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NISQUALLY EARTHQUAKE ISSUE

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EARTHQUAKE DAMAGE MINOR AT THE NATURAL RESOURCES BUILDING

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"The building performed as it was designed to," said Jim Hurst, Engineering Division Manager, about the Natural Resources Building (NRB) during the Feb. 28 Nisqually earthquake. "The cracks we see are intentional, and dust from the ductwork is perfectly normal. The building was designed to sway and absorb ground shock, rather than fight it."

"A rigid structure is brittle and would likely fail under the ground movement from a large earthquake," Hurst said. "Instead, the NRB was engineered to be flexible enough to withstand an earthquake much larger than the Nisqually quake."

Comparing the building to a whipping antenna, he said the lower floors moved much less than the top floors. This would explain the increase in workspace damage on the upper floors during the 40-second shake.

Hurst said the largest portion of the repairs will be covering superficial cracks. "Most of our work will be spackle and paint," he said.

The escalator that connects the P2 parking garage level to the first floor was closed because it "shifted a little". The stairwells were closed—not for safety reasons—but to restrict access to the building. Employees who re-entered the NRB on Friday after the quake were instructed to use the elevators, which were activated by identification cards. The cards are programmed to limit staff to the floor of their agency.

Although damage to state-owned properties has been estimated at $250 million, DNR's claims will reach only about $280,000, said Jim Smego, DNR's risk manager. Most of the cost ($180,000) was for staff time for 2.5 days of debris cleanup and restoration of services, primarily at the NRB.

Smego reported that seven DNR road segments had damage estimated at $35,200. A total of 24 building sites had damage estimated at $65,100, which includes $15,500 in damages to computer hardware in the NRB.

According to Dennis Flynn, project manager/civil engineer, the NRB was inspected just after the earthquake on Feb. 28, and there was a detailed inspection the next day. On March 9 and 10, there was a thorough engineering evaluation by Sergeant Engineers with the assistance of General Administration and DNR engineers.

There was no significant damage to the building or parking garage. There were 13 broken or cracked windows in the rotunda and cracks in the sheetrock around many windows in the building. Some ceramic tiles came loose in restrooms. Also, there were several places in the building where access floors shifted where they transitioned to solid floors. ■

Cover photo: Parapet failure on the south side of the Washington Federal Savings building in downtown Olympia. View to the east. Downtown Olympia and the South Capitol neighborhood suffered the greatest damage in the Olympia area, probably as a result of amplification. Downtown Olympia is built on relatively loose latest Pleistocene sediments, about 100 to 400 feet thick, on top of Pleistocene glacial sediments. *Photo by Joe Dragovich.*

Surviving the Nisqually Earthquake

Raymond Lasmanis, *State Geologist*
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At 10:54:32 (PST) on Wednesday, February 28, 2001, a magnitude 6.8 Benioff zone earthquake shook southern Puget Sound. The earthquake was centered at 47.1525N, 122.7197W at a depth of 52.4 km. The epicenter, located adjacent to the Nisqually River delta, was at the same location as the magnitude 7.1 earthquake on April 29, 1945. The state capital, Olympia, is located 18 km (11 mi) from the epicenter. Aftershocks followed on March 1st, with a 3.4 magnitude earthquake at 1:10 a.m. followed by a 2.7 magnitude earthquake at 6:23 a.m.

The state offices, in general, and the Department of Natural Resources, in particular, were well prepared for the earthquake. We have had a number of earthquake drills and diving under one's desk came naturally. But waiting for the shaking to stop was a scary 45-second experience, particularly for those on the higher floors. And the power went out shortly after the shaking started, leaving some of us in the dark for interminable seconds until the emergency lights came on. Evacuation of the Natural Resources Building (NRB) proceeded smoothly, although more detailed plans will have to be developed on transportation logistics for employees if entry back into the building or parking garage is prohibited. Within 5 minutes of the evacuation, Tim Walsh, Pat Pringle, and Bill Lingley were dispatched to the State Emergency Operations Center (EOC) at Camp Murray to assist with emergency response and information transfer (*see related story, p. 6*).

After the earthquake, the department activated the Emergency Management Plan created during 1996 and 1997. As per the plan, notification procedures were initiated February 28, the Executive Emergency Management Team was formed, and, since the NRB was yellow-tagged, a meeting was called in a pre-designated off-site location the morning of March 1 to establish the department's Emergency Coordination Center. From there, using the incident command system, response was directed to ensure employee safety, assessment of damage, and business recovery, including the implementation of the Information Technology Disaster Recovery Plan. The State Geologist is part of the damage assessment team, and I was instructed to enter the closed NRB on March 1 to document all of the non-structural damage on the first, third, and fourth floors, occupied by the Department of Natural Resources, and the sixth floor, occupied by another state agency. On Friday, March 2, power was restored and key staff were permitted to enter the NRB to begin clean-up operations and prepare for resumption of business by Monday, March 5.

Non-structural damage was extensive on the sixth floor, where shaking was severe and no mitigation measures were applied. Filing cabinets, lateral files, book cases, and unsecured wall panels were overturned (Figs. 1–5). These were a hazard to individuals working in cubes and blocked evacuation routes. Major equipment losses resulted from unsecured computer

Figure 1. Sixth floor cubicle damage. *Photo by Dennis Heryford, Department of Natural Resources.*

Figure 2. Sixth floor cubicle damage. *Photo by Ray Lasmanis.*

monitors and printers. In contrast, the fourth floor showed only minor non-structural damage due to a 1996 mitigation program. The Division of Geology and Earth Resources (DGER), located on the first floor, sustained little damage. The shaking was moderate compared to the upper floors and almost everything had been fastened down. We did, however, lose an unsecured computer monitor. The Geology Library fared particularly well due to mitigation work done by Eric Schuster on the bookshelves with overhead and cross bracing. We only lost a few lighter volumes from the top shelves (Fig. 6). We could tell the bookshelves had been lifted as a unit because one of the magazines slid underneath (Fig. 7).

Figure 3. Sixth floor cubicle damage. *Photo by Ray Lasmanis.*

Figure 4. Sixth floor cubicle damage. *Photo by Jim Blake, Department of Natural Resources.*

Thirteen of the upper windows in the rotunda were badly cracked and part of the rotunda was closed to traffic for almost three months while we waited for replacement safety glass.

During the weeks following the earthquake, DGER project and full-time geologists fanned out from Olympia to document

Figure 5. Sixth floor cubicle damage. *Photo by Jim Blake, Department of Natural Resources.*

Figure 6. The Geology library came through with minimal damage, losing books from the top shelf only. That is a casualty from the toy dinosaur collection in the lower righthand corner. *Photo by Ray Lasmanis.*

Figure 7. Proof that library shelves were lifted off the floor by the quake. *Photo by Karl Wegmann.*

PERSONAL ACCOUNT
Rich Phipps, Environmental Specialist 3, Regulatory Section, DGER

A little before 11:00 a.m., I went to the post office because I didn't want to get stuck in the noon rush. As I pulled out of the parking lot, heading back to the NRB, my car started wobbling and shaking like something really expensive was broken. I pulled over and got out of the car and it was still shaking. It was an earthquake!

I noticed I was under some power lines and pulled the car forward. The first wave had passed, and with the second wave, the power poles started rocking back and forth, the tops moving a good 4 feet. I was amazed that all the power lines stayed attached to the poles.

The road was twisting and waving like Galloping Gertie. In the crosswalk, a man in a nice business suit, briefcase in hand, was doing a boogie dance, waving his arms for balance. It was actually pretty funny!

After the intense shaking stopped, I was still vibrating and maybe the ground was too. A wind rushed past, blowing the dead leaves along with it. I looked for a safe place to park the car while I recovered. I chose the parking lot across the street from the credit union. It turned out that was a bad choice—it was the staging area for the credit union and employees started pouring out of the building.

As I got back to the NRB, I realized I was fortunate to have a vehicle outside the parking garage, since nobody was allowed back in to get their car. After I checked in with the division, now all standing on the sidewalk behind the NRB, I was able to head home for Belfair (by way of McCleary, because of the landslide on 101). It took me three hours instead of the usual one hour to get home.

ground deformation features (see Fig. 1, Table 1, p. 7). They photographed landslides, lateral spreading, and evidence of liquefaction such as sand boils. They were joined by Walsh, Pringle, and Lingley upon completion of their duties at the EOC. Other division staff, including librarians Connie Manson and Lee Walkling, were busy responding to public inquiries and answering the numerous questions of employees returning to work in the NRB.

On March 21, Steve Palmer was invited to present a statement before the Subcommittee on Research, House of Representatives Committee on Science, in Washington, DC. His testimony focused on the nature of the Nisqually earthquake, its effects as observed by our staff and other investigators, the lessons learned, and additional work that needs to be undertaken to understand the earthquake framework of the Pacific Northwest and the application of appropriate mitigation measures. You will find testimony from the hearing at http://www.house.gov/science/reshearings.htm, the House of Representatives Committee On Science website. ■

MISSOULA FLOODS SLIDE SHOW AVAILABLE

A professionally developed slide show on the Missoula floods, with script, is available from Lake Roosevelt National Recreation Area. The set is sold at the cost of duplicating the slides. For more information, call Dan Hand at (509) 633-9441 x 130.

ASCE Infrastructure Report Card for King and Snohomish Counties

The American Society of Civil Engineers (ASCE), Seattle Section, has posted their 2000 Report Card for King and Snohomish County Infrastructure on their website at http://sections.asce.org/seattle/ITUP/00reportcard.htm. Our public infrastructure is made up of physical systems that provide essential public services. A functioning infrastructure is vital to the quality of life, economic vitality, and safety of the citizens of Washington. Although not specifically designed for the purpose, the report card gives us some idea of how our infrastructure would fare in a natural disaster, such as an earthquake.

ASCE released its National Report Card for America's Infrastructure in March 1998 (http://www.asce.org/reportcard/). The purpose was to raise public awareness of infrastructure systems and the need to maintain, rebuild, and expand them, and to influence citizens and key decision makers to support infrastructure renewal.

The Infrastructure/Transportation and Urban Planning Committee of the Seattle Section of ASCE decided to evaluate the infrastructure of King and Snohomish counties. As a body, it saw urgent needs in several infrastructure systems, some obvious to the general public (such as highway capacity) and some less obvious (such as new drinking water treatment facilities). Categories evaluated were roads, bridges, mass transit, aviation, schools, drinking water, waste water, dams, solid waste, and hazardous waste. Each category was evaluated on the basis of condition and performance, capacity vs. need, and funding vs. need.

On the whole, the ASCE feels that our local infrastructure system is reliable and in good condition, but they are worried that a lack of funding may lead to critical problems.

Working a Geologic Disaster

Timothy J. Walsh, Patrick T. Pringle, and Stephen P. Palmer
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Timothy J. Walsh, Geologist 4, Environmental Section, DGER

Immediately after the Nisqually earthquake, the Division of Geology and Earth Resources (DGER) dispatched Bill Lingley, Pat Pringle, and me to the State Emergency Operations Center (EOC) at Camp Murray near Tacoma to assist with emergency response and information transfer. At the EOC, every state agency has a desk, a phone, and a computer and is part of a pod or cluster of four or five desks. Our pod included representatives from the Departments of Natural Resources, Ecology, Parks, and Fisheries.

Tom Pratt, U.S. Geological Survey (USGS) at the University of Washington (UW), and I had the job of coordinating field people within the state who were looking for earthquake damage—ground failure, liquefaction, etc. We sent the USGS and UW people north of Tacoma and the DGER people south (Figs. 1–14, Table 1). It took a while for the USGS people from Denver to get there. At an evaluation meeting at the UW on Friday night, they agreed to pitch in where ever they were needed.

Coordinating information gathered by our field people were Bill Steele (seismology), Steve Kramer (geotechnical), Gregory MacRae (buildings), Marc Eberhard (bridges), Donald Ballantyne (lifelines), and Peter May (socio-economics), all from the University of Washington (UW).

Most of the time, we were busy answering phones, with three or four lines going at a time. If one line was busy, it rang at the next open line in the cluster. We were taking reports of where things had happened, questions about what to look for, and calls from field people feeding us information or making requests for help. When a request came in from Fox Island for

Figure 1. *(top)* Earthquake-induced landslide at Salmon Beach near Tacoma. View to the east. Salmon Beach has experienced previous landslides. This slide was reactivated by the Nisqually earthquake, destroying two houses at its toe and putting several more in danger. A previous slide scar is to the left and the scar caused by the Nisqually earthquake is to the right. The slide occurred on a fairly steep section of the coastal bluff. The slope is approximately 0.5:1 (horizontal:vertical) with a height of about 90 feet. The failure is relatively surficial. *Photo from Bray and others (2001), a NSF-PEER sponsored reconnaissance effort.*

Figure 2. *(right)* Closeup of the Salmon Beach landslide as it encroaches on the rear of a house. There used to be a path between the back of the building and the hillside. Workers are cleaning up debris. *Photo by Josh Logan.*

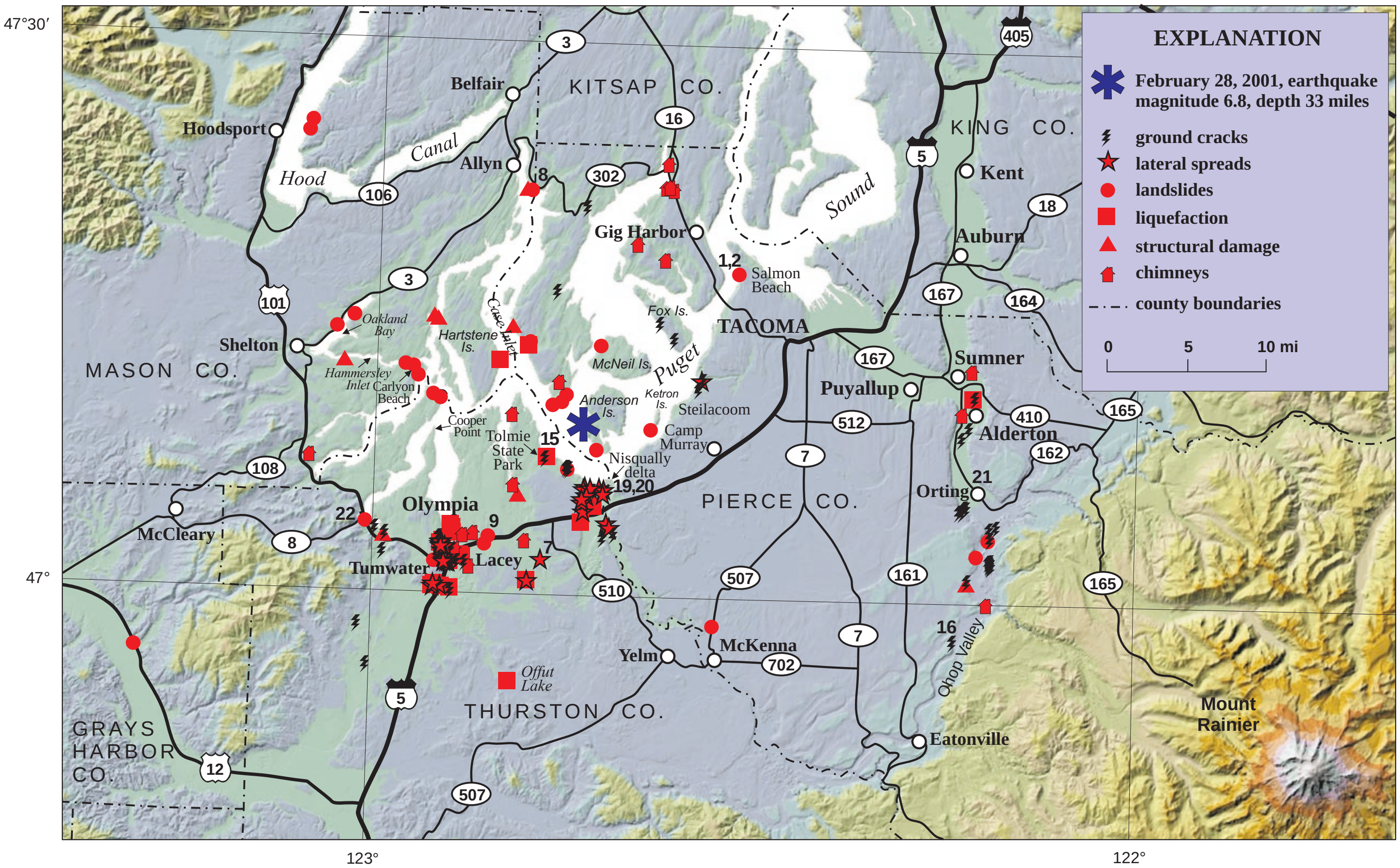

Figure 3. Locations of earthquake-related features from the 2001 Nisqually earthquake in the south Puget Sound area. Photo locations are indicated by the figure number in bold sans serif type. *Map by Karl Wegmann.*

Table 1. Washington Division of Geology and Earth Resources geologists response to Nisqually earthquake—areas of reconnaissance and service

Geologist	Areas of earthquake reconnaissance and service
Loren Baker	Southeast portion of Hood Canal; Fox Island; Steilacoom
Joe Dragovich	Olympia area—Downtown, Capitol Lake, Deschutes Parkway; Port of Tacoma; lower Puyallup River valley; Puyallup; Sumner; Alderton
Andy Dunn	Cowlitz Co.—greater Kelso–Longview; Olympia—Capitol Lake; Shelton—Oakland Bay
Bill Lingley	Camp Murray; south Puget Sound aerial reconnaissance; Lacey; lower Nisqually River; Johnson Point; Shelton; southern Hood Canal; Hartstene Island; Key Peninsula; Gig Harbor
Josh Logan	Centralia–Chehalis area; Salmon Beach–Tacoma Narrows; Fox Island; Ketron Island; Anderson Island; McNeil Island; southern Key Peninsula
Sam Magsino	Olympia area—Downtown, Deschutes Parkway, Capitol Lake; Cowlitz Co.—Kelso–Longview–Castle Rock; Shelton—Oakland Bay
Mac McKay	Nisqually delta
Dave Norman	Olympia area—Capitol Campus, Capitol Lake, Deschutes Parkway; Nisqually delta
Steve Palmer	Olympia area—Downtown, Capitol Lake, Deschutes Parkway, Black Lake, West Olympia
Mike Polenz	Olympia area—Downtown, Capitol Lake, Deschutes Parkway, Black Lake; Ketron Island; Anderson Island; McNeil Island; southern Key Peninsula; Cooper Point; Carlyon Beach; Hammersley Inlet; Oakland Bay
Pat Pringle	Camp Murray; Steilacoom; Nisqually delta; Luhr Beach; Beachcrest; Tolmie State Park; Millersylvania State Park; Downtown Olympia; Lacey; Offut Lake; Ohop Valley; Electron; middle Puyallup River valley
Hank Schasse	Olympia area—Capitol Campus, Capitol Lake, Deschutes Parkway; Port of Tacoma; lower Puyallup River valley; Puyallup; Sumner; Alderton
Tim Walsh	Camp Murray; south Puget Sound aerial reconnaissance; FEMA Disaster Field Office, Olympia
Karl Wegmann	Olympia area—Downtown, Mud Bay, Black River corridor, Tumwater–Deschutes valley; Ohop Valley; Electron; middle Puyallup River valley; Orting; Nisqually delta

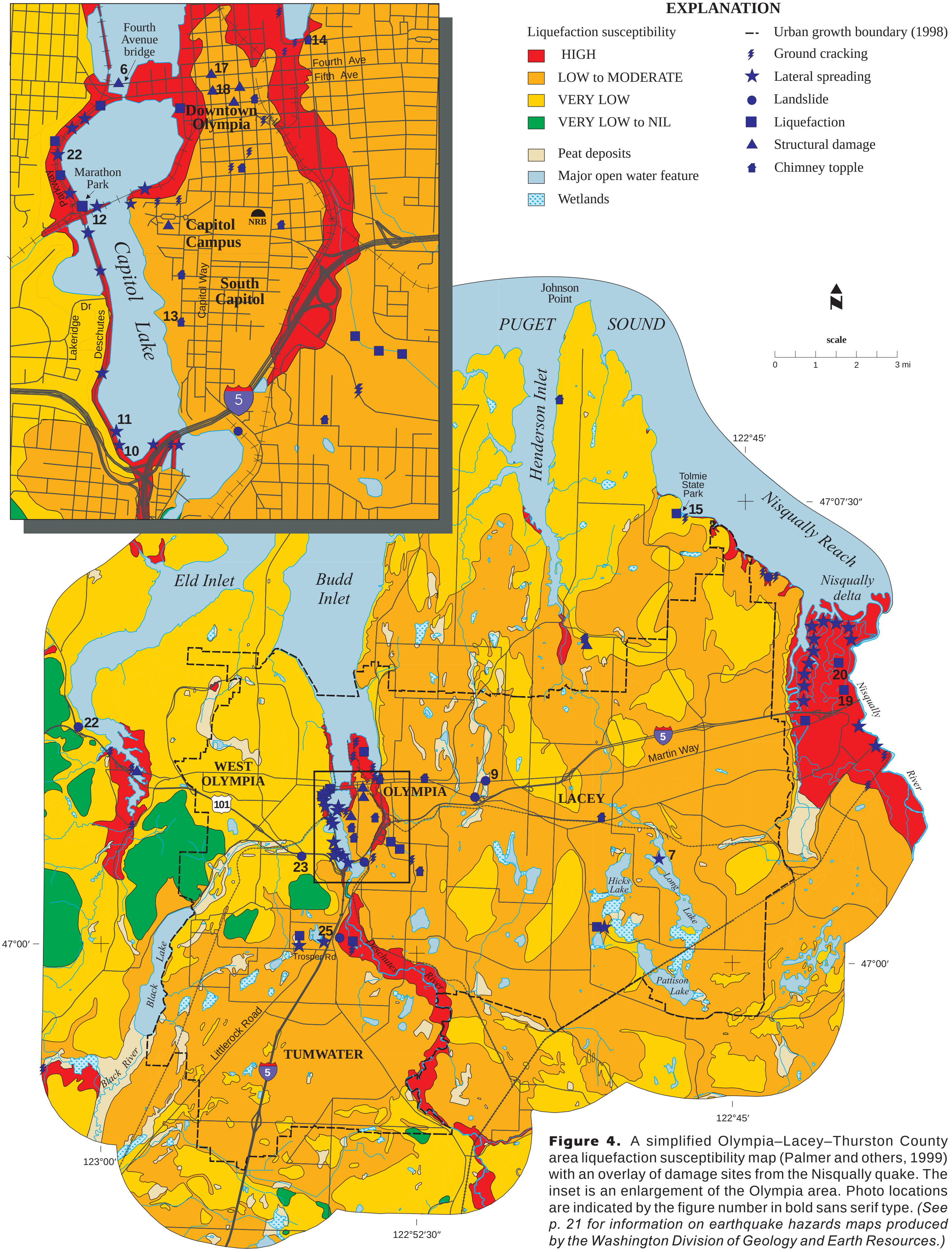

Figure 4. A simplified Olympia–Lacey–Thurston County area liquefaction susceptibility map (Palmer and others, 1999) with an overlay of damage sites from the Nisqually quake. The inset is an enlargement of the Olympia area. Photo locations are indicated by the figure number in bold sans serif type. *(See p. 21 for information on earthquake hazards maps produced by the Washington Division of Geology and Earth Resources.)*

Figure 5. Aerial view of Olympia, looking north from just south of Capitol Lake. Interstate-5 is in the foreground. Capitol Campus is on a bluff in the center of the photo and the critical Fourth/Fifth Avenue bridge connection is just to the left and above that. Downtown Olympia occupies the flat peninsula above and to the right. Puget Sound is at the top. *Photo provided by the City of Olympia, Washington.*

someone to look at the damage, we sent Josh Logan, since he is mapping there. Homeowner calls were referred to us and, if necessary, we sent someone out to take a look at the damage.

That afternoon, I arranged for a plane from the Department of Transportation to take Bill Lingley and me to fly the Puget Sound coastline looking for landslides. Pat Pringle set up at a desk to use his outside e-mail account to find out what was happening at remote places like Mount Rainier. As information came in, we sent out periodic reports of our findings. We had a briefing for the EOC staff (and the governor's staff and congressional delega-

Figure 6. Damage to the Fourth Avenue bridge parapet is visible in the center of the photo. A major bottleneck to traffic, the bridge was slated to be replaced in the next few years. The bridge remains closed due to earthquake damage while efforts are made to speed up the schedule for bridge replacement. *Photo copyright 2001 by Robert J. Reid.*

tion when they were there) every four hours. We'd go around the room and everyone would report on what they had found out.

We were also in charge of rumor management, particularly about aftershocks and bogus earthquake predictions. Small crustal events are more noticeable after a large quake. People thought small quakes (M <3) in Maple Valley and Bremerton were aftershocks, although they were actually expected background activity. A rumor was circulating that there was going to be a magnitude 9 quake on March 6. It probably had its source in predictions made by Jim Berkland on his website (http://www.syzygyjob.org/syzygy/index.shtml). His predictions were that there would be an eight-day window starting on the Wednesday following the quake for a magnitude 3 to 5.5 quake in Washington or Oregon and a magnitude 7 or larger somewhere on the Pacific Rim—none of which came to pass. The rumors of a magnitude 9 quake probably resulted from a phenomenon similar to what happens in a

Figure 7. View of a lateral spread in a residential yard on Long Lake east of Lacey. The fence is attached to a retaining wall at the edge of Long Lake. This lateral spread occurred in a manmade fill that is superimposed on peat and lacustrine sediments. The failure pattern is controlled by lower root-strength between strips of new sod and by the retaining wall, which was down-dropped and back-rotated. *Photo by Bill Lingley*.

Figure 9. Landslide on Martin Way between Ensign Road and Pattison Street in Olympia. View to the east. The slide took out some utility poles but the wires remained intact. *Photo by Karl Wegmann.*

Figure 8. *(left)* View looking north to a road failure at a landslide on Highway 302 beside Case Inlet (top left) and directly east of Allyn. The landslide, which has failed repeatedly during years past, consists partly of a deep-seated rotational slide at the contact of thick outwash sand and older Pleistocene units and partly of static liquefaction of the sand (Steve Lowell, Washington State Dept. of Transportation, oral commun., 2001). Failure during the earthquake occurred mainly in a low-density fill that had been installed under the highway to reduce recurrent movement on this landslide. A engineer's notebook is propped across the crack for scale. *Photo by Bill Lingley.*

Figure 10. *(top)* DGER geologist Hank Schasse inspects liquefaction from a lateral spread along Deschutes Parkway in Olympia. *Photo by Joe Dragovich.*

Figure 11. *(middle)* Lateral spread across a path at Capitol Lake, Olympia. *Photo by Karl Wegmann.*

Figure 12. *(bottom)* Incipient lateral spread (edge of complex) near Marathon Park in Olympia. *Photo by Joe Dragovich..*

game of 'telephone'—the quake's magnitude got larger and larger with each repeat. *(See related story, p. 27.)*

I stayed at the EOC through Saturday. As long as Governor Locke and his staff were there, they wanted a geologist available to answer any questions that came up. Pat and Bill were there on Wednesday, and on Thursday, they went into the field with Karl Wegmann.

The Federal Emergency Management Agency (FEMA) disaster field office was set up on Monday at the vacant Lamonts store in Capitol Mall. My job there (at a desk under the Intimate Apparel sign) was to coordinate collation of all data sets for later evaluation of mitigation alternatives.

A clearinghouse for Nisqually earthquake information was set up at the UW (http://maximus.ce.washington.edu/~nisqually/). FEMA money was used to hire the staff and equipment.

The Cascadia Region Earthquake Workgroup (CREW) decided to extend the work of the clearinghouse and document business interruptions caused by the quake, which are hard to document properly. One of its members, Barry McDonnell, a retired Bank of America executive, took over as director. Graduate students were hired to help with damage reports.

CREW is a not-for-profit corporation of private and public representatives working together to improve the ability of Cascadia region communities to reduce the effects of earthquake events (http://www.crew.org/).

Patrick T. Pringle, Geologist 3, Environmental Section

Just before the earthquake, I was talking with Dennis Dixon and David Grinstead of Pierce County Public Works and Chuck Griffin of our Information Technology division in the plotter room on the third floor—in fact, I had printed out a copy of our geologic map of southwest Washington (Walsh and others, 1999) for them—we had been discussing recent interpretations about shallow fault zones in this area. Chuck had just walked out the door and Dennis, David, and I were still in the plotter room when the earthquake struck. I remember the P-wave hitting and having that instant realization of what was coming next, but I didn't anticipate the severity of it. What seemed like only a second or two later the shear waves hit with what I recall as an almost violent, east–west jerking. It was very loud and the lights went out; it was pitch black. About all that occurred to me at that moment was that there was a lot of equipment in the room and no cover, so I dropped to the floor as close to the east wall as I could get and protected my head.

The shaking seemed to last a long time, but by the time the emergency lighting came on (9 seconds after they went off?) I could feel that the motion was attenuating so I waited a few more seconds, jumped to my feet, and made my way to the door. I remember walking swiftly down the hall and then down into the Geology Division office where I noticed that many of the hatches on the overhead fluorescent lights were still swinging vigorously back and forth—the waves were still rolling through!

Figure 13. Chimney topple at a private residence in the South Capitol area, Olympia. *Photo by Karl Wegmann.*

One of our mandates as a division is to send someone to the EOC (Emergency Operations Center) at Camp Murray, near Fort Lewis, in case of a geologic emergency. We go there to be consultants in times of crisis, to filter what's going on through a scientific viewpoint, and to pass the information along to those in government and the media who need it. Although I'm mainly a volcano specialist, I'm an alternate in case of seismic emergencies.

The EOC is a "base-isolated" building, that is, it has a mechanism that insulates it somewhat from ground motion. Inside we were working from pods of 5 or 6 desks—ours was the natural sciences station. What we did immediately was to use the phones and Internet to gather as much information as we could about what was going on and also to get in touch with our families. Governor Locke and his staff got there not long after we did. We did have some time to get research done before they got there—I was able to go online within 20 minutes. Unfortunately, I couldn't log on to my e-mail at work, which had the address book I needed, but luckily I had access to my Yahoo account and was able to send messages to my family and other people who would be concerned to let them know I was okay. My dad had just been admitted to intensive care in a coronary unit in Ohio the night before, so I was quite concerned about getting the word back to my family that we were okay!

When Governor Locke and his staff came in for their first briefing, duty officer Ken Parrish at WADEM (Washington Department of Emergency Management) introduced everyone at the various stations and explained what their expertise was. We know Ken because we have worked closely with him and others at the DEM in teams such as the Mount Baker–Glacier Peak Volcanic Hazard Group. He really did an impressive job with the introductions. The Governor and his staff had no doubt about whom to ask about any particular questions they might have.

While Tim and Bill went on a reconnaissance flight, I stayed behind. At one point, the King County Fire Chief called

Figure 14. Chimney topple at a private residence at the south end of East Bay in Olympia. The house was built on fill over estuarine muds. *Photo by Karl Wegmann.*

Figure 15. Damage at Tolmie State Park, about 3 miles from the epicenter. Karen Rollman, Park Ranger, looks at a lateral spread at the northwest corner of the kitchen shelter. The shelter, which was constructed on fill, was damaged beyond repair. The concrete foundation pillars supporting the shelter rose buoyantly about 2 inches, and the road and bridge approach leading to the shelter were damaged by numerous ground cracks. *Photo by Pat Pringle, March 1, 2001.*

Figure 16. DGER geologist Pat Pringle examines cracking of sidecast material along the edge of Orville Road in Ohop Valley at the south end of Lake Kapowsin approximately 7.3 miles north of Eatonville cutoff road. Cracks persist for approximately 165 yards along the east side of the road. Individual cracks are about 24 inches long with horizontal offsets of 5 to 6 inches and vertical offsets of up to 3 inches. View to the south. *Note:* If full failure had happened here, material would have ended up on railroad tracks below the road to the east. *Photo by Karl Wegmann.*

and wanted to borrow some equipment from the Department of Natural Resources (DNR) region office. I relayed him to Pat McElroy, Executive Director, Regulatory Programs, and Bonnie Bunning, Executive Director, Policy and Administration. I took calls from reporters and the media, and continued to do Internet research on the quake and its effects.

My experience as a Public Information Officer for the Cascades Volcano Observatory (CVO) came in handy. I talked to the folks at Mount Rainier, CVO, and the Park Service by e-mail about conditions on the mountain and asked if anyone had seen any evidence of landsliding. They mentioned some snow avalanches and told me they had asked Tom Sisson of the USGS, who recently mapped Mount Rainier in great detail, to fly up from California. On that following Monday, Tom and Barbara Samora of the National Park Service took an observation flight around the mountain—they mainly saw evidence of a lot of snow avalanches.

About 4:00 p.m. on the 28th, I finally got through to Craig Weaver at the USGS by telephone and we were able to review what had been learned thus far about the earthquake and its effects. Just in time, as it turned out, because Tim had not arrived back from his flight, and there was a tap on my shoulder summoning me to participate in a briefing for the Governor and his staff. This briefing lasted about 25 minutes. I simply provided an overview of the geologic setting of the quake, a deep "Benioff" type, and stressed that we were lucky because, although the effects were felt over a large area, the intensity was dramatically lower than it would have been for a shallower quake of the same magnitude. I also reviewed the types of ground failures that had historically occurred during such quakes—although it turned out (luckily) that the "shake map" that I had found on the web and held up at the meeting had exaggerated the estimated intensity of the quake.

Within 20 minutes, we watched Governor Locke in front of the cameras, and I was impressed with the way the he picked up on the important elements of the briefing. We are fortunate to have a governor who is interested in geology and understands the nature and importance of science.

I was somewhat frustrated that I didn't get out into the field that first day, but I was happy to be of service at the EOC. We got home at about midnight, and I came back early on Thursday to take up my station at the pod. Later that day, I left the EOC to help do an inventory of various areas to evaluate the effects of the quake. I ended up going to Tolmie State Park, where damage had been reported, and checking areas just to the east and west. The State Parks representative at the pod helped me get in touch with Karen Rollman, the park ranger, and I did the tour with her. They had serious damage. Liquefaction had floated

Figure 17. Parapet failure on the south side of the Washington Federal Savings building at Fifth Avenue and Capitol Way in downtown Olympia. Building also pictured in cover photo. *Photo by Josh Logan.*

Figure 18. Damage to the Skookum Bay Outfitters building on Capitol Way in downtown Olympia. The chunks of masonry fell right where the UPS delivery truck usually parks at the time of day the quake happened. *Photo by Josh Logan.*

the septic tank for the kitchen shelter so that the top was about 3 to 4 inches above the ground surface. The kitchen shelter, which was built on fill material, was badly damaged (Fig. 15), and there were cracks in the road leading to it and the bridge approach. The rest of the day I spent looking around Steilacoom, where I found some minor structural damage to an old church and major damage to the bridge over Chambers Creek and the adjacent road that connect Steilacoom with University Place.

Thursday night, we attended the crowded meeting in Seattle at the University of Washington where people presented inventories of effects or damage they had seen. We broke into subgroups to plan recons of areas that had not yet been visited and to target sites that had been damaged or affected by the ‘49 or ‘65 quakes.

On Friday, Karl Wegmann and I traveled east from Olympia and then north up the Ohop valley to Sumner (Fig. 16). It seemed that we were just behind the Pierce County Public Works crews who were already assessing damage and patching roads. We noticed that the damage was not nearly as widespread or bad as it had been in the 1949 quake, however, we did find many cracks in roads leading out of the Puyallup Valley.

In the Orting area, this was of particular concern because of the potential danger of inundation by lahars (volcanic debris flows) from Mount Rainier. It is possible that an earthquake could trigger a lahar. These roads are the evacuation route out of the valley if a lahar is approaching. All but two roads had major cracks, and some cracks were still propagating within hours of being patched by the road crew. Karl and I also witnessed an active landslide that was threatening a water supply storage facility.

By Saturday, the adrenaline was starting to dissipate, and I was able to reconnect with my wife Leslie, who had endured a shower of ceiling tiles during the quake as she was crouched under her desk at a Department of Health building near the Olympia airport. Like many, we had been out of touch with each other for most of the day on the 28th and very much needed some time to get together and talk about what had happened. On Saturday, we walked through downtown Olympia to look at the damage (Figs. 17 and 18). On Sunday afternoon, we went out to the Nisqually delta to see some of the liquefaction features and to sample sediment that had come up in the sand blows (Figs. 19 and 20)—they were full of pumice, fragments of andesite lava from Mount Rainier, and charred wood—all from ancient lahar deposits that are suspected of coring the Nisqually delta.

One of the strange things is that in natural disasters, we find out about a lot of the damage by word of mouth. That’s the way

Figure 19. DGER geologist Mac McKay measuring sand volcanoes at Nisqually delta. Candle-like objects are new seedlings surrounded by plastic tubes to protect them from foraging deer. *Photo by Dave Norman.*

Figure 20. View of sand blows from an east–west trending crack at the Nisqually National Wildlife Refuge (Nisqually River delta).The crack is located on Center Road about 220 yards northwest of the twin barns. The ejected sediments contain abundant crystals, as well as lithics and pumice, of Mount Rainier andesite. Marker pen is for scale (5.3 inches). *Photo by Pat Pringle, March 4, 2001.*

humans communicate. For example, a neighbor came to my house to sell Girl Scout cookies and told me about a landslide at Timberline High School. I went over to take a look. There were liquefaction features on the baseball field, a sand blow behind the backstop, cracks through the center of the infield, and settlement.

I made an interesting connection while talking with a woman I had met during our Mount Rainier outreach efforts a few years ago. Amy Meighan called from Orting and said, “Pat, remember me? I was watching Mount Rainier when the earthquake happened. I thought the mountain was coming down (Fig. 21). What happened is it got all cloudy all of a sudden.” Although she did not know it at the time, Amy was probably seeing the effects of the numerous snow avalanches triggered by the earthquake whose features Sisson and Samora had seen during their overflight.

Some time after the earthquake, I called *The Olympian* to see about getting a tree-ring sample from an old-growth oak tree that had been cut down in Lacey. They referred me to arborist Dave Williams at Olympic Tree Service, whom I found out is brother to Doug Williams of our Aquatic Lands Division. While talking to Dave about getting the sample, I happened to ask, “Where were you when the earthquake happened?” He was 65 feet up in a Douglas fir he had just topped. He watched the earthquake coming as a wave through the treetops. Luckily he was belted on, but even so, he held on for dear life as the treetop tried to go in three directions at once.

In one of our most memorable calls from out of town, a friend’s first question was “Did the Mount St. Helens Jim Beam bottle survive the earthquake?” It had—I would hate to have lost one of my most grotesquely beautiful pieces of kitsch, with its stopper in the form of a Plinian eruption column and its attached vial of Mount St. Helens ash!

Quake experiences, like everything else, are relative. In 1994, Barbara Blubaugh of our Information Technology

Figure 21. Mount Rainier looms over Orting, some 30 miles flow distance from the volcano. About 600 years ago, the Electron mudflow was initiated when a 260,000+ cubic yard sector of the volcano’s west flank slid away from its source area at Sunset Amphitheater and flowed along the Puyallup River valley as far downstream as Puyallup. It buried an old growth forest composed mainly of Douglas fir in as much as 25 feet of rock and mud. The higher terrace with farm buildings is topped by the Electron mudflow, and the lower terrace with horses is post-Electron alluvium. *Photo by Pat Pringle, 1995.*

Division survived the much shallower, magnitude 6.8 Northridge, California, earthquake near its epicenter. I stopped by her desk about a week after the Nisqually quake and asked how she had done in this quake. "Just fine," she said. "I thought this one was a 5.0!"

Stephen P. Palmer, Geologist 3, Environmental Section

After the earthquake, I got out of the Natural Resources Building (NRB) with a cell phone and the number of the Emergency Operations Center. Before I went anywhere else, I checked on my wife Lynn, who works at the Washington State Department of Transportation (WSDOT) lab in Tumwater. We had been a little worried about the safety of the building during an earthquake. As it turned out, ceiling tiles were coming down, water pipes had burst, water was pouring down on copy machines and computers, and there was about 3 inches of water on the floor. In a department of engineers, Lynn, a geologist, was one of two people authorized to check out the building for damage.

As I was driving to the WSDOT lab along Capitol Way, I saw over my shoulder a landslide failure at Capitol Lake. Later that day Lynn and I looked at it from the far side of the lake. All of my equipment—cameras and notebooks—was back in the NRB and I couldn't get back in the building to get it.

From there, we went to check on my mom, who is 89. She had had a box of 'strike-anywhere' matches sitting on an antique writing desk in her bedroom. They were probably there to light candles in case of a power outage. During the earthquake, a picture frame fell on them and set them on fire. She was in the living room, and her cat was in the bedroom. The cat came racing out of the bedroom, made a circle around the living room, and headed back to the bedroom to escape out the kitty door. She followed him there and found the desk on fire. The dry, varnished mahogany caught quickly. If she had found the fire just a few minutes later, it would have spread to the clothes in her closet and the whole place would have gone up. She was able to put out the fire with wet towels before we got there. The desk was badly charred.

We stayed with her for a while, then left to check out our own home, and then to investigate the damage from the earthquake. We went out to look at the landslide on Highway 101 (Fig. 22), took pictures, then went back to look at Deschutes Parkway, but were pulled in by the retaining wall failure at the Extended Stay America (Fig. 23). To reach the Deschutes Parkway failure, we came down Lakeridge Drive and walked to Marathon Park. We didn't see the really bad part till later. We talked to a professor from South Puget Sound Community College who was on the Highway 101 overpass during the quake and saw the Extended Stay America retaining wall fail.

The next day Michael Polenz, Lynn, and I evaluated slope failures on Capitol Campus for General Administration (GA),

Figure 22. Landslide on U.S. Highway 101 northwest of Olympia. The north lane of the four-lane roadbed liquefied and slid down a ravine. The toe came to rest on a frontage road (foreground). The slide volume is estimated at about 18,000 cubic yards. *Photo by Karl Wegmann.*

Figure 23. The earthquake-induced retaining-wall failure at Extended Stay America just off Highway 101 in Tumwater. *Photo by Steve Palmer.*

including a lateral spread failure along the shore by the steam plant. We took a closer look at the Capitol Lake landslide to see if it extended to the retaining wall along Interstate 5; it didn't.

Thursday evening, Michael Polenz and I drove up to Seattle to the first clearinghouse meeting held to organize the reconnaissance investigation of the earthquake. During the day I contacted Sammantha Magsino, a temporary geologist working for the Division, and had her check out damage in the Longview area where she lives.

On Friday, Lynn and I went out to look at the Puyallup Valley. We got a draft map from GeoEngineers that traced abandoned channels of the Puyallup River. We went to all the historic liquefaction failure sites, tramped the fields, and talked to farmers. There was no evidence of new failure at any of the historic sites. Joe Dragovich found sand blows at one of the historic liquefaction sites near Sumner. That night, we attended the second meeting of the clearinghouse for what was being called the 'Seattle' earthquake.

The next day Lynn and I went out to Sunset Lake and checked out the start of a landslide behind the Best Western Motel on Trosper Road. The slope failure was almost to the back of the building. We came back to the NRB when it reopened to get copies of the liquefaction hazard map for the Olympia area that was published in 1999 and my field equipment. On Sunday we went to view the mysterious new islands in Offut Lake, a mystery Pat Pringle has since cleared up. (*See related story, p. 19.*) We documented the Best Western landslide and went back to photograph the Deschutes Parkway (Fig. 24) and Sunset Lake (Fig. 25) failures. During the following few days, I consulted with GA about Deschutes Parkway and connected them with WSDOT, which is taking the lead on the repair of the roadway.

I had enough ground failures in the 10 square miles I was covering to keep me busy for a long time. Steve Kramer of the University of Washington, through a research grant from WSDOT, is working on the residual strength of liquefied soils in the Deschutes Parkway and Sunset Lake areas. WSDOT has provided me funding to perform the geotechnical investigation at Sunset Lake.

In mid-March, I had the opportunity of testifying before the U.S. House of Representatives Sub-Committee on Research on the Nisqually earthquake. This committee authorizes the National Earthquake Hazard Reduction Program, which has provided most of the funding for my work on earthquake hazard assessment while with DNR. A copy of my written testimony is on the House of Representatives Committee On Science website (http://www.house.gov/science/reshearings.htm).

Figure 24. Lateral spreads and settlement with localized sand boils along Deschutes Parkway, Olympia. Damage to the parkway was more extensive in the Nisqually earthquake than in the 1965 Seattle–Tacoma quake. Liquefaction-induced lateral spreading seriously damaged this road on the west side of Capitol Lake. As of this report, ground failures are still occurring and the road is severely damaged along about one-half mile of roadbed. The roadbed is made up of loose fill placed on modern estuarine muds of the Deschutes River, which was dammed in 1956 to form Capitol Lake. *Photo by Hank Schasse.*

Figure 25. View of the Sunset Lake liquefaction failure about 3 weeks after the earthquake. Fir trees to the left of the failed sidewalk are tilted to the right of vertical, indicating that the toe of this failure has rotated into the lake (to the left of the photo). A drilling rig is located between the two trees, collecting data as part of a research investigation of the failure. *Photo by Steve Palmer.*

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Editor's note: Within the next year or two, as people have time to analyze their data, we will be publishing more technical reports on the Nisqually earthquake. ■

USGS Map Projections Poster Available Online

The USGS has handed out thousands of its Map Projections Posters over the years. This information is now online at http://mac.usgs.gov/mac/isb/pubs/MapProjections/projections.html. The online version is even better than the original poster, as it contains a great deal more information.

A map projection is used to portray all or part of the round Earth on a flat surface. This cannot be done without some distortion. Every projection has its own set of advantages and disadvantages. There is no "best overall" projection. The mapmaker must select the projection best suited to his or her needs, the one that will reduce distortion of the most important features.

This website gives the key properties, characteristics, and preferred uses of many historically important projections and of those frequently used by mapmakers today.

USGS Contracts $100 Million to U.S. Mapmaking Companies

From planning for the Olympics to documenting the effects of natural disasters, digital orthophoto quads (DOQs) produced by the U.S. Geological Survey are proving to be the working maps of the 21st century. They also are an excellent example of a government–private industry partnership that is working.

During the past decade, the USGS has directed nearly $100 million to private-sector mapping contractors, who have produced the DOQs for government agencies through cooperative agreements.

The national DOQ program is managed and operated by about 100 cartographers and technicians at the USGS Western Mapping Center in Menlo Park, California. The raw materials for making DOQs are supplied by several other USGS facilities across the nation. In 1999, the Menlo Park group received the Department's Unit Award for Excellence in recognition of its outstanding achievements in developing and managing the DOQ program.

The technical name for these electronic maps may be a mouthful, but DOQs, as they are known to those who use them, are in some ways less technical and more accurate than the standard USGS topographic maps. DOQs are computer-generated images of aerial photographs that have been mathematically corrected for changes in ground elevations and the position of the aerial camera.

They combine the image characteristics of a photograph with the geometric qualities of a map and are delivered and duplicated quickly on demand, making them more practical and cost-effective for the mapping and commercial communities than traditional paper maps.

Photographs used to make DOQs are processed and stored in the archives of the National Aerial Photography Program, housed at the Earth Research Observation Satellite (EROS) Data Center in Sioux Falls, South Dakota. These 1- to 4-year-old images, which cover almost every corner of the United States, are high-resolution photographs taken from an altitude of 20,000 feet at a scale of 1:40,000.

Because the DOQs can serve as a layer in geographic information systems (GIS), they are especially useful for community and special events planners and for hazard-response personnel. Planners for the 1996 Summer Olympics in Atlanta, Georgia, used DOQs to produce the site maps needed for security and venue coordination. DOQs are being used in a similar manner by planners for the 2002 Salt Lake City Winter Olympics to map out the event sites and plan transportation corridors.

The USGS developed the initial concept of DOQs at its Menlo Park mapping center in 1991, in response to a request from the U.S. Department of Agriculture for more efficient methods of producing up-to-date maps used to map the nation's soils. More recently and more dramatically, DOQs have been used to support relief efforts during the Midwest flooding of the 1990s and to help fight wildfires in the national forests. Since 1991, many other agencies, such as the Natural Resources Conservation Service, Farm Service Agency, U.S. Environmental Protection Agency, U.S. Forest Service, and many state and local mapping departments, have requested DOQs to build their mapping databases.

Ten years later, nearly 65,000 DOQs are available to the public, with complete coverage of the conterminous United States expected by 2002. After that, most DOQs will be updated every 10 years, with a quicker repeat coverage for those areas of rapid land-use change. Because the USGS has limited budgets and personnel to staff the nationwide DOQ production program, it has worked out cooperative agreements with public agencies to produce the DOQs under federal contract with private mapping companies.

DOQs are now available on CD and can be ordered through the Earth Science Information Centers (l-888-ASK-USGS). Since 1998, the Microsoft TerraServer site has served as an access point for viewing samples of the images and retrieving web-compatible versions of DOQs over the Internet. More information on DOQs can be found at http://mapping.usgs.gov/digitalbackyard/.

by Dale Russell
from People, Land & Water, U.S. Department of the Interior, October/November, 2000, vol. 7, no. 7

Earthquake Creates Gassy Mounds In Offut Lake

Department of Natural Resources geologists have been investigating and analyzing several effects of the Feb. 28 Nisqually earthquake. One of the most curious has been the diapirs of gassy muck that appeared near the shallow east end of Offut Lake near Olympia (Fig. 1).

After several lakeside residents reported mounds of muck and vegetation rising from the bottom, Thurston County geologist Mark Biever visited the site and photographed the features. Later, DNR geologist Pat Pringle, along with geology professor Jim Stroh of The Evergreen State College, visited the lake to examine the mounds and sample for gases (Fig. 2). While they were taking samples, they noticed the telltale rotten-egg smell of hydrogen sulfide. Later testing of the samples revealed that the gas consisted mostly of methane and minor carbon dioxide in addition to traces of hydrogen sulfide, a mixture popularly known as “swamp gas”.

Figure 1. Diapir of mud and vegetation at Offut Lake. Surface exposure of the mound is about 20 meters by 6 meters in size. View is to the east. The mound evidently formed when shaking liquefied gas-rich bottom sediments. Most of the diapirs appeared where herbicide had been applied for control of non-native water lilies. Tests of the gases revealed a combination of methane, carbon dioxide, and hydrogen sulfide, or “swamp gas”. *Photo by Mark Biever, Thurston County geologist.*

The gases were disturbed during the earthquake, probably as sediments in the bottom of the lake liquefied. The gases inflated the sediments, thus causing the vegetable matter and muck to rise, particularly in areas where herbicides had been applied to non-native water lilies a year or two previous to the earthquake. Pockets of gas caused by natural decomposition of vegetation are not uncommon in western Washington's lakes, Pringle said.

The mounds were of varying sizes, and some protruded above the water, while others were just below the surface. The largest were up to 60 feet in diameter and four feet high. The mounds were subsiding by March 14.

Figure 2. Gas bubbles rising from the mounds in Offut Lake. *Photo by Pat Pringle.*

On March 28, Pringle and Maggie McKinnon from the Washington State Department of Ecology went out to sample the lake for temperature, dissolved oxygen, conductivity, and pH, and the lake appeared to be in good condition—the gas effects were quite localized.

There was some local concern about danger from the mounds. Probably the greatest danger was that they appeared to be islands of solid sediment. However, they were basically fragile piles of muck buoyed up by gas bubbles. If anyone tried to walk on the mounds, they would sink. If the gases were in a great enough concentration, a person sinking into one of the mounds could become asphyxiated, because the gases are heavier than air. Furthermore, the tangle of dead vegetation could cause entrapment. Fortunately, that did not happen. ■

PERSONAL ACCOUNT
Josh Logan, Geologist 4,
Geology and Resources Section, DGER

I was down in the Marina District when the quake hit. It was 10:54 am by my watch. My car was rocking side to side, and I watched the walls and windows of the Swantown Marina bulge and wave. A guy pulled up to the stop sign, got out, went around his car, and looked underneath. I timed the duration of shaking in that area at about 2 minutes. My watch didn’t have a second hand, but it said 10:56 when the shaking finally stopped. I spent the rest of the afternoon photographing damage to the downtown Olympia area.

How We Measure an Earthquake—Magnitude and Intensity

Magnitude is a measure of the strength of an earthquake or strain energy released by it, as determined by seismographic observations. This is a logarithmic value originally defined by Charles Richter (1935). The Richter Scale is not used to express damage. An earthquake in a densely populated area, which results in many deaths and considerable damage, may have the same magnitude as a quake in a remote area that does nothing more than frighten the wildlife.

Intensity is a measure of the effects of an earthquake at a particular place on humans, structures and (or) the land itself. The intensity at a point depends not only upon the strength of the earthquake (magnitude) but also upon the distance from the earthquake to the point and the local geology at that point.

Describing Magnitude

When scientists refer to a "great" earthquake, they do not mean the earthquake was fabulous, they mean it was huge. Informally, earthquakes are classified according to their magnitude size:

under 5.0	small
5.0–6.0	moderate
6.0–7.0	large
7.0–7.8	major
7.8+	great

From the U.S. Geological Survey [http://www.scecdc.scec.org/eqcountry.html]

The Richter Magnitude Scale

Seismic waves are the vibrations from earthquakes that travel through the Earth. They are recorded on instruments called seismographs. Seismographs record a zigzag trace that shows the varying amplitude of ground oscillations beneath the instrument (Fig. 1). Sensitive seismographs, which greatly magnify these ground motions, can detect strong earthquakes from sources anywhere in the world. The time, locations, and magnitude of an earthquake can be determined from the data recorded by seismograph stations.

The Richter magnitude scale was developed in 1935 by Charles F. Richter of the California Institute of Technology as a mathematical device to compare the size of earthquakes. The magnitude of an earthquake is determined from the logarithm of the amplitude of waves recorded by seismographs. Adjustments are included for the variation in the distance between the various seismographs and the epicenter of the earthquakes. On the Richter Scale, magnitude is expressed in whole numbers and decimal fractions. For example, a magnitude 5.3 might be computed for a moderate earthquake, and a strong earthquake might be rated as magnitude 6.3. Because of the logarithmic basis of the scale, each whole number increase in magnitude (for example, from 4.6 to 5.6) represents a ten-fold increase in measured wave amplitude on a seismogram. As an estimate of energy, each whole number step in the magnitude scale corresponds to the release of about 30 times more energy than the amount associated with the preceding whole number value.

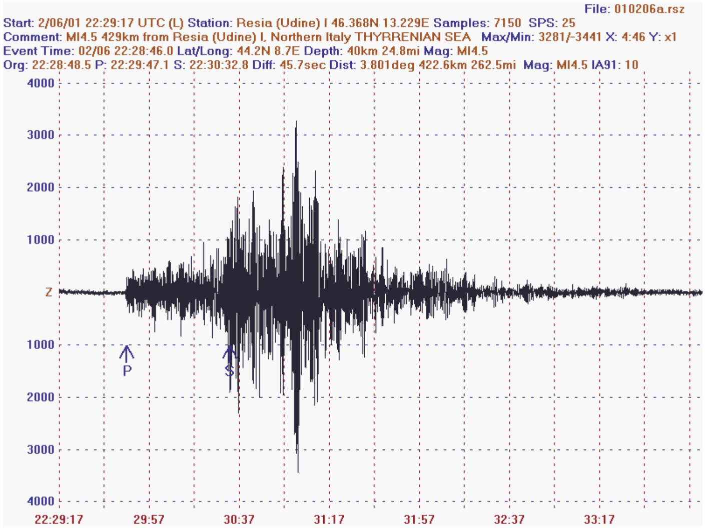

Figure 1. Seismogram of the Nisqually earthquake from a station in northern Italy. Frequently a more complete record can be obtained from stations further away from a large quake. 'P' indicates the arrival of the P-wave, a compressional wave that travels fast, and the 'S', the S-wave, a shear wave that is slower but larger and does most of the damage. Rapid shaking dies off quickly with distance, so nearby earthquakes are 'jolting' and far away earthquakes are 'rolling'. Duration of the shaking increases with the magnitude of the earthquake. Seismogram downloaded from http://www.seismicnet.com/quakes/0102/.

In other words, a magnitude 6.7 earthquake releases over 900 times (30 times 30) the energy of a 4.7 earthquake—or it takes about 900 magnitude 4.7 earthquakes to equal the energy released in a single 6.7 earthquake! There is no beginning or end to this scale. However, rock mechanics seems to preclude earthquakes smaller than about -1.0 or larger than about 9.5. A magnitude -1.0 event releases about 900 times less energy than a magnitude 1.0 quake. Except in special circumstances, earthquakes below magnitude 2.5 are not generally felt by humans.

Earthquakes with magnitude of about 2.0 or less are usually call microearthquakes. They are not commonly felt by people and are generally recorded only on local seismographs. Events with magnitudes of about 4.5 or greater—there are several thousand such shocks annually worldwide—are strong enough to be recorded by sensitive seismographs all over the world. Great earthquakes, such as the 1964 Good Friday earthquake in Alaska, have magnitudes of 8.0 or higher. On the average, one earthquake of this size occurs somewhere in the world each year. Although the Richter Scale has no upper limit, the largest known shocks have had magnitudes in the 8.8 to 8.9 range. Recently, another scale called the moment magnitude scale has been devised for more precise study of great earthquakes.

The Modified Mercalli Intensity Scale

The effect of an earthquake on the Earth's surface is called the intensity. The intensity scale consists of a series of certain key responses such as people awakening, movement of furniture, damage to chimneys, and finally—total destruction. Although numerous intensity scales have been developed over the last several hundred years to evaluate the effects of earthquakes, the one currently used in the U.S. is the Modified Mercalli Intensity Scale (MMI). It was developed in 1931 by the American seismologists Harry Wood and Frank Neumann. This scale, composed of 12 increasing levels of intensity that range from imperceptible shaking to catastrophic destruction, is designated by Roman numerals. It does not have a mathematical basis; instead it is an arbitrary ranking based on observed effects.

The Modified Mercalli Intensity value assigned to a specific site after an earthquake has a more meaningful measure of severity to the nonscientist than the magnitude because inten-

Table 1. Magnitude/intensity comparison. Magnitude and intensity measure different characteristics of earthquakes. Magnitude measures the energy released at the source of the earthquake. Magnitude is determined from measurements on seismographs. Intensity measures the strength of shaking produced by the earthquake at a certain location. Intensity is determined from effects on people, human structures, and the natural environment. The table below gives intensities that are typically observed at locations near the epicenter of earthquakes of different magnitudes. Downloaded from http://neic.usgs.gov/neis/general/handouts/mag_vs_int.html.

Richter magnitude	MMI equivalent		Modified Mercalli Intensity Scale (MMI)
1.0–3.0	I	I.	Not felt except by a very few under especially favorable conditions.
3.0–3.9	II–III	II.	Felt only by a few persons at rest, especially on upper floors of buildings.
		III.	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
4.0–4.9	IV–V	IV.	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
		V.	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
5.0–5.9	VI–VII	VI.	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
		VII.	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
6.0–6.9	VII–IX	VIII.	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
		IX.	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
7.0 and higher	VIII or higher	X.	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.
		XI.	Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.
		XII.	Damage total. Lines of sight and level are distorted. Objects thrown into the air.

sity refers to the effects actually experienced at that place. After the occurrence of widely felt earthquakes, the U.S. Geological Survey mails questionnaires to postmasters in the disturbed area requesting the information so that intensity values can be assigned. The results of this postal canvass and information furnished by other sources are used to assign an intensity within the felt area. The maximum observed intensity generally occurs near the epicenter.

The lower numbers of the intensity scale generally deal with the manner in which the earthquake is felt by people. The higher numbers of the scale are based on observed structural damage. Structural engineers usually contribute information for assigning intensity values of VIII or above.

Although they measure different characteristics of an earthquake, the Richter Scale and the Modified Mercalli Intensity Scale can be roughly equated near the epicenter as shown in Table 1.

Abridged from "The Severity of an Earthquake",
U. S. Geological Survey General Interest Publication,
http://pubs.usgs.gov/gip/earthq4/severitygip.html

WASHINGTON DIVISION OF GEOLOGY EARTHQUAKE HAZARD MAPS AVAILABLE

Preliminary maps of liquefaction susceptibility for the Renton and Auburn 7.5′ quadrangles, Washington, by S. P. Palmer, 1992. Washington Division of Geology and Earth Resources Open File Report 92-7, 24 p., 2 plates. Free.

Liquefaction susceptibility for the Des Moines and Renton 7.5-minute quadrangles, Washington, by S. P. Palmer, Henry W. Schasse, and D. K. Norman, 1994. Washington Division of Geology and Earth Resources Geologic Map GM-41, 2 sheets, scale 1:24,000, with 15 p. text. $3.71 + .29 tax (Wash. residents only) = $4.00.

Relative earthquake hazard map for the Vancouver, Washington, urban region, by M. A. Mabey, I. P. Madin, and S. P. Palmer, 1994. Washington Division of Geology and Earth Resources Geologic Map GM-42, 2 sheets, scale 1:24,000, with 5 p. text. Free.

Liquefaction susceptibility for the Auburn and Poverty Bay 7.5-minute quadrangles, Washington, by S. P. Palmer, T. J. Walsh, R. L. Logan, and W. J. Gerstel, 1995. Washington Division of Geology and Earth Resources Geologic Map GM-43, 2 sheets, scale 1:24,000, with 15 p. text. $4.63 + .37 tax (Wash. residents only) = $5.00.

Liquefaction susceptibility for the Sumner 7.5-minute quadrangle, Washington, with a section on liquefaction, by S. P. Palmer, by J. D. Dragovich and P. T. Pringle, 1995. Washington Division of Geology and Earth Resources Geologic Map GM-44, 1 sheet, scale 1:24,000, with 26 p. text. $2.32 + .18 tax (Wash. residents only) = $2.50.

Geologic folio of the Olympia–Lacey–Tumwater urban area, Washington—Liquefaction susceptibility map, by S. P. Palmer, T. J. Walsh, and W. G. Gerstel, 1999. Washington Division of Geology and Earth Resources Geologic Map GM-47, 16 p., 1 plate, scale 1:48,000. $2.32 + .18 tax (Wash. residents only) = $2.50.

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Earthquakes in Washington State

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GEOLOGIC SETTING

More than 1,000 earthquakes occur in the state annually. Washington has a record of at least 20 damaging earthquakes during the past 125 years. Large earthquakes in 1946, 1949, and 1965 killed 15 people and caused more than $200 million (1984 dollars) in property damage. Most of these earthquakes were in western Washington, but several, including the largest historic earthquake in Washington (1872), occurred east of the Cascade crest. Earthquake histories spanning thousands of years from Japan, China, Turkey, and Iran show that large earthquakes recur there on the order of hundreds or thousands of years. Washington's short historical record (starting about 1833) is inadequate to sample its earthquake record. Using a branch of geology called paleoseismology to extend the historical record, geologists have found evidence of large, prehistoric earthquakes in areas where there have been no large historic events, suggesting that most of the state is at risk.

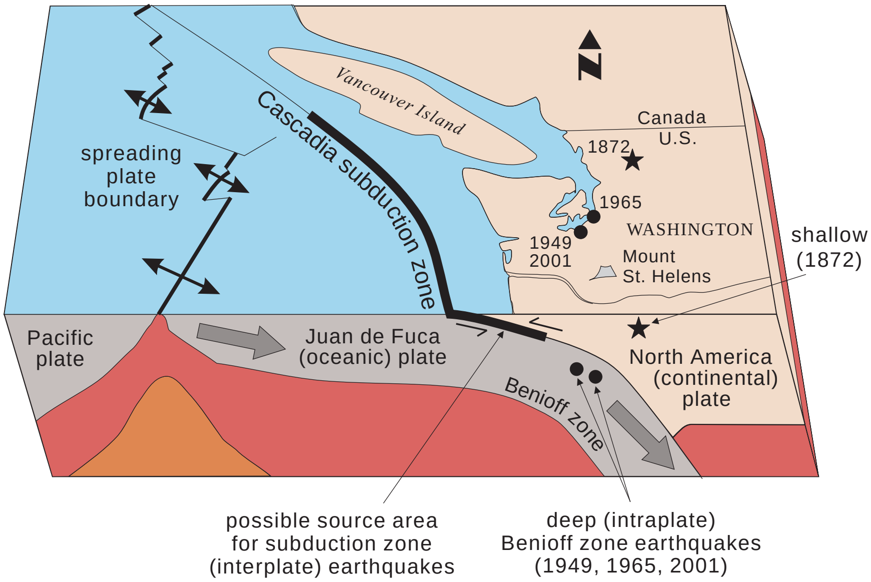

Figure 1. Block diagram of the Cascadia subduction zone near Washington State. The arrows on the plan view show where the interplate boundary is pulling apart forming an oceanic ridge. The large arrows on the cross section show the movement of the Juan de Fuca plate as it subducts under the North America plate. Modified from http://www.geophys.washington.edu/SEIS/PNSN/INFO_GENERAL/eqhazards.html.

EARTHQUAKE TYPES IN WASHINGTON

Washington is situated at a convergent continental margin, the collisional boundary between two tectonic plates (Fig. 1). The Cascadia subduction zone, the convergent boundary between the North America plate and the Juan de Fuca plate, lies offshore from northernmost California to southernmost British Columbia. The two plates are converging at a rate of about 3–4 centimeters/year (~2 inches/year); in addition, the northward-moving Pacific plate is pushing the Juan de Fuca Plate north, causing complex seismic strain to accumulate. Earthquakes are caused by the abrupt release of this slowly accumulated strain.

Intraplate or Benioff Zone Earthquakes

Intraplate or Benioff zone earthquakes occur in the subducting Juan de Fuca plate at depths of 25–100 km. The largest of these recorded were the magnitude (M) 7.1 Olympia earthquake in 1949, the M6.5 Seattle–Tacoma earthquake in 1965, the M5.1 Satsop earthquake in 1999, and now the M6.8 Nisqually earthquake of 2001. Strong shaking during the 1949 Olympia earthquake lasted about 20 seconds; during the 2001 Nisqually earthquake, about 40 seconds. Since 1870, there have been six earthquakes in the Puget Sound basin with measured or estimated magnitudes of 6.0 or larger, making the quiescence from 1965 to 2001 one of the longest in the region's history.

As the Juan de Fuca plate subducts under the North America plate, earthquakes are caused by the abrupt release of slowly accumulated strain. Benioff zone ruptures usually have dip-slip or normal faulting and produce no large aftershocks. These earthquakes are caused by mineral changes as the plate moves deeper into the mantle. Temperature and pressure increase, and the minerals making up the plate alter to denser forms that are more stable at the increased temperature and pressure. The plate shrinks and stresses build up that pull the plate apart.

For the February 28, 2001, Nisqually earthquake, the hypocenter, or point beneath the surface at which the rupture starts, was at 52 kilometers (32 miles). The area of rupture was approximately 30 kilometers by 10 kilometers (18 miles by 6 miles) and slipped approximately one yard. The epicenter was just off the Nisqually delta in Puget Sound. The quake was felt as far north as Vancouver, British Columbia, as far south as Salem, Oregon, as far east as Spokane, Wash., and as far southeast as Salt Lake City, Utah. Most of the damage was sustained in the Olympia and Seattle areas.

Shallow Crustal Earthquakes

Shallow crustal earthquakes occur within about 30 km of the surface. Recent examples occurred near Bremerton in 1997, near Duvall in 1996, off Maury Island in 1995, near Deming in 1990, near North Bend in 1945, just north of Portland in 1962, and on the St. Helens seismic zone (a fault zone running north-northwest through Mount St. Helens) in 1981. All these earthquakes were about M5–5.5. In Oregon, historically a low-seismicity state, crustal earthquakes have recently occurred just south of Portland (M5.7) and in Klamath Falls (M6.0). The largest historic earthquake in Washington (estimated at M7.4), the North Cascades earthquake of 1872, is also thought to have been shallow. It may rank as Washington's most widely felt earthquake. Because of its remote location and the relatively small population in the region, though, damage was light.

Recent paleoseismology studies are demonstrating previously unrecognized fault hazards. New evidence for a fault system that runs east–west through south Seattle (the Seattle fault) suggests that a major earthquake, M7 or greater, affected the area about 1,000 years ago. Similar large faults occur elsewhere in the Puget Sound but have not been studied in detail.

Subduction Zone (Interplate) Earthquakes

Subduction zone (interplate) earthquakes occur along the interface between tectonic plates. Compelling evidence for great-magnitude earthquakes along the Cascadia subduction zone has recently been discovered. These earthquakes were evidently enormous (M8–9+) and recurred on average every 550 years. The recurrence interval, however, has apparently been irregular, as short as about 100 years and as long as about 1,100 years. The last of these great earthquakes struck Washington about 300 years ago.

HOW EARTHQUAKES CAUSE DAMAGE

The principal ways in which earthquakes cause damage are by strong ground shaking, by the secondary effects of ground failures (surface rupture, ground cracking, landslides, liquefaction, subsidence), or by tsunamis and seiches. Most building damage is caused by ground shaking. *(For more information on damage caused by the Nisqually earthquake, see the related story on p. 6.)*

Ground Shaking

The strength of ground shaking (*strong motion*) generally decreases with distance from the earthquake source (*attenuation*), but locally can be much higher than adjacent areas, due to *amplification* (an increase in strength of shaking for some range of frequencies). At the same time, there is a decrease, or deamplification, in strength of shaking for other frequencies. Amplification occurs where earthquake waves pass from bedrock into softer geologic materials such as sediments.

Strong shaking of long duration is one of the most damaging characteristics of great subduction zone earthquakes. Strong shaking during the 1964 Alaska earthquake lasted about 90 seconds with an additional 90 seconds of strong ground motions "still of alarming magnitude", followed by "swaying…and shaking a little". The total time of shaking was about 3 minutes 40 seconds. Strong shaking is a hazard both near the epicenter of an earthquake and in areas where amplification occurs. West Seattle and certain areas of downtown Olympia are examples of places where ground motion has been documented as being significantly stronger than in adjacent areas during the same earthquake. The extensive damage to the Cypress Structure viaduct in Oakland, California, was a classic example of strong ground motion damage during the M7.1 Loma Prieta earthquake of 1989. Most of the damage and deaths in earthquakes are caused by strong ground motion.

Ground Failures

Ground failures accompanying earthquakes include fault rupture (surface faulting), ground cracking, subsidence, liquefaction, and landslides.

Fault rupture occurs as offsets of the ground surface and is limited to the immediate area of the fault. Other ground failures can occur over a wide area and can have several causes.

Landslides, including debris avalanches from volcanoes, have been caused by earthquakes. Earthquake-induced acceleration can produce additional downslope force, causing otherwise stable or marginally stable slopes to fail. In the 1964 Alaska earthquake, for instance, most rockfalls and debris avalanches were associated with bedding plane failures in bedrock, probably triggered by this mechanism. In addition, liquefaction of sand lenses or changes in pore pressure in sediments trigger many coastal bluff slides. Rockfalls, such as those that caused two deaths in the 1993 Klamath Falls earthquake in Oregon, can be triggered at great distances from earthquake epicenters.

Liquefaction occurs when water-saturated sands, silts, or (less commonly) gravels are shaken so violently that the grains rearrange and the sediment loses strength, begins to flow out as sand boils (also called sand blows or volcanoes), or causes lateral spreading of overlying layers. Ground failures, such as ground cracking or lateral spreads (landslides on very shallow slopes) commonly occur above liquefied layers. Noteworthy liquefaction took place in Puyallup during the 1949 earthquake. The sands that failed in many cases were sand deposits from Mount Rainier debris flows; similar hazards could be expected in other valley floors downstream from other stratovolcanoes, such as Mount Baker, Mount St. Helens, and Mount Adams.

Subsidence (including differential ground settlement) can result in the flooding and (or) sedimentation of subsided areas, as occurred over broad areas in Chile (1960) and Alaska (1964).

Tsunamis and Seiches

Tsunamis (seismic sea waves) are long-wavelength (large distance between wave crests), long-period (several minutes to several hours between wave crests) sea waves that can be triggered by earthquakes or by landslides into a body of water. These are erroneously called tidal waves even though they are not caused by tides because they are sometimes preceded by a recession of water resembling an extreme low tide. Tsunamis are more damaging when they strike a coastline that has suffered earthquake-induced subsidence. *(See related article, p. 31.)*

Seiches resemble tsunamis but occur as standing waves (or sloshes) in enclosed or partially enclosed bodies of water. ■

Lasmanis Donates Collection to University of Wyoming

Washington State Geologist Raymond Lasmanis has donated exploration and mining files covering the years 1960 to 1982 to the Raymond Lasmanis Collection at the American Heritage Center of the University of Wyoming. The record of years of work in mining and geology, the donation includes progress reports, property reports, maps, and other materials from the U.S.—Alaska, Arizona, California, Idaho, Missouri, Montana, Nevada, Oregon, Tennessee, Utah; Canada—British Columbia, Manitoba, New Brunswick, Northwest Territories, Nova Scotia, Ontario, Saskatchewan, and Yukon Territory; and worldwide from Australia, Chile, Costa Rica, Greenland, Mexico, Portugal, and Spain. This material, which might otherwise have been lost, will be of value to geological scholars in the future.

Natural Resources Building Earthquake Mitigation

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Geologic history and common sense play major roles in preparing for earthquakes, according to State Geologist Ray Lasmanis.

Before completion of the Natural Resources Building (NRB) in 1992, the design and components were markedly changed on the advice of DNR geologists. About the same time, concerns about the safety of government buildings in an earthquake led to retrofitting many other Capitol Campus buildings in Olympia.

When they first saw the original drawings for the NRB, geologists Steve Palmer and Tim Walsh were stirred to action. Both had experience testing for ground motion. They had analyzed ground motion results from the 1949 Olympia earthquake and felt that the NRB's architects had "underdesigned for ground motion from a deep subduction-type earthquake."

Both felt that the building's support needed enhancement for two reasons:

1. The area's history of major earthquakes. The likelihood of a subduction earthquake is high for western Washington, and data was available from the 1949 earthquake.
2. The type of soil at the building site. As indicated by the discovery of layers of peat, the building site is an ancient lake bed that could easily amplify ground movement during an earthquake.

After Palmer and Walsh met with the architects in 1989, the building's foundation was reinforced with additional pilings and other modifications. This caused shuffling of the construction budget. Since the building was approved by the State Legislature for a fixed cost, the extra expense for the pilings came from the allocations for furniture and other interior expenditures.

Also before the building was constructed, Lasmanis drew $10,000 from the division's budget and received a matching $10,000 grant from the U.S. Geological Survey to purchase and install 17 strong motion sensors. The sensors were designed to measure vertical and horizontal acceleration on various levels of the building during an earthquake.

Lasmanis reported that 11 of the 17 sensors (powered by car batteries) worked during the Feb. 28 earthquake (Table 1). The data, which is being processed, will show the difference in movement among the upper and lower floors and the parking garage.

Lasmanis said the NRB's sensors will prove invaluable. They were the closest strong-motion sensors in a major building to the earthquake's epicenter just off the Nisqually delta. The only other nearby sensors were installed at the Department of Transportation building and at the home of geophysicist and photographer Harry Halverson who founded Kinemetrics, Inc., the primary manufacturer of seismic instruments worldwide. (One of their seismographs was donated to DNR and can be seen in the rotunda of the NRB.)

The Capitol Campus probably was saved from more severe structural and office damage through the recommendations of a 1991 committee called the Seismic Safety Advisory Committee. Prompted by several agencies' concern for Washington's vulnerability to earthquakes, the legislature funded a multidisciplinary effort that produced "A Policy Plan for Improving Earthquake Safety in Washington". DNR contributed leadership and expertise, such as geologic maps, studies, assessments, and a wealth of material from the Geology Division library.

Implementation of the 1991 policy plan and the formation of the Cascadia Region Earthquake Workgroup (CREW) in 1995 and Project Impact (Seattle and King County in 1998 and Pierce County in 2000) led to a major campaign to retrofit building and transportation corridors and improve safety for schools and homes.

All of the recommendations they made to secure your work area still hold true today:

- Tie down bookcases and computers using straps or hook-and-loop tape.
- Attach bookshelves and cabinets to walls and floors with brackets.
- Brace library (free-standing) bookshelves for side-to-side and front-and-back movement.
- Keep clutter to a minimum, particularly overhead.
- Thread chains through handles on filing and map cabinet drawers to keep them from opening and causing the cabinet to tip over.
- Place rubber matting on the shelves for better grip. ■

Table 1. Data from the strong-motion sensors in the NRB for the magnitude 6.8 Nisqually earthquake of February 28, 2001. The complete preliminary corrected dataset may be seen at http://nsmp.wr.usgs.gov/data_sets/20010228_1.html

Location	Orientation	Peak acceleration cm/s/s	Peak velocity cm/s	Percent gravity
Parking Level 3 @ M 16.5	east–west	144.2	12.97	0.15
Parking Level 3 @ M 16.5	north–south	–92.3	8.60	–0.09
Parking Level 3 @ M 16.5	up	215.4	–24.47	0.22
Ceiling, P. Level 2 @ K/L 27	north–south	271.5	26.21	0.28
Ceiling, P. Level 2 @ K/L 27	east–west	252.7	–18.02	0.26
Parking Level 3 @ F 27 **	north–south	–240.5	48.49	0.25
Parking Level 3 @ F 27	east–west	81.2	–6.90	0.08
Ceiling, P. Level 2 @ M 16.5	north–south	–229.4	24.75	–0.23
Ceiling, 4th Floor @ M 16.5	north–south	–374.5	35.20	–0.38
Ceiling, 4th Floor @ K/L 27	north–south	252.9	–35.04	0.26
Ceiling, 4th Floor @ K/L 27	east–west	–322.6	30.81	–0.33

Observations during the Nisqually Earthquake on Harbor Island, Seattle, Washington

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Note from Tom Holzer of the U.S. Geological Survey, the original editor: The following is one of the most exciting scientific descriptions of the Nisqually earthquake that I have read. It recounts the strong shaking produced by the earthquake, and most interestingly, describes the formation of a sand boil in the Port of Seattle on Harbor Island. Sand boils result from the liquefaction of sand layers that contain abundant water. This description by Bob Norris, a seismologist with the U.S. Geological Survey, is one of the few known observations of the formation of a sand boil by a scientist. Bob wrote his account about 6 days after the earthquake on March 6, 2001.

This is a narrative of my observations of strong ground motion and a sand blow I observed on Harbor Island from the Nisqually earthquake. I apologize about the length of this ramble, but the details might be helpful in reconstructing a rough time history of the events I witnessed.

Harbor Island is located on the south shore of Elliot Bay, south of downtown Seattle. The island consists largely of artificial fill and overlies former tidal flats of the Duwamish River delta. In common with other sites on artificial fill, Harbor Island shows high site response during earthquakes. (I can now verify that from personal experience.)

At 10:54 a.m. on Wednesday, I was driving a GSA Chevy Suburban, turning west off 11th Ave SW on Harbor Island. The K2 is in an outbuilding on a large level lot owned by Arco, immediately southwest of the junction of 11th Ave SW and SW Florida streets. This lot is mostly empty, except for a line of poles supporting a power transmission line of unknown voltage. Within the last few weeks, the lot had been graded, fresh gravel put down, and most of it had been paved for a new parking lot.

I had just entered the gravel driveway that gives access to the site when the truck started yawing from side to side as if I'd just driven diagonally over a large speed bump. I thought I had driven over something I hadn't seen, and went through several seconds of confusion because the truck was still rocking sharply after I had stopped. It wasn't until I looked up and saw the high tension wires overhead swaying and their support poles leaning back and forth that I realized this was not only an earthquake, but an unholy BIG earthquake! I was utterly amazed that all this ground motion could go on so quietly—I could hear things creaking and clanging from all the swaying, but the ground itself was silent.

When I stopped gawking and resumed intelligent thought, I remembered the wires overhead and gunned the truck into an open area about 20 meters (20 yards) ahead, which looked like a safe area to wait it out. At this point, about 15 to 20 seconds into the strong ground motion, its amplitude seemed relatively constant and, although the ride was bumpy, I had no problem steering the truck into the open area. It seemed the worst was over, but as I stopped the truck again, the amplitude of shaking abruptly increased. In less than a second, the truck was rocking so violently I lost sight of everything outside and could do nothing but hold on to the steering wheel and hope my flying head didn't strike anything. This violent phase was brief, perhaps 5 to 7 seconds, but long enough to give me a mild whiplash strain in my neck and bring on several unpleasant thoughts. I had the impression no structure could withstand this for long, and this was quickly turning from an exciting professional experience to a survival situation. I remembered I was next to an oil tank farm and had a visualization of the huge oil fire in Valdez, Alaska, after the 1964 quake, which I could have done without.

When it eased enough for me to be able to look around again, perhaps 25 to 30 seconds after the strong shaking began, I saw the dozen or so 60-to-70-meters (70–80 yards)-tall cargo cranes that line the waterways of Harbor Island quivering and

Figure 1. Sand volcanoes (medium sand) in Marathon Park near Capitol Lake in Olympia. *Photo by Joe Dragovich.*

Figure 2. Sand boils (incipient lateral spread) at the Port of Olympia in an area with several boils and extensive cracking. *Photo by Hank Schasse.*

flexing in place, resembling huge steel giraffes trying to dance. I remember hoping no one was in them. It was at least another minute before I felt safe enough to get out of the truck. Outside, there was a pervasive background din of car and industrial alarms going off all over the city. I walked over to a crew of Arco people in hardhats about 100 meters (100 yards) away to see if they were all right. As I walked over to them, I could plainly feel the asphalt gently moving back and forth with about a 2 to 3 second period under my feet; they could too. We traded our stories for a short time, perhaps 2 to 3 minutes, then I walked back to the truck. At this time I could still feel subtle ground motion if I stopped walking.

Since my cell phone was out and I no longer felt in danger there, I thought I might as well get the data from the K2, especially now! I estimate that what happened next occurred at least 5 minutes after the onset of strong shaking at that point, perhaps as long as 10 minutes, but that's probably an upper limit.

I had just opened the side door of the Suburban to get my laptop and notebook when I was distracted by a wet swishing sound coming from the ground nearby. I looked over to its source and saw a smooth dome of brown fluid, perhaps half a meter (1.5 feet) wide and high, issuing from the ground a few meters away from the southeast corner of the fire control house where the K2 was located. This dome lasted perhaps two seconds, then grew and burst into a muddy geyser. The geyser issued three or four very fluid splashes over the next few seconds, about a meter (yard) high each, then it widened and collapsed into a column about a half meter wide that discharged a tremendous volume of muddy water. This flood emerged much faster than it could spread, so that within a few seconds the flow front had become a surge several centimeters high, like a small wave traveling up a dry beach. Its velocity was nearly 1 meter (yard)/second as far as I could tell. Within an estimated 30 seconds, the surge had grown into a shallow rotating pool about 6 or 7 meters (6–7 yards) across with bits of suds floating on it, still vigorously fed by the column of water at the original breakout site.

I confess I didn't think it was a liquefaction feature at all; the delayed onset, the limited amount of sediment in the water, and the high flow rate convinced me it was a water main break—particularly as it occurred near a building containing fire control equipment. In fact, I was annoyed because I thought the growing pool might engulf the driveway and strand me there or prevent me from getting to the K2 and downloading data! The feeder column remained centralized at the breakout site but began to gradually wane after a couple of minutes. I walked over to get a closer look and was surprised to find the water was relatively clear; I could see to a depth of several centimeters in the pond.

Unfortunately, I paid no further attention to it and focused on the K2 in the fire control house. When I left the site about 90 minutes later, I noticed that the column had dwindled to a disturbed patch of water in the now-quiet pool, which had approximately doubled in size.

After learning that this was indeed a sand blow (Figs. 1 and 2), I returned to the site as soon as time allowed—about 3 days after the quake. Its deposit consisted mostly of dark sand-sized material, much coarser than the fine muds emitted by similar features along First Avenue South (Pioneer Square area in Seattle). This may explain why the eruption was so fluid—the sand quickly settled out of the water. The main vent area had been filled in with gravel by Arco and the area covered by emitted sand was approximately 16 meters (16 yards) in maximum diameter. I was surprised to see several other vents in the sand (closer to where my truck had been!). These may have contributed to the tremendous surge of ground water that emerged after the collapse of the geyser, but were submerged before they were ever visible. It's also possible that they vented after I left.

I was luckier to get out of there than I realized. Subsurface piping had opened an oblique collapse pit about 1 meter (1 yard) in diameter and of uncertain depth only a few meters from where my truck had been parked. ■

In Memoriam: Barbara Ann Bjorkman Preston

Barbara Ann (Bjorkman) Preston passed away in her home Thursday, January 11, 2001, of natural causes. She is survived by her mother Ingrid Morris, her daughter Tiffany L. Preston, and her two sons, Alan Preston and Robbie Preston, all of Olympia, and her two brothers Robert Bjorkman of Faribault, Minnesota, and Leif Dahl of Richmond, Virginia, and many nieces and nephews. She was born February 19, 1947, in Hinesville, Georgia, to Ingrid Morris and Oscar Bjorkman. In the spring of 1948, the family moved to California, later to Oregon, and finally to Olympia in 1953. She attended Garfield and Boston Harbor grade schools and Jefferson Junior High, and graduated from Olympia High School. She earned her Associate of Arts degree from Centralia Community College and later her Bachelor of Arts degree from Central Washington University. She began her state employment with the Department of Licensing and worked for the State of Washington for the past 23 years. She worked for the Department of Natural Resources and the Division of Geology as office manager for 13½ years, and for the past seven years worked for the Washington Health Care Authority.

Barbara was an exceptional human being. She had a great sense of humor and always found the humor in every situation. She spent a few years popping in on local parades around the state as Borky the Clown with the infamous Walter the Wonder Dog. She was truly funny and loved by so many! She was extremely intelligent and always sought after for her words of wisdom, encouragement, and wit. Those of us who knew and loved her were honored and blessed to have been a part of her life. Barb set an example for us all. She was the salt of the earth…she was the best. We will miss her. ■

GUIDE TO 'BEST AVAILABLE SCIENCE'

The Revised Code of Washington (RCW 36.70A.172) requires that the 'best available science' be used when designating and protecting environmentally critical areas. For those still trying to figure out what 'best available science' means, there is "A State Official's Guide to Sound Science" by C. J. Lackey, Malissa McAlister, H. H. Bakondy, and Barry Tonning. This is a user-friendly, non-technical guide to sound science and public policy. It features quick-reference lists of questions and of "warning signs" to recognize unreliable research. Published by The Council of State Governments in 1999, it is 28 pages in length. It may be purchased on the web for $20.00 at http://www.statesnews.org/store/.

Earthquake Prediction

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Because of their devastating potential, there is great interest in predicting the location and time of large earthquakes. Although a great deal is known about where earthquakes are likely, there is currently no reliable way to predict the days or months when an event will occur in any specific location.

Each year there are about 18 earthquakes magnitude (M) 7.0 or larger worldwide. Actual annual numbers since 1968 range from lows of 6 to 7 events a year in 1986 and 1990 to highs of 20 to 23 events a year in 1970, 1971, and 1992. Although we are not able to predict individual earthquakes, the world's largest earthquakes do have a clear spatial pattern, and “forecasts” of the locations and magnitudes of some future large earthquakes can be made. Most large earthquakes occur on long fault zones around the margin of the Pacific Ocean. This is because the Atlantic Ocean is growing a few inches wider each year, and the Pacific is shrinking as ocean floor is pushed beneath Pacific Rim continents. Geologically, earthquakes around the Pacific Rim are normal and expected. The long fault zones that ring the Pacific are subdivided by geologic irregularities into smaller fault segments that rupture individually. Earthquake magnitude and timing are controlled by the size of a fault segment, the stiffness of the rocks, and the amount of accumulated stress. Where faults and plate motions are well known, the fault segments most likely to break can be identified. If a fault segment is known to have broken in a past large earthquake, recurrence time and probable magnitude can be estimated based on fault segment size, rupture history, and strain accumulation. This forecasting technique can only be used for well-understood faults, such as the San Andreas. No such forecasts can be made for poorly understood faults, such as those that caused the 1994 Northridge, California, and 1995 Kobe, Japan, quakes. Although there are clear seismic hazards in our area, Pacific Northwest faults are complex, and it is not yet possible to forecast when any particular fault segment in Washington or Oregon will break.

Along the San Andreas Fault, the segment considered most likely to rupture is near Parkfield, California. In the last century it produced a series of identical earthquakes (about M 6.0) at fairly regular time intervals. USGS scientists are monitoring Parkfield for a wide variety of possible precursory effects. Using a set of assumptions about fault mechanics and the rate of stress accumulation, the USGS made a more precise Parkfield prediction—of a M 6.0 earthquake between 1988 and 1992.

Though that prediction was not fulfilled, a M 6.0 earthquake is still expected at Parkfield. “Capturing” the Parkfield earthquake in a dense network of instrumentation will establish whether precursory effects exist and give new insights on the mechanics of fault rupture. The segment of the San Andreas fault that broke in the 1989 M 7.1 Loma Prieta or “World Series” earthquake had been identified by the USGS as one of the more likely segments of the San Andreas to rupture. Magnitude 5+ earthquakes 2 and 15 months before the damaging earthquake were treated as possible foreshocks, and the USGS issued five-day public advisories through the California Office of Emergency Services. Even in areas where foreshocks are fairly common, there is no way of distinguishing a foreshock from an independent earthquake. In the Pacific Northwest, there is no evidence of foreshock activity for most historic earthquakes.

One well-known successful earthquake prediction was for the Haicheng, China, earthquake of 1975, when an evacuation warning was issued the day before a M 7.3 earthquake. In the preceding months, changes in land elevation and ground water levels, widespread reports of peculiar animal behavior, and many foreshocks had led to a lower-level warning. An increase in foreshock activity triggered the evacuation warning. Unfortunately, most earthquakes do not have such obvious precursors. In spite of their success in 1975, China had no warning of the 1976 Tangshan earthquake, magnitude 7.6, which caused an estimated 250,000 fatalities.

Earthquake prediction is a popular pastime for psychics and pseudo-scientists, and extravagant claims of past success are common. Predictions claimed as “successes” may rely on a restatement of well-understood long-term geologic earthquake hazards or be so broad and vague that they are fulfilled by typical background seismic activity. Neither tidal forces nor unusual animal behavior have been useful for predicting earthquakes. If an unscientific prediction is made, scientists can not state that the predicted earthquake will not occur, because an event could possibly occur by chance on the predicted date, though there is no reason to think that the predicted date is more likely than any other day. Scientific earthquake predictions should state where, when, how big, and how probable the predicted event is, and why the prediction is made. The National Earthquake Prediction Evaluation Council reviews such predictions, but no generally useful method of predicting earthquakes has yet been found.

It may never be possible to predict the exact time when a damaging earthquake will occur, because when enough strain has built up, a fault may become inherently unstable, and any small background earthquake may or may not continue rupturing and turn into a large earthquake. While it may eventually be possible to accurately diagnose the strain state of faults, the precise timing of large events may continue to elude us. In the Pacific Northwest, earthquake hazards are well known and future earthquake damage can be greatly reduced by identifying and improving or removing our most vulnerable and dangerous structures.

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From http://www.geophys.washington.edu/SEIS/PNSN/INFO_GENERAL/eq_prediction.html. This site also has links to interesting statistics and other earthquake information provided by the U.S. Geological Survey Earthquake Hazards Program, such as earthquake facts and statistics, number of earthquakes worldwide (M>7.0) since 1900, the 15 largest earthquakes in the United States, map of M>7 earthquakes in past 15 years. ■

MAP OF MISSOULA FLOODS BACK IN PRINT

The second printing of Jeff Silkwood's map of "Glacial Lake Missoula and the Channeled Scabland" is now available. The map is published by the Regional Office of the Forest Service in Missoula. To order directly from the Regional Office, contact Kathy Daugherty at (406) 329-3511. The price is $6.00, plus $3.50 for shipping and handling; several copies can be sent with only one shipping charge. Sheet size is 36.75 inches x 45.5 inches. The maps are mailed rolled, not folded. Dealers should contact Jim Polich at (406) 329-3209 for information on vendor sales arrangements. The map is also available over the counter at the sales outlets at Lake Roosevelt National Recreation Area in Washington and Farragut State Park in Idaho.

BOOK REVIEW: Hiking Washington's Geology

by Scott Babcock and Bob Carson
ISBN 0-89886-548-4
2000, softcover, $16.95 U.S.
published by The Mountaineers
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Seattle, WA 98134
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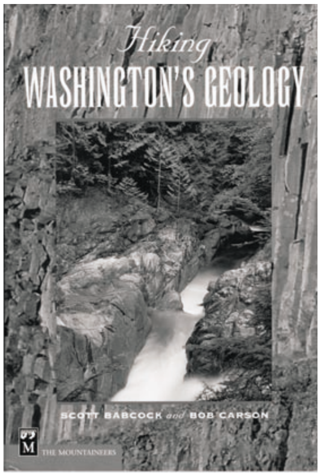
www.mountaineersbooks.org

Do you enjoy walking in the outdoors? Do you ever wonder about the age and origin of the rock formations you are hiking across? Perhaps, once the summit is obtained, you ponder the varied landscape below, speculating upon the intricacies of its formation? If you answered yes to one or more of these questions, you may enjoy picking up a copy of the recently published *Hiking Washington's Geology*. Authors and geology professors Babcock (Western Washington University) and Carson (Whitman College) combine their collective knowledge of and expertise in the regional geology of Washington State to deliver a first-rate guidebook for the hiking geology enthusiast.



Hiking Washington's Geology contains fifty-six different hikes extending to all four corners of the state. The book divides the state into seven regions: Coast Ranges, Puget Lowland and the San Juan Islands, North Cascades, South Cascades, Columbia Basin, Okanogan Highlands, and Blue Mountains. There are between four and thirteen hikes in each region. As the authors state, "[t]hese fifty-six hikes have been selected with the intent of covering all regions and as many rock types and landforms as possible." They do just that. The hikes are as varied as Washington's geologic history and outcrops, ranging from a short wheelchair-accessible stroll through the enigmatic Mima Mounds of south Puget Sound to a more strenuous 10-mile backpack to Copper Ridge in the heart of the North Cascades, to a relatively easy walk along the deeply incised meanders of the Grande Ronde River in the Blue Mountains of southeastern Washington.

The book begins with sections on "Gearing Up For Field Geology" and "Geology 101: What you need to know to read the rocks of Washington". The latter is a synopsis of the basic principles of geology, covering topics such as geologic time, landforms, volcanism, tectonism, and agents of erosion and landscape change. The book is well illustrated and contains eighty-five photos, numerous detailed maps and thoughtfully drafted figures. Each chapter focuses upon a particular geographic region, beginning with an overview of the geologic history, including the rock types to be found and the tectonic and geomorphic events important in shaping the landforms of the specific region. A glossary of important terms from the text and bibliographic references for further study are found at the end of the book.

Individual hikes were well thought out and researched by the authors. Hike descriptions begin with necessary information such as hike distance, assessed level of difficulty, appropriate topographic and geologic maps, and key references. The geologic landscape pertaining to each hike is described in simple and understandable prose. The trail guide for each hike is detailed and easy to follow. The authors continually ask the readers to do more than merely walk down a trail, rather encouraging active engagement in seeking out and understanding the surrounding geologic and biologic world.

This is a guidebook that will be enjoyed by both recreational and professional students of geology and natural history, by earth science teachers and their students, and by parents and their children. *Hiking Washington's Geology* is a book that encourages one to experience, enjoy, and learn from the varied and complex geologic history of Washington State.

Karl W. Wegmann
Washington Division of Geology & Earth Resources

The Charlatan Game

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The next time you get together with your friends or take a coffee break, you can really impress people. You too can make earthquake predictions and be 100 percent accurate. Here's how:

There are three components to an earthquake prediction. Those three components answer the questions, when?, where?, and how big? All you have to do is make vague predictions whose components will be fulfilled by normal earthquake activity.

So here are the four earthquakes you can predict and get it right every time.

1. There will be a magnitude 5 or 6 earthquake in Los Angeles. (The when is just sometime in the future, and you probably mean the Los Angeles region, but when that earthquake happens, those details won't matter.)
2. There will be an earthquake in Japan next month. (Leave the size unstated but, if pressed, say a big one. If pressed further, say at least a magnitude 4 and consider getting some less picky friends.)
3. There will be an earthquake of at least magnitude 6 in the next two weeks. (The where is left unstated, but 'somewhere on Earth' is the answer. What do they want? You're new at this!)
4. There will be an earthquake in southern California in the next 48 hours. (It could be any size. You will probably have to contact the various seismic research organizations in California to find out exactly where and how big it was because it likely won't be big enough to make the news. But trust me! It will happen! If the earthquake is actually in, for example, Palm Springs, that is close enough to take credit. Is two weeks or a month (or two or three) too long to sleep in a tent in your back yard in order to be safe from a big quake?)

Then just sit back and wait. In two days, your skeptical friends may call you. In two weeks, they'll start thinking "Maybe this is for real." In a month, they'll really be pressing you for your secret, and when that earthquake hits Los Angeles, they'll be on the phone for sure!

The technique has three components that make it work. First, earthquakes are more frequent than people realize. There are lots of earthquakes, even 'big' ones, all over the world every month. Most simply never make the headlines. Second, the vast majority of earthquakes occur in very narrow, specific regions of the world. Third, this technique relies on being vague about one of the three essential characteristics of a useful prediction. Remember the three characteristics were (1) Where will the earthquake be located?, (2) When will the earthquake occur?, and (3) How big will the earthquake be?

Every year, worldwide, there are about:

6,200 magnitude 4 to 4.9 earthquakes,
800 magnitude 5 to 5.9 earthquakes,
120 magnitude 6 to 6.9 earthquakes,
18 magnitude 7 to 7.9 earthquakes

(U.S. Geological Survey, National Earthquake Information Center, http://wwwneic.cr.usgs.gov/neis/eqlists/eqstats.html).

Most of these earthquake are concentrated along narrow bands that coincide with the boundaries of the tectonic plates that make up the earth's rigid outer surface. It is the movement of these plates that gives rise to earthquakes, so it's easy to know where earthquakes occur most often. It's easy to know how frequent they are. Finally, we know that the bigger earthquakes are less frequent than smaller ones. The vagueness of the timing for the first prediction is because the bigger earthquakes are much less frequent.

I first devised the Charlatan Game in Spring of 1993. At the time, I was the Geotechnical Earthquake Specialist for the Oregon Department of Mineral Industries. On March 28, 1993, a magnitude 5.3 earthquake occurred 34 miles south of Portland, Oregon, causing a moderate amount of damage, only a couple of minor injuries, and no deaths. (For more information on the Scotts Mills earthquake, see http://www.geophys.washington.edu/SEIS/EQ_Special/ScottsMills/scottsmills.html.) Shortly after the earthquake, reports began appearing in the media about someone having predicted the earthquake. Although the details have always remained in the shadows, it appears that someone did indeed predict something for that general time frame somewhere in the Pacific Northwest of some magnitude. But given what *is* known about the prediction, it is obvious that the magnitude was supposed to have been greater and the location wasn't supposed to have been in the remote foothills of the Cascades.

But I took note of these reports because I had witnessed the circus and frenzy created by another prediction a few years earlier. I thought I had learned some lessons from those events, and I didn't want to repeat the mistakes.

In Memphis in 1989, Iben Browning, a New Mexico 'climatologist' who sold long-range weather forecasts to businesses, was quoted in *The Commercial Appeal* as predicting that something called 'earth tides' could cause an earthquake in the New Madrid seismic zone on or around December 3, 1990. The New Madrid zone runs through parts of Illinois, Kentucky, Missouri, Tennessee, and Arkansas. While the main focus always remained on the New Madrid area, the media coverage and Iben Browning himself spread the threat around the world in the 'middle latitudes'. (For the full story, see http://www.journalism.indiana.edu/Ethics/day.html.)

As I watched this circus unfold, I wondered why those who knew better and knew the New Madrid region weren't in front of the cameras debunking this prediction. Eventually the experts did respond, but too little and too late (see Gori, 1993; Spence and others, 1993). Schools closed, businesses closed, and events were canceled. Stores did a land-office business in earthquake supplies. My students from the New Madrid area still vividly remember the fiasco. Iben Browning has since passed away.

So my response has been to try and keep ahead of unsubstantiated claims of earthquake predictions. Media references to earthquake prediction were beginning to die down when the Northwest Timber Summit came to Portland in April of 1993.

During the summit, numerous luminaries were in Portland, including the President of the United States. While the President was in town a 'rumor' started. The details of this rumor are even more shadowy than those surrounding the Scotts Mills earthquake. I will only comment on my first-hand experience. I spent an entire day on the phone answering calls from emergency response leaders and workers in both the public and private sectors. They wanted to know what was the basis for the prediction they were being asked to respond to and if it was credible. When I wasn't getting calls, I was making calls, trying to find out the source of all the hoopla. The prediction and the stir it caused did make the news, but as a secondary story. I think our fast and decisive action in informing the public about the unreliability of earthquake prediction prevented a Pacific Northwest version of the Iben Browning incident.

As *we* predicted, there was no earthquake, but I do have a few gray hairs I attribute to that day. I devised the Charlatan Game to help people understand why other people can appear to predict earthquakes even when they really can't.

By the way, when you're predicting, refuse to talk about the dozens of magnitude 5, 6, and 7 earthquakes that happen around the world each month that you don't predict with this technique. What does it matter if you miss a few, as long as you are 100 percent accurate on the ones you do get? This is a harmless game really, isn't it? What could possibly go wrong? Is anyone being hurt? After all, the Chinese saved lives in 1975 by getting one earthquake prediction right. That must have been comforting to the more than 250,000 who died in an unpredicted Chinese earthquake in 1976.

The fact of the matter is that unless you want to become a homeless, jobless refugee after an earthquake, the solution isn't predicting earthquakes, but preparing for them. This February's Nisqually quake that shook the Puget Sound region is a perfect example. If the earthquake had been predicted, the death toll would likely have been the same (or bigger if anyone panicked). But what if the citizens and leaders of Washington had been lulled into complacency by someone claiming the ability to predict earthquakes? Maybe, in order to save money, the bridges and buildings would not have been strengthened or built to resist earthquakes. Just think how much more disruptive the earthquake could have been, even if the deaths and injuries were equally minimal.

There are precursors to earthquakes. We can't yet use them to reliably or usefully predict earthquakes. Some day we may very well be able to. But even then, the correct response will be to get your own 72-hour emergency kit together, bolt that hot water heater to the wall, establish a family plan, and know how to duck, cover, and hold on. We will still want to build to resist earthquakes. Once you've done these things, you can relax and enjoy life with or without predictions.

Besides, now YOU can 'predict' earthquakes.

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Editor's note: After the Nisqually earthquake, the Division of Geology was inundated by requests for information about the 'really big' earthquake that was predicted to follow in the next week—people were afraid to go back to work or school, in case the big one hit. It may be that this type of rumor is a predictable result of post-traumatic stress disorder from an earthquake. I know I still jump whenever the building shudders, and I was on the first floor where the shaking was relatively mild compared to what they felt on the upper floors. ■

THE PERILS OF QUAKE PREDICTION

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The weekend after the quake, a friend called our house, very upset, and said he heard some guy on TV or over the Internet [Jim Berkland] predict a magnitude 9 earthquake will happen on March 6, and he's supposed to be right 9 times out of 10. "Is that true?" he asked.

Monday was when the phones really started ringing. A woman caller stated, "My daughter came home from school saying there's going to be a magnitude 9 earthquake. Can we survive an earthquake that big? What should we do?" She was practically crying. I tried to calm her down and told her we have no reliable way of predicting earthquakes. She said I made her feel better. I sent her earthquake information and the flyer on earthquake prediction from the UW (see p. 27.)

A woman from the Hands On Children's Museum came in saying her daycare parents were frantic because they heard that some guy on National Public Radio said there was going to be a magnitude 9 quake. I called both the local and national NPR and visited their websites, and although they had interviews with scientists, there was nothing about a 9-point quake prediction. How do these rumors get started? I gave her a printout of Berkland's website to post at the museum. "Would you believe a prediction from this man," I asked. She agreed that posting the printout so they could see where the prediction was coming from would be very reassuring to the parents.

A group of freaked out people came in from upstairs (third floor, I think) and said, "You guys can predict earthquakes, can't you? You've got to tell us more about this prediction. We need an alarm!"

Puget Sound Landslides Website

The Washington Department of Ecology has a new Puget Sound landslides website. The site contains information about how landslides occur, who to go to for help, how to recognize landslides, and how to reduce risks from them. The site is aimed primarily at coastal property owners, real estate professionals, shoreline consultants, and local governments, but should be useful to a variety of other folks as well. Although focused on Puget Sound bluffs, much of the information is applicable to steep slopes and landslides in other environments, too.

Besides plenty of information and pictures, the site includes the slope stability maps from the Coastal Zone Atlas, which still serve as a standard reference for many local ordinances. The project was supported financially by FEMA.

Puget Sound landslides website:
http://www.ecy.wa.gov/programs/sea/landslides/

Other DOE website worth visiting are the shoreline air photo and Puget Sound shorelines websites:

http://www.ecy.wa.gov/apps/shorephotos/
http://www.ecy.wa.gov/programs/sea/pugetsound/

Sand Dune Reactivation and Subduction Zone Earthquakes in the Grayland Area

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Introduction

The geomorphic processes that create dune ridge systems similar to the one along the coast of southwestern Washington have been described as the result of an abundant sand supply interacting with shoreline vegetation (Johnson, 1919; Cooper, 1958). In addition to these processes, the dunes of southwestern coastal Washington are influenced by subduction zone earthquakes. During these seismic events, there is commonly an apparent abrupt sea level rise of 1 to 2 m (3–6 ft) created by a belt of coseismic subsidence (Atwater, 1987; Meyers and others, 1996). The apparent rise in sea level moves the shoreline landward, eroding a scarp into the existing dunes.

In the Grayland area of the central Washington coast (Fig. 1), there is a dune system of beach-parallel ridges that has been investigated as part of a regional survey using ground-penetrating radar (GPR), vibracores, and sand auger samples. The dune system is dominated by a large (15–18 m or 50–60 ft high) continuous dune ridge that extends for 21 km (13 mi) across the entire interbay area. This unusually high dune was created by seismic events that reactivated dune-forming processes and essentially put a new dune on top of an older dune.

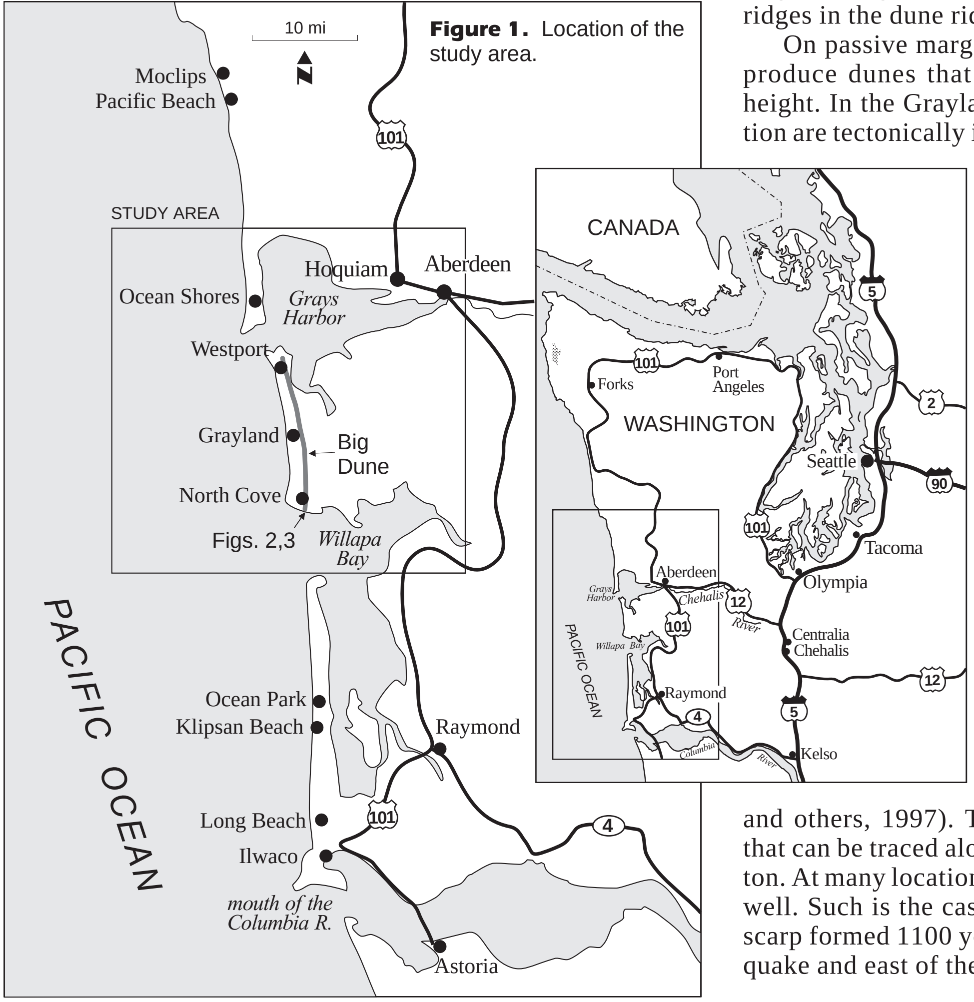

Figure 1. Location of the study area.

Dune Ridge Systems

Dune ridge systems are formed on prograding shorelines (shorelines building out into the sea) where there is an abundance of sand. The formation process is aided by pioneering beach plants that trap the blowing sand. As the shoreline progrades, new ridges form and are vegetated, causing the old ones to be cut off from their sand supply.

Since the introduction of European beach grass in the 1930s, the dune-building process in southwestern Washington has become more efficient because this grass is far more effective at trapping sand than native plant species (Wiedemann and Pickert, 1996). Native grasses were also able to form dune ridges, though more slowly, as one can observe from the older ridges in the dune ridge systems.

On passive margins, sand supply and dune grasses tend to produce dunes that are evenly spaced and about the same height. In the Grayland area, where the dune height and position are tectonically influenced, there is one dune that is significantly higher than the others and cuts across some of the older dunes. It is locally called the 'Big Dune' (Fig. 2) and is similar to what Cooper (1958) called 'dune A'. The origin of the Big Dune is the topic of this article.

Earthquakes

Meyers and others (1996) and Doyle (1996) first described the relationship between great subduction zone earthquakes and the beaches of southwestern Washington. Specifically, they showed that the coseismic subsidence associated with such earthquakes creates an erosional scarp inland. These scarps become the depositional sites for heavy mineral placers, which can be seen on GPR images of the subsurface (Fig. 4). The dates of the last several earthquakes are well known from work in the nearby estuaries (Atwater, 1997; Yamaguchi and others, 1997). The scarps therefore represent time lines that can be traced along the beaches of southwestern Washington. At many locations, the dune ridges lie along these scarps as well. Such is the case with the Big Dune, which lies over the scarp formed 1100 years ago by a great subduction zone earthquake and east of the most recent earthquake scarp.

Figure 2. View from the south showing a cross section through the Big Dune. New forest is on the left and older trees are on the right. *(See Fig. 6D.)*

Figure 3. Author Jim Phipps with a buried tree in the Big Dune. *(See Fig. 5.)*

The relationship between the dunes, scarps, and earthquakes is simply this: Three hundred years ago, a great subduction zone earthquake occurred. This earthquake was accompanied by a belt of coseismic subsidence of 1 to 2 m (3–6 ft) and a tsunami. At the beach, the subsidence manifested as an abrupt rise in sea level that eventually cut an erosional scarp. The tsunami sent a series of large waves surging inland, tearing up existing vegetation, as well as transporting sand inland from offshore. The tsunami provided sand for wind transport to reactivate the dune ridges.

In the case of the Big Dune, this fresh supply of sand piled on top of the existing dune, reactivating it. At both ends of the Grayland plains, where the Big Dune is exposed by beach erosion and sand mining, there are buried soils or paleosols. These paleosols represent reactivation surfaces buried by eolian sand made available for transport some time after the tsunami. The reason the Big Dune is higher than the rest is that it is really two dunes stacked one on top of the other (Fig. 5).

At the same time this was happening, the scarp from the earthquake 300 years ago was forming at the edge of the beach and another dune was starting to build over it. West of that dune and scarp, subsequent dunes continue to prograde and wait for a future seismic event (Fig. 6).

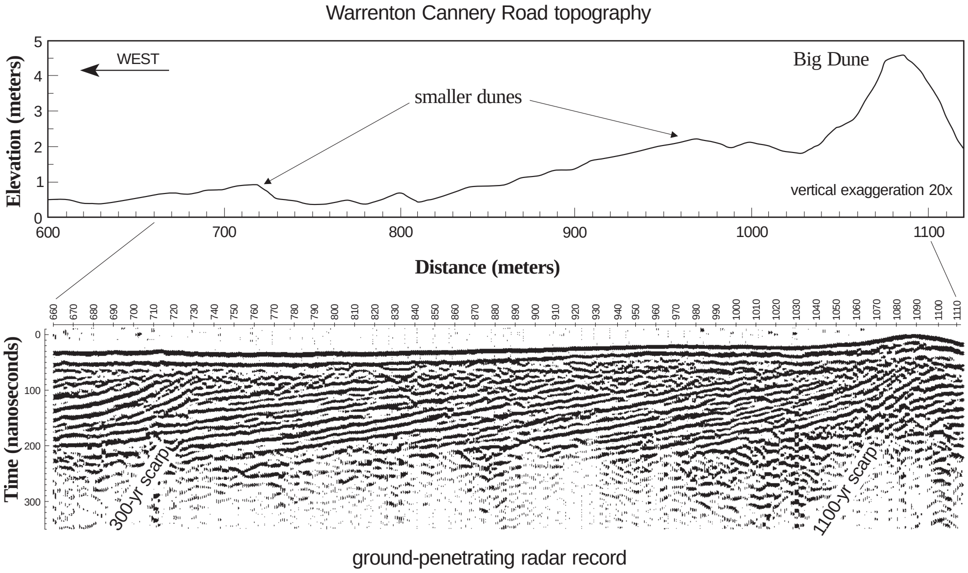

Figure 4. The ground-penetrating radar (GPR) record and the superjacent topography on the south end of the Big Dune (Warrenton Cannery Road). The elevations have been lowered and smoothed as the profile was shot along the road. The horizontal distances are measured from the approximate highest high tide line. The GPR record shows the seaward dipping reflectors interrupted by the more steeply dipping reflectors interpreted as scarps. The dunes form above and seaward of the scarps.

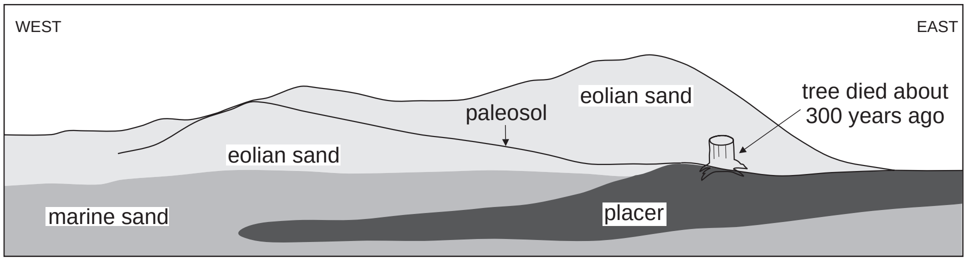

Figure 5. An idealized cross section of the Big Dune.

Timing

Studies of the Big Dune where it is exposed by erosion reveal a stratigraphic sequence of placer and beach deposits topped by an eolian sand and overlain by a paleosol (Fig. 5). The paleosol is covered by younger eolian sand. Rooted in the paleosol and buried by the younger eolian sand is a large spruce that was buried as the dune migrated landward. The ^{14}C kill date on the tree (BETA 22386) is compatible with the time of the last great subduction earthquake 300 years ago. This date, taken from wood near the center of the tree (approximately 40 rings in from the bark), is 190 ±70 years B.P. The 190 years, plus 40 years for the rings, plus 50 years (for radiocarbon dates the present is A.D. 1950) equals 280 calendar years, a date that is well within the ±70-year error bar. In addition, the tree did not die instantly. Narrow growth rings next to the bark show that it died several years after the earthquake, so one would expect a slightly younger kill date for the tree.

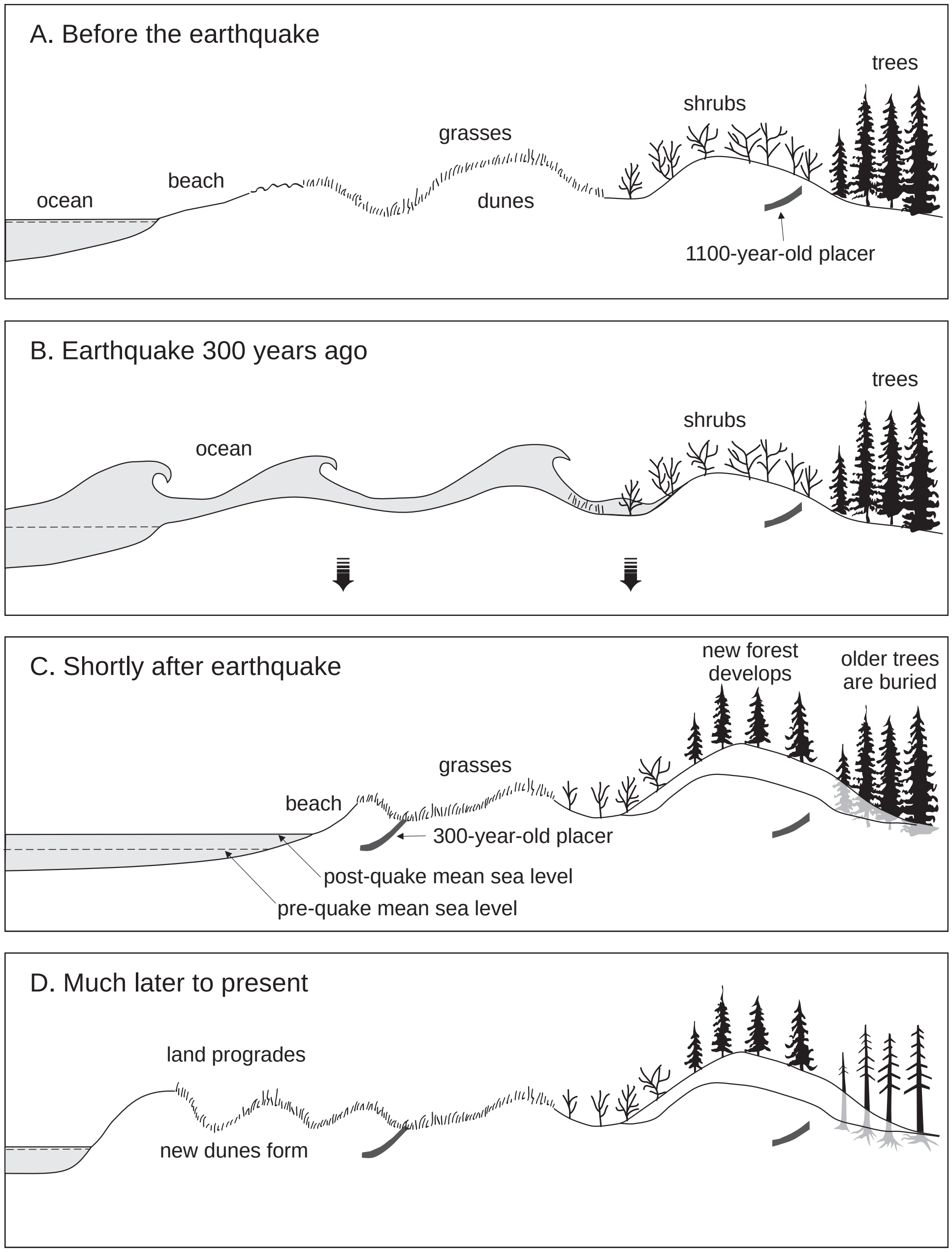

Figure 6. The sequence of events leading up to the formation of the Big Dune. **A.** Initial conditions. Mature shoreline with vegetation successions clearly developed. **B.** Earthquake 300 years ago. The most recent great subduction zone earthquake creates a large tsunami and coseismic subsidence (shown by arrows) of approximately a meter. The tsunami sweeps across the dunes, tearing up the vegetation. The subsidence moves the shoreline landward. **C.** Shortly after the earthquake. Wind-transported sand accumulates on an old dune. The trees, which slow the wind enough to deposit the sand, enhance the accumulation process. The rejuvenated dune grows very high due to the abundant sand in the tsunami surge plain. The dune suffocates the older trees. The kill date is approximately 300 years ago. **D.** From much later to the present. Subsequent dunes have formed seaward of the most recent scarp, and sea level has rebounded to its pre-quake position.

Conclusions

The dune ridge system of southwestern Washington has been altered by the events associated with great subduction zone earthquakes. These earthquakes are accompanied by 1 to 2 m of coseismic subsidence, as well as tsunamis. The beaches respond by eroding inland, forming scarps, and reactivating older dune ridges. In recent, tectonically stable times, the beaches have prograded as they would on a passive margin.

Acknowledgments

We would like to acknowledge the U.S. Geological Survey–Washington Department of Ecology Southwest Washington Coastal Erosion Study for funding. This manuscript was improved greatly by editor Jari Roloff of the Washington Division of Geology and Earth Resources.

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Kirk Bryan Award Presented to Brian F. Atwater and Eileen Hemphill-Haley

Citation by John J. Clague[1]

The Kirk Bryan Award recognizes an outstanding contribution in the field of Quaternary geology and geomorphology. It is my distinct pleasure, on behalf of GSA's Quaternary Geology and Geomorphology Division, to present the award this year to Brian Atwater and Eileen Hemphill-Haley for their splendid monograph *Recurrence intervals for great earthquakes of the past 3,500 years at northeastern Willapa Bay, Washington* (U.S. Geological Survey Professional Paper 1576, published in 1997).

Brian F. Atwater

I can think of no more important and influential publication in Quaternary science in recent years than USGS Professional Paper 1576. It is a summary of a decade of careful, innovative research by Atwater and Hemphill-Haley on the geologic record of great earthquakes in southwestern Washington. If you wish to show students how science should be done, have them read USGS Professional Paper 1576.

I remember Brian commenting to me in 1985 or 1986, after one of his first forays into the muddy tidal marshes at Willapa Bay, that he thought he had found evidence for repeated sudden coseismic subsidence of the land, but that he wasn't sure he believed the implications of what he had seen. Brian is not a scientist who jumps to conclusions or cuts corners testing a hypothesis. He spent summer after summer in the late 1980s and 1990s documenting in extraordinary detail physical evidence of recent, very large earthquakes. To do this, he enlisted the help of Eileen Hemphill-Haley, a diatom paleoecologist. At first blush, Brian and Eileen would appear to be an odd couple, scientifically speaking, yet their collaboration proved to be critical to demonstrating that the region had experienced repeated large earthquakes. Eileen showed, through analysis of fossil diatoms and comparison of fossil and modern diatom assemblages, that the buried marsh and forest soils that Brian mapped in tidal channels at Willapa Bay had subsided abruptly 1 to 2 m during earthquakes. She also showed that the sand layers that directly overlie some of the soils contain marine diatoms, indicating landward transport and deposition of coarse sediment. This proved to be a critical piece of evidence for a tsunami origin for the sand layers.

USGS Professional Paper 1576 is a comprehensive document, far exceeding in scope what can be presented in a journal paper. To their credit, Brian and Eileen took the time to present the wealth of their findings in a single publication rather than slicing it up, salami-style, in a series of shorter, less complete journal papers. The monograph is, however, more than thorough, well-argued science; it's a great read—the writing is elegant and illustrative material is beautiful.

I can't overemphasize the impact that Brian and Eileen's research has had on our understanding of earthquakes in the Pacific Northwest. Improved public awareness of earthquake hazards in the region is rooted, in part, in their work. Brian was one of only a few geologists working on earthquakes in the Pacific Northwest when the USGS transferred him to Seattle in 1985. Today, scores of government and university researchers, private-sector geologists, and students are working on Cascadia earthquakes, and most of them have been encouraged and supported by Brian.

USGS Professional Paper 1576 exemplifies how seamless basic and applied geoscience can be and, further, how important Quaternary geoscience is to society. The contribution that Brian and Eileen have made to our understanding of Cascadia earthquake hazards has proved to be vital.

Let me close with a few anecdotes of a more personal nature. Brian is a well-known figure in the communities around Willapa Bay. Most local residents remember the man with the white hat paddling his canoe up and down every tidal channel around the bay. This man went out of his way to tell people what he was doing and why, and he explained to them how all those tree stumps rooted in tidal muds in the bay came to be. Anyone who has ever done field work with Brian learns very quickly to either stand back as he cleans off an outcrop or be hit by flying mud—he's a human backhoe. Also, if you stay in Brian's field camp, you will at some time be included in the bread-baking detail. Brian turns up his nose at the store-bought stuff, and late in the evenings somebody, often Brian, bakes fresh bread for sandwiches the next day. Finally, Brian always has chocolate on hand to make cocoa on cold mornings. God help you if you get between Brian and his chocolate!

Eileen Hemphill-Haley

Eileen met Brian at the first special session on Cascadia earthquake research at the American Geophysical Union meeting in San Francisco in 1987. At

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[1] Award presented at Summit 2000: GSA Annual Meeting and Exposition, Nov. 9–16, 2000, in Reno, Nevada, by Dr. John J. Clague. Dr. Clague is Shrum Research Professor in the Department of Earth Sciences at Simon Fraser University in Burnaby, British Columbia. He is one of Canada's leading authorities in Quaternary and environmental earth sciences.

that time, she was a graduate student at the University of California at Santa Cruz and was employed by the USGS. Up until then, all her research experience had been in Quaternary paleoclimatology working with the Marine Branch of the USGS. Her original plans for Ph.D. research weren't working out, and she was shopping for another project. She introduced herself to this forceful scientist with what many people at the AGU session considered outlandish ideas. Brian suggested that perhaps Eileen would like to look at a few samples from Willapa Bay, and the rest, as they say, is history. Eileen liked the idea of applying paleontology to paleoseismology, so she began working full time on the project the following summer. Eileen no longer works for the USGS, although she continues her collaboration with Brian to this day. After leaving the government, Eileen has pursued a career in music and is an accomplished singer and songwriter. Her songs are unusual and beautiful. Check them out on one of her CDs or her website, www.h2tunes.com.

With *Recurrence intervals for great earthquakes of the past 3,500 years at northeastern Willapa Bay, Washington,* Brian and Eileen have shown what Quaternary scientists can contribute to both science and society. I present to you the 2000 recipients of the Kirk Bryan Award, Brian Atwater and Eileen Hemphill-Haley.

Response by Eileen Hemphill-Haley

It is my great honor, along with Brian Atwater, to receive the 2000 Kirk Bryan Award. My sincerest thanks to the Quaternary Geology and Geomorphology Division of GSA for this recognition.

As wonderful as it is to receive this award, the greatest joy for me has been the opportunity to participate in about a decade's worth of research on problems I have found engaging, and with people I admire. My work with Brian along Willapa Bay represents our initial attempts to apply micropaleontology to aspects of Quaternary paleoseismology, and helped to lay the groundwork for a series of additional studies focusing on earthquakes and tsunamis along the Cascadia margin. I have nothing but the highest regard for Brian and won't embarrass him by expounding about it too much. But it is significant that, at his request, I have slogged through knee-deep mud in search of the perfect sample and have on many occasions gotten up before God to beat the tides. Believe me, these are not things that I would do for many people. But I'm happy for the work we've done together in the past and have no doubt that we will continue to figure out ways to work together in the future.

Looking back over the past years, there are a number of people who helped me along the way, and for whose support I am grateful. I had several mentors at the USGS, including James V. Gardner, Michael Field, and John Barron. Denise Armstrong and Carter Borden made important contributions to the project. But of the many people with whom I have worked or conferred, there are two I especially want to acknowledge for their help and friendship. The first worked with me through a student appointment at the USGS, and the second was a volunteer in the diatom department at the California Academy of Sciences.

Roger Lewis came to work for me on a student appointment at the USGS in 1992 and soon became my right-hand man in both the lab and field. During his years in the USGS micropaleontology lab in Menlo Park, he greatly refined our diatom sample-processing techniques and always maintained a good attitude, although the work could be very tedious at times. His skills in the lab were surpassed only by his abilities in the field, where he maintained the same dependable, upbeat attitude and clear excitement for the science. Roger has since moved on to pursue graduate studies in marine geochemistry, but I am happy to thank him here for all his past contributions to paleoseismology and paleoecology in the Pacific Northwest.

Mr. Albert Dell Mahood is a former high school biology teacher, who in his retirement worked as a volunteer in the diatom department at the California Academy of Sciences in San Francisco. I spent many afternoons researching diatom taxonomy and ecology with Dell and depended greatly on his help—and humor—during this research. As a volunteer for science, he shared knowledge and experience that helped us to better understand the results of our diatom analyses, and I'm pleased to have the opportunity to formally thank him at this time.

My thanks once again to GSA for the Kirk Bryan Award, and my deepest gratitude to the friends and colleagues who helped Brian Atwater and me to achieve this honor.

Response by Brian Atwater

In Cascadia paleoseismology, Eileen Hemphill-Haley is known for careful and productive work with fossil diatoms. I hope the Kirk Bryan Award brings this work the wider recognition it deserves. I join Eileen in thanking our co-workers. Many of them were volunteers or low-paid assistants. Others provided tough reviews of a long manuscript—or of three versions of that manuscript, in the case of an outstanding reviewer. Still others worked as administrators, accountants, and editors. In the few moments remaining, let me mention some of the additional work that contributed to our report.

Much in Cascadia paleoseismology depends on analogies with great earthquakes at other subduction zones—1944 and 1946 in Japan, 1960 in Chile, 1964 in Alaska. These examples provide a basis for recognizing earthquakes from geologic signs of their land-level changes and tsunamis.

Geophysicists were probably the first to think about great earthquakes at Cascadia. Some of them did so as regulators of nuclear power plants in the early 1980s.

By the early 1990s, "marsh jerks" had identified geologic signs of subsidence and tsunamis at bays and river mouths in British Columbia, Washington, Oregon, and California. Later in the 1990s came exact dating of Cascadia's most recent great earthquake—to January 26, 1700. This dating, like so much else in Quaternary geology, is founded on the radiocarbon time scale. Also essential were ring-width pattern matching at Cascadia and historical scholarship in Japan.

These efforts, among others, built the giant on whose shoulders Eileen and I stand.

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Editor's note: Although this is really the December 2000 issue of *Washington Geology*, it is coming out in 2001 because of a lack of staff time, the earthquake, and other problems. We are doing our best to get back on schedule. Please bear with us.

We have upgraded our website at http://www.wa.gov/dnr/htdocs/ger/. We have a new look and have been posting information as fast as we can. *Washington Geology*, the publications list, and surface mining info are now available as PDF files.

EARTH CONNECTIONS

Resources For Teaching Earth Science

READING A WALL

Have you ever looked at a stone wall and wondered where all the different rocks came from and what story each might tell? Some stone walls are made of angular rocks, probably mined from a quarry. Others are made of rounded stones. Observing the differences in shape, size, color, mineralogy, and other characteristics of the stones in a wall can tell us a lot about the history of the stones and of the wall. Stone wall builders usually take advantage of the most readily available and, of course, best looking materials. Walls can be used to support a building or to hold back a hillside or as decorative landscaping (Fig. 1). Here in western Washington, many of the walls, such as those facing the buildings on the Capitol Campus, are built of angular stones quarried from the Wilkeson Sandstone near Tenino. In eastern Washington, many walls are made of basalt because of the abundance of that rock type there. A wide variety of metamorphic rocks can be found in the walls of north-central Washington.

Figure 1. A mortared stone wall in western Washington. Notice that it is thinner and more vertical than the wall in Figure 2. *Photo by Wendy Gerstel.*

In the Puget Sound area, we have an abundance of rounded stones of all sizes, carried here by glaciers that covered the area about 13,000 years ago. These stones have been tumbled, scraped, rolled, smoothed, and sculpted by the ice and its meltwater streams. The more rounded the stones, the longer they were rolled in streams. If they are faceted, that is, have rounded but distinct faces, they were probably deposited directly by the ice.

Rounded stones do not fit snugly against other stones in a wall and usually need mortar to hold them together. In New England and other areas on glacial deposits, however, farmers build walls with the stones cleared from their fields. Careful placement of the stones and annual spring maintenance preserve many miles of these walls built without any mortar. In Figure 2, the larger stones are at the bottom so they were probably put in place by hand. The smaller ones could be lifted, so were used in the upper layers.

This lesson will teach observation, analytic, and note-taking skills. It will encourage the observer to think about geology, history, transportation, engineering, and social sci-

ESSENTIAL SCIENCE LEARNING BENCHMARKS/OBJECTIVES

1.1 Uses properties to identify, describe and categorize landforms.

3.2 Understands that science and technology are human endeavors, interrelated to each other, to society. and to the workplace.

GRADE LEVELS

Grades 2–6, answer questions 1–3
Grades 7–12, answer questions 1–6

SUBJECTS

Earth science
Geography
Social science
Mechanics/engineering

CONCEPTS

Interpreting geologic origin of building materials and methods of transport and use

SKILLS

Observations; identifying relationships of rocks to where they originated; hypothesizing rock transport.

TIME NEEDED

30–45 minutes (more if field trip)

> THE SMALL STONES WHICH FILL UP THE CREVICES HAVE ALMOST AS MUCH TO DO WITH MAKING THE FAIR AND FIRM WALL AS THE GREAT ROCKS; SO WISE USE OF SPARE MOMENTS CONTRIBUTES NOT A LITTLE TO THE BUILDING UP IN GOOD PROPORTIONS A MAN'S MIND.
>
> *Edwin Paxton Hood*

Lesson created by:
Wendy Gerstel
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and Earth Resources
PO Box 47007
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e-mail: geology@wadnr.gov

Earth Connections No. 4

ences—and other aspects of wall building left to the creativity of the participants.

Figure 2. A dry-stacked stone wall in Connecticut. Notice the rounded edges of the stones, the wide base, and the placement of the largest stones at the bottom of the wall. *Photo by Eric Gerstel.*

QUESTIONS

Find your own stone wall and answer the following questions:

1. What do you notice about the shape of the individual stones? Are all of them rounded? Are any of them angular? Are some of them faceted? Was it built for decoration, to protect a garden, or to support a structure?

2. Did the wall builders use mortar? Why is this important? Could the wall have been built without it? What is the mortar made from?

3. What can you say about the color of the stones? Look closely. Do you recognize any of them from Washington State? from Canada? from Idaho? What do you notice about the mineralogy—the individual crystals within a stone?

4. How did the stones get here? Are they local? Were they transported by glaciers or streams, by trucks or trains?

5. Note the size and relative placement of the stones in the wall. Is this important? Does it tell you anything about how the wall was built—by humans or machine?

6. What can you say about the age of the wall? What do the surroundings (the building, the landscaping, the rock source, etc.) tell you? What condition is the wall in?

DISCUSSION

1. How does geology control/affect the availability of building materials and how they are used? And how does access to and transportation of the materials?

2. What can you say about the age of a wall and the use of particular materials? (How far they were transported? How they were put into place, etc.?)

3. How might the function of a wall have changed through human history in an area? In different areas, climates, cultures?

4. What are the advantages/disadvantages of stone walls? As compared to wooden fences? (Costs, resource availability, other?)

5. What might cause a wall to degrade or weather (chemical and mechanical [wind and water] break down)? Which would be more susceptible to weathering, a rounded wall or a wall of blocky, tight-fitting stones?

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Rocks and Minerals—Student Activity Book, by the National Science Resources Center, Smithsonian Institution, National Academy of Science: Carolina Biological Supply Co., 153 p., 1994.

Sermons in Stone—The Stone Walls of New England & New York, by Susan Allport with ink drawings by David Howell: W. W. Norton & Co., 205 p., 1990.

Time worships a well-built wall, for a wall's stones can wend through silent woods with an eerie eloquence, suggesting the lives and labors of settlers long gone. As Susan Allport demonstrates in this charming book, the stone walls of New England and New York speak with the voices of Native Americans and Yankee farmers, of slaves, servants, and children, evoking the past from the elemental geological struggles of the Ice Age through the fencing dilemmas of neighbors in the 19th century. Allport's scaling of these humble but pervasive walls—who built them? when? why? how?—is a narrative of fascinating and offbeat attention to the enduring tracks of the past. [downloaded January 1, 2001, from http://www.commonreader.com/cgi-bin/rbox/ido.cgi?7248]

Stone Wall Secrets, by Kristine and Robert Thorson: Tilbury House Publishers, 40 p., 1998. [grades 3-6]

Stone Wall Secrets—Exploring Geology in the Classroom (Teachers' Guide), by Ruth Deike: Tilbury House Publishers, 80 p., 1998.

Website:

Discovery.com has lessons, weblinks, and vocabulary at http://school.discovery.com/lessonplans/programs/rocks/index.html. ■

Free CD Available to Teachers

"Salmon Recovery Data Viewer: Lower Chehalis Watershed (WRIA 22)" gives data on the limiting factors that affect the recovery of salmon in the lower Chehalis watershed. For your copy, send a request by fax to Dave Wischer (360) 902-1790 or J. Roach, Association of Black Lake Enhancement, at (360) 357-9662 or Lee Hansmann, Grays Harbor Deputy Director of Community Development, at (360) 249-4222.

EARTH CONNECTIONS

Resources For Teaching Earth Science

DO ROCKS LAST FOREVER?

We think rocks last forever. The boulder we played on in our parents' front yard when we were children is still there for our grandchildren to enjoy. The rock steps to the church are still in use a hundred years later, and the gravestones in the cemetery still mark where our ancestors were laid to rest. These rocks, to us, have lasted forever. But, if you look closely, change is taking place.

This change is called weathering. The term weathering refers to the destructive processes that change the character of rock at or near the Earth's surface. There are two main types of weathering: mechanical and chemical. Processes of mechanical weathering (or physical disintegration) break up rock into smaller pieces but do not change the chemical composition. The most common mechanical weathering processes are frost action and abrasion. The processes of chemical weathering (or rock decomposition) transform rocks and minerals exposed to water and atmospheric gases into new chemical compounds (different rocks and minerals), some of which can be dissolved away. The physical removal of weathered rock by water, ice, or wind is called erosion.

Weathering is a long, slow process, which is why we think rocks last forever. In nature, mechanical and chemical weathering typically occur together. Commonly, fractures in rocks are enlarged slowly by frost action or plant growth (as roots pry into the fractures). This action causes more surface area to be exposed to chemical agents. Chemical weathering works along contacts between mineral grains. Crystals that are tightly bound together become looser as weathering products form at their contacts. Mechanical and chemical weathering continue until the rock slowly falls apart into individual grains.

We often think of weathering as destructive and a bad thing because it ruins buildings and statues. However, as rock is destroyed, valuable products are created. The major component of soil is weathered rock. The growth of plants and the production of food is dependent on weathering. Some metallic ores, such as copper and aluminum, are concentrated into economic deposits by weathering. Dissolved products of weathering are carried in solution to the sea, where they nourish marine organisms. And finally, as rocks weather and erode, the sediment eventually becomes rock again—a sedimentary rock.

Two experiments to illustrate the effects of mechanical and chemical weathering are presented below.

PLASTER AND ICE (MECHANICAL WEATHERING)

WHAT YOU NEED: plaster of paris, water, a small balloon, two empty pint milk cartons (bottom halves only), a freezer

WHAT TO DO: (1) Fill the balloon with water until it is the size of a ping-pong ball. Tie a knot at the end. (2) Mix water with plaster of paris until the mixture is as thick as yogurt. Pour half of the plaster in one milk carton and the other half in the other. (3) Push the balloon down into the plaster in one carton until it is about ¼ inch under the surface. Hold the balloon there until the plaster sets enough so that the balloon doesn't rise to the surface. (4) Let the plaster harden for about 1 hour. (5) Put both milk cartons in the freezer overnight. (6) Remove the containers the next day to see what happened.

WHAT TO THINK ABOUT: What happened to the plaster that contained the balloon? What happened to the plaster that had no balloon? Why is there a difference? Which carton acted as a control? Why? How does this experiment show what happens when water seeps into a crack in a rock and freezes?

WHAT SHOULD HAVE HAPPENED: The plaster containing the balloon should have cracked as the water in the balloon froze and expanded. Explain that when the water seeps into cracks in rocks and freezes, it can eventually break rocks apart.

ESSENTIAL SCIENCE LEARNING BENCHMARKS/OBJECTIVES

1.1 Uses properties to identify, describe and categorize weathering processes.

1.2 Understands that interactions within and among systems cause changes in matter, energy, and decomposition.

2.1 Develops abilities necessary to do scientific inquiry.

GRADE LEVELS

6th–10th grades

SUBJECTS

Earth science

CONCEPTS

Decomposition of rocks: mechanical and chemical weathering; observations while conducting experiments.

SKILLS

Observation; hypothesizing; analyzing; comparing and contrasting.

TIME NEEDED

45 minutes (not including freezing time)

> I HEAR AND I FORGET.
> I SEE AND I REMEMBER.
> I DO AND I UNDERSTAND.
>
> *Ancient Chinese proverb*

Lesson created by
Sherry L. Weisgarber

Reprinted with permission from *Ohio Geology*, Winter 1997, a publication of the Ohio Department of Natural Resources, Division of Geological Survey, http://www.dnr.state.oh.us/odnr/geo_survey/.

Earth Connections No. 4

A SOUR TRICK (CHEMICAL WEATHERING)

WHAT YOU NEED: lemon juice, vinegar, medicine droppers, two pieces each of limestone, calcite, chalk, and quartz

WHAT TO DO: (1) Put a few drops of lemon juice on one piece of each of the four rock types. (2) Put a few drops of vinegar on the other piece of each of the four types. (3) Look and listen carefully each time you add the lemon juice or the vinegar.

WHAT TO THINK ABOUT: What happens when you put lemon juice on each rock? What happens when you put vinegar on each rock? Did the lemon juice and vinegar act the same way on each rock? Why did some of the rocks react differently? What does this experiment have to do with weathering?

WHAT SHOULD HAVE HAPPENED: Lemon juice and vinegar are both weak acids. The lemon juice contains citric acid and the vinegar contains acetic acid. These mild acids can dissolve rocks that contain calcium carbonate. The lemon juice and vinegar should have bubbled or fizzed on the limestone, calcite, and chalk, which all contain calcium carbonate. There should not have been a reaction on the quartz, which does not contain calcium carbonate. Explain that water commonly contains weak acids that dissolve rocks containing calcium carbonate and other minerals.

Source: Ranger Rick's Nature Scope: Geology—The active Earth: National Wildlife Federation, 1988.

LIVE EARTHQUAKE COVERAGE

To see how guinea pigs react to an earthquake, go to http://www.oinkernet.com/equake.htm.

UPCOMING EVENTS

We would be happy to post your event on our calendar, both on our website and in Washington Geology. We need to know the topic, speaker and affiliation, sponsoring organization, date, time, place, and who to contact for more information, preferably a website or e-mail address. Send this information to lee.walkling@wadnr.gov.

Discover Washington's Natural Resources—A Two-Day Workshop for Middle and High School Educators

June 20 and 21, 8:00–5:00
Spokane/Dishman Hills

June 26 and 27, 8:00–5:00
Vancouver/CASEE Center

Registration deadline is June 1, 2001.
http://www.wa.gov/dnr/
teacherworkshop@wadnr.gov
360-902-132

2001 Northwest Regional Meeting of the National Association of Geoscience Teachers

June 21–24; Bellevue, Washington

http://www.btia.net/nagt/

Geological Society of America and Geological Society of London Global Meeting: Earth System Processes

June 24–28; Edinburgh, Scotland

http://www.geosociety.org or
http://www.geolsoc.org.uk

Geological Society of America GeoVentures Field Trip: Geology of Glacier National Park

July 14–19; Columbia Falls, Montana

http://www.geosociety.org/meetings/gv/gh012.htm

Crowding the Rim, 2001: International Geohazards Summit

August 1–3; Stanford University, California

http://www.crowdingtherim.org/

Tobacco Root Geological Society 26th Annual Field Conference

August 2–5; Wallace, Idaho

http://trgs.org/conference.htm

International Tsunami Symposium 2001

August 7–10; Seattle, Washington

http://www.pmel.noaa.gov/its2001

Northwest Geological Society (field trip)

September, TBA

Southern Coast Mountains of British Columbia—Murray Journeay

http://www.scn.org/tech/nwgs/index.htm

National Emergency Management Association Annual Conference

September 8–12; Big Sky Resort, Montana

thembree@csg.org
http://www.nemaweb.org

Mine Fill 2001: International Symposium on Mining with Backfill

September 17–19; Seattle, Washington

http://www.smenet.org/meetings/Minefill2001.cfm

Washington State Ground Water Association Fall Convention

September 28–29; Spokane, Washington

http://www.wsgwa.org/

Association of Engineering Geologists/American Institute of Professional Geologists 2001 Annual Meeting

Sept. 29–Oct. 5; St. Louis, Missouri

http://www.aegweb.org/
http://www.aipg.org/

Canadian Dam Association 2001 Annual Conference

September 30–October 4;
Fredericton, NB, Canada

cda2001@engineering.ca
http://www.cda.ca/cda2001

American Geological Institute's Earth Science Week

Oct. 7–13

http://www.earthscienceworld.org/week/
http://www.usgs.gov/earthscience/

Northwest Geological Society (meeting)

The state-of-affairs at the state survey—Ron Teissere of the Washington Division of Geology and Earth Resources

October 9; 7:30; University Plaza Hotel
NE 45th St., Seattle, Washington

http://www.scn.org/tech/nwgs/index.htm

Western States Seismic Policy Council Annual Conference

October 21–24; Sacramento, California

wsspc@wsspc.org or http://www.wsspc.org

Geological Society of America Annual Meeting: A Geo-Odyssey

November 1–10; Boston, Massachusetts

meetings@geosociety.org
http://www.geosociety.org

International Association of Emergency Managers Annual Conference

November 3–7; Riverside, California

iaem@aol.com or http://www.iaem.com

Northwest Mining Association Annual Meeting

December 3–7; Spokane, Washington

(509) 624-1158 or http://www.nwma.org

Association of Ground Water Scientists and Engineers Annual Meeting

December 7–8; Nashville, Tennessee

http://www.ngwa.org/education/cfpnat01.html ■

A River Runs By It

Alma Hale Paty

As the Columbia River flows through Washington State to the Pacific Ocean, it meanders close to a small but vibrant museum known as the Columbia River Exhibition of History, Science and Technology (CREHST). Located in the city of Richland, part of the Tri-Cities area encompassing the cities of Pasco and Kennewick, CREHST houses a diverse yet fascinating array of materials and exhibits aimed at educating the visitor about the natural and man-made history—and future—unique to this region.

Steered by the slogan "Where Knowledge Flows Through Time and Technology," CREHST's exhibits flow from those recounting the geologic history of the Pacific Northwest to those documenting the area's human history—rich in an area that served as a secret, government-sponsored city supporting the United States' research into nuclear energy and defense.

Ice-age floods, rocks, fossils, fish and animals all vied for my attention. The tour begins with "The Great Floods: Cataclysms of the Ice Age," a video documenting the latest in geologic thinking about the unusual landforms of Washington, Idaho and Montana.

It is thought that during the ice age of 15,000 years ago, an ice dam on the Clark Fork River in Montana created Lake Missoula, 2000 feet deep and estimated to be as large as a present-day Great Lake. Its faint shoreline is still visible today. When the ice dam broke, the lake drained in 48 hours, with the water rushing through present-day Washington to the Pacific at 65 miles per hour, carving out 50 cubic miles of earth. Deep channels known as coulees were formed, resulting in a tell-tale, braided landscape dotted with transported basalt blocks 30 feet in diameter.

Although geologist J Harlan Bretz first postulated the idea of ice age floods in 1923, it was not until the advent of aerial photography that the geologic evidence of 30-foot-high, two-mile-wide ripple marks came to light. The video helped me understand the topography I saw driving from Spokane to Richland.

Continuing the geologic story, a permanent exhibit at CREHST features the geologic history of the Northwest, with a mural on the "Cascade volcanic activity and its relationship to the Northwest junction of the continental and oceanic plates." Offering a quick Geology 101 lesson, 15 numbered, hands-on rock samples are situated below the mural. I could match the rocks to the numbers on the mural and thus learn where and how the rocks were formed.

The Columbia River Exhibition of History, Science and Technology

Details

The Columbia River Exhibition of History, Science and Technology is at 95 Lee Boulevard in Richland, WA 99352.

Hours: 10 a.m. to 5 p.m., Monday through Saturday. Noon to 5 p.m., Sunday. Closed New Year's Day, Easter, Thanksgiving and Christmas.

Phone and website: (509) 943-9000 and www.crehst.org.

Appropriately placed next to this display is an active seismic monitoring station. Because this area of the country is prone to earthquakes, this station duplicates the monitoring taking place at the Hanford nuclear reservation. (I was comforted by the low activity it recorded.)

Continuing to the museum's lower level, I moved from rocks into biology. Lining the stairwell are models, designed by artist Jim Martin, of 35 of the Columbia River's fish species, including Lamprey, King Chinook Salmon, Black Crappie and Dace.

And moving the visitor's attention to larger species, two dioramas form a bridge from natural history to human history: a diorama of stuffed animals and birds local to this dry area of southeast Washington and another of the Native Americans who first lived in the area.

Most of the remaining exhibits focus on the lives and culture surrounding the secret Hanford Engineering Works. Established during the height of World War II, the Tri-Cities area was home to 51,000 construction workers and engineers. These workers helped build the T-plant, a chemical separation plant that is the crucial third step in the production of radioactive plutonium. CREHST exhibits highlight the culture of secrecy and control that permeated this area.

One exhibit records how Hanford's workers donated a day's wages to support the construction of a Boeing B-17, the Flying Fortress. Christened on July 12, 1944, the Hanford-supported plane was named *Day's Pay.*

A result of 40-plus years of plutonium production is the millions of gallons of radioactive chemical waste stored in the center of the 560-square-mile Hanford site.

Another series of panels highlights the ongoing environmental restoration of the Hanford site taking place under the 1989 Tri-Party Agreement among the Department of Energy, the Environmental Protection Agency and the State of Washington.

Several objects and exhibits were not on display only because the current housing of CREHST is temporary. In keeping with its mission statement of preserving "the future of science and technology in the Columbia Basin," CREHST plans to build and move to a new facility within the next five years. It will be near the flowing Columbia River, *where knowledge flows through time and technology*.

Paty is founder and president of A Capital Resource, a Washington-based consulting firm specializing in mineral resource issues and education.

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Selected Additions to the Library of the Division of Geology and Earth Resources

May, 2000 through January, 2001

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Buijsman, M. C.; Peterson, C. D.; Gelfenbaum, Guy, Prehistoric sediment budget study—Geological-scale modeling. p. 35-36.

Côté, J. M.; Ruggiero, Peter, Nearshore bathymetry within the Columbia River littoral cell. p. 147-156.

Cowell, P. J., Modeling shoreface translation. p. 59-60.

Daniels, R. C.; McCandless, Diana; Huxford, R. H., Coastal change rates for southwest Washington and northwest Oregon. p. 65.

Daniels, R. C.; Ruggiero, Peter, Use of light detection and ranging data for volume and elevation change calculation at Connor Creek, Washington. p. 164.

Fenical, S.; Bermudez, H., Wave spectra transportation in Willapa Bay, Washington. p. 133-136.

Gelfenbaum, Guy; Kaminsky, G. M., The southwest Washington coastal erosion study—Status and update. p. 20-23.

Gibbs, A. E.; Gelfenbaum, Guy, Regional bathymetric change off the Washington–Oregon coast. p. 72-76.

Hanson, Kurt; Haines, J. W.; Howd, Peter, Wave modeling of the SW Washington coast with SWAN. p. 103-106.

Herb, April, Compilation of geotechnical and water well borehole data for the Columbia cell barrier beaches. p. 49.

Huxford, R. H.; Daniels, R. C., NOAA, topographic sheets—Vectorization and error analysis—Update. p. 64.

Jimenez, J. A., Comparative analysis of the Ebro delta coast (Spain) with the Washington coast. p. 132.

Jol, H. M.; Kaminsky, G. M.; Ruggiero, Peter, Recent beach progradation and high resolution ground penetrating radar lines. p. 86-89.

Jol, H. M.; Peterson, C. D.; Roberts, M. C.; Vanderburgh, Sandy; Phipps, J. B., Drill core correlation with ground penetrating radar profiles. p. 55-57.

Jol, H. M.; Peterson, C. D.; Ruggiero, Peter; Vanderburgh, Sandy; Phipps, J. B., Beach morphology using ground penetrating radar. p. 143-146.

Kaminsky, G. M., Historical shoreline change interpretations. p. 66-71.

Lippmann, T. C.; Worley, C. R.; Haines, J. W.; Sallenger, A. H.; Gelfenbaum, Guy; Ruggiero, Peter; Kaminsky, G. M., An aerial video system for measuring large scale coastal features along the NW U.S. coastline. p. 157-163.

Moritz, H. R., Activities at the mouth of the Columbia River. p. 130.

Nelson, C. H.; Wolf, S. C.; Dunhill, Gita, Dams and potential effects on delta and coastline erosion. p. 129.

Peterson, C. D.; Qualman, D. R.; Herb, April; Jol, H. M., Vibracoring of surf zone deposits in the Columbia River littoral cell. p. 50.

Peterson, C. D.; Vanderburgh, Sandy; Phillips, R. L.; Herb, April; Twichell, D. C., Jr., Deep borehole at the Columbia River mouth. p. 29.

Phillips, R. L.; Dunhill, Gita; Wolf, S. C., Stratigraphy and tephra occurrences in cores from the southwest Washington shelf. p. 30-34.

Phipps, J. B., Origin and interpretation of sand dunes in the Grayland plain. p. 58.

Ruggiero, Peter; Kaminsky, G. M., Morphologic length scales of high energy dissipative beaches. p. 137-142.

Simpson, D. P., Linking nearshore depth and shoreline change around Grays Harbor. p. 77-85.

Twichell, D. C., Jr.; Cross, V. A.; Parolski, K. F., Evolution of the SW Washington inner shelf since the last lowstand of sea-level. p. 24-28.

Twichell, D. C., Jr.; Cross, V. A.; Parolski, K. F., Surficial geology of and annual changes to the SW Washington inner shelf. p. 112-117.

Vanderburgh, Sandy; Roberts, M. C.; Peterson, C. D.; Jol, H. M.; Phipps, J. B., 1998 drilling program on the Columbia River littoral cell—SW Washington coastal erosion study. p. 51-54.

Voight, B. G., Communicating study results through education and product development. p. 165-168.

Wolf, S. C.; Nelson, C. H.; Reiss, C. A.; Hamer, M. R., The Washington and Oregon mid-shelf silt deposit and its relation to the late Holocene Columbia River sediment budget. p. 126-128.

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Cowell, Peter, Modeling shoreface and barrier response to subsidence events. p. 36-41.

Daniels, R. C.; Ruggiero, Peter; McCandless, Diana, Interpretation of the average high water line from aerial photography—Variability and repeatability. p. 58-74.

Flood, R. D.; Ferrini, V. L.; Giosan, Liviu; Zaleski, Laurie, Preliminary results of a multibeam bathymetry and backscatter survey. p. 81-83.

Gelfenbaum, Guy; Sherwood, C. R.; Hanson, Kurt; Howd, Peter; Palmsten, M. L., Grays Harbor wave refraction experiment. p. 114-119.

Gelfenbaum, Guy; Sherwood, C. R.; Twichell, D. C., Jr.; Gibbs, A. E.; Peterson, C. D.; Buijsman, M. C.; Kaminsky, G. M.; Ruggiero, Peter, Columbia River littoral cell sediment budget—what can we say about the source? p. 141-148.

Gibbs, A. E., Bathymetric volume change—Data and analysis. p. 75-80.

Jay, D. A.; Naik, Pradeep, Climate effects on Columbia River sediment transport. p. 97-106.

Jol, H. M.; Junck, Brian; Kaminsky, G. M.; McCandless, Diana, High resolution ground penetrating radar imaging of late prehistoric and historical barrier progradation. p. 89-91.

Kaminsky, G. M., Historical evolution of the Columbia River littoral cell barriers. p. 52-57.

Lindstrum, Emily; Ruggiero, Peter; Franklin, J. F.; Twichell, D. C., Jr.; Kaminsky, G. M., Sediment size distribution within the Columbia River littoral cell. p. 125-159.

Moore, L. J., Climate change and variability—Considering impacts on coastal morphology in the Columbia River littoral cell. p. 95-96.

Moritz, Rod, U.S. Army Corps of Engineers activities at the mouth of the Columbia River 1998–2000. p. 126-127.

Morton, R. A., Morphostratigraphic and chronologic similarities of late Holocene deposition on three US coasts, resolving tectonic, eustatic, and climatic influences. p. 49-51.

Morton, R. A.; Peterson, C. D.; Sorenson, Oscar; Qualman, D. R.; Vanderburgh, Sandy, History of sand sequestering in a Holocene bay-margin spit complex, Willapa Bay, Washington. p. 42-44.

Percy, David, Presenting geologic data in a web-based GIS. p. 47-48.

Peterson, C. D.; Reckendorf, Frank; Phipps, J. B.; Percy, David; Vanderburgh, Sandy; Woxell, L. K.; Jol, H. M., Dune ridge correlation between the Clatsop Plains and the northern subcells of the Columbia River littoral cell—Late Holocene paleo-shoreline reconstruction of southwest Washington and northwest Oregon, USA. p. 33-35.

Phillips, R. L.; Dunhill, Gita, Sedimentation rates and occurrences of tephra in cores from the southwest Washington shelf. p. 27-30.

Ruggiero, Peter; Gelfenbaum, Guy; MacMahan, Jamie; Kaminsky, G. M., Medium–large-scale nearshore morphologic variability along the Columbia River littoral cell. p. 160-176.

Ruggiero, Peter; Kaminsky, G. M., Scales of morphologic variability from event response to interannual change. p. 132-140.

Shepsis, Vladimir, Columbia River mouth dredged material disposal—Coastal communities plans. p. 128-131.

Simpson, D. P., Shoreline change near Grays Harbor entrance and south jetty testing update. p. 108-110.

Twichell, D. C., Jr.; Cross, V. A.; Parolski, K. F., The inner shelf—Source or sink for beach sand? p. 84-87.

Voigt, B. G.; Ruggiero, Peter; Kaminsky, G. M., Evaluating coastal susceptibility, working toward a decision support system. p. 149-152.

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Dresel, P. E.; Barnett, D. B.; Hodges, F. N.; Johnson, V. G.; Mercer, R. B.; Swanson, L. C.; Williams, B. A., 200 West area. p. 2.111-2.188.

Gee, G. W.; Ward, A. L., Hanford site surface barrier technology. p. 3.69-3.72.

Hartman, M. J., Purpose and scope. p. 1.1-1.2.

Hartman, M. J., Related reports. p. 1.2-1-3.

Hartman, M. J., Supporting information. p. A.1-A.106.

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Hartman, M. J.; McMahon, W. J.; Raidl, R. F., 100 N area. p. 2.43-2.62.

Horton, D. G., Soil remediation at 116-C-1 trench. p. 3.3-3.4.

Horton, D. G., Soil sampling and analysis at 1301-N and 1325-N trenches. p. 3.4-3.6.

Horton, D. G., Spectral gamma-ray and neutron moisture monitoring of 200 East area specific retention facilities. p. 3.39-3.68.

Horton, D. G., Vadose zone. p. 3.1.

Horton, D. G.; Kirkham, R. R., Hanford site lysimeters. p. 3.69.

Horton, D. G.; Kos, S. E., Rapid scan gross gamma-ray logging at single-shell tank C-106. p. 3.38-3.39.

Lindberg, J. W., 300 area. p. 2.255-2.268.

Lindberg, J. W.; Barnett, D. B.; McDonald, J. P.; Mercer, R. B.; Narbutovskih, S. M.; Sweeney, M. D.; Williams, B. A., 200 East area. p. 2.189-2.234.

Lindberg, J. W.; Dresel, P. E., 600 area. p. 2.241-2.254.

McCain, R. G., Baseline spectral gamma-ray logging at B and T tank farms. p. 3.30-3.34.

McDonald, J. P.; Hartman, M. J., Overview of Hanford site groundwater. p. 2.3-2.14.

McMahon, W. J.; Swanson, L. C., Modeling to support pump-and-treat operations. p. 4.6-4.8.

Mercer, R. B.; Williams, B. A.; Auten, J. E., Well installation, maintenance and decommissioning. p. 5.1-5.5.

Myers, D. A., New vadose zone borehole at single-shell tank SX-115. p. 3.29.

Myers, D. A., Temperature and other geophysical logging at single-shell tank farms. p. 3.30.

Newcomer, D. R., Richmond North area. p. 2.269-2.280.

Olsen, K. B.; Patton, G. W.; Dresel, P. E.; Evans, J. C., Measurement of tritium in soil moisture and helium-3 in soil gas at the Old Hanford Townsite and KE reactor. p. 3.72-3.81.

Peterson, R. E.; Hartman, M. J.; McMahon, W. J.; Raidl, R. F., 100 H area. p. 2.83-2.104.

Peterson, R. E.; McMahon, W. J.; Raidl, R. F., 100 K area. p. 2.19-2.42.

Rohay, V. J.; Horton, D. G., Carbon tetrachloride monitoring and remediation, p. 3.34-3.38.

Serne, R. J.; Horton, D. G., Bench scale distribution coefficient and leach studies on hexavalent chromium in contaminated vadose zone sediment from 100 D area. p. 3.10-3.26.

Serne, R. J.; Horton, D. G.; Myers, D. A., Decommissioning of borehole 41-09-39 at the SX tank farm. p. 3.27-3.29.

Sklarew, D. S., Quality assurance and quality control; Holding times. p. B.5.

Sklarew, D. S.; Stewart, D. L.; Thompson, C. J., Quality assurance and quality control; Laboratory performance. p. B.5-B.12.

Sweeney, M. D.; Raidl, R. F., 100 B/C area. p. 2.15-2.18.

Sweeney, M. D.; Raidl, R. F., 100 F. area. p. 2.105-2.110.

Thompson, C. J., Quality assurance and quality control; Sample collection and analysis. p. B.1-B.2.

Thompson, C. J.; Weiss, R. W., Quality assurance and quality control; Field quality control samples. p. B.2-B.5.

Thorne, P. D.; Bergeron, M. P.; Wurstner, S. K., Site-wide groundwater model consolidation process. p. 4.1-4.6.

Thornton, E. C., 400 area. p. 2.235-2.240.

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PBS PLANS EVOLUTION SERIES

A new "Evolution" series is planned by PBS this fall. They now have a website at http://www.pbs.org/wgbh/evolution/. There will be tie-ins with a variety of science groups nationwide.

DGER Is Now a USGS Earth Science Information Center!

In November 2000, the Washington Department of Natural Resources was designated the newest U.S. Geological Survey local Earth Science Information Center (ESIC).

Local ESICs are commonly state geological surveys or major universities. Through this partnership, the USGS improves public access to local geologic information across the nation. In turn, the local organizations get better access to USGS materials and better communication with each other. (For more information on ESICs, see http://mapping.usgs.gov/esic/esic1.html and http://ask.usgs.gov/.)

All local ESICs provide information about the geology of their regions to the public. That has always been a function of the DNR Division of Geology and Earth Resources, both through the Division's library and its staff. Many local ESICs sell various USGS products, especially the topographic maps. The DNR Photo and Map Sales unit has always been a sales outlet for those materials and will continue in that role.

Our librarian, Connie Manson, attended the November 2000 ESIC meeting in Menlo Park, Calif. There, she learned about programs at the other local ESICs in the western U.S.—what they're doing about print and electronic publishing, consolidated book and map sales, outreach to teachers and the public, their websites, and more. She learned about the USGS's current plans for issuing books, open-files, and maps, both electronically and in print, and about new products (like the customizable USGS topographic maps available through the National Geographic Society's map kiosks).

We are pleased with this new designation and with the advantages it gives us—new tools to make our work more informed and efficient and increased communication with our peers.

USGS Earth Science Corps Marks Anniversary

The U.S. Geological Survey's Earth Science Corps, which this year marks its sixth anniversary as a research resource for the National Mapping Program, is reaching out to other disciplines and bureaus to expand the types of support services it provides.

The corps began in 1994 with 20 people and now has a nationwide membership of 2,500 volunteers who work in all 50 states as well as in the U.S. territories of Guam, Puerto Rico, and the U.S. Virgin Islands.

A part of the USGS Volunteer for Science Program, the corps is unique because almost all of its members work independently at their own pace and in their own communities, rather than in an office with a USGS employee. Following detailed instructions, the volunteers' primary activity has been annotating topographic maps with revised information. The work also involves name and boundary research and, because of the nature of that research, community relations.

"Despite our cartographic orientation, our widely diverse members have varied backgrounds, including science, engineering, and environmental studies," said corps founder Melvin Ellis, a 33-year veteran cartographer with the USGS National Mapping Program. "Therefore, we encourage other USGS disciplines, such as biology, geography, geology, and hydrology, as well as other Interior bureaus, to tap our volunteer resources when they have a specific need."

Ellis is assisted by two experienced coordinators, Richard Pirtle, for the eastern states, and Robert Elsloo, for the western states, plus a small volunteer staff at USGS headquarters in Reston, Virginia. In addition to their key cartographic duties at Rolla, Missouri, and Lakewood, Colorado, Pirtle and Elsloo devote part of their workweek to receiving and evaluating data submitted by corps members and responding to technical questions from volunteers.

Mapping projects are currently underway with Corps' support in California, Louisiana, Pennsylvania, Texas, and West Virginia. Members of the corps recently collected field data for a 70-map revision project to support the 2002 Winter Olympics in the Salt Lake City area. They also contributed to a near-statewide project in Hawaii.

The USGS National Mapping Program has over 54,000 maps of the lower 49 states. About 3,000 of those maps are currently assigned to corps members for revision, so there is plenty of work for additional members. If you would like to join the Earth Science Corps, call 800-254-8040; e-mail escorps@usgs.gov; or write to the Earth Science Corps at Mail Stop 513, USGS, Reston, VA 20192.

from People, Land & Water, U.S. Department of the Interior, October/November, 2000, vol. 7, no. 7

STAFF NEWS

State Geologist Ray Lasmanis attended the Tucson Gem and Mineral Show while on vacation in February. Also in February, he took part in two Department of Licensing Geologist Advisory Committee meetings preparing draft WACs, and in early March, a meeting of the Department of Natural Resources Information Technology Board.

Geologists Chuck Gulick, DNR Northeast Region, and **Dave Knoblach**, University of Washington, have authored a paper entitled “Industrial minerals in Washington State”. Dave will be presenting the paper at the 37th Forum on the Geology of Industrial Minerals 2001 in May in Victoria, BC. This is a prestigious international conference.

Geologist Bill Lingley presented a paper to the Northwest Geological Society on the structural geology of the Olympic Mountains. His coauthors were Richard Stewart (University of Washington), Steve Boyer (Charles Wright Academy), and Leslie Lingley (Leslie Geological Services). Lingley and **geologist Andy Dunn** presented the results of the sand and gravel inventories of Whatcom and Yakima Counties to their respective governments.

Senior Librarian Connie Manson is the 2001 President of the Northwest Geological Society. She edited the February and April 2001 issues of the Geoscience Information Society’s *GIS Newsletter* and attended the Geological Society of America’s two-day Publications Committee meeting in Boulder, Colo., as the GIS representative. In April, she went to Washington, DC, as an invited grant reviewer for the Dept. of Commerce, and on May 23, she did a Brown Bag at the University of Washington Dept. of Geological Sciences on geoscience information sources.

Geologist Pat Pringle, our tree-ring and volcano expert, was interviewed by *Tacoma News Tribune* reporter Rob Tucker, whose article on the Fife buried forest appeared in the paper on Martin Luther King Day and was also released on the AP wire. On the same day, as he worked on tree ring samples in his backyard, Pat got a call from KING 5 TV news director Chris Alsop, who wanted Pat to meet reporter Chris Ingalls in Fife for an interview. The story aired at 11:00 pm and also the next day. The story was mentioned on KIRO radio, both when Pat was driving up to Seattle to be interviewed and returning.

The AP story came out all over, including in almost all of the regional papers. “The story has apparently cloned itself because people have been telling me all day that they heard it on National Public Radio,” Pat said.

On January 16, Pat attended a meeting of the Mount Rainier Volcanic Hazards Work Group in Orting, where they discussed the upcoming Mount Rainier eruption scenario exercise at the Mount Weather facility in Maryland and the ongoing educational efforts of the group. He and Kevin Scott of the USGS led the group on a field trip to Mud Mountain Dam to inspect lahar deposits there.

Pat and Carolyn Driedger of the USGS then drove to Packwood for a town meeting on Mount Rainier volcanic processes, history, and hazards. KIRO 7 news covered the meeting, as well as several newspapers. More than 200 people attended.

On January 17, Pat went with State Senator Debbie Regala and Tim Farrell of Senator Jim Kastama’s office to examine buried trees in Fife. They then drove to Orting to look at trees exposed in developments there and at Ptarmigan Elementary School.

Later that week, he was interviewed via telephone by Diane Evans of the East County Journal in Morton.

On February 22, Pat, along with Mount St. Helens National Volcanic Monument scientist Peter Frenzen, put up an exhibit about the volcano at the request of Mark Plotkin, the Director of Tourism for Cowlitz County, for the annual meeting and banquet of the Cowlitz–Wahkiakum County Council of Governments.

On March 26, Pat attended a meeting of the Mount Baker–Glacier Peak Volcanic Hazards Working Group at the Snohomish County Department of Emergency Management. They discussed printing of the response plan and upcoming exercises and presentations to county governments and communities about volcanic processes and the history of the volcanoes. On March 27, Pat led a field trip for the group to examine deposits from Glacier Peak volcano.

Geologist Tim Walsh gave talks to the Office of the Administrator of the Courts, the Emergency Management Council, Henderson House Museum, the Tumwater Planning Commission, the Cascadia Region Earthquake Workgroup (CREW), the Northwest Geological Society (on tsunamis), the Assistant Directors for Administration and Management, a USGS–DOGAMI earthquake hazard mapping workshop, the Black Lake Neighborhood Association, and the Panorama City chapter of AARP. At the Seismological Society of America meeting in San Francisco, he displayed Division posters on ground failures in southern Puget Sound (Walsh and many others) and damage to the Natural Resources Building (Lasmanis).

Geologist Karl Wegmann addressed the Kalama Urban Growth Steering Committee on the status of landslide hazard mapping within the

Northwest Stone Sculptors Association

Northwest Stone Sculptors Association (NWSSA) is a nonprofit organization dedicated to the education for and promotion of stone sculpture in the Pacific Northwest. Although most of its members hail from Oregon, Washington, Idaho, and British Columbia, about 75 percent are Washington Staters. Of its 200 members, three are geologists. About 5 to 10 percent are full-time artists; others either consider it a serious second profession or a hobby.

If there is one thing all stone sculptors share, it’s a love of the medium. At one time in its history, NWSSA members debated a proposal to drop the word ‘stone’ from the moniker in order to appeal to a wider group of artists. A resounding affirmation of ‘stone’ solidified the purpose of the association.

NWSSA members regularly work steatite, alabaster, sandstone, siltstone, black chlorite, brucite, slate, limestone, marble, basalt, granite, and jade. Similar to geologists, the artists tend to be ‘hard rockers’ or ‘soft rockers’; few cross the line, although marble is a transition stone.

Three symposia are held each year (two in Washington and one in Oregon) with from 30 to 90 in attendance. At these gatherings, novices mix with professionals, and educational instruction is the feature. Most important of all, it’s a chance to buy stone and tools that are not available on the local market. Three stone vendors and one tool vendor bring their wares, and the artists take them home. The three stone vendors don’t compete so much as compliment each other, so all stone needs are met.

The remaining two symposia for this year are at Camp Brotherhood, Mt. Vernon, Washington, from July 13 to 22, 2001, and at Silver Falls State Park, Oregon, from September 25 to 29, 2001. Participants will have access to air compressors, generators, water, and limited covered working space, as well as lodging, three meals daily, and all workshops. Workshop instructors present at designated times; the rest of their time is dedicated to their own work.

For more information, call or e-mail NWSSA at (888) 237-0677 or NWSSA@world.att.net. The NWSSA website can be viewed at www.scn.org/arts/stonesculpt. ■

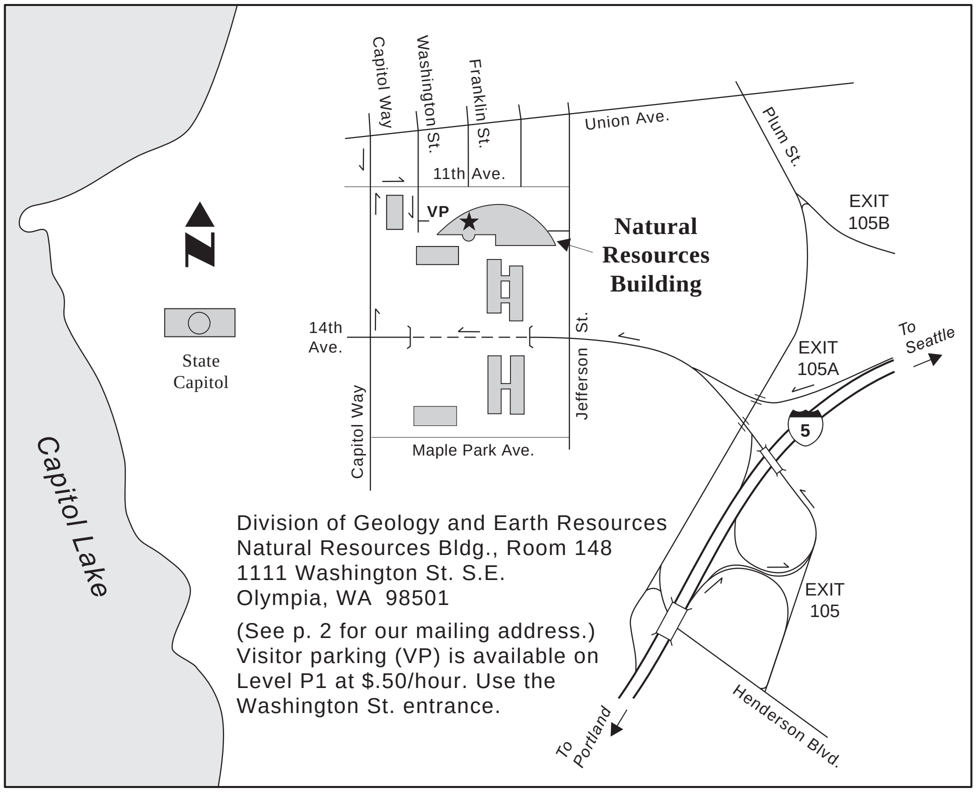
proposed Kalama Urban Growth Boundary in October. In January, he presented a talk to natural resource staff of Olympic National Park concerning the geologic evolution of the Olympic Mountains. In February, he gave a talk to citizens of Mercer Island on landslide hazards in the Puget Sound area.

New Staff

Betty Avila is our temporary Office Assistant (OA), while our permanent OA is working as an Office Assistant Senior in our office. She is an asset to our division. Betty has worked in clerical support for the Department of Health and the Commissioner of Public Lands office. She has extensive experience as an environmental specialist and is actively pursuing a career in that field.

Diane Frederickson has been hired as a temporary Office Assistant to work on records retention in our office. She has jumped in and (under supervision) started sorting, recycling, and shredding and is being trained to use the records retention schedule. We are very happy to have Diane in our office for as long as we can keep her. ■

HOW TO FIND OUR MAIN OFFICE



Division of Geology and Earth Resources
Natural Resources Bldg., Room 148
1111 Washington St. S.E.
Olympia, WA 98501

(See p. 2 for our mailing address.) Visitor parking (VP) is available on Level P1 at $.50/hour. Use the Washington St. entrance.

American Geophysical Union's Position Statement on Meeting the Challenges of Natural Hazards

Natural hazards (earthquakes, floods, hurricanes, landslides, meteors, space weather, tornadoes, volcanoes, and other geophysical phenomena) are an integral component of our dynamic planet. These can have disastrous effects on vulnerable communities and ecosystems. By understanding how and where hazards occur, what causes them, and what circumstances increase their severity, we can develop effective strategies to reduce their impact. In practice, mitigating hazards requires addressing issues such as real-time monitoring and prediction, emergency preparedness, public education and awareness, post-disaster recovery, engineering, construction practices, land use, and building codes. Coordinated approaches involving scientists, engineers, policy-makers, builders, lenders, insurers, news media, educators, relief organizations, and the public are therefore essential to reducing the adverse effects of natural hazards.

In order to reduce our vulnerability to natural hazards, AGU strongly endorses:

- fundamental research on Earth and space and monitoring of natural hazards,
- dissemination of the relevant results to the public, especially vulnerable communities, and
- implementation of multidisciplinary efforts needed to apply effective mitigation strategies worldwide.

Adopted by AGU Council, December 1996,
revised and reaffirmed December 2000
Used with permission.

FINAL BILL REPORT: Geologist Licensing (SB 5206)

Brief Description: Modifying geologist licensing provisions.

Sponsors: Senators Gardner, Prentice, Winsley, and Fraser by request of Department of Licensing; Senate Committee on Labor, Commerce and Financial Institutions; House Committee on Commerce and Labor.

Background: A law regulating the profession of geology was enacted in 2000. Provisions of the law included the creation of a geologist licensing board, specific requirements for licensure as a geologist, and penalties for practicing geology without a license. The effective date of this law is July 1, 2001.

Summary: Three separate effective dates for the law are specified.

- April 1, 2001, is the effective date for provisions of the law, including the creation of the geologist licensing board, a geologist's account at the Office of the State Treasurer, and the director's power to adopt rules to carry out the provisions of the law.
- July 1, 2001, is the effective date for provisions of the law, including requirements for licensure, administration of examinations and certificates, and criteria and penalties for unprofessional conduct.
- July 1, 2002, is the effective date for the provision that practicing geology without a license is a Class 1 civil infraction, punishable by a maximum $250 fine.

Votes on Final Passage: Senate 44–0; House 86–0

Effective: Immediately

DIVISION PUBLICATIONS

New Releases

Interpreted geologic history of the Sedro-Woolley North and Lyman 7.5-minute quadrangles, western Skagit County, Washington, Open File Report 2000-1, by Joe D. Dragovich, David K. Norman, and Garth Anderson. 71 p., 10 figs., 1 plate. $2.78 + .22 tax (Wash. residents only) = $3.00.

Bibliography of the geology and mineral resources of Washington, 1991–1995, Open File Report 2000-2, compiled by Connie J. Manson. 192 p. $5.56 + .44 tax (Wash. residents only) = $6.00. *Supersedes OFRs 92-4, 93-2, 94-15, and 96-6.*

Mining regulations in Washington, Open File Report 2000-3, by David K. Norman. 22 p. Free. *Supersedes OFR 94-4.*

Geologic map of the Forks 1:100,000 quadrangle, Washington, Open File Report 2000-4, compiled by Wendy J. Gerstel and William S. Lingley, Jr. 36 p., 5 figs., 2 plates, scale 1:100,000. $6.02 + .48 tax (Wash. residents only) = $6.50.

Geologic map of the Bellingham 1:100,000 quadrangle, Washington, Open File Report 2000-5, by Thomas J. Lapen. 36 p., 3 figs., 2 plates, scale 1:100,000. $6.02 + .48 tax (Wash. residents only) = $6.50.

Geologic map of the Anacortes South and La Conner 7.5-minute quadrangles, western Skagit County, Washington, Open File Report 2000-6, by Joe D. Dragovich, Minda L. Troost, David K. Norman, Garth Anderson, Jason Cass, Lea A. Gilbertson, and Donald T. McKay, Jr. 4 plates, scale 1:24,000. $12.04 + .96 tax (Wash. residents only) = $13.00.

Geologic map of the Carlsborg 7.5-minute quadrangle, Clallam County, Washington, Open File Report 2000-7, by Henry W. Schasse and Karl W. Wegmann. 27 p., 5 figs., 2 plates, scale 1:24,000. $6.48 + .52 = $7.00.

Reconnaissance investigation of sand, gravel, and quarried bedrock resources in the Bellingham 1:100,000 quadrangle, Washington, Information Circular 91, by Jeffrey S. Loen, William S. Lingley, Jr., Garth Anderson, and Thomas J. Lapen. 2001. 45 p., 1 plate, scale 1:100,000. $4.17 + .33 tax (Wash. residents only) = $4.50.

Reconnaissance investigation of sand, gravel, and quarried bedrock resources in the Yakima 1:100,000 quadrangle, Washington, Information Circular 92, by Kevin D. Weberling, Andrew B. Dunn, and Jack E. Powell. 2001. 34 p., 1 plate, scale 1:100,000. $4.17 + .33 tax (Wash. residents only) = $4.50.

Tsunami hazard map of the southern Washington coast—Modeled tsunami inundation from a Cascadia subduction zone earthquake, Geologic Map GM-49, by Timothy J. Walsh, Charles G. Caruthers, Anne C. Heinitz, Edward P. Myers III, Antonio M. Baptista, Garnet B. Erdakos, and Robert A. Kamphaus. 2000. 12 p., 1 plate, scale 1:100,000. $3.71 + .29 tax (Wash. residents only) = $4.00.

Digital Bibliography of the geology and mineral resources of Washington State, 1798–2000, Digital Report 1, 2001 edition, compiled and edited by Connie J. Manson. Contains the citations and indexing for more than 35,000 items and includes both items listed in our printed bibliographies and those non-Washington items held in our library. CD-ROM with search software; runs on Windows 3.1 or higher. $0.92 + .08 tax (Wash. residents only) = $1.00.

(Our address and phone number are on p. 2. Orders must be prepaid. Make check or money order payable to the Department of Natural Resources. Taxes apply to Washington residents only. Please include $1.00 for postage and handling of orders.)

Washington Geologists in the News

Kathy Goetz Troost of the University of Washington Department of Geological Sciences was elected a Fellow of the Geological Society of America on Nov. 13, 2000.

Weldon Rau has just published “Surviving the Oregon Trail, 1852; As Told by Mary Ann and Willis Boatman and Augmented with Accounts by Other Overland Travelers”. This book includes firsthand accounts of the journey to Oregon in the words of a young married couple, Mary Ann and Willis Boatman. Rau, who lives in Olympia, is now retired but worked as a research geologist for the U.S. Geological Survey and the Washington Division of Geology and Earth Resources. He is the great grandson of Puyallup pioneers Mary Ann and Willis Boatman. The book is the culmination of 15 years of extensive field investigations and archival/library study. In addition to historical information, Rau also provides geological insights. Available from WSU Press at http://www.wsu.edu/wsupress/.

Wes Wehr is the author of “The Eighth Lively Art—Conversations with Painters, Poets, Musicians, and the Wicked Witch of the West”. An accomplished artist and musician himself, Wehr was a friend and often a confidant of many of the painters, poets, and musicians who lived or worked in the Northwest in the 1950s and 60s. Wehr profiles painters Mark Tobey, Pehr Hallsten, Helmi Juvonen, Guy Anderson, and Morris Graves; poets Theodore Roethke, Richard Selig, Elizabeth Bishop, and Leonie Adams; musicians Ernest Bloch and Berthe Poncy Jacobson; photographer Imogen Cunningham; gallery owner Zoe Dusanne; philosopher Susanne Langer; and actor Margaret Hamilton (famous for her role as the Wicked Witch of the West in The Wizard of Oz). Wehr is affiliate curator of paleobotany at the Burke Museum of Natural History and Culture, University of Washington. Available from University of Washington Press at http://www.washington.edu/uwpress/.

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