest-trending faults are located in the vicinity of Elgin. Jones Butte, about 4.4 km (2.7 mi) northwest of this stop, is a volcanic dome complex exposed by erosion. With an age of only 2 Ma, it is the youngest known volcanic rock of this area (Mark Ferns, Oregon Department of Geology and Mineral Industries, written communication, 1999). The cliff that is visible 6.5 km (4 mi) north-northwest of this stop, a landslide scarp known as Rockwall, is an andesite flow tentatively assigned to the Miocene-Pliocene Powder River volcanic rocks and informally named here the andesite of Rockwall (Figure 6). The andesite of Rockwall overlies tuff; this creates a huge area of landslide terrain between the Rockwall and the Grande Ronde River.
A similar situation exists at the Twin Coves: Basalt capping the hill to the east overlies felsic tuff exposed in the road cut here. Each of the Twin Coves is a landslide, with a slump at the top and an earthflow below.
To the northwest, on the west side of the Grande Ronde River, a railroad cut exposes 10 m (30 ft) of sandy gravels containing basalt cobbles. There appears to be a buried soil or overbank deposits 2–3 m (6–10 ft) below the top. The gravels are interpreted to be fluvial, with some hyperconcentrated flow events. They were mapped as Quaternary by Walker (1979).

21.2 The northern of the Twin Cove landslides to the east.

21.3 Tuff exposed in failing road cut.

Figure 6. Columns of the andesite of Rockwall discussed at Stop 5. Rockwall is a landslide scarp in an andesite flow 6 km (3.7 mi) north of Elgin. The andesite is tentatively assigned to the Miocene-Pliocene Powder River volcanic rocks.

24.8 Tuff in road cuts.

25.4 *Turn right (south) onto Hindman Road.*

27.4 *Turn left (east) onto the south part of Roulet Loop.*

28.1 Stop 6 — Pumicite

Small road cut of pumicite on south side of hill. A lava flow caps the hilltop (elevation 3,570 ft). This consolidated pumice is exposed here and there for almost a mile to the east. Buttes of pumicite occur north of the Roulet Loop just 0.5 mi to the east. The pumicite is probably related to the Powder River volcanic rocks. No source for the pumice clasts is known, but a vent is assumed to be close. According to Mark Ferns (Oregon Department of Geology and Mineral Industries, written communication, 1999), similar pyroclastics are found along Indian Creek to the south, and Ferns observes that they may make a useful "stratigraphic marker between the top of the Grande Ronde [Basalt] and the base of the olivine basalt flows."

Return to the intersection of Hindman Road and Oregon Highway 82 and park here for Stop 7.

Part 3 — Cricket Flat to Minam

0.0 Stop 7 — Volcanic rocks

Exposure on Oregon Highway 82 just east of Hindman Road. From the intersection, walk east along the north side of Oregon Highway 82 (being very careful of traffic!). The ditch and road cut contain tuff with lithic clasts up to 40 cm across. The clasts are mostly from Tertiary lava flows, but some are from Mesozoic rocks and quartzites of unknown age (probably Proterozoic or Paleozoic). Quartzite-rich alluvium and scattered boulders and cobbles are known from a wide area of northeastern Oregon. Where in place, they overlie Mesozoic rocks and are below Tertiary volcanic rocks (Allen, 1991; Carson and others, 1995; Trafton, 1999). The tuff also contains abundant pumice clasts of various sizes and scattered obsidian Apache tears up to 3 cm across. Also found are rare fossils (imprints) of leaves of deciduous trees and fragments of partially carbonized wood. The tuff, probably related to the Powder River volcanic rocks, may be a lahar but is more likely to be a pyroclastic flow deposit. Wood was charred where the pyroclastic flow was hotter, closer to the vent, but here the temperature had cooled enough so that leaves did not burn. The fragments of Mesozoic rocks may have been ripped out of the conduit, but some are rounded, suggesting that they were incorporated into the pyroclastic flow as it crossed stream gravels.

At the east end of the exposure, the tuff is capped by a paleosol with vertical prisms (Figure 7).

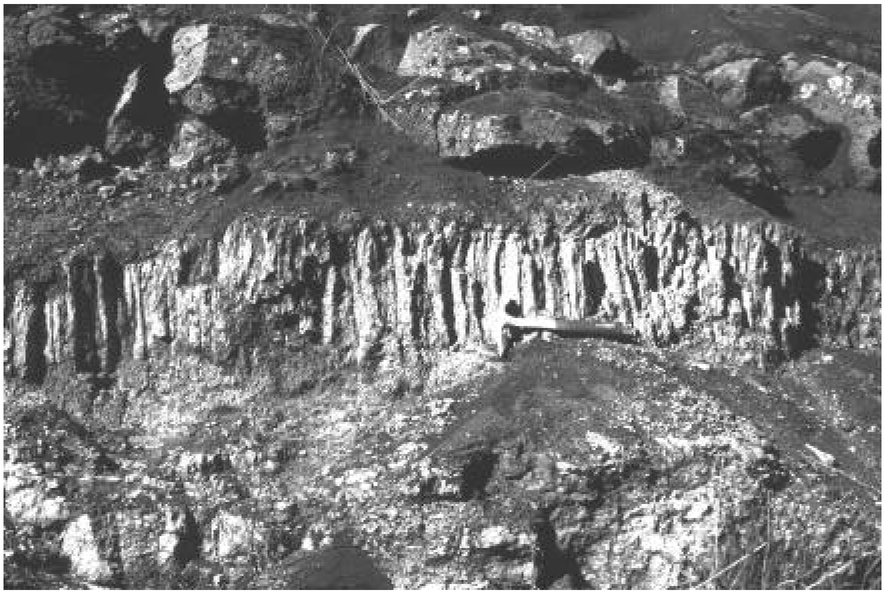


Figure 7. Volcanic rocks at Cricket Flat, in road cut discussed at Stop 7. From bottom to top, we see the top of a pyroclastic flow deposit, a soil and/or bake zone with vertical prisms, and the base of an olivine basalt flow.

The feature may be related to baking by the overlying basalt flow. Hooper and Swanson make brief reference to the geology of this area: "The Cricket Flat [olivine basalt] flow is locally underlain by a silicic ash-flow tuff" (Hooper and Swanson, 1990, p. 89).

Return to vehicle and continue east on Oregon Highway 82.
Between here and Minam Summit the patterned ground (Figure 8) is similar to that on the tops of Washington's Yakima Hills and Oregon's Deschutes-Umatilla Plateau. The silt mounds are about 1 m (3 ft) high and 10 m (30 ft) in diameter. They appear to be remnants of a loess cover over the youngest basalt flow (Figure 8).

1.0 Quarry in basalt flow.

3.4 *Minam Summit* (elevation 3,660 ft).

4.4 Beginning of an almost continuous exposure of Grande Ronde Basalt of the Columbia River Basalt Group. To the east, the Minam River has cut through about 300 m (1,000 ft) of these lava flows.

5.8 Stop 8 — Grande Ronde Basalt in canyon of Minam River
Park on the east side of the road just north of a "bridge" over the west side of the canyon.
Note the small landslide scars on the east side of the canyon. Some of the mass-wasting occurred during a rain-on-snow event in February, 1996 (Carson and others, 1998).
The basalt flows exhibit columnar jointing, flowtop breccias, and vesicles of various sizes. Exposures of red tuffaceous paleosols between lava flows are common in these road cuts. Enough time passed between eruptions for lateritic soils to develop in the subtropical climate. The climate interpretation is substantiated by the species of trees at Ginkgo Petrified Forest State Park in central Washington (Carson and others, 1987).

Figure 8. Patterned ground on Cricket Flat west of Minam Summit. The silt mounds, about 1 m (3 ft) high and 10 m (30 ft) in diameter, overlie basalt. Photo by Pat Spencer.

In places, spiracles are found: cones of fractured basalt extending from a breccia at the base of a lava flow perhaps to its top. A spiracle is probably created by a steam blast derived from superheating in a local pocket of water-saturated sediments (Mackin, 1961).

Walk uphill (south) along the west side of the highway
to a horizontal 1-m-diameter (3-ft) cylindrical hole in the cliff. This is the largest of several lava tree molds with bark impressions.

6.9 Beginning of an area of unstable slope—unstable because of the presence of a fault zone and a thick paleosol. The Oregon State Highway Department has put concrete and drains at the weak paleosol, visible where the concrete has fallen.

7.6 *Union-Wallowa County line.*

7.9 *Stream gage on Minam River.*

8.2 *Minam* (elevation 2,537 ft).
Turn left (north), off Highway 82, toward Minam State Park along the west bank of the Wallowa River.

9.7 Stop 9 — Columbia River basalt dike at Minam State Park
Park your vehicle just ahead at the state park; walk back to the dike.
The constriction in the Wallowa River (the water turns into a rapid here, at some discharges) is due to the presence of a north-striking dike of Grande Ronde Basalt which cuts through slightly older Grande Ronde Basalt flows.

Return south to the junction with Oregon Highway 82 at Minam.

Part 4 — Minam to Lostine

0.0 *Junction of Oregon Highway 82 with road to Minam State Park. Go east toward Wallowa Valley.*

0.1 *Bridge over Wallowa River and its tributary, the Minam River.*
Like the Minam River, the Wallowa River is incised about 300 m (1,000 ft) into the Grande Ronde Basalt.

2.8 *Wallowa Wayside State Park.*

5.7 Stone stripes straight ahead on west-facing slope of canyon wall (north side of Wallowa River). Stone stripes are a form of sorted patterned ground in which stripes of coarse rock fragments occur between stripes of finer material (Washburn, 1956).

6.0 *Rest area.*

8.3 Leave canyon of Wallowa River. Cross Olympic-Wallowa lineament. Enter Wallowa Valley. The Olympic-Wallowa lineament strikes southeast, with the Wallowa Mountains uplifted to the southwest, and the Joseph Upland, capped with Grande Ronde Basalt, located to the northeast of the Wallowa Valley.

12.1 *Cross Wallowa River.*

12.5 *Enter Wallowa* (elevation 2,948 ft).

16.0 The right lateral moraine of the valley glacier that occupied the glacial trough along the Lostine River is straight ahead. An alluvial fan complex is at the base of the Wallowa Mountains to the south.

20.6 *Enter Lostine* (elevation 3,363 ft).

20.9 *Go straight (south) toward "Lostine River campgrounds," leaving Oregon Highway 82 where it veers left (east) toward Enterprise.*

21.9 Drop from outwash terrace and onto floodplain of Lostine River. Outwash gravels are exposed here.

22.8 Climb up from floodplain to lowest terrace.

23.1 Climb up onto prominent outwash terrace. Boulders to the east are associated with right lateral moraines of the Lostine glacier. The Lostine valley glacier (Figure 9), 35 km (22 mi) long when it was at its maximum about 15,000–20,000 years ago, was the longest in the Wallowa Mountains, originating near Eagle Cap (elevation 9,595 ft) in the center of the range and descending to an elevation of 3,380 ft (Allen, 1975).

24.1 Road goes through gap in largest end moraine; smaller terminal and recessional moraines are to the north and south.

25.1 Small end moraine with dirt road on top loops westward across valley floor. The lake just to the south is impounded with a low, moraine-looking, artificial levee or earthen dam.

26.0 Miocene Grande Ronde Basalt crops out immediately to the east; yet straight ahead, high on the eastern wall of the glacial trough, is Triassic Martin Bridge Limestone (limestone and marble). These outcrops must be separated by a major fault along the Olympic-Wallowa lineament.

26.9 The quarry to the east is in the Triassic Lower Sedimentary Series (see Stop 10), which here consists of weakly metamorphosed shale, sandstone, and black limestone.

Do not enter the quarry without permission!

27.5 *Cross Lostine River.*

28.4 Stop 10 — Triassic Lower Sedimentary Series
This unit is mostly marine shale and sandstone that have been altered to hornfels and schist near the Wallowa batholith (Smith and Allen, 1941). Here the foliation, which is parallel to the bedding, dips east. The thickness of the Lower Sedimentary Series is 0–600 m (0–2,000 ft). It rests conformably on top of the Clover Creek Greenstone and is separated from the overlying Martin Bridge Limestone (Martin Bridge formation of Smith and Allen, 1941) by an unconformity. Look high on the west side of the glacial trough to see the Martin Bridge Limestone and, above that, the Columbia River basalts.

28.5 Pleistocene till in road cut.

28.8 *Enter Wallowa-Whitman National Forest.*

28.9 Folded rocks of the Lower Sedimentary Series.

29.3 Stop 11 — Mesozoic Wallowa batholith at Pole Bridge
The old wooden bridge over the Lostine River has been replaced by a concrete bridge. The batholith was intruded during the Late Jurassic and Early Cretaceous, between 160 and 120 million years ago (Orr and others, 1992). The Wallowa batholith is a composite

Figure 9. View north from Eagle Cap down the Lostine glacial trough. In the foreground are snowfields and Holocene moraines at the base of Eagle Cap. Granitic bedrock in the middle ground is part of the Wallowa batholith.

intrusion that commenced with many small gabbroic bodies, continued with four major units of zoned tonalite-granodiorite, and terminated with many small felsic masses (Taubeneck, 1987). Above the northwest end of the bridge the granodiorite has been smoothed by the overriding Lostine glacier.

The gorge just upstream is due, at least in part, to erosion by glacial meltwater and the Lostine River. Look at the east wall of the glacial trough. At bridge level you see the Triassic Lower Sedimentary Series. Above it lies the Triassic Martin Bridge Limestone (limestone and marble). Conformably overlying the Martin Bridge Limestone is the Late Triassic-Early Jurassic Hurwal Formation, composed of shale, sandstone, slate, and hornfels up to 1,500 m (~4,900 ft) thick (Baldwin, 1981). These Triassic and Jurassic strata are part of the Wallowa terrane (Vallier, 1998). Fossils of mollusks, corals, and ichthyosaurs in the Martin Bridge Limestone and the Hurwal Formation are similar to fossils found in rocks across southern Eurasia (Orr and others, 1992).

Walk 100 m (300 ft) along the road to the southeast and a road cut in a small, steep, postglacial alluvial fan.

Near the top you see a large lens of Mazama ash (Figure 10). Mount Mazama underwent a catastrophic eruption and caldera-forming collapse that led to today's Crater Lake 6,845 ± 50 ^{14}C yr B.P. (Bacon, 1983), or 5,677 ± 150 B.C. (Zdanowicz and others, 1999). The original tephra fall here was perhaps 10–20 cm thick (Farren and Carson, 1998), but it was eroded from the uplands and concentrated in this alluvial fan.

Return north to the junction with Oregon Highway 82 in Lostine.

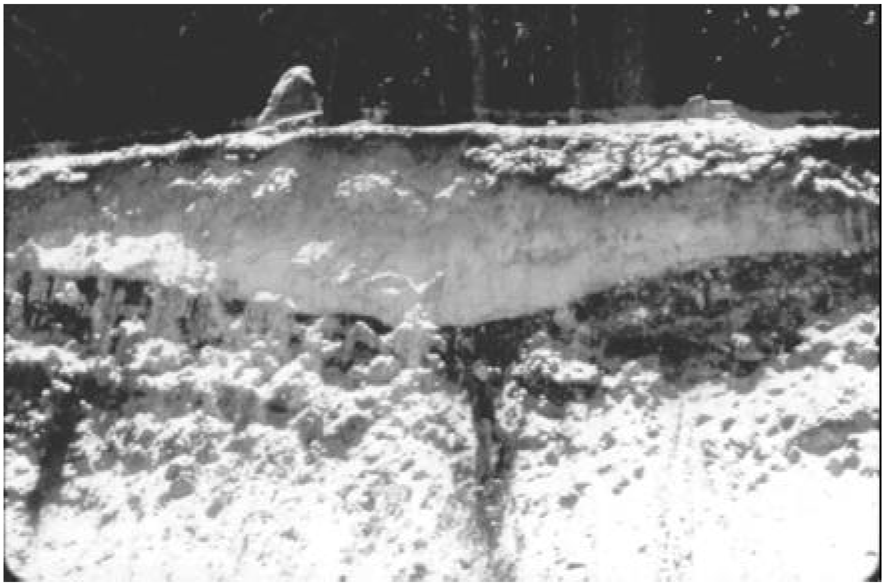


Figure 10. Lens of Mazama ash near top of aluvial fan near Pole Bridge over the Lostine River, as seen at Stop 10. The Mazama ash was erupted about 6,800 years ago, in the eruption that produced Crater Lake.

Part 5 — Lostine to Joseph

0.0 *Junction of Lostine River Road with Oregon Highway 82. Go east on Oregon Highway 82 toward Enterprise.*

2.2 Road cuts in Grande Ronde Basalt of the Columbia River Basalt Group on the east side of Wades Point. Note the prominent red lateritic paleosol just above road level.

5.0 *Cross the Wallowa River.*

7.9 Stop 12 — Grande Ronde Basalt

This stop is near the middle of 1.6 mi of road cuts in the Grande Ronde Basalt (about 16 m.y. old) of the Columbia River Basalt Group. To the west of a fault (dipping steeply west) is a single thick flow of weathered basalt. To the east of the fault are dozens of thin flows including black glassy basalt and red scoriaceous basalt (Figure 11). Four small, west-dipping dikes may be associated with a larger vent (not visible in the road cut) that was the source of the east-dipping thin flows. These thin flows may be the eastern part of a cone. To the east of the small dikes, an abrupt steepening of the thin flows may be due to collapse accompanied by rafting away of a portion of the cone by a thick lava flow exposed in the east part of the road cut.

Columbia River Basalt Group flows are also on top of Sheep Ridge, about 7 km (4.4 mi) to the southwest at an elevation of more than 7,600 ft. Sheep Ridge is on the upthrown side of the Wallowa Fault (part of the Olympic-Wallowa lineament). The maximum displacement along the Wallowa Fault is 2–2.4 km (1.2–1.5 mi) (Taubeneck, 1997).

9.3 *Enter Enterprise* (elevation 3,757 ft).

In the road cut just ahead on the left you see Enterprise Gravel (see Stop 13).

9.5 Stop 13 — East end of type locality for Enterprise Gravel

Visible to the southwest are (1) the modern course of the Wallowa River; (2) Alder Slope, a complex of alluvial fans; (3) the Olympic-Wallowa lineament; and (4) the Wallowa Mountains, with northeast-facing cirques. To the south, the Hurricane Creek glacial trough shows small moraines at its mouth. To the southeast, you

Figure 11. Columbia River basalt along Oregon Highway 82, discussed at Stop 12. Gray, massive basalt and red, scoriaceous basalt are cut by a small gray dike.

see the huge moraines of Wallowa Lake.

The Enterprise Gravel was defined and characterized by Spencer and Carson (1995). The unit includes silt, sand, gravel, and diamict and represents a braided-stream complex associated with a glaciofluvial environment and probable mudflows. Clast lithology and paleocurrent indicators show that the Enterprise Gravel was deposited by the ancestral Wallowa River that flowed north across the Joseph Upland—not northwest in the Wallowa Valley and parallel to the Olympic-Wallowa lineament as today. On the basis of magnetic polarity analyses and the presence of paleosols, a large assemblage of vertebrate fossils, and the Chief Joseph tephra of Spencer and Carson (1995), it was determined that the Enterprise Gravel is late Pliocene to middle Pleistocene. Vertebrates found at this exposure and in a gravel pit north of Enterprise include horse, pig, wolf or coyote, mammoth or mastodon, and bird (Figure 12). The unit is tilted to the south, which suggests neotectonism along the Olympic-Wallowa lineament.

Continue east on Oregon Highway 82 through Enterprise.

10.2 *At stop sign in downtown Enterprise, turn right (south) toward Joseph and Wallowa Lake.*

10.6 *Veer left (east), staying on Oregon Highway 82.*
The road straight ahead (south) is one route to Hurricane Creek.

14.0 Wallowa Lake moraines are straight ahead. The road goes south up the outwash fan.

16.2 *Enter Joseph* (elevation 4,190 ft).

16.7 *Turn right (west) on Wallowa Avenue.*
Note the cirques and avalanche tracks along the steep northeastern front of the Wallowa Mountains.

17.1 *Cross Wallowa River.*

17.9 The Joseph airport is on the right. The road climbs the Hurricane Creek outwash fan.

18.5 Moraines of the Hurricane glacier are visible ahead.

18.8 *Cross Hurricane Creek.*

18.9 *Turn left (south) on gravel road at Hurricane Grange.*

19.0 Cross terminal moraine of the Hurricane glacier, which was 21 km (13 mi) long and terminated at an elevation of about 4,200 ft (Allen, 1975). The next 1.1 mi show many small end moraines.

20.6 Till exposure.

20.8 *Enter Wallowa-Whitman National Forest.*
Here the west side of the Hurricane glacial trough has a huge talus accumulation. The cliffs above are Clover Creek Greenstone.

21.3 In the spring of 1999, the small creek here was subject to a hyperconcentrated flow event, which is transitional between water floods and debris flows. The sediment concentration in a hyperconcentrated flow is 40–70 percent by weight (Costa, 1987). The event occurred on the steep west slope of the Hurricane glacial trough, with most of the debris piling up at the base of the slope (see mile 22.6).

21.6 Stop 14 — Clover Creek Greenstone in Hurricane Creek valley
Road cuts for the next 0.4 mi are in the Clover Creek Greenstone of Permian and/or Triassic age (Baldwin, 1981). These volcanic and metavolcanic and associated rocks are the oldest part of the Wallowa terrane (Vallier, 1998). The unit includes lavas, pyroclastic rocks, and sediments, and, in the Hurricane Creek valley, greenstone breccia and conglomerate (Smith and Allen, 1941). These rocks are part of an ancient volcanic arc on which carbonate and clastic sedimentary rocks were deposited (Orr and others, 1992).

22.6 A large hyperconcentrated flow event (Costa, 1987) or debris torrent occurred here in the spring of 1999. A mud line high on the Douglas firs indicates the maximum height of the debris torrent. The debris extended across the valley and temporarily blocked Hurricane Creek. Above the road, natural levees can be seen beside the channel. Such events are common in the Wal-

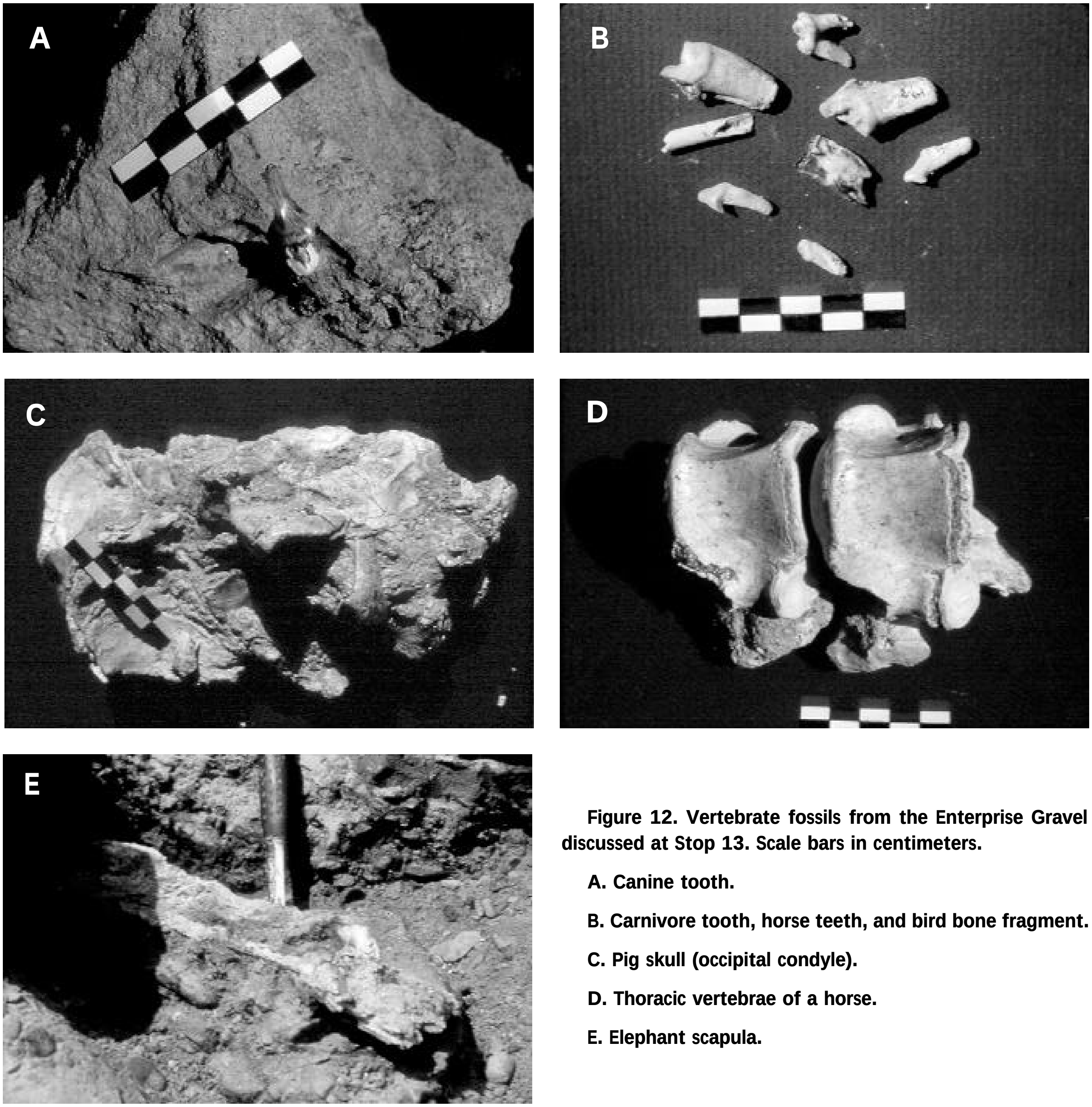


Figure 12. Vertebrate fossils from the Enterprise Gravel discussed at Stop 13. Scale bars in centimeters.

A. Canine tooth.

B. Carnivore tooth, horse teeth, and bird bone fragment.

C. Pig skull (occipital condyle).

D. Thoracic vertebrae of a horse.

E. Elephant scapula.

lowa Mountains. Slope and precipitation appear to be more important factors than bedrock lithology.

22.7 Stop 15 — Martin Bridge Limestone

Park in the lot at the end of the road.

Trail park permit required! Obtain at U.S. Forest Service office in Enterprise.

Walk south along the west side of the valley bottom of Hurricane Creek. In 200 m (650 ft), at a trail junction, go right (southwest) up Falls Creek trail. In another 200 m, you come to a switchback from which you have a good view. You can hear and see the falls of Falls Creek about 250 m (800 ft) to the southwest. The falls are supported by a cliff of Martin Bridge Limestone.

The Triassic Martin Bridge Limestone contains not only limestone and (where metamorphosed) marble but also sandstone and siltstone. The shallow-water platform limestone is as much as 500 m (1,600 ft) thick. In the southeastern Wallowa Mountains, the unit includes a coral reef (Vallier, 1998). Here, the Martin Bridge contains many sandstone layers and exhibits spectacular folds. Climb uphill a short way from the switchback to examine the strata. A summary of the sedimentology and stratigraphy of the Martin Bridge Limestone is contained in Follo (1994).

Falls Creek has been subject to floods and debris torrents. The surface of the alluvial fan downstream from here has been very active.

Walk back to the parking area and return to Joseph.

Part 6 — Joseph to the south end of Wallowa Lake

0.0 *Intersection of Oregon Highway 82 and Wallowa Avenue in Joseph.* This is close to the former terminus of the Wallowa glacier (Allen, 1975).

Drive south toward Wallowa Lake.

0.5 *Veer left at the sign to Wallowa Lake State Park.*

Moraines are visible approximately 1 km (0.6 mi) to the east and west.

0.8 Start crossing huge moraine complex.

1.5 Old Chief Joseph Gravesite and Cemetery on innermost end moraine.

1.6 *Parking lot for Wallowa County Park at south end of Wallowa Lake.*

The elevation (4,382 ft) of this moraine-dammed lake is controlled by the spillway at a small dam just to the west. The glaciolacustrine beds formerly exposed at the south end of the lake and recently covered with riprap indicate that in the past the lake was once a few meters higher. The lake is approximately 200 m (650 ft) deep, and the lateral moraines rise 250 m (800 ft) above the lake surface. The south end of the lake lies in the north end of a glacial trough.

2.0 Stop 16 — Till in right lateral moraine damming Wallowa Lake

From here you have an excellent view of both lateral moraines, the Olympic-Wallowa lineament along the steep northeast front of the Wallowa Mountains, and the glacial troughs along the East Fork and West Fork Wallowa Rivers. To the southwest, note the cirques on the northeast side of Chief Joseph Mountain (elevation 9,616 ft). Two of the major outlet glaciers from the so-called Wallowa ice cap (Allen, 1975) were along the Wallowa River; the West Fork Wallowa valley glacier was 21 km (13 mi) long, whereas the East Fork glacier was 9 km (5.6 mi) long.

Most of the large boulders in this till are granitics from the Wallowa batholith, but some are Clover Creek Greenstone. Some of the boulders are faceted and striated indicating subglacial transport.

Over the years, considerable controversy has raged over land use on the lateral moraines, concerning visual and water-pollution issues as well as potential geologic hazards. Developers want to build on the moraines because of the spectacular views from them and the proximity to Wallowa Lake. Yet the views are so magnificent partly because so few buildings exist on the moraines.

The gondola lift up Mount Howard, the peak on the south-southeast, is on the northwest side of the mountain. Other ski lifts and ski runs are proposed for the north and east sides of the mountain. Many of the lifts and runs, which would necessitate timber clearing, would be visible from the lake. The ski area would be linked to a destination resort.

5.6 View of the Wallowa River delta (ahead on right) and of the glacial trough along the West Fork of the Wallowa River.

6.0 *Junction, veer left (south).*

Road to the right (west) leads to Wallowa Lake State Park, just across the bridge over the Wallowa River.

6.2 Stop 17 — Gondola lift up Mount Howard

The Wallowa Lake Tramway is generally open from late May through September, from 10 a.m. to 4 p.m. or later (information phone number is 541-432-5331). Take warm clothes, buy tickets, and get on the tram (food and drink are available at the top of the tramway).

The tramway climbs up the east side of the glacial trough from 4,450 ft to 8,150 ft. In contrast to the cottonwoods, Douglas and grand firs, western larch, Engelmann spruce, and ponderosa and lodgepole pines in the valley bottom, the summit of Mount Howard has only Engelmann spruce, subalpine fir, and whitebark pine.

On the top of Mount Howard you will find more than 3 km (~2 mi) of walking trails (Figure 13). Early in the season, portions of the trails will be under snowbanks.

At the top, be sure to note the time of the last tram down the mountain!

At the head of the tramway (A in Figure 13), walk southwest to a junction (B); turn right (west), crossing a minor saddle and ascending a small hill (C) of vesicular lava of the Miocene Grande Ronde Basalt (Columbia River Basalt Group).

At point C, clockwise from south to northwest, the view is

South: East Peak, Miocene Columbia River basalt

Southwest: Bonneville Mountain on the arete between the glacial troughs along the East Fork and West Fork Wallowa Rivers—Jurassic-Cretaceous quartz diorite and granodiorite of the Wallowa batholith. Behind and just to the right of Bonneville Mountain, Eagle Cap—also part of the Wallowa batholith.

West-southwest: Matterhorn (bright white), marble of the Triassic Martin Bridge Limestone.

West: Hurwal Divide, an arete of the Triassic-Jurassic Hurwal Formation

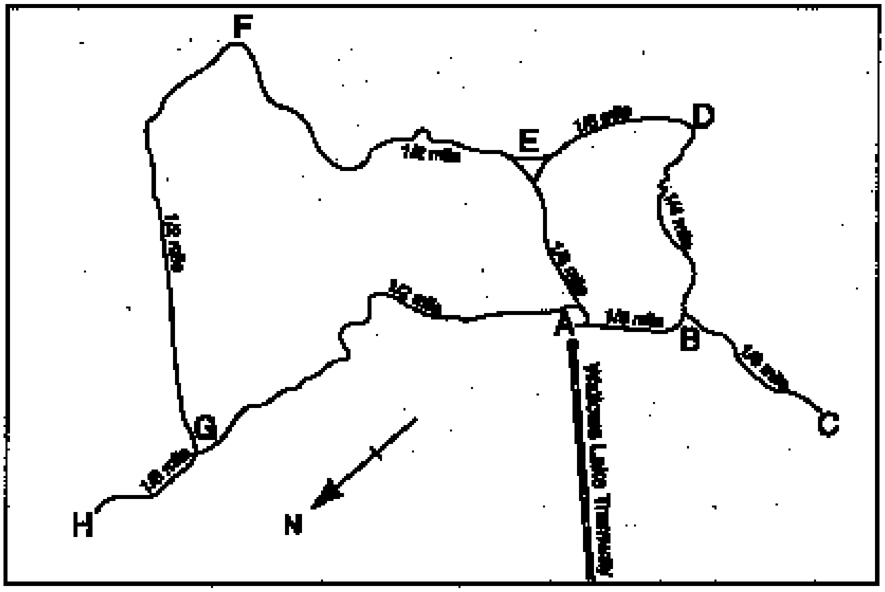


Figure 13. Map of walking trails on top of Mount Howard, Stop 17. A = top of tramway; D = summit of Mount Howard. Other letters used in text directions.

(clastic sedimentary rocks). Sacajawea Peak, at 9,839 ft the highest in the Wallowa Mountains, is hidden behind the Hurwal Divide.

West-northwest: Chief Joseph Mountain, mostly Triassic Lower Sedimentary Series

Northwest: Olympic-Wallowa lineament across Wallowa Lake

Return to the junction (B) and climb to the ***summit (D) of Mount Howard*** *(elevation 8,241 ft).*

The rocks here consist of porphyritic lava of the Permian and/or Triassic Clover Creek Greenstone. To the southeast, you see east-dipping lava flows of the Miocene Columbia River Basalt Group. The dips of up to 25° show the arching of the Wallowa Mountain uplift (Taubeneck, 1987). Due east, across the canyon of the Imnaha River and Hells Canyon of the Snake River, lie the Seven Devils Mountains in Idaho. Most of these mountains are composed of the Triassic Wild Sheep Creek Formation, which is the younger part of the Clover Creek Greenstone (Vallier, 1998).

Continue counterclockwise around the top of Mount Howard. After a gentle descent to the northeast, you come to a junction (E). To the left (northwest) the top of the tramway (A) is only a short distance away. If you have time, go right, continuing northeast downhill to an overlook (F), and then northwest to another overlook at a junction (G). At this junction, turn right (north) and cross an alpine meadow to a ***small hill (H)*** *topped with what is known as a block field.*

Freeze-thaw activity has broken the Clover Creek Greenstone, which here has radiating clusters of plagioclase phenocrysts that have led to the local name "flowerstone" (Figure 14).

The view north-northwest shows the right lateral moraine complex of the Wallowa glacier (Figure 15) with more than a dozen individual moraine crests. Crandell (1967) divided the drift in the vicinity of Wallowa Lake into four ages, whereas Burke (1980) determined that only three ages of tills are present. To the northwest extends the left lateral moraine complex with about half a dozen moraine crests.

Visible also to the northwest is the Olympic-Wallowa lineament (OWL) (Figure 15). Grande Ronde Basalt is offset along the OWL more than 2 km (1.2 mi) from the Wallowa Valley on the downthrown northeastern side to outcrops high on some Wallowa peaks like Ruby Peak, Mount Howard, Aneroid Mountain, and Petes Point. About 120 km (75 mi) to the northwest along the OWL, near Milton-Freewater, where we started this field trip, a magnitude 6.1 earthquake occurred in this fault zone in 1936 (Brown, 1937).

Figure 14. "Flowerstone" or Clover Creek greenstone with cumulophyric texture, as seen at Stop 17, point H. The Permo-Triassic porphyritic basalt with clusters of radiating plagioclase phenocrysts has undergone low-grade metamorphism.

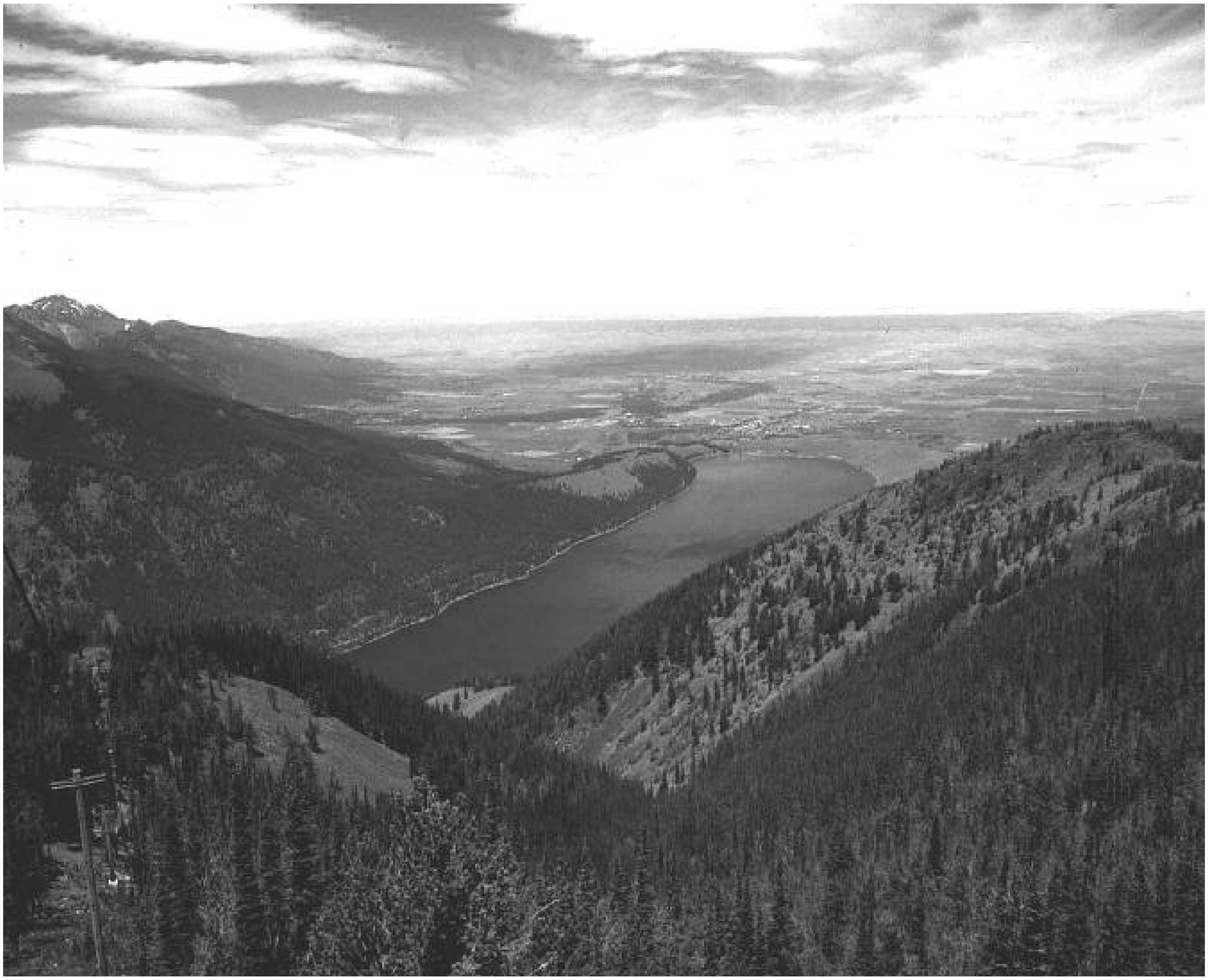


Figure 15. View northwest from near the top of Mount Howard, at Stop 17, point H. The Wallowa Mountains are in the foreground and on the left. At their base is the Olympic-Wallowa lineament (OWL). Off into the right distance is the Joseph Upland. Wallowa Lake and its prominent lateral moraines straddle the OWL.

To the north lies the Joseph Upland, capped with Grande Ronde Basalt. Beyond and more to the north-northwest, across the canyon of the Grande Ronde River, is the highest part of the Blue Mountains, located in southeastern Washington. The Blue Mountains are a giant northeast-trending anticline composed mostly of lava flows of the Columbia River Basalt Group.

Return to the junction (G) and the top of the tramway.

End of field trip guide.

REFERENCES CITED

Allen, J.E., 1975, The Wallowa "ice cap" of northeastern Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 37, p. 189–202.

———1991, The case of the inverted auriferous paleotorrent—exotic quartzite gravels on Wallowa Mountain peaks: Oregon Geology, v. 53, no. 5, p. 104–107.

Bacon, C.R., 1983, Eruptive history of Mount Mazama and Crater Lake caldera, Cascade Range, U.S.A.: Journal of Volcanology and Geothermal Research, v. 18, no. 1, p. 57–115.

Baldwin, E.M., 1981, Geology of Oregon, 3d ed.: Dubuque, Iowa, Kendall/Hunt Publishing Company, 170 p.

Barrash, W., Bond, J.G., Kauffman, J.D., Venkatakrishnan, R., 1980, Geology of the La Grande area, Oregon: Oregon Department of Geology and Mineral Industries Special Paper 6, 47 p.

Brown, B.H., 1937, The Stateline earthquake at Milton and Walla Walla: Seismological Society of America Bulletin, v. 27, p. 205–209 [also Northwest Science, v. 11, no. 3, p. 62–64].

Burke, R.M., 1980, Multiparameter relative dating techniques used to differentiate tills near Wallowa Lake, Oregon [abs.]: Geological Society of America Abstracts with Programs v. 12, no. 3, p. 99.

Carson, R.J., Beaman, M.D., and Gillanders, J.R.L., 1998, Flooding and mass wasting near Walla Walla, Washington, in February 1996 [abs.]: Geological Society of America Abstracts with Programs, v. 30, no. 5, p. 8.

Carson, R.J., Pohs, K.G., and Bixby, R.K., 1995, Geomorphology of Ice Lake area, Wallowa Mountains, Oregon [abs.]: Oregon Academy of Science, Proceedings, v. 31, p. 35.

Carson, R.J., Spencer, P.K., Hubbard, S.E., and Thurber, B.W., 1989, Late Cenozoic volcanology, sedimentology, tectonics, and geomorphology of the Elgin-Enterprise area, northeastern Oregon [abs.]: International Geological Congress, 38th, Washington, D.C., Abstracts, v. 1, p. 247.

Carson, R.J., Tolan, T.L., and Reidel, S.P., 1987, Geology of the Vantage area, south-central Washington: An introduction to the Miocene flood basalts, Yakima fold belt, and the Channeled Scabland, chap. 79 *of* Hill, M.L., ed., Cordilleran Section of the Geological Society of America: Boulder, Colo., Geological Society of America Centennial Field Guide, v. l, p. 357–362.

Costa, J.E., 1987, Rheological, geomorphic, and sedimentological differentiation of water floods, hyperconcentrated flow, and debris flows, *in* Baker, V.R., ed., Flood geomorphology: New York, Wiley and Sons, p. 113–122.

Crandell, D.R., 1967, Glaciation at Wallowa Lake, Oregon [Geological Survey Research 1966, Chapter C]: U.S. Geological Survey Professional Paper 575–C, p. 145–153.

Farren, E.C., and Carson, R.J., 1998, Origin of the forest soils of the northern Blue Mountains, Oregon and Washington: Oregon Academy of Science, Proceedings, v. 34, p. 27–28.

Fenneman, N.M., 1931, Physiography of western United States: New York, McGraw-Hill, 534 p.

Ferns, M.L., Madin, I.P., and Taubeneck, W.H., in preparation, Reconnaissance geologic map of the La Grande 30 x 60 minute quadrangle, Baker, Grant, Umatilla, and Union Counties, Oregon: Oregon Department of Geology and Mineral Industries Reconnaissance Map Series RMS–1, scale 1:100,000.

Follo, M.F., 1994, Sedimentology and stratigraphy of the Martin Bridge Limestone and Hurwal Formation (Upper Triassic to Lower Jurassic) from the Wallowa terrane, Oregon, chap. 1 *of* Vallier, T.L., and Brooks, H.C., eds., Geology of the Blue Mountains region of Oregon, Idaho, and Washington: Petrology and tectonic evolution of pre-Tertiary rocks of the Blue Mountains region: U.S. Geological Survey Professional Paper 1438, p. 1–27.

Fromwiller, G., and Van Tassell, J., 1999, Pleistocene sedimentation in the La Grande Basin, northeast Oregon: Eastern Oregon Science Journal, v. 15, p. 34–38.

Gerber, M.B., Clausen, M., and Carson, R.J., 2000, Geomorphic evolution of the Grande Ronde River, northeastern Oregon and southeastern Washington: Oregon Academy of Science, Proceedings, v. 36, p. 34–35.

Gildemeister, J., 1999, The Grande Ronde watershed history report (summary report): Pendleton, Oregon, Confederated Tribes of the Umatilla Indian Reservation, 21 p.

Hogenson, G.M., 1964, Geology and groundwater of the Umatilla River basin, Oregon: U.S. Geological Survey Water-Supply Paper 1620, 162 p.

Hooper, P.R., and Swanson, D.A., 1990, The Columbia River Basalt Group and associated volcanic rocks of the Blue Mountains province, chap. 4 *of* 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.

Hunt, C.B., 1974, Natural regions of the United States and Canada: San Francisco, W.H. Freeman and Company, 725 p.

Mackin, J.H., 1961, A stratigraphic section in the Yakima Basalt and the Ellensburg Formation in south-central Washington: Washington Division of Geology and Earth Resources, Report of Investigations 19, 45 p.

Newcomb, R.C., 1966, Lithology and eastward extension of The Dalles Formation, Oregon and Washington [Geological Survey Research 1966, Chapter D]: U.S. Geological Survey Professional Paper 550–D, p. 59–63.

Orr, E.L., Orr, W.N., and Baldwin, E.M., 1992, Geology of Oregon, 4th ed.: Dubuque, Iowa, Kendall/Hunt Publishing Company, 254 p.

Pardee, J.T., 1910, The glacial Lake Missoula: Journal of Geology, v. 18, p. 376–386.

Personius, S.F., 1998, Surficial geology and neotectonics of selected areas of western Idaho and northeastern Oregon: U.S. Geological Survey Open-File Report 98–771, 26 p.

Raisz, E.J., 1945, The Olympic-Wallowa lineament: American Journal of Science, v. 243 A, p. 479–485.

Reidel, S.P., and Lindsey, K.A., 1991, Field trip guide to the geology of the U.S. Department of Energy's Hanford Site: Unpublished report for American Geophysical Union, Pacific Northwest Regional Meeting (Tri-Cities, Washington), 30 p.

Schlicker, H.G., and Deacon, R.J., 1971, Engineering geology of the La Grande area, Union County, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-71-01, 16 p.

Shotwell, J.A., 1956, Hemphillian mammalian assemblage from northeastern Oregon: Geological Society of America Bulletin, v. 67, p. 717–738.

Smith, W.D., and Allen, J.E., 1941, Geology and physiography of the northern Wallowa Mountains, Oregon: Oregon Department of Geology and Mineral Industries Bulletin 12, 64 p.

Spencer, P.K., and Carson, R.J., 1995, The Enterprise Gravel: The ancestral Wallowa River and neotectonism in northeastern Oregon: Northwest Science, v. 69, no. 1, p. 60–71.

Swanson, D.A., Anderson, J.L., Camp, V.E., Hooper, P.R., Taubeneck, W.H., and Wright, T.L., 1981, Reconnaissance geologic map of the Columbia River Basalt Group, northern Oregon and western Idaho: U.S. Geological Survey Open-File Report 81–797, 35 p., 6 sheets, scale 1:250,000.

Taubeneck, W.H., 1987, The Wallowa Mountains, northeast Oregon, chap. 74 *of* Hill, M.L., ed., Cordilleran Section of the Geological Society of America: Boulder, Colo., Geological Society of America Centennial Field Guide, v. l, p. 327–332.

Thornbury, W.D., 1965, Regional geomorphology of the United States: New York, John Wiley and Sons, 609 p.

Tolan, T.L., and Reidel, S.P., 1989, Structure map of a portion of the Columbia River flood-basalt province, *in* Reidel, S.P., and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, plate in pocket.

Trafton, K.S., 1999, Paleogeographic implications of Late Cretaceous-Early Tertiary quartzite-bearing fluvial sediments, Elkhorn Mountains, northeast Oregon: Twelfth Keck Research Symposium in Geology, Proceedings, p. 287–290.

Vallier, T.L., 1998, Islands and rapids. A geologic story of Hells Canyon: Lewiston, Idaho, Confluence Press, 151 p.

Van Tassell, J., Ferns, M.L., and McConnell, V.S., 2000, Neogene sediment accumulation and subsidence rates, La Grande Basin, northeast

Oregon [abs.]: Geological Society of America Abstracts with Programs, v. 32, no. 6, p. A73–A74.

Waitt, R.B.,1980, About forty last-glacial Lake Missoula jökulhlaups through southern Washington: Journal of Geology, v. 88, no. 6, p. 653–679.

———1985, Case for periodic, colossal jökulhlaups from Pleistocene glacial Lake Missoula: Geological Society of America Bulletin, v. 96, no. 10, p. 1271–1286.

———1994, Scores of gigantic, successively smaller Lake Missoula floods through Channeled Scabland and Columbia Valley [guide for field trip 2, with contributions by J.E. O'Connor and G. Benito, Geological Society of America annual meeting 1994], chap. 1K *of* Swanson, D.A., and Haugerud, R.A., eds., Geologic field trips in the Pacific Northwest: Seattle, Wash., University of Washington, Department of Geological Sciences, p. 1K1-1K88.

Walker, G.W., 1973, Reconnaissance geologic map of the Pendleton quadrangle, Oregon and Washington: U.S. Geological Survey Miscellaneous Geologic Investigations Map I–727, scale 1:250,000.

———1979, Reconnaissance geologic map of the Oregon part of the Grangeville quadrangle, Baker, Union, Umatilla, and Wallowa Counties, Oregon: U.S. Geological Survey Miscellaneous Investigations Series Map I–116, scale 1:250,000.

Walker, G.W., and MacLeod, N.S., 1991, Geologic map of Oregon: U.S. Geological Survey Special Geologic Map, scale 1:500,000.

Washburn, A.L., 1956, Classification of patterned ground and review of suggested origins: Geological Society of America Bulletin, v. 67, no. 7, p. 823–865.

Wong, I.G., and Bott, J.D.J., 1995, A look back at Oregon's earthquake history, 1841–1994: Oregon Geology, v. 57, no. 6, p. 125–139.

Zdanowicz, C.M., Zielinski, G.A., and Germani, M.S., 1999, Mount Mazama eruption: Calendrical age verified and atmospheric impact assessed: Geology, v. 27, no. 7, p. 621–624. ☐

EDITOR'S GOSSIP

Honorable mention

Archie Strong deserves special praise as a stand-out volunteer for DOGAMI. He mainly helps in the Nature of the Northwest Information Center, where he is the person responsible for keeping the topographic maps in stock.

On February 20, 2001, we celebrate Archie's **91st birthday** with him! And the fact that he has volunteered **2,421 hours** of service to the department since 1992! Don't look any farther for a **shining example!**

Happy Birthday, Archie! And many more!

Dishonorable mention

With apologies we have to report that three of the latest DOGAMI publications **escaped from inclusion in the index** for volume 62 (year 2000) on page 123 of the last issue of Oregon Geology. But they did not get far: They are all listed on the same page (123) as that index, just above, not in it. Sorry!

In the neighborhood

The **Geological Society of Nevada** asks us to announce its **field conference** on May 3 to May 6, 2001, in Battle Mountain. Subject of the conference is "to study and exchange ideas on the role of tectonics and structure in the occurrence of, and search for, ore in northern Nevada and similar terranes worldwide." Participants are expected to "represent a broad spectrum of leading-edge scientists from industry, academia, and government." The conference will include **two days of talks and two days of field trips**, as well as "opportunities for poster, core, and prospect displays." Papers are to be published in a proceedings volume or a field trip guidebook. Contact for more information is Laura Ruud, Geological Society of Nevada, P.O. Box 12021, Reno, NV 89510-2021, 775/323-3500, e-mail gns@mines.unr.edu.

At home

April is Earthquake and Tsunami Preparedness Month! Statewide as well as at the local level, agencies and organizations concerned with keeping this preparedness awake and improving will soon publicize specific plans for the month. So **look for announcements** from such bodies as the Oregon Emergency Management, county emergency management agencies, local schools, or the Red Cross. Or ask them!

Remember: We may not be able to keep a natural disaster from happening, but we certainly can do a lot of things so that **a natural disaster** will not turn out to be **a civilization disaster**.

See also page 20 for a new publication available in the Nature of the Northwest Information Center. ☐

(Continued from page 12)

son Creek had higher ratios of peak/volume (20 percent increase), peak to antecedent precipitation (increases of 21–34 percent), and (peak/volume) to antecedent precipitation (increases of 32–48 percent).

The Tualatin had no streamflow changes even with a 1,000-percent increase in population. The Newaukum basin had unexpectedly large changes in basin response, given that its population density was lower than that of the Tualatin basin. The Johnson Creek basin was the most urbanized and showed significant streamflow increases in almost every category measured. These results suggest that the effects of urbanization on streamflow are a function of basin scale. Streamflow response to urbanization may become increasingly attenuated as basin size increases. ☐

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

Periodicals postage paid
at Portland, OR

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

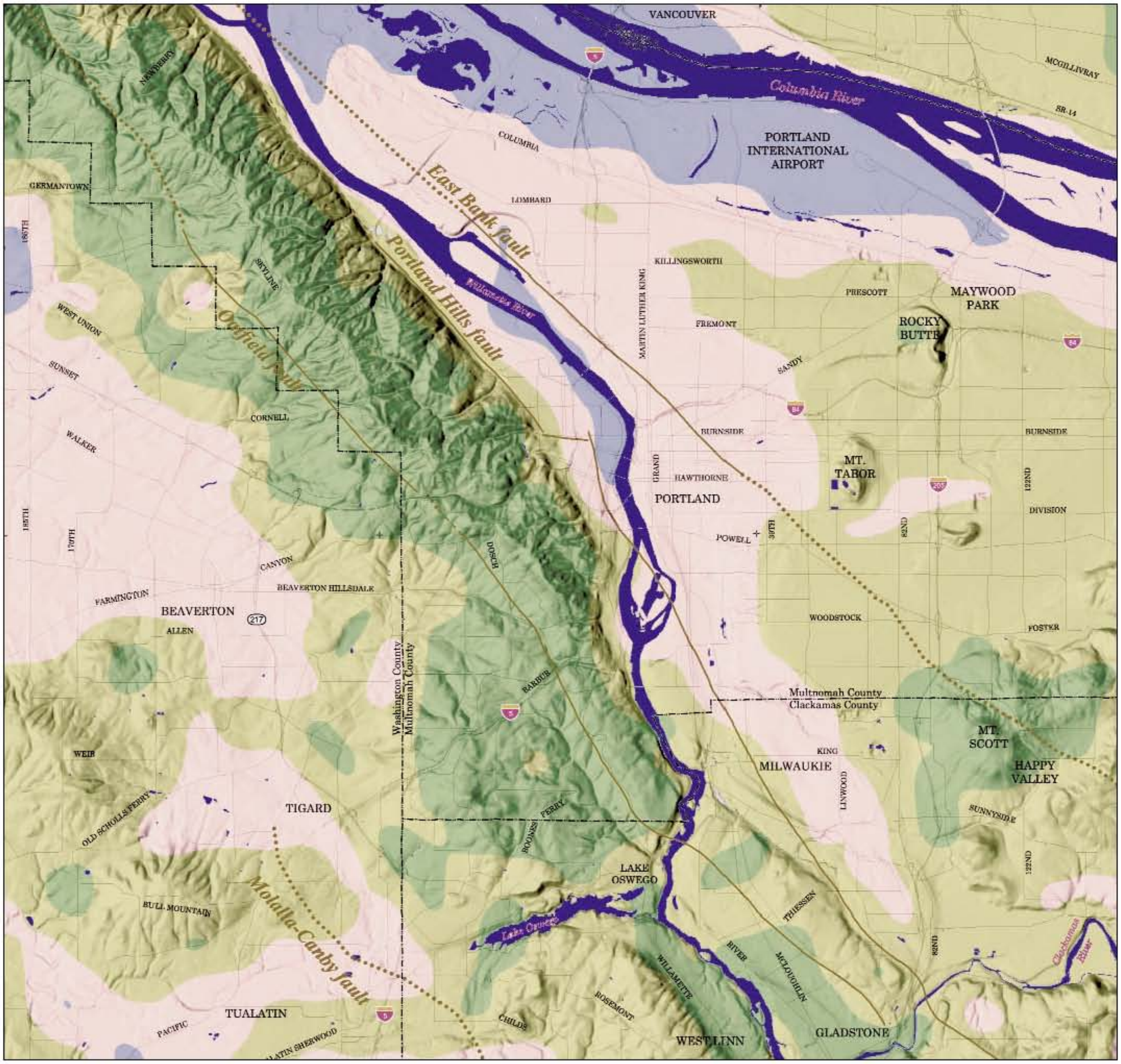
Newberry Crater, heart of the Newberry National Volcanic Monument in Deschutes County, south of Bend.

The "crater" is, strictly speaking, a caldera—the remnant of a large shield volcano that collapsed during its eruptive life between about 500,000 and less than 2,000 years ago. With many eruptions continuing after the collapse, a great diversity of volcanic landforms and rock types was created here. This view to the south shows the central pumice cone that separates East and Paulina Lakes, with the Big Obsidian Flow stretching behind to the caldera rim.

Access from U.S. Highway 97 between La Pine and Bend is open from spring to fall. In winter, the road toward the caldera is cleared for 10 mi to a snow park area. You can call the Lava Lands Visitor Center at (541) 593-2421. See also page 20 above.

OREGON GEOLOGY

Oregon Department of Geology and Mineral Industries
Volume 63, Number 2, Spring 2001



IN THIS ISSUE:

✧The Portland Hills fault✧

✧Seismic rehabilitation at the Oregon State Library in Salem✧

✧Results of a new method of Fourier grain-shape analysis✧

DOGAMI PUBLICATIONS

Publications are available from: Nature of the Northwest, 800 NE Oregon St. #5, Portland, OR 97232, info@naturenw.org or www.naturenw.org, (503) 872-2750; or from the DOGAMI field offices in Baker City, 1510 Campbell Street, (541) 523-3133, and Grants Pass, 5375 Monument Drive, (541) 476-2496. See also the gray pages at the center of this issue.

Released March 8, 2001:

Mist Gas Field Map, 2001 edition. Open-File Report O-01-01, map scale 1:24,000; includes production statistics for the years 1993 through 2000. Paper $8; CD $25.

The annually updated Mist Gas Field 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 area 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 available both as the usual paper copy and, on request, in digital format. It is offered in three different CAD formats (.DGN, .DWG, and .DXF), all on one CD-ROM, which also contains PDF versions of both the map and the production records. Using a digitized version allows customization of the map to suit individual needs.

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).

Released March 16, 2001:

Slope Failures in Oregon—GIS Inventory for Three 1996/97 Storm Events, by R. Jon Hofmeister. Special Paper 34, 20 p., 1 CD, $6.00.

The objective of this project was to collect and consolidate data on Oregon landslides associated with severe storm events in February 1996, November 1996, and December 1996/January 1997. This study builds upon previous work in the Portland Metro area by Scott Burns and others at Portland State University, as well as on a number of other landslide studies throughout the state. The February storm event led to a Feder-

***(Publications**, continued on page 67)*

OREGON GEOLOGY

(ISSN 0164-3304)

VOLUME 63, NUMBER 2 **SPRING 2001**

Published quarterly in Winter, Spring, Summer, and Fall by the Oregon Department of Geology and Mineral Industries. (Volumes 1 through 40 were entitled *The Ore Bin.*)

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

Baker City Field Office: 1510 Campbell Street, Baker City 97814, phone (541) 523-3133, FAX (541) 523-5992.
Mark L. Ferns, Regional Geologist.

Coastal Field Office: 313 SW Second Street, Suite D, Newport 97365, phone (541) 574-6642, FAX (541) 265-5241.
George R. Priest, Coastal Team Leader.

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: 229 Broadalbin Street SW, Albany 97321-2246, phone (541) 967-2039, FAX (541) 967-2075.
Internet: http://www.proaxis.com/~dogami/mlrweb.shtml
Gary W. Lynch, Supervisor. **NOTE ADDRESS CHANGE!!!**

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

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

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

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

Cover photo

This (digitally modified) map of the Portland metropolitan area is one of 11 maps (sheet 5) produced in a study of earthquake scenarios and published by DOGAMI as Interpretive Map set IMS–16. Its colored zones depict differences of expected ground shaking (spectral acceleration) from a magnitude 9 earthquake occurring at the Cascadia subduction zone off the coast. Shades of green indicate the lower, pink and blue, the higher rates of shaking. For other types of quakes, the faults identified in the Portland area play an important role. See the related article beginning on the next page.

The Portland Hills fault: An earthquake generator or just another old fault?

by Ivan G. Wong, Seismic Hazards Group, URS Corporation, 500 12th Street, Suite 200, Oakland, CA 94607; Mark A. Hemphill-Haley, Seismic Hazards Group, URS Corporation and Department of Geological Sciences, University of Oregon, Eugene, Oregon 97403; Lee M. Liberty, Center for Geophysical Investigation of the Shallow Subsurface, Boise State University, 1910 University Drive, Boise, ID 83725; and Ian P. Madin, Oregon Department of Geology and Mineral Industries, 800 NE Oregon Street, Suite 28, Portland, OR 97232

Editor's Note

During the final stages of preparing this article for publication, evidence was discovered that throws new light on the question in the title, without invalidating the essence of the paper. In a sidebar on pages 47–49, Ian P. Madin gives a preliminary assessment of the new-found evidence for activity on the Portland Hills fault in times more recent than had been known before. A more extensive description and discussion will be published by Madin in *Oregon Geology* at a later date.

ABSTRACT

Several lines of indirect evidence and preliminary interpretations of recently collected seismic reflection data have led to the conclusion that the Portland Hills fault at the eastern base of the Portland Hills appears to be capable of generating large-magnitude earthquakes. Although no historical earthquake can be associated with the Portland Hills fault, small-magnitude seismicity in the past 20 years in the vicinity of the Portland Hills fault zone, which includes the Oatfield and East Bank faults, suggests that one or all of these structures may be seismogenic. The Portland Hills fault may be 40–60 km long, probably dips to the southwest beneath the Portland Hills, and may slip in a reverse-oblique sense. Limited observations suggest that, on average, the intervals between large earthquakes are a few thousand to more than 10,000 years. Given its location in the midst of the Portland metropolitan area, rupture of the Portland Hills fault resulting in a large earthquake could be devastating. Future studies are required to characterize the earthquake potential of the fault in a more definitive manner and to provide an improved basis for predicting the hazards that would result from such a large earthquake.

INTRODUCTION

Since the mid-1960s, it has been suggested that a fault is located at the eastern base of the northwest-trending, westward-sloping Portland Hills and within the Portland metropolitan area which has a population of 1.4 million (Figure 1). Little consideration was given to the possibility that the "Portland Hills" fault was active[1] (or seismogenic, i.e., capable of generating earthquakes). This was consistent with the prevailing view held until the past decade that Oregon was not particularly seismically active. However, as speculation turned to recognition in the Pacific Northwest that the Cascadia subduction zone megathrust was seismogenic, attention began to shift also to evaluating the earthquake potential of inland crustal faults, particularly those located in or near urban areas. For example, significant efforts have been focused on the Seattle fault since the suggestion that it ruptured in a large earthquake (>M_W [moment magnitude] 7) 1,100 years ago (Bucknam and others, 1992). If urban crustal faults such as the Seattle and the Portland Hills faults are seismogenic, they could generate large, disastrous earthquakes similar to the M_W 6.9 earthquake in Kobe, Japan, in 1995.

In the following paper, we review what is known about the geology of the Portland Hills fault, particularly its characteristics, which might help quantify its earthquake potential. Recent studies, which have focused on this quantification, are discussed. Last year, Wong and others (2000a; 2000b) released scenario earthquake ground shaking hazard maps for the Portland metropolitan area. They assumed a M_W 6.8 earthquake rupturing 30 km of the Portland Hills fault at the base of the Portland Hills (Figure 2). The potential ground shaking from such an event would greatly exceed the ground motions from a M_W 9 Cascadia subduction zone megathrust event in the Portland area. This paper elaborates on the

---

[1] We consider a fault in the Pacific Northwest to be "active" if it has moved (been displaced) at least once during late Quaternary time (the past 780,000 years).

Figure 1. Oblique air photo of the Portland Hills toward the northwest and inferred location of the Portland Hills fault. The fault is mapped near the eastern base of the escarpment north of West Burnside Street. To the south, the inferred fault steps toward the east, where it traverses the downtown area and crosses the Willamette River (Figure 2). Fault location based on Madin (1990). Air photo courtesy of Northern Light Studio.

basis for selecting a M_W 6.8 scenario, although the evidence at that time was not compelling that the Portland Hills fault was seismogenic.

HISTORICAL SEISMICITY

The Portland area has exhibited a low to moderate level of historical seismicity (Figure 2), compared to other areas in the Pacific Northwest. The area is not as seismically active as the Puget Sound region to the north but may be the most active area in Oregon for events of M_W ≥3.0 based on the historical record (Wong and Bott, 1995). Detailed discussions of the historical seismicity can be found in Bott and Wong (1993) and of instrumentally recorded seismicity since 1982 in Yelin and Patton (1991) and Blakely and others (1995). Based on the historical earthquake record, seven felt earthquakes (Richter magnitude [M_L] >3.5) have occurred in the vicinity of Portland since 1850 (Bott and Wong, 1993).

The first significant earthquake to strike the Portland area occurred on October 12, 1877. It was felt in towns around Portland, but its maximum intensity was in the city (Modified Mercalli [MM] VII). This event of approximate magnitude M_L 5¼ damaged chimneys and was felt over an area of 41,000 km^2. On February 3, 1892, a "severe" earthquake of estimated M_L 5 caused brick buildings to sway and windows to rattle in Portland, terrifying its occupants. A M_L 4½ event on December 29, 1941, shook an area of about 9,000 km^2, including the towns of Portland, Hillsboro, Sherwood, and Yamhill in northwest Oregon and Vancouver and Woodland in southwest Washington. Effects included shattered windows, cracked plaster, and overturned objects. Another M_L 4½ earthquake occurred somewhere between Portland and Vancouver on December 15, 1953. Effects were similar to those encountered in 1941. An earthquake on November 6, 1961 (M_L 5) shook a large area (23,000 km^2) of northwest Oregon and southwest Washington. Damage included a fallen chimney, cracked plaster, broken interior lights, jammed doorframes, and groceries thrown from shelves. The instrumental location of this event is uncertain, although an aftershock felt mostly in Portland suggests the main shock also occurred there. On January 27,

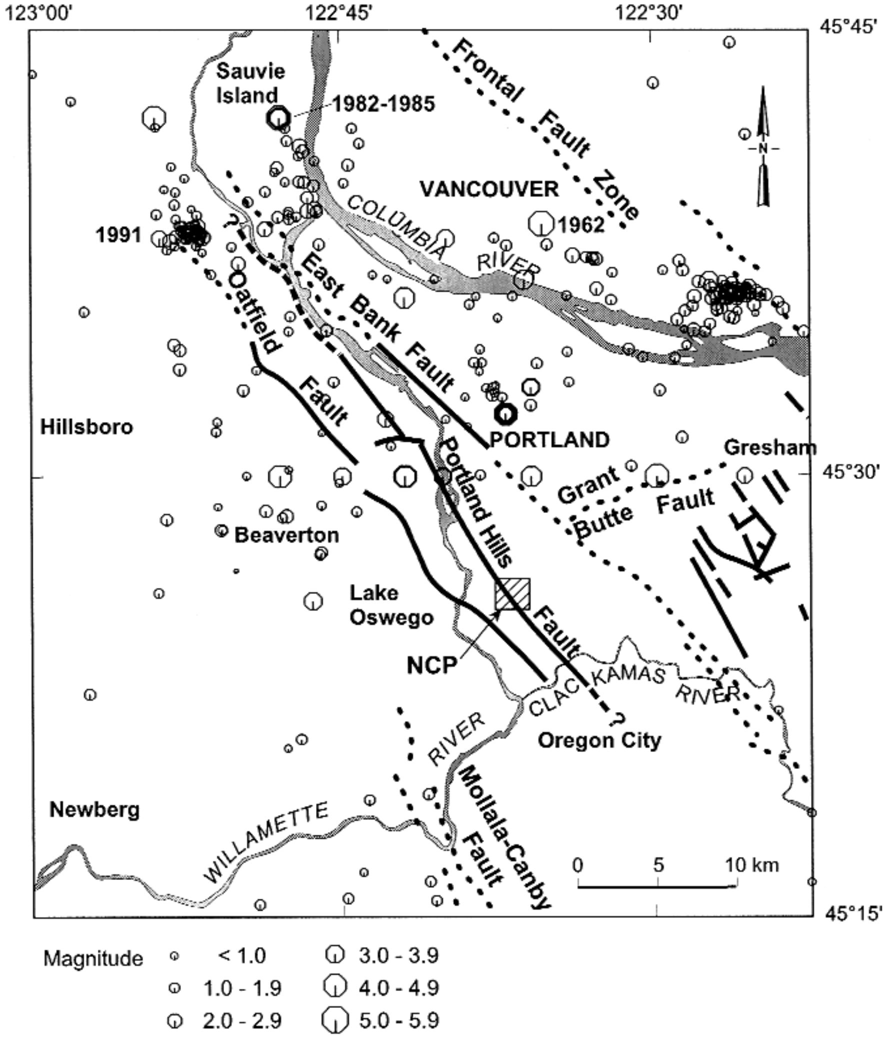


Figure 2. Portland Hills fault zone and historical seismicity in the vicinity of Portland, 1841 to 2000. Faults shown are those considered to be potentially active by Wong and others (2000b). Site NCP is also shown. Earthquake symbol size is a function of magnitude. The largest event shown is the 1962 M_L 5.5 earthquake. Smallest events are $M_L \leq 1.0$.

1968, an earthquake estimated to be M_L 3.7 in size was felt in Portland. The event is believed to have originated in east Portland but at a depth of 20 to 24 km.

The most significant local earthquake in Portland's history occurred on November 5, 1962. Yelin and Patton (1991) calculated a magnitude of M_W 5.2 for the event and Bott and Wong (1993) assigned a M_L 5.5 based on its felt area and other instrumental estimates. The earthquake was felt widely over an area of 70,000 km^2 in northwest Oregon and southwest Washington, causing damage typical for an earthquake of this size: broken windows, cracked and fallen chimneys, and cracked plaster. The main shock was followed by numerous small but unfelt aftershocks. With the exception of the 1962 earthquake, which was relocated by Yelin and Patton (1991) to a location in Vancouver (Figure 2), the large location uncertainties of the historical earthquakes with M_L >3.5 in the Portland area prior to 1982 prevent a determination of whether any of these events were associated with the Portland Hills fault or adjacent major structures.

PREVIOUS FAULT STUDIES

Numerous geologic and a few geophysical studies of the Portland Hills fault have been performed since the 1960s. The early studies stemmed from attempts to explain the presence of the Portland Hills, which are underlain by uplifted Tertiary rocks. A major obstacle in characterizing the Portland Hills fault is that nowhere has the fault been documented to be exposed at the ground surface. Given the heavy vegetation, urbanization, and catastrophic floods (i.e., the late Pleistocene Missoula floods ca. 12,000 to 15,000 years ago), there may be areas where the fault extends to the surface but has simply not been detected. The following summary is taken principally from Yelin and Patton (1991), Unruh and others (1994), and Blakely and others (1995).

The Portland Hills comprise a northwest-trending, asymmetric anticline that was uplifted principally in the late Miocene and Pliocene (after 6 Ma). Several models have been developed to explain the origin of the northeastern margin of the anticline, which forms an abrupt escarpment. Both Schlicker and others (1964) and Balsillie and Benson (1971) suggested that the escarpment (Figure 1) is the surface expression of a steeply northeast-dipping fault. Schlicker and others (1964) inferred that the fault was of normal slip. Beeson and others (1976) proposed that the fault was part of a Portland Hills-Clackamas River structural zone and that the zone accommodated right-lateral, strike-slip motion. They also suggested that the Portland basin was a pull-apart structure and that the west-bounding Portland Hills fault was a right-oblique fault. On 1:24,000-scale quadrangles of the Portland area, Madin (1990) showed the Portland Hills fault extending a distance of about 40 km along the Portland Hills (Figure 2). Yelin and Patton (1991) also inferred that the

Portland basin was a pull-apart basin and that the Portland Hills fault and their postulated Frontal fault zone to the east bound the basin (Figure 2). Their model was based in large part on a re-analysis of the 1962 Portland earthquake (M_W 5.2), which appears to have resulted from normal faulting within the Portland basin. In their model, the Portland Hills fault is a right-lateral, strike-slip fault. In contrast to previous models, Unruh and others (1994) interpreted the Portland Hills anticline as a fault-bend or fault-propagation fold and based this interpretation on surface mapping and sparse drill-hole data. In their model, the Portland Hills fault is a southwest-dipping, blind thrust fault.

In the most extensive study of faulting to date, Blakely and others (1995) performed a high-resolution aeromagnetic survey of the Portland area. On the basis of interpretations of the survey and an analysis of the contemporary seismicity, they identified two additional faults, the East Bank and Oatfield faults (Figure 2), which they include as part of the Portland Hills fault zone. Both faults were first identified by Beeson and others (1989, 1991) on the basis of geologic mapping. The Portland Hills fault, also an element of the Portland Hills fault zone, was not well imaged by the aeromagnetic data (Blakely and others, 1995). The East Bank fault was previously known through shallow well data that indicate ≤200 m of vertical displacement of the underlying volcanic basement. As mapped by Madin (1990) and Beeson and others (1991), the fault is overlain by Quaternary deposits. The Oatfield fault along the southwestern slope of the Portland Hills was also previously known from the studies by Beeson and others (1989) and Madin (1990).

The aeromagnetic data suggest that the Oatfield and East Bank faults are steeply dipping structures that exhibit principally reverse slip (Blakely and others, 1995). This slip would be consistent with earlier observations of folding and thrusting (Beeson and others, 1985, 1989, 1991; Unruh and others, 1994).

In an analysis of contemporary seismicity, Blakely and others (1995) noted that two sequences from 1982 to 1985 near Sauvie Island ($M_L \leq 2.8$) and 1991 at the north end of the Portland Hills ($M_L \leq 3.5$) may be associated with the Portland Hills fault zone, although they appear to have occurred at mid-crustal depths (15–20 km). Thus relating these events to mapped faults is problematic, given the uncertainties of the subsurface geometry of the faults and the hypocentral locations (Blakely and others, 1995). No other events appear to be associated with the fault zone, particularly along its central and southern extent (Figure 2). Focal mechanisms of the 1982 to 1985 and 1991 sequences exhibit both right-lateral and reverse slip (Blakely and others, 1995; Figure 3). A component of strike-slip motion along the Portland Hills fault zone is consistent with the pull-apart basin model.

No evidence for recent displacement on the fault had been observed prior to 1998. In a photogeologic investigation of the fault, Geomatrix Consultants (1993) did not observe evidence for Holocene or late Pleistocene activity, but the factors mentioned previously could obscure any surficial evidence (Figure 1). Balsillie and Benson (1971) noted several geomorphic features indicative of Pleistocene uplift of the Portland Hills (linear northeastern front of the Portland Hills, aligned triangular facets, and knickpoints in northeast-flowing streams), which may be suggestive of activity on the Portland Hills fault. Unruh and others (1994) judged the fault to be "potentially active" on the basis of their review of available data and geomorphic evidence for middle to late Quaternary uplift of the Portland Hills and homoclinal westward tilting of early to middle Pleistocene deposits in the Tualatin basin. The geomorphic evidence included recent stream incision and downcutting, minor deformation of Tualatin basin fill on the southwest flank, and thrust faulting of the Tertiary Troutdale Formation in the southern portion of the Portland Hills (Unruh and others, 1994).

In a seismic source characterization of the Portland Hills fault for the development of statewide ground shaking maps, Geomatrix Consultants (1995) considered two models: a relatively steeply (70°) west-dipping reverse or reverse-oblique fault and a blind shallow-dipping thrust fault. The latter model suggested by Unruh and others (1994) was assigned little weight. Although there was no definitive surficial evidence for the fault being seismogenic, Geomatrix Consultants (1995) adopted a relatively high probability of 0.70 that the fault was active and based this on possible deformation of late Pleistocene sediments and the topographic expression of the Portland Hills. They also estimated that potential rupture lengths for the Portland Hills fault range from 28 to 62 km (Figure 2). The latter value is based on lineaments observed on air photos to the north and south of the mapped trace. Slip rates of 0.05 to 0.2 mm/yr were estimated, considering the tectonic setting and regional kinematics (Geomatrix Consultants, 1995).

RECENT INVESTIGATIONS

The Portland Hills fault as well as the East Bank and Oatfield faults would pose the greatest seismic hazard to Portland because of their proximity and their potential to generate large-magnitude earthquakes ($M_W \geq 6.5$) (Wong and Silva, 1998). Wong and others (2000b) characterized the Portland Hills fault in their development of scenario and probabilistic ground shaking maps for the Portland metropolitan area by revising the assessments of Geomatrix Consultants (1995). They assumed a higher probability (0.8) that the Portland Hills as well as the East Bank and Oatfield faults were seismogenic. The basis for this assessment, were the following observations:

1. Contemporary microseismicity has been observed in the vicinity of the Portland Hills fault, with the majority of events concentrated at depths of 5–20 km (Yelin and Patton, 1991; Blakely and others, 1995). Although no earthquakes can be definitively associated with the fault, the occurrence of events is suggestive that there are active structures nearby. As observed by many (e.g., Kafka and Levin, 2000), the presence of small earthquakes, more often than not, delineates areas where larger earthquakes are likely to occur. We believe the Portland Hills fault zone or specifically the Portland Hills fault is the likely source for future large earthquakes in the Portland area.

2. The few earthquake focal mechanisms in the Portland area and surrounding region indicate that northwest-striking structures such as the Portland Hills fault are favored to be seismogenic in a north-south tectonic compressive stress field (Yelin and Patton, 1991; Blakely and others, 1995; Wong, 1997) (Figure 3). The similarly oriented northwest-striking Mount Angel fault to the south may have been the source of the M_L 5.6 Scotts Mills earthquake of 1993 (Madin and others, 1993; Thomas and others, 1996).

3. Pratt and others (2001) acquired and interpreted single-channel marine seismic reflection data across the projections of the Portland Hills and East Bank faults where they cross the Willamette River near Ross Island and near the Multnomah channel, respectively. Unfortunately, the Ross Island profiles across the Portland Hills fault are uninterpretable. The data near the Multnomah channel appear to indicate that the East Bank fault coincides with a large paleochannel. The layered strata, including a late Pleistocene unconformity at the base of the paleochannel, may be cut by a nearly vertical fault. Thus the East Bank fault appears to have been active at least in the late Pleistocene (Pratt and others, 2001).

4. Finally, the apparent youthful geomorphic expression as evidenced by the abrupt escarpment on the eastern side of the Portland Hills is suggestive of recent activity on the fault. It is possible that this youthful morphology is the product of flood sculpting and scour, but it may also indicate late Quaternary and possibly current uplift of the Portland Hills.

Wong and others (2000b) based an estimated range of slip rates for the Portland Hills fault on (1) a qualitative comparison of its geomorphic expression with faults in other regions; (2) long-term slip rates for the Gales Creek and Mount Angel faults, which are located to the southwest and south of the Portland

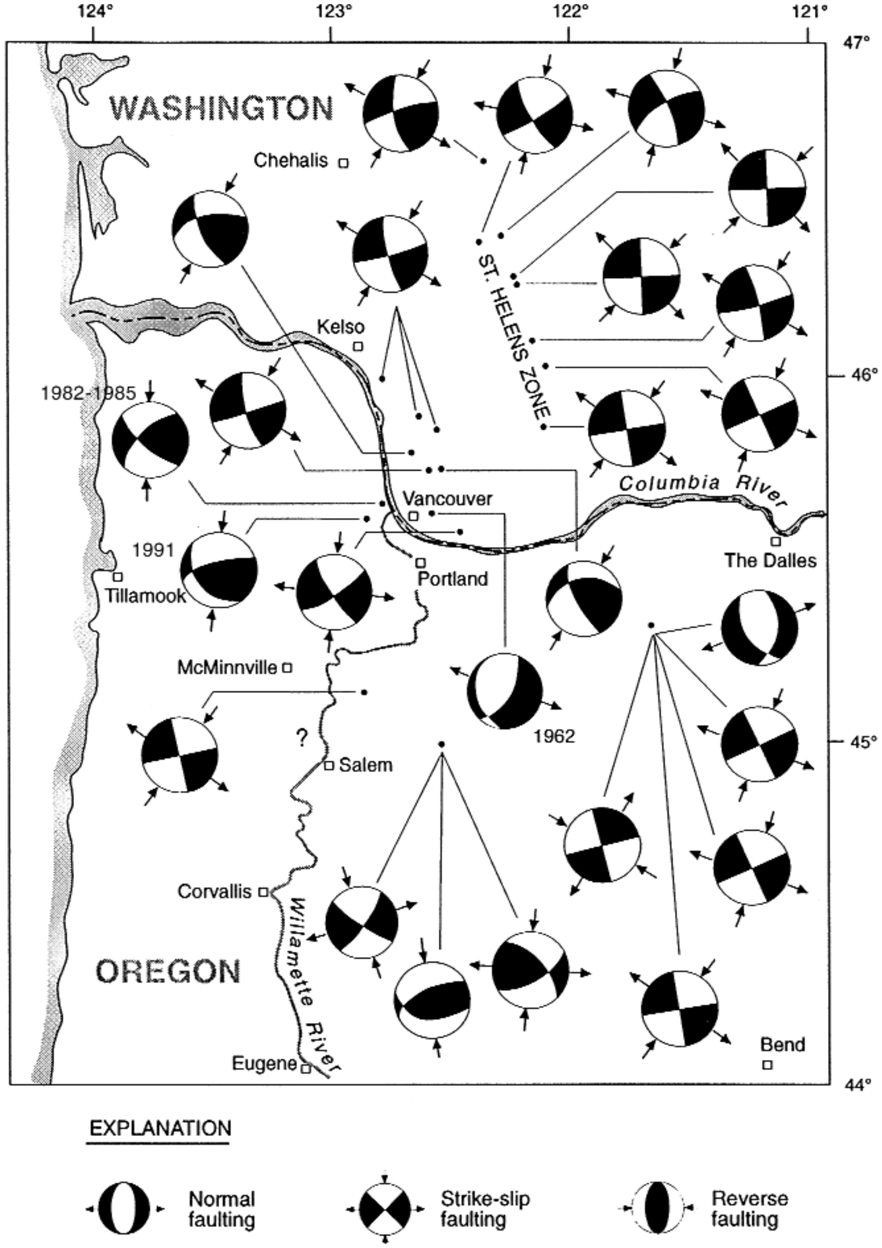


Figure 3. Crustal earthquake focal mechanisms of northwestern Oregon and southwestern Washington. Most of the mechanisms exhibit strike-slip and oblique-reverse faulting in response to a N-S to NE-SW-directed maximum compressive stress. Figure is modified from and data sources described in Wong (1997).

basin, respectively; (3) historical seismicity; and (4) estimated range of displacements by Pratt and others (2001). From detailed mapping, R.E. Wells (personal communication, 1997) estimated a long-term slip rate for the Gales Creek fault of about 0.24 mm/yr since 50 Ma and 0.6 mm/yr since 15 Ma. Wang and Madin (2001) have estimated a slip rate for the Mount Angel fault of approximately 0.23 mm/yr for the past 30 ka.

Bott and Wong (1993) calculated earthquake recurrence for the Portland region based on the historical seismicity record, which dates back to about 1850. Assuming a Gutenberg-Richter relationship, we find that the return period of earthquakes of M_L 6.5 and greater is about 1,000 years. For an average displacement of about 0.5 m, appropriate for a M_W 6.5 earthquake based on the relationship of Wells and Coppersmith (1994), the equivalent slip rate would be about 0.5 mm/yr, distributed across faults within the Portland region. If the Portland Hills fault zone (including the Portland Hills, East Bank, and Oatfield faults) and the Frontal fault zone are taking up most of this slip, the average slip per fault zone would be about 0.25 mm/yr.

Pratt and others (2001) estimate that the late Pleistocene (~15,000-yr-old) unconformity across the East Bank fault at the Multnomah channel may be displaced vertically "several" meters. Assuming that this apparent vertical displacement is at least 3 m, that would indicate a slip rate of about 0.2 mm/yr without accounting for any horizontal component of slip.

Wells and others (1998) suggested that the Cascadia forearc is migrating northward along the coast and is breaking into large rotating blocks. One of these blocks, the Oregon coastal block, is accommodating part of the 7–9 mm/yr of north-south shortening of the forearc. Wells and others (1998) also suggested that the shortening is taken up by deformation along block margins. The northeast boundary of the Oregon block is located near the Portland Hills fault zone (Wells and others, 1998).

To constrain maximum slip-rate values, we can use the convergence rate of 4–7 mm/yr proposed by Wells and others (1998) for the Oregon forearc. Of this total rate, R.E. Wells indicates that northwestern Oregon may be shortening at a rate of 2–3 mm/yr (personal communication, 1999). Within northwestern Oregon, the major fault systems appear to be the Portland Hills, the Gales Creek-Mount Angel, Mollala-Canby, and Frontal fault zones (Blakely and others, 1995, 2000; Wong and others, 2000b). If these four fault zones are taking up a significant portion of the 2–3 mm/yr of regional shortening and if the activity on the fault occurs at about the same maximum rate, the slip rates along them could range up to a maximum of 0.5–0.75 mm/yr. Such high rates seem unlikely except for possibly the Portland Hills fault, because they would result in much more pronounced geomorphic expression of the faults than is observed. Furthermore, these high slip rates assume that there is no aseismic component to the crustal deformation.

Based on the above observations, a range of slip rates of 0.05–0.4 mm/yr was adopted for the Portland Hills fault as well as the East Bank and Oatfield faults (Wong and others, 2000b). Using the relationship of Wells and Coppersmith (1994) to calculate an average displacement of 0.8 m for a M_W 6.8 earthquake), we find that the average recurrence interval would range from 2,000 to 16,000 yrs.

The maximum earthquake that the Portland Hills fault appears to be able to generate is in the range of M_W 6.8–7.2, as calculated from the potential rupture lengths of 28–62 km estimated by Geomatrix Consultants (1995). This is a significant range in magnitudes. Because the resulting hazards will also differ significantly from the low end to the high end of this range, it is critical that the extent of the Portland Hills fault and its possible segmentation and thus potential rupture lengths be better defined. In the modeling of the scenario ground motions for an event on the Portland Hills fault, Wong and others (2000a; 2000b) adopted a M_W 6.8 event rupturing 30 km of the fault, predominantly along its most geomorphically pronounced portion at the base of the Portland Hills.

The fault was assumed to rupture with oblique slip (50 percent reverse and 50 percent right-lateral strike-slip), dip 70° to the southwest beneath the hills, and extend to a depth of about 19 km (resulting in a fault width of about 20 km). Although focal mechanisms in the region exhibit predominantly strike-slip motion (Yelin and Patton, 1991; Blakely and others, 1995; Wong, 1997), with some showing reverse and oblique slip (Figure 3), the presence of the Portland Hills indicates that reverse faulting is the primary mode of deformation if uplift is still ongoing.

Future studies of the fault should also focus on constraining the dip of the fault. The assumed value of 70° is extremely uncertain. Because the dip controls the downdip width of the fault, the potential area available for rupture may be significantly larger, if the fault has a shallow dip (<50°).

The dip of the fault will also shed some light on the structural relationship between the Portland Hills and Oatfield faults. Wong and others (2000b) considered two possible structural geometries for the Portland and Oatfield faults due to the closeness of the faults (separated by 3–5 km; Figure 2) and their proposed respective westward and eastward dips as suggested by Blakely and others (1995): (1) the two faults each dip at about 70° and merge at a depth of about 5 km to form a single zone at greater depths Figure 4a), or (2) the two faults have steep dips (>80°) and are not structurally connected (Figure 4b). In the first case, i.e., if the two faults merge, they could be part of a flower structure provided they are predominantly strike-slip faults. If they are reverse faults, the Oatfield fault may be a back-thrust to the main Portland Hills fault.

The implication of both structural models is that in any given earthquake either one or both faults may rupture coseismically. If both faults rupture together in a single event, large near-field ground motions will be distributed over a wider area than if only a single fault were to rupture.

Furthermore, the proximity of the East Bank fault (Figure 2) suggests that it, too, might be structurally connected with the above faults. That is unlikely, however, at least according to Blakely and others (1995), whose interpretations of aeromagnetic data show the East Bank fault dipping away to the east (Figure 4).

CURRENT INVESTIGATION

With funding support from the U.S. Geological Survey National Earthquake Hazards Reduction Program, we employed multiple geophysical methods, including high-resolution seismic reflection, ground penetrating radar (GPR), and magnetic profiling to locate the Portland Hills fault at North Clackamas Park (NCP) south of Portland (Figure 2). We also incorporated data from nearby water wells to correlate the observed strata with horizons in the geophysical data and to aid in laying out the locations of the seismic lines.

Two high-resolution seismic profiles at the NCP site provide detailed images of the upper 100 m of the stratigraphic section, and enable us to locate significant offset in the Miocene-age Columbia River Basalt Group (CRBG) rocks and overlying sediments (Figure 5). Ground magnetic profiles along our seismic transects correlate with offset and orientation in the volcanic basement or CRBG rocks. The magnetic surveys, well logs, and ground reconnaissance show that CRBG rocks crop out near the southwest portion of

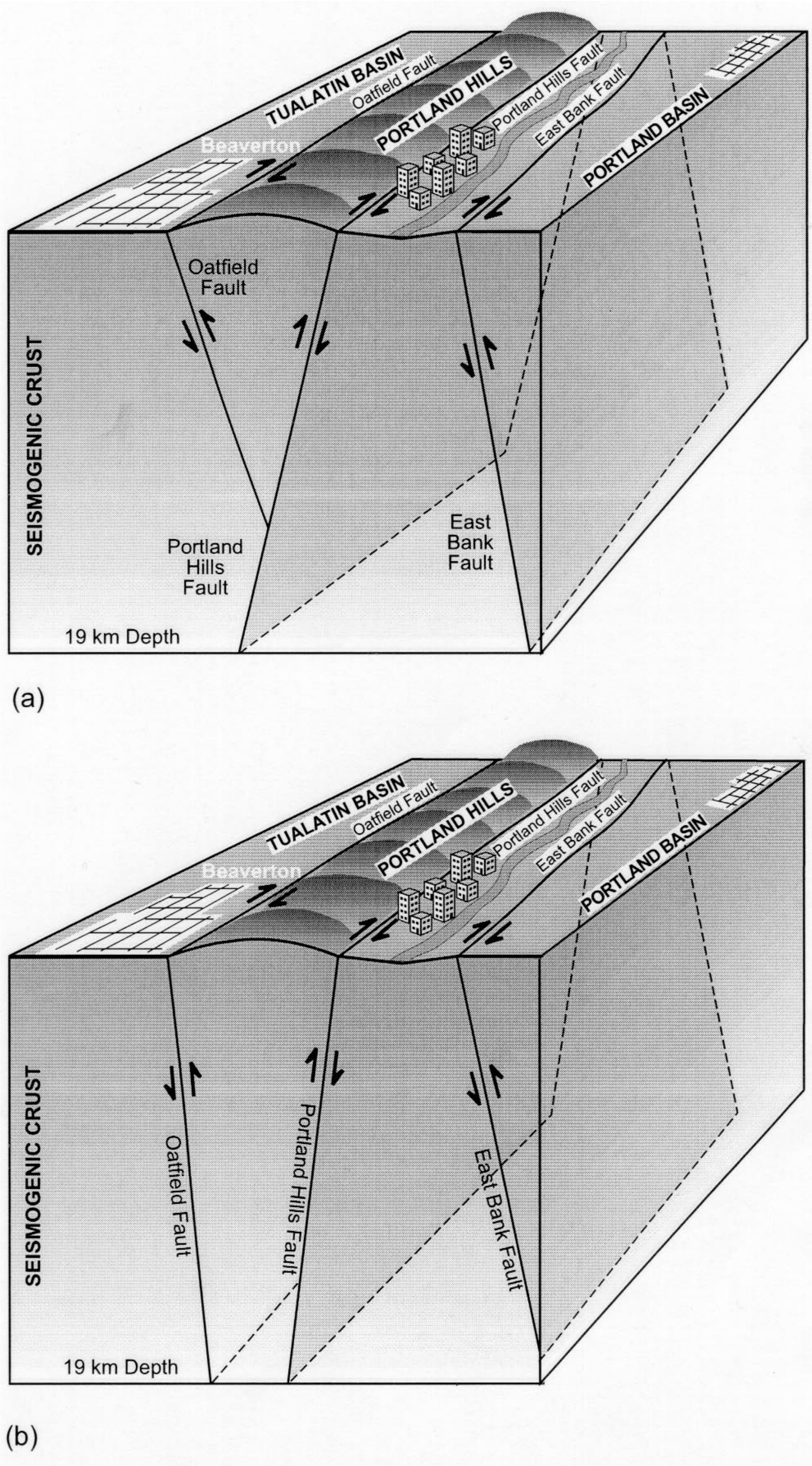


Figure 4. Schematic block diagram of the Portland Hills fault zone. Shown are two possible interpretations of its subsurface geometry. A third model is that the East Bank fault dips to the west and is structurally connected to the Portland Hills and/or Oatfield faults.

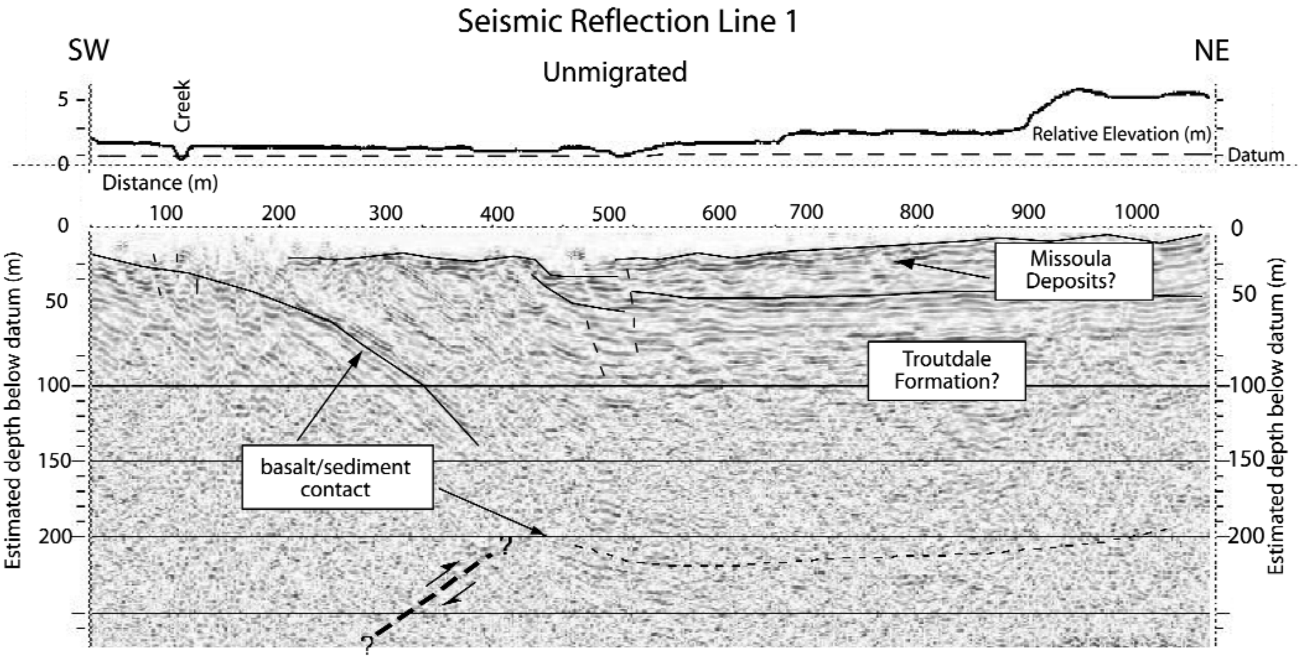


Figure 5. High-resolution seismic reflection profile at the North Clackamas Park.

the NCP site. Seismic, magnetic, and well-log information indicate that basalts dip shallowly to the northeast and are observed at depths greater than 100 m to the north of the site. The seismic data show a strong-amplitude, steeply (>20°) dipping horizon that is likely the top of the CRBG sequence (Figure 5). A well located less than 300 m to the northwest of the seismic line encountered basalt at a depth of more than 150 m. Reflections from younger sediments (possibly Tertiary Troutdale to uppermost Pleistocene Missoula flood deposits) also dip steeply. To the east, near the south-central portion of NCP, reflections associated with younger sediments appear flat lying, but are slightly folded synclinally and faulted toward the west. This major change in dip appears within the Pliocene to latest Pleistocene(?) sediments. The dipping strata are imaged to within about 10 m below the land surface (Figure 5).

We interpret these data to represent a major splay of the Portland Hills fault that offsets post-CRBG sediments. The change from flat-lying CRBG rocks and younger sediments to steeply dipping strata provides an indication of the fault location. The data do not, at present, provide unequivocal evidence for the style of deformation. However, the position of the offset CRBG marker is consistent with a southwest-dipping reverse fault which displaces the Portland Hills northeastward over the adjacent basin.

To date, evidence shows that post-CRBG sediments have been faulted. If the youngest faulted sediments imaged with high-resolution seismic-reflection methods are Missoula-flood-related deposits, then there was at least one episode of coseismic surface rupture in the past 15,000 to 12,000 years. The focus of our continuing investigation is to determine the age and extent of these deposits, to assess the number of times they have been displaced, and to determine the style of deformation.

CONCLUSIONS AND "WHAT IF?"

There are several lines of indirect evidence that suggest the Portland Hills fault is an active and seismogenic structure. Direct evidence includes the seismic reflection results at NCP, although the interpretation is still preliminary. We hope to collect more definitive evidence during field investigations during the coming summer. If doubt of the earthquake potential of the Portland Hills fault is removed, the current year's planned and future investigations will focus on characterizing the maximum earthquake potential of the fault, its subsurface dimensions and geometry, rupture characteristics, and the frequency of large-magnitude events. Regarding the latter, it will be critical to decipher the history of prehistoric earthquakes on the fault in an effort to provide some insight as to when the next event may occur.

The consequences of a future large earthquake on the Portland Hills fault could be severe. Wong and others (2000a) estimated that ground shaking, as characterized by peak horizontal acceleration, could exceed 1.0 *g* for a M_W 6.8 event[2]. (The peak horizontal acceleration recorded in the 1962 earthquake at the only existing strong-motion site was 0.10 *g*, in downtown Portland.)

---

[2] Earthquake ground motions are often expressed in terms of acceleration and the unit "*g*", which is the gravitational acceleration at the earth's surface equal to 980 cm/sec^2. The onset of light damage is at about 0.1 g.

If the Portland Hills fault were to rupture predominantly with reverse slip, an analogue for such an event would be the M_W 6.7 earthquake of 1994 in Northridge, California, which generated some of the strongest ground shaking ever recorded (as high as 1.9 *g*) and caused 58 deaths, and property damage of $20 billion. The source of the Northridge earthquake was a blind reverse fault which dips about 40°–50° to the south beneath the San Fernando Valley.

Unlike the Northridge fault, however, the Portland Hills fault is situated in the midst of a major metropolitan area, where the majority of older buildings do not meet current building code seismic design criteria, particularly those pre-code unreinforced masonry structures. Of special concern, as observed in the Northridge earthquake, is the potential for rupture directivity, which will be directed toward downtown Portland. The directivity effects will be greatest if the Portland Hills fault ruptures with reverse slip. Since directivity is a long-period effect (>1.0 sec), high-rise buildings, which are concentrated in downtown Portland, could be particularly susceptible to very strong ground shaking (These effects are not illustrated on the scenario maps of Wong and others [2000b] because they go out only to a period of 1.0 sec).

As future investigations proceed, it will be important to update the assumptions considered in the Portland Hills fault scenario ground shaking maps, (e.g., magnitude, slip, etc.) in order to provide the most realistic estimates of ground shaking possible so that adequate mitigation measures can be taken to prepare the citizens of the Portland metropolitan area for this potential disaster. Future studies of the East Bank and Oatfield faults and their relationship, if any, to the Portland Hills fault are also critically needed.

(Continued on page 50)

The Portland Hills fault at Rowe Middle School

by Ian, P. Madin, Oregon Department of Geology and Mineral Industries, and Mark A. Hemphill-Haley, Senior Geologist, URS Corporation

For decades, geologists have recognized that the Portland Hills fault is a major geologic structure that runs right through the Portland Metro area. The fault is responsible for the unusually straight and sharp edge of the Portland Hills north of downtown Portland, but is less obvious southeast of downtown. Scattered outcrops and data from water well logs were used to approximate the location of that southeast extension of the fault on recent geologic maps. Geologists from the Oregon Department of Geology and Mineral Industries (DOGAMI), URS Corporation (an engineering firm), and Boise State University began a research project in 2000 to study the Portland Hills fault in more detail. The study, funded by the U.S. Geological Survey through the National Earthquake Hazard Reduction Program (NEHRP), seeks to determine whether the fault is active, and therefore poses an earthquake threat to the region. In this case, "active" means that it has moved during the last 10,000 to 15,000 years.

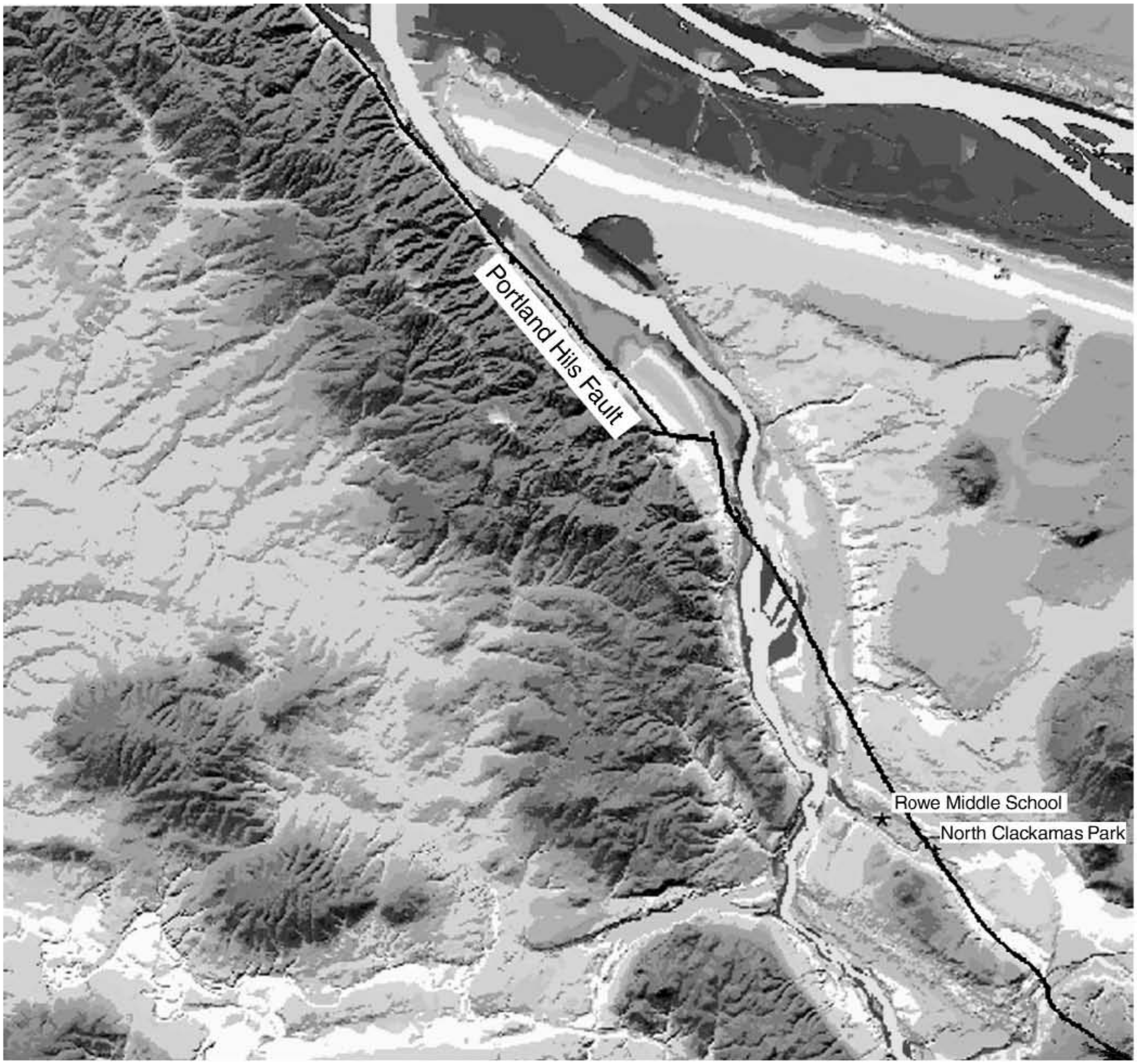
The NEHRP study used two geophysical methods to image the fault and was conducted in North Clackamas Park and on adjacent private property. The site was chosen because the inferred line of the fault passed through it, and the area was relatively undeveloped and quiet, which aided in the collection of good geophysical data. The resulting imagery confirmed the presence of a significant fault, located the main fault to within ~100 ft, and showed faulting and folding to within about 50 ft of the surface. It did not definitively show evidence of activity, because the seismic and magnetic techniques could not image the shallowest layers, and the age of those layers was unknown.

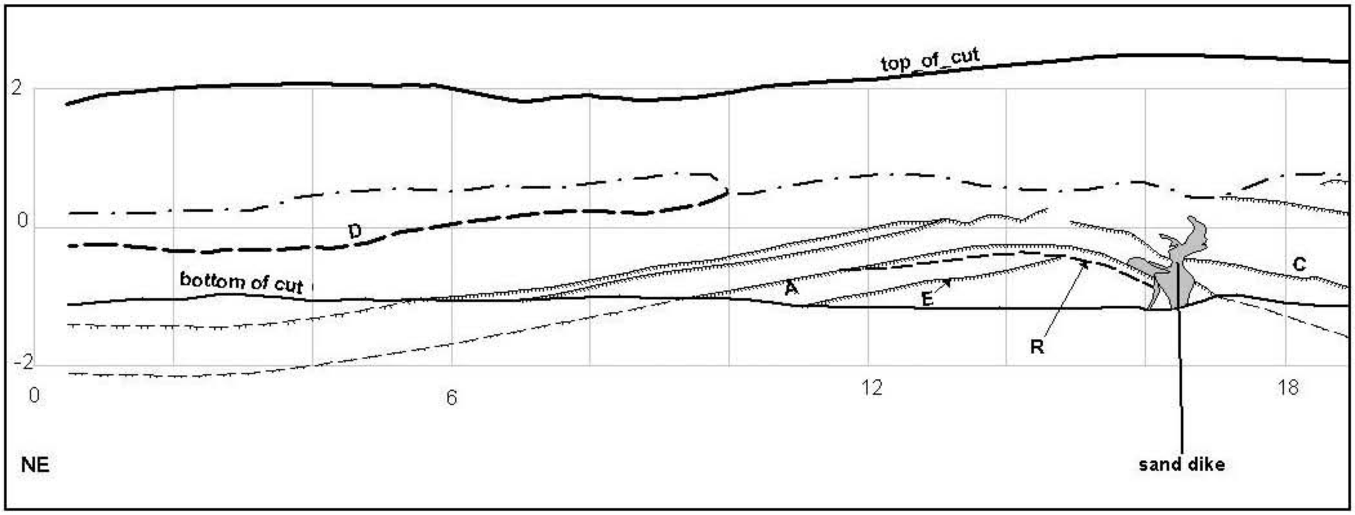
This May, a DOGAMI geologist was collecting more magnetic readings with a handheld instrument to try to map the fault line around the North Clackamas Park site. While collecting data at the site, he noticed sediment layers in a retaining-wall excavation, and these layers appeared to be folded. The deposits at this site are sand and silt layers left during the ice age by the Missoula floods and are 15,000 to 12,800 years old. Hence any faulting or folding of these sediments would point to an active fault.

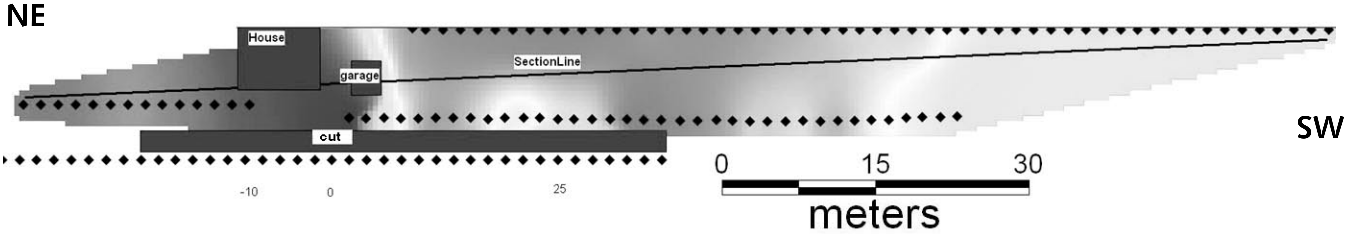
A subsequent two-day examination and logging (by DOGAMI and URS geologists) of the sediments exposed in the retaining-wall face showed that the entire sequence of sediment layers is folded. We believe that this folding is evidence for an active fault beneath the site and that the fault is either the Portland Hills fault or a closely related fault. Preliminary interpretation of the log for the cut shows that the southwest end is about 5 ft higher than the northeast end, and the whole sediment sequence has been shortened about 3 ft. This suggests a total of 6 ft of movement. This is consistent with the assumption that, during the past 12,800 years, two earthquakes may have occurred on the fault.

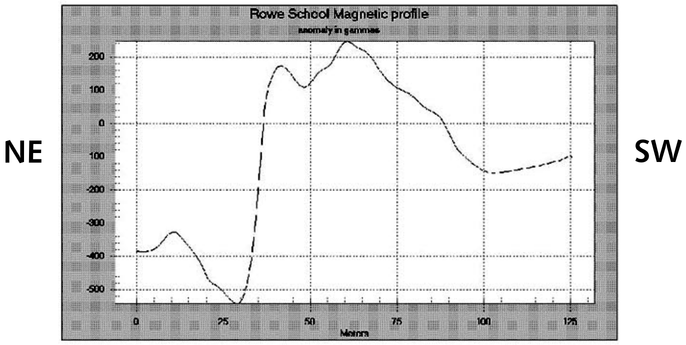
We considered other geologic processes that might have caused the appearance of folded layers but concluded that they could not produce the arrangement we observed. We intend to use more geophysical studies at the site to confirm the presence of a fault beneath the site. An example of this approach is an earlier high-resolution magnetic survey across the fault, which shows an abrupt jump in the magnetic field strength coincident with the folded sediments. We believe this occurs because the depth to highly magnetic volcanic bedrock changes abruptly across the fault. ☐

(See illustrations on next two pages)


Portland Hils Fault
Rowe Middle School
North Clackamas Park


top_of_cut
2
0
-2
D
bottom of cut
A
E
R
C
0
6
12
18
NE
sand dike



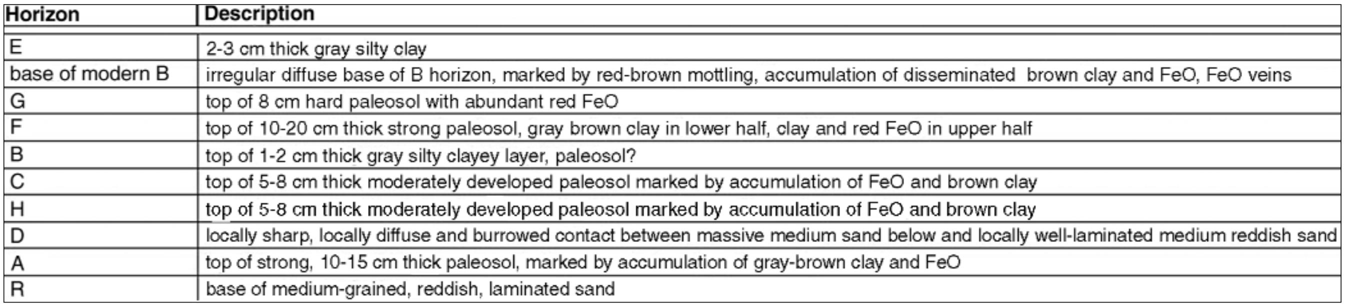


The fault at Rowe Middle School

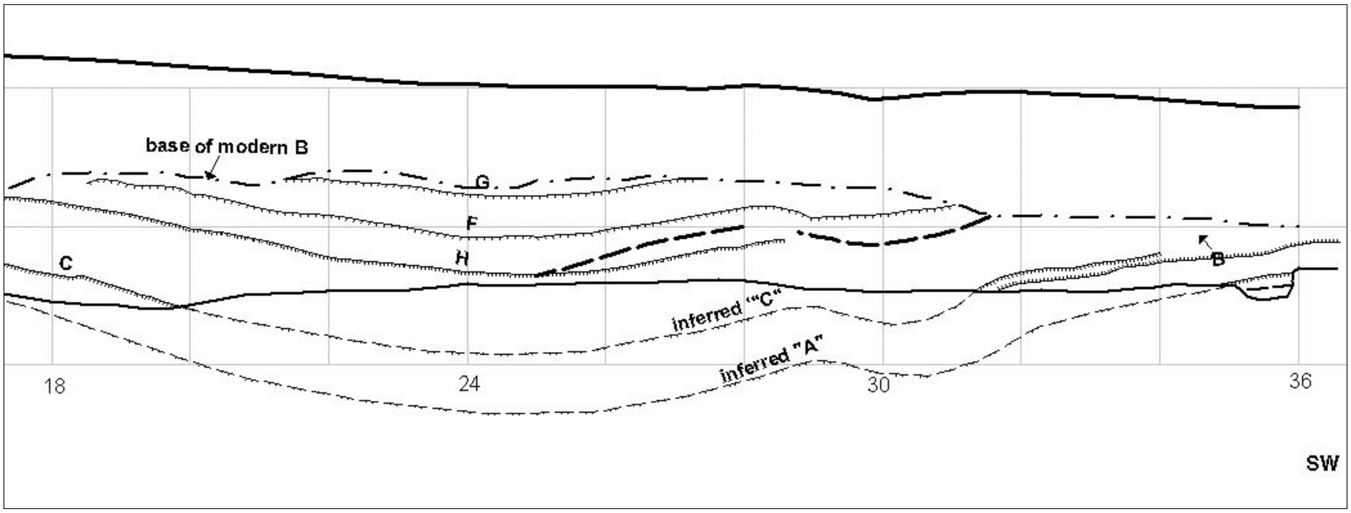
These two pages show, far left, a location map of the new discovery site; on this page, top, a magnetic grid map and graph of the cut that revealed the new information; and, below this text, a description of horizons for the preliminary log of the cut, split across both pages at the very bottom.

The magnetic grid map shows the location of magnetic datapoints (black diamonds) with respect to the cut and includes cultural features. The postion of the sharp anomaly occurs at the same location as the sharp fold in the cut. Points not included in the grid were strongly affected by piles of rebar deployed along the cut for construction. The cross section of the magnetic grid shows a sharp and relatively high-amplitude (~700 gamma) anomaly.

The preliminary log of the cut shows a series of fine sand layers deposited by the late Pleistocene Missoula Floods. Each layer, or rhythmite, represents a single flood event, and the rhythmites are typically separated by paleosols, which are marked by accumulations of clay, iron oxides, and root casts. The log shows a stack of at least seven rhythmites, all of which appear to be folded in the same form. Some channeling is evident in the form of truncated paleosols but is generally restricted to one or two rhythmites. ☐



Horizon	Description
E	2-3 cm thick gray silty clay
base of modern B	irregular diffuse base of B horizon, marked by red-brown mottling, accumulation of disseminated brown clay and FeO, FeO veins
G	top of 8 cm hard paleosol with abundant red FeO
F	top of 10-20 cm thick strong paleosol, gray brown clay in lower half, clay and red FeO in upper half
B	top of 1-2 cm thick gray silty clayey layer, paleosol?
C	top of 5-8 cm thick moderately developed paleosol marked by accumulation of FeO and brown clay
H	top of 5-8 cm thick moderately developed paleosol marked by accumulation of FeO and brown clay
D	locally sharp, locally diffuse and burrowed contact between massive medium sand below and locally well-laminated medium reddish sand
A	top of strong, 10-15 cm thick paleosol, marked by accumulation of gray-brown clay and FeO
R	base of medium-grained, reddish, laminated sand



(Continued from page 47)

ACKNOWLEDGMENTS

Our thanks to Silvio Pezzopane, Rick Blakely, Ray Wells, and Tom Pratt of the U.S. Geological Survey for their generous sharing of ideas and information, and to Marilyn Mackel, Maria Gallegos, and Fumiko Goss for their assistance in the preparation of this paper. The paper benefited from reviews by Rick Blakely, Tom Pratt, and Susan Olig.

REFERENCES CITED

Balsillie, J.J., and Benson, G.T., 1971, Evidence for the Portland Hills fault: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 33, p. 109–118.

Beeson, M.H., Fecht, K.R., Reidel, S.P., and Tolan, T.L., 1985, Regional correlations within the Frenchman Springs Member of the Columbia River Basalt Group: New insights into the middle Miocene tectonics of northwestern Oregon: Oregon Geology, v. 47, no. 8, p. 87–96.

Beeson, M.H., Johnson, A.G., and Moran, M.R., 1975, Portland environmental geology—fault identification (Final technical report to U.S. Geological Survey, in cooperation with Oregon Department of Geology and Mineral Industries): Portland, Oreg., Portland State University, Department of Earth Sciences, 107 p.

Beeson, M.H., Tolan, T.L., and Anderson, J.L., 1989, The Columbia River Basalt Group in western Oregon; geologic structures and other factors that controlled flow emplacement patterns, in Reidel, S.P., and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, p. 223–246.

Beeson, M.H., Tolan, T.L., and Madin, I.P., 1991, Geologic map of the Portland quadrangle, Multnomah and Washington Counties, Oregon, and Clark County, Washington: Oregon Department of Geology and Mineral Industries Geological Map Series GMS–75, 1:24,000.

Blakely, R.J., Wells, R.E., Tolan, T.L., Beeson, M.H., Trehu, A.M., and Liberty, L.M., 2000, New aeromagnetic data reveal large strike-slip(?) faults in the northern Willamette Valley, Oregon: Geological Society of America Bulletin, v. 112, no. 8, p. 1225–1233.

Blakely, R.J., Wells, R.E., Yelin, T.S., Madin, I.P., and Beeson, M.H., 1995, Tectonic setting of the Portland-Vancouver area, Oregon and Washington: Constraints from low-altitude aeromagnetic data: Geological Society of America Bulletin, v. 107, no. 9, p. 1051–1062.

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.

Bucknam, R.C., Hemphill-Haley, E., and Leopold, E.B., 1992, Abrupt uplift within the past 1,700 years at southern Puget Sound, Washington: Science, v. 258, p. 1611–1614.

Geomatrix Consultants, Inc., 1993, Seismic margin earthquake for the Trojan site: Final report prepared for Portland General Electric Trojan Nuclear Plant, Rainier, Oregon, Project no. 1348, var. pag.

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

Kafka, A.L., and Levin, S.Z., 2000, Does the spatial distribution of smaller earthquakes delineate areas where larger earthquakes are likely to occur?: Seismological Society of America Bulletin, v. 90, no. 3, p. 724–738.

Madin, I.P., 1990, Earthquake-hazard geology maps of the Portland metropolitan area, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O–90–2, 21 p., 8 maps, 1:24,000.

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

Pratt, T.L. Odum, J., Stephenson, W., Williams, R., Dadisman, S., Holmes, M., and Haug, B., 2001, Late Pleistocene and Holocene tectonics of the Portland basin, Oregon and Washington, from high-resolution seismic profiling: Seismological Society of America Bulletin (in press).

Schlicker, H.G., Deacon, R.J., and Twelker, N.H., 1964, Earthquake geology of the Portland area, Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 26, no. 12, p. 209–230.

Thomas, G.C., Crosson, R.S., Carver, D.L., and Yelin, T.S., 1996, The 25 March 1993 Scotts Mills, Oregon, earthquake and aftershock sequence: Spatial distribution, focal mechanisms, and the Mount Angel fault: Seismological Society of America Bulletin, v. 86, no. 4, p. 925–935.

Unruh, J.R., Wong, I.G., Bott, J.D., Silva, W.J., and Lettis, W.R., 1994, Seismotectonic evaluation of Scoggins Dam, Tualatin Project, Northwestern Oregon: Unpublished report prepared for U.S. Bureau of Reclamation, 206 p.

Wang, Z., and Madin, I.P., 2001, Mount Angel fault characterization using SH-wave refraction and reflection methods (final technical report): Unpublished report prepared for the U.S. Geological Survey, USGS Award No. 00HQGR0009.

Wells, D.L., and Coppersmith, K.J., 1994, New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement: Seismological Society of America Bulletin, v. 84, no. 4, p. 974–1002.

Wells, R.E., Weaver, C.S., and Blakely, R.J., 1998, Forearc migration in Cascadia and its neotectonic significance: Geology, v. 26, no. 8, p. 759–762.

Wong, I.G., 1997, The historical earthquake record in the Pacific Northwest: Applications and implications to seismic hazard assessment, in Wang, Y., and Neuendorf, K.K.E., eds., Earthquakes—Converging at Cascadia: Oregon Department of Geology and Mineral Industries Special Paper 28/Association of Engineering Geologists Special Publication 10, p. 19–36.

Wong, I.G., and Bott, J.D.J, 1995, A look back at Oregon's earthquake history, 1841–1994: Oregon Geology, v. 57, no. 6, p. 125–139.

Wong, I.G. and Silva, W.J., 1998, Earthquake ground shaking hazards in the Portland and Seattle metropolitan areas, in Dakoulas,P., Yegian, M., and Holtz, R.D., (eds.), Geotechnical earthquake engineering and soil dynamics III: American Society of Civil Engineers Geotechnical Special Publication 75, v. 1, p. 66–78.

Wong, I.G., Silva, W., Bott, J., Wright, D., Thomas, P., Gregor, N., Li, S., Mabey, M., Sojourner, A., and Wang, Y., 2000a, Earthquake scenario ground shaking map for the Portland, Oregon, metropolitan area. Portland Hills fault M 6.8 earthquake, peak horizontal acceleration (g) at the ground surface: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS–15, scale 1:62,500.

Wong, I.G., Silva, W., Bott, J., Wright, D., Thomas, P., Gregor, N., Li, S., Mabey, M., Sojourner, A., and Wang, Y., 2000b, Earthquake scenario and probabilistic ground shaking maps for the Portland, Oregon, metropolitan area: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS–16, 16 p., 11 sheets, scale 1:62,500.

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. ☐

PLEASE SEND US YOUR PHOTOS

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

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

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

If you have any photos that you would like to share with other readers of this magazine, please send them to us (Editor, *Oregon Geology*, 800 NE Oregon Street, Portland, OR 97232-2162) with information for a caption. If they are used, the printing and credit to you and a one-year free subscription to *Oregon Geology* is all the compensation we can offer. If you wish to have us return your materials, please include a self-addressed envelope.

Information for Contributors

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

Two copies of the manuscript should be submitted, one paper copy and one digital copy. All digital elements of the manuscript, such as text, figures, and tables should be submitted as separate files, not as incorporated, e.g., in a word processor product for a paper version. Hard-copy graphics should be camera ready; photographs should be glossies. All illustrations should be clearly marked. Captions should be placed together at the end of the text.

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

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

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

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

PUBLICATION ORDER AND *OREGON GEOLOGY* RENEWAL FORM

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

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

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

Shipping/handling charge $ ________3.00__

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

Name/Address/City/State/Zip ______________________________

____

Please charge to Visa__ / Mastercard__, account number: ______________________

Expiration date: ________ Cardholder's signature ______________________

AVAILABLE PUBLICATIONS
OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

NOTE

All publications require additional $3 for mailing.
Some maps may have to be plotted on demand. In that case, please allow two weeks for delivery.

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

GEOLOGICAL MAP SERIES	Price
GMS-113 Fly Valley 7½' quad., Union County. 1998	10.00
GMS-111 Summerville 7½' quad., Union County. 1997	10.00
GMS-110 Tucker Flat 7½' quad., Union/Baker C. 1997	6.00
GMS-109 Brownsboro 7½' quad., Jackson County. 1998	10.00
GMS-108 Rio Canyon 7½' quad., Jackson County. 1998	6.00
GMS-106 Grizzly Peak 7½' quad., Jackson County. 1997	6.00
GMS-105 EQ hazards, Salem East/West 7½' quads. 1996	12.00
GMS-104 EQ hazards, Linnton 7½' quad., Mult./Wash. C. 1996	10.00
GMS-101 Steelhead Falls 7½' quad., Desch./Jeffers. C., 1996	7.00
GMS-100 EQ hazard maps for Oregon. 1996	8.00
GMS-99 Tsunami hazard map, Siletz Bay, Lincoln C. 1996	6.00
GMS-98 Dora and Sitkum 7½' quad.s, Coos County. 1995	6.00
GMS-97 Coos Bay 7½' quad., Coos County. 1995	6.00
GMS-95 Henkle Butte 7½' quad., Deschutes County. 1998	10.00
GMS-94 Charleston 7½' quad., Coos County. 1995	8.00
GMS-93 EQ hazards, Siletz Bay area, Lincoln County. 1995	20.00
GMS-92 EQ hazards, Gladstone 7½' quad. 1995	10.00
GMS-91 EQ hazards, Lake Oswego 7½' quad. 1995	10.00
GMS-90 EQ hazards, Beaverton 7½' quad. 1995	10.00
GMS-89 EQ hazards, Mt. Tabor 7½' quad. 1995	10.00
GMS-88 Lakecreek 7½' quad., Jackson County. 1995	8.00
GMS-87 Three Creek Butte 7½' quad., Deschutes C. 1995	6.00
GMS-86 Tenmile 7½' quad., Douglas County. 1994	6.00
GMS-85 Mount Gurney 7½' quad., Douglas/Coos C. 1994	6.00
GMS-84 Remote 7½' quad., Coos County. 1994	6.00
GMS-83 Kenyon Mountain 7½' quad., Douglas/Coos C. 1994	6.00
GMS-82 Limber Jim Creek 7½' quad., Union County. 1994	5.00
GMS-81 Tumalo Dam 7½' quad., Deschutes County. 1994	6.00
GMS-80 McLeod 7½' quad., Jackson County. 1993	5.00
GMS-79 EQ hazards, Portland 7½' quad. 1993	20.00
GMS-78 Mahogany Mountain 30×60' quad., Malheur C. 1993	10.00
GMS-77 Vale 30×60' quad., Malheur County. 1993	10.00
GMS-76 Camas Valley 7½' quad., Douglas/Coos C. 1993	6.00
GMS-75 Portland 7½' quad. 1991	7.00
GMS-74 Namorf 7½' quad., Malheur County. 1992	5.00
GMS-73 Cleveland Ridge 7½' quad., Jackson County. 1993	5.00
GMS-72 Little Valley 7½' quad., Malheur County. 1992	5.00
GMS-71 Westfall 7½' quad., Malheur County. 1992	5.00
GMS-70 Boswell Mountain 7½' quad., Jackson County. 1992	7.00
GMS-69 Harper 7½' quad., Malheur County. 1992	5.00
GMS-68 Reston 7½' quad., Douglas County. 1990	6.00
GMS-67 South Mountain 7½' quad., Malheur County. 1990	6.00
GMS-66 Jonesboro 7½' quad., Malheur County. 1992	6.00
GMS-65 Mahogany Gap 7½' quad., Malheur County. 1990	5.00
GMS-64 Sheaville 7½' quad., Malheur County. 1990	5.00
GMS-63 Vines Hill 7½' quad., Malheur County. 1991	5.00
GMS-62 The Elbow 7½' quad., Malheur County. 1993	8.00
GMS-61 Mitchell Butte 7½' quad., Malheur County. 1990	5.00

	Price
GMS-60 Damascus 7½' quad., Clackamas/Multnomah C. 1994	8.00
GMS-59 Lake Oswego 7½' quad. 1989	7.00
GMS-58 Double Mountain 7½' quad., Malheur County. 1989	5.00
GMS-57 Grassy Mountain 7½' quad., Malheur County. 1989	5.00
GMS-56 Adrian 7½' quad., Malheur County. 1989	5.00
GMS-55 Owyhee Dam 7½' quad., Malheur County. 1989	5.00
GMS-54 Graveyard Point 7½' quad., Malheur/Owyhee C. 1988	5.00
GMS-53 Owyhee Ridge 7½' quad., Malheur County. 1988	5.00
GMS-52 Shady Cove 7½' quad., Jackson County. 1992	6.00
GMS-51 Elk Prairie 7½' quad., Marion/Clackamas C. 1986	5.00
GMS-50 Drake Crossing 7½' quad., Marion County. 1986	5.00
GMS-49 Map of Oregon seismicity, 1841-1986. 1987	4.00
GMS-48 McKenzie Bridge 15' quad., Lane County. 1988	9.00
GMS-47 Crescent Mountain area, Linn County. 1987	7.00
GMS-46 Breitenbush River area, Linn/Marion Counties. 1987	7.00
GMS-45 Madras West/East 7½' quads., Jefferson County. 1987	5.00
as set with GMS-43 and GMS-44	11.00
GMS-44 Seekseequa Junction/Metolius Bench 7½' quads. 1987	5.00
as set with GMS-43 and GMS-45	11.00
GMS-43 Eagle Butte/Gateway 7½' quads. 1987	5.00
as set with GMS-44 and GMS-45	11.00
GMS-42 Ocean floor off Oregon & adj. cont. margin. 1986	9.00
GMS-41 Elkhorn Peak 7½' quad., Baker County. 1987	7.00
GMS-40 Aeromagnetic anomaly maps, north Cascades. 1985	5.00
GMS-39 Bibliogr. & index: Ocean floor, cont. margin. 1986	6.00
GMS-38 NW¼ Cave Junction 15' quad., Josephine County. 1986	7.00
GMS-37 Mineral resources, offshore Oregon. 1985	7.00
GMS-36 Mineral resources of Oregon. 1984	9.00
GMS-35 SW¼ Bates 15' quad., Grant County. 1984	6.00
GMS-34 Stayton NE 7½' quad., Marion County. 1984	5.00
GMS-33 Scotts Mills 7½' quad., Clackamas/Marion C. 1984	5.00
GMS-32 Wilhoit 7½' quad., Clackamas/Marion Counties. 1984	5.00
GMS-31 NW¼ Bates 15' quad., Grant County. 1984	6.00
GMS-30 SE¼ Pearsoll Peak 15' qu., Curry/Josephine C. 1984	7.00
GMS-29 NE¼ Bates 15' quad., Baker/Grant Counties. 1983	6.00
GMS-28 Greenhorn 7½' quad., Baker/Grant Counties. 1983	6.00
GMS-27 The Dalles 1°×2° quadrangle. 1982	7.00
GMS-26 Residual gravity, north/ctr./south Cascades. 1982	6.00
GMS-25 Granite 7½' quad., Grant County. 1982	6.00
GMS-24 Grand Ronde 7½' quad., Polk/Yamhill Counties. 1982	6.00
GMS-23 Sheridan 7½' quad., Polk and Yamhill Counties. 1982	6.00
GMS-22 Mount Ireland 7½' quad., Baker/Grant C. 1982	6.00
GMS-21 Vale East 7½' quad., Malheur County. 1982	6.00
GMS-20 S½ Burns 15' quad., Harney County. 1982	6.00
GMS-19 Bourne 7½' quad., Baker County. 1982	6.00
GMS-18 Rickreall, Salem W., Monmouth, Sidney 7½' quads. 1981	6.00
GMS-17 Aeromagnetic anomaly map, south Cascades. 1981	4.00
GMS-16 Gravity anomaly maps, south Cascades. 1981	4.00
GMS-15 Gravity anomaly maps, north Cascades. 1981	4.00

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

	Price
GMS-14 Index to published geol. mapping, 1898–1979. 1981	8.00
GMS-13 Huntington/Olds Ferry 15' quads., Baker/Malheur C. 1979	4.00
GMS-12 Oregon part, Mineral 15' quad., Baker County. 1978	4.00
GMS-10 Low- to intermediate-temp. thermal springs/wells. 1978	4.00
GMS-9 Aeromagnetic anomaly map, central Cascades. 1978	4.00
GMS-8 Bouguer gravity anom. map, central Cascades. 1978	4.00
GMS-6 Part of Snake River canyon. 1974	8.00
GMS-5 Powers 15' quadrangle, Coos and Curry C. 1971	4.00

INTERPRETIVE MAP SERIES

IMS-19 Rel. EQ hazard map, Klamath Falls metropol. area. 2000	**10.00**
IMS-18 EQ-induced slope instability: Haz. map, Eola Hills. 2000	12.00
IMS-17 EQ-induced slope instab.: Haz. map, Salem Hills. 2000	12.00
IMS-16 EQ scenario and probabilistic maps, Portland. 2000	80.00
IMS-15 EQ scenario ground shaking map, Portland. 2000	10.00
IMS-14 Rel. EQ hazard map, Eugene-Springfield. 2000	12.00
IMS-13 Tsunami hazard map, Gold Beach area. 2000	10.00
IMS-12 Tsunami hazard map, Warrenton area. 1999	10.00
IMS-11 Tsunami hazard map, Astoria area. 1999	10.00
IMS-10 Rel. EQ hazard maps, coastal urban areas. 1999	20.00
IMS-9 Rel. EQ hazard maps, Cottage Grove to Ashland. 2000	20.00
IMS-8 Rel. EQ hazard maps, Canby to Sweet Home. 2000	20.00
IMS-7 Rel. EQ hazard maps, St. Helens to Monmouth. 2000	20.00
IMS-6 Water-induced landslide hazards, Salem Hills. 1998	10.00
IMS-5 Water-induced landslide hazards, Eola Hills. 2000	10.00
IMS-4 Geology/faults/sedim. thickness, Oregon City quad. 1997	10.00
IMS-3 Tsunami hazard map, Seaside area. 1998	6.00
IMS-2 Tsunami hazard map, Yaquina Bay area. 1997	6.00
IMS-1 Relative EQ hazards, Portland metro area. 1997	12.00

MINED LAND RECLAMATION PROGRAM STATUS MAPS

MLR-03 Clackamas County. 1998	10.00
MLR-10 Douglas County. 1998	10.00
MLR-17 Josephine County. 1998	10.00
MLR-24 Marion County. 1998	10.00

U.S. GEOLOGICAL SURVEY MAPS PLOTTED ON DEMAND

OFR 97-513 Volcano hazards at Newberry volcano	10.00
OFR 97-089 Volcano hazards in the Mount Hood region	10.00
OFR 94-021 Geologic map, Tillamook highlands (2 sheets)	20.00

BULLETINS

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

OIL AND GAS INVESTIGATIONS

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

SPECIAL PAPERS

34 Slope failures in Oregon–inventory, 1996/97 storms. 2000	**6.00** NEW
33 Penrose Conference summary and abstracts. 2000	15.00
32 Geologic hazards: Reducing Oregon's losses. 2000	10.00
31 Mitigating geol. hazards:Technical reference manual. 2000	20.00
30 EQ-induced slope instability: Mapping methodology. 2000	15.00
29 Earthquake damage and loss estimates for Oregon. 1999	10.00
28 Earthquakes Symposium Proceedings, AEG Meeting. 1997	12.00
27 Construction aggregate markets and forecast. 1995	15.00
26 Cross section, N. Coast Range to continental slope. 1992	11.00
25 Pumice in Oregon. 1992	9.00
24 Index to Forums on Industrial Minerals, 1965-1989. 1990	7.00
23 Forum on Industrial Minerals, 1989, Proceedings. 1990	10.00
22 Silica in Oregon. 1990	8.00
21 Geology, NW¼ Broken Top 15' quad., Deschutes Co. 1987	6.00
20 Bentonite in Oregon. 1989	7.00
19 Limestone deposits in Oregon. 1989	9.00
18 Investigations of talc in Oregon. 1988	8.00
17 Bibliography of Oregon paleontology, 1792-1983. 1984	7.00
16 Index to Ore Bin and Oregon Geology (1939-82). 1983	5.00
15 Geology/geothermal resources, central Cascades. 1983	13.00
14 Geology/geothermal resources, Mount Hood area. 1982	8.00

(Continued on next page)

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

	Price
13 Faults and lineaments of southern Cascades, Oregon. 1981	5.00
12 Geologic linears, N. part of Cascade Range, Oregon. 1980	4.00
11 Bibliography/index, theses/dissertations, 1899-1982. 1982	7.00
10 Tectonic rotation of the Oregon Western Cascades. 1980	4.00
9 Geology of the Breitenbush Hot Springs quadrangle. 1980	5.00
8 Geology and geochemistry, Mount Hood volcano. 1980	4.00
7 Pluvial Fort Rock Lake, Lake County. 1979	5.00
6 Geology of the La Grande area. 1980	6.00
5 Analysis and forecasts of demand for rock materials. 1979	4.00
4 Heat flow of Oregon. 1978	4.00
3 Rock material, Clackam./Columb./Multn./Wash. Co. 1978	8.00
2 Field geology, SW Broken Top quadrangle. 1978	5.00

MISCELLANEOUS AND SHORT PAPERS (discontinued)

MP 20 Investigations of nickel in Oregon. 1978	6.00
MP 19 Geothermal exploration studies in Oregon, 1976. 1977	4.00
MP 15 Quicksilver deposits in Oregon. 1971	4.00
MP 11 Articles on meteorites (reprints from the Ore Bin). 1968	4.00
MP 5 Oregon's gold placers. 1954	2.00
SP 27 Rock material resources of Benton County. 1978	5.00
SP 25 Petrography of Rattlesnake Formation at type area. 1976	4.00

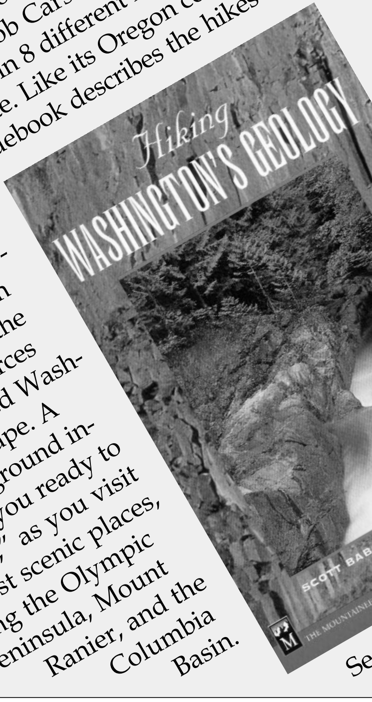
MISCELLANEOUS PUBLICATIONS

	Price
Oregon fossils.1999	40.95
Living with earthquakes in the Pacific Northwest. 1998	21.95
Islands & Rapids. Geologic story of Hells Canyon. 1998	25.00
The Pacific Northwest coast: Living with shores. 1998	18.50
Hiking Oregon's geology, E.M. Bishop and J.E. Allen, 1996	16.95
Assessing EQ hazards in the PNW (USGS Prof. Paper 1560)	25.00
Geology of Oregon, 5th ed. 1999	41.95
Geologic map of Oregon. 1991	11.50
Geologic highway map (AAPG), PNW region. 1973	8.00
Landsat mosaic map (published by ERSAL, OSU). 1983	11.00
Mist Gas Field map. 2001 (OFR O-01-01)	**8.00**
Digital version on CD (CAD formats .DGN, .DWG, .DXF)	**25.00** NEW
Mist Gas Field production 1979-1992 (OFR O-94-6)	5.00
Oregon rocks and minerals, a description. 1988 (OFR O-88-6)	6.00
Mineral information by county (OFR O-93-8), 1 CD	25.00
Directory of mineral producers. 1993 (OFR O-93-9)	8.00
Geothermal resources of Oregon (DOGAMI/NOAA map). 1982	4.00
Mining claims (State laws on quartz and placer claims)	Free
Back issues of Oregon Geology	3.00

Highlighting Recent Publications

Now available from The Nature of the Northwest Information Center

Hiking may well be on many people's minds at this time of year. That's why we wish to point out this pair of books, one quite new, the other a bit older and in its second printing:



Hiking Washington's Geology, by Scott Babcock and Bob Carson, details 56 trails in 8 different regions of the state. Like its Oregon counterpart, the guidebook describes the hikes with maps, photos, and easy-to-follow text for anyone interested in learning about the monumental forces that have shaped Washington's landscape. A wealth of background information gets you ready to "read the rocks," as you visit the state's most scenic places, including the Olympic Peninsula, Mount Ranier, and the Columbia Basin.

Seattle, The Mountaineers, 2000, 270 pages, $16.95.

Hiking Oregon's Geology, by Ellen Morris Bishop and John Eliot Allen, was announced and reviewed in Oregon Geology in Jan./Feb. 1997 (v. 59, no. 1, page 21). It takes its readers on a tour of Oregon's most scenic and geologically interesting places, including Mount Hood, Crater Lake, Oregon Caves, Smith Rock, Hells Canyon, and the John Day Fossil Beds. The hikes range from short, handicapped-accessible trails to multi-day wilderness trips. With 10 maps, 51 hikes, and 80 photos, *Hiking Oregon's Geology* makes a most useful traveling companion.

Seattle, The Mountaineers, 1996, 222 pages, $16.95.

Seismic rehabilitation in the renovation of the Oregon State Library in Salem

by Keith Robinson, P.E., Associate, KPFF Consulting Engineers, 111 SW Fifth Avenue, Suite 2500, Portland, Oregon 97204

The Oregon State Library in Salem, front entrance facing the Capitol Mall.

INTRODUCTION

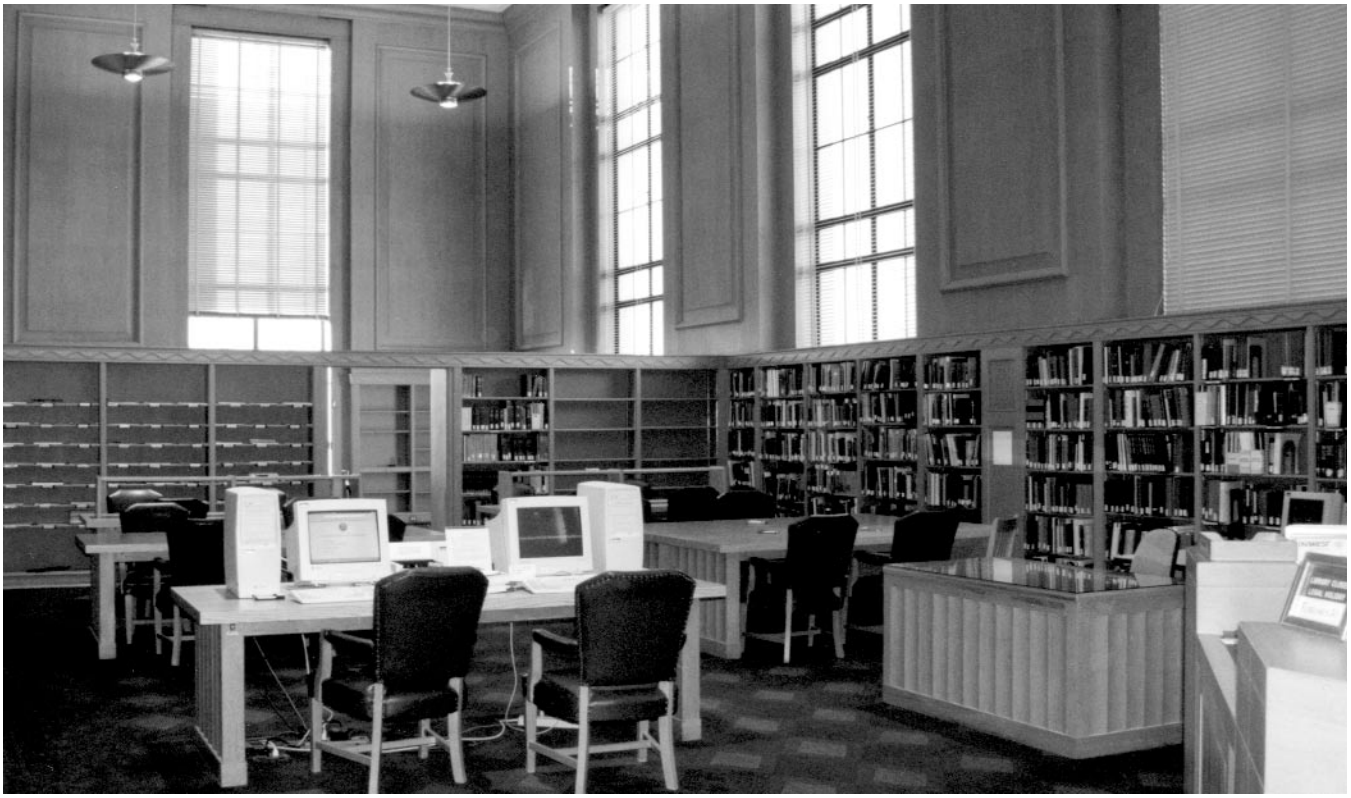
Last February 1, the Oregon State Library was formally rededicated after the completion of most of the renovation work that had been going on since 1998. An important part of that effort had been structural strengthening of the library building against possible earthquake damage. That particular work is the main focus of the presentation here.

The Oregon State Library on the Capital Mall in Salem was designed by Whitehouse and Church Architects of Portland and constructed in 1937. By now, it was in need of substantial renovation. As with many buildings of its vintage, the Oregon State Library is a nonductile concrete frame with little or no provision for seismic resistance. So the library structure itself required seismic strengthening. This strengthening of the structure was designed to meet the requirements of current seismic codes, which have changed drastically since the building was constructed. In addition, the existing mechanical systems needed upgrading; and the building required improved ADA provisions, accessibility, and space utilization. Budget limitations made it impossible to temporarily relocate the library.

The Oregon State Library is the sole provider of "Books on Tape," a program that serves the blind community. Ensuring that the blind community and other library patrons would continue to benefit from the services offered by the library necessitated maintaining the operations of the library during construction.

The design team, then, was facing the need to develop a design that would accomplish the renovation and strengthening, while not only protecting the many historic elements in the building and countless historic manuscripts but also allowing the library to remain occupied and open for business during construction. The project team accomplished these goals by creating an innovative engineering design in combination with other noninvasive renovation methods. Due to the complexity of working inside the occupied library, the owner selected the general contractor prior to completion of the design. This allowed the design to incorporate the con-

Lobby of the Oregon State Library, where the original design, paneling, and lighting were restored.



Reference room in Oregon State Library, where protection of paneling required coring of support columns.

tractor's means and methods of construction.

In addition to KPFF Consulting Engineers, the design team included Fletcher, Farr, Ayotte, PC, Architecture and Interiors; CBG Consulting Engineers, Mechanical and Electrical Engineering, and Plumbing; PBS Environmental, Environmental Engineering; Geotechnical Resources, Inc., Geotechnical Engineering; Milstead & Associates, Inc., Construction Management; and Architectural Cost Consultants, Cost Estimators.

STRUCTURAL STRENGTHENING

Reinforcement of the existing structure included preserving and reinforcing the existing historic marble finishes against seismic hazards; parapet bracing; installation of pin piles to supplement existing spread footings; installation of threaded reinforcing bars to strengthen several existing two-story columns; and construction of steel-plate shear walls.

Some of the existing two-story columns in the library's reference room required strengthening. The columns were deficient for out-of-plane seismic loads due to short, mid-span splices in the longitudinal reinforcing steel. The problem was that they were buried inside walls and carried historic finishes on both sides. To mitigate this deficiency, KPFF developed a plan to core through the center of the existing columns lengthwise and install high-strength, threaded reinforcing bars, which were post-tensioned. These rods effectively pre-compressed the existing concrete column, preventing tensile forces from developing under seismic loads. Alignment of the core bit on the center of the column was critical during the drilling process and was achieved within a one-inch tolerance through columns 40 ft in height.

The use of steel plates for shear walls is uncommon. Installing steel plate rather than concrete shear walls allowed the design team to overcome many design constraints and was less disruptive to the building's occupants. The moisture generated by pouring vast amounts of concrete in the building could have harmed the library's collection of valuable documents. The use of steel plates solved this problem. It facilitated access, allowed installation in confined spaces, and provided flexibility for architectural space planning. KPFF designed the individual steel plates comprising the walls so that two men could carry a plate and install it manually, which eliminated the need for large equipment, lifts, and cranes. The plates were spliced together with structural Tees, which also serve as stiffeners for the plates. To the extent possible, connections were made with bolts rather than welds, which minimized the risk of fire to the building's contents. The relatively thin steel walls take up much less space than thicker concrete shear walls.

Example of steel-plate shear wall in basement of Oregon State Library during construction.

"Backstairs" view of finished steel-plate shear wall in basement of Oregon State Library. Photo by Klaus Neuendorf, DOGAMI.

Because the existing building did not have a well-defined, lateral force resisting system, it was assumed that the existing structure provided no significant strength to resist lateral loads. However, the stiffness of the existing structure with its unreinforced masonry in-fill walls was considerable. The new walls were designed to resist seismic force levels for Zone 3 of the Uniform Building Code (UBC). The new steel-plate shear walls were designed and sized, using finite element modeling techniques, to provide adequate strength to resist the seismic loads and stiffness to prevent excessive deflection which could have damaged the existing structure and its contents.

In some cases, overturning forces from the new steel-plate shear walls exceeded the capacity of existing footings at the ends of the walls. To provide additional footing capacity and to hold the ends of the walls down from "uplift," pin piles were installed at strategic locations. These 40-ft-long, 100-ton capacity piles were drilled into the ground in 4-ft increments and spliced as they were installed. The piles were installed from the confines of the existing basement, which has as little as 8 ft of headroom in some areas. Because the installation involved auguring rather than driving, disruption to the building's occupants was minimal.

TECHNICAL VALUE TO THE ENGINEERING PROFESSION

Today, renovation of existing historic buildings often requires construction methods to be less intrusive and construction materials to be smaller, thinner, and more manageable. The design of this project satisfied these requirements. The unconventional and successful application of the steel-plate shear walls, in combination with other noninvasive renovation methods, provides new opportunities for engineers to accommodate more demanding preservation requirements, architectural requests, and social needs. The structural analysis involved finite element models and site-specific response data to determine accurate building response and design forces. KPFF created a computer model that analyzed all significant modes of the building's response when subjected to ground motions specified by the geotechnical engineer. Through this approach, KPFF was able to design the new steel-plate shear walls not only to provide adequate strength to resist loads but also with the stiffness necessary to limit deflections and damage to the existing structure.

SOCIAL AND ECONOMIC CONSIDERATIONS

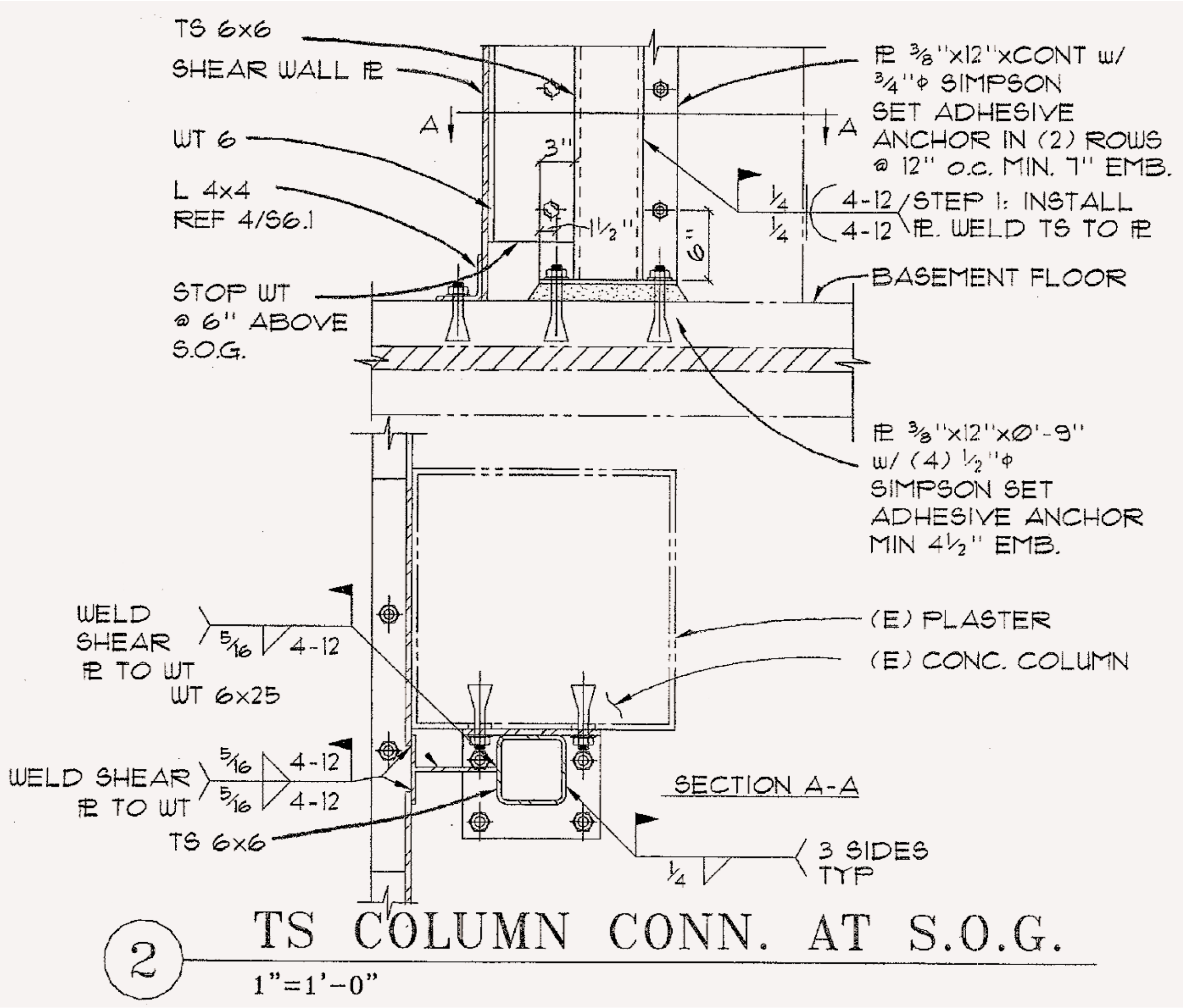
Maintaining the operations of the library during construction provided an enormous social benefit. It provided uninterrupted service to the blind community of the unique program "Books on Tape" as well as to other library patrons.

Ornate roof parapets were braced and the existing historic marble finishes were preserved and reinforced against seismic hazards maintaining the classic appearance of the building. In addition, the project involved ADA improvements, including a new accessible entrance, an elevator, and restroom facilities.

COMPLEXITY

Specific design criteria for steel-plate shear walls are not codified. The designers has to establish reasonable criteria based on various other code provisions, research, and a great deal of common sense.

Despite the fact that the building was originally designed in 1937, excellent archived drawings and specifi-



Detail of design specification of pin piles installed to strengthen footings of shear walls in Oregon State Library.

cations were available. However, in many instances, existing structural elements were not located where they were indicated on the drawings. Oftentimes, beams, columns, and footings had not been constructed as represented. This significantly contributed to the project's complexity. The design issues related to keeping the building open during construction were magnified when unexpected existing conditions were inevitably discovered. The design team was able to respond on demand to the contractor's requests for information. The engineers were on call and regularly conducted unscheduled visits to a site 50 mi away. Because this was a CM/GC process, the general contractor joined the project design team prior to the completion of the construction documents and participated in the completion of the design. This allowed the design team to tailor the design documents to accommodate the contractor's means and methods. This approach also allowed for accurate estimating so that the greatest amount of seismic risk could be mitigated within the constraints of the project budget. The end result of this collaborative effort was a project that was completed within the owner's budget and schedule. The project also exceeded the owner's needs of minimizing the impacts on the building's occupants and contents during construction. ☐

Preparation pays

All things considered, the recent Olympia [i.e., Nisqually, Feb. 28, 2001] earthquake had a very modest impact on BPA. The transmission system sustained relatively little damage —primarily a few broken insulators. No problems on BPA facilities caused any customer to lose service.

The reason BPA fared so well is simple: preparation works. BPA has spent $2.5 million since 1995 hardening facilities to prevent earthquake damage. All 500-kilovolt substations in the Puget Sound area have been hardened against seismic events. Since a single overturned transformer would cost $1 million or more to repair, the investment proved well worth it.

—*From* **Journal**: *A monthly publication of the Bonneville Power Administration, April 2001*

Results of a new method of Fourier grain-shape analysis of detrital quartz grains in sediments from Jackson County, Oregon

by Roy F. Torley, Department of Geological Sciences, University of Oregon, Eugene, OR 97403-1272

INTRODUCTION

A new method of Fourier grain-shape analysis was used to study the shapes of detrital quartz grains from creek sediments collected in the Bear Creek and Antelope Creek Valleys in Jackson County, Oregon (Figure 1). Analytical results reveal that these grains can be separated into two populations of distinctly different shape, one characteristic of a plutonic source rock and the other characteristic of a silicic volcanic source rock. Both plutonic and volcanic rocks crop out in and around Bear Creek Valley, while volcanic rocks are predominant in Antelope Creek Valley. In addition, low-grade metamorphic and first-cycle(?) sedimentary rocks crop out in the study area, but no special grain-shape population was identified for detrital quartz grains derived from these source rocks.

FOURIER GRAIN-SHAPE ANALYSIS

The new method of Fourier grain-shape analysis is based upon the notion that the change in curvature around the perimeter of a grain's outline (Figure 2) carries provenance information (Zahn and Roskies, 1972). The method traditionally used in sedimentology, called closed-form Fourier grain-shape analysis, analyzes the change in radial distance of points on the grain's perimeter from its centroid (Ehrlich and Weinberg, 1970). Two practical aspects of the new technique are its ability to analyze small changes in curvature with respect to perimeter and, more importantly, to analyze grain shapes that have significant reentrants or protuberances. Also, transformed shape data from the new method are amenable to graphic statistical presentation, feature extraction, and factor analysis in exactly the same way as data from the closed-form Fourier technique.

While the new Fourier method "sees" and registers changes in curvature on the perimeter, the closed-form method might register those same points as insignificant changes in radius, so that important but subtle information may be lost (Torley, 1998). More importantly, grains having very convoluted shapes are properly transformed by the new method and added to the shape database as viable members of the sample population. The closed-form method rejects such grains, thus immediately introducing bias into the sample population by selective grain-shape rejection.

Subsequent steps in Fourier grain-shape analysis include data mining. Chi-squared feature extraction is performed upon the many thousands of transformed grain-shapes

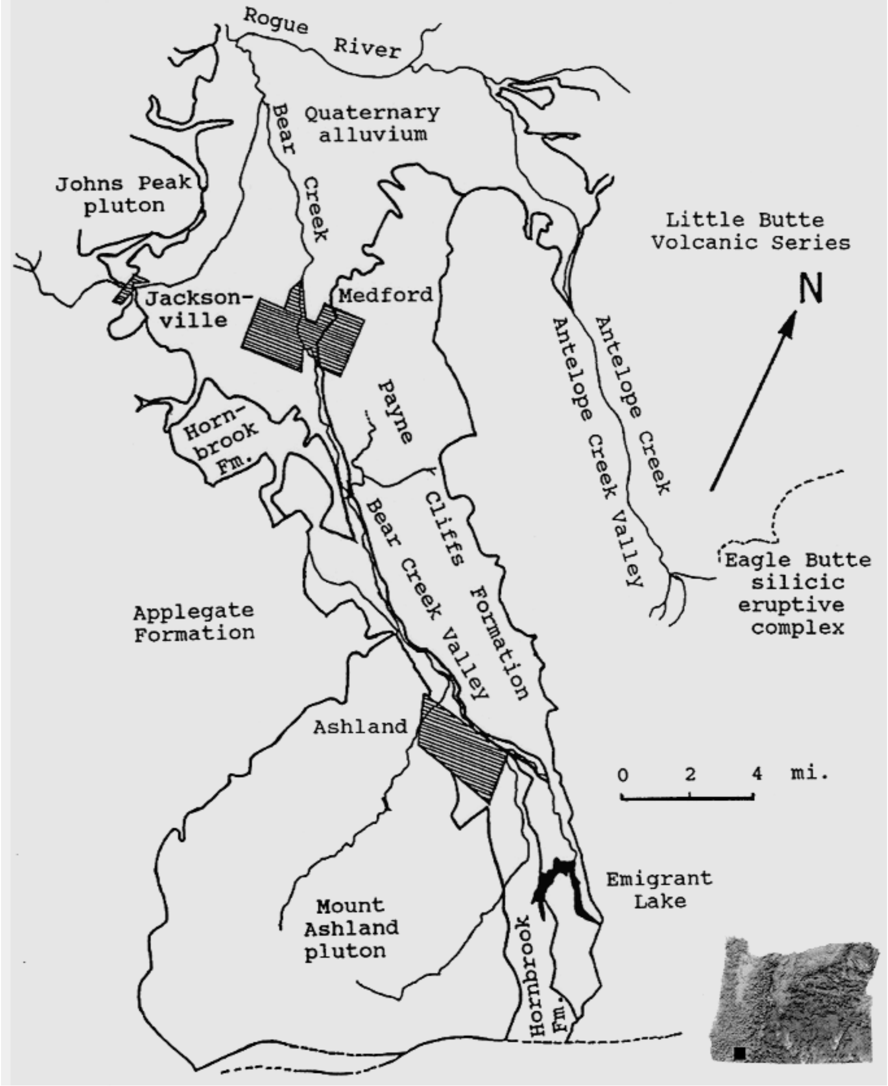


Figure 1. Generalized map of Bear Creek and Antelope Creek Valleys, Jackson County, Oregon.

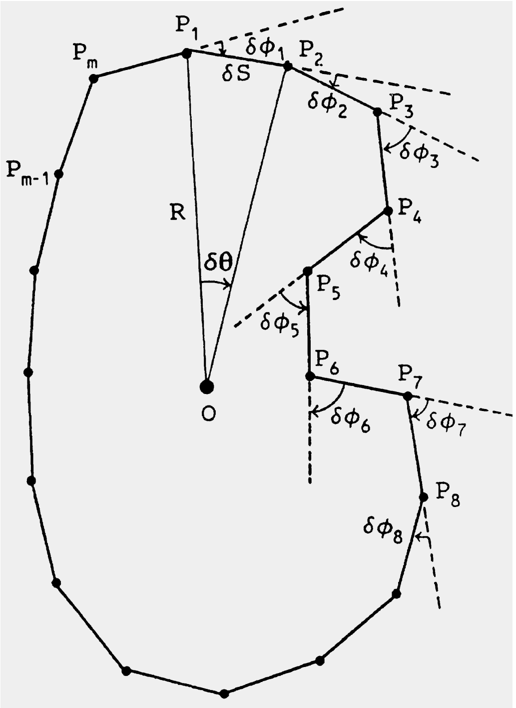


Figure 2. A grain shape approximated as a closed polygon with m vertices defined in terms of equi-length perimeter segments δS and changes in angle $\delta\phi$. The grain centroid is at O, the radius is R, and the change in radial angle about the centroid is $\delta\theta$.

amassed into the study's database to identify the most information-rich part (Full and others, 1984). Finally, factor analysis is applied to that information-rich part to analyze and record the data structure (Full and others, 1981). The outcome of these two steps includes the identification of grain-shape populations that have such extreme characteristics that they can be called end-member populations. All other samples that cannot be represented as end-member populations appear as mixtures of these end-members.

The actual science of Fourier grain-shape analysis can now be done. Sediment samples identified as containing end-member quartz grain-shape populations and/or large proportions of those end-members should cluster geographically and, ideally, geologically. Patterns in the provenance of sediments should become clear by virtue of the detrital quartz component.

Quartz is a chemically and mechanically resilient mineral. Transport studies have shown that it can retain its shape over long distances in a fluvial environment (Kuenen, 1959). The creeks sampled in and around Bear Creek Valley have small lengths on a geological scale (<10 mi). It is reasonable to infer that in this study grain shape is influenced mainly by provenance and that transport effects are negligible with regard to the detection capabilities of the new technique.

In this particular study, detrital quartz grains were divided into a medium-sand-size fraction (0.25-0.50 mm size) and a coarse-sand-size fraction (0.50-1.0 mm size) to study the effect of grain size upon the distribution of shape populations at collection sites. Analytical results are almost identical between the two size ranges. Consequently, only the results for the coarse-sand-sized fraction need be discussed.

RESULTS

In Bear Creek and Antelope Creek Valleys, two end-member grain-shape populations were identified. The first end-member shape population exhibits a very irregularly shaped outline, typical for quartz that grew as an intersertal mineral in a cooling pluton (Figure 3). The second end-member shape is characteristic of a silicic volcanic environment, ranging in form from a euhedral hexagonal dipyramid (beta-quartz pseudomorph) to fragments and shards that still show parts of crystal faces and edges (Figure 4).

One end-member population clusters preferentially around the Mount Ashland pluton (Figure 5). The other end-member clusters around Antelope Creek, which, along its middle and upper course, is located within the Little Butte Volcanic Series (Figure 6). Samples from other collection sites show mixtures of these two end members.

Detrital quartz collected along Payne Creek (Figure 7) has a dominantly volcanic character. This characteristic may be the result of contributions from quartz-rich tuffs within the Payne Cliffs Sandstone (Elliot, 1971; Nilsen, 1984) and remnant quartz-rich volcanic ash-fall from the nearby Eagle Butte silicic volcanic center (Hladky, 1996). Quartz collected from Miller Gulch and South Fork Jackson Creek has a wildly varying character (Figure 8). Collection sites that show a dominantly plutonic character may be influenced by grus eroding off the nearby Johns Peak pluton. The sites showing a dominantly volcanic provenance are situated on the valley alluvium where, perhaps, quartz-rich volcanic ash-fall from volcanic activity of the Eocene Western Cascades makes up a significant proportion of the soil profile.

When the closed-form Fourier technique was applied to the original grain-shape data, results showed no relation to geography or geology at all. The new Fourier method produced significant geographical and geological clustering of end-member shape populations that make geologic sense.

Although low-grade meta-argillites and meta-andesites of the Applegate Formation and first-cycle(?) sandstones of the Payne Cliffs Formation crop out in the study area, Fourier grain-shape analysis did not discern any other end-member grain-shape populations that would suggest the presence of quartz shapes modified by the metamorphic process or by the processes of transport, deposition, and diagenesis that form a sandstone. It is possible that the metamorphic process behind the Applegate Formation was of such a low grade (lower greenschist facies, according to Donato, 1975) that quartz grain shapes could not be

Figure 3. Scanning electron photomicrograph of a plutonic detrital quartz grain derived from Mount Ashland granodiorite. Grain is approximately 1.0 mm in length.

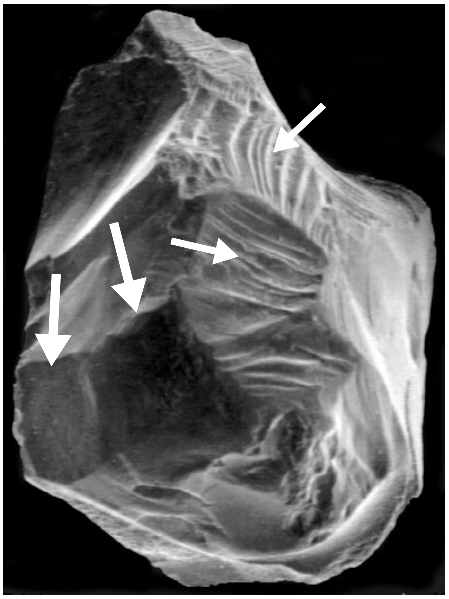


Figure 4. Volcanic quartz from Antelope Creek, showing conchoidal fractures (smaller arrows) and two crystal faces (larger arrows). Grain is approximately 0.75 mm in length.

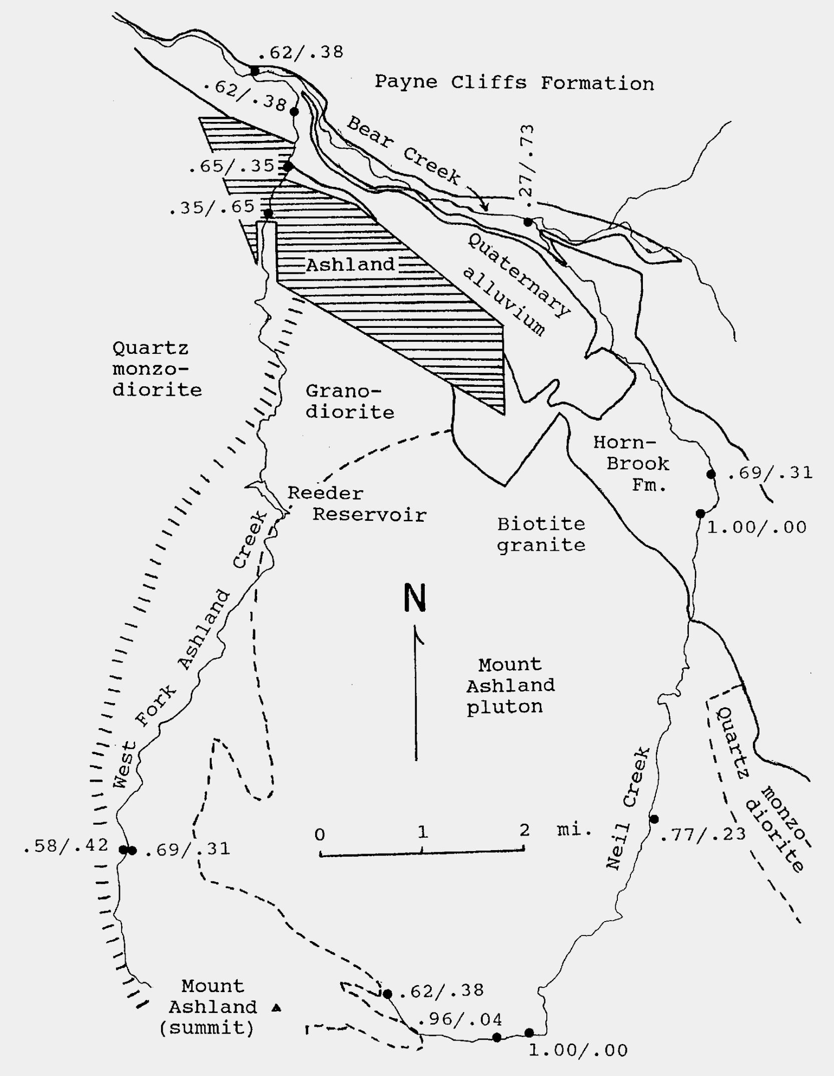


Figure 5. Generalized map of the northeastern side of the Mount Ashland pluton, showing proportions of plutonic and volcanic end-member grain-shape populations (plutonic/volcanic) for the coarse-sand-size range (0.5-1.0 mm) at sampling sites (filled circles) on West Fork Ashland and Neil Creeks.

modified significantly, especially where the protolith was mud and clay on a continental shelf. Thus, the grains retained their original shapes (plutonic and/or volcanic). Sedimentary processes also may have had little effect on original quartz grain shapes, especially if transport distances were short and the transport agent was water in a marine or fluvial environment. The Cretaceous Hornbrook Formation was not considered, since it has a restricted presence and is highly variable in character in the study area.

DISCUSSION

The new method of Fourier grain-shape analysis reveals a believable geographic and geologic distribution of two detrital quartz grain-shape populations: one showing an affinity with plutonic source rock (basement uplift provenance) and the other showing an affinity with silicic volcanic source rock (magmatic arc provenance). No reliable provenance information was produced when the closed-form Fourier technique was used.

Although the new Fourier grain-shape technique holds

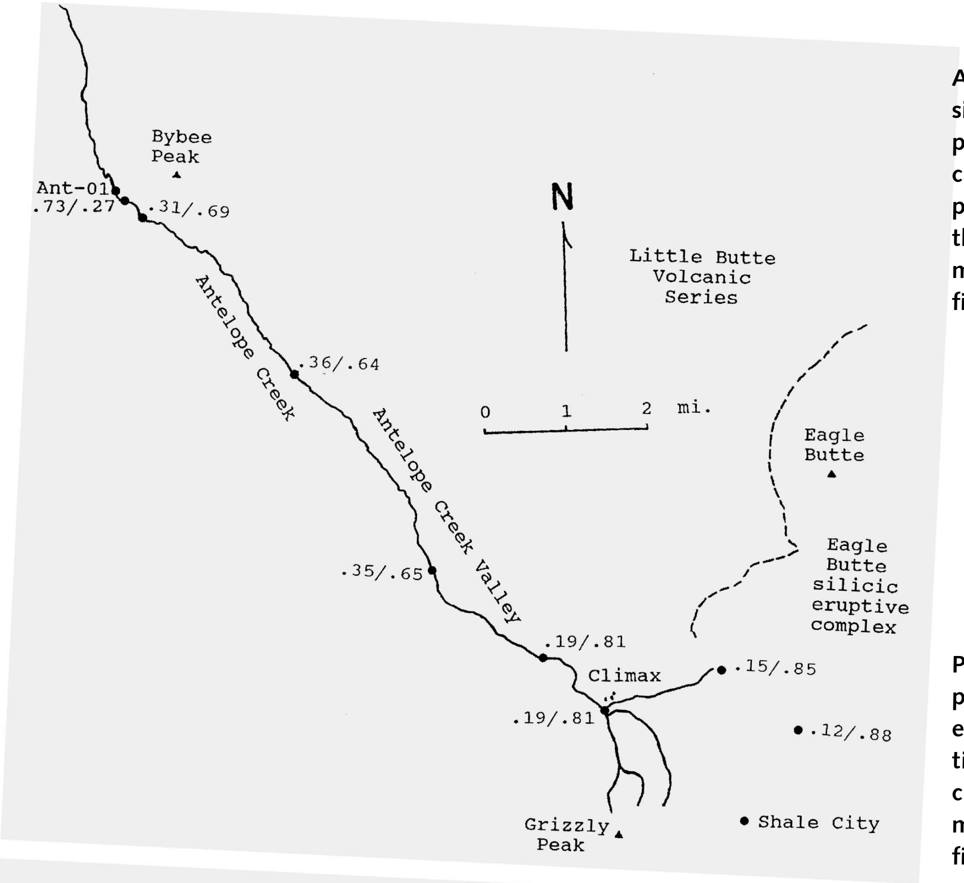
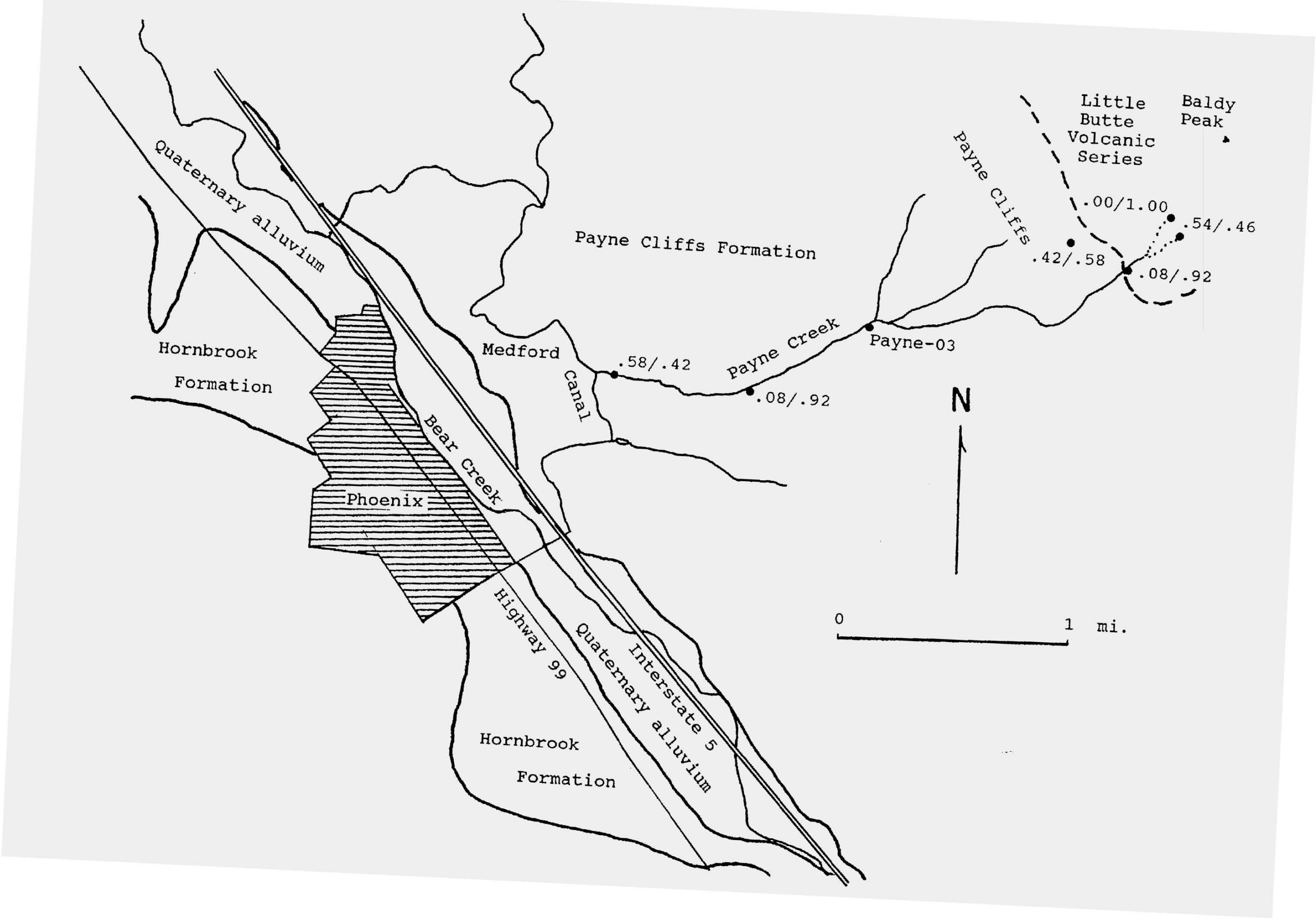


Figure 6. Generalized map of Antelope Creek and the Eagle Butte silicic eruptive complex, showing proportions of plutonic and volcanic end-member grain-shape populations (plutonic/volcanic) for the coarse-sand-size range (0.5-1.0 mm) at sampling sites marked by filled circles.

Figure 7. Generalized map of Payne Creek vicinity, showing proportions of plutonic and volcanic end-member grain-shape populations (plutonic/volcanic) for the coarse-sand-size range (0.5-1.0 mm) at sampling sites marked by filled circles.



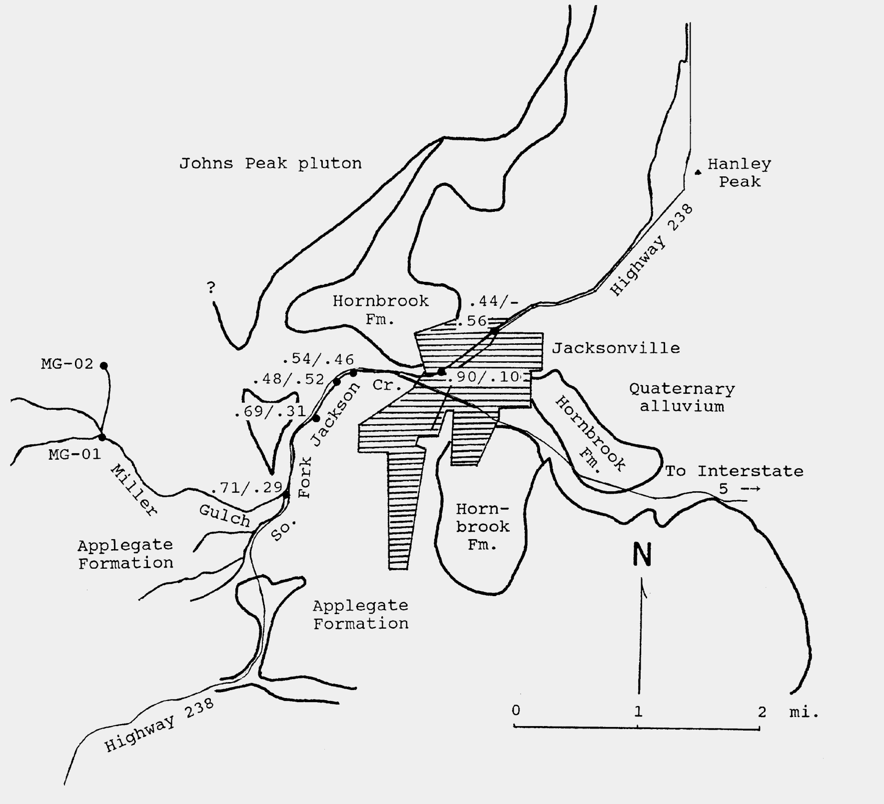


Figure 8. Generalized map of Miller Gulch and South Fork Ashland Creek vicinity, showing proportions of plutonic and volcanic end-member grain-shape populations for the coarse-sand-size range (0.5-1.0 mm) at sampling sites marked by filled circles.

promise as a viable tool for provenance analysis, it should be used intelligently like any other statistical technique. Shape information is gleaned off a very small part of a grain image—its outline. Any features within the outline are not recorded at all. Therefore, to make up for this severe "information filtering," hundreds of grains are required to construct a statistically robust sample population.

This method is not a stand-alone method. It is best used in conjunction with other time-tested techniques like optical microscopy and chemical methods. It can then lend complementary numerical support to these other methods.

I want to share and expound upon an observation that was made by another sedimentologist a few years ago: It is interesting to note that the quartz grains that are eroded off a pluton and those derived from quartz-rich tuffs create completely different shape populations, yet both come from silicic source rocks. The two grain-shape populations reflect two different processes of crystal formation, though the chemistry of the nurturing environments may be similar.

The basic difference between the magma body that makes up the Mount Ashland pluton and the one that fed the Eagle Butte silicic eruptive complex is that the former was cooling down, whereas the latter may still have been receiving heat from depth. As the Mount Ashland magma cooled, minerals crystallized out of the silicic melt or "crystal mush," faithfully following Bowen's reaction series. Quartz appeared as a last phase to occupy the interstices between those minerals that had crystallized out ahead of it, hence its intersertal or xenomorphic shape feature. On the other hand, the Eagle Butte magma chamber may have been undergoing chemical differentiation, perhaps abetted by continuing influx of heat. The upper levels of the chamber may have become sufficiently oversaturated with silica so that beta-quartz crystals could nucleate and grow without any near-neighbor effects. Hence a significant quantity of euhedral beta-quartz dipyramids was formed in the melt and is found in today's regional soil profile. Thus, the chemistry may have been similar in both cases, but temperature and kinetics may have had a stronger influence in the processes of crystal formation.

REFERENCES CITED

Donato, M.M., 1975, The geology and petrology of a portion of the Ashland pluton, Jackson County, Oregon: Eugene, Oreg., University of Oregon master's thesis, 89 p.

Ehrlich, R., and Weinberg, B., 1970, An exact method for the characterization of grain shape: Journal of Sedimentary Petrology, v. 40, p. 205-212.

Elliot, M.A., 1971, Stratigraphy and petrology of the Late Cretaceous rocks near Hilt and Hornbrook, Siskiyou County, California, and Jackson County, Oregon: Corvallis, Oreg., Oregon State University doctoral dissertation, 171 p.

Full, W.E., Ehrlich, R., and Kennedy, S.K., 1984, Optimal configuration and information content of sets of frequency distributions: Journal of Sedimentary Petrology, v. 54, p. 117-126.

Full, W.E., Ehrlich, R., and Klovan, J.E., 1981, EXTENDED QMODEL—Objective definition of external end members in the analysis of mixtures: Mathematical Geology, v. 13, p. 331-344.

Hladky, F.R., 1996, Geology and mineral resources map of the Grizzly Peak quadrangle, Jackson County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS–106, scale 1:24,000.

Kuenen, P.H., 1959, Experimental abrasion: 3. Fluviatile action on sand: American Journal of Science, v. 257, p. 172-190.

Nilsen, T.H., ed., 1984, Geology of the Upper Cretaceous Hornbrook Formation, Oregon and California: Society for Sedimentary Geology (SEPM), Pacific Section, Publication 42, 257 p.

Torley, R.F., 1998, Fourier grain-shape analysis of quartz grains in sediments of Bear Creek Valley and adjacent Western Cascade Mountains, southern Oregon: Eugene, Oreg., University of Oregon doctoral dissertation, 264 p.

Zahn, C.T., and Roskies, R.Z., 1972, Fourier descriptors for plane closed curves: IEEE Transactions on Computers, v. C-21, p. 269-281. ☐

For those who do not have the time or opportunity . . .

Geologic notes — Gleanings from recent publications that may be of interest

by Lou Clark, Oregon Department of Geology and Mineral Industries

Book reviews: *No apparent danger, by Victoria Bruce; Surviving Galeras, Stanley Williams*
Nature: March 3; Science: April 27

"Long-simmering feuds among personalities involved in volcano research are set to burst into public view…with the publication of two books detailing a 1993 volcanic eruption in Columbia that killed six researchers," begins *Nature*'s article.

Bruce charges that Williams ignored seismology data which gave an indication that the volcano's activities were expanding, putting the lives of everyone in his expedition at risk. Six people died. After the eruption, Williams said to many TV, radio, and newspaper reporters that he was the only survivor, though several other researchers also survived, some with no injuries. Williams says he made a mistake (saying he was the sole survivor), but does not feel guilty about the deaths.

Bruce also alleges that Williams took information and ideas from another scientist and used them to get grants and publish articles. Williams denies this completely. The *Nature* article details other scientists' claims about Williams' inappropriately taking the work of others.

Science suggests, "By developing and using robots and remotely controlled unmanned vehicles…we can better protect the public, and those whose research may help reduce volcanic hazards."

Science*, January 12, p. 215*
Web site: epsc.wustl.edu/~saadia /page2.html

Seismologists Michael Wysession and Saadia Baqer of Washington University in St. Louis have created animations showing earthquake waves moving through the mantle. A VHS tape with narration is also available.

—Pg. 255: Volcano fatalities—Lessons from the historical record

In the 20th century, on average 2–4 volcanic eruptions with fatalities have occurred each year. Since A.D. 1500, nearly 300,000 people have died, and 7 individual eruptions have claimed more than 10,000 victims. The number of eruptions has tended to be constant; the number of fatalities has increased because more people are living near active volcanoes. Nearly 65% of fatalities have taken place more than a month after the eruption's start. Residents are generally receptive to evacuation orders at the start of an eruption, but as weeks pass, it is more difficult to keep people away. In dealing with volcanic eruptions, it is important to have a long-term education plan in place for residents, scientists, and governments.

February 9, p. 951
Web site: www.uh.educ/~jbutler /anon/anonfield.html

University of Houston geoscience professor John Butler has created the *Virtual Geosciences Professor*. This site has links to other sites with information, maps, animations and other graphics, and a listserve for Internet education.

March 2, p. 1669
Web site: geo.ucalgary.ca/~tmg /Research/thermo_links.html

This mineralogy site links to web sites for geochemistry and thermodynamics of rock formation, mineral properties, and more. Data, software and narrative information is offered through this University of Calgary site.

April 6, p. 19
Web site: www.geology.wisc.edu /~maher/air.html

Louis Maher, University of Wisconsin has put together a website of aerial photos, mostly from the 1960s. *Geology by Lightplane* has a variety of photos of mountains, mesas and canyons.

April 13, p. 175
Web site: www.geology.sdsu.edu /how_volcanoes_work

Vic Camp of San Diego State University showcases volcanoes on this spectacular website. Explanations of eruptions, photos, maps, animations, and first-hand accounts are all accessible. Other sections deal with volcanoes on other planets or their moons, and there are links to webcams to watch volcanoes, including our old favorite, Mount St. Helens.

Nature, January 18, p. 289
"The key to the past?" by Richard B. Alley of Pennsylvania State University.

This is the initial essay in a new series called "Concepts," designed to highlight ideas that cross disciplinary lines or that deserve a reevaluation.

Alley reviews the concept of uniformitarianism and how it has been used, and misused. Current paleoclimate studies are based on this concept, which sometimes needs more specific definition. The processes of global climate change are ancient, but the understanding of them is still incomplete. In interpreting data from ice cores, for example, it seems a safe assumption that there is no new, previously unknown process operating (uniformity of *process*). Greenland's ice is colder 1 km down, because this ice has not warmed yet from the last ice age, not because space aliens have warmed up the planet.

But a uniformity of *rates* has previously been assumed in inappropriate cases. Earthquake and volcanic eruptions do not happen at evenly spaced intervals. In seeking to understand global climate, assumptions about rate may or may not be appropriate. Isotopic ratios are a common way of estimating past temperatures but may not be valid. In that case, new markers must be found for specific details, but the principle of uniformitarianism continues to give us a frame in which to place information.

—p. 417
Earth systems engineering and management, by Stephen Schneider, Stanford

As the population of the Earth continues to grow and some natural resources become scarcer, the question of geoengineering the Earth to manage the consequences of growth has been raised. Assuming technical hurdles could be overcome (an assumption with which not all agree), would it make sense to inject dust in the stratosphere, to reflect sunlight and counteract the greenhouse effect? What about damming the Mediterranean at the Straits of Gibraltar and creating a Chad Sea? The ethical questions around geoengineering, as well as some specific ideas, are discussed in this article. The author, who was on the U.S. National Academy of Science National Research Council panel on policy implications of global warming, is dubious of the potential benefits of humans trying to manipulate vast systems that are not entirely understood.

In a side box, David Keith, Carnegie Mellon University, outlines and discusses four concepts of large-scale change (such as enhancing oceanic carbon sinks). He believes that serious discussion, perhaps even implementation of geoengineering, will take place this century.

February 22
The habitat and nature of early life, by E.G. Nisbet and N.H. Sleep

This article is one of a series about astrobiology in this issue of *Nature*. A description of the beginnings and first billion or so years of the solar system yields a concise review of the current state of thinking on the beginnings of life—and, not coincidentally, the geology of Earth and Mars.

March 1, p. 74
Earthquake slip on oceanic transform faults, by Rachel Abercrombie and Göran Ekström

Many different indicators have been studied in an effort to predict earthquakes. An episode of slow slip along the Romanche transform fault was thought to precede the 1994 Romanche quake.

The authors studied 14 earthquakes along the mid-Atlantic ridge at the Romanche and Chain transform faults and concluded that the event previously considered to be a precursor is actually an artifact of the analysis process. With present data and analysis techniques, no clear, detectable precursors to oceanic transform earthquakes can be found.

***Geology**, February, p. 115*
New views of granular mass flows, by Richard Iverson and James Vallance

Granular mass flows include rock avalanches, debris flows, pyroclastic flows, and other phenomena that move rapidly downslope. High volumetric grain concentrations distinguish these from floods, which are dominated by fluid forces. Most explanations for behavior of granular mass flows are based on fixed rheologies. However, rheologies evolve as conditions change in the downslope movement. Initial and boundary conditions, grain-size segregation and changes in flow volume must be taken into account as well as mixture composition in determining flow dynamics. The authors suggest that field work should focus on those aspects, rather than on interpretation of rheology.

—p. 143
Hillslope evolution by nonlinear creep and landsliding: An experimental study, by Joshua Roering, James Kirchner, Leonard Sklar, and William Dietrich

Mechanisms of hillslope erosion are poorly understand, but are important for building accurate models. The authors used a laboratory hillslope to test how creep and landsliding contribute to hillslope erosion. Results are in accord with a recently proposed nonlinear transport model, which shows steep hillslopes rapidly affected by landsliding, but flatter downslopes more slowly affected by creep.

—April, p. 355
Geomorphic control of persistent mine impacts in a Yellowstone Park stream and implications for the recovery of fluvial systems, by W. Andrew Marcu, Grant Meyer, and Del-Wayne Nimmo

Riparian vegetation and aquatic invertebrates are still being affected by metal contamination almost 50 years after closure of the mine. Geomorphic controls on the transport of sediment along Soda Butte Creek in Yellowstone suggest that contamination may last for centuries. These mine impacts are likely to be seen in many other drainages around the world.

***GSA Bulletin**, April, p. 482*
Geologic evidence of earthquakes at the Snohomish delta, Washington, in the past 1,200 years, by Joanne Burgeois and Samuel Johnson

Field research suggests that this area was subjected to stronger ground shaking in the past 1,200 years than in the last 150 years of written records. Evidence exists for at least three episodes of liquefaction, one event of abrupt subsidence, and at least one tsunami since A.D. 800. The tsunami and liquefaction were dated at A.D. 800–980, similar to an earthquake known on the Seattle fault found 50 km to the south. Inconclusive evidence was found for two other tsunamis before A.D. 800. Other liquefaction events were dated at A.D. 910–990 and A.D. 1400–1640. The abrupt lowering of a marsh surface was dated at A.D. 1040–1400. ☐

(**Publications**—*continued from page 38*)

al disaster declaration for 27 counties, the November event for 3 counties, and the December/January storms for 14 counties. Over 98 percent of the landslides were recorded in the western portion of the state, mainly in the Coast and Cascade Ranges, with fewer in the Willamette Valley and the Klamath Mountains.

The products of this study are (1) a digital Geographic Information System (GIS) inventory of Oregon landslide locations, (2) a spreadsheet version of the inventory for those not using GIS, and (3) an explanatory text. The inventory database includes 9,582 slide location entries, with varying amounts of information reported for each individual entry. The database entries contain several items describing the geographic location of each landslide and up to 15 additional items relating to failure mechanism, size, geometry, associated damage, etc., depending upon the information obtained from the contributing sources.

The Oregon storm events of 1996 and early 1997 were particularly damaging, and each received a Federal "major disaster" declaration. The February 1996 storm affected most of the western and northern portions of the state. The November storm originated offshore and swept primarily through Coos, Douglas, and Lane Counties. The late 1996 and early 1997 storms heavily hit the southern portion of the state as well as the northeastern counties. Each of these storms produced near-record rainfall, which triggered extensive landslide activity throughout the impact areas.

A preliminary estimate for the February 1996 event alone was $280 million in total damage. Landslides are not separated from total flood damage in this estimate, but the percentage directly related to slide activity is believed to be significant. In the Portland metropolitan region, for example, approximately 40 percent of the $10 million in infrastructure damage from the February 1996 storm is attributed to landslides.

Released March 7, 2001:

The Nisqually, Washington, earthquake of February 28, 2001. Summary report, by Yumei Wang, R. Jon Hofmeister, Greg Graham, Lou Clark, Neva Beck, Tova Peltz, Mark Darienzo, William Elliott, and Carol Hasenberg. Open-File Report O-01-02, 23 p., incl. 18 photos. 1 CD, $6.

Over the weekend of March 2–4, the Oregon Department of Geology and Mineral Industries (DOGAMI) sent an investigation field team to Olympia and Seattle to study the effects of the magnitude 6.8 earthquake of February 28, 2001, at Nisqually, Washington.

The summary report includes preliminary basic information on the earthquake, the team's field observations, a short discussion of the Nisqually earthquake, an outline of Oregon's earthquake needs and images of earthquake damage observed by the team. ☐

EDITOR'S GOSSIP

More power on the coast

Jonathan C. Allan

Jonathan C. Allan has joined George R. Priest on the professional staff of the Oregon Department of Geology and Mineral Industries (DOGAMI) at its Coastal Field Office in Newport. Jonathan comes to the Department from New Zealand, where he earned a doctorate in coastal processes at the University of Canterbury in Christchurch. He specializes in coastal geomorphology and has been working for the last 18 months with Dr. Paul Komar at Oregon State University on a postdoctoral study of U.S. West Coast wave climate, probabilistic analyses of extreme storm events and ocean water levels, and the characteristics and effects of large storms experienced during the recent 1997-98 El Nino and 1998-99 La Nina climate events. His work at OSU is being published in various scientific journals.

At the Field Office, Jonathan recently completed an analysis of coastal hazards in Tillamook County, specifically the erosion of dune-backed beaches. This work is part of the Department's studies in coastal hazard mitigation in that county and is partially supported by the Federal Emergency Management Agency under its Project Impact. He is currently working on a similar study for Clatsop County and has recently formed a partnership with the Oregon Parks and Recreation Department to examine the effects of coastal engineering structures on adjacent unprotected beaches. Jonathan's talents and training are unique within the agency and further broaden its abilities to serve the needs of the public.

Jonathan's e-mail address is jonathan.allan@dogami.state.or.us; his phone is 541-574-6658. DOGAMI's Coastal Field Office in Newport is at 313 SW Second Street, Suite D. ☐

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

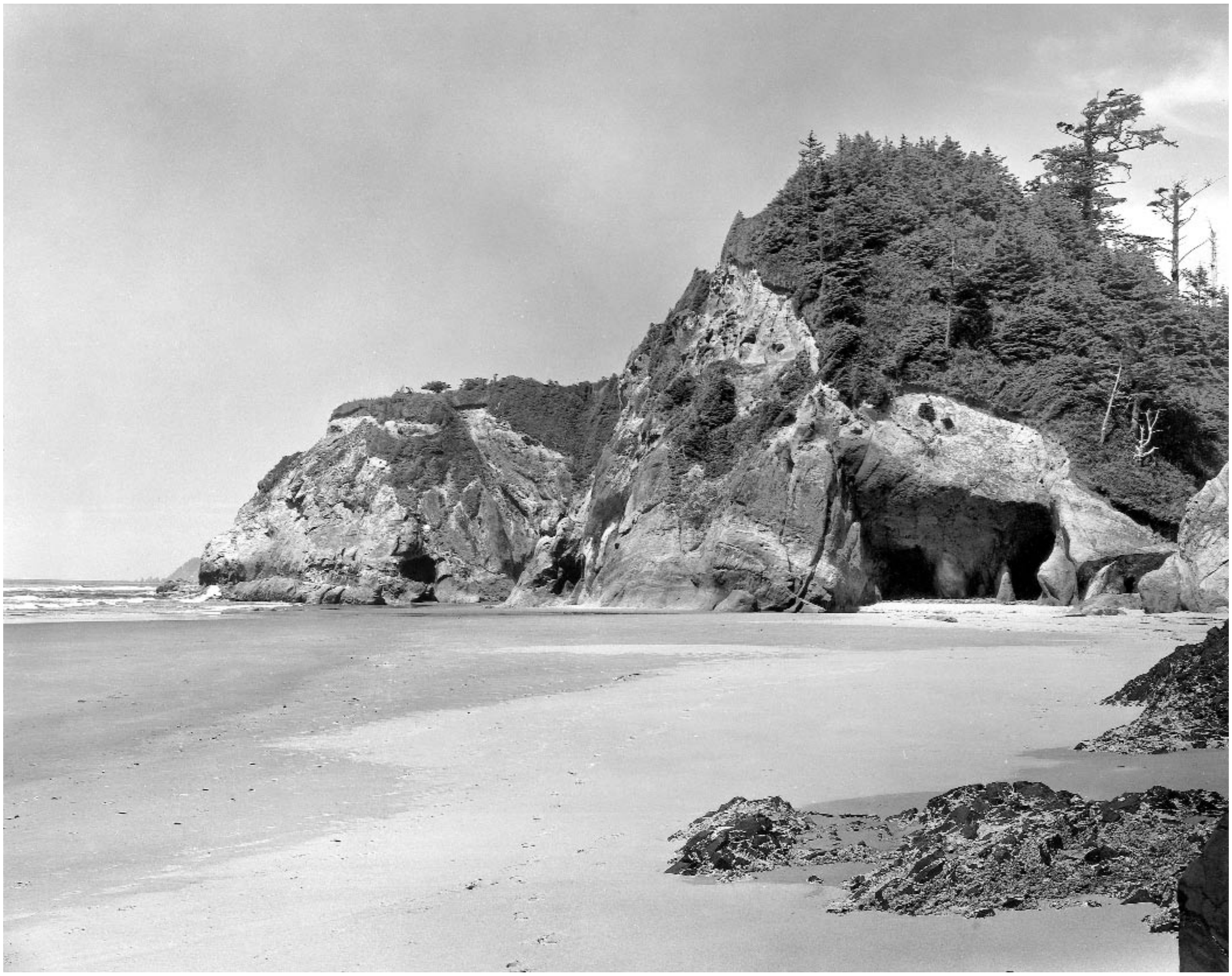
Periodicals postage paid
at Portland, OR

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

Hug Point, site of Hug Point State Park, on the Clatsop County coast, south of Cannon Beach.

Hug Point is one of several small promontories along the northern Oregon coast between Cape Falcon and Tillamook Head. It was reportedly so named because, in the days before big coastal highways, people or roads had to hug the rock to get around the point without getting wet. In the mixture of hard volcanic rock and more easily eroded sedimentary deposits of this stretch of the coast, the ocean's constant erosive action has formed a sequence of rocky points and sandy beaches, as well as numerous sea caves.

Access from U.S. Highway 101, five miles south of Cannon Beach.



OREGON GEOLOGY

Oregon Department of Geology and Mineral Industries Volume 63, Number 3, Summer 2001

IN THIS ISSUE:

Partial melting of tonalite at the margins of a Columbia River Basalt Group dike

The mid-Pliocene Imbler fish fossils, Grande Ronde Valley, Union County

Statewide Mined Land Reclamation annual awards

TO OUR READERS — A new publishing format for *Oregon Geology*

This is the last issue of *Oregon Geology* you receive in the traditional fashion — the magazine will continue, but on our website.

As a public agency, we must balance the need to distribute information with limited resources at hand. To a large extent, that's why we publish *Oregon Geology*. It is an avenue to disseminate information about our area to the people who are most likely to need it.

The content and format of the magazine has changed dramatically through the years. Our editor is now a desktop publisher on top of the traditional editing responsibilities of review, correction, and improvement of text.

As the price of postage, ink, and paper continues to rise, we are at a point where we must make major changes to *Oregon Geology* to allow it to survive.

We've already made one change. We have redirected the content to technical papers, not information for the general public. Although that limits the potential audience, it reinforces one of the department's core values: providing scientific information of use to our state.

We are now getting ready to take another step. Subscription prices no longer cover the expense of publishing the magazine. There are no easy choices to fix that. One option is to raise prices several-fold. Another is to publish an electronic version on our web page.

A web version offers some advantages. For example, there would be no restriction on using color photos or charts. In addition, having issues on the web site would allow researchers complete access to issues. (We are working on getting back issues scanned for the website, but that project will not be done until at least next year.)

If you are a contributor, the good news is that readership of magazines goes up when they go online. More people will read the articles. We will continue to request peer review, so the quality of articles will not decline.

It is now commonplace to have documents on the Internet that can be opened with Adobe Acrobat Reader, a free software program easily found on the web. This is the file format we will use, making it possible to open and print articles from any computer. We believe that moving *Oregon Geology* to our web page will

(Continued on page 96)

OREGON GEOLOGY

(ISSN 0164-3304)

VOLUME 63, NUMBER 3 SUMMER 2001

Published quarterly in Winter, Spring, Summer, and Fall by the Oregon Department of Geology and Mineral Industries. (Volumes 1 through 40 were entitled *The Ore Bin.*)

State Geologist . . . . John D. Beaulieu
Deputy State Geologist . . . . Dennis L. Olmstead

Editor . . . . Klaus K.E. Neuendorf
Production Assistants . . . . Kate Halstead, James Roddey

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: 1510 Campbell Street, Baker City 97814, phone (541) 523-3133, FAX (541) 523-5992.
Mark L. Ferns, Regional Geologist.

Coastal Field Office: 313 SW Second Street, Suite D, Newport 97365, phone (541) 574-6642, FAX (541) 265-5241.
George R. Priest, Coastal Team Leader.

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: 229 Broadalbin Street SW, Albany 97321-2246, phone (541) 967-2039, FAX (541) 967-2075.
Internet: http://www.proaxis.com/~dogami/mlrweb.shtml
Gary W. Lynch, Supervisor. **NOTE ADDRESS CHANGE!!!**

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

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

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

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

Cover photo

Air photo of former gravel pit (McNutt site) of Morse Brothers, Inc., winners of this year's Oregon Plan Award for their reclamation work here. The location is adjacent to the Willamette River, just upstream of Harrisburg. This pit was inundated during the 1996 flood event and was found to have salmon stranded when the water receded; so the pond was connected to the river for fish passage (barely visible in northwest corner of pond). This one and similar ponds now offer important off-channel habitat for endangered fish. Digitally modified MLR photo by David Shear. Report on 2001 Mined Land Reclamation Awards begins on page 97.

Partial melting of tonalite at the margins of a Columbia River Basalt Group dike, Wallowa Mountains, northeastern Oregon

by Heather L. Petcovic and Anita L. Grunder, Department of Geosciences, and Roger L. Nielsen, College of Oceanic and Atmospheric Sciences, Oregon State University,Corvallis, OR 97331

ABSTRACT

Columbia River Basalt Group feeder dikes cut the tonalite-granodiorite Wallowa batholith in northeastern Oregon, providing a unique setting in which to examine the process of partial melting. This paper summarizes the progressive partial melting reactions in biotite- and hornblende-bearing tonalite at the margin of a near-vertical Grande Ronde basalt dike. Samples collected from the dike margin represent five progressive stages of melt reaction from unmolten wall rock to about 40 volume quenched melt. This melt is now represented by devitrified glass plus plagioclase, pyroxene, and magnetite quench crystals.

With progressive melting, hornblende, biotite, and orthoclase are entirely consumed, but plagioclase, quartz, and magnetite persist in the restite. Hornblende dehydration produces a dusty intergrowth of augite, pigeonite, lesser enstatite, and sparse magnetite. Biotite dehydration produces magnetite and lesser ilmenite aligned in bands in an intergrowth of enstatite and plagioclase. Residual plagioclase develops a spongy texture, as the albite component is lost to the melt. In the initial stages of melting, the reaction of hornblende, quartz, and feldspars produces silicic melt localized around decomposed mafic sites and as seams on quartz-feldspar grain boundaries. The melt composition was modified during cooling by the formation of quench crystals and later by devitrification of the glass. At higher temperatures, the reaction of orthoclase, clinopyroxene, and plagioclase produces additional silicic melt.

INTRODUCTION

Although there is general consensus that basalt input is fundamental to crustal melting, there are few places where this interaction can be directly sampled. The Wallowa Mountains of northeastern Oregon provide a rare natural setting in which to examine shallow crustal melting. Here, hundreds of Columbia River Basalt Group (CRBG) feeder dikes cut granitoids of the Wallowa batholith. Dikes have interacted with wall rock in a variety of ways, including some contact melting in the wall rock. We have examined the 5-m-wide partially melted zone in tonalite at the margin of a near-vertical Grande Ronde Basalt dike in the vicinity of Maxwell Lake (Figure 1). Samples collected from the western margin of this dike represent five progressive stages of melt reaction, from unmelted tonalite (Stage 1) to about 40 volume percent quenched melt (Stage 5). This melt is represented by devitrified silicic glass containing plagioclase, pyroxene, and magnetite quench crystals.

This paper summarizes the natural partial melting reactions fully characterized by Petcovic (2000).

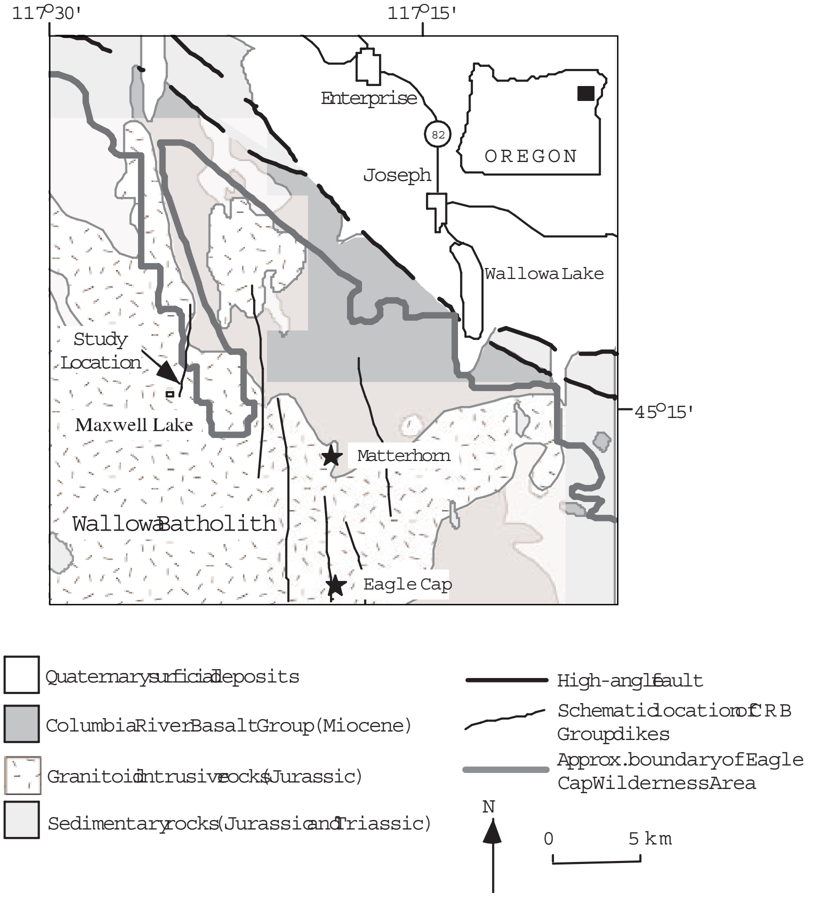


Figure 1. Generalized location and geologic map of the study area and vicinity in the Wallowa Mountains. Modified after Taubeneck (1995).

THE WALLOWA BATHOLITH AND CRBG DIKES

The Wallowa Mountains are largely composed of the Wallowa batholith, a series of Late Jurassic intrusions (140–160 Ma; Armstrong and others, 1977) related to the accretion of island-arc terranes onto the former margin of North America. The batholith is composed of biotite- and hornblende-bearing tonalite to granodiorite. During the Miocene, CRBG flood basalt was erupted from vents primarily in northeastern Oregon, with the Wallowa Mountains hosting over 90 percent of the CRBG dikes in Oregon (Grunder and Taubeneck, 1997). Feeder dikes of both the Imnaha Basalt (16.8–17.3 Ma; Hooper and Hawkesworth, 1993) and the Grande Ronde Basalt (15.6–16.8 Ma; Hooper and Hawkesworth, 1993) lace the batholith (Figure 1). Uplift and Pleistocene glaciation have resulted in exposure of both the Wallowa batholith and the CRBG dikes to a paleodepth of 1–2 km (Grunder and Taubeneck, 1997).

Individual basalt dikes within the Wallowa batholith extend up to several kilometers along strike, are a few centimeters to 50 m wide, are steeply dipping (average 70°), and strike generally northwest-southeast (Taubeneck, 1987). Dikes have one or more of the following morphologies (Grunder and Taubeneck, 1997):

- Dikes with quenched margins and no interaction with the wall rock,
- Dikes with partially melted wall rock at their margins,
- Dikes that have eroded their wall rock, and
- Dikes containing whole to disaggregated crustal xenoliths.

The presence of a melted zone in the wall rock correlates with a thin or absent quenched edge of the dike and larger grain size in the CRBG dike (Taubeneck, 1987). In general, melted margins are typically one quarter of the width of the dike, and in cases where dikes are not vertical, the hanging wall has a thicker melted zone (Grunder and Taubeneck, 1997).

THE MAXWELL LAKE DIKE

This study focuses on a single, well-exposed Grande Ronde Basalt dike with partially melted wall rock at its margins. Located within the Eagle Cap Wilderness Area, the dike is exposed on the western side of the Lostine River Valley in the vicinity of Maxwell Lake (Figure 1). The dike strikes about N. 20° E., dips steeply to the west (about 75°), and is from 2.7 to 8.1 m wide. It extends for at least 1 km along strike. Paleodepth at the time of dike emplacement was at most 2 km, as reconstructed from regional geology.

The partial-melt margin along the hanging wall (western margin) of the dike is generally 2–2.5 m wide but reaches a width of 5 m at the southern end of the outcrop, whereas the partial melt margin along the footwall (eastern margin) is about 1.5 m wide. The dike margins are divided into four zones based on field characteristics: the unmelted wall-rock zone, the mafics-out zone, the mottled zone, and the mush zone (Figure 2). Individual zones are 10 cm to 2 m wide with gradational transitions from one zone to the next. Partial melt zones parallel the dike along strike, vary in thickness with dike thickness, and are wider along the western margin (hanging wall) than the eastern margin.

Five stages of melt reaction can be distinguished within the wall-rock partial melt zones at the dike margin. Unmelted wall rock (Stage 1) is found 2–5 m from the dike margin. The mafics-out zone (Stages 2 and 3) is 1–2 m wide and characterized by the breakdown of biotite and hornblende, which yields fine-grained reaction products (predominantly pyroxene and iron-titanium oxides) that form pseudomorphs after the original minerals. Quartz and feldspar are unaltered, and glass may be present as thin seams around felsic grains. The mottled zone (Stages 4 and 5) is characterized by a blue-gray mottled texture in outcrop and is generally 1–2 m wide. Biotite and hornblende are entirely decomposed; both mafic reaction sites and residual quartz and feldspar lack distinct margins; and seams of brown glass commonly surround grains. The mush zone is a discontinuous, 10- to 50-cm-wide zone paralleling the dike margin. This zone contains sparse amorphous blebs of quartz and feldspar in a fine-grained blue-gray groundmass. The presence of the mush zone appears to correlate with thicker areas of the dike. A dense network of blue-gray veins cut through the partially melted tonalite at the southern end of the outcrop, giving this end of the outcrop a cataclastic texture. Samples representing Stages 2 and 4 were collected from this end of the outcrop. Within the range of samples we have examined, there appears to be no exchange of mass between the CRBG dike and partially melted wall rock.

TEXTURAL AND COMPOSITIONAL CHANGES DURING EACH STAGE OF MELTING

Unmelted (Stage 1) tonalite is medium to coarse grained and composed of, in decreasing abundance, plagioclase, quartz, hornblende, biotite, orthoclase, magnetite, and traces of fluorapatite, titanite, and zircon (Figure 3). Biotite is commonly altered to chlorite at crystal margins and is found in clumps with hornblende, apatite, and magnetite.

In Stage 2, biotite, hornblende, orthoclase, and plagioclase show incipient reaction, but modal proportions of these phases remain more or less unchanged (Figure 3). The sample representing Stage 2 has a cataclastic texture as expressed in extensively fractured quartz and plagioclase. Hornblende is dusted with submicroscopic reaction products and has lost K_2O, Cl, and F relative to Stage 1 hornblende. Magnetite occupies cleavages and rims of bi-

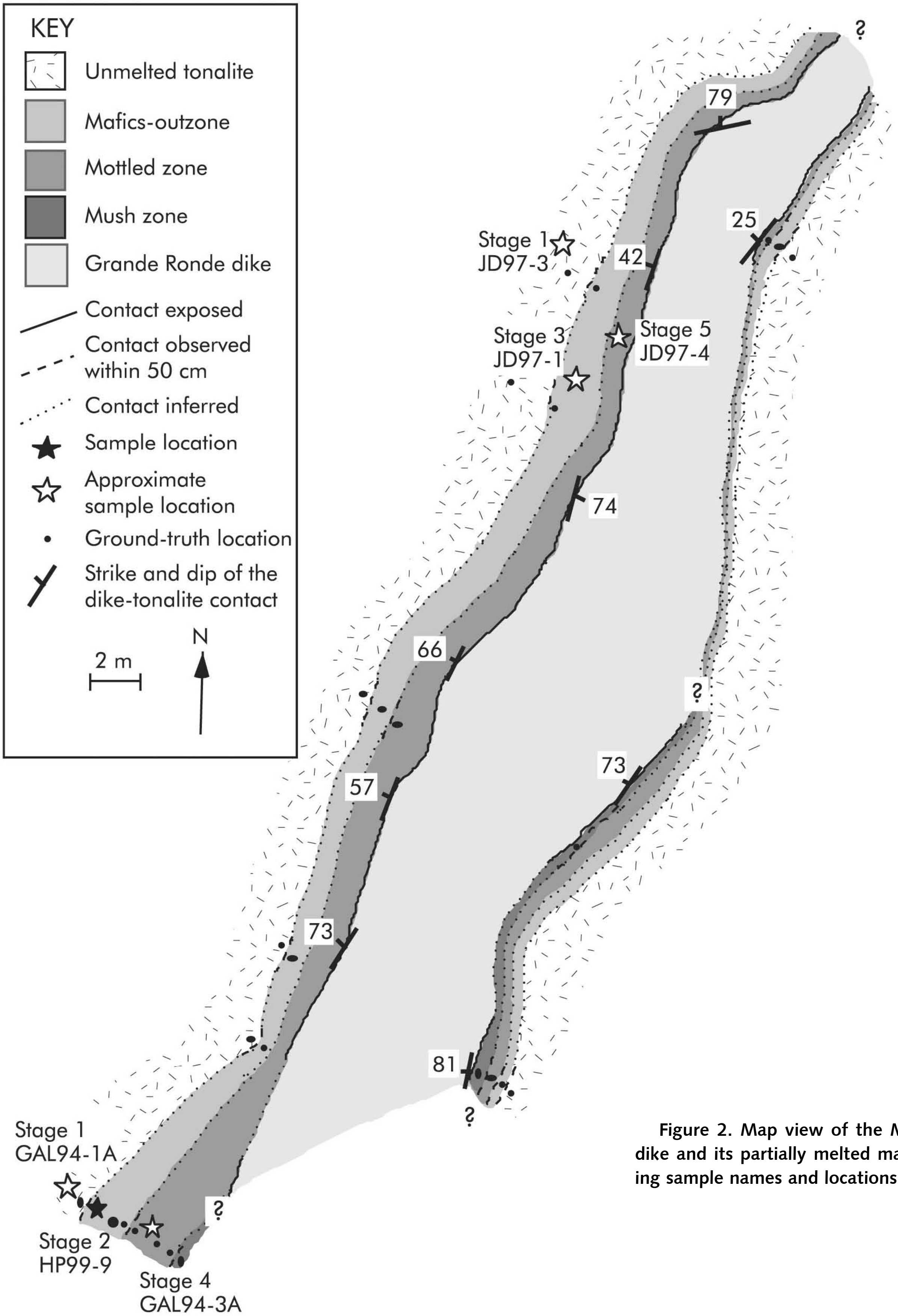


Figure 2. Map view of the Maxwell Lake dike and its partially melted margins, showing sample names and locations.

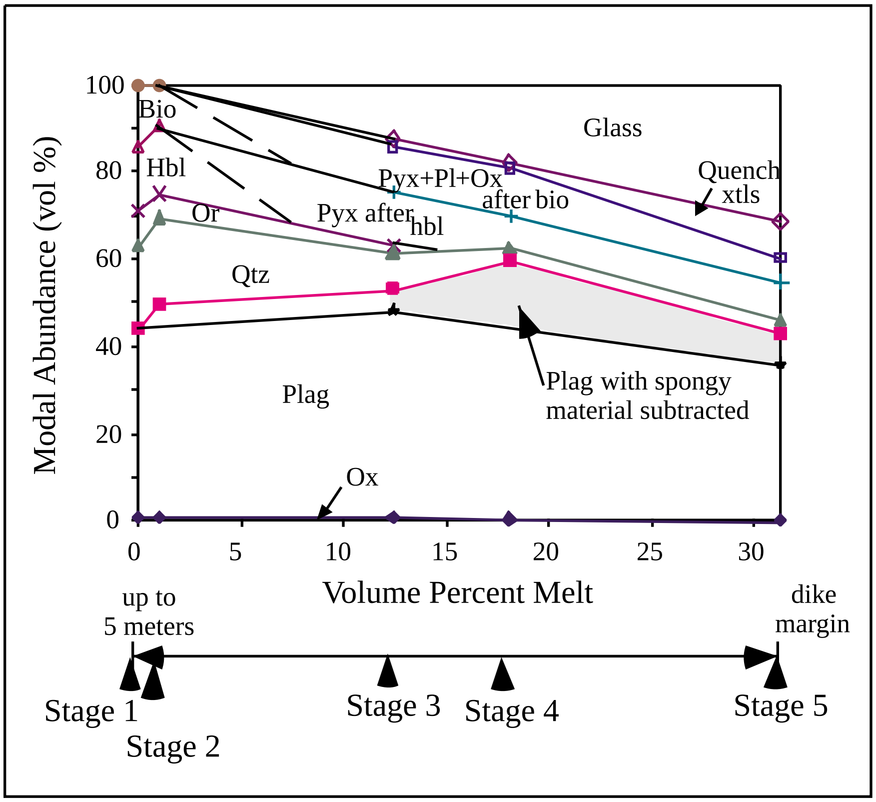


Figure 3. Modal abundance (in volume percent) of phases in unmelted and partially melted tonalite plotted against melt fraction (also in volume percent). Abbreviations are as follows: Ox = iron-titanium oxide (magnetite and ilmenite), Plag or Pl = plagioclase feldspar, Qtz = quartz, Or = orthoclase feldspar, Hbl = hornblende, Bio = biotite, Pyx = pyroxene, xtls = crystals. Modal abundances were determined by point counting on multiple thin sections except for the shaded region, which was determined by visual estimates.

otite, which is depleted in K_2O and Cl but enriched in TiO_2 and F relative to Stage 1 biotite. Dehydration melting of biotite has produced at least one thin (<50 µ wide) glass seam on a biotite-quartz contact.

In Stage 3, widespread mineral breakdown reactions have produced about 15 volume percent glass found around mafic sites that have undergone reaction and as up to 1-mm-wide seams on feldspar-quartz contacts. Modal proportions of orthoclase and quartz have decreased significantly, and the spongy texture of plagioclase indicates that a minor amount of this phase has also been consumed (Figure 3). Spongy-textured plagioclase may contain up to 4 volume percent glass. Plagioclase composition is more calcic than in Stage 1, which indicates that the albite component is lost to the melt. Hornblende dehydration has yielded micron-sized, Al_2O_3- and Na_2O-rich augite and pigeonite, lesser enstatite, and sparse magnetite. Biotite dehydration produces magnetite and ilmenite aligned along former biotite cleavage planes in an intergrowth of enstatite and plagioclase. The glass is complexly devitrified into several domains (Table 1): a dominant, high-K brown glass domain; a high-Ca domain of dark brown glass; and a minor domain of clear, high-Si glass. About 2 volume percent quench crystals of plagioclase, pyroxene, and magnetite are associated with the devitrified brown glass domains (Figure 3).

Stage 4 is characterized by the absence of orthoclase and the creation of an additional 6–7 volume percent glass (Figure 3). The sample representing Stage 4 has a cataclastic texture, including finely fractured quartz and plagioclase crystals. The abundance of augite in decomposed hornblende sites has decreased, and enstatite is enriched in MgO. Concentrations of TiO_2, Al_2O_3, and MgO in magnetite and ilmenite replacing biotite have also increased. The three devitrified glass domains are present in Stage 4, as are about 1.5 volume percent quench crystals.

By Stage 5, a total of about 30 volume percent glass is produced by the breakdown of clinopyroxene and the consumption of plagioclase (Figure 3). Stage 5 residual plagioclase is slightly higher in K_2O and CaO than Stage 1 plagioclase. When in contact with glass, residual plagioclase has developed a spongy texture, fritted margins, and 25-µ-wide rims high in CaO, FeO, and MgO. As much as 7 volume percent glass may be trapped in spongy feldspar (Figure 3). Optically aligned enstatite is the lone pyroxene in decomposed hornblende sites. Pyroxene microlites are aligned with their c-axes parallel to the c-axis of the parent hornblende. Decomposed biotite sites remain occupied by aligned magnetite and lesser ilmenite in a slightly coarser matrix of plagioclase and enstatite. Devitrified brown glass containing quench crystals of plagioclase, augite, enstatite, and magnetite is localized on quartz-plagioclase contacts and around former biotite and hornblende sites; a minor amount of clear glass is also present.

DEHYDRATION MELTING REACTIONS

Recent studies point to the importance of hydrous minerals in crustal melting (e.g., Beard and Lofgren, 1991; Skjerlie and Johnston, 1993; Vielzeuf and Montel, 1994; Patiño Douce and Beard, 1995; Singh and Johannes, 1996a & 1996b). Dehydration melting is the breakdown of a hydrous mineral (such as biotite or amphibole) to form melt plus anhydrous minerals. The Wallowa tonalite contains both biotite and hornblende, important sources of melt in dehy-

Table 1. Compositional data for bulk rock, glass domains, and bulk melt (glass + quench crystals), in weight percent

(* = all Fe reported as FeO; — = concentrations below detection limits)

	Unmelted wallrock[1]	High-Ca glass domain[2]		High-K glass domain[2]		High-Si glass domain[2]	Bulk melt[3]	
Oxide	**Stage 1**	**Stage 3**	**Stage 5**	**Stage 3**	**Stage 5**	**Stage 3**	**Stage 3**	**Stage 5**
SiO_2	59.32	74.18	78.90	75.99	76.26	90.48	68.37	68.43
TiO_2	0.70	0.21	0.58	0.49	0.87	—	0.50	0.78
Al_2O_3	17.97	11.49	11.46	11.62	11.02	1.76	10.73	13.20
FeO*	5.35	0.49	0.56	0.44	0.95	—	6.00	3.85
MgO	3.84	—	—	—	0.05	—	2.45	1.83
CaO	6.45	3.51	3.36	0.53	0.73	0.61	1.68	2.91
Na_2O	4.12	3.15	3.51	2.17	2.81	0.32	2.22	2.92
K_2O	1.35	0.31	0.33	6.21	5.35	0.21	3.86	3.97
P_2O_5	0.18	0.07	0.19	0.08	0.27	—	0.07	0.18
Total	99.37	93.57	99.03	98.45	98.45	93.69	96.10	98.27

[1] Bulk rock analyzed by x-ray fluorescence at Washington State University.

[2] Glass analyzed by electron microprobe at Oregon State University using a 20 micron beam diameter, a beam current of 30 nA, and an accelerating voltage of 15 kV. Data reported are the average of between 4 and 50 spot analyses on glass domains.

[3] Data reported are calculated melt compositions by mass balance (see text for explanation). High concentrations of FeO, MgO, and TiO_2 in Stage 3 bulk melt is likely due to overcounting fine-grained magnetite quench crystals in the modal analysis.

dration reactions. Between Stage 1 and Stage 3, biotite and hornblende are consumed, and the abundances of quartz and orthoclase decrease. Pyroxene, magnetite, and glass occupy sites where hornblende has undergone reaction, whereas pyroxene, plagioclase, magnetite, ilmenite, and glass occupy corresponding biotite sites. According to these textural and compositional considerations, the initial melt-producing reactions are

> hornblende + quartz + orthoclase = orthopyroxene + clinopyroxene + minor magnetite + melt (glass + quench crystals)

and

> biotite + quartz + orthoclase = orthopyroxene + plagioclase + magnetite + ilmenite + melt (glass + quench crystals).

These reactions are terminal for biotite and hornblende.

Since its formation, the melt was modified both by the growth of quench crystals during cooling and by devitrification. The original melt composition at the time of basalt cooling, therefore, is equivalent to the present devitrified glass domains plus quench crystals. We have been able to reconstruct the original melt composition by mass-balance calculations, using the modal abundance and compositions of the devitrified glass domains and plagioclase, pyroxene, and magnetite quench crystals (Table 1). In Stage 3, the bulk reconstructed melt is granitic; however, the high concentrations of MgO, FeO, and TiO_2 may be due to overestimation of magnetite in point counts during modal analysis.

Between Stages 3 and 5, orthoclase is entirely consumed as well as the clinopyroxene produced during initial hornblende dehydration, and the modal proportions of quartz and plagioclase decrease. No new phases are created, although breakdown reactions produce nearly an additional 20 volume percent glass. Plagioclase has developed a spongy texture, and the albite component is lost to the melt. This textural and compositional information suggests that the higher temperature melt-producing reactions are

> plagioclase + quartz + orthoclase + clinopyroxene = melt (glass + quench crystals)

and

> andesine plagioclase = labradorite plagioclase + albitic melt trapped in spongy plagioclase.

These reactions are terminal for orthoclase and clinopyroxene, leaving a restite of plagioclase, quartz, orthopyroxene, and iron-titanium oxides coexisting with melt (now represented by glass and quench crystals). A bulk melt composition was calculated by mass balance for Stage 5 (Table 1); the Stage 5 calculated melt is higher in concentrations of CaO and Al_2O_3 than the Stage 3 melt.

SUMMARY

Partial melting of the Wallowa tonalite took place over a distance of 4–6 m from the western margin of a Grande Ronde basalt dike. During partial melting, hornblende, biotite, and orthoclase were entirely consumed. The absolute modal abundance of plagioclase, quartz, and magnetite decreased, which indicates that these phases were also consumed; however, these phases persisted in the restite with as much as 40 volume percent quenched melt (31 volume percent glass and 9 volume percent quench crystals). Orthopyroxene, clinopyroxene, sparse magnetite, and glass occupy decomposed hornblende sites, with pyroxene microlites aligned along the original amphibole c-axis. Decomposed biotite sites are occupied by aligned magnetite and ilmenite in an intergrowth of orthopyroxene, plagioclase, and glass. Glass seams are localized around decomposed mafic sites and also as seams up to 2 mm wide between relict quartz and plagioclase. The original melt composition was modified during quenching by the formation of plagioclase, pyroxene, and magnetite quench crystals and by devitrification. However, bulk compositional data indicate that melting and quenching took place in a chemically closed system. The microcosm of partial melting that we have examined in the Wallowas provides an excellent starting point for understanding the complex problems of crustal magmatism.

ACKNOWLEDGMENTS

We would like to thank Bill Taubeneck for his assistance with the petrographic analysis and his advice on the field component of this research. This research was supported in part by a grant from the Geological Society of America awarded to H. Petcovic, grant number 6514–99.

REFERENCES CITED

Armstrong, R.L., Taubeneck, W.H., and Hales, P.O., 1977, Rb-Sr and K-Ar geochronometry of Mesozoic granitic rocks and their Sr isotopic composition, Oregon, Washington, and Idaho: Geological Society of America Bulletin, v. 88, no. 3, p. 397-411.

Beard, J.S., and Lofgren, G.E., 1991, Dehydration melting and water-saturated melting of basaltic and andesitic greenstones and amphibolites at 1, 3, and 6.9 kb: Journal of Petrology, v. 32, p. 365-401.

Grunder, A.L., and Taubeneck, W.H., 1997, Partial melting of tonalite at the margins of Columbia River Basalt Group dikes, Wallowa Mountains, Oregon [abs.]: Geological Society of America Abstracts with Programs, v. 29, no. 5, p. 18.

Hooper, P.R., and Hawkesworth, C.J., 1993, Isotopic and geochemical constraints on the origin and evolution of the Columbia River basalt: Journal of Petrology, v. 34, p. 1203-1246.

Patiño-Douce, A.E., and Beard, J.S., 1995, Dehydration-melting of biotite gneiss and quartz amphibolite from 3 to 16 kbar: Journal of Petrology, v. 36, p. 707-738.

Petcovic, H.L., 2000, Partial melting of tonalite at the margins of a Columbia River Basalt Group dike, Wallowa Mountains, northeastern Oregon: Corvallis, Oreg., Oregon State University master's thesis, 186 p.

Singh, J., and Johannes, W., 1996a, Dehydration melting of tonalites, part I: Beginning of melting: Contributions to Mineralogy and Petrology, v. 125, p. 16-25.

———1996b, Dehydration melting of tonalites, part II: Composition of melts and solids: Contributions to Mineralogy and Petrology, v. 125, p. 26-44.

Skjerlie, K.P., and Johnston, A.D., 1993, Fluid-absent melting behavior of an F-rich tonalitic gneiss at mid-crustal pressures: Implications for the generation of anorogenic granites: Journal of Petrology, v. 34, p. 781-815.

Taubeneck, W.H., 1987, Crustal contamination in dikes of the Columbia River Basalt Group in the Wallowa batholith, northeast Oregon [abs.]: Geological Society of America Abstracts with Programs, v. 19, no. 6, p. 457.

———1995, A closer look at the Bald Mountain batholith, Elkhorn Mountains, and some comparisons with the Wallowa batholith, Wallowa Mountains, northeastern Oregon, chap. 2 of Vallier, T.L., and Brooks, H.C., eds., Geology of the Blue Mountains region of Oregon, Idaho, and Washington: Petrology and tectonic evolution of pre-Tertiary rocks of the Blue Mountains region: U.S. Geological Survey Professional Paper 1438, p. 45–123.

Vielzeuf, D., and Montel, J.M., 1994, Partial melting of metagreywackes, part I: Fluid-absent experiments and phase relationships: Contributions to Mineralogy and Petrology, v. 117, p. 375-393. ☐

BOOK REVIEW

Geology of the Pacific Northwest, 2d ed., by William N. Orr and Elizabeth L. Orr, 2001. New York, McGraw-Hill, 409 pages, $67.75.

Geology of the Pacific Northwest, second edition edition, is geared to provide, for the casual reader as well as for those with geologic training, an overview of the geologic processes that shaped the Pacific Northwest through time.

After an introductory chapter including "cornerstones" of Pacific Northwest geology, the main body of the book is made up of ten chapters treating successively various physiographic provinces from the Coast Range Province of British Columbia and Alaska south to the Klamath Mountains and west to Central Idaho. The book therefore covers an immense, widespread geographic area while attempting to reach at the same time an audience with wide-ranging backgrounds. The result is therefore a strong compromise between simple explanations of geologic concepts, complex stratigraphic columns, brief regional summaries, and extra points of interest such as histories of regional mineral exploration. What is welcome by one audience may be overwhelming or too simple to another audience.

The book would have benefitted from a narrowing of its target audience, especially after the first edition had already revealed such concerns. I find many illustrations excellent (a trademark of Orr and Orr), although many could have been better reproduced. For the casual reader, the reference basis is substantial, but professionals will miss recent publications in areas of their expertise.

In summary, this book is a welcome addition to my shelf despite some reservations. It will serve me well whether I need an overview of a physiographic province of the Pacific Northwest that is less familiar to me or where my memories demand a quick brush up.

—Martin Streck
Department of Geology
Portland State University
Portland, OR 97207-0751, USA
Phone: (503) 725-3379
FAX: (503) 725-3025
Email: streckm@pdx.edu

The mid-Pliocene Imbler fish fossils, Grande Ronde Valley, Union County, Oregon, and the connection between Lake Idaho and the Columbia River

by Jay Van Tassell, Science Department, Eastern Oregon University, La Grande, Oregon 97850; Mark Ferns and Vicki McConnell, Oregon Department of Geology and Mineral Industries, Baker City, Oregon 97814; and Gerald R. Smith, Museum of Paleontology, The University of Michigan, Ann Arbor, Michigan 48109-1079

ABSTRACT

The Grande Ronde Valley began to form ~9 m.y. ago. Diatoms, sponge spicules, and peat in the lower Grande Ronde Valley sedimentary sequence indicate that alluvial and fluvial sedimentation in the valley was interrupted by deposition of marshes and shallow lakes from ~9 to 7.5 Ma and by bogs and marshes at ~6 Ma during the late Miocene. Alluvial and fluvial sedimentation was broken by a later period of deep to shallow lake and marsh sedimentation which occurred from ~4 to 2 Ma.

During the spring of 2000, fossilized Pliocene fish bones were recovered from a water well located near Imbler, Oregon, at a depth of 138-141 m, just above andesitic bedrock. The fish species include a pikeminnow (*Ptychocheilus* sp.), catfish (*Ameiurus* cf. *reticulatus*), a sunfish (*Archoplites* sp.), and a whitefish (*Prosopium* sp.). Rough estimates based on the stratigraphic position of the fish fossils relative to ~7.5 Ma and ~3 Ma tephras in the valley-fill sedimentary sequence suggest that the fish fossils are ~3.7-3.8 m.y. old. The Imbler fish fossils are warm-water species with the exception of the cool-water whitefish. The sizes of the catfish and sunfish were limited by cool summer temperatures and a reduced growing season. Individual bones of the Imbler fish fossils are most similar to the late Pliocene Taunton Fauna of the Ringold Formation of eastern Washington, although there are some similarities to fish in the Pliocene Glenns Ferry Formation of the Lake Idaho Group. Several characteristics of the pectoral spine bony base and muscle attachment area indicate that the Grande Ronde Valley catfish, *Ameiurus* cf. *reticulatus*, is most like that of the Pliocene Ringold Formation and less like *Ameiurus vespertinus* of the Glenns Ferry Formation of Idaho. On the basis of the proportion of shared species, the Imbler fish fossils are most similar to the Blufftop Fauna of the Ringold Formation because of the absence of three species of minnows found in both the Lake Idaho sequence and the Taunton Fauna. This suggests a drainage connection to the Columbia River at ~3.7-3.8 Ma. A whitefish is known from the Glenns Ferry Formation of the Snake River Plain, but not known from Taunton or the White Bluffs Faunas of the Columbia River drainage basin. The presence of the whitefish vertebra in the Imbler fish fossil suite is a possible indicator of a connection between Lake Idaho and the Grande Ronde Valley.

Two rare diatoms, *Tetracyclus stellare* v. *eximia* and *Aulacoseira* (*Alveolodiscus*) *jouseana*, found in the sediments just above the fish fossils, appear to have been reworked from earlier sediments. They may have been washed into the Grande Ronde Valley area from the Snake River Plain, although it is possible that they were dispersed by anticyclonic winds. Abundant *Stephanodiscus* sp. and *Aulacoseira* sp. aff. *A. solida*, which were deposited just after the fish fossils, are probable equivalents to diatoms in the Pliocene Glenns Ferry Formation of the Lake Idaho sequence. This is evidence of a connection between the Grande Ronde Valley and Lake Idaho shortly after the Imbler fish fossils were deposited during the mid-Pliocene.

INTRODUCTION

Earthquake hazards and water supply are becoming ever bigger issues in the interior valleys of eastern Oregon. In order to understand the geology relevant to these problems, it is also becoming ever more critical to improve the knowledge of geologic correlations within and between sedimentary basins. Increasing demand for water resources in the Grande Ronde Valley has prompted the Oregon Department of Geology and Mineral Industries to begin detailed studies of the bedrock geology and sediments in the basin. Techniques used in these investigations include geologic mapping, seismic profiling and magnetic and gravity measurements. The discovery of ash layers, diatoms, sponges, and fish bones in cuttings from four recently drilled water wells (from north to south, Bing '00, Bing '98, Terry, and La Grande) (Figure 1), provide new insights into the early geologic history of the Grande Ronde Valley.

The modern Grande Ronde Valley (Figure 1) is a large structural basin situated along the east flank of the Blue Mountain uplift. The valley is bounded on the east and west by active or potentially active faults (White, 1981; Bishop and others, 1992; Liberty and Barrash, 1998; Personius,1998; Ferns and others, in press; Ferns and others, in preparation), and the present-day valley floor is at an elevation of ~1,000 m. It may have originated as a graben formed along en echelon tension fractures related to right-lateral strike-slip motion along the Olympic-Wallowa lineament (Hooper and Conrey, 1989) and evolved into a northwest-trend-

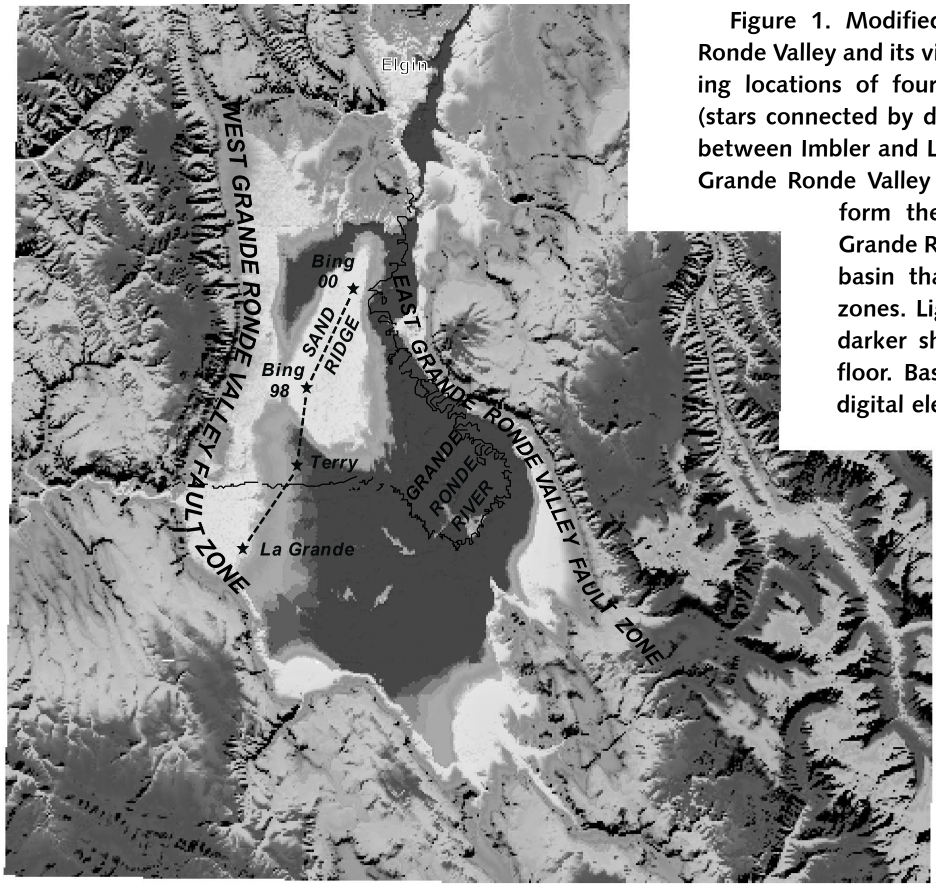


Figure 1. Modified shaded-relief map of the Grande Ronde Valley and its vicinity in northeastern Oregon, showing locations of four recently drilled, deep water wells (stars connected by dashed line). These wells are situated between Imbler and La Grande in the northern part of the Grande Ronde Valley and provided the drill cuttings that form the basis for the present paper. The Grande Ronde Valley is a deep, sediment-filled basin that is now bordered by major fault zones. Lighter shades of gray indicate higher, darker shades lower elevation of the basin floor. Based on U.S. Geological Survey 30-m digital elevation model (DEM) data.

ing, tectonically active pull-apart (strike-slip) basin (Davis, 1980; Gehrels and others, 1980; Gehrels, 1981; White, 1981; Simpson and others, 1989). Barrash and others (1983) suggested that the Grande Ronde Valley was downfaulted during the late Tertiary, between 10±2 and 4 Ma, with faulting continuing on into the Quaternary. The shape of the valley is controlled by northwest- and northeast-trending fractures and an older set of north- and east-trending fractures (Barrash and others, 1980).

The modern-day floor of the Grande Ronde Valley is a broad, flat alluvial plain, ringed by terrace, alluvial-fan, debris-flow, landslide and debris-avalanche deposits and youthful faults. Large alluvial fans have formed where major streams enter the valley. These fans have coalesced along the bounding escarpments and merged to form broad bajada surfaces. The valley's modern alluvial plain is traversed by tortuously meandering streams and is marked by marshes and shallow lakes in the south. Fromwiller and Van Tassell (1999) noted that the sediments of the marshes and lakes of the Grande Ronde Valley contain sponge spicules and abundant diatoms, including *Aulacoseira*, *Cymbella*, *Epithemia*, *Gomphonema*, *Navicula*, *Nitzschia*, *Rhoicosphenia*, and *Synedra*. Diatoms are present also in the channel and floodplain sediments of the Grande Ronde River but are less abundant there. Low-relief, windswept ridges of aeolian sand and silt occur in the north. As much as 600 m of late Miocene to Pleistocene sediment underlies the alluvial plain (Hampton and Brown, 1964; Walker, 1990; Ferns and others, in press). Faults in the valley subsurface offset Holocene alluvium (White, 1981; Bishop and others, 1992; Liberty and Barrash, 1998; Personius, 1998).

As the Grande Ronde Valley began to form during the late Miocene, the existing drainage was deranged by faulting. Hampton and Brown (1964) suggested that the basin fill consisted mainly of lacustrine deposits. Sequences of laterally discontinuous gravels, sandy gravels, and sandy muds on the order of meters thick suggest codeposition of stream sediments as the basin was forming. The valley margins are marked by interfingering, poorly sorted bouldery fanglomerate and well-sorted alluvial-fan gravel deposits. Bishop and others (1992) suggested that the basin fill was largely alluvial and fluvial and that the presence of several widespread muds and sands suggested damming of the outflow: Possibly by uplifting of fault blocks in the area of the basin's outlet, short-lived lacustrine environments may have been created. Seismic profiling by Boise State University showed clearly that the sediments in the southern part of the basin have been tilted to the west (Liberty and Barrash, 1998). During the Holocene, the outlet of the basin has been eroded down to bedrock, and more than 30 m of the valley fill has been removed (Hampton and Brown, 1964).

METHODS

A total of 776 cutting samples were collected for analysis from the four wells at intervals of 0.3–3.0 m. The cuttings were air-dried and examined under the binocular microscope for color, sediment type, and other characteristics as well as wood, ash, and fish fossils. A 20-g subsample of each cutting interval was wet-sieved through a 63-μ sieve with 1 liter of distilled water. The mud that washed through the sieve was stirred, and a 10-ml subsample of the solution was pipetted onto a glass slide, dried, and mounted in mineral oil. Each slide was examined under a petrographic microscope, and the number of individuals of each of the different genera of diatoms, sponge spicules, and pollen in a 1-cm^2 area was determined (Figure 2). The presence of volcanic ash was also noted. Four samples were sent to J. Platt Bradbury (U.S. Geological Survey, retired) for identification of selected diatom species.

The >63-μ-size fraction of each subsample was sieved and the type of sediment determined, based on the percentages of gravel, sand, and mud, according to the classification of Folk (1974). A representative subsample of the gravel was placed on a gridded petri dish, and the percentages of different types of rock fragments and minerals in the sample were counted. The sand fraction was examined under the binocular microscope for ash, wood, fish bones, and the types of lithic fragments and minerals present. Three ash samples, one from the Terry well (Terry 356) and two from the Bing '98 well (Bing 1502, Bing 1553), were analyzed for whole-rock and trace-element composition at the Washington State University GeoAnalytical Laboratory with XRF techniques. Glass separates from the Terry 356 and Bing 1553 tephra were radiometrically dated by $^{40}Ar/^{39}Ar$ at the University of Alaska, Fairbanks, Geochronology Laboratory. The Bing 1502 ash is chemically distinct but has not yet been dated.

The fish bones were separated from the sediment and identified. Representative examples are illustrated in Figures 3–6. Repositories for the fossils are Eastern Oregon University and the University of Michigan Museum of Paleontology. Accordingly, fossil numbers include the institutional abbreviations EOU and UMMP.

BASIN STRATIGRAPHY

The thick sedimentary sequence in the Grande Ronde Valley unconformably overlies lavas from the Powder River Volcanic Field. This 14.5- to 9-Ma sequence of olivine basalt, andesite, and dacite lava flows postdates flows of Columbia River Basalt Group lavas (Hooper and Conrey, 1989; Hooper and Swanson, 1990; Reidel and others, 1996; Ferns and others, in press). The most detailed information on the sediments in the valley comes from cuttings from the four water wells mentioned above (Figures 1 and 2). In the deepest well (Bing '98), the lower section coarsens upward from an 8-m-thick section dominated by organic-rich clays and silts into a 280-m-thick section of sandy silt interbedded with thin seams of gravel and sand. Judging by well cuttings, individual gravel-bearing zones are no more than 3 m thick and make up less than 18 percent of the section. The upper 200 m of section in the Bing '98 well is composed primarily of sandy silt with thin (<3 m) seams of sand and gravel.

Correlations between individual wells (Figure 2) are based on the lithology and the relative abundance and types of diatoms in the sequence. The stratigraphy of the Pleistocene terrace sediments just south of the city of La Grande, based on the observations of Pilling (1998), is also shown in Figure 2, along with the depth to bedrock in the City of La Grande well at 12th Street. A mammoth tooth *(Mammuthus washingtonii)* from the silt loam sediments on top of the terrace was radiocarbon-dated (^{14}C) by Geochron Laboratories at 15,280±180 yr B.P. (see Table 1).

Several tephra layers of high-silica ash were discovered in the cuttings from the Grande Ronde Valley wells. Glass shards from tephras from the wells Terry and Bing '98 were dated with $^{40}Ar/^{39}Ar$ techniques and yielded ages of 3.1±0.3 Ma and 7.5±0.11 Ma, respectively. F.F. Foit, Jr. (Department of Geology, Washington State University, written communication, 1999) reported a similarity coefficient of 0.93 between the ~3.1-Ma ash from the Terry well and ash from Lake Bonneville, Utah. Williams (1994) suggested a possible age of 2.9 Ma for a tephra sample from the Bonneville Basin (his sample BUR-871.11) and compares it with an ash of similar composition from an upper Lake Idaho section near Grandview, Idaho.

Average sediment accumulation rates were calculated from the ages of ~9 Ma for the andesitic bedrock (Ferns and Madin, 1999) and ~7.5 Ma and ~3 Ma for the ash layers mentioned above. These data suggest that the basin has filled with alluvial, fluvial and lacustrine sediments at rates ranging from ~0.03-0.06 mm/yr since it began forming ~9 m.y. ago. The southwest side of the basin has subsided at a rate ~0.03 mm/yr faster than the northeast side of the basin over the past 9 m.y. (Van Tassell and others, 2000).

IMBLER FISH SPECIES ACCOUNTS

Drilling of the Bing '00 well, located just west of the city of Imbler, Union County, Oregon, at lat 45°27'24" N., long 117°57'11" W., recovered fish bones from depths of 452–462 ft (138–141 m). The Bing '00 well is located ~2.15 km east of the H.L. Wagner well, where fish fossils are reputed to have been recovered in 1949. The fish fossils in the Imbler well (Figures 3–6) belong to four species, a pikeminnow (*Ptychocheilus* sp.), a catfish (*Ameiurus* cf. *reticulatus*), a sunfish (*Archoplites* sp.), and a whitefish (*Prosopium* sp.).

Family CYPRINIDAE
Genus *Ptychocheilus* sp.
Pikeminnow
Figure 3a,b

The family Cyprinidae is represented in the Bing '00 well samples by two distinctive bones of the predaceous minnow *Ptychocheilus*. One, a canine pharyngeal tooth (UMMP 35046), 4 mm long, is elliptical in cross section, robust, enlarged near its midpoint, and hooked posteriorly at its point. It is not distinguishable from teeth of similar

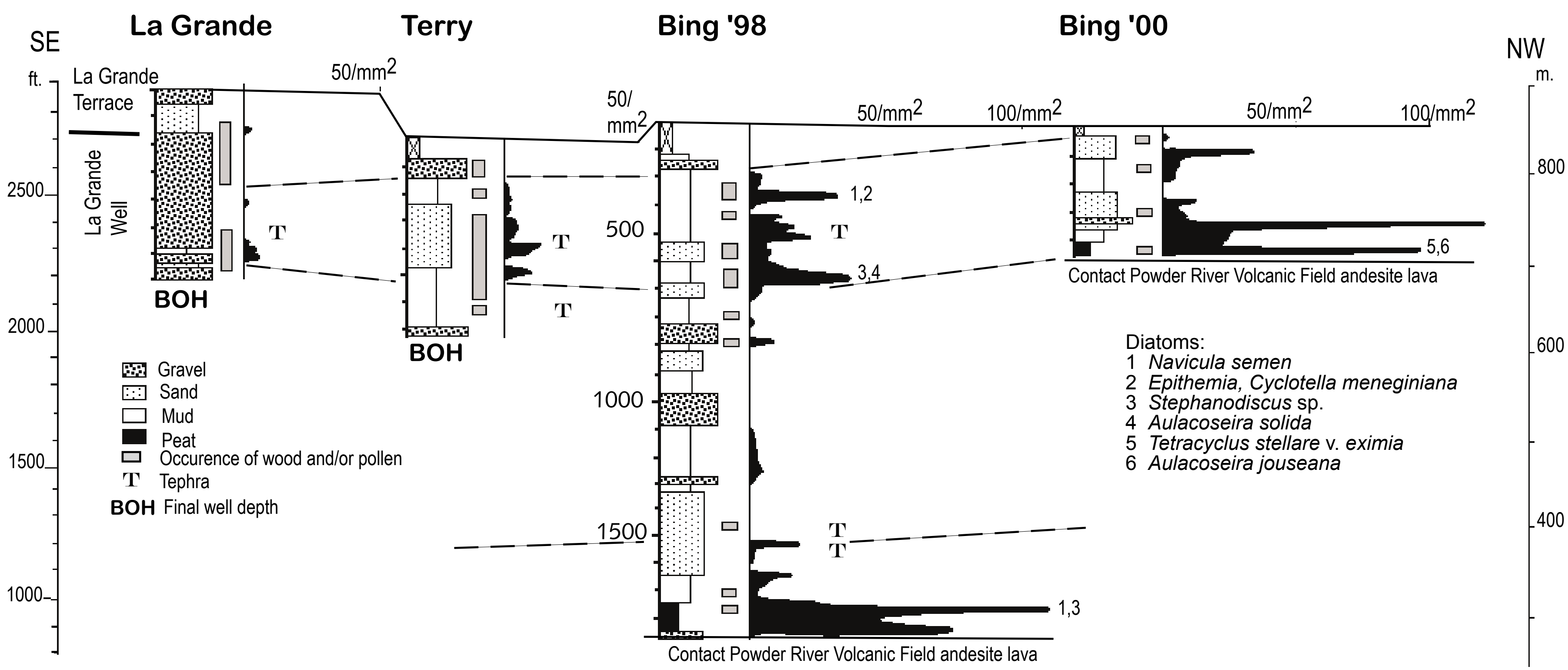


Figure 2. Stratigraphy of the Grande Ronde Valley and frequency counts of diatoms, based on analysis of the recovered sediments from the four water wells identified in Figure 1. Stratigraphy of the La Grande terrace gravel deposits is stacked upon the La Grande well stratigraphy in order to simplify the diagram. Bars on extreme left and right show elevation in feet and meters, respectively; tick marks on left side of well diagrams show depth in 100-ft increments. Sediments in the wells range from gravel-rich beds indicative of stream-channel, alluvial-fan, and fan-delta deposits to mud and peat layers that were deposited in floodplains, shallow lakes, and marshes. Dashed lines show borders of two periods when the valley floor was relatively wet, as shown by the abundances of benthic and planktic diatoms in the valley sediments. Wells Bing '98 and Bing '00 bottomed in volcanic rock; wells Terry and La Grande did not reach bedrock. The fish fossils were recovered from the Bing '00 well at a depth of 452–642 ft (138–141m). The mammoth tooth mentioned in the text (see Table 1) was found in silty loam atop the La Grande terrace gravels.

Table 1. Radiometric age determinations for selected samples discussed in this paper

Sample ID	Material	Well	Depth (ft.)	Age	Dating Technique
EO-613	Mammoth tooth	N/A	surface	15.3±0.18 ka	Carbon 14
Terry 356	Volcanic ash	Terry	356	3.1±0.3 Ma	^{40}Ar/^{39}Ar
Bing 1553	Volcanic ash	Bing '98	1553	7.5±0.4 Ma	^{40}Ar/^{39}Ar

position (anterior #1 or 2, main row) from *P. arciferus* Cope from the Miocene and Pliocene of the Snake River Plain and the Ringold Formation in south-central Washington, or from *P. oregonensis* from the Holocene fish fauna of the Columbia River drainage. The fish from which the fossil tooth was derived was about 25–30 cm in length. The second *Ptychocheilus* bone (UMMP 35046), an anterodorsal fragment of an opercle, 7 x 7 mm, is diagnosed by the angle of the hymandibular socket, its broad, robust reinforcing bar, and the shape and curvature of the levator arm and its dorsal flange. It is from a fish about 14 cm long.

Pikeminnows (formerly known as squawfish) are piscivores. Their distribution is western, ranging from the Colorado and Sacramento River basins, north to the Nass River, British Columbia. They are the largest North American minnows, although the Imbler fossils are not large. The *Ptychocheilus* fossil record extends from 15 Ma to the Holocene in the Columbia River drainage (Smith and others, 2000).

The Imbler collection also contains one small fragment of an unidentified cleithrum. This fragment is probably a cyprinid, but it is not possible to tell whether it is a pikeminnow.

Family ICTALURIDAE
Genus *Ameiurus* cf. *reticulatus*

Bullhead Catfish
Figure 4b,d,e

Bullhead catfishes are represented in the Bing '00 well samples by 14 pectoral spines (10 items EOU 634, 4 items UMMP 35041); 1 supraoccipital (UMMP 35043), 12 mm long; 1 partial premaxilla (UMMP 35042), 10 x 7 mm; 1 dorsal spine (EOU 634); 1 pterygiophore (UMMP 35041), 12 mm long; 6 vertebrae (EOU 634); 1 Weberian vertebra (EOU 634); and several skull fragments (EOU 634).

The supraoccipital bone is reticulated on its dorsal surfaces, like those of *Ameiurus reticulatus* of the Ringold Formation (see also Smith and others, 2000, Figure 9g). The supraoccipital has a deeper median-

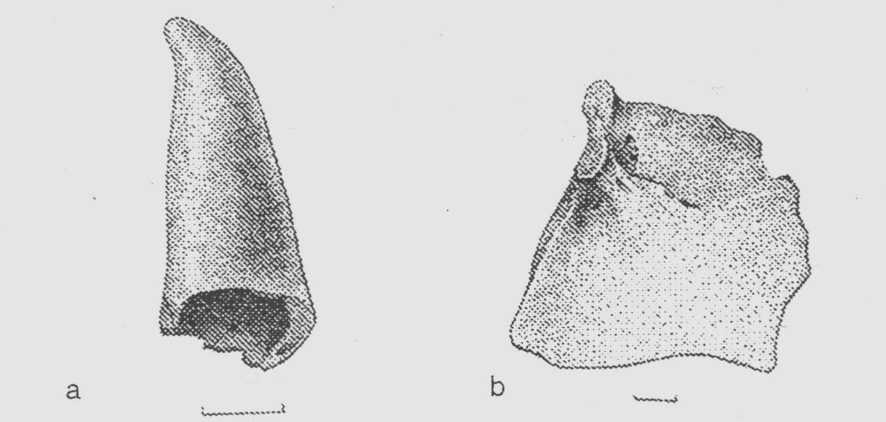


Figure 3. *Ptychocheilus* sp., pikeminnow from the well Bing '00: (a) Pharyngeal tooth (UMMP 35046); (b) right opercle (UMMP 35046), mesial view, (scale bars = 1 mm). Drawings by Emily Damstra.

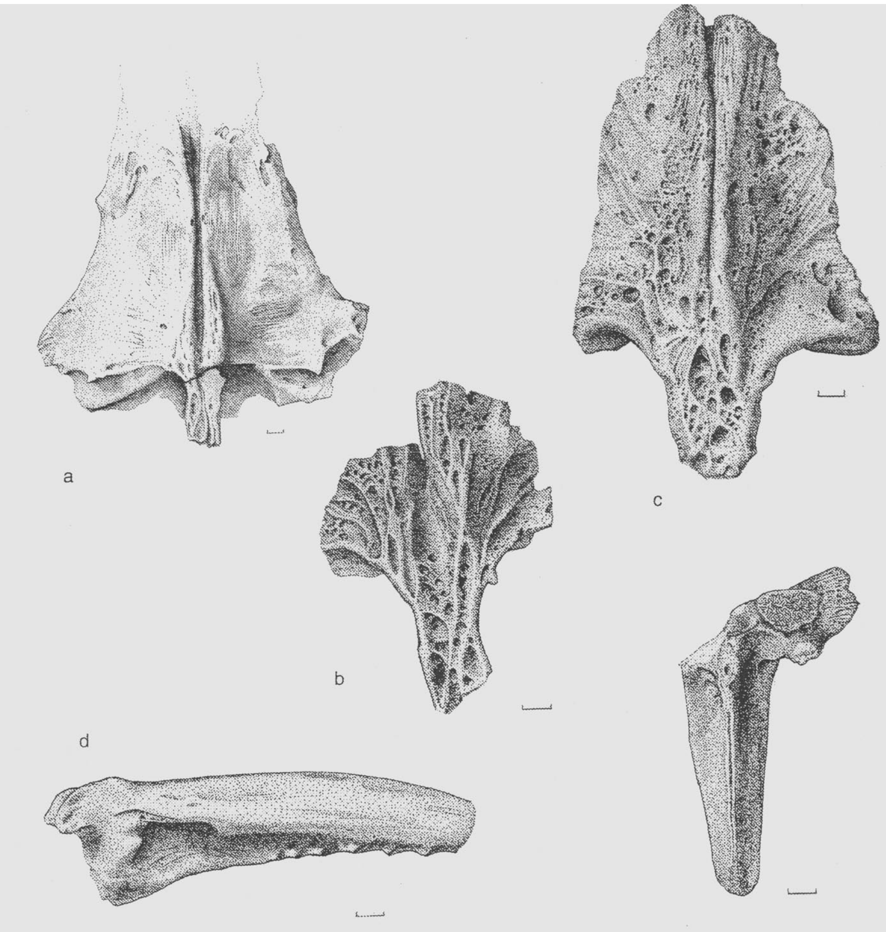


Figure 4. *Ameiurus*, bullhead catfish from Bing '00 well, with comparison specimens (a and c): (a) *Ameiurus vespertinus* from Glenns Ferry Formation, dorsal view of posterior part of skull, showing supraoccipital with its smooth surface and open fontanelle (UMMP 62443); (b) *Ameiurus* cf. *reticulatus* (UMMP 35043), dorsal view of posterior part of skull, showing supraoccipital with its reticulate surface and closed fontanelle; (c) *Ameiurus reticulatus* from Ringold Formation, Washington, dorsal view of posterior part of skull, showing supraoccipital with its reticulate surface (UMMP 104031); (d) *Ameiurus* cf. *reticulatus*, first dorsal pterygiophore, anterior view (UMMP 35041); (e) *Ameiurus* cf. *reticulatus,* basal part of left pectoral spine, ventral view (EOU 634); (scale bars = 1 mm). Drawings by Emily Damstra.

dorsal longitudinal groove or fontanelle, somewhat like those of *A. vespertinus* from the Glenns Ferry Formation of Owyhee County, Idaho, described by Smith (1975). The longest of the pectoral spines is a fragment, 20 mm long (apparently 26 mm long in life). They are striated like *A. reticulatus* and *vespertinus*. The dorsal pterygiophore has characteristics of each of those species. The bones indicate fishes about 20 cm long.

Bullhead catfishes are lowland, warm-water fishes whose present-day range is mainly in eastern North America. These catfishes are found in low-gradient streams and lakes generally below 1,000 m in elevation, in warm-temperate climatic zones that experience at least 230 frost-free growing days and at least 40 cm of rainfall. *Ameiurus* lived in western North America from the Eocene through the Pliocene, but became extinct west of the Rocky Mountains during the late Pliocene; they have been successfully reintroduced in the western U.S. over the past 120 years. The large sample of relatively small bones suggests slow growth. The small size of the *Ameiurus* in the Imbler assemblage suggests that the catfish were limited by cool summer temperatures and a reduced growing season.

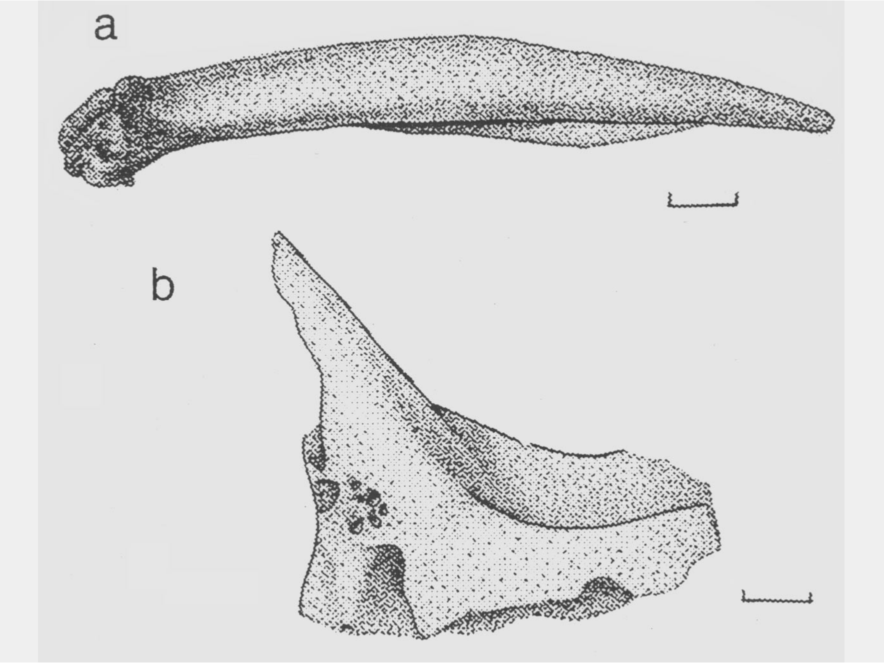


Figure 5. (a) *Archoplites* sp., western sunfish: median spine (UMMP 35044), lateral view; (b) partial right cleithrum (UMMP 35045), lateral view; Scale bars = 1 mm. Drawings by Emily Damstra.

Family CENTRARCHIDAE
Genus *Archoplites* sp.
Western Sunfish
Figure 5a,b

Sunfishes are represented in the Bing '00 well samples by 131 dorsal and anal spines (126 items EOU 635, 9–14 mm long; 5 items UMMP 35044); an incomplete right cleithrum (UMMP 35045); and several small fragments. The cleithrum is similar to Pliocene preopercles of *Archoplites taylori* from the Glenns Ferry Formation described by Smith (1975) and *A. molarus* from the Ringold Formation described by Smith and others (2000). The large sample of bones from small sunfish suggests slow growth.

Modern sunfish, *Archoplites interruptus*, are found today in low-gradient streams, lakes, and reservoirs generally below 1,000 m in elevation. They are native to the Central Valley of California in areas where they experience a yearlong growing season and at least 40 cm of annual rainfall. They have been successfully reintroduced into western waters in areas with eight months of frost-free temperatures.

Family SALMONIDAE
Subfamily COREGONINAE
Genus *Prosopium* sp.
Mountain Whitefish
Figure 6a-d

The whitefish identification is based on one complete, well-preserved mid-thoracic vertebra (and one partial vertebra). The specimen (UMMP V35064) is 5 mm wide, 4.5 mm high, and 2.8 mm long. It is identified as a salmonid by the pitted, lacework texture of the lateral surfaces between the neural arch and rib fossae (Figure 6a); however, the texture is much coarser than in the Salmonidae. There are large ventro-lateral fossae for rib attachments and moderately large dorso-lateral fossae for the neural arch attachments (Figure 6b). The mid-dorsal pair of fossae (Figure 6a) is asymmetrical and elongate; the ventral fossae are symmetrical, elongate, and separated by an long, narrow longitudinal ridge that is characteristic for the thoracic vertebrae of the family and the genus (Figure 6c). The vertebra is distinguished from vertebrae of Catostomidae, Cyprinidae, Ictaluridae, and Centrarchidae, because those families lack the paired longitudinal ventral fossae separated by a narrow ridge.

Whitefish of the genus *Prosopium* were common in Pliocene Lake Idaho. There, the appearance of the genus, according to Smith and others (1982), indicates immigration from the north facilitated by a cooling climate. *Prosopium* is now found in cool waters from the Great Lakes and streams in western North America, northwest to Siberia. The fish are now common in Oregon streams, but have not been recorded from the Taunton or White Bluffs Faunas (Ringold Formation) of the Columbia River drainage basin.

Prosopium is indicative of cooler waters than suggested by the other families represented in the Imbler

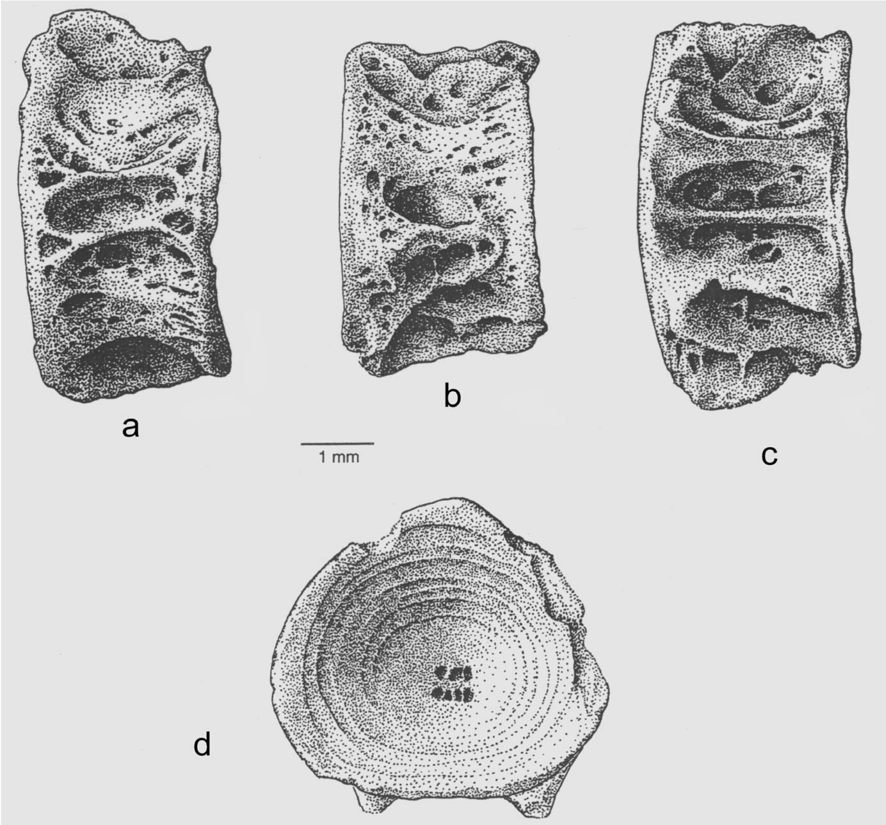


Figure 6. *Prosopium* sp., mountain whitefish, vertebra (UMMP V35064) from Bing '00 well; (a) dorsal view; (b) lateral view; (c) ventral view; (d) anterior view showing growth rings. The growth rings indicate that the whitefish was 8 years old. Scale bar = 1 mm. Drawings by Emily Damstra.

fauna. Whitefish would not ordinarily live with catfish and sunfish. Either the summers were cool enough for the *Prosopium* to coexist with *Ameiurus* and *Archoplites*, or the whitefish specimens were washed into the warmer lowland and its ponded environment from upstream. The number of growth rings on the vertebra shows that the specimen was eight years old (Figure 6d), which indicates that the diameter of the whitefish vertebra grew at an average rate of ~0.6 mm/yr. This growth rate is similar to those of whitefish that live today in the cold waters of the Laurentian Great Lakes.

DIATOMS AND SPONGES

Diatom genera in the Grande Ronde Valley well cuttings include *Aulacoseira*, *Cyclotella*, *Cymbella*, *Epithemia*, *Fragilaria*, *Navicula*, *Nitzschia*, *Stephanodiscus* (large and small), *Synedra*, *Tetracyclus*, and rare *Amphipleura*, *Anomoeoneis*, *Asterionella*, *Diatoma*, *Eunotia*, *Gyrosigma*, *Meridion*, *Pinnularia*, *Reimeria*, *Rhoicosphenia*, *Rhopalodia*, *Surirella*, and *Tabellaria*. The lower diatom-rich zone (see Figure 2), deposited after emplacement of the andesitic bedrock and until slightly after the Bing 1553 ash (~9-7.5 Ma), is characterized by abundant benthic diatoms and the planktic diatom *Aulacoseira* sp. From interpolation between dated horizons, the upper diatom zone is estimated to have been deposited between ~4 and 2 Ma. It is characterized by an abundance of the planktic diatoms *Aulacoseira*. sp. and *Stephanodiscus* sp. but also contains abundant benthic diatoms.

J.P. Bradbury identified the diatoms *Navicula semen*, *Epithemia*, and *Cyclotella meneghiniana*? in a sample from the upper diatom zone at a depth of 253 ft (77.1 m) in the Bing '98 well (Bradbury, written communication, 2001). Abundant *Stephanodiscus* sp. and another centric diatom, *Aulacoseira* sp. aff. *Aulacoseira solida*, were identified in the upper diatom zone at a depth of 550 ft (167.7 m) in the same well. An organic-rich sample from a level of 1,769 ft (539.6 m) in the lower diatom zone in the Bing '98 well contained abundant *Navicula* semen and pollen. A sample from the upper diatom zone at a depth of 452 ft (137.8 m) in the Bing '00 well contained the relatively rare diatom *Tetracyclus stellare* v. *eximia* and an even rarer species, *Aulacoseira jouseana* (Figure 2).

Sponge spicules in the Grande Ronde Valley well cuttings include *Ephydatia lacustris*, *E. mulleri* and *Spongilla lacustris*. Sponge spicules are most common in cuttings containing abundant benthic diatoms.

The Bing '00 well cuttings that contain the fish fossils consist of peat, quartz- and feldspar-rich sand, andesite fragments, and fragments of diatomite which may have been mixed in from an overlying layer as a result of the drilling process. The diatomite includes the planktic genera *Aulacoseira*, *Stephanodiscus*, and *Synedra*, plus the benthic and epiphytic genera Nitzschia, *Tetracyclus*, *Cymbella*, *Epithemia*, *Fragilaria*, and *Gomphonema*. The diatomite also contains sponge spicules which are dominantly *Ephydatia fluviatilis*, plus *E. mulleri* and *Spongilla lacustris.*

AGE OF THE IMBLER FISH FOSSILS

The age of lava flows that floor the Grande Ronde Valley area without ponding suggests that the valley began to subside ~9 m.y. ago. A similar date for the initiation of sedimentation can be derived by (1) dividing the thickness of sediment between bedrock and the ~7.5-Ma ash layer in the Bing '98 well by the average sediment accumulation rate between the ~3.1-Ma and 7.5-Ma layers, and (2) adding this time to the age of the ~7.5-Ma ash.

The relatively rare diatom, *Tetracyclus stellare* v. *eximia*, present in the Bing '00 well sediments at a depth of ~138 m, just above the fossil fish bones, was identified by VanLandingham (1985) in the lower Idaho Group in Mann Creek, Washington County, Idaho. The even rarer diatom *Aulacoseira jouseana* in the Bing '00 sediments was found abundantly in another lower Lake Idaho Group outcrop on Sagebrush Hill, Washington County, Idaho (Bradbury and Krebs, 1982; Bradbury, written communication, 2001). The age of these sediments is poorly constrained, however (Bradbury and Krebs, 1982). According to VanLandingham (1985), *A. jouseana* is not restricted and extends to the Blancan and possibly into the Pleistocene. On the other hand, *T. stellare* v. *eximia* is known only from sediments of 14 Ma and older. It was found in the Mann Creek district with other middle Miocene diatoms that are also found in the middle Miocene Truckee Formation of Nevada. Since it occurs in the Bing '00 well just above the fish fossils, it is possible evidence that the Imbler fish fossils are middle Miocene in age; however, the occurrence of the diatoms above ~9-Ma bedrock argues against this. The scarcity of these diatoms in the samples suggests redeposition, and it seems likely that the *A. jouseana* and *T. stellare* v. *eximia* diatoms in the Grande Ronde Valley sediments have been reworked from older sediments (Bradbury, written communication, 2001). The presence of *Stephanodiscus* sp. and *Aulacoseira* sp. aff. *A. solida*, which are probable equivalents of similar diatoms in the Pliocene Glenns Ferry Formation of the Lake Idaho sequence, in the sediments just above the fish bones suggests that the fish bones are Pliocene in age.

The types and sizes of the Imbler fish fossils provide important clues to their age. The pikeminnow is not helpful in assigning age—northern pikeminnows span a period from 15 Ma to Holocene in the Columbia River drainage (Smith and others, 2000). The large sample of bones from unusually small sunfish and catfish suggests slow growth as expected in cooling Pliocene climates. Miocene sunfishes in Oregon and Idaho reached sizes three to four times larger, and Miocene catfishes in the western United States were several times larger than the Imbler catfish. Miocene fish faunas from Oregon, Washington, and Idaho include several species of large salmon and trout, not seen in the Bing '00 samples. Earlier Pliocene faunas from Washington, Oregon, and Idaho include not only many more species than the Imbler fauna, but larger specimens of the comparable species. The whitefish *Prosopium* is known from Pliocene and Holocene on the Snake River Plain and Pleistocene to Holocene in the Bonneville Basin. Catfish became extinct in the western United States during the late Pliocene, establishing an upper limit of 1.6 Ma for the age of the Imbler fish fossils. This evidence suggests a mid- to late Pliocene age for the Imbler fish fossils.

Of all of the Neogene fish faunas in western North America, the individual bones in the Imbler fauna are most like the late Pliocene Taunton Local Fauna of the Ringold Formation, 13 km (8 mi) west-southwest of Othello, Washington, 180 km (112 mi) to the north-northwest of the Grande Ronde Valley. Three Imbler species—-bullhead catfish (*Ameiurus* cf. *reticulatus*), western sunfish (*Archoplites* sp.), and northern pikeminnow (*Ptychocheilus* sp.)—are similar taxonomically and ecologically to their counterparts among the Taunton fishes.

On the basis of the proportion of shared species, the Imbler fish fauna is most similar to the early Pliocene Blufftop Fauna of the Ringold Formation (described by Smith and others, 2000). Three Imbler fish fossil species are also present in the Blufftop Formation. The Taunton and other Pliocene Ringold faunas include several additional suckers and minnows as well as muskellunge and sturgeon. For these reasons, the Imbler (Bing '00) fishes are interpreted to have an age somewhere between the age of the Blufftop Fauna (3.9 Ma) and the age of the Taunton Fauna (~2.8–3 Ma), namely ~2.8–3.9 Ma.

Vertical variations in the abundance of *Stephanodiscus* sp. (a deep-water species) in the Bing '98 well match with vertical variations in the abundance of *Aulacoseira* sp. (a shallow-water species), benthic diatoms, and sponge spicules in nearby wells (Figure 7). These correlations suggest that the position of the Imbler fish fossils in the Bing '00 well is stratigraphically below the Terry 356 ash. Since the Terry 356 ash matches geochemically with the 2.9-Ma Bonneville Basin ash of Williams (1994) mentioned above, the age of the Terry 356 ash may also be ~2.9 Ma. Based on its stratigraphic position between the Terry 356 and Bing 1553 ashes (Table 1), the estimated age of the Imbler fishes, is ~3.7–3.8 Ma. (Figure 7). This age should be regarded as only a rough estimate, since average sedimentation rates are often not representative of the real sedimentation rates, which tend to be more episodic, particularly in alluvial and fluvial sediments.

PALEOENVIRONMENTS

The diatoms and sponges in the Grande Ronde Valley sequence indicate that, in addition to alluvial environments, a wide range of marsh and lacustrine environments have been present in the Grande Ronde Valley over the past 9 Ma (Figure 8). These include (1) marsh, bog, and shallow-water environments dominated by sponge spicules and benthic diatoms; (2) shallow, open-water environments dominated by benthic diatoms and *Aulacoseira* sp.; and (3) deep-water environments dominated by *A.* sp. and *Stephanodiscus* sp. Rainy, wet periods during the history of the basin occurred at ~9–7.5 Ma, 6.5 Ma, 4–2 Ma, and 1.2 Ma (ages based on average sedimentation rates interpolated between dated horizons).

Diatoms present in the ~9–7.5 Ma sequence suggest that the Grande Ronde Valley was dominated by marsh and bog environments with scattered areas of open water during that pe-

(Continued on page 89

PLEASE SEND US YOUR PHOTOS

Since we have started printing color pictures on the front cover of *Oregon Geology*, we are finding ourselves woefully short of good color photographs showing geologic motifs in Oregon. We also want to make recommendations for scenery well worth looking at in a new series of photos on the back cover of *Oregon Geology*. For that, too, your contributions are invited. Since we are going to the Web now, we expect to use even more color.

"Hard copy" will be best submitted in the form of good, glossy prints or transparencies, while digital versions are best in TIFF or EPS format, on the PC or Mac platform.

If you have photos that you would like to share with other readers of this magazine, please send them to us (Editor, *Oregon Geology*, 800 NE Oregon Street, Portland, OR 97232; e-mail klaus.neuendorf@dogami.state.or.us) **with detailed information for a caption**. If they are used, the printing and credit to you is all the compensation we can offer. If you wish to have us return your materials, please include a self-addressed envelope.

Information for Contributors

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

Two copies of the manuscript should be submitted, one paper copy and one digital copy. All digital elements of the manuscript, such as text, figures, and tables should be submitted as separate files, not as incorporated, e.g., in a word processor product for a paper version. Hard-copy graphics should be camera ready; photographs should be glossies. All illustrations should be clearly marked. Captions should be placed together at the end of the text.

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

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

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

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

PUBLICATION ORDER FORM

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

Name/Address/City/State/Zip ______________________________

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

$3.00 shipping/handling charge $ ______3.00___

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

____

Please charge to Visa__ / Mastercard__, account number: ______________________

Expiration date: __________ Cardholder's signature ______________________

AVAILABLE PUBLICATIONS
OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

NOTE

All publications require additional $3 for mailing.
Some maps may have to be plotted on demand. In that case, please allow two weeks for delivery.

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

GEOLOGICAL MAP SERIES	**Price**
GMS-113 Fly Valley 7½' quad., Union County. 1998	10.00
GMS-111 Summerville 7½' quad., Union County. 1997	10.00
GMS-110 Tucker Flat 7½' quad., Union/Baker C. 1997	6.00
GMS-109 Brownsboro 7½' quad., Jackson County. 1998	10.00
GMS-108 Rio Canyon 7½' quad., Jackson County. 1998	6.00
GMS-106 Grizzly Peak 7½' quad., Jackson County. 1997	6.00
GMS-105 EQ hazards, Salem East/West 7½' quads. 1996	12.00
GMS-104 EQ hazards, Linnton 7½' quad., Mult./Wash. C. 1996	10.00
GMS-101 Steelhead Falls 7½' quad., Desch./Jeffers. C., 1996	7.00
GMS-100 EQ hazard maps for Oregon. 1996	8.00
GMS-99 Tsunami hazard map, Siletz Bay, Lincoln C. 1996	6.00
GMS-98 Dora and Sitkum 7½' quad.s, Coos County. 1995	6.00
GMS-97 Coos Bay 7½' quad., Coos County. 1995	6.00
GMS-95 Henkle Butte 7½' quad., Deschutes County. 1998	10.00
GMS-94 Charleston 7½' quad., Coos County. 1995	8.00
GMS-93 EQ hazards, Siletz Bay area, Lincoln County. 1995	20.00
GMS-92 EQ hazards, Gladstone 7½' quad. 1995	10.00
GMS-91 EQ hazards, Lake Oswego 7½' quad. 1995	10.00
GMS-90 EQ hazards, Beaverton 7½' quad. 1995	10.00
GMS-89 EQ hazards, Mt. Tabor 7½' quad. 1995	10.00
GMS-88 Lakecreek 7½' quad., Jackson County. 1995	8.00
GMS-87 Three Creek Butte 7½' quad., Deschutes C. 1995	6.00
GMS-86 Tenmile 7½' quad., Douglas County. 1994	6.00
GMS-85 Mount Gurney 7½' quad., Douglas/Coos C. 1994	6.00
GMS-84 Remote 7½' quad., Coos County. 1994	6.00
GMS-83 Kenyon Mountain 7½' quad., Douglas/Coos C. 1994	6.00
GMS-82 Limber Jim Creek 7½' quad., Union County. 1994	5.00
GMS-81 Tumalo Dam 7½' quad., Deschutes County. 1994	6.00
GMS-80 McLeod 7½' quad., Jackson County. 1993	5.00
GMS-79 EQ hazards, Portland 7½' quad. 1993	20.00
GMS-78 Mahogany Mountain 30×60' quad., Malheur C. 1993	10.00
GMS-77 Vale 30×60' quad., Malheur County. 1993	10.00
GMS-76 Camas Valley 7½' quad., Douglas/Coos C. 1993	6.00
GMS-75 Portland 7½' quad. 1991	7.00
GMS-74 Namorf 7½' quad., Malheur County. 1992	5.00
GMS-73 Cleveland Ridge 7½' quad., Jackson County. 1993	5.00
GMS-72 Little Valley 7½' quad., Malheur County. 1992	5.00
GMS-71 Westfall 7½' quad., Malheur County. 1992	5.00
GMS-70 Boswell Mountain 7½' quad., Jackson County. 1992	7.00
GMS-69 Harper 7½' quad., Malheur County. 1992	5.00
GMS-68 Reston 7½' quad., Douglas County. 1990	6.00
GMS-67 South Mountain 7½' quad., Malheur County. 1990	6.00
GMS-66 Jonesboro 7½' quad., Malheur County. 1992	6.00
GMS-65 Mahogany Gap 7½' quad., Malheur County. 1990	5.00
GMS-64 Sheaville 7½' quad., Malheur County. 1990	5.00
GMS-63 Vines Hill 7½' quad., Malheur County. 1991	5.00
GMS-62 The Elbow 7½' quad., Malheur County. 1993	8.00
GMS-61 Mitchell Butte 7½' quad., Malheur County. 1990	5.00

	Price
GMS-60 Damascus 7½' quad., Clackamas/Multnomah C. 1994	8.00
GMS-59 Lake Oswego 7½' quad. 1989	7.00
GMS-58 Double Mountain 7½' quad., Malheur County. 1989	5.00
GMS-57 Grassy Mountain 7½' quad., Malheur County. 1989	5.00
GMS-56 Adrian 7½' quad., Malheur County. 1989	5.00
GMS-55 Owyhee Dam 7½' quad., Malheur County. 1989	5.00
GMS-54 Graveyard Point 7½' quad., Malheur/Owyhee C. 1988	5.00
GMS-53 Owyhee Ridge 7½' quad., Malheur County. 1988	5.00
GMS-52 Shady Cove 7½' quad., Jackson County. 1992	6.00
GMS-51 Elk Prairie 7½' quad., Marion/Clackamas C. 1986	5.00
GMS-50 Drake Crossing 7½' quad., Marion County. 1986	5.00
GMS-49 Map of Oregon seismicity, 1841-1986. 1987	4.00
GMS-48 McKenzie Bridge 15' quad., Lane County. 1988	9.00
GMS-47 Crescent Mountain area, Linn County. 1987	7.00
GMS-46 Breitenbush River area, Linn/Marion Counties. 1987	7.00
GMS-45 Madras West/East 7½' quads., Jefferson County. 1987	5.00
as set with GMS-43 and GMS-44	11.00
GMS-44 Seekseequa Junction/Metolius Bench 7½' quads. 1987	5.00
as set with GMS-43 and GMS-45	11.00
GMS-43 Eagle Butte/Gateway 7½' quads. 1987	5.00
as set with GMS-44 and GMS-45	11.00
GMS-42 Ocean floor off Oregon & adj. cont. margin. 1986	9.00
GMS-41 Elkhorn Peak 7½' quad., Baker County. 1987	7.00
GMS-40 Aeromagnetic anomaly maps, north Cascades. 1985	5.00
GMS-39 Bibliogr. & index: Ocean floor, cont. margin. 1986	6.00
GMS-38 NW¼ Cave Junction 15' quad., Josephine County. 1986	7.00
GMS-37 Mineral resources, offshore Oregon. 1985	7.00
GMS-36 Mineral resources of Oregon. 1984	9.00
GMS-35 SW¼ Bates 15' quad., Grant County. 1984	6.00
GMS-34 Stayton NE 7½' quad., Marion County. 1984	5.00
GMS-33 Scotts Mills 7½' quad., Clackamas/Marion C. 1984	5.00
GMS-32 Wilhoit 7½' quad., Clackamas/Marion Counties. 1984	5.00
GMS-31 NW¼ Bates 15' quad., Grant County. 1984	6.00
GMS-30 SE¼ Pearsoll Peak 15' qu., Curry/Josephine C. 1984	7.00
GMS-29 NE¼ Bates 15' quad., Baker/Grant Counties. 1983	6.00
GMS-28 Greenhorn 7½' quad., Baker/Grant Counties. 1983	6.00
GMS-27 The Dalles 1°×2° quadrangle. 1982	7.00
GMS-26 Residual gravity, north/ctr./south Cascades. 1982	6.00
GMS-25 Granite 7½' quad., Grant County. 1982	6.00
GMS-24 Grand Ronde 7½' quad., Polk/Yamhill Counties. 1982	6.00
GMS-23 Sheridan 7½' quad., Polk and Yamhill Counties. 1982	6.00
GMS-22 Mount Ireland 7½' quad., Baker/Grant C. 1982	6.00
GMS-21 Vale East 7½' quad., Malheur County. 1982	6.00
GMS-20 S½ Burns 15' quad., Harney County. 1982	6.00
GMS-19 Bourne 7½' quad., Baker County. 1982	6.00
GMS-18 Rickreall, Salem W., Monmouth, Sidney 7½' quads. 1981	6.00
GMS-17 Aeromagnetic anomaly map, south Cascades. 1981	4.00
GMS-16 Gravity anomaly maps, south Cascades. 1981	4.00
GMS-15 Gravity anomaly maps, north Cascades. 1981	4.00

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

	Price
GMS-14 Index to published geol. mapping, 1898–1979. 1981	8.00
GMS-13 Huntington/Olds Ferry 15' quads., Baker/Malheur C. 1979	4.00
GMS-12 Oregon part, Mineral 15' quad., Baker County. 1978	4.00
GMS-10 Low- to intermediate-temp. thermal springs/wells. 1978	4.00
GMS-9 Aeromagnetic anomaly map, central Cascades. 1978	4.00
GMS-8 Bouguer gravity anom. map, central Cascades. 1978	4.00
GMS-6 Part of Snake River canyon. 1974	8.00
GMS-5 Powers 15' quadrangle, Coos and Curry C. 1971	4.00

INTERPRETIVE MAP SERIES

IMS-19 Rel. EQ hazard map, Klamath Falls metropol. area. 2000	**10.00**
IMS-18 EQ-induced slope instability: Haz. map, Eola Hills. 2000	12.00
IMS-17 EQ-induced slope instab.: Haz. map, Salem Hills. 2000	12.00
IMS-16 EQ scenario and probabilistic maps, Portland. 2000	80.00
IMS-15 EQ scenario ground shaking map, Portland. 2000	10.00
IMS-14 Rel. EQ hazard map, Eugene-Springfield. 2000	12.00
IMS-13 Tsunami hazard map, Gold Beach area. 2000	10.00
IMS-12 Tsunami hazard map, Warrenton area. 1999	10.00
IMS-11 Tsunami hazard map, Astoria area. 1999	10.00
IMS-10 Rel. EQ hazard maps, coastal urban areas. 1999	20.00
IMS-9 Rel. EQ hazard maps, Cottage Grove to Ashland. 2000	20.00
IMS-8 Rel. EQ hazard maps, Canby to Sweet Home. 2000	20.00
IMS-7 Rel. EQ hazard maps, St. Helens to Monmouth. 2000	20.00
IMS-6 Water-induced landslide hazards, Salem Hills. 1998	10.00
IMS-5 Water-induced landslide hazards, Eola Hills. 2000	10.00
IMS-4 Geology/faults/sedim. thickness, Oregon City quad. 1997	10.00
IMS-3 Tsunami hazard map, Seaside area. 1998	6.00
IMS-2 Tsunami hazard map, Yaquina Bay area. 1997	6.00
IMS-1 Relative EQ hazards, Portland metro area. 1997	12.00

MINED LAND RECLAMATION PROGRAM STATUS MAPS

MLR-03 Clackamas County. 1998	10.00
MLR-10 Douglas County. 1998	10.00
MLR-17 Josephine County. 1998	10.00
MLR-24 Marion County. 1998	10.00

U.S. GEOLOGICAL SURVEY MAPS PLOTTED ON DEMAND

OFR 97-513 Volcano hazards at Newberry volcano	10.00
OFR 97-089 Volcano hazards in the Mount Hood region	10.00
OFR 94-021 Geologic map, Tillamook highlands (2 sheets)	20.00

BULLETINS

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

OIL AND GAS INVESTIGATIONS

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

SPECIAL PAPERS

34 Slope failures in Oregon–inventory f. 1996/97 storms. 2000	6.00
33 Penrose Conference summary and abstracts. 2000	15.00
32 Geologic hazards: Reducing Oregon's losses. 2000	10.00
31 Mitigating geol. hazards:Technical reference manual. 2000	20.00
30 EQ-induced slope instability: Mapping methodology. 2000	15.00
29 Earthquake damage and loss estimates for Oregon. 1999	10.00
28 Earthquakes Symposium Proceedings, AEG Meeting. 1997	12.00
27 Construction aggregate markets and forecast. 1995	15.00
26 Cross section, N. Coast Range to continental slope. 1992	11.00
25 Pumice in Oregon. 1992	9.00
24 Index to Forums on Industrial Minerals, 1965-1989. 1990	7.00
23 Forum on Industrial Minerals, 1989, Proceedings. 1990	10.00
22 Silica in Oregon. 1990	8.00
21 Geology, NW¼ Broken Top 15' quad., Deschutes Co. 1987	6.00
20 Bentonite in Oregon. 1989	7.00
19 Limestone deposits in Oregon. 1989	9.00
18 Investigations of talc in Oregon. 1988	8.00
17 Bibliography of Oregon paleontology, 1792-1983. 1984	7.00
16 Index to Ore Bin and Oregon Geology (1939-82). 1983	5.00
15 Geology/geothermal resources, central Cascades. 1983	13.00
14 Geology/geothermal resources, Mount Hood area. 1982	8.00

(Continued on next page)

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

	Price
13 Faults and lineaments of southern Cascades, Oregon. 1981	5.00
12 Geologic linears, N. part of Cascade Range, Oregon. 1980	4.00
11 Bibliography/index, theses/dissertations, 1899-1982. 1982	7.00
10 Tectonic rotation of the Oregon Western Cascades. 1980	4.00
9 Geology of the Breitenbush Hot Springs quadrangle. 1980	5.00
8 Geology and geochemistry, Mount Hood volcano. 1980	4.00
7 Pluvial Fort Rock Lake, Lake County. 1979	5.00
6 Geology of the La Grande area. 1980	6.00
5 Analysis and forecasts of demand for rock materials. 1979	4.00
4 Heat flow of Oregon. 1978	4.00
3 Rock material, Clackam./Columb./Multn./Wash. Co. 1978	8.00
2 Field geology, SW Broken Top quadrangle. 1978	5.00

MISCELLANEOUS AND SHORT PAPERS (discontinued)

MP 20 Investigations of nickel in Oregon. 1978	6.00
MP 19 Geothermal exploration studies in Oregon, 1976. 1977	4.00
MP 15 Quicksilver deposits in Oregon. 1971	4.00
MP 11 Articles on meteorites (reprints from the Ore Bin). 1968	4.00
MP 5 Oregon's gold placers. 1954	2.00
SP 27 Rock material resources of Benton County. 1978	5.00
SP 25 Petrography of Rattlesnake Formation at type area. 1976	4.00

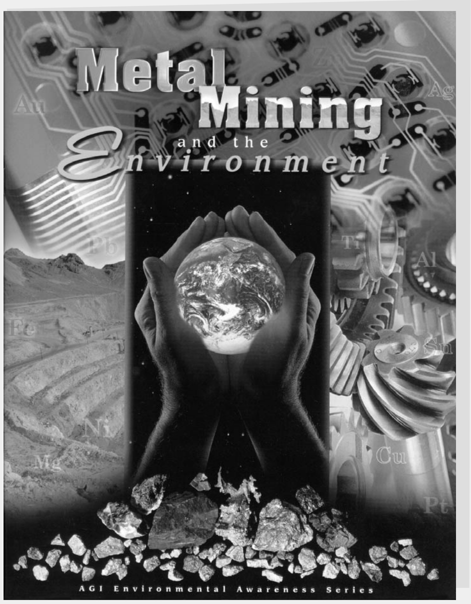
MISCELLANEOUS PUBLICATIONS

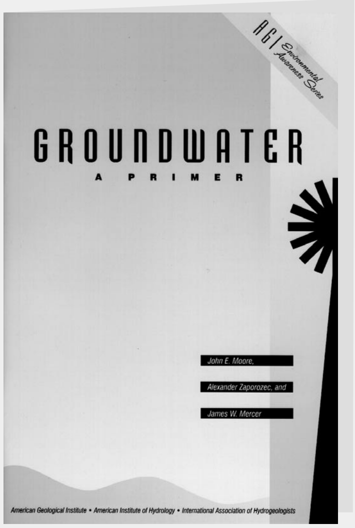
	Price
Oregon fossils.1999	40.95
Living with earthquakes in the Pacific Northwest. 1998	21.95
Islands & Rapids. Geologic story of Hells Canyon. 1998	25.00
The Pacific Northwest coast: Living with shores. 1998	18.50
Hiking Oregon's geology, E.M. Bishop and J.E. Allen, 1996	16.95
Assessing EQ hazards in the PNW (USGS Prof. Paper 1560)	25.00
Geology of Oregon, 5th ed. 1999	44.95
Geologic map of Oregon. 1991	11.50
Geologic highway map (AAPG), PNW region. 1973	9.00
Landsat mosaic map (published by ERSAL, OSU). 1983	11.00
Mist Gas Field map. 2001 (OFR O-01-01)	8.00
Digital version on CD (CAD formats .DGN, .DWG, .DXF)	25.00
Mist Gas Field production 1979-1992 (OFR O-94-6)	5.00
Oregon rocks and minerals, a description. 1988 (OFR O-88-6)	6.00
Mineral information by county (OFR O-93-8), 1 CD	25.00
Directory of mineral producers. 1993 (OFR O-93-9)	8.00
Geothermal resources of Oregon (DOGAMI/NOAA map). 1982	4.00
Mining claims (State laws on quartz and placer claims)	Free
Back issues of Oregon Geology	3.00

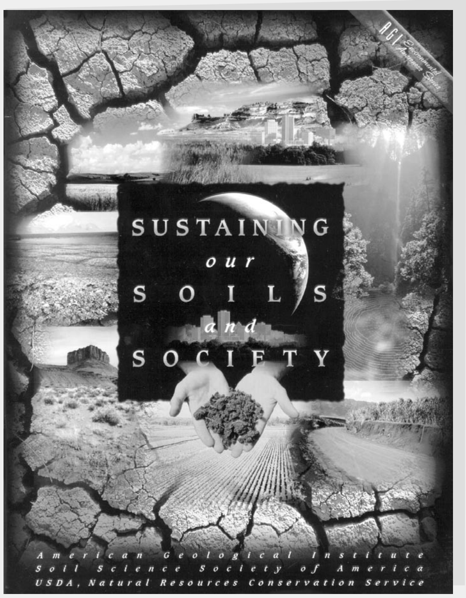
Highlighting Recent Publications

Now available from The Nature of the Northwest Information Center

Earth Science Week (October 7–13) is getting a proper boost by the new "Environmental Awareness Series" of the American Geological Institute (AGI). In cooperation with its member societies, AGI has produced the first booklets in this series as ways to increase public understanding of important natural systems and how humans interact with them.







Each of the books is about 65 pages long, is lavishly illustrated, and provided with a list of references, a glossary, and an index. Books 2 and 3, on soils and metal mining, respectively, are in full color throughout and come with an equally colorful poster. Prices at the Nature of the Northwest Information Center are $6.50 for Book 1 (Groundwater), and 15.95 each for Books 2 (Sustaining our Soils) and 3 (Metal Mining and the Environment).

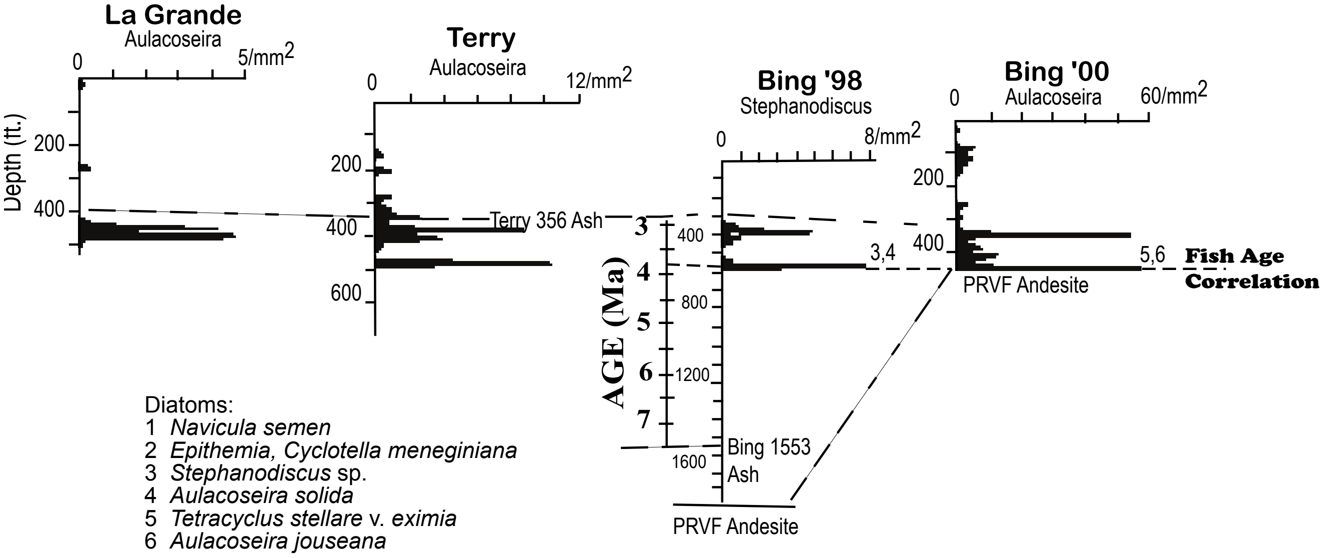


Figure 7. Age correlation diagram illustrating how the ~3.7- to 3.8-Ma age of the Bing '00 fish fossil horizon was determined. The peaks in diatom abundance (upper dashed line) were used as a guide to determine which layers in the Bing '98 well match those that contain the Imbler fish fossils in the Bing '00 well and those that contain the Terry 356 ash in the Terry well. The stratigraphic position of the fish fossil horizon between the Bing 1553 and Terry 356 ash horizons was then used to estimate the age of the fish fossils (lower dashed line). The age of the Terry ash was adjusted to be ~2.9 Ma to match the age of geochemically similar ashes from the Bonneville basin. Note that the peak abundances of the shallow-water diatom genus, *Aulacoseira*, in the La Grande, Terry, and Bing '00 wells correlate with peaks in the abundance of *Stephanodiscus*, a deep-water diatom genus, in the well Bing '98. This suggests that between ~2.9 and 3.7 Ma water depth was greater in the area of the Bing '98 well than it was at the other well sites.

(Continued from page 89)

riod, while mainly marsh and bog environments were present at ~6.5 Ma. The diatoms in the ~2- to 4-Ma sediments suggest that deepwater lakes were present during this period in addition to marshes and bogs. According to J. Platt Bradbury (written communication, 2001), the presence of *Navicula semen* at a depth of 253 ft (77.1 m) in the Bing '98 well suggests a shallow, oligotrophic marsh or bog environment. However, *Epithemia* and *Cyclotella meneghiniana?* in the same sample imply greater alkalinity and nutrient status. This may be the result of mixing during transport. Abundant *Stephanodiscus* sp. and another centric diatom, *Aulacoseira* sp. aff. *Aulacoseira solida*, in the upper diatom-rich zone in the same well suggest a nutrient-rich lake. The brief period of marsh and bog sedimentation at ~1.2 Ma interrupted a period of alluvial and fluvial sedimentation that has dominated the area over the past two million years.

The sedimentary sequence just above bedrock in the Bing '00 well records a change from alluvial to shallow, open-water lacustrine environments. The Imbler sunfish and catfish fossils are shallow-water and warm-water species and appear to indicate a small pond or oxbow-lake habitat. Their presence suggests an elevation below 1,000 m, at least 230 frost-free growing days, and at least 40 cm of annual rainfall. Cool summer temperatures and a reduced growing season are indicated by the small size of the *Ameiurus* in the Imbler assemblage. The occurrence of a large pikeminnow suggests that the size of the habitat was not a factor limiting the size of the Imbler sunfish and catfish. Nearby mountain streams may have been a source of cool water, limiting the size of the Imbler catfish and sunfish, perhaps from the nearby Wallowa and Elkhorn Mountains, as indicated by the presence of the mountain whitefish vertebra. The Imbler fish fauna includes fewer species and smaller specimens of comparable species than the earlier Pliocene fish faunas from Washington, Oregon, and Idaho; this indicates shorter growing seasons and/or smaller aquatic habitats. The Imbler fishes indicate that the mid-Pliocene Grande Ronde Valley was higher in elevation and had smaller habitats and slightly lower fish diversity than the late Pliocene Taunton locality.

The organic-rich, peaty sediments in the Bing '00 well, just above the layer containing the most abundant fish fossils, are rich in benthic and epiphytic diatoms. Some fish bones were found in these peaty sediments but fewer than in the mixture of rock fragments, quartz sand, and diatomite in the layer just above andesite bedrock. The diatoms in this layer resemble diatoms in the upper detrital peats of the Pleistocene American Falls Lake beds of southeastern Idaho (noted by Bright, 1982, and Scott and others, 1982) and in certain facies of the uppermost Glenns Ferry Formation (described by Bradbury and Krebs, 1982).

The Bing '00 samples that contain fish bones also contain abundant sponge spicules. The sponge spicules resemble specimens in some peats of the American Falls Lake beds, which, in turn, are similar to those found in modern freshwater (very low chloride) ponds and lakes in southeastern Idaho and western Wyoming. These sponge spicules indicate water temperatures of 12°–4°C and water depths less than 1.5 m (Bright, 1982).

The sediments above the peaty layers in the Bing '00 well are rich in *Aulacoseira* and benthic diatoms (although the percentages of benthic diatoms are less than in the peaty sediments). This suggests a change to shallow, open-water, lake environments at the Bing '00 well site after the deposition of the peats. The abundance of the diatom *Stephanodiscus* deposited in the Bing '98 well at the same time (Figure 7) suggests that the water depth was greater at the site of the Bing '98 well than at the site of the Bing '00 well during the same period (~3.6–2.9 Ma).

DISCUSSION: THE LAKE IDAHO-COLUMBIA RIVER CONNECTION

"The Blue Mountains abound in physiographic problems caused by many changes in river courses . . . many of them, and the most important ones, among which is the origin of the Snake River Canyon, are still unsolved and a rich field here remains for future work." (Lindgren, 1901, p. 598).

The hypothesis that a large lake occupied the western and central parts of the Snake River Plain during the Tertiary was proposed by Cope (1870, 1883a,b) after he examined fish bones collected from the area by the Hayden expedition (Hayden, 1872) and the King survey (King, 1878). Cope named this great lake "Lake Idaho." This conclusion was supported in later work by Russell (1902). Lindgren and Drake (1904) divided the depositional sequence into two distinct basin-filling episodes, the Payette and Idaho Formations, separated by an unconformity. Malde and Powers (1962) revised this terminology by calling the sequence the Idaho Group and subdividing it into the late Miocene Chalk Hills Formation, the Pliocene Glenns Ferry Formation, and several other volcanic and sedimentary units. Workers have studied fossil fish (Miller and Smith, 1967; Smith, 1975; Smith and others, 1982; Drummond and others, 1993; Patterson and others, 1993; Smith and Patterson, 1994; Coburn and others, 1996), lavas and volcanic ash layers (Swirydczuk and others, 1982; Jenks and Bonnichsen, 1989), and sediments (Malde, 1972; Kimmel, 1982; Middleton and others, 1985, Wood, 1994) of the central and western Snake River Plain and have documented a complex lake system and accompanying floodplains, in which lake-basin sedimentation alternated between lacustrine, fluvial, and fluvial-deltaic environments. Lake Idaho was drained when the Salmon River eroded headward and captured a tributary of the Snake River, creating a

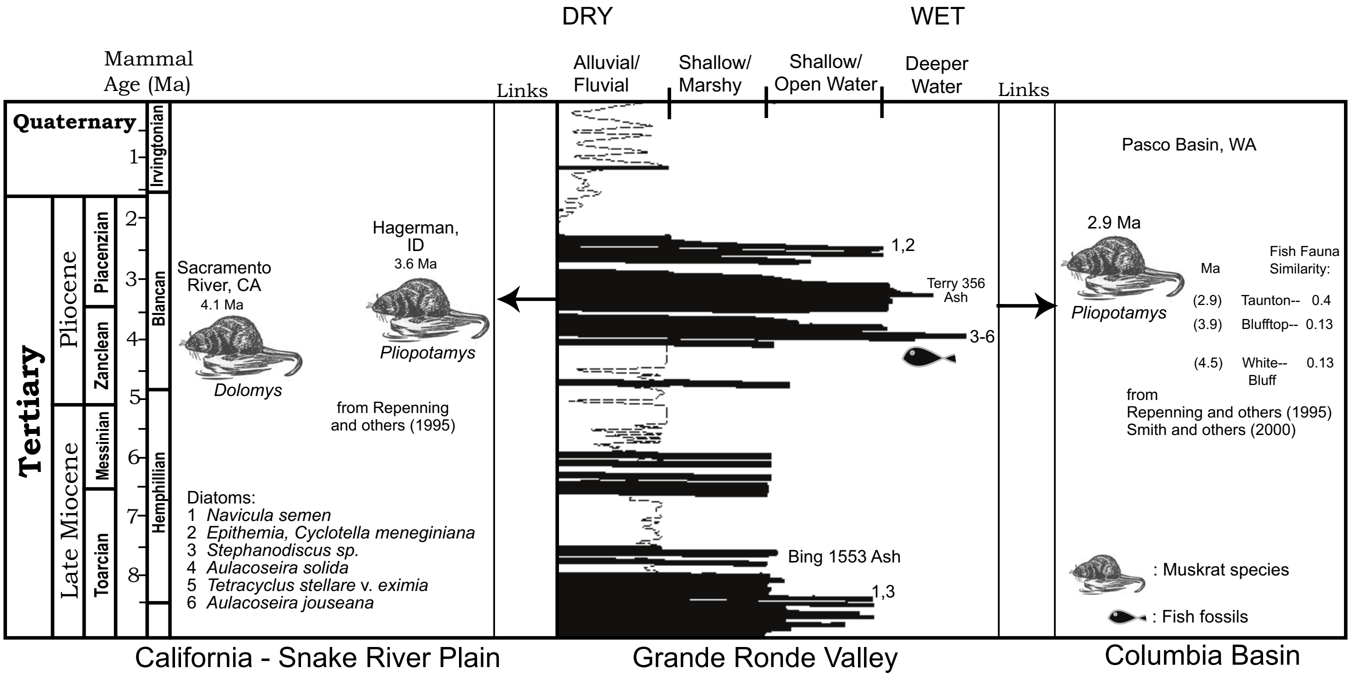


Figure 8. Composite diagram of the stratigraphy and diatom species identified in the four water wells, indicating environmental/climatic changes over time in the Grande Ronde Valley. The dashed peaks plot times of predominantly gravel deposition indicating alluvial and fluvial environments and the black peaks indicate times of abundant shallow- to deep-water diatom species deposition.

drainageway through Hells Canyon (Livingston, 1928; Wheeler and Cook, 1954; Cook and Larrison, 1954; Othberg, 1988, 1994; Malde, 1991; Othberg and others, 1995). This caused canyon-cutting and deposition of gravels in the river valleys, as the lake levels dropped (Lindgren, 1901). As the lake receded, braided streams and stream deltas spread across the basin, capping the Lake Idaho sequence with gravels (Othberg, 1988; Jenks and Bonnichsen, 1989).

Livingston (1928) proposed that the original outlet for Lake Idaho was through northeast Oregon via the Burnt, Powder, and Grande Ronde Rivers to the Columbia River. He based his opinion on the geomorphology of the area and, in particular, the presence of barbed stream tributaries. Wheeler and Cook (1954; see Figure 9) suggested that Livingston's proposed drainage course was improbable for several reasons: (1) there are no barbed tributaries in the Burnt River area; (2) the pass through which the diversion to the Powder River system supposedly occurred is at a higher elevation than the Oxbow in Hells Canyon, which both Livingston (1928) and Wheeler and Cook (1954) proposed as the point where a tributary of the Salmon River captured the Snake River at the start of the Quaternary; (3) there are no known lacustrine sediments in the Powder River (Baker) Valley that can be related to the Snake River's history; and (4) there is no evidence that the Grande Ronde River accommodated a stream of the Snake River's magnitude.

Wheeler and Cook (1954) were careful to note that the timing of the Snake River capture with respect to the stratigraphy and history of the Snake River Plain was still incompletely understood, but suggested that capture took place at ~2 Ma. This date is supported by stratigraphic evidence that suggests a drop of ~120 m in the level of Lake Idaho at Glenns Ferry Formation age (~2 Ma), and by biostratigraphic evidence that indicates the time when the Snake River became part of the Columbia River drainage: through the distribution record of the snail *Fisherola nuttali* (Taylor, 1985; Othberg, 1988; Malde, 1991).

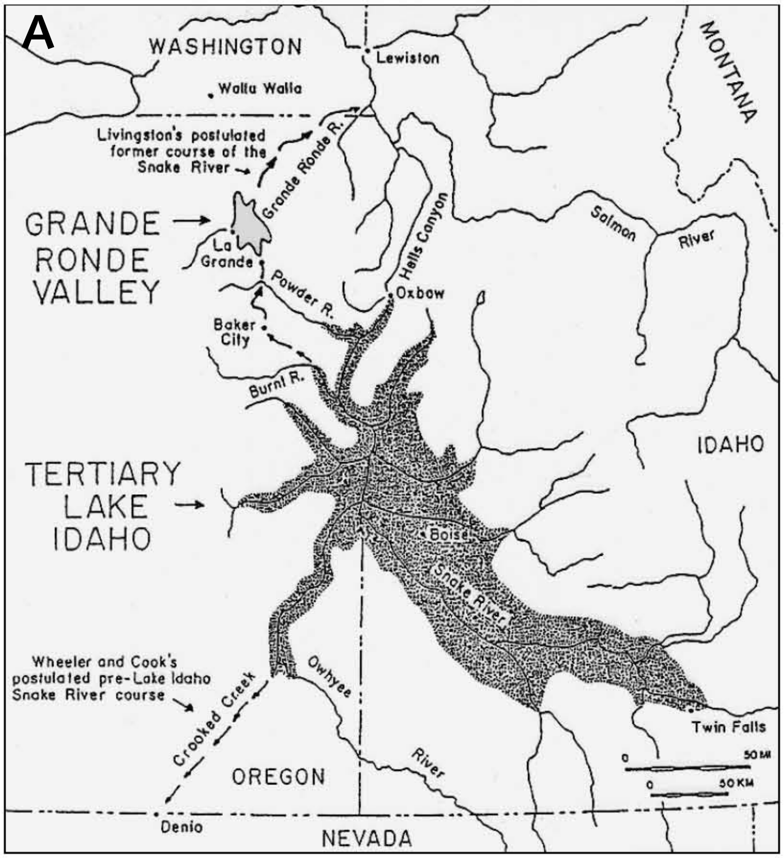
Othberg (1994) pointed out that evidence from the Snake River Plain cannot prove that the capture of the Snake River by the Salmon occurred as the Pleistocene ice ages began and that it is possible that the drainage diversion may have occurred during the late Pliocene. Recent paleontologic studies support the possibility that the Snake River-Hells Canyon-Columbia River connection may have been established even earlier during the Pliocene. Repenning and others (1995) noted fossil assemblages that suggest an expansion of the range of muskrats during the Pliocene from the Sacramento River drainage (4.1 Ma) to Lake Idaho (Glenns Ferry Formation, 3.6 Ma) and then to the Columbia River drainage (Ringold Formation, 3-4 Ma). The study by Smith and others (2000) of fishes in the Ringold Formation at Pasco, Washington, supports the late Pliocene date suggested by Repenning and others (1995) for the advent of the Lake Idaho-Columbia River connection through Hells Canyon. Faunal similarity and the absence of Glenns Ferry fishes in the Taunton fauna of the Ringold Formation at Pasco, Washington, suggest that the connection was prior to 3 Ma or that a substantial ecological barrier was established (Figure 8). Wood (2000) has suggested that the spillover of Lake Idaho into Hells Canyon may have occurred even earlier, at ~4.5 Ma, although the timing is poorly constrained.

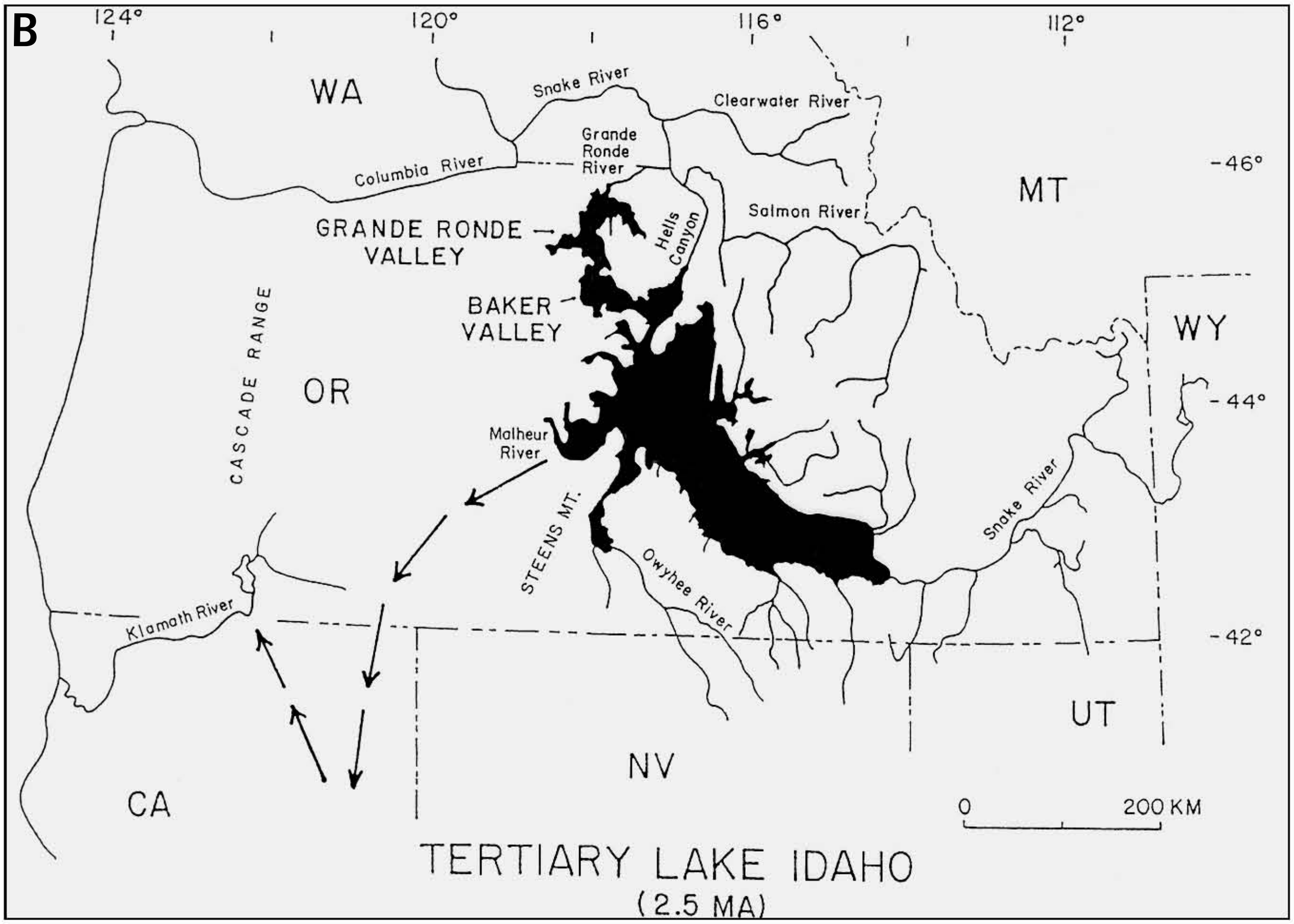
Recent estimates of the maximum elevation of Lake Idaho during the Pliocene, ~2–3 m.y. ago, range from 1,070 to 1,160 m (Smith and others, 1982; Jenks and Bonnichsen, 1989). Smith and others (2000) pointed out that these estimates negate the dismissal by Wheeler and Cook (1954) of the Lake Idaho drainage route proposed by Livingston (1928). They pointed out further that (1) lack of barbed tributaries on the Burnt River was not relevant, because the Burnt River was submerged by the Powder River embayment of Lake Idaho (Figure 9b); (2) the upper Powder River flows at an acute angle and in reversed direction to the trunk stream, which indicates a reversal of drainage as noted by Livingston (1928); (3) the Wheeler and Cook argument against Livingston that was based on elevation differences is also negated, because those elevations depend on the relative rates of uplift of the Blue Mountains-Wallowa Mountains-Seven Devils Mountains area. Smith and others (2000) concluded that, if Livingston's hypothetical connection occurred, it was after the Blufftop Fauna at Ringold (3.9 Ma) and before the late Pliocene capture of Lake Idaho through Hells Canyon, which probably occurred no later than 2 Ma.

Fish fossils and diatoms in the Grande Ronde Valley sequence provide new evidence of possible Lake Idaho-Columbia River drainage connections, but larger sample sizes are necessary before firm conclusions can be drawn. The similarity of *Ameiurus* cf. *reticulatus* fossils in the Imbler and Taunton suites and the estimated age of the Imbler fish fossils suggest a connection between the Grande Ronde Valley and the Columbia River at ~3.7–3.8 Ma. (Figure 8).

The Imbler fish fossils share some characteristics with mid-Pliocene Lake Idaho fishes but not enough to establish a link between the Grande Ronde Valley and Lake Idaho. Three species of minnows (*Lavinia*, *Acrocheilus,* and *Klamathella*) that were present in the Snake River Plain prior to 3 Ma are absent from the 3.9-Ma Blufftop Fauna of the Ringold Formation and from the ~3.7- to 3.8-Ma Imbler fish fossil suite (although additional Imbler fish specimens are needed to confirm this). These same minnows are found in the 2.8- to 3.0-Ma Taunton Fauna of the Ringold Formation, which indicates the initiation of a connection between the lower Columbia River drainage and the Snake River Plain between ~3.9 and 3 Ma. This evidence suggests that the Imbler fish fossils probably rep-

Figure 9. Lake Idaho and its possible drainages: (A) based on Wheeler and Cook (1954). The boundaries of Lake Idaho are based the distribution of Lake Idaho sediments, and (B) The maximum extent of Lake Idaho at ~ 2.5 Ma, assuming a lake level of 1160 m, based on Jenks and Bonnichsen (1989). Note that the lake may have flooded the Baker, Grande Ronde and Wallowa Valleys. Arrows indicate routes of Pliocene drainage from Lake Idaho inferred by Taylor (1985) from biogeographic evidence.





resent a time prior to the drainage of the Snake River to the Columbia. The presence of the whitefish vertebra in the Imbler fish fossil suite is a possible indicator of a connection between Lake Idaho and the Grande Ronde Valley.

The relatively rare diatom *Tetracyclus* v. *eximia* and the even rarer *Aulacoseira jouseana* in the Bing '00 well, just above the horizon containing the Imbler fish fossils, also occur in the Idaho Group. These reworked diatoms may have been blown into the Grande Ronde Valley from the western Snake River Plain by anticyclonic winds (J.P. Bradbury, written communication, 2001). It is also possible that they were washed in.

The zone of possibly reworked Lake Idaho diatoms just above the Imbler fish fossils in the Bing '00 well correlates with the occurrence of abundant *Stephanodiscus* sp. and the centric diatom *Aulacoseira*. sp. aff. *A. solida* at the 550-ft (167.7-m) level in the Bing '98 well in the Grande Ronde Valley (Figure 7). These two species probably relate to Glenns Ferry units in Idaho (J.P. Bradbury, written communication, 2001). The presence of these diatoms and the abrupt change to deep-water lake environments in the Grande Ronde Valley after the Imbler fish fossils were deposited suggest that a water connection between Lake Idaho and the Grande Ronde Valley was established at ~3.7 Ma. This conclusion provides support for the Jenks and Bonnichsen (1989) hypothesis that Lake Idaho flooded the Grande Ronde Valley area during the Pliocene (Figure 9b).

Another possible point of evidence for a connection between the Grande Ronde Valley and Lake Idaho is the presence of the 3.1±0.3-Ma Terry 356 ash which, geochemically, matches ashes of the same age from the Bonneville Basin and from the late Pliocene Glenns Ferry Formation of the Lake Idaho Group. One possible explanation for the presence of this ash in the sedimentary fill of the Grande Ronde Valley is that it was washed in from the Snake River Plain. But the ash is very pristine, good enough to determine an eruption age by radiometric dating. This suggests that the ash must have been rapidly transported and buried, so it is also possible that it was deposited by airfall.

Although this evidence does not prove the Livingston (1928) hypothesis that the Snake River drained from Lake Idaho through the Grande Ronde Valley to the Columbia, it does indicate that the Grande Ronde Valley was linked to both areas during the mid-Pliocene. This suggests the possibility that, starting at ~3.7–3.8 Ma, Lake Idaho may have flooded the Grande Ronde Valley and drained down the Grande Ronde River to the Snake and Columbia Rivers. This connection may have been open episodically until ~2 Ma, the time when the deep-water diatom, *Stephanodiscus* sp., largely disappears from the Grande Ronde Valley well sediments.

One possibile scenario is that the Lake Idaho drainageway during the mid-Pliocene was through the Grande Ronde Valley as proposed by Livingston (1928). This hypothesis provides an alternate route, other than Hells Canyon, for the migration of fish (Smith and others, 2000) and muskrats (Repenning and others, 1995) from Lake Idaho to the lower Columbia River during the Pliocene. The route could have existed until Lake Idaho was drained at ~2 Ma, the time when the Snake River was captured by a tributary of the Salmon River. A second possibility is that the main connection between Lake Idaho and the lower Columbia (Taunton Fauna) was established during the mid-Pliocene through Hells Canyon, with the drainage from the Grande Ronde Valley flowing, as it does today, as a tributary into the Snake River. This would explain the similarity between the Imbler fish fossils and the Taunton fauna. Perhaps both drainageways were active at various times, depending on the relative rates of uplift in the Blue Mountains-Wallowas-Seven Devils area (as proposed by Smith and others, 2000).

CONCLUSION

The Grande Ronde Valley began to form ~9 m.y. ago and is filled with a complex mixture of alluvial, fluvial, and lacustrine sediments. It experienced two distinct wet periods when diatom-rich sediments were deposited. The first wet period occurred during the late Miocene (~9-7.5 Ma), when the valley was occupied by marshes and shallow lakes. Deeper water lakes were present in the Grande Ronde Valley during the second wet period that occurred during the Pliocene (~4-2 Ma).

The Imbler fish fossils (pikeminnow, catfish, sunfish, and whitefish) suggest that the Grande Ronde Valley area during the mid-Pliocene (~3.7-3.8 Ma) was at an elevation below 1,000 m but higher than the Taunton locality near Othello, Washington. The sizes of the catfishes and sunfishes were limited by cool summer temperatures and a reduced growing season. The individual bones of the Imbler fish fossils are most similar to the 2.8- to 3.0-Ma Taunton fauna of the Ringold Formation of eastern Washington, although there are some similarities to fishes in the late Pliocene Glenns Ferry Formation of the Lake Idaho Group. On the basis of shared species, the Imbler fish fauna is most similar to the 3.9-Ma Blufftop fauna of the Ringold Formation. The presence of the whitefish vertebra in the Imbler fish fossil suite is a possible indicator of a connection between Lake Idaho and the Grande Ronde Valley.

Two rare diatoms, *Aulacoseira jouseana* and *Tetracyclus stellare* v. *eximia*, were reworked from Lake Idaho deposits and may have been blown into the Grande Ronde Valley area, although river transport is also a possibility. Abundant *Stephanodiscus* sp. and the centric diatom *Aulacoseira*. sp. aff. *A. solida* , which probably also relate to the Lake Idaho Glenns Ferry units (J.P. Bradbury, written communication, 2001), suggest a water connection between the two basins. The presence in the Grande

Ronde Valley of a 3.1±0.3-Ma ash that is geochemically similar to an ash in the Lake Idaho sequence and a 2.9-Ma ash in the Bonneville Basin, is also a possible indicator of a connection between the Grande Ronde Valley area and Lake Idaho at ~3 Ma, although this ash could also have been deposited by airfall.

This evidence suggests links between the Grande Ronde Valley and both Lake Idaho and the lower Columbia River drainage during the mid-Pliocene. The diatoms in the sequence suggest that the link between the Grande Ronde Valley and Lake Idaho started at ~3.7 Ma, after the deposition of the Imbler fish fossils. This link may have recurred episodically until ~2 Ma. The evidence suggests that Lake Idaho spilled over into the Grande Ronde Valley (as proposed by Jenks and Bonnichsen, 1989), but it is not clear whether the Snake River flowed through the Grande Ronde Valley (as proposed by Livingston, 1928). If a connection between Lake Idaho and the Columbia River through the Grande Ronde Valley did exist during the Pliocene, it would provide an alternate route in addition to Hells Canyon for the migration of fish and muskrats from the Snake River Plain to the Columbia Basin after the deposition of the ~3.7- to 3.8-Ma Imbler fish fossils and prior to the draining of Lake Idaho at ~2 Ma.

Further work is needed to determine whether the Grande Ronde Valley area was connected to Lake Idaho earlier in its history, during the late Miocene. More seismic profiling would add greatly to our knowledge of the stratigraphy of the Grande Ronde Valley sediments and pave the way for better modeling of the groundwater flow through the sequence. More drilling and analysis of the microfossils in the sediment samples down to the species level would provide the samples necessary to unravel the link between climate variations, tectonics, and sedimentation in the basin and possibly produce additional fossils that would help us better understand the migration of fish and other animals between Lake Idaho and the lower Columbia River drainage during the Pliocene.

ACKNOWLEDGMENTS

Special thanks go to Waldo Lowe and his assistants, the well drillers who found the fish fossils in the well cuttings and put in an incredible effort collecting many of the well cuttings analyzed in this study. We also thank Ross Bingaman, owner of the Imbler fish fossil well, for his genuine interest in the scientific aspects of a water well. We are grateful to J. Platt Bradbury, U.S. Geological Survey, retired, for identifying the diatoms in samples from the Bing '98 and Bing '00 wells and for reviewing an early draft of this paper. Emily Damstra created the illustrations of the fish bones. The manuscript was greatly improved by a thorough, detailed, and insightful review by Tom Wiley of the Oregon Department of Geology and Mineral Industries.

Thanks go to John Rinehart and Denny Swanger of the Eastern Oregon University Biology Department, who helped in the preliminary identification of the fish and diatoms. Ted Fremd, paleontologist at the John Day Fossil Beds National Monument, identified a limb cast from the Terry well. The City of La Grande provided cuttings from the La Grande well. The students of the Eastern Oregon University Historical Geology class of Spring 2000 helped pick the fish bones out of the Bing '00 well cuttings. Early studies of sediment samples from Grande Ronde Valley wells by Curt Peterson and his students at Portland State University helped provide insights that made this study possible.

This research was funded in part by a grant from the Grande Ronde Model Watershed Program and the U.S. Geological Survey National Cooperative Geologic Mapping Program under assistance award #99HQAG0036. Jay Van Tassell was funded in the early stages of this project by an Eastern Oregon University summer research stipend.

REFERENCES CITED

Barrash, W., Bond, J.G., Kauffman, J.D., and Venkatakrishnan, R., 1980, Geology of the La Grande area, Oregon: Oregon Department of Geology and Mineral Industries Special Paper 6, 47 p.

———1983, Structural evolution of the Columbia Plateau in Washington and Oregon: American Journal of Science, v. 283, p. 897–935.

Bishop, E.M., Thompson, L.L., and Woodward, J., 1992, Sedimentation and tectonics in the Grande Ronde graben, northeast Oregon: A preliminary assessment [abs.]: Geological Society of America Abstracts with Programs, v. 24, no. 5, p. 7.

Bradbury, J.P., and Krebs, W.N., 1982, Neogene and Quaternary lacustrine diatoms of the western Snake River Basin, Idaho-Oregon, USA: Acta Geologica Academiae Scientiarum Hungaricae, v. 25 (1-2), p. 97–122.

Bright, R.C., 1982, Paleontology of the lacustrine member of the American Falls Lake beds, southeastern Idaho, *in* Bonnichsen, B., and Breckenridge, R.M., eds., Cenozoic Geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26, p. 597–614.

Coburn, J.C., Patterson, W.P., and Smith, G.R., 1996, Regional climate variation of the Mio-Pliocene western North American interior: Stable oxygen isotope evidence from fish-bone phosphate [abs.]: American Geophysical Union Annual Meeting, San Francisco, Abstracts (http://128.230.24.91/Bill/Abstracts/Mioplio.html).

Cook, E.F., and Larrison, E.J., 1954, Late Pleistocene age of the Snake River diversion [abs.]: Geological Society of America Bulletin, v. 65, no. 12, pt. 2, p. 1241.

Cope, E.D., 1870, On the fishes of a fresh-water Tertiary in Idaho, discovered by Capt. Clarence King: Proceedings of the American Philosophical Society, v. 11, p. 538–547.

———1883a, On the fishes of the Recent and Pliocene lakes of the western part of the Great Basin, and of the Idaho Pliocene lake: Proceedings of the Academy of Natural Sciences of Philadelphia, p. 134–166.

Cope, E.D., 1883b, A new Pliocene formation in the Snake River valley: American Naturalist, v. 17, no. 8, p. 867–868.

Davis, G.A., 1980, Preliminary report on the late Cenozoic tectonics of the Pacific Northwest: Washington Public Power Supply System, Richland, Washington, 33 p.

Drummond, C.N., Wilkinson, B.H., Lohmann, K.C., and Smith, G.R., 1993, Lacustrine isotopic record of late Miocene topography and hydrology in the southern Rocky Mountains: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 101, p. 67–79.

Ferns, M.L., and Madin, I.P., 1999, Geologic map of the Summerville quadrangle, Union County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-111, 1:24,000.

Ferns, M.L., Madin, I.P., McConnell, V.S., and Johnson, J.J., in preparation, Surface and subsurface geology of the southern Grande Ronde Valley and lower Catherine Creek drainage, Union County, Oregon: Oregon Department of Geology and Mineral Industries.

Ferns, M.L., McConnell, V.S., Madin, I.P., and Van Tassell, J., in press, Geology of the Imbler quadrangle, Union County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series, 1:24,000.

Folk, R.L., 1974, Petrology of sedimentary rocks: Austin, Texas, Hemphill Publishing, 182 p.

Fromwiller, G., and Van Tassell, J., 1999, Pleistocene sedimentation in the La Grande Basin, northeast Oregon: Eastern Oregon Science Journal, v. XV, p. 34–38.

Gehrels, G.E., 1981, The geology of the western half of the La Grande Basin, northeastern Oregon: Los Angeles, Calif., University of Southern California master's thesis, 97 p.

Gehrels, G.E., White, R.R., and Davis, G.A., 1980, The La Grande pull-apart basin, northeastern Oregon [abs.]: Geological Society of America Abstracts with Programs, v. 12, no. 3, p. 107.

Hampton, E.R., and Brown, S.G., 1964, Geology and groundwater resources of the upper Grande Ronde River basin, Union County, Oregon: U.S. Geological Survey Water-Supply Paper 1597, 99 p.

Hayden, F.V., 1872, U.S. geological survey of the Territories: Fourth Annual Report and Annual Preliminary Report (of Wyoming and portions of contiguous territories), v. 4, no. 4, 511 p.

Hooper, P.R., and Conrey, R.M., 1989, A model for the tectonic setting of the Columbia River basalt eruptions, *in* Reidel, S.P., and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, p. 293–306.

Hooper, P.R., and Swanson, D.A., 1990, The Columbia River Basalt Group and associated volcanic rocks of the Blue Mountains province, chap. 4 *of* 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., Breckinridge, 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, Oregon and Idaho, *in* Bonnichsen, B., and Breckenridge, R.M., eds., Cenozoic geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26, p. 559–578.

King, C., 1878, Systematic geology: U.S. geologic exploration of the 40th parallel (King), v. 1, 803 p.

Liberty, L.M., and Barrash, W., 1998, Southern Grande Ronde Valley seismic project–Phase II: Reflection seismic results: Boise State University, Center for Geophysical Investigation of the Shallow Subsurface (CGISS), Technical Report BSU CGISS 98–05 (unpublished report prepared for the Oregon Department of Geology and Mineral Industries), 10 p.

Lindgren, W., 1901, The gold belt of the Blue Mountains of Oregon: U.S. Geological Survey Annual Report 22, pt. 2, p. 551–776.

Lindgren, W., and Drake, N.F., 1904, Nampa folio, Idaho-Oregon: U.S. Geological Survey Geologic Atlas, Folio 103, 1:125,000.

Livingston, D.C., 1928, Certain topographic features of northeastern Oregon and their relation to faulting: Journal of Geology, v. 36, no. 8, p. 694–708.

Malde, H.E., 1972, Stratigraphy of the Glenns Ferry Formation from Hammett to Hagerman, Idaho: U.S. Geological Survey Professional Paper 596, 52 p.

———1991, Quaternary geology and structural history of the Snake River Plain, Idaho and Oregon, chp. 9 *of* Morrison, R.B., ed., Quaternary nonglacial geology: Conterminous U.S.: Geological Society of America, The Geology of North America, v. K-2, p. 251–281.

Malde, H.E., and Powers, H.A., 1962, Upper Cenozoic stratigraphy of western Snake River Plain, Idaho: Geological Society of America Bulletin, v. 73, no. 10, p. 1197–1219.

Middleton, L.T., Porter, M.L., and Kimmel, P.G., 1985, Depositional settings of the Chalk Hills and Glenns Ferry Formations west of Bruneau, Idaho, *in* Flores, R.M., and Kaplan, S.S., eds., Cenozoic paleogeography of the west-central United States: Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, Denver, Colorado, p. 37–53.

Miller, R.R., and Smith, G.R., 1967, New fossil fishes from Plio-Pleistocene Lake Idaho: University of Michigan Museum of Zoology Occasional Papers, v. 654, p. 1–24.

Othberg, K.L., 1988, Changeover from basin filling to incision in the western Snake River Plain [abs.]: Geological Society of America Abstracts with Programs, v. 20, no. 6, p. 461.

———1994, Geology and geomorphology of the Boise Valley and adjoining areas, western Snake River Plain, Idaho: Idaho Geological Survey Bulletin 29, 54 p.

Othberg, K.L., O'Connor, J.E., and McDaniel, P.A., 1995, Field guide to the Quaternary geology of the Boise Valley and adjacent Snake River Valley: Idaho Geological Survey Staff Report S-96-1, 48 p.

Patterson, W.P., Smith, G.R., and Lohmann, K.C., 1993, Continental paleothermometry and seasonality using the isotopic composition of aragonitic otoliths of freshwater fishes, *in* Swart, P., Lohmann, K.C., McKenzie, J., and Savin, S., eds., Climate change in continental isotopic records: American Geophysical Union Geophysical Monograph 78, p. 191–202.

Personius, S.F., 1998, Surficial geology and neotectonics of selected areas of western Idaho and northeastern Oregon: U.S. Geological Survey Open-File Report 98–771, 26 p.

Pilling, S., 1998, Sedimentology of a Pleistocene outcrop, Waite Bluff, Foothill Road, south of La Grande, Oregon: Eastern Oregon Science Journal, v. XIV, p. 29–33.

Reidel, S.P., Beeson, M.H., Tolan, T., and Lindsey, K.A., 1996, The age of La Grande Basin (LGB), northeast Oregon: New evidence for middle Miocene deformation and basin formation [abs.]: Geological Society of America Abstracts with Programs, v. 28, no. 5, p. 104.

Repenning, C.A., Weasma, T.R., and Scott, G.R., 1995, The early Pleistocene (latest Blancan-earliest Irvingtonian) Froman Ferry fauna and history of the Glenns Ferry Formation, southwestern Idaho: U.S. Geological Survey Bulletin 2105, p. 1–86.

Russell, I.C., 1902, Geology and water resources of the Snake River Plains of Idaho: U.S. Geological Survey Bulletin 199, 192 p.

Scott, W.E., Pierce, K.L., Bradbury, J.P., and Forester, R.M., 1982, Revised Quaternary stratigraphy and chronology in the American Falls area, southeastern Idaho, *in* Bonnichsen, B., and Breckenridge, R.M., eds., Cenozoic geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26, p. 581–595.

Simpson, G.D., Hemphill-Haley, M.A., Wong, I.G., Bott, J.D., Silva, W.J., and Lettis, W.R., 1989, Seismotectonic evaluation, Burnt River Project-Unity Dam, and Baker Project-Thief Valley Dam, northeast Oregon: Final Report prepared for U.S. Bureau of Reclamation by W.R. Lettis & Associates and Woodward-Clyde Federal Services, 167 p.

Smith, G.R., 1975, Fishes of the Pliocene Glenns Ferry Formation, southwest Idaho: University of Michigan Museum of Paleontology Papers on Paleontology, v. 14, p. 1–68.

Smith, G.R., Morgan, N., and Gustafson, E., 2000, Fishes of the Pliocene Ringold Formation of Washington and history of the Columbia River drainage: University of Michigan Museum of Paleontology Papers on Paleontology, v. 32, 42 p.

Smith, G.R., and Patterson, W.P., 1994, Mio-Pliocene seasonality on the Snake River Plain: Comparison of faunal and oxygen isotopic evidence: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 107, p. 291–302.

Smith, G.R., Swirydczuk, 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* Bonnichsen, B., and Breckenridge, R.M., eds., Cenozoic geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26, p. 519–541.

Swirydczuk, K., Larson, G.P., and Smith, G.R., 1982, Volcanic ash beds as stratigraphic markers in the Glenns Ferry and Chalk Hills Formations from Adrian, Oregon, to Bruneau, Idaho, *in* Bonnichsen, B., and Breckenridge, R.M., eds., Cenozoic geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26, p. 543–558.

Taylor, D.W., 1985, Evolution of freshwater drainages and molluscs in western North America, *in* Smiley, C.J., Leviton, A.E., and Berson, M., eds., Late Cenozoic history of the Pacific Northwest: Interdisciplinary studies on the Clarkia fossil beds of northern Idaho: San Francisco, American Association for the Advancement of Science, Pacific Division, p. 265–321.

VanLandingham, S.L., 1985, Potential Neogene diagnostic diatoms from the western Snake River Basin, Idaho and Oregon: Micropaleontology, v. 31, p. 167–174.

Van Tassell, J., Ferns, M.L., and McConnell, V.S., 2000, Neogene sediment accumulation and subsidence rates, La Grande Basin, northeast Oregon [abs.]: Geological Society of America Abstracts with Programs, v. 32, no. 6, p. A–73/74.

Walker, G.W., 1990, Miocene and younger rocks of the Blue Mountains region, exclusive of the Columbia River Basalt Group and associated mafic lava flows, *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. 101–118.

Wheeler, H.E., and Cook, E.F., 1954, Structural and stratigraphic significance of the Snake River capture, Idaho-Oregon: Journal of Geology, v. 62, p. 525–536.

White, R.R., 1981, Structural geology of the eastern half of the La Grande Basin, northeastern Oregon: Los Angeles, Calif., University of Southern California master's thesis, 133 p.

Williams, S.K., 1994, Late Cenozoic tephrostratigraphy of deep sediment cores from the Bonneville Basin, northwest Utah: Geological Society of America Bulletin, v. 106, p. 1517–1530.

Wood, S.H., 1994, Seismic expression and geological significance of a lacustrine delta in Neogene deposits of the western Snake River Plain, Idaho: AAPG Bulletin, v. 78, p. 102–121.

Wood, S.H., 2000, Filling and spilling of Pliocene Lake Idaho: Hot-spot tectonics, stream capture, climate? [abs.]: Geological Society of America Abstracts with Programs, v. 32, no. 7, p. A–470/471. □

(Continued from page 70)

make it a more accessible, more useful publication.

Now, not everyone has chosen to become part of the digital community and we don't want to abruptly desert our loyal readers: This is the last issue that will be sent to you automatically. If you prefer to have a paper copy sent to you of the issues remaining on your subscription, please let us know.

You can contact us through e-mail or the post office (Editor, 800 NE Oregon St. #28, Portland, OR 97232) and let us know if you prefer a paper copy. Please remember that future issues may be photocopied, rather than printed by offset press as has been done in the past, so the print quality may not be quite the same.

Lou Clark
Earth Science Information Officer
Oregon Department of Geology and Mineral Industries
lu.clark@state.or.us
503-731-4100 x 232
800 NE Oregon St. #28
Portland, OR 97232

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

Publication title: OREGON GEOLOGY, no. 600040; filing date 9-13-01. Published quarterly, 4 issues per year, annual subscription price $10. Address of publication office, publisher's business office, editor, and owner: State Office Building, 800 NE Oregon St., #28, Portland, OR 97232-2162. Publisher and owner: Oregon Department of Geology and Mineral Industries; editor: Klaus K.E. Neuendorf. No bondholders. Circulation during last 12 months/of single issue, respectively: Net press run 2,625/2,500; paid outside-county mail 1,091/1,069; paid in-county mail 0/0, total paid circulation 1,266/1,119; free distribution outside county 123/79; free distribution inside county 0/0, other classes mailed 0/0; free distribution outside the mail 146/165; total free distribution 268/244; total distribution 1,534/1,363; not distributed 1,091/1,137; total 2,625/2,500; percent paid and/or requested circulation 82/82. I certify that the statements made by me above are correct and complete.

Klaus K. Neuendorf, Editor

Statewide Mined Land Reclamation annual awards announced

Helping endangered salmon during flood events, reclaiming historically mined-out areas and controlling waste water at mine sites are some of the highlights of this year's Reclamation Awards presented by the Mined Land Reclamation (MLR) Program of the Oregon Department of Geology and Mineral Industries (DOGAMI) in July.

Winners were chosen by a panel of regulatory, industry, and environmental experts, and the awards were presented at the annual conference of the Oregon Concrete and Aggregate Producers Association. The MLR awards recognize mining companies and individuals that lead by example, surpassing the basic requirements of planning, operation, and reclamation at Oregon mine sites.

This year's MLR Award winners, judged on performance in the past year include the following:

Outstanding Operator:
Pendleton Ready-Mix, Inc.,
Pendleton, Oregon
Contact: Terry & Jayne Clarke, (541) 276-6951, prminc@oregontrail.net

The Pendleton Ready-Mix, Inc. (PRM), operation is located 4 mi east of Pendleton, south of and adjacent to the Umatilla River. Up until 1989, Umatilla County administered a mined land reclamation program for all aggregate sites in the county. In 1989, DOGAMI assumed administration of mined land reclamation from the county.

PRM operates a plant site where aggregate is processed into the raw product, concrete, and asphalt. No mining occurs at the plant site. Aggregate is mined at five permitted sites in Umatilla County. The two areas where PRM has concentrated its efforts are the reclamation of sites and the wise use and protection of water.

In the late 1980s, discharge of wastewater became a very important issue for aggregate producers and ready-mix operations, and an engineered hydrologic plan was developed for the PRM plant site. Lined ponds with leak-detection equipment were constructed for process water. A 750,000-gal, welded-seam, lined pond was constructed along with a pump/piping system that controls water to all aspects of the plant operation. Water is conveyed from the storage pond to the crusher and asphalt plants for reuse. Even with a valid water right on the Umatilla River, PRM went to the water storage system, so that negative impacts to the river during low flows could be minimized or eliminated. Storm water is collected in several sumps around the plant site and pumped to the storage pond for operations use and thus turned into a beneficial commodity.

Another phase of water recovery at the plant site involves the water used to wash rock at the crusher: it is cleaned through a series of ponds. Water from the outlet of these ponds is then piped to the storage pond for reuse. To protect against an accidental release, all ponds are monitored by an alarm system, which may be disarmed only at the point of alarm.

People at PRM have worked hard to establish a positive role in the community and to insure that their operation does not create adverse off-site impacts. Their commitment to improving the plant site over the past several years as well as stabilizing extraction areas puts PRM in the category of Outstanding Operator.

Oregon Plan Award:
Morse Brothers, Inc., McNutt Site
(see front cover)
Morse Brothers, Inc.,
Tangent, Oregon
Contact: Jeff Steyaert, 541-928-6491

Morse Brothers, Inc. (MBI), began mining the McNutt site in Linn County in 1974. This site is located one mile upstream from Harrisburg, adjacent to the Willamette River. It is within the active floodway and typically floods during high-water events. There is a steep channel gradient through this reach, and the river is also continually changing channels. During floods in 1996, the river breached an extraction pond, and a subsequent fish survey indicated that listed salmonids were in the pond. Working with Peter Bailey of Oregon State University, the Oregon Department of Fish and Wildlife, and the National Marine Fisheries Service, MBI constructed a habitat restoration project involving three mine ponds now connected to the Willamette River.

MBI is being recognized for its proactive approach to creating beneficial uses of existing ponds (by restoring them as off-channel fish habitat. The operators' goal is to show state and local agencies and individuals working on the Oregon Plan that floodplain mining can work, and they succeeded impressively by restoring fish and wildlife habitat along the Willamette River system in areas that make sense.

Outstanding Reclamation:
Cascade Pumice Company,
Bend, Oregon
Contact: Richard Pearsall,
(541) 382-2051

Cascade Pumice Company has been mining pumice, fill gravels, and cinders west of Tumalo in Deschutes County since the 1940s. The company is recognized for two decades of exemplary approaches to concurrent reclamation, reclamation of exempt areas, and innovative techniques that have allowed this operation to exceed state requirements. A significant portion of the company's mined areas has been exempt from the DOGAMI reclamation rules, because the land was disturbed prior to 1972.

DOGAMI inspection reports from 1984 and 1986 show that exempt mine areas were being reclaimed and revegetated and that disturbed areas were being reclaimed faster than new mining areas were being opened up. A 1994 report noted mined-out areas being regraded, topsoiled, and reseeded with cereal rye and native grasses.

Cascade Pumice Company has shown a great willingness to look beyond operating requirements by reclaiming lands outside of the permitting and reclamation process.

Outstanding Reclamation:
Paul Mathews,
Baker City, Oregon

Contact: Paul Mathews,
(541) 523-2460

Paul Mathews is recognized for restoring a historically mined area to a beneficial use of higher value than before his mine operation began.

Mathews operated a small gold placer mine on U.S. Bureau of Land Management (BLM) claims in Baker County, along Clarks Creek, 3 mi east of Bridgeport and 30 mi south of Baker City. Historic mining in the Clarks Creek area extends back to the late 1800s, with evidence of hydraulic mining still apparent. The landowner is the BLM.

Beginning in 1989, as mine excavation expanded, mined-out areas were concurrently backfilled and then covered with soil and reseeded. These mined and reclaimed areas produced better grazing ground than the land in its pre-mining condition. By salvaging all available soil materials and supplementing with process fines, a good growing medium was placed over graded areas and then seeded in native-species bunchgrasses. Careful placement and construction of process water ponds assured that there were no discharges to the creek. By 1994, when operations ceased, 10–12 acres had been disturbed by mining. Mr. Mathews oversaw the final reclamation and took care that the revegetation of the land was a success.

Outstanding Operator – Government Agency:
Clackamas County, Fernwood Quarry
Clackamas County, Oregon City, Oregon

Contact: Darrel Burnum,
(503) 650-3210,
Darrelb@co.clackamas.or.us

Clackamas County is being recognized for extra effort in planning and development to protect adjacent natural resources at its Fernwood quarry.

The Clackamas County Road Department has operated this upland quarry located 4 mi southeast of Molalla since 1955. DOGAMI assumed administration of this site in 1991, when Clackamas County returned the responsibility of reclamation oversight to the state. An initial inspection report of February 1992 confirmed that at least 5 acres were eligible for exemption from the reclamation rules, but Clackamas County has committed to reclaim all areas of the quarry.

In 1999, a new Operating and Reclamation Plan was submitted, which accomplished three main goals: minimize the area of mine disturbance, stabilize disturbed areas, and treat and/or reduce storm water on the site.

Mining is done in 50-ft-wide strips, and mined-out areas are reclaimed concurrently. All overburden stockpiles are seeded annually. Internal haul roads have been graveled to reduce dust from truck traffic. Brow ditches have been excavated above the quarry to intercept storm water before it can enter the mine site.

The storm water control system consists of a sediment retention pond to collect large debris and suspended particles and an engineered overflow to take water from the pond to a treatment bioswale. The bioswale is a half-acre vegetated structure below the quarry that acts as a fine filter. During an inspection in October 2000, the off-site discharge from a rain event was significantly less turbid than the receiving stream.

The sod used to stabilize the bioswale was laid down in one day. People who drive by this site every day saw a rock quarry in the morning and half an acre of green grass on the drive home. This prompted several calls by people who were wondering whether the County was building a golf course. Calls continued until the County erected a sign that explained the goals of the project.

Reclamationist of the Year:
Bill Murphy, Garrett Construction,
Drain, Oregon

Contact: Bill Murphy,
(541) 836-2166

Bill Murphy of Garrett Construction is responsible for the day-to-day operation of the Parker Creek and Bear Creek quarry sites. Both of these properties have had storm water problems in the past, and both are located adjacent to streams. Bill has taken an active role in designing storm water control systems that have become a model for MLR Best Management Practices. He promotes the attitude that all employees should become involved, not only attending to problems as they see them, but also helping to improve the overall design of the storm water control systems. An oil residue problem at the Bear Creek site has also been eliminated, and many of the ditches and ponds are now supporting wetland vegetation, which acts to improve sediment filtration. Through the use of ditches, check dams, French drains, and sumps, nearly all storm water discharge from both sites has been eliminated. There is a pride evident for environmental considerations in these operations that goes beyond basic regulations.

For more information on the Mined land Reclamation (MLR) Program at DOGAMI, please visit the DOGAMI website at www.OregonGeology.com or call the MLR office in Albany at (541) 967-2039. ☐

For those who do not have the time or opportunity . . .

Geologic notes — Gleanings from recent publications that may be of interest

by Lou Clark, Oregon Department of Geology and Mineral Industries

***Nature**, June 14*
"Seismic Sleuths," by Larry Hanlon

There is no degree in forensic seismology, but the increasing sensitivity of instruments meant to measure earthquakes sometimes makes seismologists into detectives.

Seismographic identification of underground nuclear explosions is now routine. But the small amount of movement on the earth's surface that can now set off seismometers means that a great deal of noise must be filtered out. Other people have found uses for some of that information.

For example, microseisms from ocean waves can suggest changes in long-term weather patterns. One researcher used 40 years of seismic data to show that the northeast Atlantic Ocean has had more storms in the past 20 years.

Since some stations are so sensitive they can track kangaroos jumping, one alternative to an oversupply of data is a new network of satellite-based seismometers.

***Nature**, July 12*
***Science**, August 24*
A review of a biography of William Smith, "The Father of English Geology"

Few scientists, even fewer geologists, have biographies written about them. In 1815, William Smith published a geologic map of England, at a scale of five miles to the inch. His dedication and perseverance at the young science of geology makes him an ideal figure for later generations to remember.

Smith's map was plagiarized, he went to a debtor's prison, but he was eventually recognized for his achievements. He received the very first Wollaston Medal from the Geological Society of London and was given a lifetime pension by the King.

His maps were innovative and artistic, an important step in the ability to communicate geologic information.

***Nature**, August 16*
Direct observation of a submarine volcanic eruption from a sea-floor instrument caught in a lava flow (Letter to the editor by Fox, Chadwick and Embley)

The Juan de Fuca Ridge is an active rift zone. In 1997, two monitoring instruments were placed at Axial volcano. When Axial erupted in 1998, serendipity provided researchers a wealth of information about deep-sea eruptions. One of the instruments placed to monitor the area was overrun with lava but survived.

Researchers were able to recover it and get a detailed record of a two-hour eruption and several days of post-eruption subsidence.

***Geotimes**, June*
"Silent earthquakes," by M. Rudolph

From August 18 to September 22, 1999, Washington experienced a cumulative magnitude 6.7 earthquake along the Cascadia subduction zone—but the quake produced no seismic shock. The total slip over the month was roughly equivalent to six months of typical plate movement.

Although similar silent quakes have been known to precede large earthquakes, the importance of this particular movement is not currently known. The stress field of the Cascadia subduction zone is not well understood, and it is unknown how this unusual type of event affected it.

"Listening to undersea quakes" ("Geophenomena," compiled by Christina Reed)

Equipment that was once used by the U.S. Navy to track submarines is now being used to hear undersea eruptions. On April 3, hydrophones picked up the sound of an eruption off the Oregon coast. To hear the rumbling online, go to www.pmel/noaa.gov/vents/acoustics/seismicity/nepac./gordaridge01.html

***Geotimes**, July*

Short summaries of the year's major research efforts are included in this issue. Topics reviewed include seismology, volcanoes, geothermal energy, hydrology, and other disciplines.

***Geotimes,** August*
"Hunting Mount Rainier's danger zones," by Carol Finn and Thomas Sisson

Because of Mount Rainier's proximity to urban areas, evaluating future hazards is essential. U.S. Geological Survey staff used high-resolution, helicopter-borne magnetic and electromagnetic surveys to see if they can help identify landslide-prone areas. These tools are safe and cost-effective alternatives to field work in rugged, dangerous terrain.

The results of the experiment were encouraging. A three-dimensional view of altered rock was developed. The most likely future landslide site is on the upper west side, although all sides are at risk during volcanic eruptions.

***Science**, August 17*
"Researchers target deadly tsunamis," by Robert Koenig

A tsunami devastated villages in Papua, New Guinea, in 1998, and researchers are intensely studying the event to help make other areas safer. The size and destructive force of the waves was out of proportion to the moderate earthquake that preceded them.

Costas Synolakis (USC) believes that many local tsunamis, those generated just offshore, are caused not directly by earthquakes, but by the underwater landslides they may induce.

Besides detailing the New Guinea event, this article describes some of the monitoring, modelling, and mapping that is rapidly increasing our understanding of these hazards. ☐

THESIS ABSTRACTS

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

A methodology for regional seismic damage assessment and retrofit planning for existing buildings, by Thomas McCormack (Ph.D., Portland State University, 1996), 285 p.

Recent geologic research has shown that earthquakes more destructive than formerly expected are likely to occur in the Pacific Northwest. To mitigate catastrophic loss, planners are gathering information to make decisions on implementing regional seismic retrofit programs.

This research develops a model to estimate regional earthquake losses for existing buildings and determine optimal retrofit priorities and budgets.

Fragility curves are developed to provide earthquake damage estimates for a range of seismic intensities. The published earthquake damage estimates of a large group of prominent earthquake-engineering experts are extended to include the combined effect of structure type, earthquake-sensitive variations in building design, site-specific soil conditions, and local seismic design practice.

Building inventory data from a rapid visual screening survey of individual buildings form the basis for modeling structural variations. Earthquake hazard maps are the basis of modeling the effect on building damage of ground motion amplification, soil liquefaction, and slope instability.

Published retrofit effectiveness estimates and retrofit cost data are used to estimate post-retrofit damage avoided, lives saved, and retrofit cost. A Building Classification System is formulated to aggregate buildings with similar retrofit benefit magnitudes.

A cost-benefit analysis is used as the basis for a retrofit prioritization and efficiency analysis, to establish the cutoff point for an optimal retrofit program. Results from an Expected Value and a Scenario Earthquake Event are compared.

Regional EArthquake Loss and Retrofit Analysis Program (REAL-RAP) software was developed and used to make a loss estimate for more than 7,500 buildings inventoried in the 1993 Portland Seismic Hazards Survey. One hundred percent of the loss of life is attributed to only 10 percent of the buildings.

A retrofit analysis is made for a Design Basis Earthquake. Twelve percent of the building inventory was identified for the optimal retrofit program, wherein 98 percent of the loss of life is avoided at less than one-quarter the cost of retrofitting all the buildings.

An alternate optimal retrofit program was determined, using an Expected Value Analysis. Most of the buildings in the Design Basis Earthquake optimal retrofit program are also contained in the alternate program.

Analysis of tephra components from Rock Mesa, South Sister volcano, Oregon: Implications for evolution of the explosive phase, by James P. Rogers (M.S., University of Oregon, 1996), 85 p.

The Rock Mesa obsidian flow and associated airfall deposits lie on the southwest flank of South Sister volcano in central Oregon. This thesis examines the tephra sequence generated during the 2,300-year-old eruption. Grain-size distributions, component distributions, density distributions, and groundmass textures (microlites) were determined for juvenile clasts from the deposits at three sites. Eruptions of larger magnitude (bed thickness) and/or intensity (clast size) produced primarily microlite-free white pumice and dense juvenile obsidian. In contrast, tephra beds from eruptions of smaller magnitude and/or intensity contained microlite-bearing gray pumice. I interpret these deposits to reflect a series of small, pulsatory eruptions preceding the major phase of dome growth at Rock Mesa. High-density, high-crystallinity clasts that were erupted during the explosive phase may reflect early phases of dome growth.

Changes in the distribution of selected conifer taxa in the Pacific Northwest during the last 20,000 years, by Ann Margaret Tattersall (M.S., University of Oregon, 1999), 111 p.

Regional patterns of vegetation change since the last glacial maximum are portrayed by pollen maps for four conifer taxa plus *Artemisia* and Poaceae at 72 sites in western North America west of long 110° W. and between lat 42° N. and 51° N. These maps are records of vegetation change against which paleoclimate modelling predictions of past climate may be tested. The maps suggest variations in precipitation trends across the region, with maximum Holocene dry periods ranging from 9,000 to 6,000 ^{14}C years B.P. Temperature trends were similar throughout the region, with maximum warmth around 9,000 ^{14}C years B.P. These maps contribute to understanding the responses of individual tree taxa to past climate change in western North America. This study addresses the question of glacial refugia of *Pseudotsuga*. Coastal *Pseudotsuga* was located in the Pacific Northwest of the U.S. during the last glacial maximum, although the locations of the refugia are uncertain.

Alpine glacier and pluvial lake records of late Pleistocene climate variability in the western United States, by Joseph M. Licciardi (Ph.D., Oregon State University, 2000), 155 p.

This investigation focuses on the development of Quaternary dating techniques to construct high-resolution numerical chronologies of late

Pleistocene climate variability in the western United States. Cosmogenic ^{3}He concentrations were measured in radiocarbon-dated, olivine-bearing Holocene lava flows in Oregon, yielding a mean production rate of 116±3 ^{3}He atoms per gram per year. This value is consistent with previous estimates at mid-latitudes and helps refine the accuracy of the cosmogenic ^{3}He dating technique. Cosmogenic ^{3}He and ^{10}Be chronologies were developed for well-preserved moraine sequences in the northern Yellowstone region, Montana, and in the Wallowa Mountains, Oregon. Cosmogenic data indicate that the northern outlet glacier of the Yellowstone ice cap reached its terminal moraine at 16.7 ^{3}He ka / 16.2 ^{10}Be ka, and retreated to ~50 percent of its maximum extent by ~13.8 ka. In the Wallowa Mountains, two major late Pleistocene alpine glacier advances occurred at ~21 ka and ~17 ka, and a minor advance occurred at ~11 ka. The ~21-ka advance in the Wallowa Mountains coincides with the last glacial maximum and is correlative with the last Pinedale maximum advance in the Wind River Mountains. The ~17-ka advance in the Wallowa Mountains is probably correlative with the advance of the northern Yellowstone outlet glacier. The youngest event in the Wallowa Mountains, at ~11 ka, may be correlative to an advance that deposited the Titcomb Lakes moraines in the Wind River Mountains during the Younger Dryas. New accelerator mass spectrometry radiocarbon ages from gastropods in shore deposits within the pluvial Lake Chewaucan basin, Oregon, identify a significant lake-level high at ~12 ^{14}C ka. The Chewaucan lake-level high is coeval with lake-level lows in the Bonneville and Lahontan basins, and with a period of relatively wet conditions in the more southerly Owens Lake basin. This spatial pattern of pluvial lake levels in the western U.S. at ~12 ^{14}C ka indicates a variable synoptic response to climate forcing at this time. These new data contribute critically needed geographic coverage to existing glacial and pluvial lake records for examining spatial and temporal late Pleistocene climate variability in western North America.

The distribution of naturally occurring soil radionuclides and radon potential of southwest Oregon, by W.H. Douglas (M.S., Portland State University, 1999), 124 p.

Naturally occurring uranium and thorium in rocks and soil, through a series of radioactive decays, produce radon gas, the second leading cause of pulmonary cancer. Soil samples from 143 B-horizons from the main geologic units in southwest Oregon were analyzed using gamma spectroscopy to quantify the activities of five soil radionuclides. The mean and range values in Bq/kg for Ac^{228}, Cs^{137}, K^{40}, Th^{232}, and Bi^{214} (a decay product of radon) are 17.4 (4.0 to 48.3), 5.1 (0.7 to 37.3), 303.7 (18.0 to 719.7), 14.2 (1.7 to 41.6), and 19.8 (2.9 to 51.3), respectively.

Bi^{214} activity of B-horizon soil samples is used to define three radon potential zones, Low 1 (less than 25 Bq/kg), Low 2 (25 to 45 Bq/kg), and Moderate (greater than 45 Bq/kg). 73 percent of the Bi^{214} values fall within Low 1 zone, 24 percent fall within Low 2 zone, and 3 percent fall within the Moderate zone. Based on soil radionuclide concentrations, southwest Oregon is not considered to be a high-potential area for radon.

The percent map areas for Low 1, Low 2, and Moderate radon potentials for the study area are 62, 32, and 6 percent, respectively. The highest radon potential is found in the Coast Range, where most sites are Low 2 and Moderate potential. The Coastal Plain region has the lowest potential and is mapped mostly as Low I radon potential. The Cascade Range, Basin and Range, and High Lava Plains regions contain Low 1 and Low 2 radon potentials. The Klamath Mountains region contains a mix of all three radon potential areas. The formations with Moderate radon potentials are units Ty (Yamhill Formation) and Jss (Jurassic black to gray shale, mudstone, and sandstone) and are found mainly in the Coast Range.

The Th^{232}/K^{40} ratio and the Buntley-Westin color index of the soils both generally increase with soil development. Soils developed on sedimentary formations generally have a higher range in naturally occurring radionuclide values than those developed on igneous formations. Soils developed on felsic rocks tend to have higher Bi^{214} values than those derived from mafic rocks. The Basin and Range region has the lowest range in soil radionuclide activities.

Middle Cretaceous sedimentation and tectonics of the Mitchell inlier, Wheeler County, central Oregon, by Robert J. Lenegan (M.S., University of Oregon, 2001), 125 p.

Cretaceous (Albian) sedimentary rocks of the Ochoco basin are exposed on the limbs of the Mitchell anticline in central Oregon. The Basal Member of the Hudspeth Formation contains sandstone and conglomerate that rest unconformably on metamorphic basement rocks and grade laterally into mudstone. The Main Mudstone Member of the Hudspeth shows an increase in thickness from ~200 m on the northwest to ~900 m on the southeast limb of the Mitchell anticline and records southeastward tilting during mudstone deposition. Tight folds are found in the Basal Member and lower Main Mudstone Member, but not in the overlying Gable Creek Formation (submarine conglomerate and sandstone). This, combined with stereonet fold analysis, indicates that tight folds formed during Main Mudstone time and were later refolded by the Tertiary Mitchell anticline. A growth normal fault is recognized in the lower Gable Creek Formation, providing further evidence for tectonic activity during Albian basin development. ☐

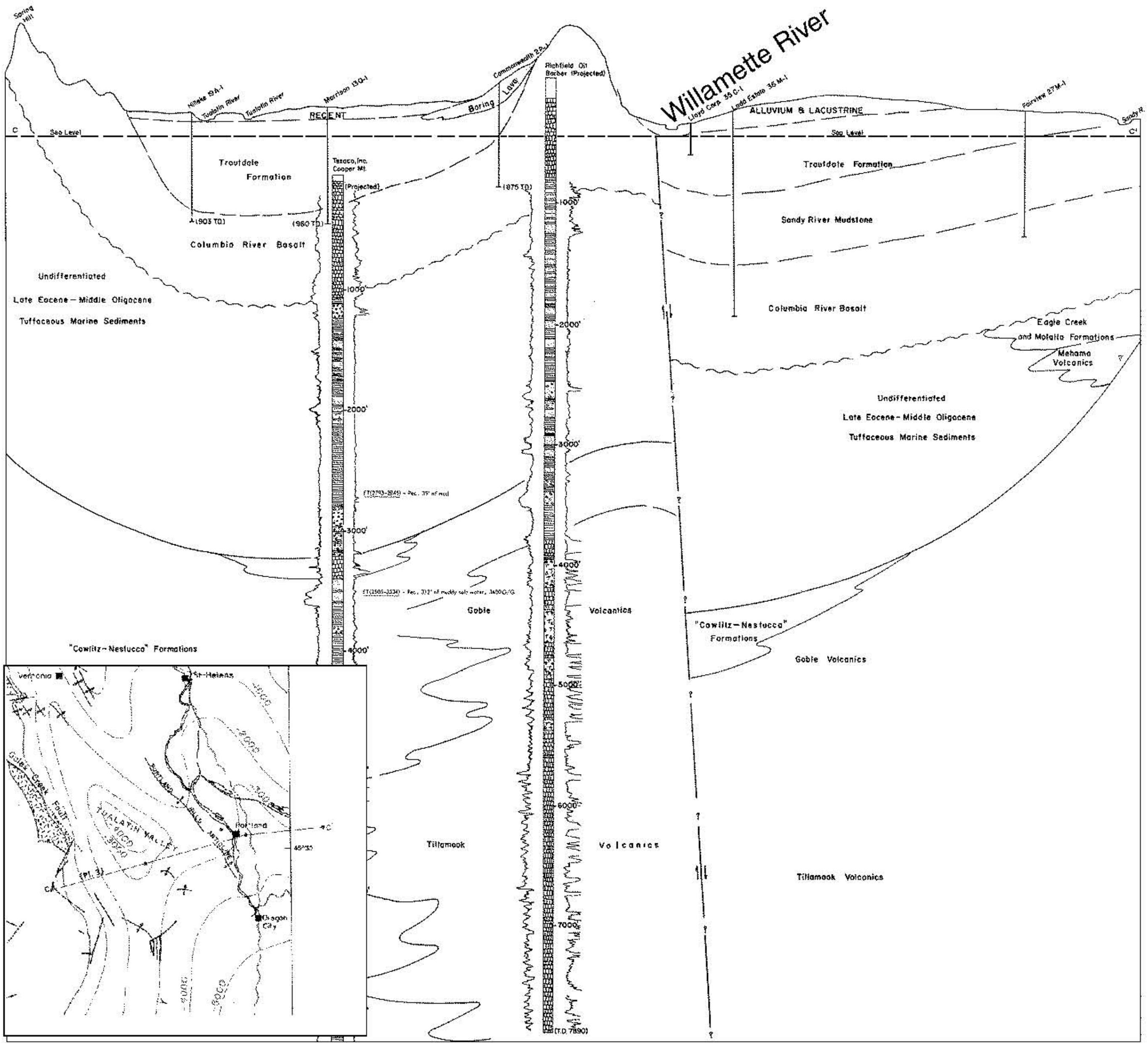
LETTER TO THE EDITOR

I was very interested in the article on the Portland Hills fault in the last issue of *Oregon Geology*. I was the author of [DOGAMI] Oil and Gas Investigation 2, 1969. I made several cross sections for this publication, using deep oil and gas test holes and deep water wells. On Plate III of this report, I show a cross section through the Tualatin Valley eastward to the front of the Cascade Range. In making stratigraphic correlations, it was necessary to put a large fault at the east front of the Portland Hills. What is disturbing in constructing this cross section is that most of the high buildings in west Portland are situated on silts and gravels adjacent to the Portland Hills fault. A large earthquake on this fault could result in very serious damage and probable loss of life.

Vertical offset indicated on my cross section must be several hundred feet. This movement has occurred since late Miocene time. The recent article indicates that there has been movement on faults in the area in late Pleistocene time. More study is needed of faulting in the Portland area to learn how to mitigate seismic damage from large earthquakes.

—Vernon C. Newton, Jr.
Beaverton, Oregon
[First DOGAMI petroleum engineer,
1957–1980]

Below: Portions from DOGAMI Oil and Gas Investigation 2 published in 1969. They show the cross section mentioned in Vern Newton's letter above and, in the inset, the location of this cross section (C–C') from Plate VII of that publication. ***—ed.***



DOGAMI PUBLICATIONS

Publications are available from: Nature of the Northwest, 800 NE Oregon St. #5, Portland, OR 97232, info@naturenw.org or www.naturenw.org, (503) 872-2750; or from the DOGAMI field offices in Baker City, 1510 Campbell Street, (541) 523-3133, and Grants Pass, 5375 Monument Drive, (541) 476-2496. See also the gray pages at the center of this issue.

Released August 21, 2001:

Tsunami hazard maps for coastal communities, reissued on CD-ROM. One disk, $25.

The Oregon Department of Geology and Mineral Industries (DOGAMI) has released a digital reissue of tsunami hazard maps of the entire coast of Oregon on one CD-ROM. The maps were originally produced in 1995 to help implement Senate Bill 379 (SB 379), which was passed that same year by the Oregon Legislature. SB 379, implemented as Oregon Revised Statutes (ORS) 455.446 and 455.447, limits construction of new essential facilities and special-occupancy structures in tsunami flooding zones. The focus of the maps is therefore on implementation of this public safety bill and not on land use or emergency planning. (Learn more about Senate Bill 379 at: http://arcweb.sos.state.or.us/rules/OARS_600/OAR_632/632_005.html)

The CD-ROM was released as DOGAMI Open-File Report O-00-05. It contains maps in .pdf and GIS formats and a separate explanatory text. The maps cover one 7½-minute quadrangle each (scale 1:24,000) and were released as Open-File Reports O-95-09 through O-95-66, while the explanatory text is Open-File Report O-95-67. Because of changes adopted in 1997, the maps O-95-39 and O-95-42 were withdrawn and O-95-40 and O-95-41 were replaced by new maps O-97-31 and O-97-32. The maps and report were produced by George R. Priest of DOGAMI, (541) 574-6642, george.priest@state.or.us.

Tsunamis are generally caused by earthquakes, landslides, or volcanic eruptions on the sea floor. The mapping project addressed only the most common cause: simultaneous uplift and subsidence of the sea floor accompanying undersea earthquakes on the Cascadia subduction zones.

The CD-ROM is available for $25 from the Nature of the Northwest Information Center and DOGAMI Field Offices in Grants Pass and Baker City. See the addresses on the first inside page (p. 70) or the instructions on the gray pages in the middle of this issue. ☐

EDITOR'S CORNER

In memoriam

Archie Kelly Strong was mentioned in this place just two issues ago–on the occasion of his 91st birthday. Now we mourn his death.

The "Supervolunteer" in the Nature of the Northwest Information Center came within six months of completing an entire decade of volunteer work. Between 1992 and this summer, Archie donated 2,488 hours of work, mainly in managing the stock of USGS topographic maps.

Archie had a Master of Science degree from Oregon State University, had been a biology instructor and coach in Oregon high schools, and had worked for the USDA Forest Service before he retired in 1975. He also was an avid and much honored flower and vegetable gardener.

He was born February 20, 1910, in Marcola, Oregon, died September 24, 2001, in West Columbia, South Carolina, and found his final resting place in Portland, Oregon, in Skyline Memorial Gardens.

We miss him.

At home

The **DOGAMI library** has added to its shelves paper copies of some recent maps published by the **U.S. Geological Survey (USGS) as Open-File Reports**: OFRs 01-226, geologic map of the Dixonville quadrangle, and 01-294, color shaded relief map of the Willamette Valley.

The USGS offers them on its web sites. For our "Western Region," these maps and other USGS publications are most easily accessible under the (Menlo Park, CA) address: **http://geopubs.wr.usgs.gov/**.

In the neighborhood

The **Western States Seismic Policy Council** has announced that it **has moved**. The new address is

WSSPC
Palo Alto Central Building
125 California Avenue
Suite D201, #1
Palo Alto, CA 94306.
Phone (650) 330-1101
Fax (650) 326-1769

E-mail addresses and website have not changed. You can still find WSSPC under www.wsspc.org.

Do you need **geologic information about Washington**? You can **search** now on the Washington Division of Geology and Earth Resources website

http://www.wa.gov/dnr/htdocs/ger/washbib.htm

in the agency's "Digital Bibliography of the Geology and Mineral Resources of Washington." ☐

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

Periodicals postage paid
at Portland, OR

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

North Umpqua River in the southern Cascade Range.

The North Umpqua River drains the southern Cascades to the west and to the Pacific Ocean, joining its "South" counterpart near Roseburg in Douglas County. The picture shows Old Man Rock, rising well over 1,000 feet above the river, on the edge of the Boulder Creek Wilderness Area in the Umpqua National Forest. Typically heavy rainfall on the western slopes of the Cascade Range has brought about deep weathering and created spectacular stream valleys.

Access: From Roseburg to the east, Oregon Highway 138 follows the North Umpqua River for much of the distance, crosses the Cascades, and connects with U.S. Highway 97 near Crater Lake National Park.

OREGON GEOLOGY

Oregon Department of Geology and Mineral Industries
Volume 63, Number 4, Fall 2001

IN THIS ISSUE:

Scenario ground-motion maps, western Oregon, Seaside and Portland

DOGAMI PUBLICATIONS

Publications are available from: Nature of the Northwest, 800 NE Oregon St., #5, Portland, OR 97232, info@naturenw.org, (503) 872-2750; or from the DOGAMI field offices in Baker City, 1510 Campbell Street, (541) 523-3133, and Grants Pass, 5375 Monument Drive, (541) 476-2496. For online purchasing, go to www.naturenw.org (**click here**), select "Store" and "Maps and Reports" and use the short identification of the publication (e.g., RMS-1) for a search.

Released December 4, 2001:

Reconnaissance geologic map of the La Grande 30'x 60' quadrangle, Baker, Grant, Umatilla, and Union Counties, Oregon, by M.L. Ferns and I.P. Madin, Oregon Department of Geology and Mineral Industries, and W.H. Taubeneck, Professor Emeritus, Oregon State University. Reconnaissance Map Series map RMS–1, scale 1:100,000; 1 CD, $10. Printed color copies of the map are available on request for $15.

The La Grande quadrangle map covers 1,680 mi^2 (4,350 km^2) in four counties of eastern Oregon. This geologic map with its 77 identified rock units presents a new, more detailed and yet more unified view of the complex nature of this region's complex stratigraphy.

Among the significant advances in understanding the geologic evolution of the area, the following are most noteworthy: (1) The recognition that the unusually high grade metamorphic rocks exposed south of Pendleton cannot be correlated with any of the previously identified pre-Tertiary terranes of northeastern Oregon but are distinctive enough to warrant grouping together as the Mountain Home metamorphic complex. (2) The discovery of the Tower Mountain caldera, a large rhyolite eruptive center of late Oligocene age. This caldera, like most of the quadrangle, was partially buried by the Miocene flood lavas that make up the Columbia River Basalt Group. (3) The recognition that the dacite, andesite, and olivine basalt flows exposed at the top of the section near La Grande are not part of the Columbia River Basalt Group but instead form part of the Powder River Volcanic Field

The accompanying 54-page text highlights the geologic history of the area, water and mineral resources, semiprecious gemstones, geothermal energy, and fossil fuels. It also points out the earthquake and landslide hazards that are most evident along the active margins of the Grande Ronde Valley. For the hurried or less technically interested user, this report has been summarized on a separate two-page sheet.

RMS–1 is being released on one CD-ROM which contains not only GIS data files that make up the map and can be used in various mapping software pro-

(Continued on page 124)

OREGON GEOLOGY

(ISSN 0164-3304)

VOLUME 63, NUMBER 4 FALL 2001

Published quarterly in Winter, Spring, Summer, and Fall by the Oregon Department of Geology and Mineral Industries. (Volumes 1 through 40 were entitled *The Ore Bin.*)

State Geologist	John D. Beaulieu
Deputy State Geologist	Dennis L. Olmstead
Editor	Klaus K.E. Neuendorf
Production Assistants	Kate Halstead, James Roddey

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

Baker City Field Office: 1510 Campbell Street, Baker City 97814, phone (541) 523-3133, FAX (541) 523-5992.
Mark L. Ferns, Regional Geologist.

Coastal Field Office: 313 SW Second Street, Suite D, Newport 97365, phone (541) 574-6642, FAX (541) 265-5241.
George R. Priest, Coastal Team Leader.

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: 229 Broadalbin Street SW, Albany 97321-2246, phone (541) 967-2039, FAX (541) 967-2075.
Internet: http://www.proaxis.com/~dogam i/mlrweb.shtml
Gary W. Lynch, Supervisor.

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

Cover photos

Oregon Sunstone—proclaimed State Gemstone by Governor Neil Goldschmidt in August 1987—still attracts mining interests to remote areas of the state (article in *Oregon Geology*, February 1987).

The photos on the cover show (from the top) a mine location in southeast Harney County, one of only three known areas in Oregon where sunstone occurs; the raw gemstones; and a characteristic outcrop. The photos were provided by mine owners Larry and Virginia Kribs who operate Desert Dog Mines, Inc., in Bend, Oregon.

Scenario ground-motion maps for western Oregon and comparison of scenario, probabilistic, and design response spectra for Seaside and Portland, Oregon

by Kenneth W. Campbell, EQE International, Inc., 1030 NW 161st Place, Beaverton, Oregon 97006, and Zhenming Wang, Oregon Department of Geology and Mineral Industries*

INTRODUCTION

Earthquake hazards have been recognized as one of the major natural hazards in Oregon since the 1980s. Scientists have revealed that Oregon has experienced many damaging earthquakes in the past (Atwater, 1987; Heaton and Hartzell, 1987; Weaver and Shedlock, 1989; Atwater and others, 1995). Great Cascadia Subduction Zone earthquakes have occurred many times in the past along the northwest Pacific coast, most recently on January 26, 1700 (e.g., Clague and others, 2000). Shallow crustal earthquakes like the magnitude 5.6 Scotts Mills earthquake in 1993 (Madin and others, 1993) and the magnitude 5.9 and 6.0 Klamath Falls earthquakes in 1993 (Wiley and others, 1993), which caused more than $30 million and $10 million of damage, respectively, also threaten communities in Oregon.

This new information has dramatically changed the ground motion estimates and the building seismic design practice in Oregon. In 1990, the U.S. Geological Survey (USGS) estimated the peak ground acceleration (PGA) with a 475-year return period (i.e., a 10-percent probability of exceedance in 50 years) to be between 0.05 and 0.10 *g* (Building Seismic Safety Council, 1994). In 1995, Geomatrix Consultants (1995), using new scientific information, revised this estimate to range up to 0.60 *g*. In a major revision to the national seismic hazard maps in 1996, the USGS (Frankel and others, 1996, 2000) confirmed the increased hazard proposed by Geomatrix Consultants, which was later adopted by the Building Seismic Safety Council (1997) and the International Building Code (International Code Council, 2000). This significant increase in seismic hazard has resulted in a substantial change in the building seismic design code in Oregon, which is based on the Uniform Building Code, from UBC Zone 2 in 1988 to UBC Zones 2B, 3, and 4 in 1998 (International Council of Building Officials, 1988, 1998). A more recent estimate of ground motion in the Portland area by Wong and others (2000) is higher still.

All of the above ground motion hazard estimates were derived from probabilistic seismic hazard analysis (PSHA) based on available geologic and seismologic data. However, the geology and seismology of Oregon are still relatively poorly understood. This can lead to large uncertainty in the probabilistic hazard derived from PSHA. In this paper, we use deterministic seismic hazard analysis (DSHA) as an alternative to PSHA to develop scenario ground-motion maps for four hypothetical earthquakes in western Oregon and scenario response spectra for the Oregon cities of Seaside and Portland. The first two scenarios were moment magnitude (M_W) 8.5 and 9.0 earthquakes on the Cascadia Subduction Zone. The second pair of scenarios were M_W 6.5 and 7.0 earthquakes on the Portland Hills fault, which crops out along the eastern side of the Portland Hills within the city. The resulting scenario maps can be used for policy development, for seismic risk assessment, for emergency and response planning, and to compare scenario response spectra with available probabilistic and design response spectra for communities in western Oregon.

SCENARIO GROUND-MOTION ESTIMATES

We assumed rupture along the entire length and width of the faults in each of the hypothesized scenarios. While the entire fault is not expected to rupture during the smaller scenarios, we made this assumption in order to represent a worst-case scenario at a given location, whereby the earthquake is assumed to occur anywhere along the fault. We created ground-motion scenarios for the median estimate of the average horizontal components of PGA and 5-percent-damped pseudo-acceleration response spectra (PSA) for natural periods of 0.2 s and 1.0 s. We produced median ground-motion maps for a grid of sites in western Oregon spaced at intervals of 0.1° between lat 42.0° and 46.3°N. and long 121.0° and 124.6°W. We also produced scenario response spectra for natural periods ranging from 0.03 s to 2.0 s for the cities of Seaside and Portland.

We defined local site conditions as the boundary of site classes B and C (the B-C boundary). B and C refer to the site classes defined in the 1997 edition of the *Uniform Building Code* (International Council of Building Officials, 1998), the 1997 edition of the NEHRP *Recommended*

---

* Current address: Geologic Hazard Section, Kentucky Geological Survey, 228 Mine and Mineral Resource Building, University of Kentucky, Lexington, KY 40506-0107; phone 859-257-5500 ext 318; fax 859-257-1147; e-mail zwang@kgs.mm.uky.edu

Provisions for Seismic Regulations for New Buildings and other Structures (Building Seismic Safety Council, 1997), and the 2000 edition of the *International Building Code* (International Code Council, 2000), to which we will refer as UBC-1997, NEHRP-1997, and IBC-2000, respectively. The B-C boundary represents a site profile with an average shear-wave velocity in the top 30 m of 760 m/s. This site condition is consistent with the probabilistic seismic hazard maps developed by the USGS (Frankel and others, 1996; 2000); however, this same level of ground motion was conservatively assigned to site class B in the seismic design procedures used in NEHRP-1997 and IBC-2000 (e.g., Leyendecker and others, 2000). These seismic design maps are formally referred to as Maximum Considered Earthquake (MCE) ground-motion maps.

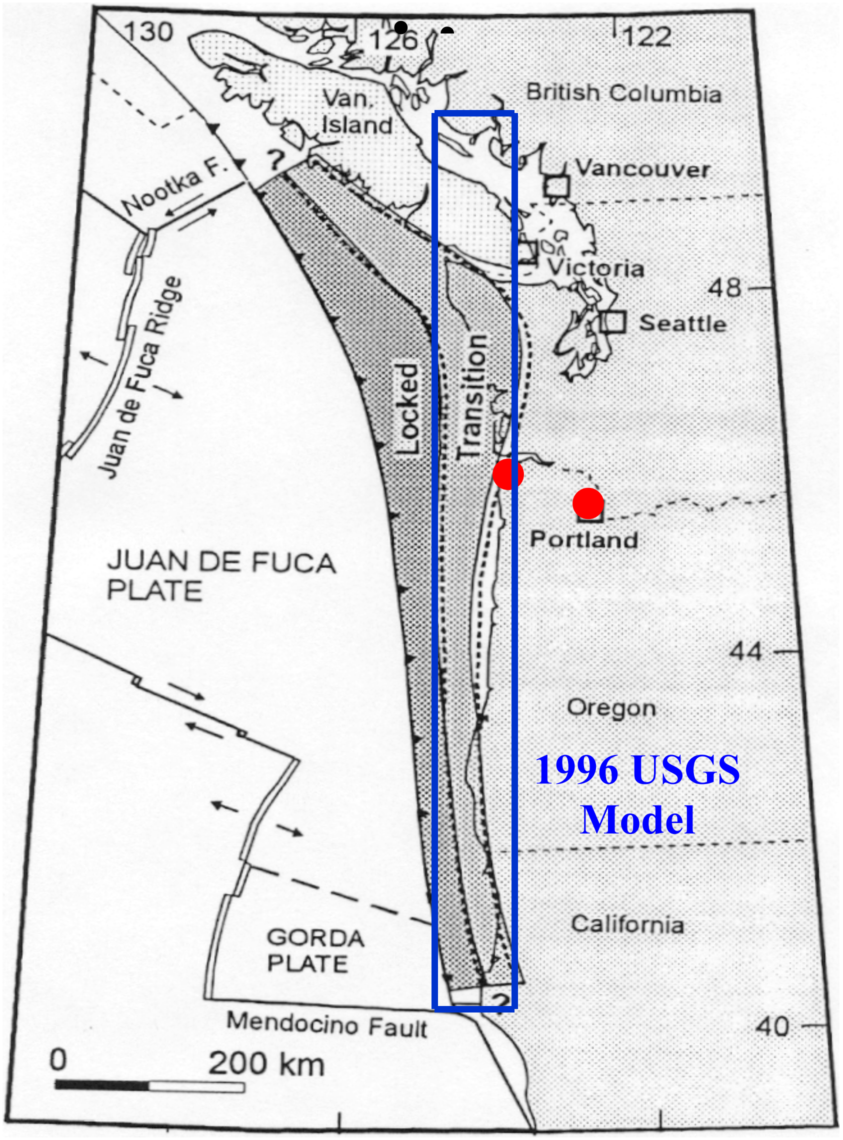


Figure 1. Location of the Cascadia Subduction Zone plate interface proposed by Flück and others (1997), superimposed on the 1996 USGS source zone model of Frankel and others (1996, 2000). The seismogenic zone used in this study included the locked zone and the adjacent (upper) half of the transition zone. The solid red circles are the locations of the cities of Seaside (left) and Portland (right).

CASCADIA SUBDUCTION ZONE SCENARIOS

The assumed rupture surface for the earthquake scenarios on the Cascadia Subduction Zone are shown in Figure 1. Seismologists commonly believe that the entire locked zone, as defined in this study by the model given by Flück and others (1997), will rupture seismogenically during a great earthquake. However, there is disagreement regarding how much of the transition zone might support seismogenic rupture. Flück and others (1997) assume that coseismic displacement will decrease linearly, from a maximum in the locked zone to zero at the lower (eastern) boundary of the transition zone, without specifying whether this displacement will be seismogenic. For purposes of this study, we assumed that seismogenic rupture would extend halfway into the transition zone during both the M_W 8.5 and M_W 9.0 scenarios.

Also shown in Figure 1 is the source zone for the Cascadia Subduction Zone used by Frankel and others (1996, 2000) in the generation of the USGS probabilistic seismic hazard maps. The assumed location of the simple rectangular USGS zone is located farther east than that estimated by Flück and others (1997), who used a three-dimensional analysis of geodetic and geothermal data. In fact, the USGS location puts this source zone on land, whereas the more realistic downdip extent of the seismogenic part of the subduction zone assumed in this study lies totally off the Oregon coast.

The depth to the top of the Cascadia Subduction Zone interpreted by Flück and others (1997) is shown in Figure 2. These contours indicate that the rupture surface assumed in this study dips to the east at a relatively shallow angle from a depth of about 5 km at the deformation front to a depth of about 15 km halfway down the transition zone. The bottom of the transition zone occurs at a depth of around 20 km.

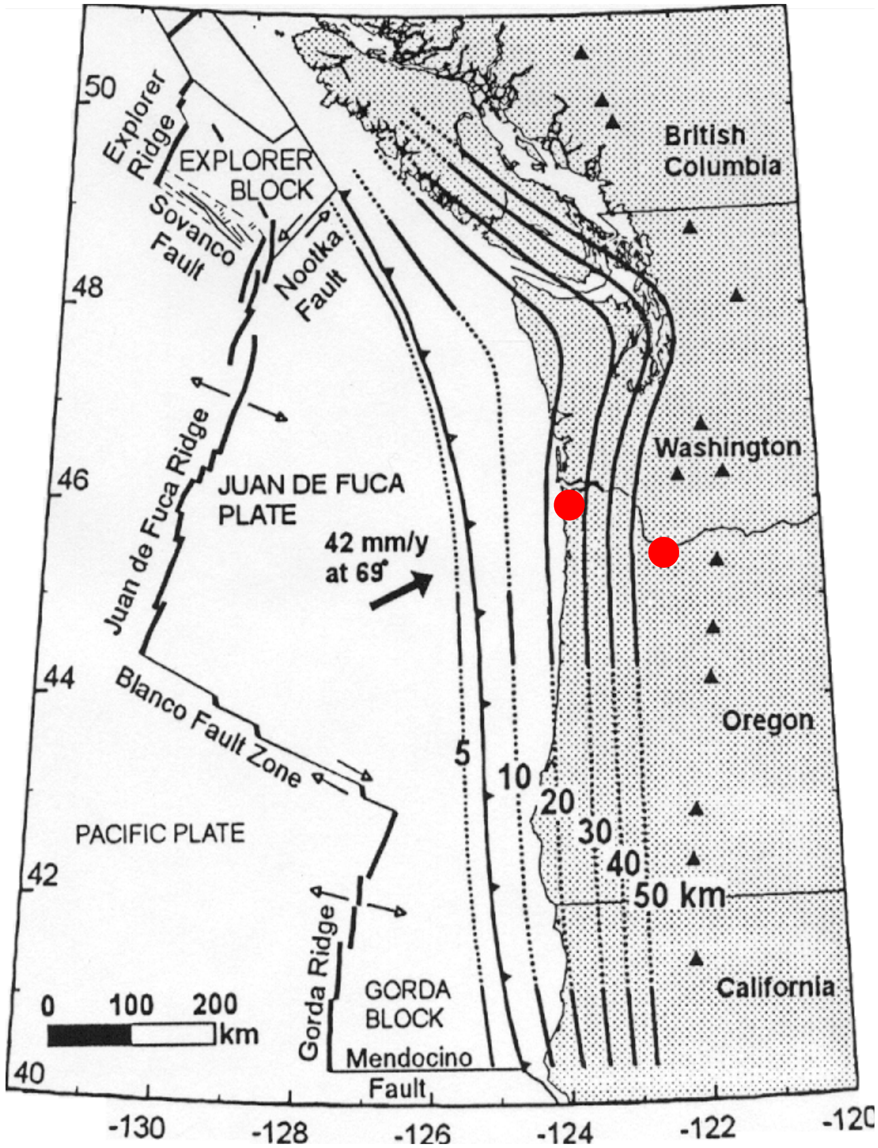


Figure 2. Contours showing the depth to the top of the Cascadia Subduction Zone plate interface (after Flück and others, 1997). The solid red circles are the locations of the cities of Seaside (left) and Portland (right).

We used the attenuation relationship of Youngs and others (1997) to estimate ground motions at each of the grid sites from the two Cascadia Subduction Zone scenario earthquakes. This relationship was developed from strong-motion recordings of subduction-zone earthquakes located throughout the world and currently represents the state of the art for estimating ground motions on rock sites. This is a departure from the model used by Frankel and others (1996, 2000) for their smaller magnitude scenario on the Cascadia Subduction Zone. For their M_W 8.3 scenario, they used both the Youngs and others (1997) relationship and a shallow crustal attenuation relationship developed by Sadigh and others (1997), and they averaged the ground motions predicted from each. For their M_W 9.0 scenario, they used only the Youngs and others (1997) relationship, since the Sadigh and others (1997) relationship is not valid for such a large magnitude. We used only the Youngs and others (1997) attenuation relationship even for the smaller magnitude scenario because, in our opinion, the shallow crustal relationship attenuates much too rapidly and would result in unconservative ground-motion estimates in Portland and other areas located relatively distant from the subduction zone. The crustal attenuation relationship will produce higher ground motions at short distances; however, for the earthquake scenarios used in this study, this affects only a few sites located primarily along the southern Oregon coast.

The median PGA map for the M_W 8.5 Cascadia Subduction Zone scenario is shown in Figure 3. Similar scenario maps for the 0.2-s and 1.0-s values of the 5-percent-damped PSA response spectra are shown in Figures 4 and 5. Median PGA and PSA maps for the M_W 9.0 scenario are shown in Figures 6–8. Estimated 5-percent-damped PSA response spectra for the city of Seaside, which is located approximately 37 km from the hypothesized rupture surface, are compared in Figure 9. Also shown on this figure are the uniform hazard response spectra (UHS) with return periods of 475 years (10-percent probability of exceedance in 50 years) and 2,500 years (2-percent probability of exceedance in 50 years) from Frankel and Leyendecker (2001), the recommended IBC-2000 design response spectrum (International Code Council, 2000; Leyendecker and others, 2001), and the recommended UBC-1997 design response spectrum (International Council of Building Officials, 1998). Seaside currently uses the UBC-1997 Zone 3 seismic provisions for its building design.

PORTLAND HILLS FAULT SCENARIOS

We took the geometry and rupture mechanism of the Portland Hills fault from the USGS seismic hazard study (Frankel and others, 1996, 2000), with one exception. We found that the trace of the Portland

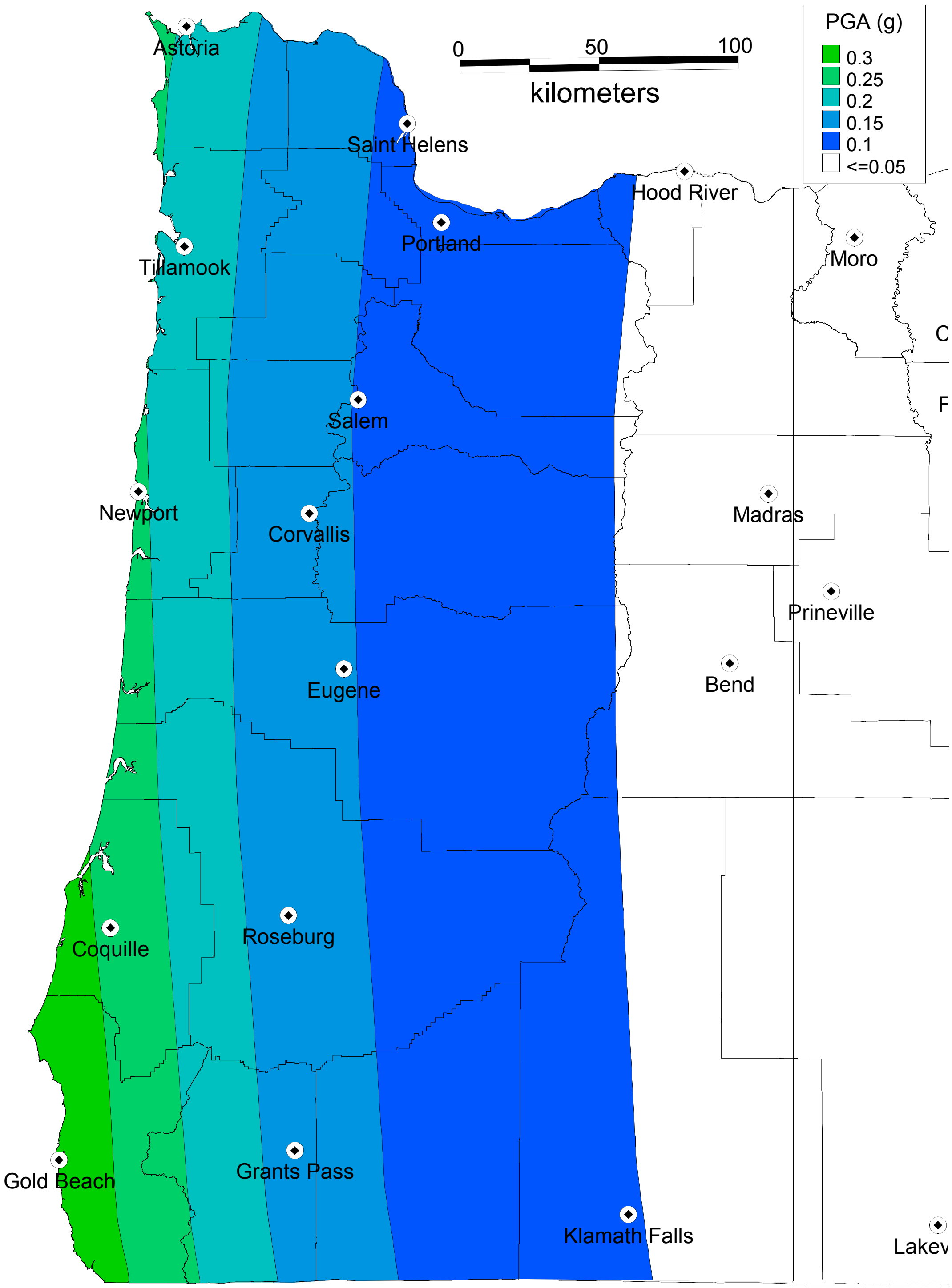


Figure 3. Map of median peak ground acceleration (PGA in *g*) on firm rock (B-C boundary) for a M_W 8.5 earthquake located anywhere along the Cascadia Subduction Zone plate interface.

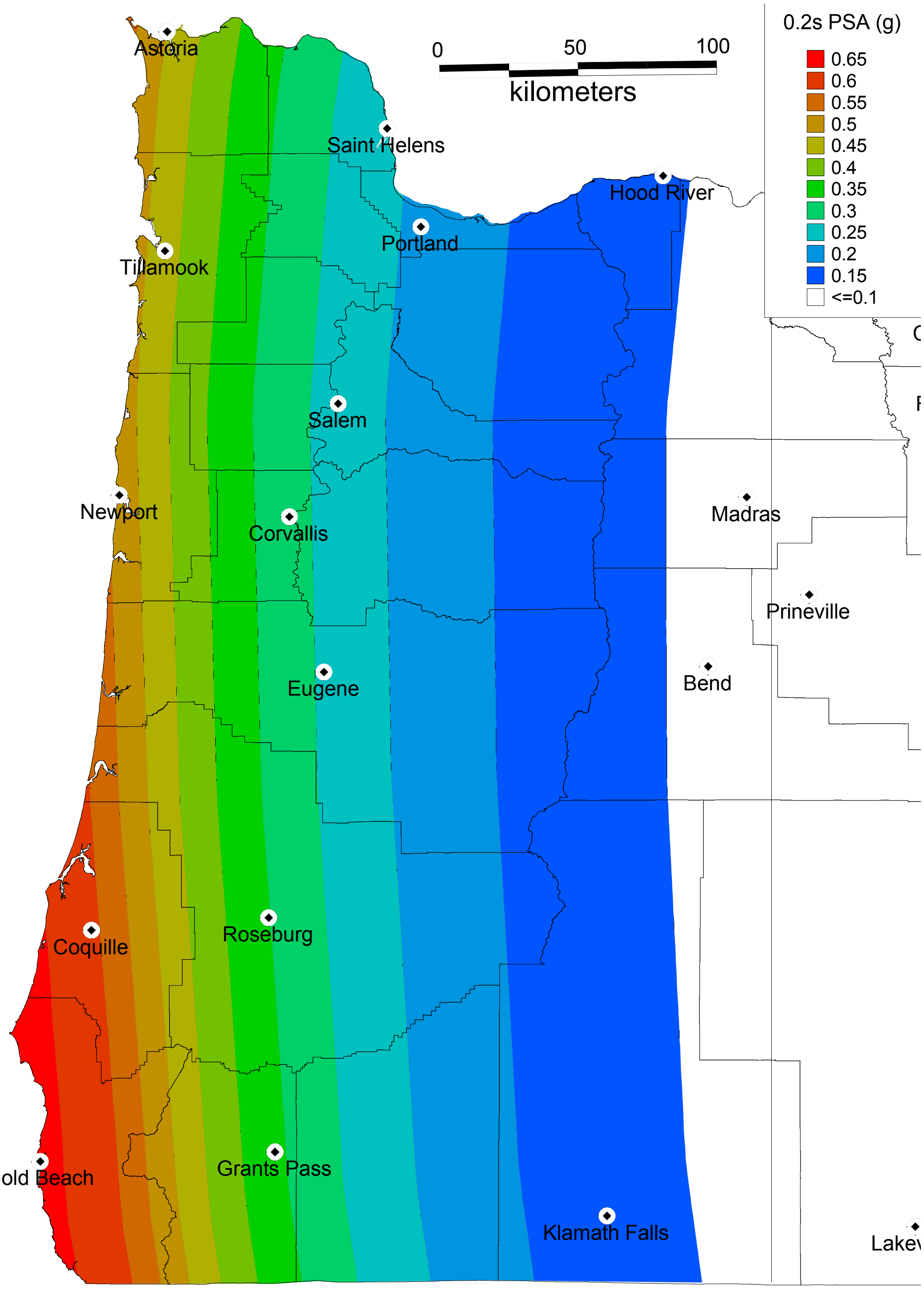


Figure 4. Map of median 5-percent-damped pseudoacceleration (PSA in *g*) at 0.2-s period on firm rock (B-C boundary) for a M_W 8.5 earthquake located anywhere along the Cascadia Subduction Zone plate interface.

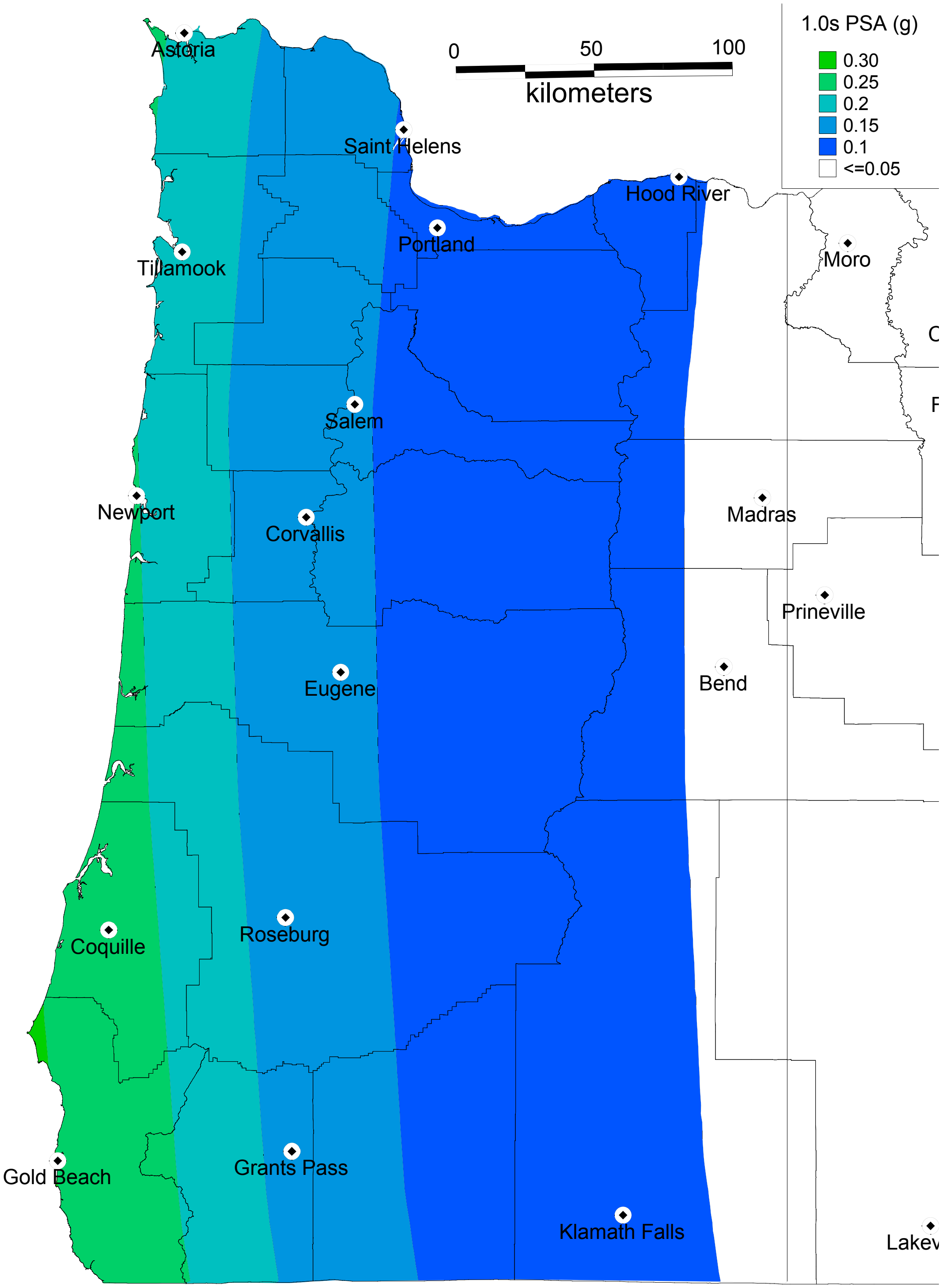


Figure 5. Map of median 5-percent-damped pseudoacceleration (PSA in *g*) at 1.0-s period on firm rock (B-C boundary) for a M_W 8.5 earthquake located anywhere along the Cascadia Subduction Zone plate interface.

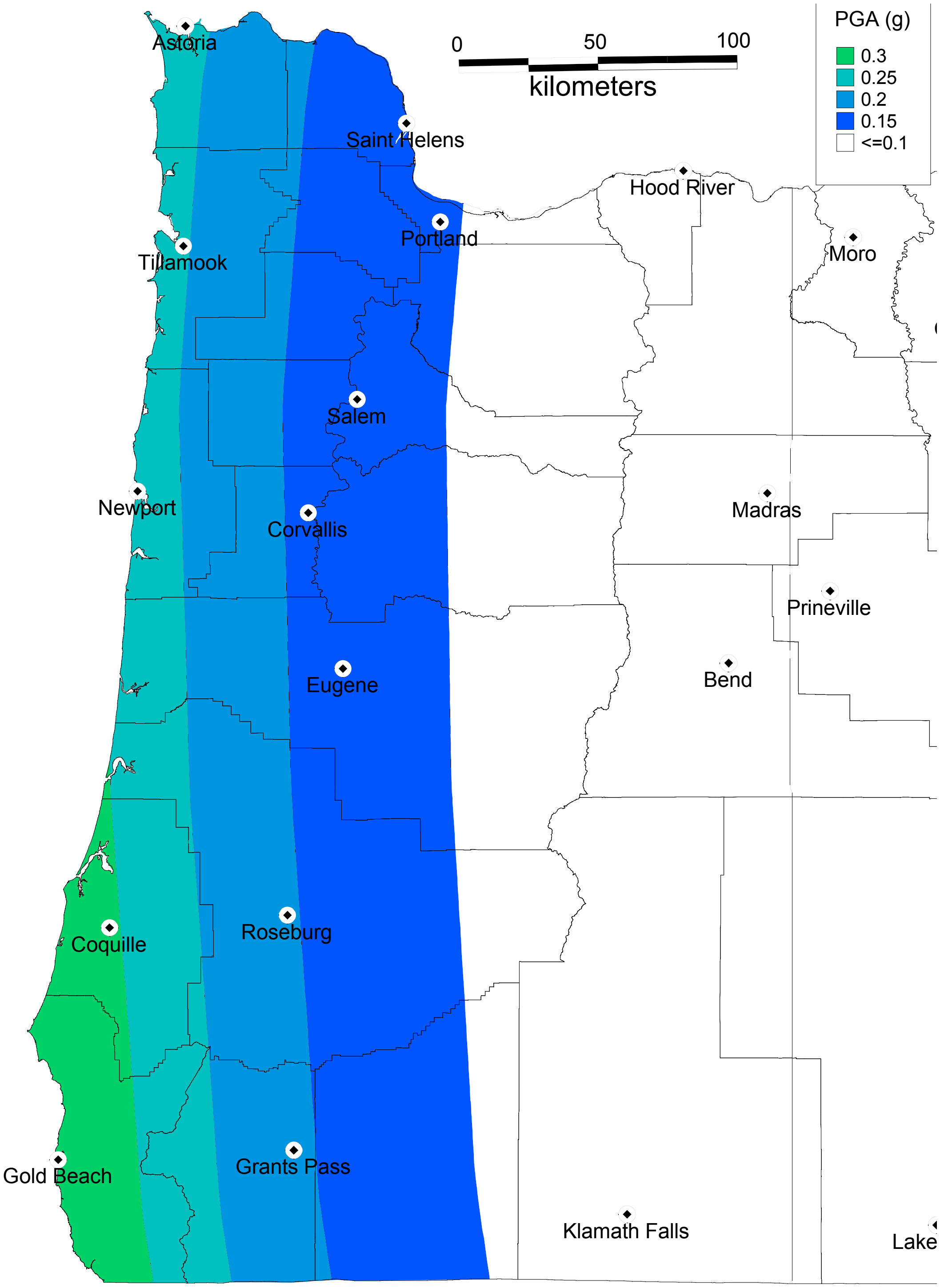


Figure 6. Map of median peak ground acceleration (PGA in *g*) on firm rock (B-C boundary) for a M_W 9.0 earthquake located anywhere along the Cascadia Subduction Zone plate interface.

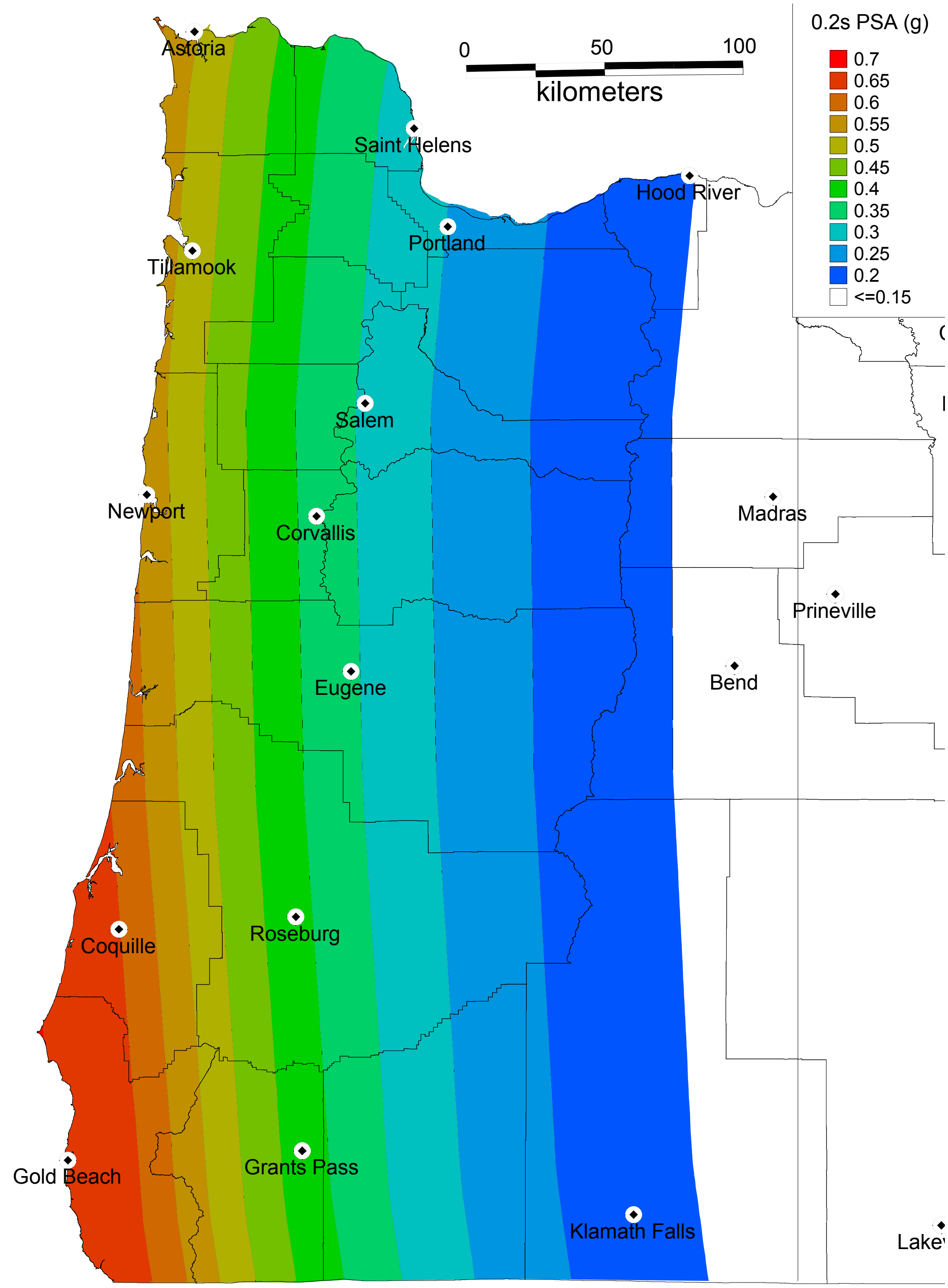


Figure 7. Map of median 5-percent-damped pseudoacceleration (PSA in *g*) at 0.2-s period on firm rock (B-C boundary) for a M_W 9.0 earthquake located anywhere along the Cascadia Subduction Zone plate interface.

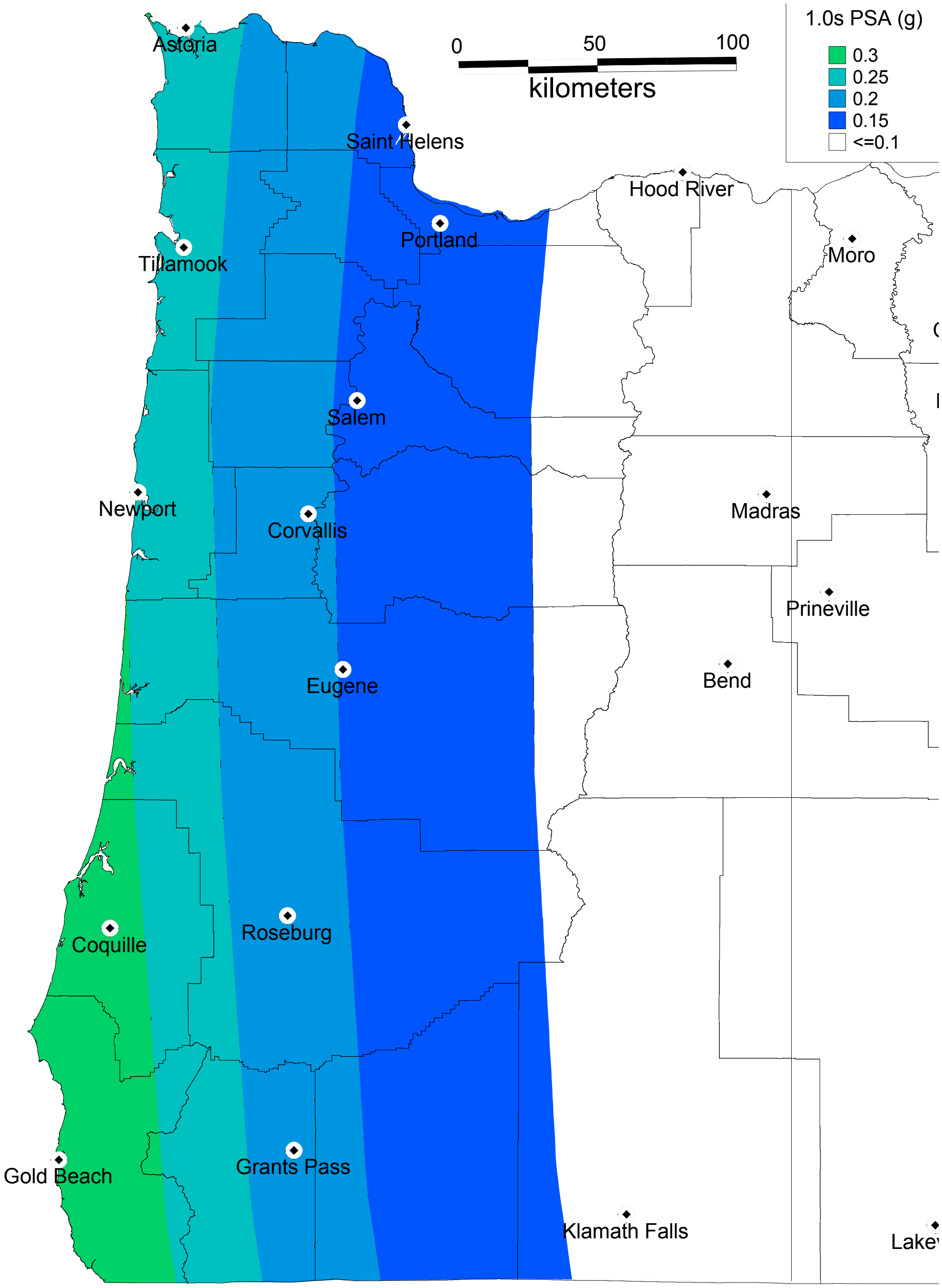


Figure 8. Map of median 5-percent-damped pseudoacceleration (PSA in *g*) at 1.0-s period on firm rock (B-C boundary) for a M_W 9.0 earthquake located anywhere along the Cascadia Subduction Zone plate interface.

Hills fault determined from the coordinates provided by the USGS was located on the western side instead of the eastern side of the Portland Hills. Ted Barnhard (personal communication, 2001), an EQE staff member who developed the Oregon fault database while employed by the USGS, believes that this mislocation is due to a registration error during the creation of the GIS database. Therefore, we have relocated the fault to lie along the eastern side of the Portland Hills as confirmed from geologic studies. According to the USGS, this 47-km-long, steeply dipping strike-slip fault extends from the ground surface to a depth of 15 km and has a maximum magnitude of 7.0.

We used the attenuation relationships of Abrahamson and Silva (1997), Boore and others (1997), Campbell (1997), and Sadigh and others (1997) to estimate median ground motions at each of the grid sites from the M_w 6.5 and 7.0 scenario earthquakes on the Portland Hills fault. We used the geometric mean (average of the logarithms) of these four estimates as the mapped ground-motion value. We evaluated these relationships for local site conditions that we believed were most consistent with the B-C boundary. As a result, we evaluated the relationships of Abrahamson and Silva (1997) and Sadigh and others (1997) for generic rock, the relationship of Boore and others (1997) for $V_S = 760$ m/s, and the relationship of Campbell (1997) for $S_{SR} = 1$, $S_{HR} = 0$, and $D = 1$ km, values recommended by Campbell (2000) for generic rock. This is a departure from the USGS study, which used only the relationships of Boore and others (1997), Campbell (1997), and Sadigh and others (1997) for the PGA estimates and only the relationships of Boore and others (1997) and Sadigh and others (1997) for the PSA estimates. Our use of the four relationships is more consistent with the current state of the practice.

The median PGA map for the M_w 6.5 scenario is shown in Figure 10. Similar scenario maps for the 0.2-s and 1.0-s values of the 5-percent-damped PSA response spectra are shown in Figures 11 and 12. Median PGA and PSA maps for the M_w 7.0 scenario are shown in Figures 13–15. The scenario 5-percent-damped PSA response spectra for downtown Portland, which is located approximately 1.6 km from the hypothesized rupture surface, are compared in Figure 16. Also shown on this figure are the 475-year and 2,500-year UHS (Frankel and Leyendecker, 2001), the recommended IBC-2000 design response spectrum (International Code Council, 2000; Leyendecker and others, 2001), and the UBC-1997 design response spectrum (International Council of Building Officials, 1998). Portland currently uses the UBC-1997 Zone 3 seismic provisions for its building design.

We should caution the reader that the scenario ground-motion maps provided in this study represent a site on firm rock, defined as the B-C boundary on the USGS seismic hazard maps and site class B in the recent building codes. So the ground motions represented by these maps are not those that would be expected at an actual site with different site conditions. In general, the local site conditions will be softer than those represented by the B-C boundary. Actual ground motions could be as much as two to three times higher on soft soils typical of coastal estuaries and river flood plains. In order to modify the ground motions on firm rock for other types of soil conditions, one would need to determine the soil conditions for the sites of interest, classify these conditions according to a soil-classification system, and apply an appropriate site factor consistent with this classification. Dobry and others (2000) describe the site classes and site factors used in the recent building code provisions. Wong and others (2000) developed a more comprehensive and region-specific set of site classes and site factors which they then used to develop earthquake scenario and probabilistic ground shaking maps for the Portland metropolitan area. Either of these approaches could be used to modify the earthquake scenario maps developed in this study for local site conditions.

DISCUSSION

City of Seaside

Inspection of the Seaside response spectra in Figure 9 indicates that the 475-year and 2,500-year UHS and the recommended IBC-2000 and UBC-1997 design spectra are all higher than our deterministic median response spectrum for the M_w 9.0 earthquake scenario on the Cascadia Subduction Zone. This unusual result is caused, we believe, by three conservative assumptions in the USGS model: (1) the location of the Cascadia Subduction Zone well inland, which places it directly beneath the city of Seaside and other coastal communities; (2) the two-thirds weight given to the more frequent M_w 8.3 earthquake scenario, which results in an average recurrence interval of only 240 years for a great Cascadia Subduction Zone event; and (3) the use of the shallow crustal attenuation relationship of Sadigh and others (1997) as an alternative ground-motion model for the more highly weighted and more frequently occurring M_w 8.3 scenario, which predicts significantly higher ground motions for the relatively short distances to the Cascadia Subduction Zone implied by the USGS location.

At a USGS seismic hazard workshop held April 30, 2001, at Portland State University, Art Frankel indicated that he would likely make several changes to the Cascadia Subduction Zone model in the next revision of the USGS seismic hazard maps—changes that would probably reduce the calculated seismic hazard along the Oregon coast: (1) use only

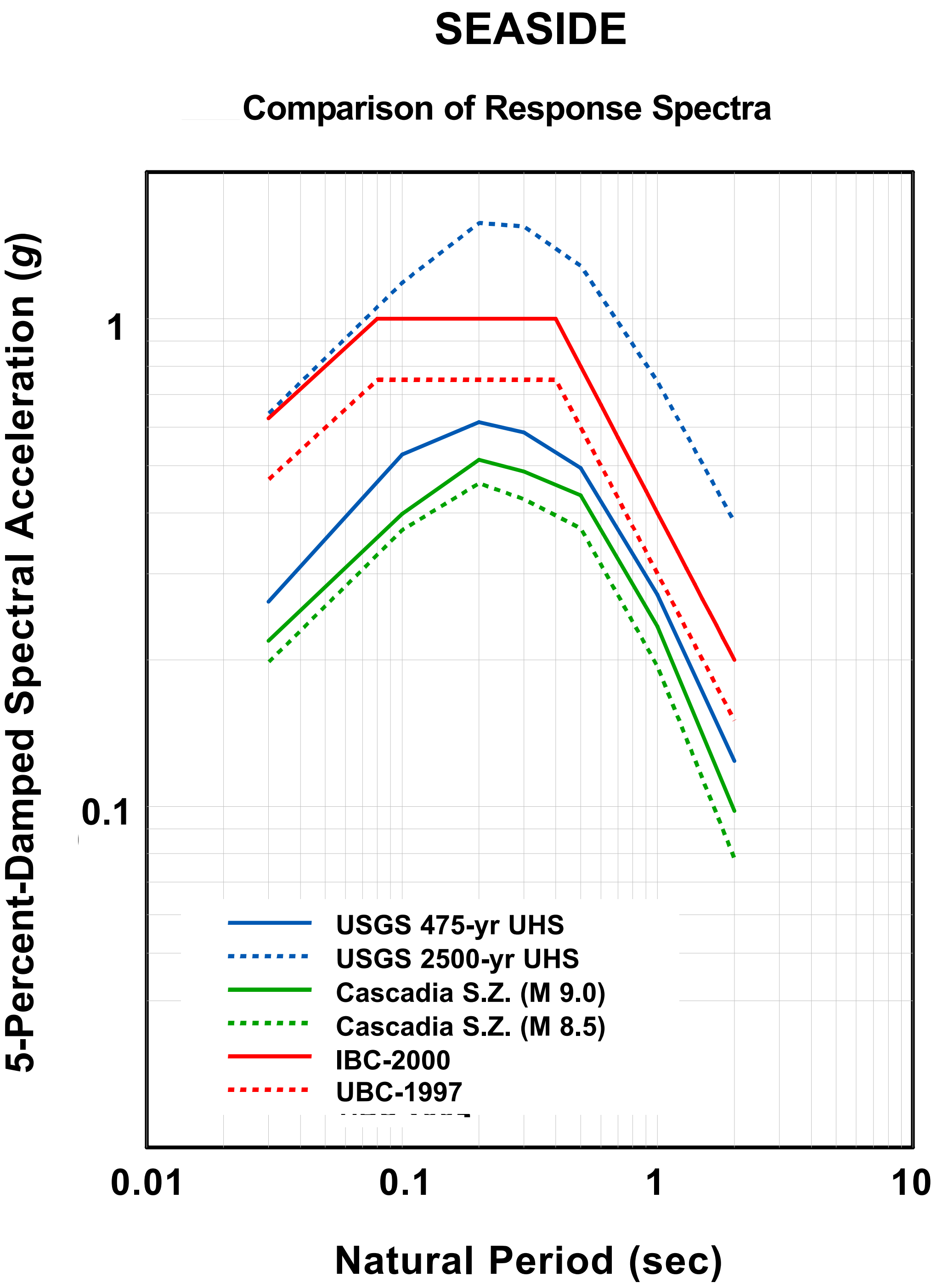


Figure 9. Comparison of response spectra on firm rock (B-C boundary) for the city of Seaside showing: in blue, the 1996 USGS 475-year and 2,500-year uniform hazard spectra; in red, the IBC-2000 and UBC-1997 design response spectra; and in green, the median response spectra for the M_W 8.5 and 9.0 scenario earthquakes on the Cascadia Subduction Zone plate interface.

subduction zone attenuation relationships for all subduction zone scenarios, (2) give equal or greater weight to the less frequent M_w 9.0 earthquake scenario, and (3) revise the location of the Cascadia Subduction Zone to be more consistent with that proposed by Flück and others (1997). However, he is also planning to incorporate uncertainty in the location, magnitudes, and recurrence intervals of his modeled Cascadia Subduction Zone events that can be expected to offset somewhat the anticipated decrease in UHS. For example, he will consider seismogenic rupture of both the locked and transition zones as one possible scenario. Nonetheless, the proposed changes will likely lower the UHS at Seaside and other locations along the Oregon coast. E.V. Leyendecker, a research engineer with the USGS, who also spoke at the Portland State workshop, expressed considerable doubt that the IBC-2000 seismic design parameter maps would be changed based on the upcoming revision, unless the differences are deemed to be important politically.

Frankel and others (1996, 2000) currently assume a recurrence interval of 500 years for a M_w 9.0 scenario and 110 years for a M_w 8.3 scenario in the 1996 USGS hazard model. Since they weight the latter by two-thirds, the average recurrence interval is 240 years, as noted above. While a mean recurrence interval of 110 years cannot be ruled out, a time-dependent probability analysis using an average recurrence interval of 550 years and a standard deviation (natural log) of 0.5 derived from geophysical, paleoseismological, and turbidite data, suggests that such a short recurrence interval is unlikely and should be given smaller weight (Campbell and others, 2001). The USGS model also assumes that great Cascadia Subduction Zone earthquakes can be treated as Poissonian (time-independent) events, even though it is generally accepted that the last great earthquake occurred about 300 years ago during the winter of 1700 (Satake and others, 1996) and strain has been building up ever since. Frankel showed at the Portland State University workshop that, since the Cascadia Subduction Zone is still relatively early in its seismic cycle, the seismic hazard is similar—whether time-dependent or Poissonian behavior is assumed. Cramer and others (2000) came to a similar conclusion based on a time-dependent probabilistic seismic hazard analysis for California.

Several observations regarding the design response spectra in Figure 9 are worth noting. First, the IBC-2000 design spectrum is much higher than the UBC-1997 design spectrum. This we attribute to the conservatism in the USGS seismic hazard maps that are the basis for the IBC-2000 design provisions. The IBC-2000 spectrum is consistent with UBC-1997 Zone 4 but might eventually be lowered, once this conservatism is reduced in the next revision of the USGS seismic hazard maps. Second, the IBC-2000 design spectrum is significantly higher than the 475-year UHS. The 475-year hazard is the nominal basis for the UBC-1997 seismic zone map, although each zone is conservatively defined by a seismic zone factor that represents the upper boundary of the range of ground motions used to define the zone. The IBC-2000 design provisions represent a return period that ranges from around 1,000 years at long periods to nearly 2,500 years at short periods. This is typical of areas outside coastal California, where the IBC-2000 design spectrum more closely corresponds to the 475-year UHS.

One factor that is not effectively dealt with in the building codes is the duration of strong ground shaking. While there are provisions for nonlinear time-history analysis in the codes, these provisions are usually used only for high-rise buildings and other important structures where time-history analysis is warranted. Otherwise a static analysis, an elastic response-spectrum analysis, or an elastic time-history analysis is used without consideration of duration effects. Great earthquakes on the Cascadia Subduction Zone will cause significant ground shaking over a period of minutes rather than seconds or tens of seconds as is typical during smaller magnitude earthquakes. Such a long duration, even at moderate levels of shaking, can cause structures that would ordinarily be left standing during events of normal duration to degrade structurally to the point of collapse. How many times have we heard a structural engineer say that had the earthquake lasted only a few seconds longer that a particular structure would have collapsed? How about minutes longer? One simple remedy is to require additional detailing and strength in the design. This can be done by increasing the UBC-1997 zone factor along the Oregon coast for low-rise buildings and further inland for high-rise buildings to Zone 4, regardless of the current zone, or by adopting the more conservative IBC-2000 design provisions along the coast. Other methods that have been proposed to account for long-duration shaking in design are to decrease the R-factor—the numerical coefficient used to reduce the design forces to account for the inherent overstrength and global ductility capacity of lateral force-resisting systems—or to modify the design elastic response spectrum to account for the inelastic demand of long-duration shaking (e.g., Tremblay, 1998; Tremblay and Atkinson, 2001).

City of Portland

Inspection of the downtown Portland response spectra in Figure 16 shows a complete reversal in the relative amplitudes of the UHS and deterministic response spectra for the M_w 6.5 and 7.0 scenario earthquakes on the Portland Hills fault. In this case, the scenario response spectra envelop the 2,500-year UHS. This result is typical of an assumed large-magnitude earthquake on a low-slip-rate fault. Frankel and others (1996, 2000) use a 0.1 mm/yr slip rate for the Portland Hills fault, which corresponds to a recurrence interval of about 17,000 years for their assumed M_W 7.0 characteristic earthquake on this fault. Even their more conservative Gutenberg-Richter recurrence model, which is given 50 percent weight in their seismic hazard model, implies a recurrence interval of about 6,000 years for earthquakes of M_W 6.5–7.0. The Portland Hills fault is the only major fault in the 1996 USGS model that impacts the downtown Portland area.

Such relatively long recurrence intervals for the Portland Hills fault suggest that the seismic hazard in downtown Portland based on the USGS model, even for the 2,500-year return period, is dominated by background seismicity (random earthquakes) and great earthquakes on the Cascadia Subduction Zone and not by events on the Portland Hills fault. Frankel indicated at the Portland State University workshop that he will likely decrease the weight of the Gutenberg-Richter recurrence model on Type B faults, such as the Portland Hills fault, in the next revision of the USGS seismic hazard maps. If so, this will shift more weight to the less frequent characteristic event and lower the seismic hazard contribution from this fault even more. However, it will probably have little impact on the UHS because of the already relatively large recurrence intervals on the Portland Hills fault. Frankel also mentioned at the workshop that he is considering including other faults identified by Wong and others (2000) in the downtown Portland area, which might increase the contribution of individual faults to the hazard.

The relatively long recurrence intervals for the Portland Hills fault assumed in the USGS model should not be construed to imply similarly long recurrence intervals for moder-

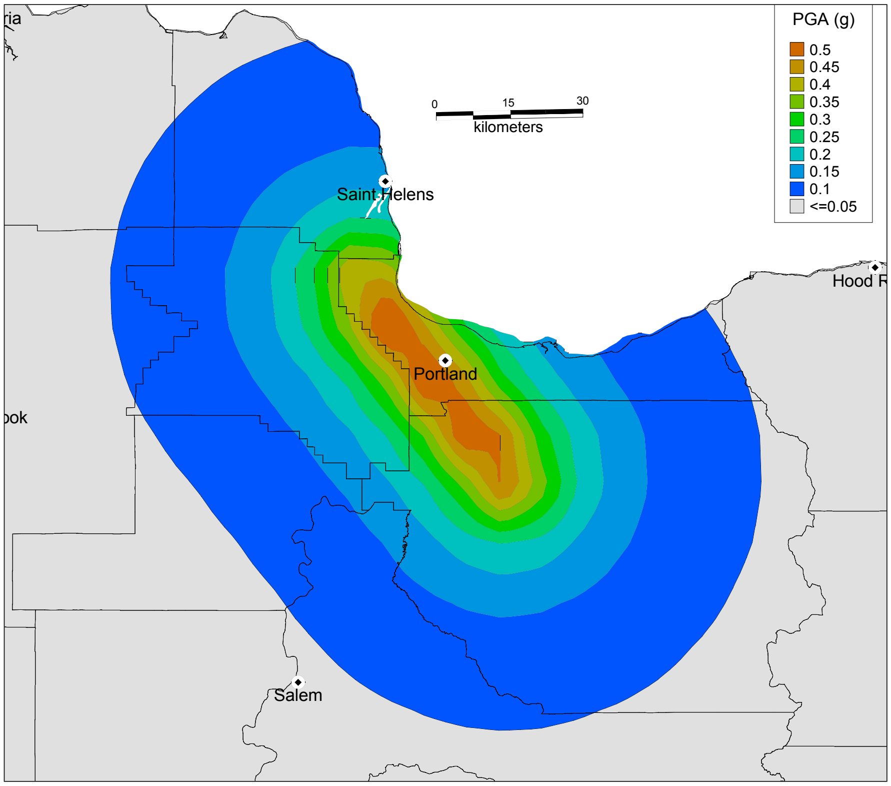


Figure 10. Map of median peak ground acceleration (PGA in *g*) on firm rock (B-C boundary) for a M_W 6.5 earthquake located anywhere along the Portland Hills fault.

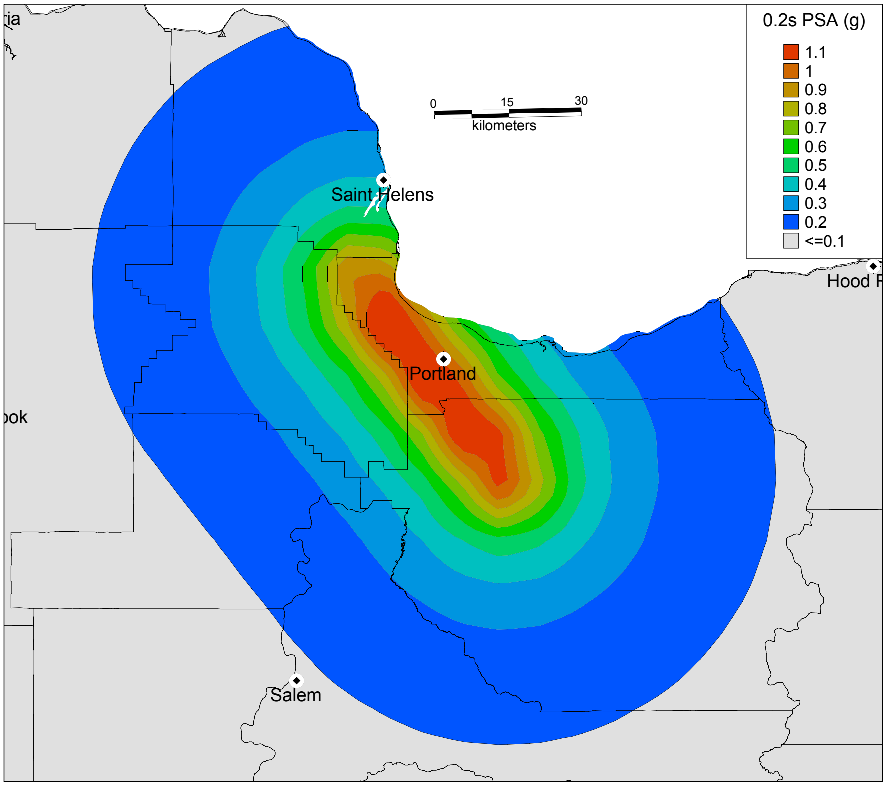


Figure 11. Map of median 5-percent-damped pseudoacceleration (PSA in *g*) at 0.2-s period on firm rock (B-C boundary) for a M_W 6.5 earthquake located anywhere along the Portland Hills fault.

ate to large earthquakes in the Portland region in general. For example, an analysis of historical seismicity by Bott and Wong (1993) indicates that magnitude 6.0 earthquakes can be expected to occur in the Portland area on average every 300 to 350 years and magnitude 6.5 earthquakes every 800 to 900 years. Wong and others (2000) estimated 500-year peak ground accelerations in the Portland metropolitan area that are 50 percent higher than those estimated by Frankel and others (1996, 2000). They attribute this result to three factors that were not considered in the latter study: (1) the inclusion of the Oatfield, East Bank, and Mollala-Canby faults, (2) the use of a two-times-higher slip rate on the Portland Hills fault, and (3) the assignment of a higher weight to the occurrence of a M_W 9.0 Cascadia Subduction Zone earthquake.

We can see that the IBC-2000 and UBC-1997 design response spectra are more alike for Portland than they are for Seaside. In this case, the UBC-1997 spectrum is actually more conservative, at least at moderate to long periods. However, note again that both design spectra correspond to return periods that are significantly higher than 475 years. Effective return periods for the IBC-2000 spectrum range from around 1,000 years at long periods to over 2,500 years at short periods.

CONCLUSIONS

In summary, we offer the following conclusions based on our study of deterministic median ground motions from scenario earthquakes on the Cascadia Subduction Zone and the Portland Hills fault:

1. Scenario ground-motion maps similar to those developed in this study for western Oregon can be used for seismic risk assessment, mitigation policy development, emergency and response planning, and communication of earthquake hazards to the public.

2. The 1996 USGS seismic hazard maps and the design parameters in the IBC-2000, which are based on these maps, are possibly overestimated for sites located along the Oregon coast due to several conservative assumptions in the modeling of the Cascadia Subduction

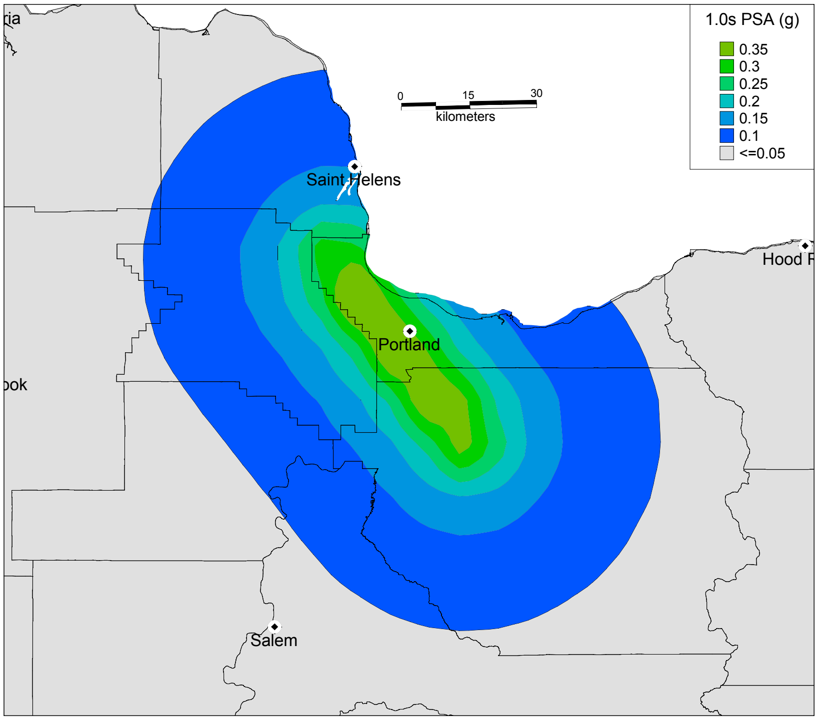


Figure 12. Map of median 5-percent-damped pseudoacceleration (PSA in *g*) at 1.0-s period on firm rock (B-C boundary) for a M_W 6.5 earthquake located anywhere along the Portland Hills fault.

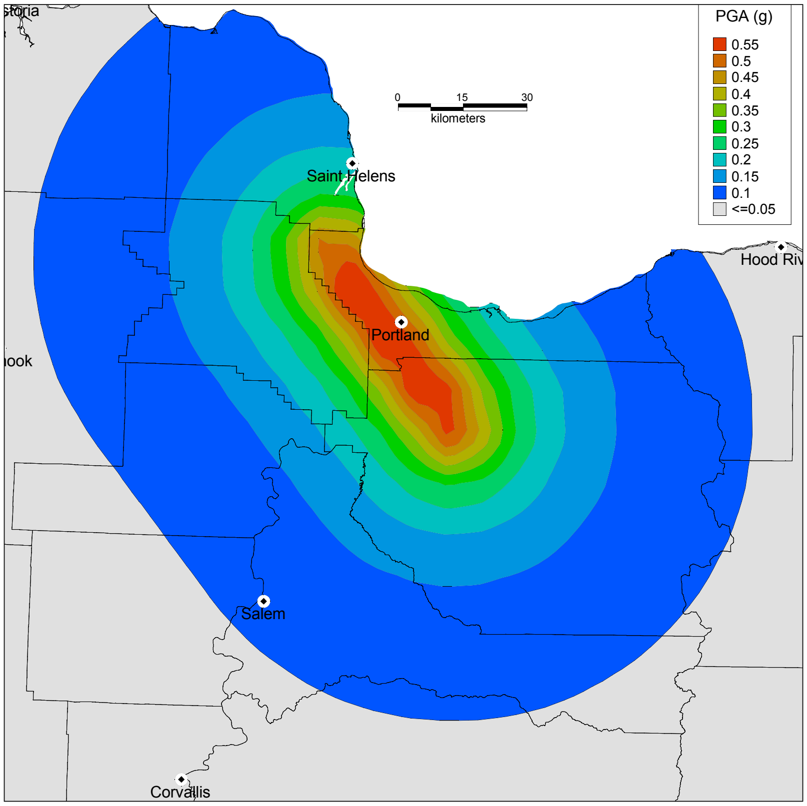


Figure 13. Map of median peak ground acceleration (PGA in *g*) on firm rock (B-C boundary) for a M_W 7.0 earthquake located anywhere along the Portland Hills fault.

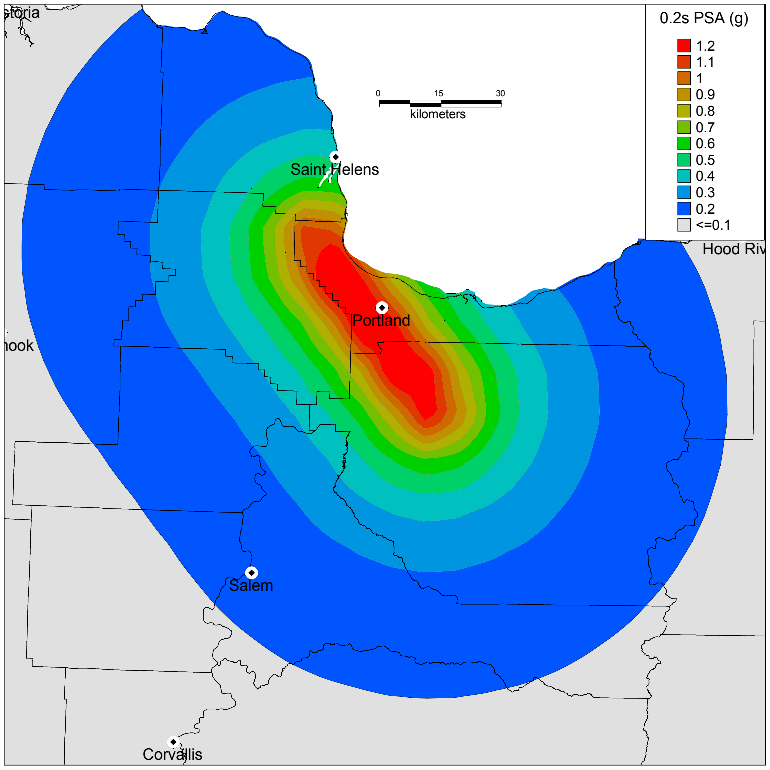


Figure 14. Map of median 5-percent-damped pseudoacceleration (PSA in *g*) at 0.2-s period on firm rock (B-C boundary) for a M_W 7.0 earthquake located anywhere along the Portland Hills fault.

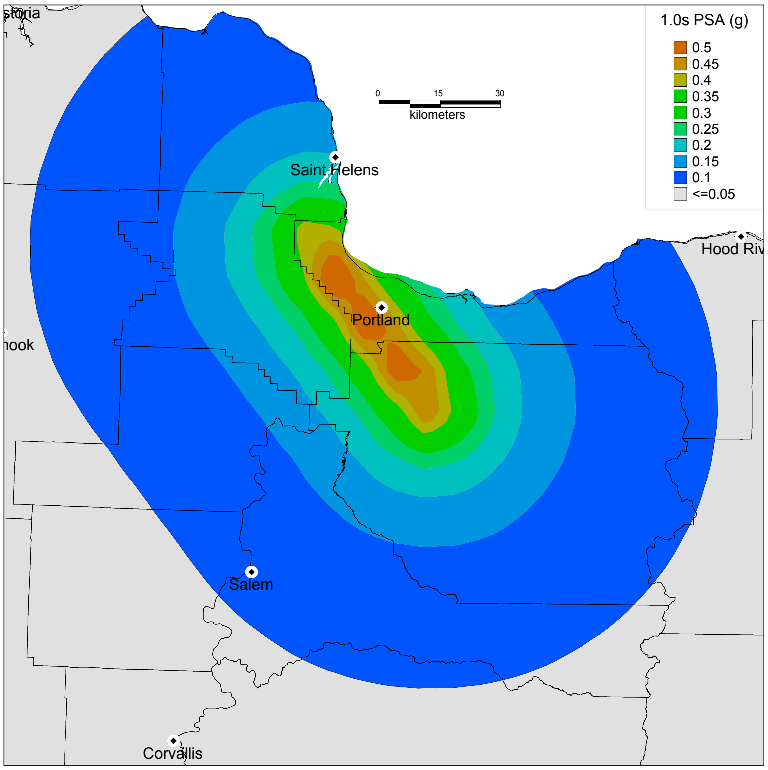


Figure 15. Map of median 5-percent-damped pseudoacceleration (PSA in *g*) at 1.0-s period on firm rock (B-C boundary) for a M_W 7.0 earthquake located anywhere along the Portland Hills fault.

Zone by Frankel and others (1996, 2000). For this reason, the scenario response spectra for the city of Seaside fall well below the 475-year uniform hazard spectrum and the IBC-2000 and UBC-1997 design response spectra. The USGS is expected to apply less conservative assumptions in the next revision of the maps, which should reduce the seismic hazard along the coast (however, see item 6).

3. The 1996 USGS seismic hazard maps and the design parameters in the IBC-2000, which are based on these maps, are dominated by background earthquakes and events on the Cascadia Subduction Zone in the Portland area because of the relatively long recurrence intervals on the Portland Hills fault. For this reason, the scenario response spectra for the downtown Portland area rise above the 2,500-year uniform hazard response spectrum and the IBC-2000 and UBC-1997 design response spectra.

4. The IBC-2000 design response spectrum exceeds the UBC-1997 design response spectrum for the city of Seaside. The reverse is true for downtown Portland. The higher IBC-2000 spectrum in Seaside is due in part to the conservative nature of the USGS seismic hazard maps in that region (see item 2).

5. The IBC-2000 and UBC-1997 design response spectra for both Seaside and downtown Portland correspond to return periods in excess of 475 years. The IBC-2000 spectra are consistent with return periods ranging from about 1,000 years at long periods to 2,500 years at short periods. The UBC-1997 spectra are associated with somewhat shorter return periods in Seaside and longer return periods in Portland.

6. The duration of strong shaking from great earthquakes on the Cascadia Subduction Zone will last several minutes, causing many structures to collapse that would otherwise be left standing after an earthquake of shorter, more normal duration. Since duration is not effectively dealt with in the building codes, one means of protecting against such long-duration ground motion is to increase the required detailing and strength of all buildings along the Oregon coast and high-rise buildings further inland by increasing the design provisions (for example, to UBC-1997 Zone 4 or to the more conservative IBC-2000 design provisions along the coast). Alternatively, modifications could be made to the elastic design spectra

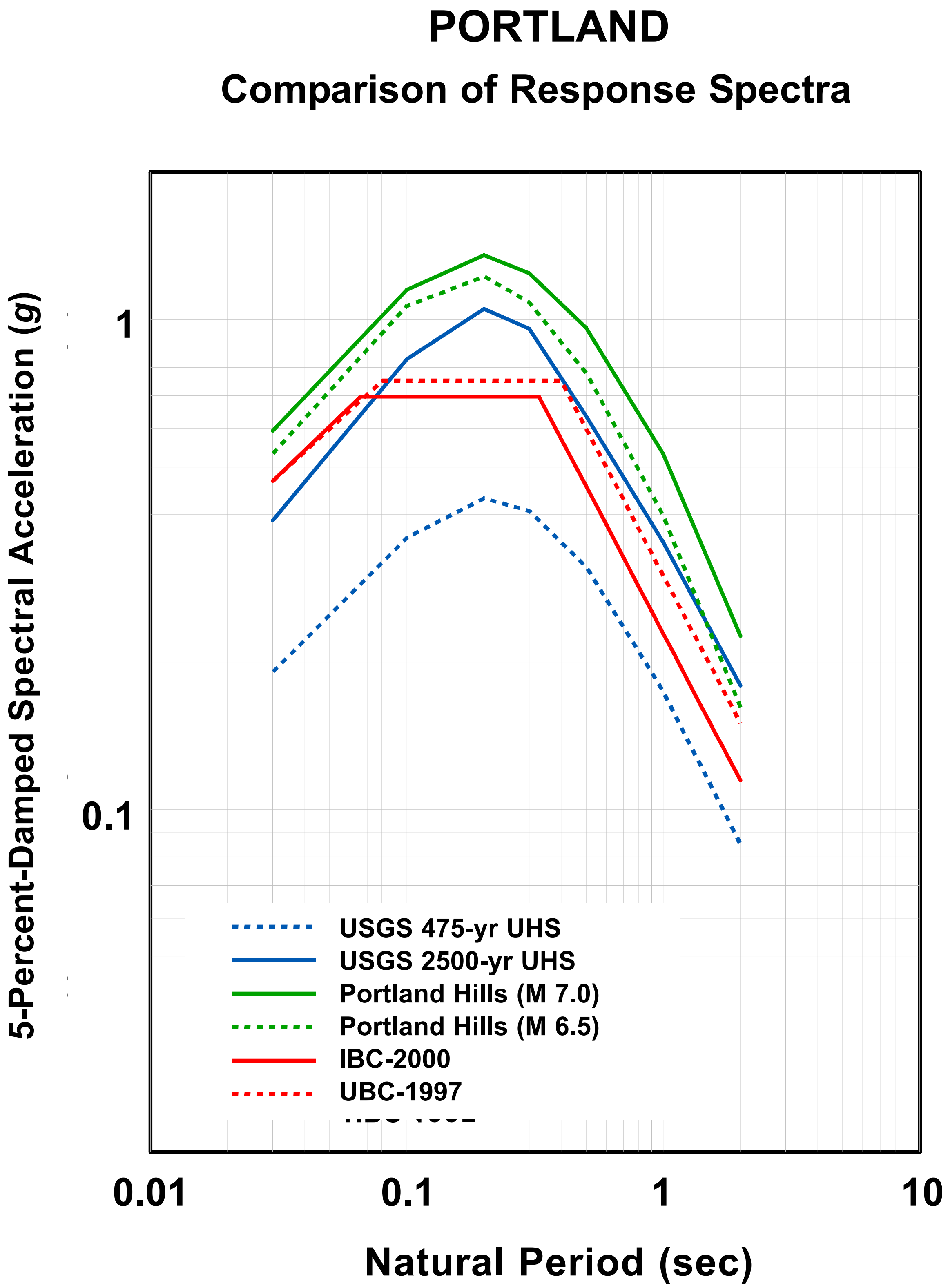


Figure 16. Comparison of response spectra on firm rock (B-C boundary) or downtown Portland showing: in blue, the 1996 USGS 475-year and 2,500-year uniform hazard spectra; in red, the IBC-2000 and UBC-1997 design response spectra; and in green, the median response spectra for the M_W 6.5 and 7.0 scenario earthquakes on the Portland Hills fault.

or to the R-factors used to incorporate inelastic demand.

ACKNOWLEDGMENTS

This work was funded in part by the Oregon Department of Geology and Mineral Industries (DOGAMI) and by EQE International Inc., an ABS Group Company based in Oakland, California. We appreciate many valuable comments from John D. Beaulieu, Oregon State Geologist and Director of DOGAMI, and George R. Priest, Coastal Program Director at DOGAMI. The views and conclusions contained in this paper are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the State of Oregon.

REFERENCES

Abrahamson, N.A., and Silva, W.J., 1997, Empirical response spectral attenuation relations for shallow crustal earthquakes: Seismological Research Letters, v. 68, p. 94–127.

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.

Boore, D.M., Joyner, W.B., and Fumal, T.E., 1997, Equations for estimating horizontal response spectra and peak acceleration from western North American earthquakes: A summary of recent work: Seismological Research Letters, v. 68, p. 128–153.

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.

Building Seismic Safety Council, 1994, NEHRP recommended provisions for seismic regulations for new buildings, 1994 edition, Part 1: Provisions: Federal Emergency Management Agency Publication FEMA 222A / May 1995, 290 p.

———1997, NEHRP recommended provisions for seismic regulations for new buildings and other structures, 1997 edition, Part 1: Provisions: Federal Emergency Management Agency Publication FEMA 302 / February 1998, 337 p.

Campbell, K.W., 1997, Empirical near-source attenuation relationships for horizontal and vertical components of peak ground acceleration, peak ground velocity, and pseudo-absolute acceleration response spectra, Seismological Research Letters, v. 68, p. 154–179.

———2000, Erratum: Empirical near-source attenuation relationships for horizontal and vertical components of peak ground acceleration, peak ground velocity, and pseudo-absolute acceleration response spectra, Seismological Research Letters, v. 71, p. 353–355.

Campbell, K.W., Thenhaus, P.C., Hampson, D., and Barnhard, T., 2001, Uncertainty in ground shaking hazard in Seattle and Portland from great earthquakes on the Cascadia Subduction Zone [abs.], Seismological Research Letters, v. 72, p. 255.

Clague, J.J., Atwater, B.F., Wang, K., Wang, Y., and Wong, I., eds., 2000, Penrose Conference "Great Cascadia Earthquake Tricentennial" program summary and abstracts: Oregon Department of Geology and Mineral Industries Special Paper 33, 156 p.

Cramer, C.H., Petersen, M.D., Cao, T., Toppozada, T.R., and Reichle, M., 2000, A time-dependent probabilistic seismic-hazard model for California: Seismological Society of America Bulletin, v. 90, p. 1–21.

Dobry, R., Borcherdt, R.D., Crouse, C.B., Idriss, I.M., Joyner, W.B., Martin, G.R., Power, M.S., Rinne, E.E., and Seed, R.B., 2000, New site coefficients and site classification system used in recent building seismic code provisions: Earthquake Spectra, v. 16, p. 41–67.

Flück, P., Hyndman, R.D., and Wang, K., 1997, Three-dimensional dislocation model for great earthquakes of the Cascadia Subduction Zone: Journal of Geophysical Resarch, v. 102, p. 20,539–20,550.

**Frankel, A.D., and E.V. Leyendecker (2001). Seismic hazard curves and uniform hazard response spectra for the United States: U.S. Geol. Surv. CD-ROM Ver. 3.10—March, 2001.

Frankel, A., Mueller, C., Barnhard, T., Perkins, D., Leyendecker, E.V., Dickman, N., Hanson, S., and Hopper, M., 1996, National seismic-hazard maps; documentation June 1996: U.S. Geological Survey Open-File Report 96–532, 110 p.

Frankel, A.D., Mueller, C.S., Barnhard, T.P., Leyendecker, E.V., Wesson, R.L., Harmsen, S.C., Klein, F.W., Perkins, D.M., Dickman, N.C., Hanson, S.L., and Hopper, M.G., 2000, USGS national seismic hazard maps: Earthquake Spectra, v. 16, 1–19.

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

Heaton, T.H., and Hartzell, S.H., 1987, Earthquake hazards on the Cascadia Subduction Zone: Science, v. 236, p. 162–168.

International Code Council, 2000, International building code: Falls Church, Va., International Code Council, Inc., 756 p.

International Conference of Building Officials, 1988, Uniform building code, 1988 edition: Whittier, Calif., International Conference of Building Officials.

International Conference of Building Officials, 1998, Uniform building code, 1997 edition: Whittier, Calif., International Conference of Building Officials.

**Leyendecker, E.V., Frankel, A.D., and Rukstales, K.S., 2001, Seismic design parameters: U.S. Geological Survey CD-ROM, ver. 3.10—February, 2001. Published jointly by the U.S. Geological Survey, Federal Emergency Management Agency, and Building Seismic Safety Council.

Leyendecker, E.V., Hunt, R.J., Frankel, A.D., and Rukstales, K.S., 2000, Development of maximum considered earthquake ground motion maps: Earthquake Spectra, v. 16, p. 21–40.

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

Sadigh, K., Chang, C.-Y., Egan, J.A., Makdisi, F., and Youngs R.R., 1997, Attenuation relationships for shallow crustal earthquakes based on California strong motion data: Seismological Research Letters, v. 68, p. 180–189.

Satake, K., Shimazaki, K., Tsuji, Y., and Ueda, K., 1996, Time and size of a giant earthquake in Cascadia inferred from Japanese tsunami records of January 1700: Nature, v. 379, p. 246–249.

Tremblay, R., 1998, Development of design spectra for long duration ground motions from Cascadia subduction earthquakes: Canadian Journal of Civil Engineering, v. 25, p. 1078–1090.

Tremblay, R., and Atkinson, G.M., 2001, Comparative study of the inelastic seismic demand of eastern and western Canadian sites, Earthquake Spectra, v. 17, p. 333–358.

Weaver, C.S., and Shedlock, K.M., 1989, Potential subduction, probable intraplate, and known crustal earthquake source areas in the Cascadia Subduction Zone, *in* Hays, W.W., ed., 3rd Annual Workshop on "Earthquake Hazards in the Puget Sound, Portland Area," Proceedings: U.S. Geological Survey Open-File Report 89–465, p. 11–26.

Wiley, T.J., Sherrod, D.R., Keefer, D.K., Qamar, A., Schuster, R.L., Dewey, J.W., Mabey, M.A., Black, G.L., and Wells, R.E., 1993, Klamath Falls earthquakes, September 20, 1993—including the strongest quake ever measured in Oregon: Oregon Geology, v. 55, no. 6, p. 127–134.

Wong, I.G., Silva, W.J., Bott, J., Wright, D., Thomas, P., Gregor, N., Li, S., Mabey, M., Sojourner, A., and Wang, Y., 2000, Earthquake scenario and probabilistic ground shaking maps for the Portland, Oregon, metropolitan area. Portland Hills fault M 6.8 earthquake, peak horizontal acceleration (*g*) at the ground surface: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS–15, 1 map sheet, scale 1:62,500.

Youngs, R.R., Chiou, S.J., Silva, W.J., and Humphrey, J.R., 1997, Strong ground motion attenuation relationships for subduction zone earthquakes: Seismological Research Letters, v. 68, p. 58–73. ☐

(Continued from page 106)

grams, but also a printable, full-size (36"x60") color map in PDF form, as well as the above-mentioned text and a complete list of DOGAMI publications. A PDF viewer (Adobe Acrobat Reader) to open and view the map and the text files is available free online from Adobe Systems, Inc., at the following internet address, which is also given in the README file on the CD: http://www.adobe.com/products/acrobat/readstep2.html.

Map RMS-1 represents the culmination of a three-year geologic mapping program partially funded under the U.S. Geological Survey (USGS) National Cooperative Geologic Mapping program. Geologic data were compiled at a scale of 1:24,000 from a combination of new mapping and published and unpublished data. Compilation of the map used air photos, orthophoto quads, Side Looking Airborne Radar, and digital shaded relief images derived from USGS grids. Mapping was supplemented with numerous X-ray fluorescence geochemical and limited argon radiometric age determinations.

Contact persons for the La Grande Quadrangle map are Mark Ferns, Regional Geologist, Baker City field office, at (541) 523-3133 or mark.ferns@dogami.state.or.us; Ian Madin, Geologic Mapping Director, Portland office, at (503) 731-4100 x241 or ian.madin@dogami.state.or.us, and James Roddey, Community Education Coordinator, Portland office, at (503) 731-4100 x242 or james.roddey@dogami.state.or.us.

Released December 27, 2001:

Evaluation of coastal erosion hazard zones along dune- and bluff-backed shorelines in Tillamook County, Oregon: Cascade Head to Cape Falcon. Preliminary technical report to Tillamook County, by J.C. Allan and G.R. Priest, Oregon Department of Geology and Mineral Industries. Open-File Report O-01-03, 1 CD, $10.

Coastal erosion hazard zones along the Clatsop Plains, Oregon: Gearhart to Fort Stevens. Preliminary technical report to Tillamook County, by J.C. Allan and G.R. Priest, Oregon Department of Geology and Mineral Industries. Open-File Report O-01-04, 1 CD, $10.

Preliminary earthquake hazard and risk assessment and water-induced landslide hazard in Benton County, Oregon, by Z. Wang, G.B. Graham, and I.P. Madin, Oregon Department of Geology and Mineral Industries. Open-File Report O-01-05, 1 CD, $10

Preliminary seismic hazard and risk assessments in Tillamook County, Oregon, by Z. Wang, C.S. Hasenberg, G.B. Graham, and F.N. Rad. Open-File Report O-01-06, 1 CD, $10

These four reports have been released for timely information by the Oregon Department of Geology and Mineral Industries upon conclusion of the respective studies. Final reports for these projects are expected to be released in 2002.

The reports are intended mainly for planners, emergency managers, and other technical users who work with geographic information systems (GIS). Each report consists of map data, metadata, and an explanatory PDF text. Each is available only on CD and can be purchased for $10.

For more information, contact James Roddey at 800 NE Oregon St., #28, Portland, OR 97232, (503) 731-4100, ext. 242 (james.roddey@state.or.us). For purchases, **click here**, look for "Store-Maps and Reports" on the naturenw.org web page and search for "O-01-". ☐

For those who do not have the time or opportunity . . .

Geologic notes — Gleanings from recent publications that may be of interest

by Lou Clark, Oregon Department of Geology and Mineral Industries

Geology, September

"Volcano collapse promoted by hydrothermal alteration and edifice shape, Mount Rainier, Washington," by Mark Reid, Thomas Sisson, Dianne Brien

Using a new three-dimensional slope analysis technique, researchers have determined that Mount Rainier's upper west slope is the part of the volcano with walls substantially weakened from hydrothermal alteration. This technique may be used on other peaks to produce quick and relatively cheap volcanic hazard assessments.

October

"Flood enhancement through flood control," by Robert Criss and Everett Shock

The net effect of the attempt to control floods on the Mississippi River has been to increase the frequency of flooding and increase the potential energy of individual floods. Wing dams and levees created more severe effects than locks and dams.

November

"Historical science, experimental science, and the scientific method," by Carol Cleland

An editor of Nature claimed that all hypotheses about the remote past are unscientific because they cannot be tested by experiment. The implications for geology are obvious. Cleland compares the traditional scientific method with historical science and finds that claims for experimental methods are sometimes overvalued, and problems with historical science are sometimes over-emphasized. The result is that the classic scientific method is not inherently superior to historical science in testing hypotheses.

Nature, October 11

"US lays out bare bones of fossil protection package"

The Paleontological Resources Preservation Act was introduced in Congress on October 2. It has the support of the Society of Vertebrate Paleontology. The Act would increase criminal penalties for stealing fossils from federal land among other things. It is based on the 1979 Archeological Resources Protection Act which was designed to control looting of Native American sites.

"Volunteers flock to donate computer time"

SETI@home distributes packets of data to volunteers who use their idle computer time to analyze the data. The project examines radio telescope data for signs of extraterrestrial life. It has more volunteers than data, so the scope of research may be expanded.

Another project is run by the National foundation for Cancer Research. Since it began in April, a million volunteers have tested 3.5 billion molecules to determine their importance in cancer development.

October 18

"Lessons for the future of journals"

This issue contains an entire section devoted to new journals, including a discussion of electronic publishing. Almost two-thirds of scientific journals are available both in print and on-line, and there are more than 1,000 electronic-only peer-reviewed journals.

A survey showed that about a third of readings are now from electronic sources, scientists rely more on online search tools to find articles, and there is more reading from copies of individual articles than whole issues of journals.

"The Earth cubed"

Geochemistry, Geophysics, Geosystems (G^3): an Electronic Journal of the Earth Sciences is an open-access electronic publication of the American Geophysical Union. It emphasizes cross-disciplinary approaches to understanding the Earth as a system. Because of the electronic format, one goal is to offer authors unique publishing opportunities: large databases, virtual-reality images, and movies.

Science, September 7

"Networking to beat the shakes"

The Network for Earthquake Engineering Simulation will give earthquake engineers access to data and software and also allow experiments to be operated over the Internet. Cyberspace shake tables may help in the design of better earthquake-resistant structures. The network will begin operation in the fall of 2004.

September 14

"Top down tectonics?" by Don Anderson

How does mantle convection relate to plate tectonics? The conventional wisdom is that the lithosphere simply reacts to mantle convection. New research suggests that plate tectonics actually organize mantle convection. Subducting slabs cool the mantle and create the gradients needed for convection. In this model, the plates control the thermal evolution of the mantle, rather than being controlled by a dissipative mantle convection system.

September 21

"Peer review and quality: A dubious connection?"

A meta-anaylsis presented at a September conference of editors of medical journals and academics found little evidence that the quality of scientific papers is improved by peer review. Most people, however, agree that the peer review process should continue. Some disagreed that the importance of peer review could be measured in a quantitative way. One participant said, "I could name scores of scientists who have had their reputations saved by peer review."

"Changes in seismic anisotrophy after volcanic eruptions: Evidence from Mount Ruapehu," by Vicki Miller and Martha Savage

It is difficult, but extremely important, to predict volcanic eruptions. Mount Ruapehu is an andesitic volcano in New Zealand that erupted in 1988 and 1995/96. Researchers found changes in shear-wave polarization that could be caused by increased magmatic pressure. They suggest that abrupt changes in shear-wave splitting polarizations may be indicators of volcanic activity and an important tool in the future to forecast eruptions.

October 12

"From Earth's core to African oil"

Africa hasn't moved much for 200 million years. Geologist Kevin Burke argues that plate tectonics is less important to the development of that continent than lava plumes coming from the mantle or even the core. The African plate is pushed by mid-ocean ridges almost all around it. Because it has no cold, subducting slabs around it, the mantle underneath it is heating. That provides the energy for long-lived plumes that raised what is now Ethopia. Erosion of these uplifts produced sediments that were carried offshore and deposited in organic-rich sediments produced from a previous plume. That process created the oil found in the Niger delta and the Congo deep-sea fan.

November 23

"Under the surface"

The Digital Earth project of Cornell University in Ithaca, New York ("Building the Digital Earth") has gathered about 100 geology, geography, and geophysics data sets. You can use an Interactive Mapping Tool to create custom multi-layered maps and cross-sections on line — at atlas.geo.cornell.edu. ☐

THESIS ABSTRACTS

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

While reserving the right to determine the desirability of each acquisition, the Department is interested in purchasing two copies of each accepted master's thesis or doctoral dissertation, bound, and complete, for the amount of $150 or $200, respectively, if such a thesis or dissertation concerns the geology of Oregon. Part of the acquisition will be the right to publish the abstract in Oregon Geology.

Alkaline and peraluminous intrusives in the Clarno Formation around Mitchell, Oregon: Ramifications on magma genesis and subduction tectonics, by Michael Appel, (M.S., Oregon State University, 2001), 222 p.

The Clarno Formation is a series of volcanic, volcaniclastic, and related intrusive rocks located in central Oregon. It is the westernmost extent of a broader Eocene magmatic belt that covers much of the western United States. The magmatic belt stretches eastward from Oregon to western South Dakota, and from the Canadian Yukon to northern Nevada. While the creation of the belt was once attributed to subduction of the Farallon Plate under North America, more recent work suggests that a more complex tectonic regime involving extension was in place during the early Cenozoic.

In the vicinity of Mitchell, Oregon, the Clarno Formation is well represented along with Mesozoic metamorphic and sedimentary units and younger Tertiary volcanic and volcaniclastic units. In this area, Clarno volcanic activity occurred from ~52–42 Ma, producing mostly andesites and related volcaniclastic rocks. The Mitchell area is also underlain by related intrusive bodies ranging from basalt to rhyolite in composition. The Clarno was most active at ~49 Ma, and is dominantly calc-alkaline. In addition, there are several coeval alkaline and peraluminous intrusives also scattered throughout the Clarno Formation. While these suites are less voluminous than the calc-alkaline magmatism, they offer insight into the tectonic and magmatic processes at work in this area during the Eocene.

Whereas silicic intrusions are common in the Clarno, the high-silica rhyolite dike on the south face of Scott Butte is unusual due to its large garnet phenocrysts. The existence of primary garnet in rhyolitic magmas precludes middle to upper crustal genesis, a common source for silicic magmas. ^{40}Ar/^{39}Ar age determinations of the biotite indicate an age of ~51 Ma. This is after andesitic volcanism had commenced but prior to the most active period of extrusion. The presence of the almandine garnet indicates that the dike represents partial melting of lower (18–25 km) crustal material. The presence of a high field strength element (HFSE) depletion commonly associated with subduction arc magmatism indicates that either the source material had previously been metasomatised or that some subduction melts/fluids (heat source) mixed with the crustal melt.

Two alkaline suites, a high-K calc-alkaline basanite (Marshall and Corporate Buttes) and alkaline minette/kersantite lamprophyres (near Black Butte and Mud Creek), were emplaced at ~49 Ma, during the height of calc-alkaline activity. The basanite lacks the HFSE depletion common in the other Clarno rocks. Instead it has a HIMU-type (e.g., St. Helena) ocean-island basalt affinity, resulting from partial melting of enriched asthenospheric mantle. In contrast, the lamprophyres represent hydrous partial melts of metasomatized lithospheric mantle veins and bodies.

Alkaline magmatism was not limited to the most active periods of calc-alkaline activity. The emplacement of an alkali basalt (Hudspeth Mill intrusion) at ~45 Ma occurred four million years after the largest pulse of volcanism, but still during calc-alkaline activity. This alkali basalt represents partial melting of metasomatized lithospheric mantle.

The occurrence of these alkaline suites coeval with the calc-alkaline activity is significant in that it disputes prior subduction theories for the broader Eocene magmatism that are based on spatial and temporal variations from calc-alkaline to alkaline magmatism. These suites also give further insight into the complex tectonic regime that existed in Oregon during the Eocene. The occurrence of asthenospheric melts not caused by fluid fluxing and the accompanying lower lithospheric alkaline melts are normally associated with extension. Extension provides these magmas with both the mechanism for melting, and the ability to reach shallow crust with little or no contamination. Extension is in agreement both with the 1992 interpretation of White and Robinson (Sedimentary Geology, v. 80, p. 89–114) —that most Clarno Formation deposition occurred in extensional basins —and with other provinces in the broader Eocene magmatic belt.

Distribution of heavy metals and trace elements in soils of southwest Oregon, by R.A. Khandoker (M.S., Portland State University, 1997), 281 p.

Soil samples from 118 sites on 71 geologic units in southwest Oregon were collected and analyzed to determine the background concentrations of metals in soils of the region. Sites were chosen in areas that were relatively undisturbed by human activities. The U.S. Environmental Protection Agency-approved total-recoverable method was used to recover metals from samples for analysis. The 26 metals analyzed were: Ag, Al, As, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, La, Li, Mg, Mn, Mo, Na, Ni, Pb, Sb, Se, Tl, V, and Zn.

The Klamath Mountains, followed by the Coast Range, contain the highest soil concentrations of Al, Ca, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Ni, V, and Zn. Soils of the Coastal Plain and High Lava Plains contain the lowest concentrations of these metals. Unusually high soil As concentrations are found at two sites in the Klamath Mountains. All Be and Cd values above laboratory's reporting limits are also from the Klamath Mountains and Coast Range. Concentrations of soil Ba and La are fairly uniform throughout the region. Soil Pb levels are generally low with a few exceptions in the Klamath Mountains and Coast and Cascade Ranges. The region west of the Cascade Range has higher soil Hg contents than in the east.

Soil metal concentrations are generally much higher in the region west of the Cascade Range, excluding the Coastal Plain, than in the east, with the exception of Na because of more ultramafic rocks and a wetter climate. Soil metal concentrations are directly related to soil development, with the highest concentrations being found in well-developed Alfisols and Ultisols and the lowest concentrations in poorly developed Entisols. Most metals have similar averages and ranges of concentration compared to the rest of the United States. Metals with high values compared to the rest of the U.S. are Cr, Co, Cu, Mn, and Ni.

In general, Al, Co, Cr, Cu, Fe, La, Li, Mg, Na, Ni, and V are concentrated in the B horizon, while Ba, Ca, Hg, K, Mn, Pb, and Zn are concentrated in the A horizon.

Relationships between landscape stability, clay mineralogy, and stream turbidity in the South Santiam watershed, Western Cascades, Oregon, by John M. Pearch (M.S., Oregon State University, 2000), 199 p.

The clay mineralogy of suspended sediments (SS), recent sediments (RS), and soils was studied to understand the relationships between stream and reservoir turbidity and sediment delivery processes in the South Santiam watershed of the Western Cascades. Smectite is the most abundant clay mineral in SS and is the primary cause of persistent turbidity in municipal water treatment plants in the watershed. Smectite is common in many unstable soils of the watershed and is the dominant clay component in (1) deep-seated earthflows, (2) low-elevation or poorly drained (older alluvium) soils, and (3) altered volcanic host rocks of the Western Cascades. Smectite was less abundant in soils of older, stable geomorphic surfaces of the Willamette Valley (i.e., late Pleistocene Missoula flood deposits) that also included mixed proportions of chlorite, illite, and vermiculite. Pedogenic alteration was the source of smectite in (Pleistocene) terrace deposits. Advanced pedogenic alteration was common in older glacial soils containing abundant gibbsite, chloritic integrades, and kaolinite, where smectite was completely absent. Thus, clay mineralogy shows a strong relationship to geomorphology and landscape stability in the Western Cascades.

Suspended sediments were also sampled for clay mineral analysis during several peak flow periods of the winter 1998-1999 rainy season. Sample sites included inflowing tributaries to and outflow from Green Peter and Foster Reservoirs, as well as below-dam tributaries of the South Santiam River. Most importantly, the clay mineralogy of most sampled tributaries contained dominant smectite and included minor amounts of chlorite, illite, kaolinite, and zeolite (heulandite). Smectite in the SS of major inflowing tributaries and Foster outflow was derived mostly from active unstable, deep-seated earthflows present in the upper South and Middle Santiam sub-watersheds. The minor chlorite, kaolinite, and illite components in the Middle Santiam River represent widespread propylitic alteration of the volcanic host rocks, commonly eroded by debris flows and debris avalanches. Below-dam tributaries flowing into the lower South Santiam River were also dominated by smectite with minor amounts of kaolinite. These clays reflected continuous bank erosion of poorly drained soils.

The SS clay mineralogy of the Foster outflow of Foster Reservoir is generally enriched in smectite relative to the SS of inflowing streams. This indicates that coarse clay particles (kaolinite, illite, chlorite, and zeolite) tend to settle from suspension during water storage in the reservoir. Dam outflow differs in mineralogy from below-dam streams (enriched in kaolinite and halloysite relative to Foster outflow), and is considerably different from sediment derived from Missoula flood deposits (illite, chlorite, and vermiculite).

Source area and storm intensity affect relationships between turbidity and SS clay mineralogy in water treatment plants of the South Santiam municipal watershed. The clay minerals present in each water treatment plant correspond to different sources: (1) chronic long-term earthflow movement, (2) episodic short-term debris flow activation, (3) reservoir release periods, (4) chronic bank erosion of poorly drained soils, or (5) bank slump of Missoula flood deposits. Even though the clay mineralogy of suspended sediments may vary spatially or temporally for a given storm event, erosion of active, deep-seated earthflows is by far the dominant controlling mechanism on suspended sediment regimes throughout the watershed. ☐

EDITOR'S CORNER

Birth pangs

The start of the department's latest map series, **Reconnaissance Maps**, on December 4, 2001, completes our triad of geologic map offerings — the "Geologic Map Series" (GMS), "Interpretive Map Series" (IMS), and "**Reconnaissance Map Series**" (RMS).

However, it did not come without a few painful slips for which this editor asks your forgiveness. In particular, the erroneous affiliation – on the title page! — of coauthor W.H. Taubeneck with the University of Oregon instead of Oregon State University is reason for much contrition. Apologies, Professor Taubeneck!

Corrections have been made by now, but **if you obtained an uncorrected copy of RMS-1**, please do not hesitate to contact this editor or the Nature of the Northwest Information Center to request a corrected version.

Reminders and news

The **Oregon Academy of Science** will hold its annual **meeting for 2002** on February 23 at Pacific University in Forest Grove—the westernmost part of the Portland Metropolitan Area. Chair of the Geology Section is Charles Lane of Southern Oregon University, who can be reached at the following e-mail address: lane@sou.edu or by phone at (541) 552-6479.

One week earlier, on February 16, 2002, the **Oregon Junior Academy of Science** will meet at Western Oregon University. Contact person is Adele Schepige at schepia@wou.edu or (503) 838-8485.

Basalt is in many photos by **Terry Toedtemeier**, curator of photography at the Portland Art Museum. We were fortunate to get to print one picture on the cover of the September 1995 issue of *Oregon Geology*. Now Terry is one of the three Oregonians who were selected for **Flintridge Foundation 2001/2002 Awards for Visual Artists**, each carrying an unrestricted grant of $25,000. Congratulations! More information can be found at www.FlintridgeFoundation.org.

The Oregon State Office of the **U.S. Bureau of Land Management** announces a **change of address**: The new address is 333 SW First Avenue, Portland, OR 97204. (The mailing address is unchanged: BLM, Oregon State Office, P.O. Box 2965, Portland, OR 97208.) The **telephone prefix** for all BLM numbers has also changed, to (503) **808**-XXXX (last four digits unchanged).

In its new location, the Robert Duncan Plaza, the BLM is joining the USDA Forest Service Regional Office. Maps, mining records, and official public land records can be obtained from the BLM Land Office located on the first floor of the Robert Duncan Plaza.

At home

If you wish to find DOGAMI publications on the **DOGAMI home page**, best use the publication lists. Searching is possible but calls for patience. If you wish to purchase publications, go to the address of the Nature of the Northwest and look under Store-Maps and Reports, which covers all DOGAMI serial publications. ☐

Index to OREGON GEOLOGY, volume 63, 2001

Numbers refer to issue and first page of entry. Most subject entries cross-referenced to authors (in parentheses).

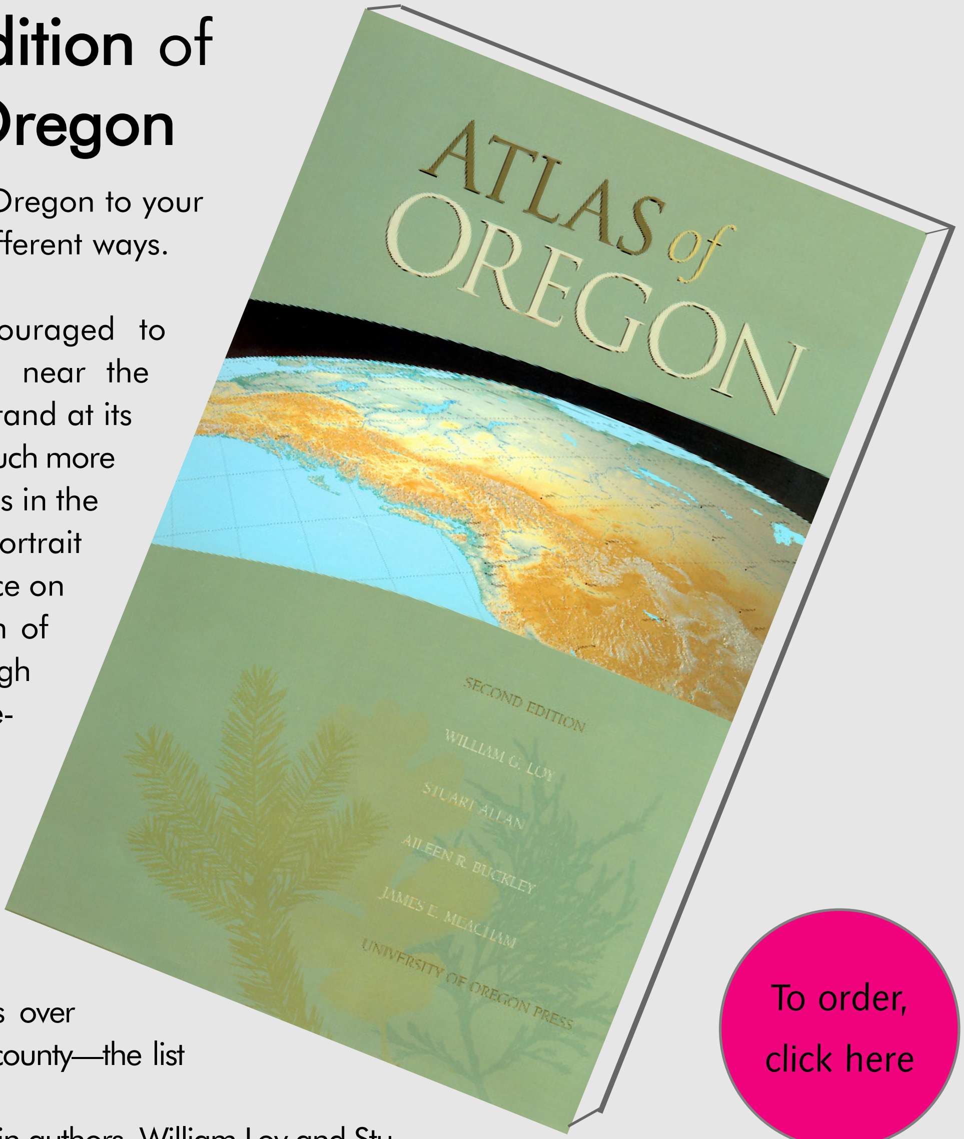
Abstracts of theses.....1:12; 3:100; 4:126
Allan, J.C., joins DOGAMI Coastal Field Office.....2:67
Appel, M., Alkaline and peraluminous intrusives in the Clarno Formation around Mitchell, Oregon: Ramifications on magma genesis and subduction tectonics (thesis abs.).....4:126
Campbell, K.W., and Wang, Z., Scenario ground-motion maps for western Oregon and comparison of scenario, probabilistic, and design response spectra for Seaside and Portland, Oregon.....4:107
Carson, R.J., Where the Rockies meet the Columbia Plateau: Geologic field trip from the Walla Walla Valley to the Wallowa Mountains, Oregon.....1:13
Clark, J.L., Effects of urbanization on streamflow in three basins in the Pacific Northwest (thesis abs.).....1:12
—Geologic notes—gleanings from recent publications that may be of interest.....2:65, 3:99, 4:125
Columbia River Basalt Group (Petcovic and Grunder).....3:71
DOGAMI news:
—About using the DOGAMI home page on the Internet.....4:128
—Allan, J.C., joins DOGAMI Coastal Field Office.....2:67
—Archie Strong, volunteer ....(turned 91) 1:35; (in memoriam) 3:103
—Errata: Omitted from index of v. 62 (2000).....1:35
—Mined Land Reclamation Awards of 2001.....3:97
—*Oregon Geology* goes digital.....3:70; 4:131
—Reconnaissance Map Series launched with some slips.....4:128
—USGS OFRs from web site on paper in DOGAMI library.....3:103
Douglas, W.H., The distribution of naturally occurring soil radionuclides and radon potential of southwest Oregon (thesis abs.) 3:101
Earthquakes:
—A homeowner's guide to earthquake safety (highlight).....1:20
—Methodology for regional seismic damage assessment and retrofit planning for existing buildings (McCormack).....3:100
—Portland Hills fault:.....2:39; 2:47; 3:102
—Preparation pays (reprinted note from BPA Journal).....2:59
—Scenario ground-motion maps (Campbell and Wang).....4:107
—Seismic rehabilitation at Oregon State Library (Robinson).....2:55
—The HAZUS-RVS form (Theodoropoulos and Wang).....1:3
Ferns, M.L., coauthor, Van Tassell and others.....3:77
Field trip guides:
—Wallowa/Blue Mountains (Carson).....1:13
—Newberry Volcano roadside guide (highlight).....1:20
Grunder, A.L., coauthor, Petcovic and Grunder.....3:71
HAZUS risk studies (Theodoropoulos and Wang).....1:3
Hemphill-Haley, M.A., coauthor.....2:39; 2:47
Hiking Oregon's and Washington's geology (highlight).....2:54
Khandoker, R.A., Distribution of heavy metals and trace elements in soils of Southwest Oregon (thesis abs.).....4:127
Lenegan, R.J., Middle Cretaceous sedimentation and tectonics, Mitchell inlier, Wheeler County, central Oregon (thesis abs.)..3:101
Liberty, L.M., coauthor, Wong and others.....2:39
Licciardi, J.M., Alpine glacier and pluvial lake records of late Pleistocene climate variability, W. United States (diss. abs.)....3:100
Madin, I.P., and Hemphill-Haley, M.A., The Portland Hills fault at Rowe Middle School (new evidence).....2:47
Madin, I.P., coauthor, Wong and others.....2:39
McConnell, V., coauthor, Van Tassell and others.....3:77
McCormack, T., A methodology for regional seismic damage assessment and retrofit planning for existing buildings (diss. abs.)..3:100
Mined Land Reclamation: Statewide Annual Reclamation Awards 3:97
Newberry Volcano, Roadside guide by R.A. Jensen (highlight).....1:20
Newton, V.C., Letter re. Wong and others, Portland Hills fault (v. 62, no. 3, p. 39).....3:102
Paleoclimate:
—Distribution of selected conifer taxa (Tattersall).....3:100
—Alpine glacier and pluvial lake climate variability (Licciardi).....3:100
Paleontology: Imbler fish fossils (Van Tassell and others).....3:77
Pearch, J.M., Relationships between landscape stability, clay mineralogy, and stream turbidity in the South Santiam watershed (thesis abs.).....4:127
Petcovic, H.L., and Grunder, A.L., Partial melting of tonalite at the margins of a Columbia River Basalt Group dike, Wallowa Mountains, northeastern Oregon.....3:71
Places to see:
—Newberry Crater.....1:36
—Hug Point.....2:68
—North Umpqua River.....3:104
—Mitchell, Wheeler County, area.....4:130
—Moccasin Lake (omitted in index for 2000).....v. 62, no. 4, p. 124
Portland, Design response spectra (Campbell and Wang).....4:107
Publications by DOGAMI, announced:
—Errata: Omitted from index of v. 62 (2000):
——IMS-13, Tsunami hazard map, Gold Beach area.....4:123
——IMS-17, Slope instability, Salem Hills, Marion County.....4:123
——IMS-18, Slope instability, Eola Hills, Polk County.....4:123
—IMS-19, Rel. earthquake hazard map, Klamath Falls area.....1:2
—O-95-09 through O-95-66, O-97-31, O-97-32, tsunami hazard maps, reissued on CD.....3:103
—O-00-04, Guidelines for engineering geologic reports
—O-01-01, Mist Gas Field Map, 2001 edition.....2:38
—O-01-02, Nisqually, Washington, earthquake report.....2:67
—O-01-03, Coastal erosion hazard, Tillamook County.....4:124
—O-01-04, Coastal erosion hazard, Clatsop Plains.....4:124
—O-01-05, Earthquake and landslide hazard, Benton Co......4:124
—O-01-06, Seismic hazard and risk, Tillamook Co......4:124
—RMS-1, Reconnaissance geol. Map, La Grande quad......4:106
—Special Paper 34, Slope failures in Oregon.....2:38
Publications by others, announced and reviewed:
—Geologic notes—gleanings from recent publications that may be of interest (Clark).....2:65, 3:99, 4:125
—Loy and others, *Atlas of Oregon* (highlight).....4:130
—Orr, W.N., and Orr, E.L., *Geology of the Pacific Northwest*, 2d ed. (review by Streck).....3:76
—AGI Environmental Awareness Series: *Metal Mining, Groundwater, Sustaining Our Soils and Society* (highlight).....3:88
—Babcock and Carson, Hiking Washington's geology (highlight)..2:54
—Bishop, E.M., Hiking Oregon's geology (highlight).....2:54
—Jensen, R.A., Roadside guide to the geology of Newberry Volcano (highlight).....1:20
—Institute for Business and Home Safety, A homeowner's guide to earthquake safety (highlight).....1:20
Robinson, K., Seismic rehabilitation in the renovation of the Oregon State Library, in Salem.....2:55
Rogers, J.P., Analysis of tephra components from Rock Mesa, South Sister volcano, Oregon: Implications for evolution of the explosive phase (thesis abs.).....3:100
Rowe Middle School: Fault evidence (Madin & Hemphill-Haley)....2:47
Seaside, Design response spectra (Campbell and Wang).....4:107
Sedimentology:
—Clay mineralogy, South Santiam watershed (Pearch).....4:127
—Fourier grain-shape analysis, S. Oregon (Torley).....2:60
Smith, G.R., coauthor, Van Tassell and others.....3:77
Soils:
—Clay mineralogy, South Santiam watershed (Pearch).....4:127
—Heavy metals and trace elements, SW Oregon (Khandoker)....4:127
Streck, M., Geology of the Pacific Northwest, 2d ed. (review).....3:76
Tattersall, A.M., Changes in the distribution of selected conifer taxa in the Pacific Northwest during the last 20,000 years (thesis abs.).....3:100
Theodoropoulos, C., and Wang, Y., The HAZUS-RVS form: A new HAZUS-compatible rapid visual screening form for buildings......1:3
Torley, R.F., Results of a new method of Fourier grain-shape analysis, detrital quartz grains in sediments, Jackson County, Oregon....2:60
Van Tassell, J., Ferns, M.L., McConnell, V., and Smith, G.R., The mid-Pliocene Imbler fish fossils, Grande Ronde Valley, Union County, Oregon, and the connection between Lake Idaho and the Columbia River.....3:77
Volcanology: Tephra components from Rock Mesa (Rogers).....3:100
Wallowa batholith: partial melting (Petcovic and Grunder).....3:71
Wang, Y., coauthor, Theodoropoulos a nd Wang.....1:3
Wang, Z., coauthor, Campbell and Wang.....4:107
Wong, I.G., Hemphill-Haley, M.A., Liberty, L.M., and Madin, I.P., The Portland Hills fault: An earthquake generator or just another old fault?.....2:39

Highlighting Recent Publications

Now available from The Nature of the Northwest Information Center

Second Edition of Atlas of Oregon

will bring the State of Oregon to your mind in a hundred different ways.



"The reader is encouraged to browse," this invitation near the end of the book could stand at its beginning: The *Atlas* is much more than a collection of maps in the common sense: It is a portrait of the state, from its place on our globe to the growth of downtown Portland through time, from its geologic beginnings hundreds of millions of years ago to currently protected wild and scenic areas, from the earliest traces of human habitation to the ratio of males to females over 60 years of age in each county—the list could go on and on.

It is obvious that the main authors, William Loy and Stuart Allen, who already produced the first edition 25 years ago, did mean it when they concluded their introduction with the statement: "The *Atlas* . . . is also the authors' tribute to this wonderful state."

Since the time of the first edition, computer technology has made the creation of images much easier, and so most of the information in this edition is visual, with just enough text to make the many kinds of images easy to understand. Interspersed short essays help to keep the detail information in perspective.

The *Atlas of Oregon* is available in both hardcover ($100) and softcover ($60) editions. It has 301 pages and is approximately 10x14 inches in size. Look for "Books" on the naturenw.org web page.

To order, click here

Publication of *Oregon Geology* will continue!

Budget cutbacks and changing technology require that we make changes to the magazine, but we are fully committed to keeping it alive.

Over the timespan of (so far) sixty-three years, the appearance, the subject emphasis, even the name have undergone changes, reflecting the changes of the times in which we live, the changes of the Department's role in them, and the changes of the role of the earth sciences for the welfare of Oregon. What has not changed is the need for the services the magazine has provided-and will not stop providing.

We are now implementing another major change—we hope it will be the last one for a while: Increased demand for the talents of our staff editor, and a reduction in resources mean that we can no longer publish four edited issues a year. One possibility was that we would have to stop production of *Oregon Geology*, which we are not willing to do. Instead, we will now publish two issues a year as a journal on our website.

We will also predominantly compile rather than extensively edit the material submitted. Consequently, we are now asking that material be submitted to us in production-ready quality. For details and the new publication schedule, see "Information for Contributors" below.

We believe *Oregon Geology* is an important publication, offering a unique and suitable place to share information about Oregon that is useful for the geoscience community and ultimately for all Oregonians. Please help us by continuing to read the journal *Oregon Geology* and submit articles.

Information for Contributors

Oregon Geology is designed to reach a wide spectrum of readers in the geoscience community who are interested in all aspects of the geology of Oregon and its applications. Informative papers and notes, particularly research results are welcome, as are letters or notes in response to materials published in the journal.

Two copies of the manuscript should be submitted, one paper copy and one digital copy. While the paper copy should document the author's intent as to unified layout and appearance, all digital elements of the manuscript, such as text, figures, and tables should be submitted as separate files. Hard-copy graphics should be camera ready; photographs should be glossies. Figure captions should be placed 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*.) References are limited to those cited. Pre-submission reviewers should be included in the acknowledgments. In view of increasing restrictions on editing time, adherence to such style will be required more strictly than in the past.

For the foreseeable future and beginning with volume 64 for the year 2002, *Oregon Geology* will be published twice annually on the Department web site http://www.oregongeology.com, a spring issue on or shortly after March 15 and a fall issue on or shortly after October 1. Deadline for submission of scientific or technical articles will be January 31 and August 15, respectively. Such papers will be subjected to outside reviews as the Department will see appropriate.

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

Authors will receive a complimentary CD with a PDF version of the issue containing their contribution.

Manuscripts, letters, notices, and photographs should be sent to Klaus Neuendorf, Editor, *Oregon Geology*, 800 NE Oregon Street, Portland, OR 97232-2162, e-mail contact klaus.neuendorf@dogami.state.or.us.

Please send us your photos

Since we have started printing color pictures in *Oregon Geology*, we are finding ourselves woefully short of good color photographs showing geologic motifs in Oregon. That is why we invite your contributions.

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

If you have any photos you would like to share with other readers, please send them to us (Editor, *Oregon Geology*, 800 NE Oregon Street, Portland, OR 97232-2162, # 28; e-mail klaus.neuendorf@dogami.state.or.us.) with information for a caption. If they are used, publication and credit to you is all the compensation we can offer. If you wish to have us return your materials, please include a self-addressed envelope.

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

Mitchell area, Wheeler County, land of Oregon's geologic roots.

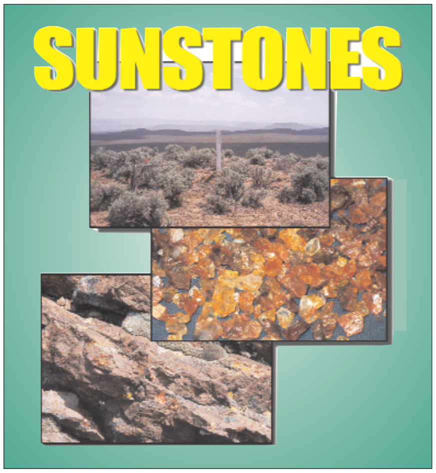
The picture, taken from a point near the junction of State Highway 207 with U.S. Highway 26 just west of Mitchell, offers a view to the southwest toward Bailey Butte in the foreground, White Butte behind it, and the north flank of the Ochoco Mountains in the background.

Here we are on the southwestern edge of the Blue Mountains province and in a region whose underpinnings contain some of the oldest rocks and fossils of the state. These basement rocks are considered to be part of the Baker terrane—fragments of 250-million-year-old oceanic islands that wandered a long way across the ancestral Pacific Ocean before crunching into the North American landmass near the Oregon-Idaho border. Thus began the process that extended the continent farther and farther to the west and created most of the land on which we live today.

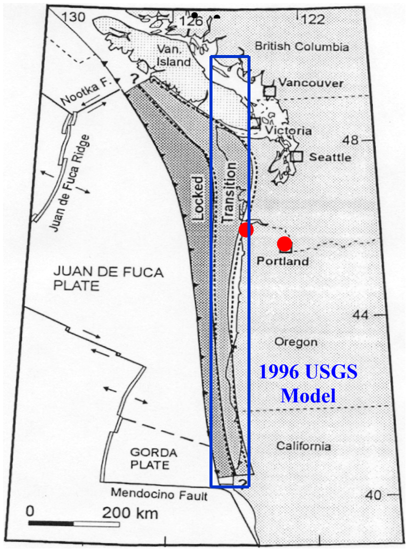
Much of this area is underlain by Cretaceous marine sediments that were deposited in 100-million-year-old offshore basins The buttes seen in the photo mark the deeply eroded roots of 40- to 50-million-year-old volcanoes. Folding, faulting, continental volcanism, uplift, and erosion over the last 50 million years have combined to produce an extremely complex and interesting geologic province. (Photo contributed by one of our readers: Jamie Sands of Pendleton)

Access: Mitchell is situated about 50 mi east from Prineville on U.S. Highway 26, which crosses the entire state, from the northern coast near Seaside to the Idaho border at Ontario. From Mitchell, one can easily reach the three units of the John Day Fossil Beds National Monument: the Painted Hills Unit to the northwest, the Sheep Rock Unit (headquarters) to the east near Picture Gorge, and, a little farther, the Clarno Unit to the north. Useful, if somewhat outdated guides, maps, pictures (great aerial view of Mitchell!), and exploration hints, can be found in an unpretentious booklet produced by the Geological Society of the Oregon Country for its President's Campout in 1969 ($1 at the Nature of the Northwest Information Center).

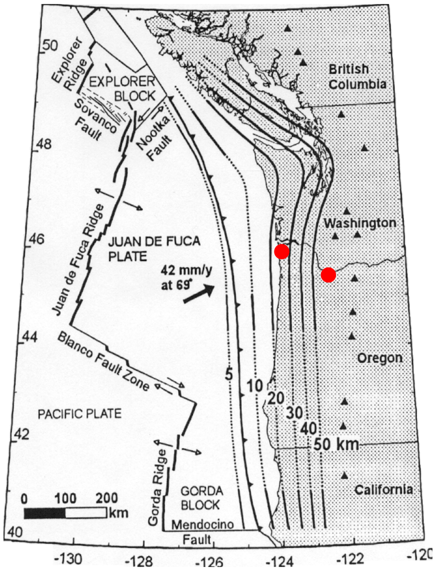
Color reference for illustrations, *Oregon Geology*, volume 63, number 4 (2001)



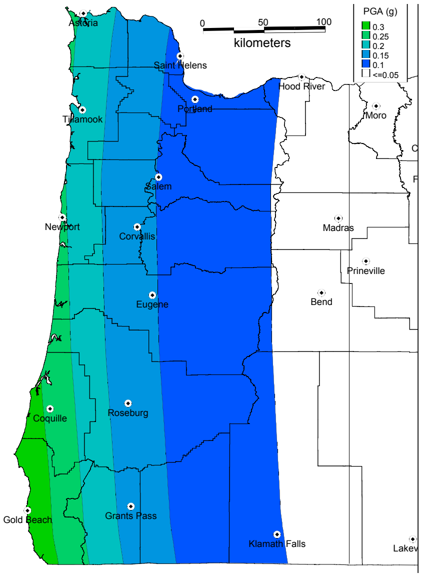
Front cover



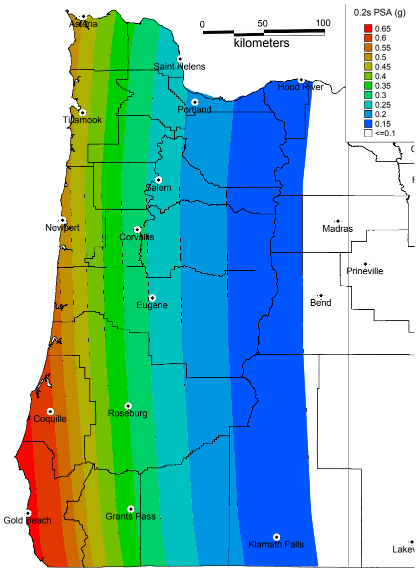
Page 108



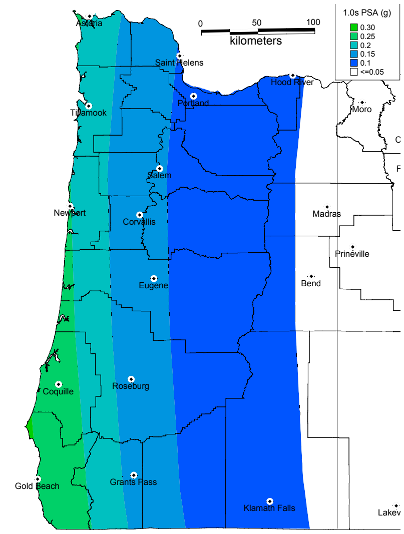
Page 109



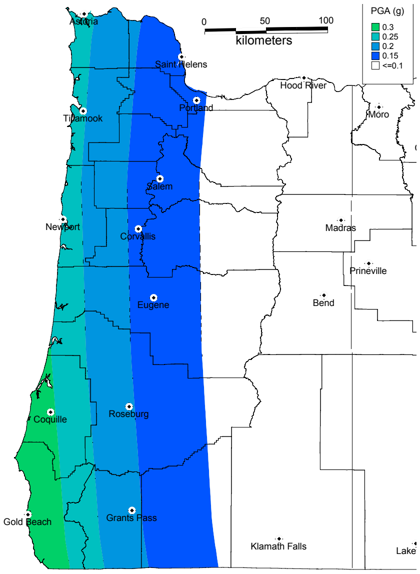
Page 110



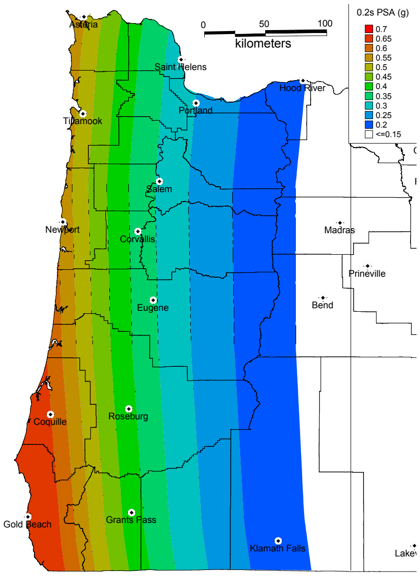
Page 111



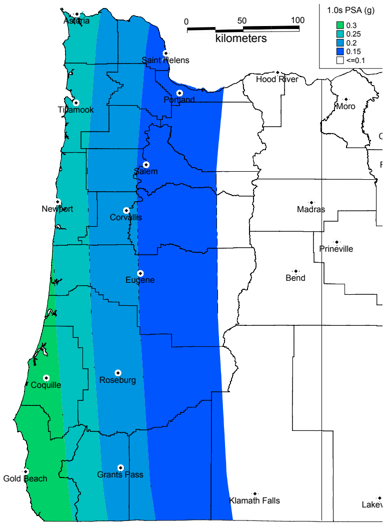
Page 112



Page 113

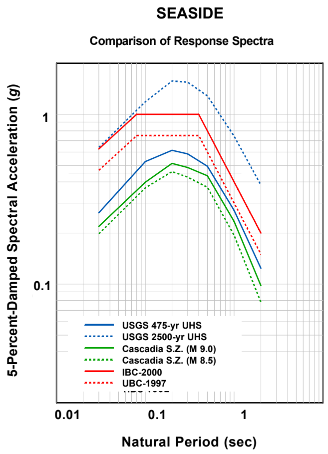


Page 114

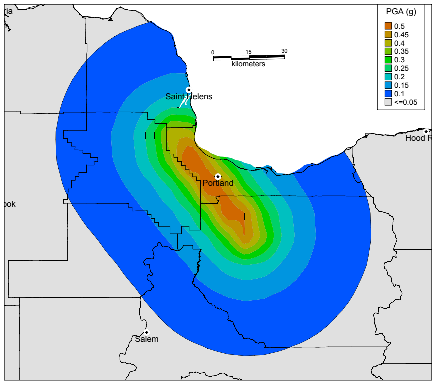


Page 115

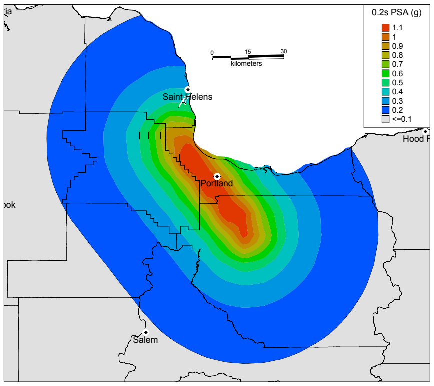
Color reference for illustrations, *Oregon Geology*, volume 63, number 4 (2001)



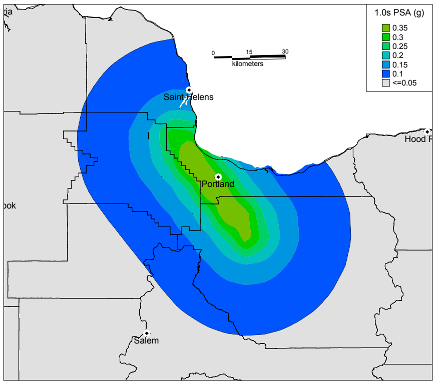
Page 117



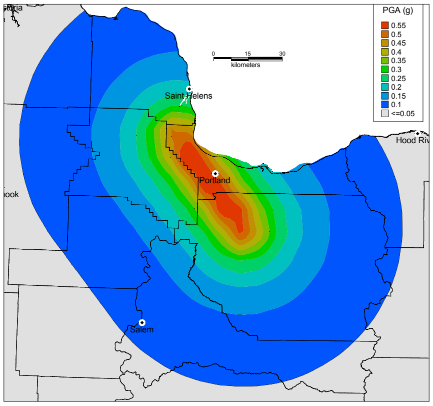
Page 119, top



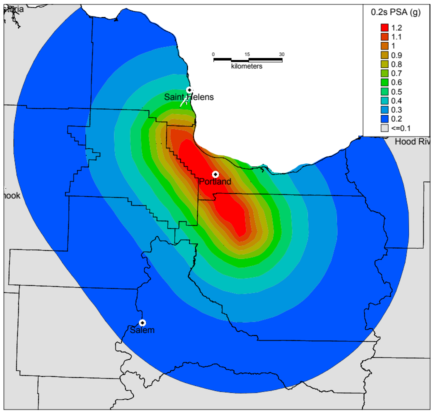
Page 119, bottom



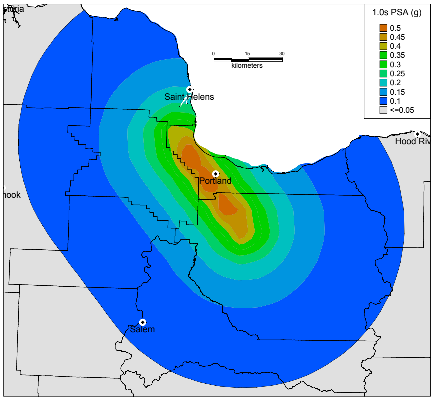
Page 120, top



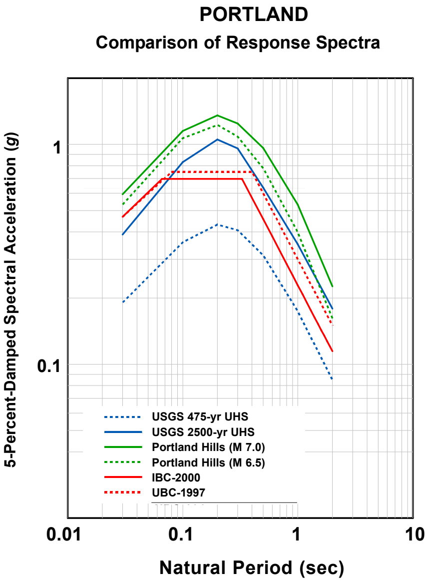
Page 120, bottom



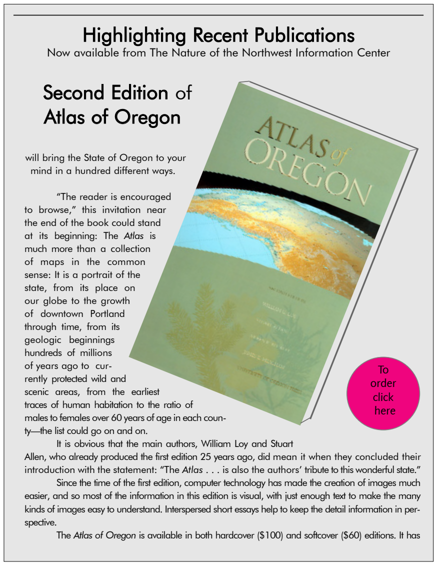
Page 121, top



Page 121, bottom



Page 122



Highlighting Recent Publications

Now available from The Nature of the Northwest Information Center

Second Edition of
Atlas of Oregon

will bring the State of Oregon to your mind in a hundred different ways.

"The reader is encouraged to browse," this invitation near the end of the book could stand at its beginning: The *Atlas* is much more than a collection of maps in the common sense: It is a portrait of the state, from its place on our globe to the growth of downtown Portland through time, from its geologic beginnings hundreds of millions of years ago to currently protected wild and scenic areas, from the earliest traces of human habitation to the ratio of males to females over 60 years of age in each county—the list could go on and on.

It is obvious that the main authors, William Loy and Stuart Allen, who already produced the first edition 25 years ago, did mean it when they concluded their introduction with the statement: "The *Atlas* . . . is also the authors' tribute to this wonderful state."

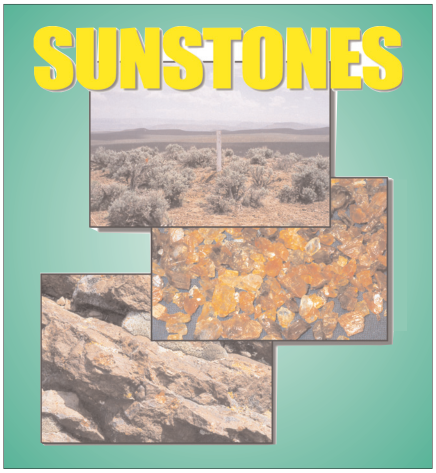
Since the time of the first edition, computer technology has made the creation of images much easier, and so most of the information in this edition is visual, with just enough text to make the many kinds of images easy to understand. Interspersed short essays help to keep the detail information in perspective.

The *Atlas of Oregon* is available in both hardcover ($100) and softcover ($60) editions. It has

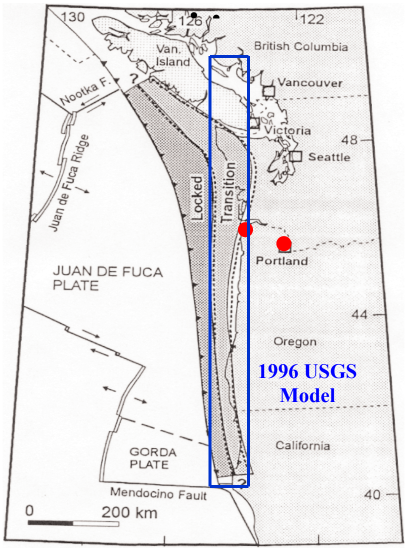
Page 130

Page 132 (sky cropped)

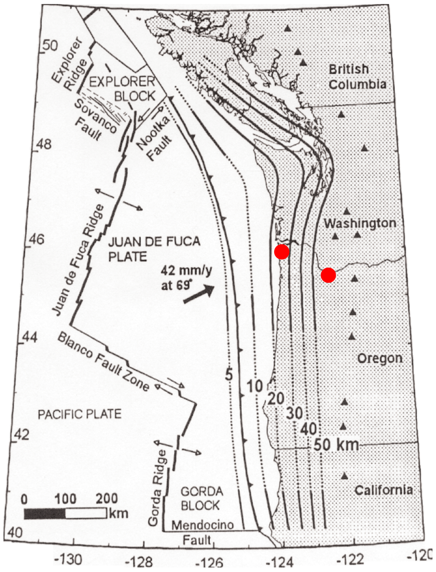
Color reference for illustrations, *Oregon Geology*, volume 63, number 4 (2001)



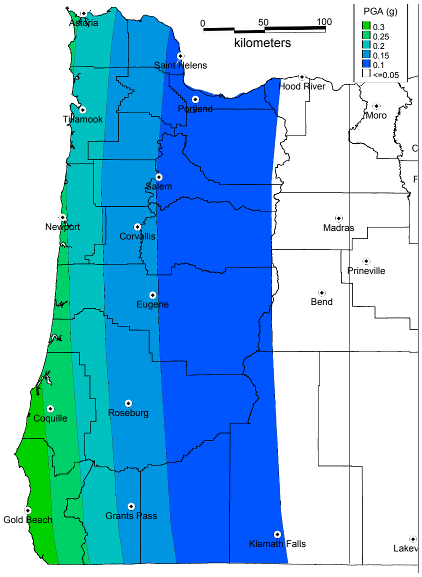
Front cover



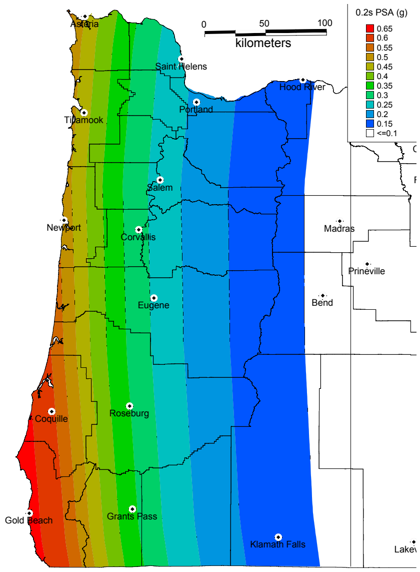
Page 108



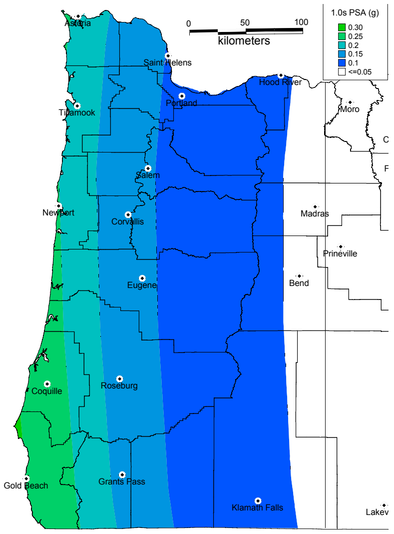
Page 109



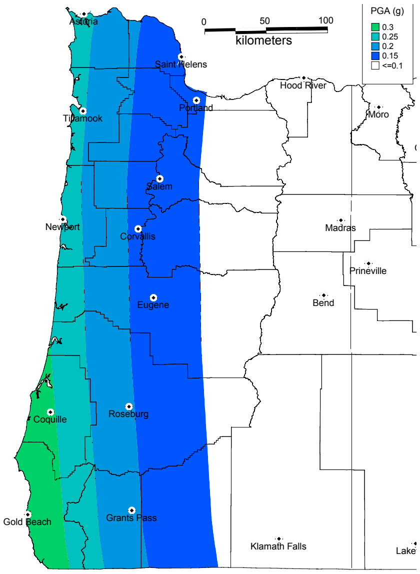
Page 110



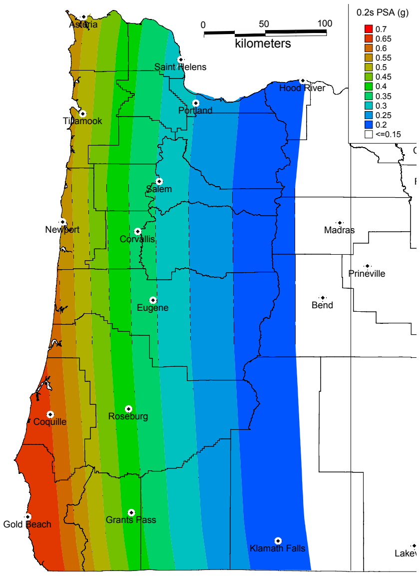
Page 111



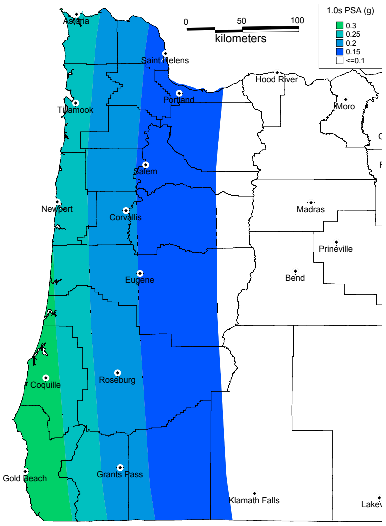
Page 112



Page 113

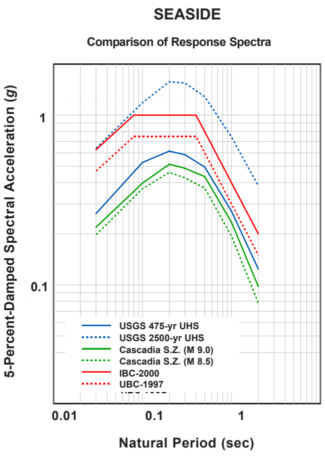


Page 114

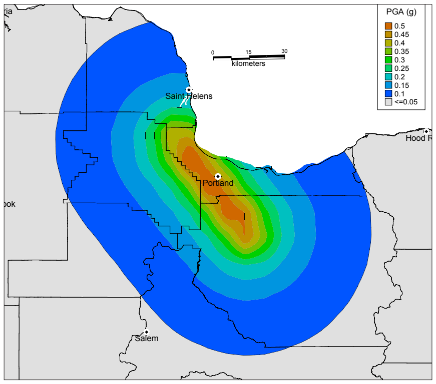


Page 115

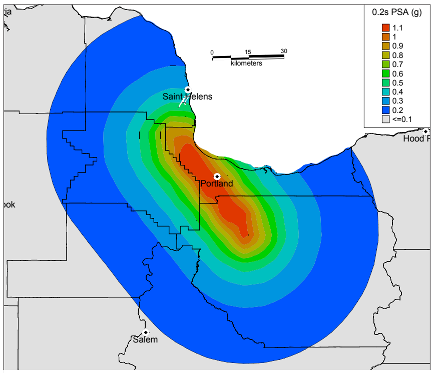
Color reference for illustrations, *Oregon Geology*, volume 63, number 4 (2001)



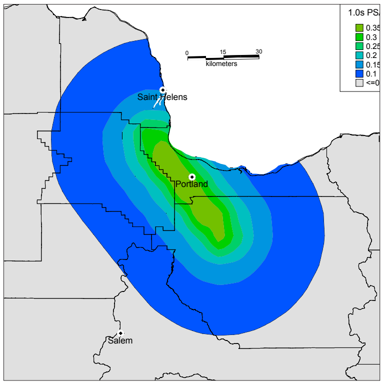
Page 117



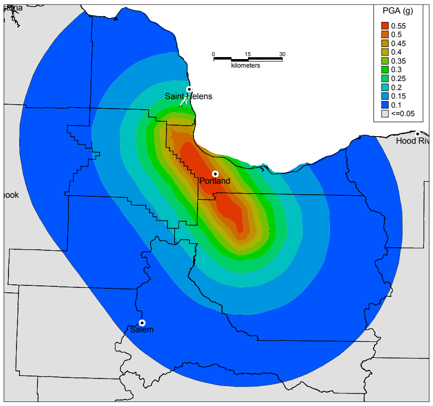
Page 119, top



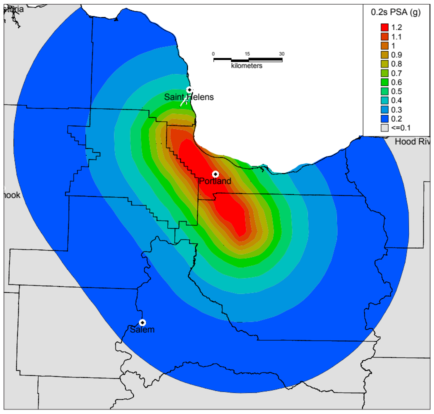
Page 119, bottom



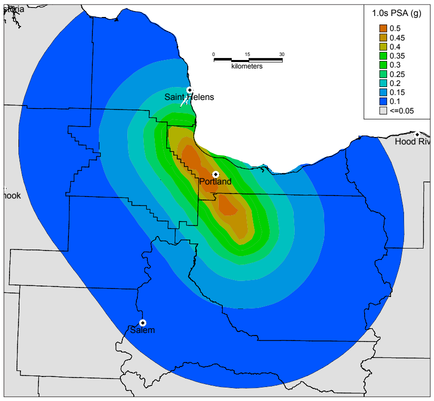
Page 120, top



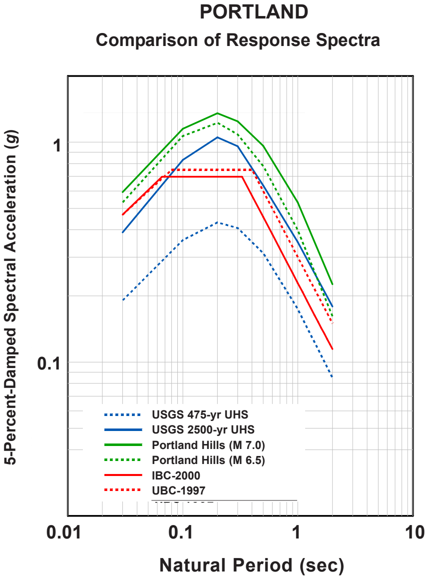
Page 120, bottom



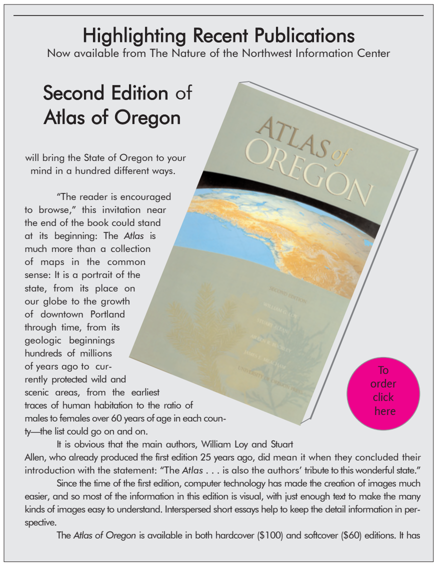
Page 121, top



Page 121, bottom



Page 122



Highlighting Recent Publications

Now available from The Nature of the Northwest Information Center

Second Edition of Atlas of Oregon

will bring the State of Oregon to your mind in a hundred different ways.

"The reader is encouraged to browse," this invitation near the end of the book could stand at its beginning: The *Atlas* is much more than a collection of maps in the common sense: It is a portrait of the state, from its place on our globe to the growth of downtown Portland through time, from its geologic beginnings hundreds of millions of years ago to currently protected wild and scenic areas, from the earliest traces of human habitation to the ratio of males to females over 60 years of age in each county—the list could go on and on.

It is obvious that the main authors, William Loy and Stuart Allen, who already produced the first edition 25 years ago, did mean it when they concluded their introduction with the statement: "The *Atlas* . . . is also the authors' tribute to this wonderful state."

Since the time of the first edition, computer technology has made the creation of images much easier, and so most of the information in this edition is visual, with just enough text to make the many kinds of images easy to understand. Interspersed short essays help to keep the detail information in perspective.

The *Atlas of Oregon* is available in both hardcover ($100) and softcover ($60) editions. It has

Page 130

Page 132 (sky cropped)