# OREGON GEOLOGY

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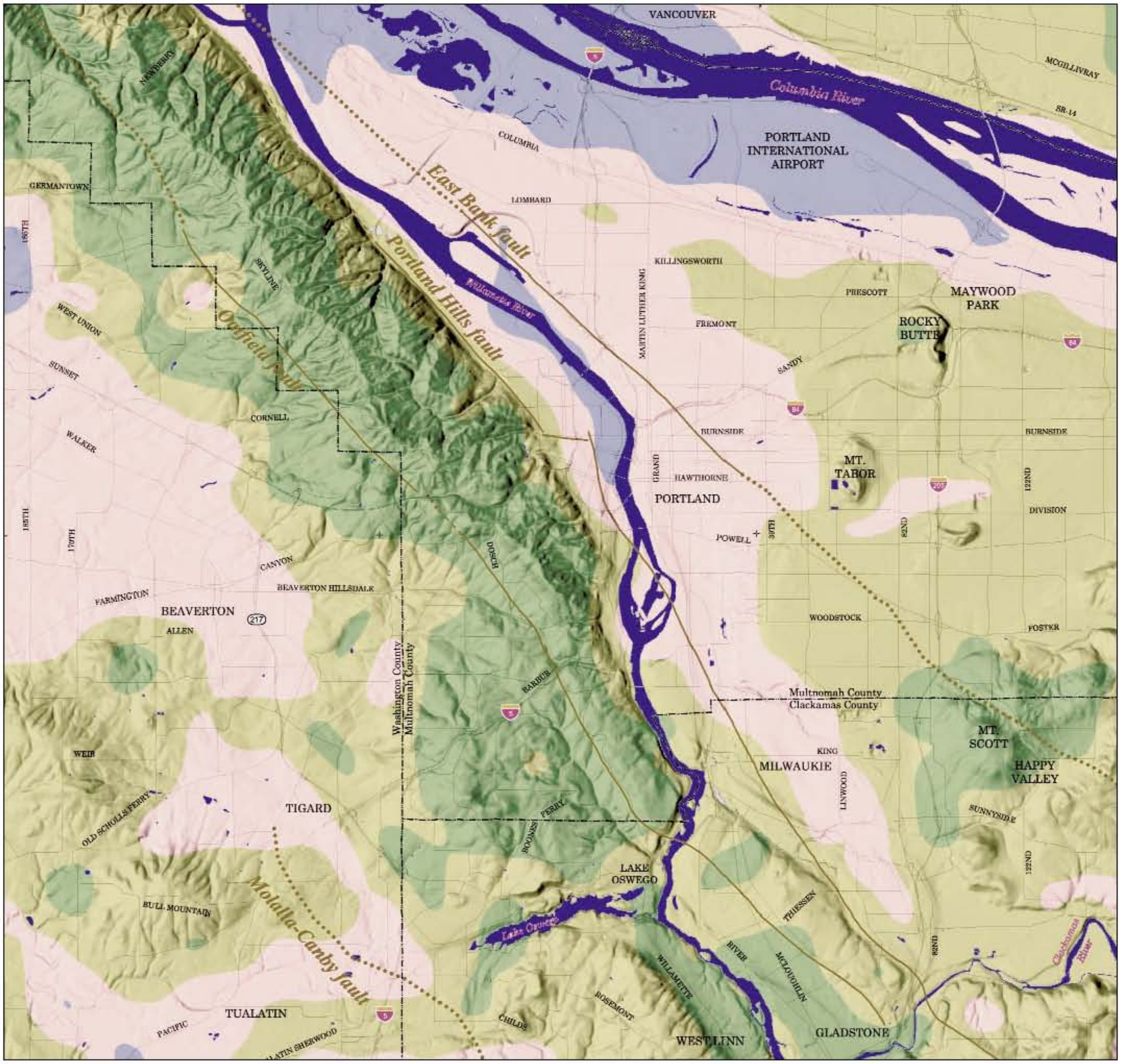


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✧The Portland Hills fault✧

✧Seismic rehabilitation at the Oregon State Library in Salem✧

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

# DOGAMI PUBLICATIONS

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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-

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## 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,

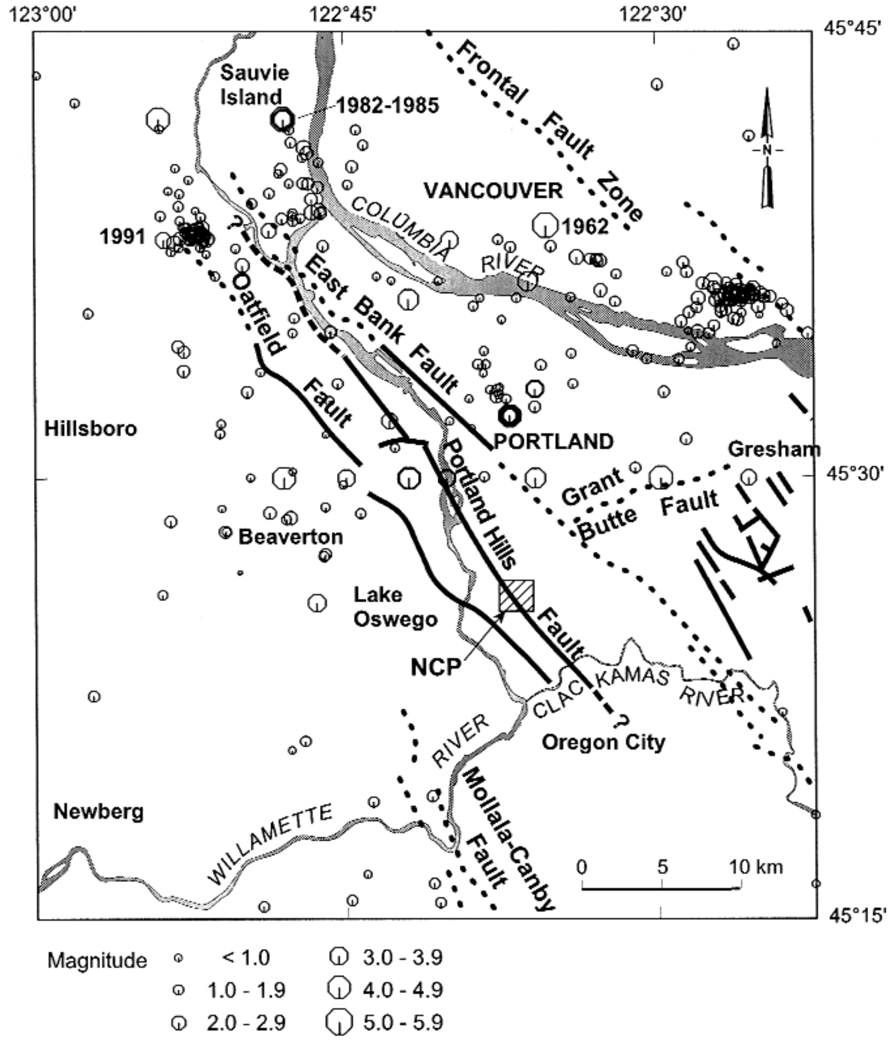



**Figure 2. Portland Hills fault zone and historical seismicity in the vicinity of Portland, 1841 to 2000. Faults shown are those considered to be potentially active by Wong and others (2000b). Site NCP is also shown. Earthquake symbol size is a function of magnitude. The largest event shown is the 1962 $M_L$ 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 ($M_L$ ≤2.8) and 1991 at the north end of the Portland Hills ($M_L$ ≤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 (70º) 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 ($M_W$ ≥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

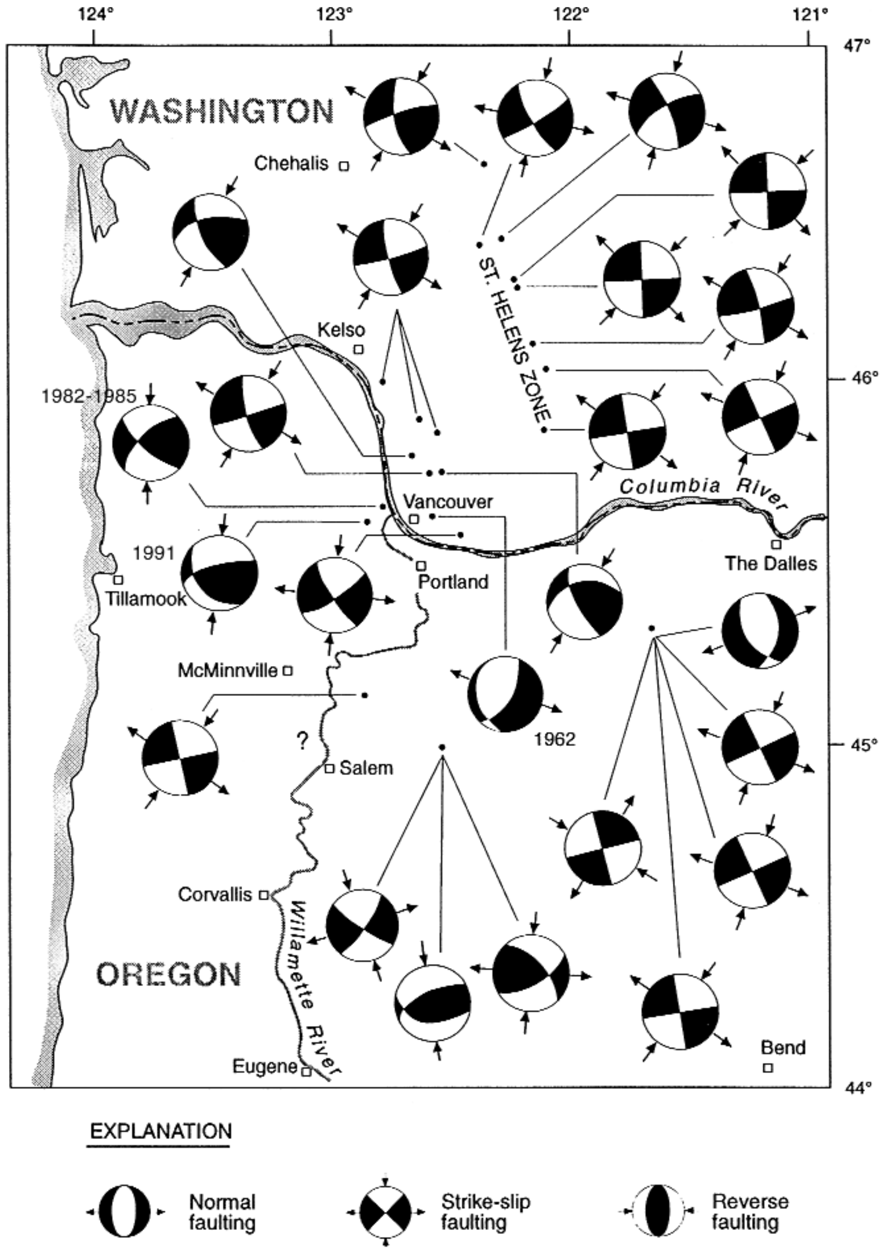



**Figure 3. Crustal earthquake focal mechanisms of northwestern Oregon and southwestern Washington. Most of the mechanisms exhibit strike-slip and oblique-reverse faulting in response to a N-S to NE-SW-directed maximum compressive stress. Figure is modified from and data sources described in Wong (1997).**

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

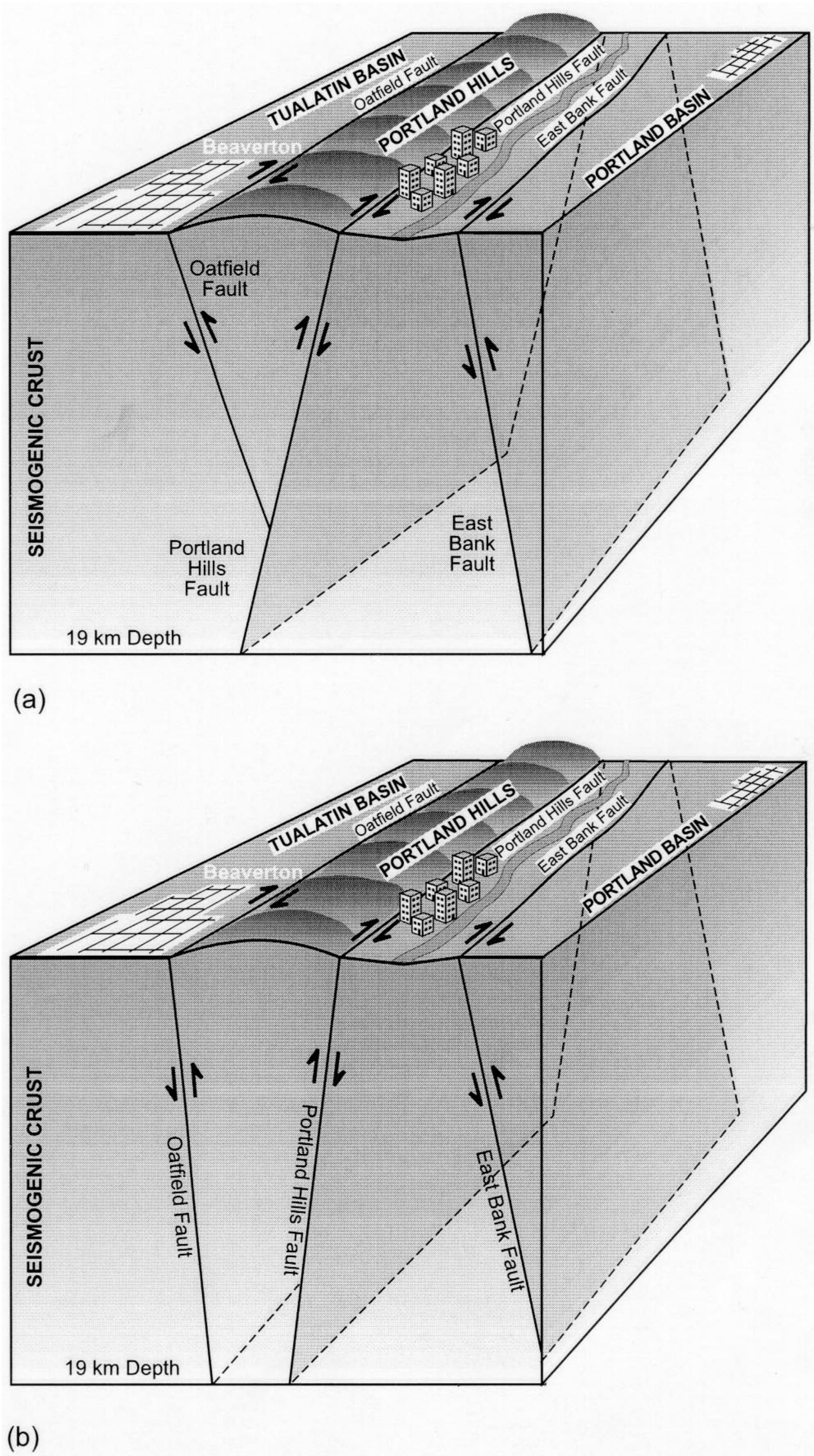



**Figure 4. Schematic block diagram of the Portland Hills fault zone. Shown are two possible interpretations of its subsurface geometry. A third model is that the East Bank fault dips to the west and is structurally connected to the Portland Hills and/or Oatfield faults.**

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

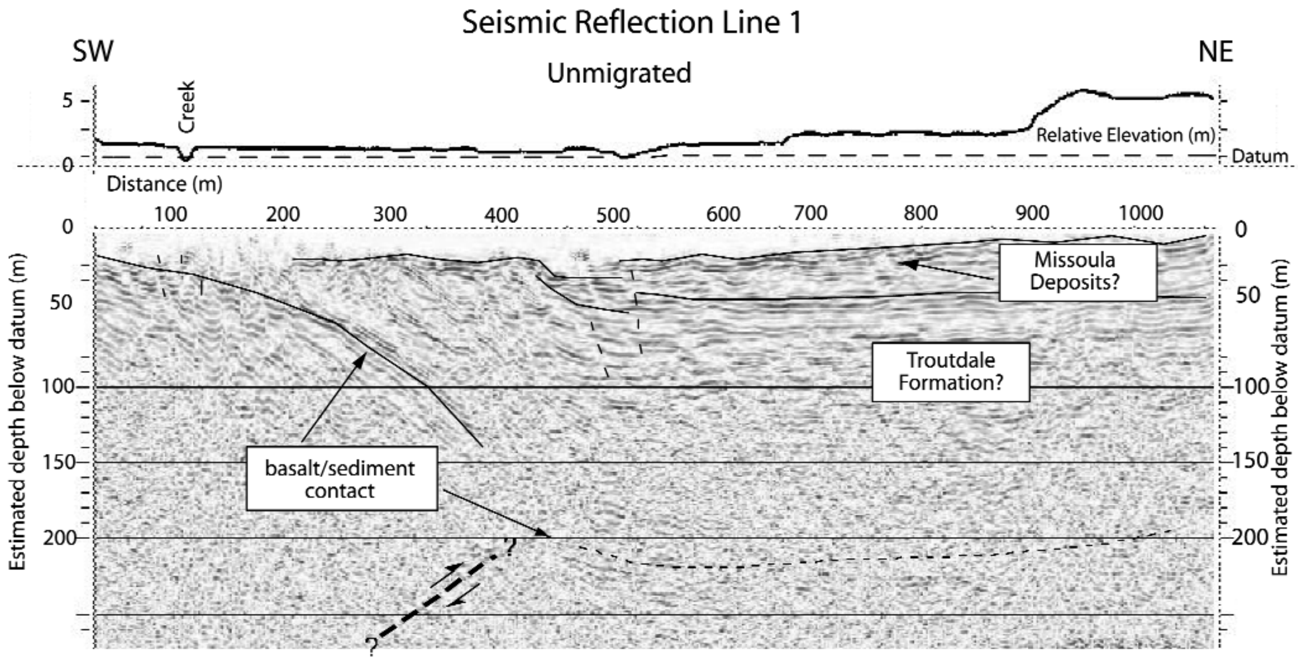



**Figure 5. High-resolution seismic reflection profile at the North Clackamas Park.**

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.

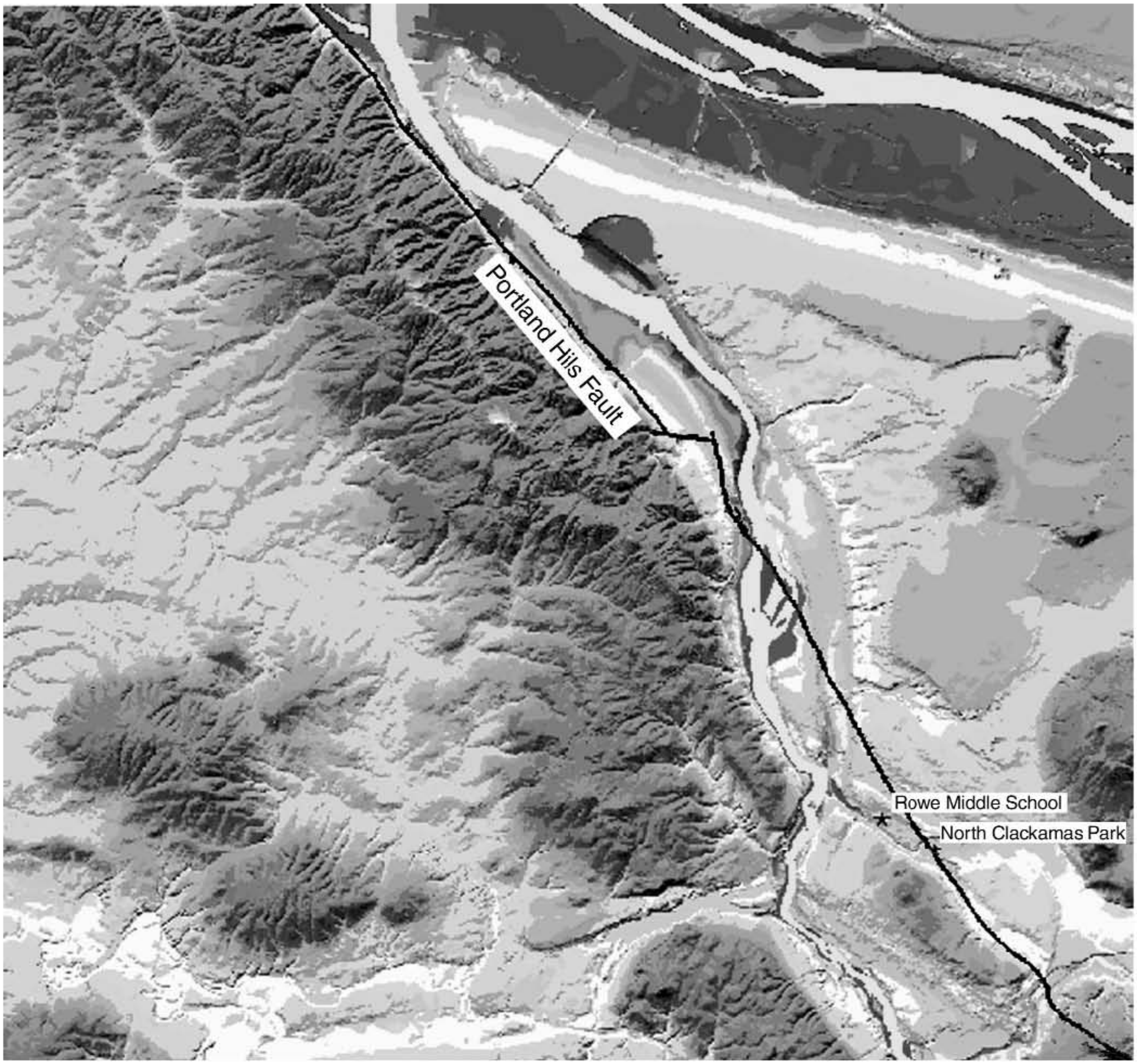
The NEHRP study used two geophysical methods to image the fault and was conducted in North Clackamas Park and on adjacent private property. The site was chosen because the inferred line of the fault passed through it, and the area was relatively undeveloped and quiet, which aided in the collection of 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)***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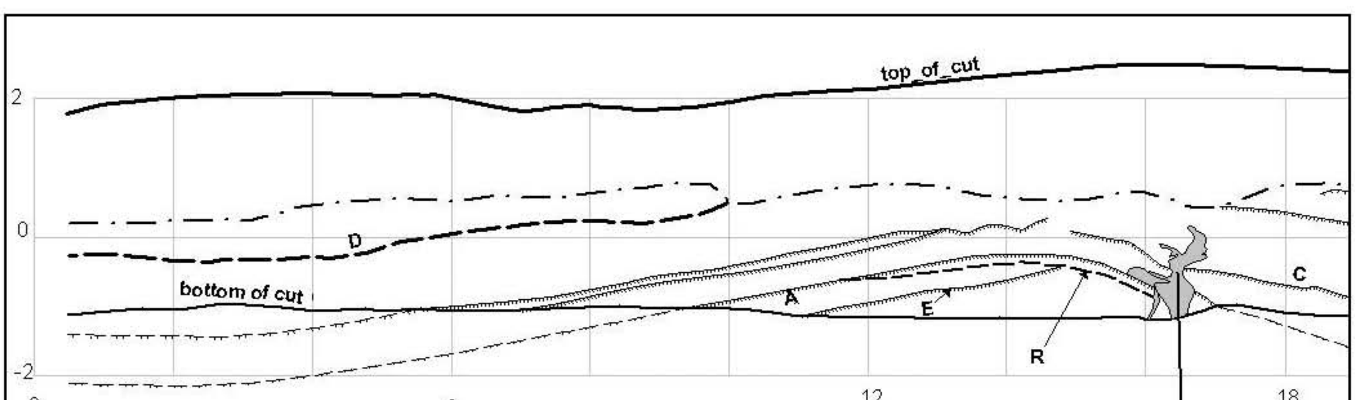
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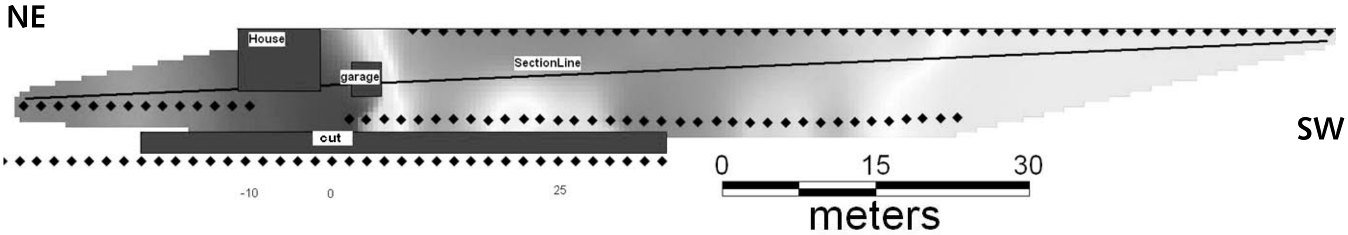
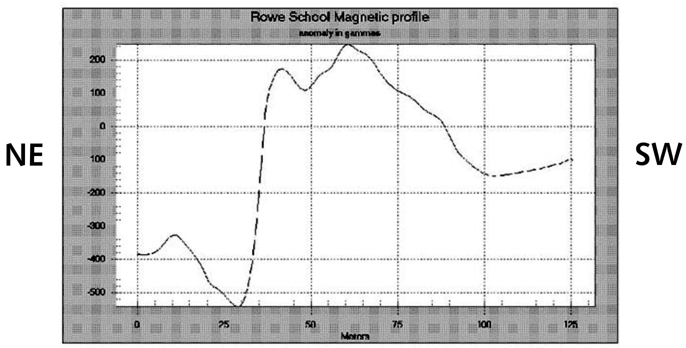


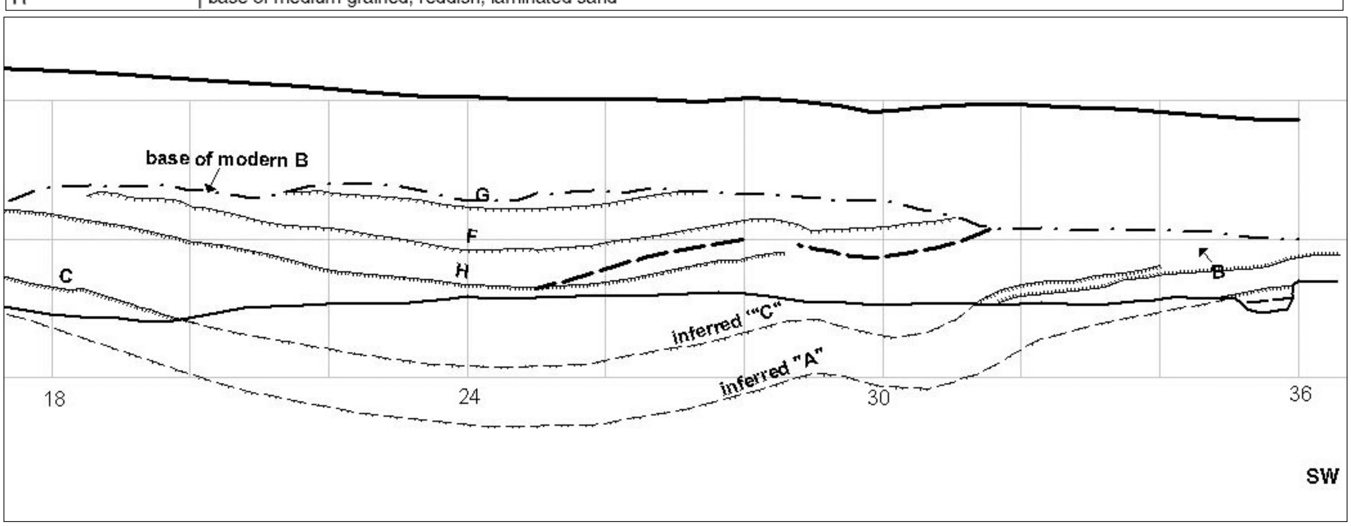

## The fault at Rowe Middle School

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

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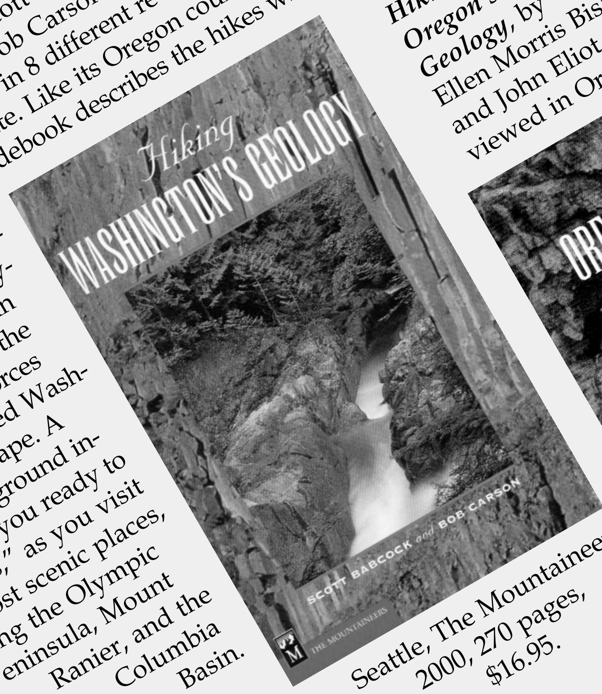
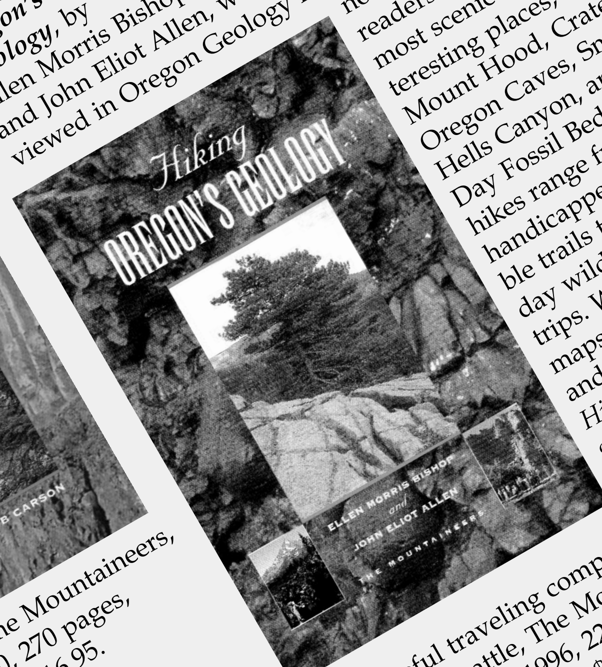
**Hiking may well be on many people's minds at this time of year. That's why we wish to point out this pair of books, one quite new, the other a bit older and in its second printing:**

***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

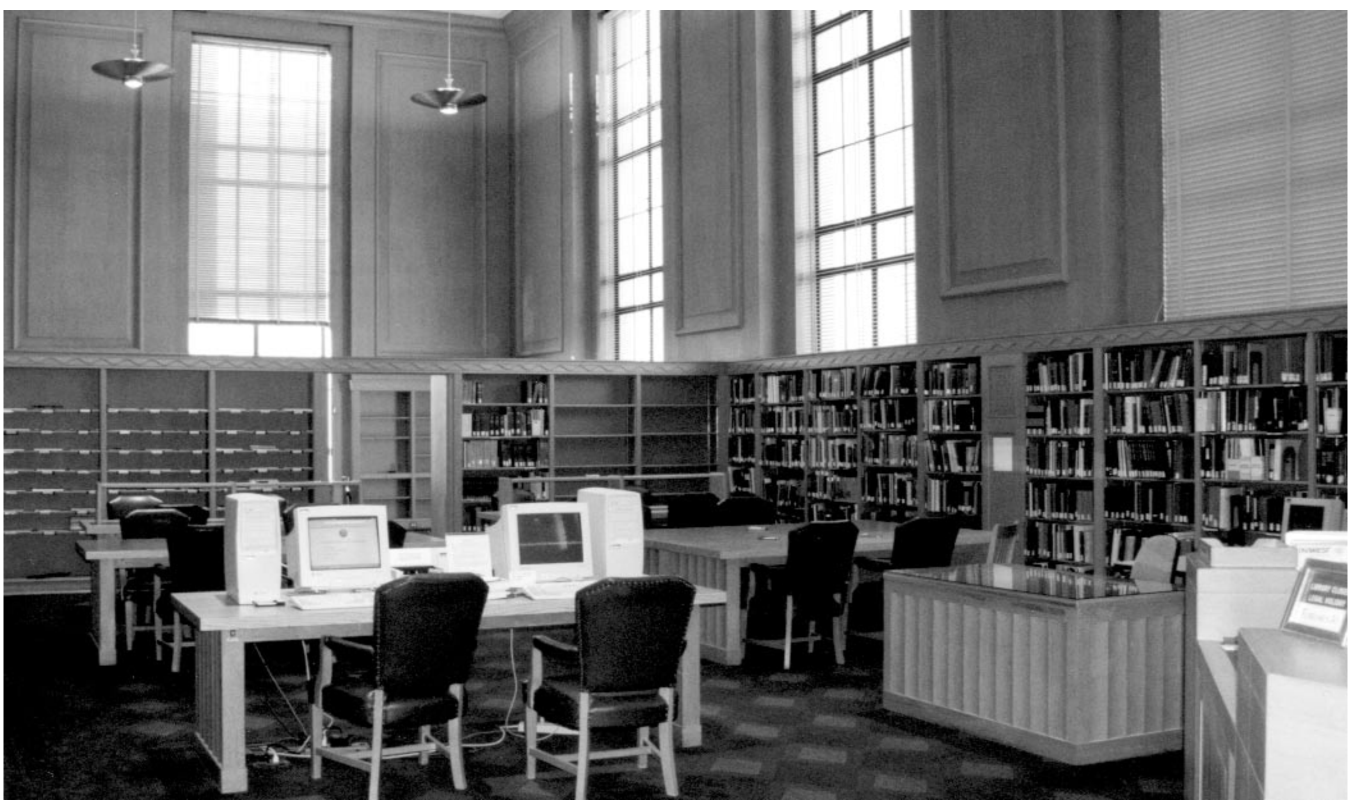
Last February 1, the Oregon State Library was formally rededicated after the completion of most of the renovation work that had been going on since 1998. An important part of that effort had been structural strengthening of the library building against possible earthquake damage. That particular work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

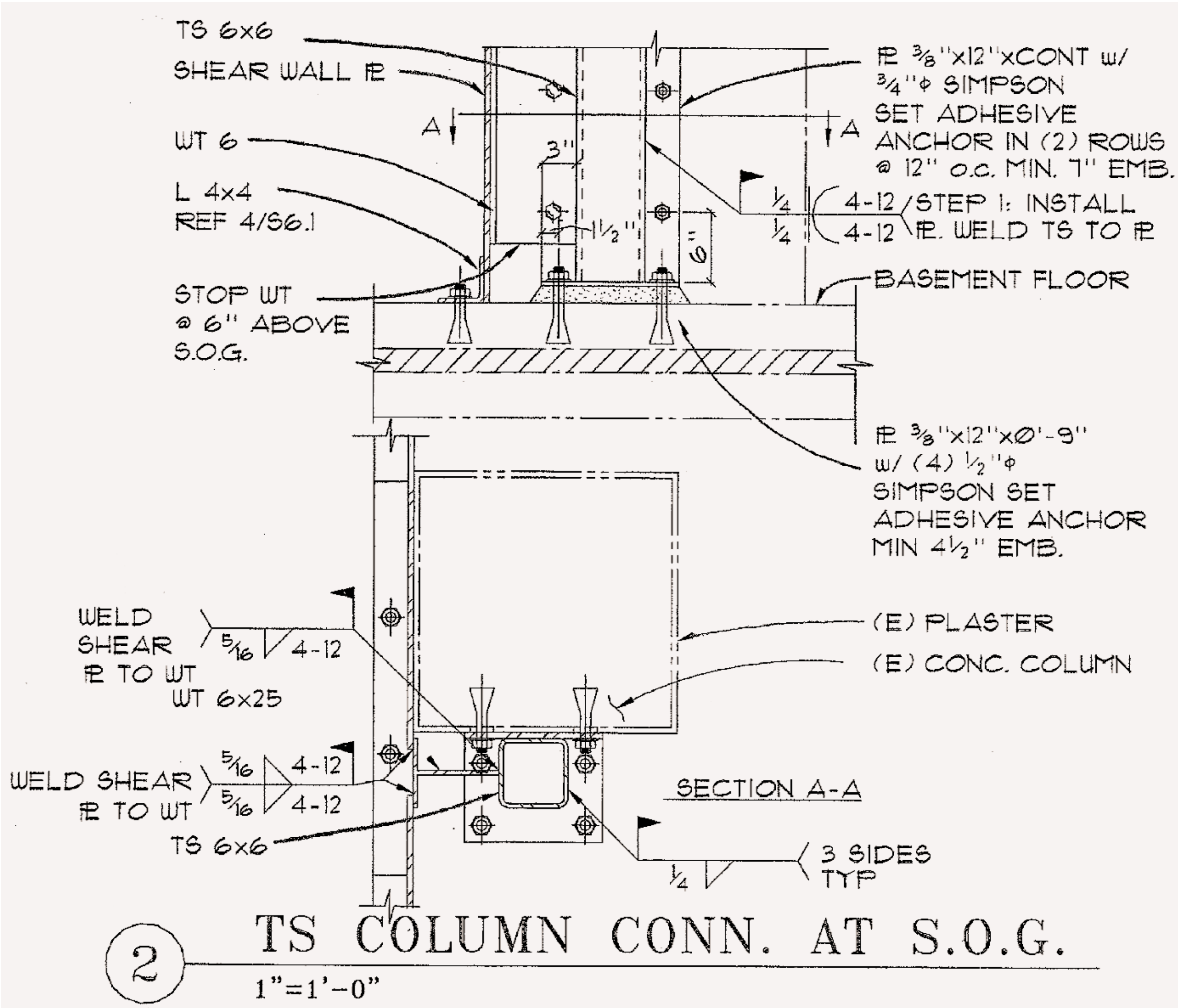
Maintaining the operations of the library during construction provided an enormous social benefit. It provided uninterrupted service to the blind community of the unique program "Books on Tape" as well as to other library patrons.

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

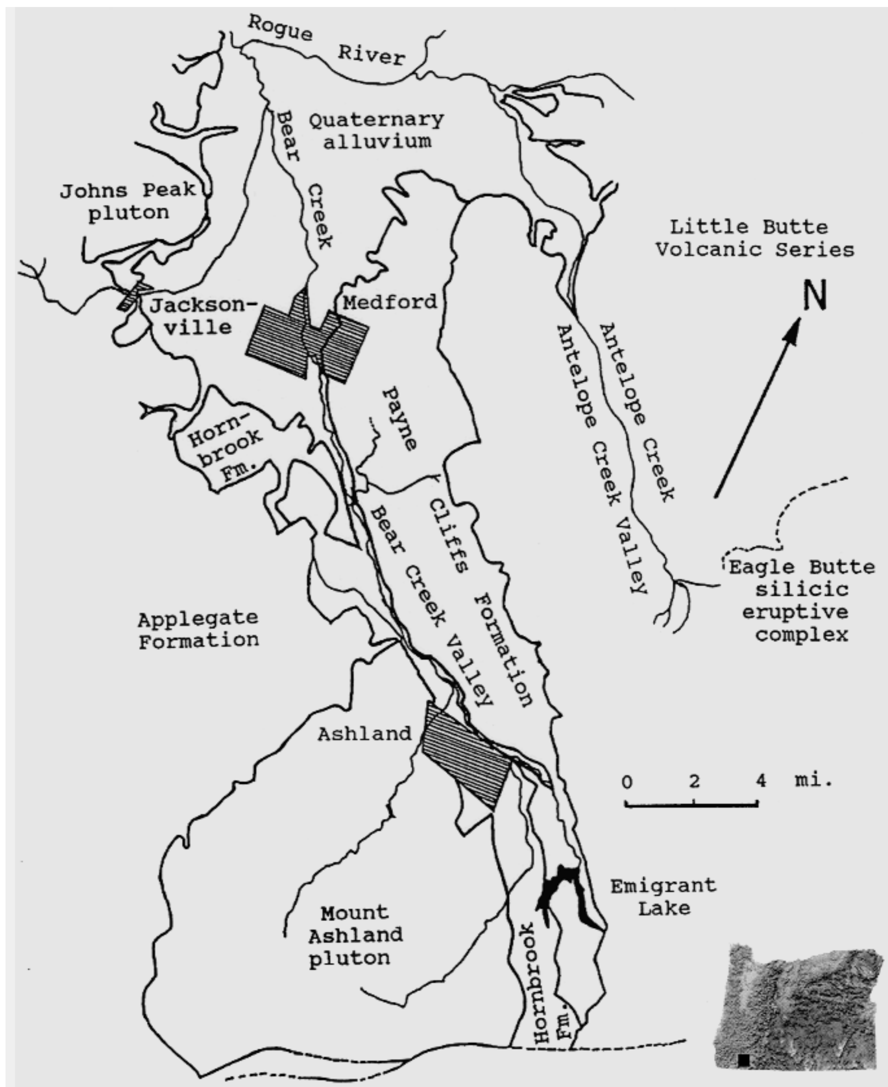



**Figure 1. Generalized map of Bear Creek and Antelope Creek Valleys, Jackson County, Oregon.**

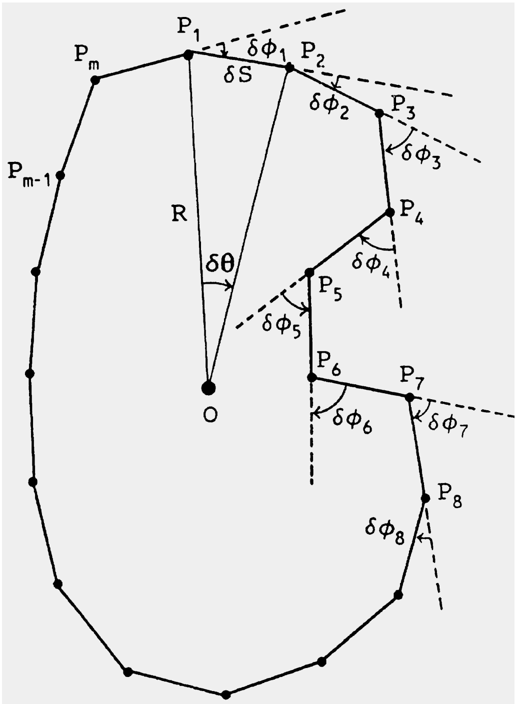



**Figure 2. A grain shape approximated as a closed polygon with m vertices defined in terms of equi-length perimeter segments δS and changes in angle δϕ. The grain centroid is at O, the radius is R, and the change in radial angle about the centroid is δθ.**

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.**

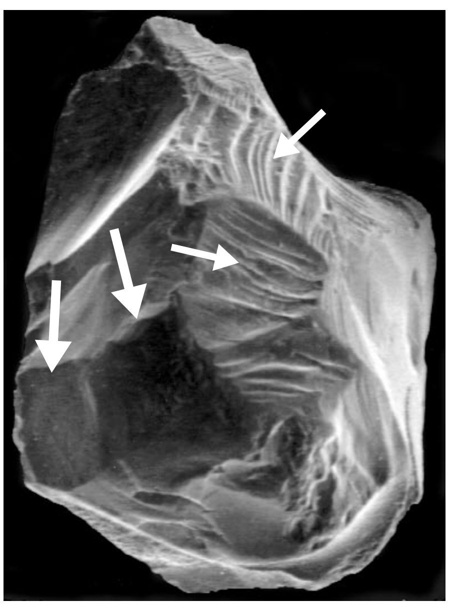


**Figure 4. Volcanic quartz from Antelope Creek, showing conchoidal fractures (smaller arrows) and two crystal faces (larger arrows). Grain is approximately 0.75 mm in length.**

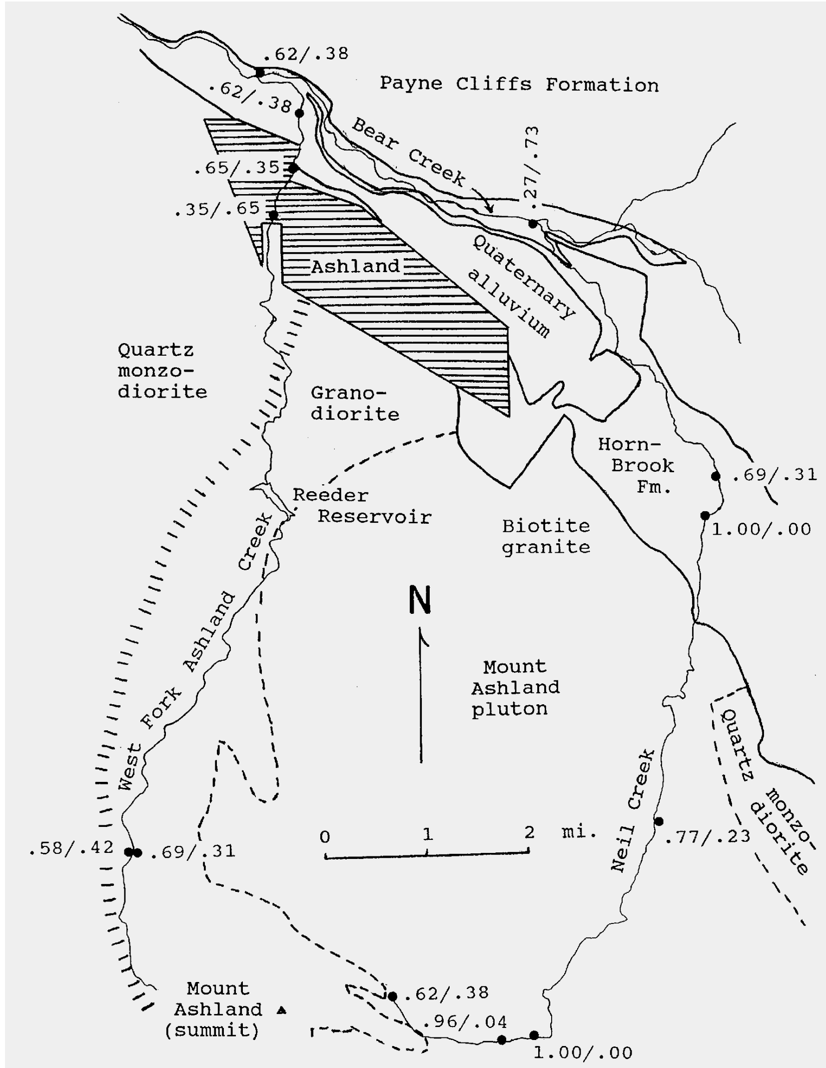



**Figure 5. Generalized map of the northeastern side of the Mount Ashland pluton, showing proportions of plutonic and volcanic end-member grain-shape populations (plutonic/volcanic) for the coarse-sand-size range (0.5-1.0 mm) at sampling sites (filled circles) on West Fork Ashland and Neil Creeks.**

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

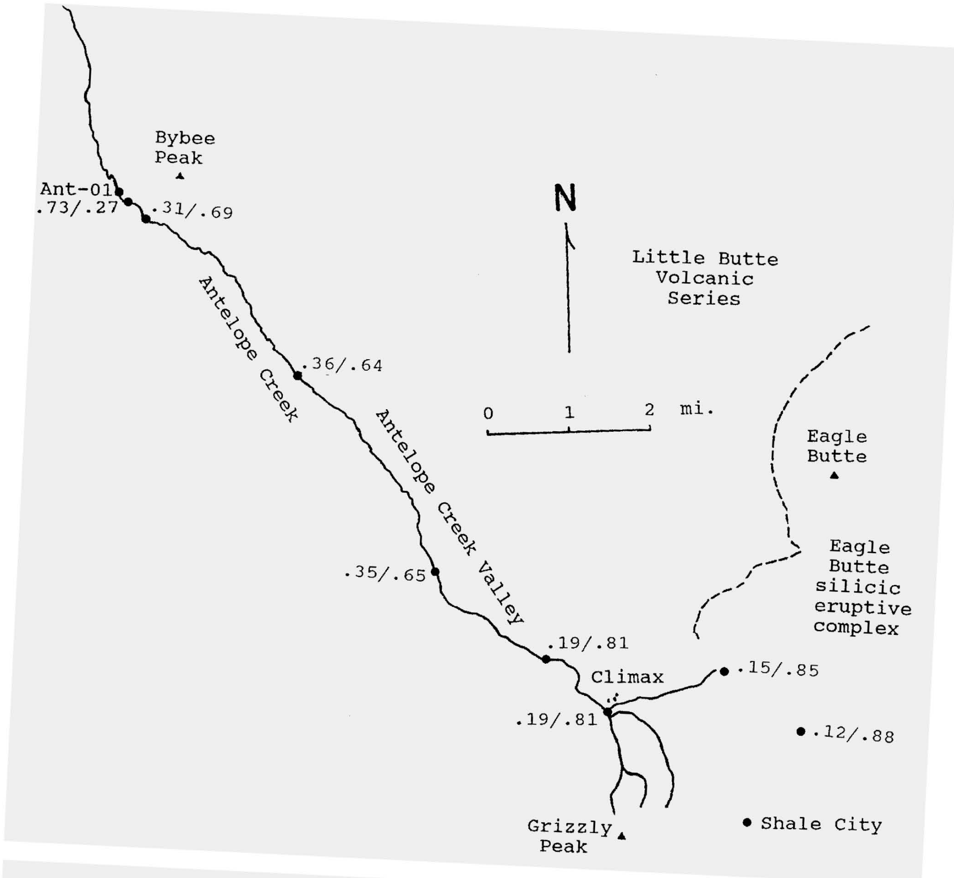



Figure 6. Generalized map of Antelope Creek and the Eagle Butte silicic eruptive complex, showing proportions of plutonic and volcanic end-member grain-shape populations (plutonic/volcanic) for the coarse-sand-size range (0.5-1.0 mm) at sampling sites marked by filled circles.

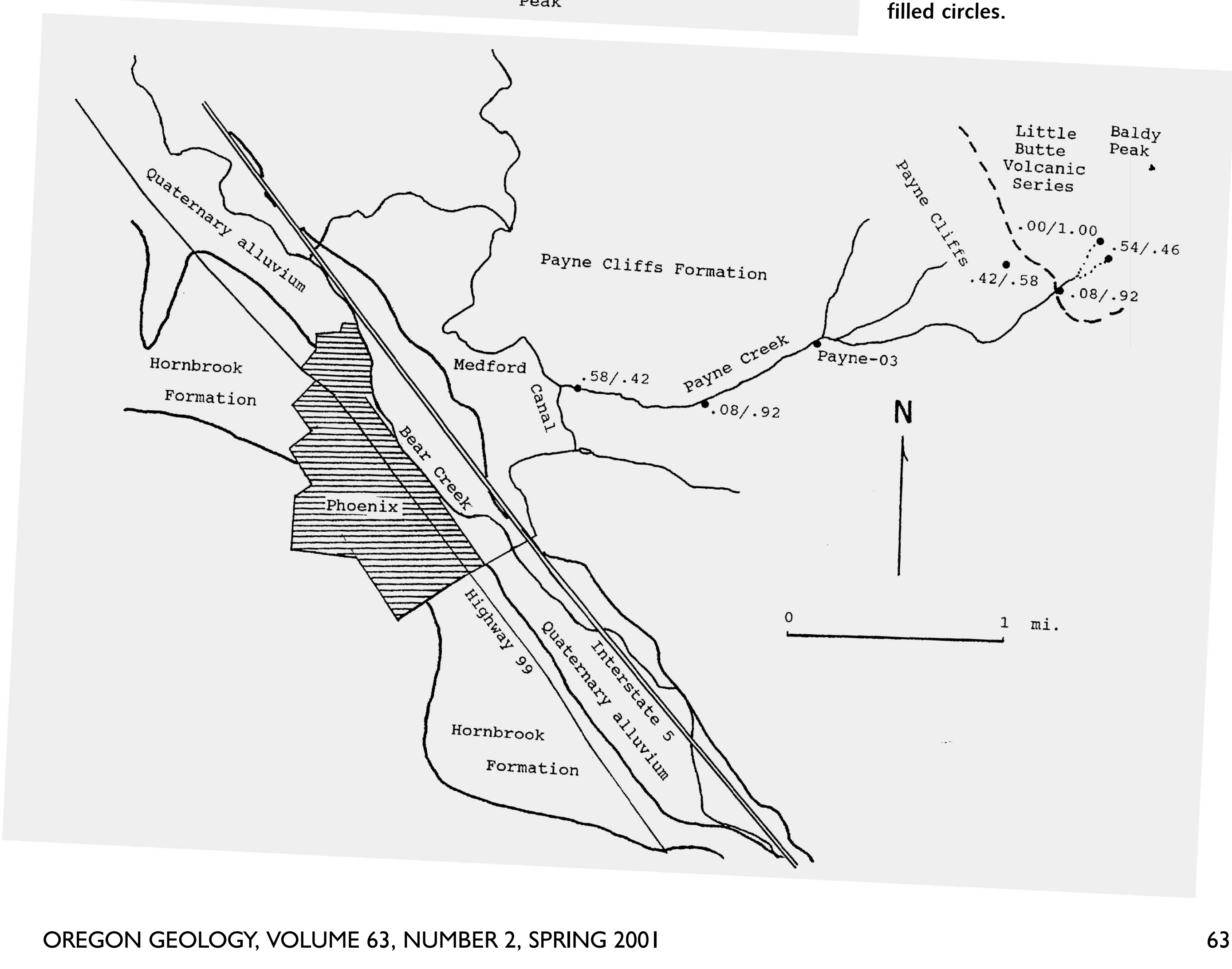



Figure 7. Generalized map of Payne Creek vicinity, showing proportions of plutonic and volcanic end-member grain-shape populations (plutonic/volcanic) for the coarse-sand-size range (0.5-1.0 mm) at sampling sites marked by filled circles.

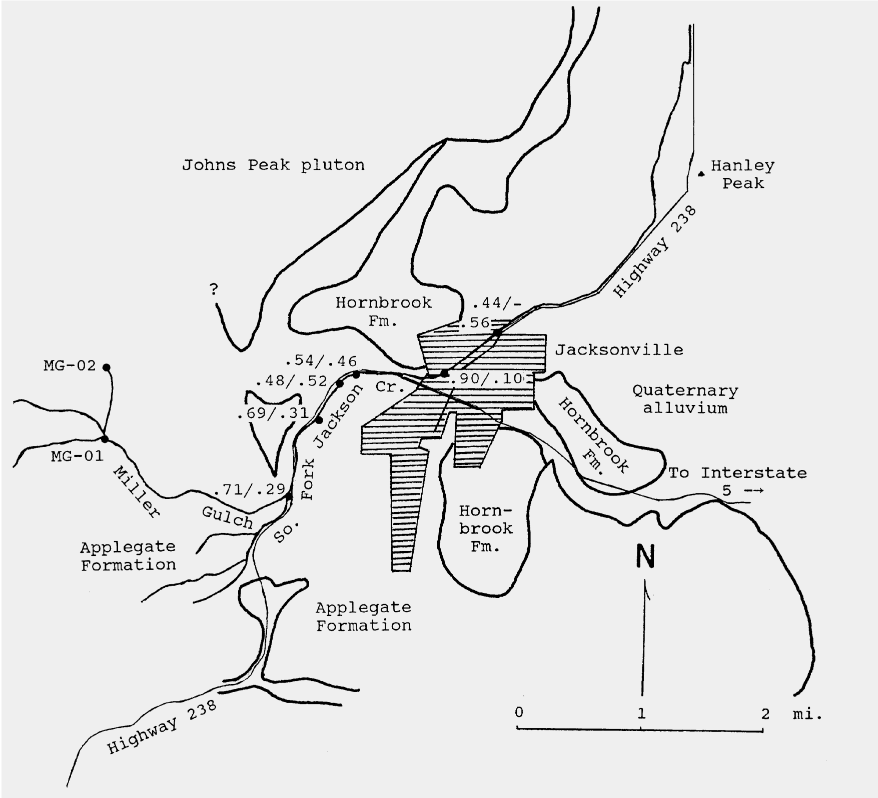



**Figure 8. Generalized map of Miller Gulch and South Fork Ashland Creek vicinity, showing proportions of plutonic and volcanic end-member grain-shape populations for the coarse-sand-size range (0.5-1.0 mm) at sampling sites marked by filled circles.**

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.

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*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. □

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## 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.