April 1984 Volume 12 Number 2

# WASHINGTON GEOLOGIC NEWSLETTER

**Falling building ornamentation, rooftop water towers, chimney, and other objects caused widespread damage during both the 1965 and 1949 events. This 1949 Seattle Times photo was taken on Yesler Way in Seattle.**

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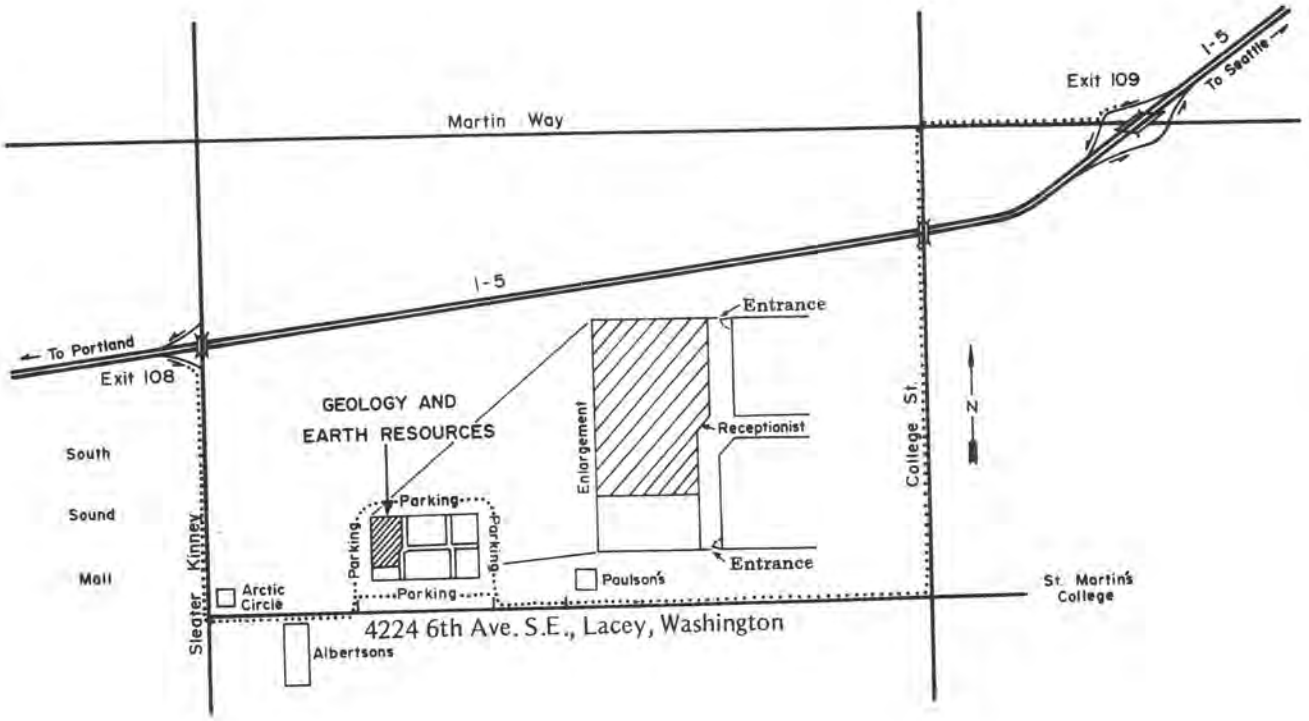


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Laura Bray, Editor

The Washington Geologic Newsletter, a quarterly report of geologic articles, is published by the Division of Geology and Earth Resources, Department of Natural Resources. The newsletter is free upon request.

The division also publishes bulletins, information circulars, and geologic maps. A list of these publications will be sent upon request.

## PROCLAMATION

*WHEREAS, earthquakes have caused death and damage in Washington State in the past; and*

*WHEREAS, earthquakes are a natural threat that will always be part of our lives in Washington State; and*

*WHEREAS, a damaging earthquake could occur anywhere in Washington with absolutely no warning; and*

*WHEREAS, the citizens of the state of Washington must be made aware of the potential threat of earthquakes and of those things that can be done before, during, and after an earthquake to save lives, protect property, and mitigate damages and injuries;*

*NOW, THEREFORE, I, John Spellman, Governor of the state of Washington, do hereby proclaim April 8 through April 14, 1984, as*

**EARTHQUAKE AWARENESS WEEK**

*in Washington State, and I urge all citizens, government officials, educators, and others to become more aware of the hazards and the threat of earthquakes, to take whatever steps necessary to make homes, schools, businesses, and public places as earthquake-safe as possible, and to support increased public information and public awareness programs on earthquake safety.*

*Signed, this 27th day of January, 1984.*

**GOVERNOR JOHN SPELLMAN**

## EARTHQUAKE AWARENESS WEEK

The Governor's proclamation should remind natives as well as alert newcomers that we live in an active seismic zone. Our most historically active area, the Puget Lowland, also happens to be a population center and area of fastest growth. (Population has roughly doubled since 1950). Thus, most of us were either too young to remember or not here to witness the 1949 earthquake. At least two aspects of this situation contribute to earthquake hazard: (1) many of us are complacent, and (2) there are many more people here today subject to injury, and complex structures subject to damage than during past events.

The third paragraph of the proclamation may be viewed with some doubt by those living outside the Puget Lowland. However, recent studies (discussed below) suggest that there is little justification for complacency in southwestern or coastal Washington. Likewise, eastern Washington is not immune to seismic hazard. Many are unaware of the shallow 5.8 magnitude quake of 1936 near Walla Walla. Possibly the most severe quake in Washington's history was the December 14, 1872 event that appears to have been centered in north-central Washington. It was felt over an area of approximately 500,000 square miles (Coombs and others, 1976, p. 21). It was felt as far east as Bozeman, Montana, and as far south as Eugene, Oregon.

### REFERENCES CITED

Coombs, H. A., Milne, W. G.; Nuttli, O. W.; Slemmons, D. B., 1977, Report of the Review Panel on the December 14, 1872 earthquake; Subappendix 2RA: Washington Public Power Supply System (WPPSS) Preliminary Safety Analysis Report Amendment 23, v. 2A, p. 1-31.

**This landslide in Tumwater occurred during the 1965 earthquake. It may have been triggered by shaking alone or by liquefaction of the saturated toe of the embankment.**

## SEISMIC SUMMARY

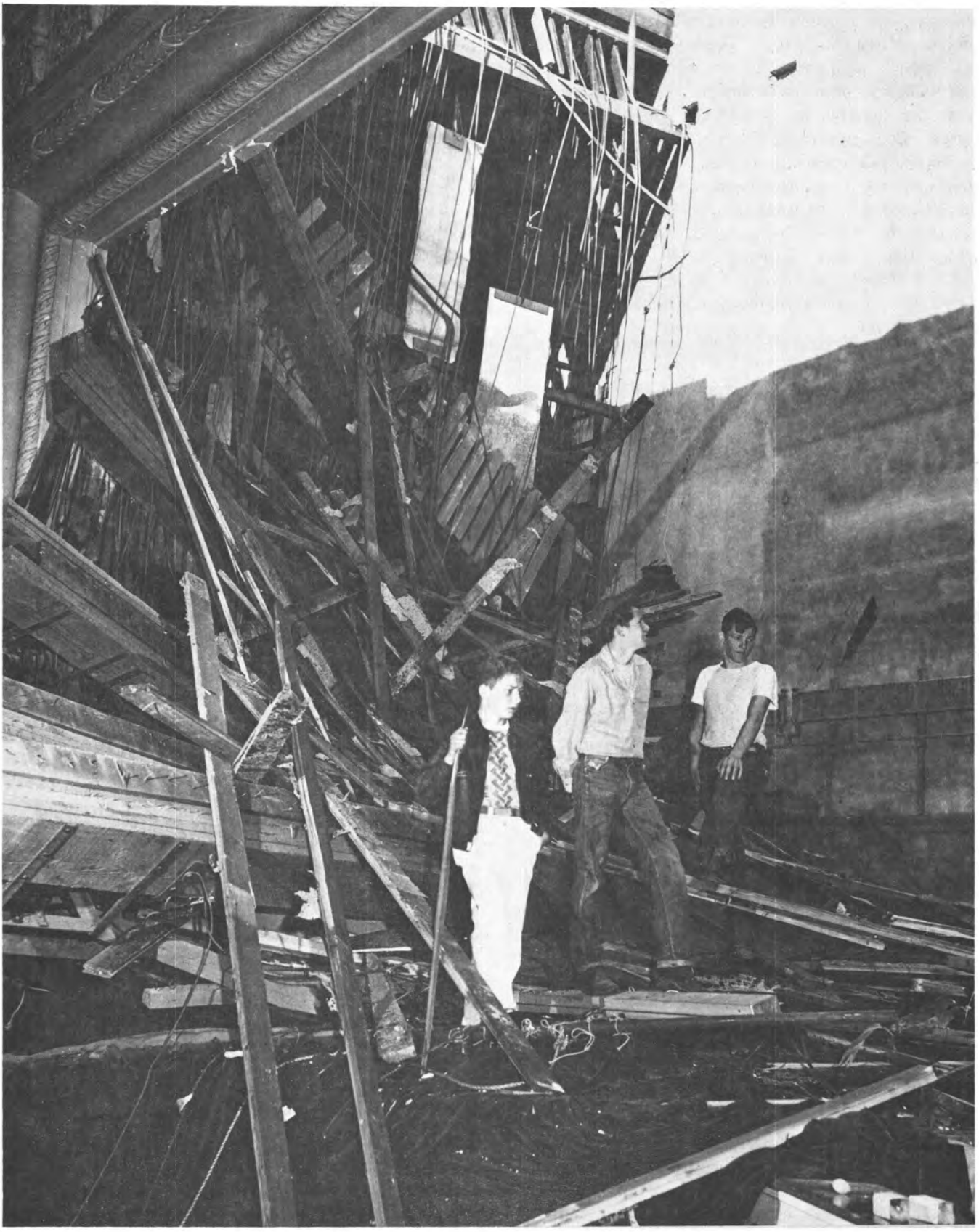
by Linda Lawrance Noson*

Since 1840 there have been nearly 1000 earthquakes large enough to have been felt by residents in the State of Washington. Many of these caused localized property damage. Some past earthquakes were felt throughout Washington, northern Oregon, and southern British Columbia. Two of these events, a magnitude 7.1 in Olympia (1949) and a magnitude 6.5 between Tacoma and Seattle (1965) caused damage totaling well in excess of $200 million (1983 dollars), many injuries, and 15 deaths. Seismologists agree that earthquakes comparable to those in 1965 and 1949 will occur in Washington State again.

Recent studies (Heaton and Kanamori, in press; Savage, Lisowski, and Prescott, 1981; Weaver and Smith, 1983) suggest that much more damaging earthquakes than those that have already occurred in the state in historic times are possible. Weaver and Smith discuss recent seismic data from southwestern Washington that outline a 90 km (54 mile) nearly north-south striking crustal earthquake zone. They have interpreted this as a fault capable of generating a moderate- to large-magnitude shallow earthquake. The general tectonic model proposed by Weaver and Smith to explain recent earthquake observations in Puget Sound makes it necessary to consider the possibility of an earthquake comparable to the devastating magnitude 8.5 Alaska earthquake in 1964. Neither a sizable shallow earthquake in southwestern Washington nor a large Alaska type event have been considered in the current earthquake hazard assessment for Washington.

On the basis of past earthquake activity, the Applied Technology Council (1978) assigned most of the Olympics, Puget Sound, and the north Cascades a seismic hazard index of 4 on a scale of 1 (lowest) to 4 (highest) in regard to expected ground accelerations and ground velocities. The seismic hazard index is used in the development of seismic regulations for the design of buildings. Even without considering the interpretation of recent seismic data, which suggests the possibility of even larger ground accelerations and ground velocities, most of Washington has been classified as an area of high earthquake risk.

* Seismologist, University of Washington.



Collapsed roof over stage of Puyallup High School, 1949 earthquake. Photo by Seattle Times.

When the possibility of a large damaging earthquake is discussed, most people assume one is talking about California, Alaska, or perhaps Turkey. Those areas do have a higher occurrence rate of earthquakes. Public awareness of an indigenous earthquake hazard is likewise greater than in areas where such earthquakes are less frequent. Consequently, more effort and funding have been devoted to finding ways to reduce the personal and economic effects of future earthquakes in those locations. Unfortunately, in places like Washington State where such earthquakes occur less often, public awareness of the potential dangers from earthquakes is disturbingly low. Without awareness, the motivation to act effectively to develop and implement earthquake hazards reduction measures is absent.

**Poorly attached ceiling fixtures are a common source of injury during a damaging quake. This 1965 picture shows damage in an Olympia school.**

The earthquake risk in the State of Washington cannot be restricted to one jurisdiction. Past large earthquakes located deep beneath southern Puget Sound were felt strongly in the state and caused significant damage throughout western Washington. More catastrophic events would similarly affect large areas. The economic impact of severe damage to the major metropolitan areas of the state would adversely affect all state resources. Eastern Washington has had moderate, very shallow earthquakes historically. The shallow depth of eastern Washington earthquakes somewhat limits the area over which damages are high, but increases the extent of damages near the epicenter. Therefore, earthquakes must be seen as a statewide concern.

### REFERENCES CITED

Applied Technology Council, 1978, Tentative provisions for the development of seismic regulations for buildings: National Bureau of Standards Publication no. NBS SP-510, 505p.

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

Weaver, C. S.; Smith, S. W., 1983, Regional tectonic and earthquake hazard implications of a crustal fault zone in southwestern Washington: Journal of Geophysical Research, v. 88, no. B12, p. 10, 371-10, 383.

## SEATTLE EARTHQUAKE SAFETY AND EDUCATION PROJECT

In response to the Earthquake Hazards Reduction Act of 1977, the Federal Emergency Management Agency (FEMA) initiated the Earthquake Education Program. Congress also identifed Washington State as an area subject to moderate or major seismic risk. To further this program FEMA awarded a grant to the Washington State Department of Emergency Services. This agency has asked the University of Washington's Geophysics Department to initiate an Earthquake Education Program within the Seattle School District. This 3-year project began in September 1983.

The Seattle Earthquake Safety and Education Project was designed to address both the safety and education elements of the earthquake hazards problem. Two Seattle schools, Adams and Brighton, have chosen to participate as pilot schools in this project. School earthquake committees composed of teachers, parents, and other staff members are currently helping to field test a Guidebook for Developing a School Earthquake Program. "This guidebook is designed to assist the school community of principals, teachers, parents, and students to develop and tailor an earthquake safety program for their school"(from the Introduction to the Guidebook).

The safety element of the project addresses areas including school site hazard assessment, earthquake response preparation, and various post-earthquake problems, such as shelter and communications. The education element addresses the need to educate the children on the causes, effects, and safe reponse should an earthquake occur. By understanding the nature of the event and

realizing that an earthquake is a real, naturally occurring part of our environment, the fears of the children should be reduced and allow them to take constructive actions in the event of an earthquake.

Questions or suggestions should be directed to Linda Noson or Bob Norris , University of Washington, Geophysics Program, AK-50, Seattle, WA 98195. (206) 543-7640 or 543-7010.

## RECENT PUBLICATIONS – WASHINGTON EARTHQUAKES

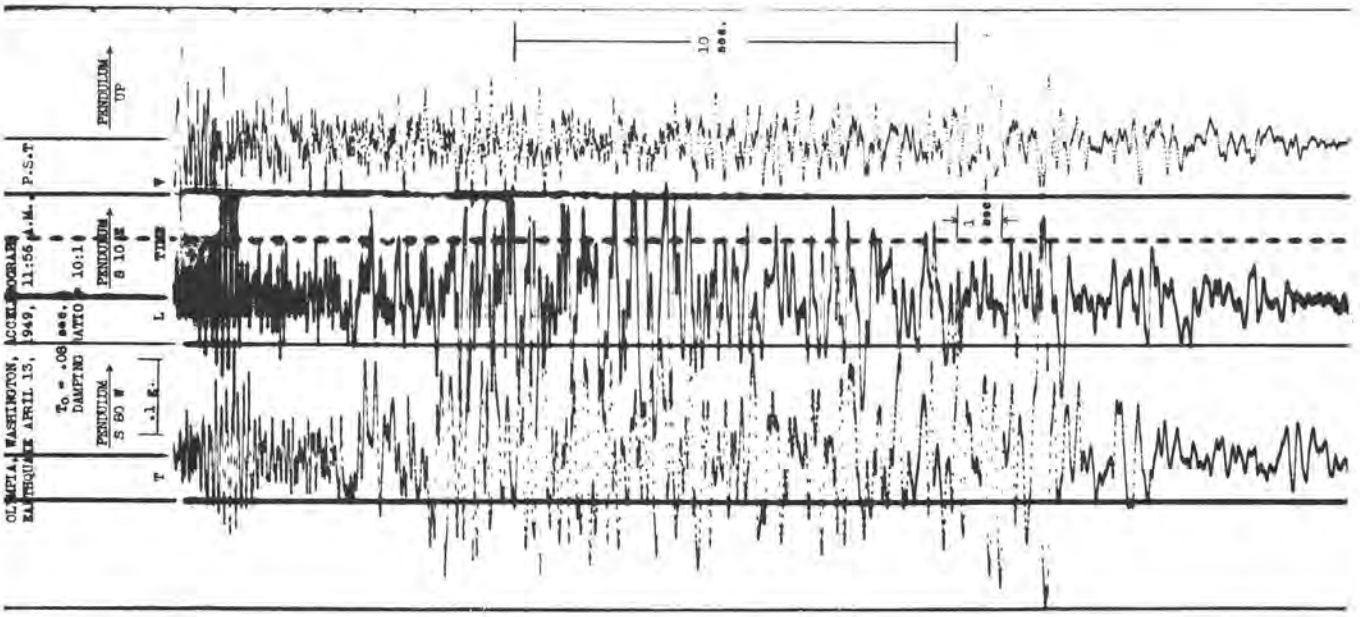
"Earthquake Safety of School Buildings – A discussion of the minimum seismic safety standards for the Seattle School District." The foregoing publication written by Carole Martens, was prepared at the request of the Seattle School Board Facilities and Operations Committee and released in January, 1984. The background presented and the problems discussed are applicable to many school districts, especially those with unreinforced masonry buildings. This booklet and its appendices are recommended reading for anyone interested in seismic safety of schools. It is available for $5.00 from the Seattle Public Schools, Facilities Planning Department, 815 - 4th Ave. North, Seattle, WA 98109.

Another report that may have escaped some students of Washington earthquakes is "Earthquake Mitigation Policy: The Experience of Two States" (Washington and Missouri). It reports the findings of a National Science Foundation-supported study by Thomas E. Drabek, Alvin H. Mushkatel, and Thomas S. Kilijanek. "The basic research question of this study was: What happened during the 1970's with regard to earthquake mitigation policy . . . " (p. 2). The authors note progress at various levels after the 1965 Puget Sound quake and as a result of the eruption of Mt. St. Helens. In the chapter "A closer look at Washington," the issues of school safety in Seattle and the now-abandoned Skagit nuclear power plant site are examined in depth. The 1983 report (Monograph no. 37) is available for $8.00 through the Natural Hazard Center, Box 480, University of Colorado, Boulder, Colorado 80309.

The U.S. Geological Survey has just released "United States Earthquakes, 1981" as a Special Publication. This report is especially interesting because of its coverage of the February Elk Lake earthquake of the evening of February 13. This magnitude 5.5 event, with epicenter just north of Mount St. Helens was only 6.7 km (4 miles) deep (vs 70 km and 60 km for 1949 and 1965 Puget Sound quakes). It was felt over an area of 105,000 square km and had 17 aftershocks. In addition to the excellent instrument record from the University of Washinton seismograph net, almost 4000 "intensity questionaires"

**Isoseismal map for the Elk Lake earthquake. The large numbers of questionaires returned will enable much more detailed maps to be compiled for some local areas.**

**Sand boils" or "mud volcanoes" along Capitol Lake in Olympia indicate local soil liquefaction during the 1965 quake. Such features are formed by geysers of muddy water escaping from saturated sediments.**



**Old paper accelerograph record of 1949 earthquake at Olympia. (Modern accelerographs use film or tape to record longitudinal, vertical, and transverse ground motion.) Note that strong shaking lasted only about 20 seconds. "Probably 5,000 persons . . . and property damage of $100 million ($550 million 1983 dollars) was spared solely because the quake . . . did not last a little longer" (Edwards, 1950).**

**Edwards, H. H., 1950, Discussion of damage caused by the Pacific Northwest earthquake of April 13, 1949, and recommendations of measures to reduce property damage and public hazards due to future earthquakes: American Society of Civil Engineers, Seattle Section, 29 p.**

were received (Linda Noson, manuscript in preparation). This quake and its aftershocks were among 2700 earthquakes recorded in Washington and northern Oregon during 1981.

## ENVIRONMENTAL VOLUNTEERS

"Earthquake geology and preparedness" is one of the four programs addressed by this group of volunteer teaching assistants. They stress "creative classroom presentations" and "hands-on activities." (The earthquake education kit they have prepared certainly attests to both.) The EVs ("ee-vees") recently put on several training workshops in Seattle. The training sessions were organized by Linda Noson of the University of Washington's Department of Geophysics, as part of her Seattle Earthquake Safety and Education Project.

The EV's instructional kit mentioned has dozens of props aimed at taking the mystery out of earthquakes for elementary school children. Besides abundant printed material and graphics, there are many models that move and(or) can be taken apart. There are fault zone models, a "sea floor spreading box," and an earth hemisphere model showing the earth's interior. A 9-foot square "plate tectonics rug" has labels and arrows showing plate movements. The "plate tectonics globe" has movable plates. A favorite is the "shaking table." It demonstrates the effects of a quake on different foundation materials (even soil liquefaction), different kinds of construction, and different building heights. There is even a doll house to show what happens in a typical home.

Two such kits have been obtained by the Seattle Earthquake Safety and Education Project. One will be available to schools and the other will be at the Pacific Science Center. As you might expect, much time, thought, hard work, and quality went into these kits. They cost $6,500 and are built to last. Anyone interested should contact:

Environmental Volunteers
2253 Park Blvd.
Palo Alto, CA 94306
(415) 327-6017

## ACCELEROGRAPH NETWORK EXPANDING

Only two accelerographs, or strong-motion seismographs, recorded the 1949 earthquake. By 1965 the U.S.

**One of the many failures along Deschutes Parkway in Olympia from the 1965 quake.**

Coast and Geodetic Survey had six instruments in the Puget Lowland and all were triggered on April 29 (Steinbrugge and Cloud, 1965, p. 43). Now, there are approximately 46* instrumented sites in the state. This includes 34 sites of various ownerships serviced by the U.S. Geological Survey, five City of Tacoma sites, and seven Washington Public Power Supply System sites. Some of these sites have as many as five instruments. Large dams, especially, are apt to be well instrumented. These multiple stations are necessary to measure the behavior of different parts of the structure during a damaging earthquake. Such instrument complexes usually include a "ground station" in an attempt to record seismic input to the site relatively uncontaminated by feedback from the structure.

Data on the acceleration of gravity during an earthquake are essential to the structural engineer in designing large and(or) complex structures. Such data are not gathered by conventional seismographs, as such supersensitive instruments go off-scale at the onset of damaging shocks. The City of Tacoma appears to be leading the state with its accelerograph program. It is financed through a 10 percent surcharge on building permits. (Such a fee has been in effect statewide in California since 1971.) So far, Tacoma General Hospital is the only multistory structure that is fully instrumented; however, plans are to instrument a new 16-story building as soon as it is completed (Charles Pearson, City of Tacoma, oral communication). In addition, four other city-owned structures house accelerographs. These instruments, plus the ones at the County-City Building and the V.A. Hospital that are serviced by the U.S. Geological Survey, should provide Tacoma with much valuable data from our next damaging Puget Lowland earthquake.

Unfortunately, vast areas of the state still remain uninstrumented or inadequately instrumented. The Wynoochee Dam is the only structure known to be instrumented west of Shelton, although there is currently a ground station near Satsop. The Division of Geology and Earth Resources has been unable to learn of any stations between Tumwater and Mount St. Helens or in the central Puget Lowland between Bremerton and Anacortes. The entire Olympic Peninsula, as well as the coast, appears to be devoid of stations and, excluding dams, larger gaps exist in eastern Washington. California's State Strong-Motion Instrumentation Program recognized three categories of need for additional sites:

"Geographic areas not yet covered"

"Representative soil and rock sites throughout the state"

"A broad range of representative buildings and structures"

Washington State is seriously lacking in all three categories.

*There may be other instruments at private structures we don't know about.

## SELECTED REFERENCES


Behram, Gonen, 1974, Building standards and the earthquake hazard for the Puget Sound Basin. University of Washington M.S. thesis in Civil Engineering, 146 p.

California Division of Mines and Geology, 1972, Facts about California's new strong-motion instrumentation program: California Division of Mines and Geology, CDMG Notes 72-26.

Steinbrugge, K. V.; Cloud, W. K., 1965, Preliminary Engineering Report. *In* The Puget Sound, Washington Earthquake of April 29, 1965: U.S. Department of Commerce, Coast and Geodetic Survey, p. 27-51.

## PROPOSED BOOKLET ON EARTHQUAKES AND FAULTING

Sources of publication money for a booklet on "Earthquakes and Faults in Washington" are currently being explored. Much of the booklet is still in the planning stage but the Division of Geology and Earth Resources hopes to publish it by late fall. It will be co-authored by the State Seismologist (Linda Noson) and someone from the staff of the State Geologist (probably Jerry Thorsen). The booklet is in response to the many inquiries on such subjects received by both offices.

Inquiries come in from a spectrum of people ranging from school children to insurance underwriters to people contemplating moves to Washington. Too often they ask the wrong questions. For example, the prospective immigrant from California may request a map showing faults. Such maps are available but in almost every instance show long-inactive faults that are irrelevant to earthquake hazard. Thus, it is often necessary to "back up," and explain the vast differences between Washington's and California's seismic settings. It is hoped that the proposed booklet will serve such needs.

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## GEOLOGIC RESEARCH PROJECTS

Geological research activities conducted by colleges and universities on the geology of Washington State during 1983 are listed below:

### CENTRAL WASHINGTON UNIVERSITY

#### Faculty Research Projects

Geologic quadrangle mapping of the Yakima fold belt (Robert Bentley).

Paleomagnetic studies in the Columbia River basalts (Robert Bentley).

Stratigraphy and structural evolution of the Columbia River basalts and Ellensburg group in Washington and Oregon (Robert Bentley).

Computer automation systems for geochemical instrumentation (James Hinthorne).

Electron and ion microprobe study of trace elements in borosilicate and aluminum silicate minerals (James Hinthorne).

Microprobe study of phenocrysts in Frenchman Springs basalt (James Hinthorne).

Glacial deposits on the northern Columbia Plateau (Don Ringe).

Paleobotany of the Swauk Formation and other Tertiary units of central Washington (Edward Klucking).

### CLARK COLLEGE

#### Faculty Research Projects

Structural, metamorphic, and plutonic history of the southern margin of the Skagit crystalline core of the north Cascades (Robert B. Miller).

Structure and metamorphism of the Gabriel Peak Orthogneiss and the movement history of the Ross Lake fault zone (Robert B. Miller).

Tectonic evolution of the Rimrock Lake pre-Tertiary inlier, southern Washington Cascades (Robert B. Miller).

### EASTERN WASHINGTON UNIVERSITY

#### Faculty Research Projects

Compilation of computer data base of whole-rock chemical analyses of alkaline igneous rocks from gold deposits (Felix E. Mutschler).

Geochemistry of granitic rocks of northeastern Washington (Mohammed Ikramuddin).

Geochemistry of platinum-group elements (Mohammed Ikramuddin).

Geochemistry of the Sanpoil Volcanics and its relationship to gold-silver mineralization (Mohammed Ikramuddin).

Geologic map of the Inchelium quadrangle, Washington (James R. Snook).

Hydrogeochemical methods of exploration for gold and silver (Mohammed Ikramuddin).

Major and trace element chemistry of "porphyry" molybdenum, tin-tungsten systems (Felix E. Mutschler).

Mineralogy of alkalic plutonic rocks including the Golden Horn batholith, northern Cascades, Washington (Russell C. Boggs).

Paleomagnetism of intrusive igneous rocks of northeastern Washington (William K. Steele).

Permian bryozoans of the carbonate units of the Mission Argillite, northeastern Washington (Ernest H. Gilmour).

Quaternary geology of the northeastern Columbia Plateau (Eugene P. Kiver and Dale F. Stradling).

Surficial geologic maps and Quaternary history in the Grand Coulee, Wilbur, Lincoln, Turtle Lake, Little Falls, Wilmont Creek, Hunters, Inchelium, Bangs

Mountain, Kettle Falls, Marcus, Boyds, Orient, Bossburg, and Laurier quadrangles, northeastern Washington (Eugene P. Kiver and Dale F. Stradling).

Use of remanent magnetization in correlating eastern Washington tephra deposits (William K. Steele).

Use of thallium as a potential guide to mineral deposits (Mohammed Ikramuddin).

### Student Research Projects

A mineralogical and chemical study of manganese-bearing and associated rocks of the Crescent Formation, Olympic Peninsula, Washington (Eric R. Ridgway).

Carbonate petrology and microfacies in the Carboniferous rocks near Springdale, Washington (Mehemed S. Gheddida).

Computer data base for alkaline rock-hosted precious metal deposits of western North America (Mark E. Griffin and D. Scott Stevens).

Depositional environment and correlation of the sediments of the Ellensburg Formation northwest of Yakima, Washington (James A. Luker, Jr.).

Depositional model of catastrophic flood bars in the Pine Creek channel, eastern Washington (Robert A. Pinotti).

FERROS—A computerized data base for Precambrian auriferous banded iron-formations and related rocks (Glen R. Carter).

Geochemical characteristics of tin-bearing granites (Fred Langston).

Geochemistry and petrography of veins and wall rocks associated with gold-silver mineralization in the Republic district, Ferry County, Washington (Walter M. Martin).

Geochemistry and petrology of the Sanpoil Volcanics and associated granitic rocks of a part of the Colville Indian Reservation, Washington (Sharon J. M. Digby).

Geochemistry of alaskite and quartz monzonite of Mount Spokane, northeastern Washington, and its relation to uranium mineralization (Roy Bongiovanni).

Geology and energy resources of part of the Manastash-Taneum Creek areas, Kittitas County, Washington (Curtis D. Cushman).

Gold deposits associated with alkaline plutons and volcanics — Selected trace element geochemistry (Robbin Finch).

Induced polarization-direct current resistivity methods in exploration for pre-Miocene paleo-drainage channels in eastern Washington (John S. McBeth).

Paleoenvironment reconstruction of the upper member of the Roslyn Formation of Kittitas County, Washington, with emphasis on coal exploration (D. Brent Barnett).

Paleomagnetic characteristics of the Touchet beds of the Walla Walla Valley of southeastern Washington (Cole Lovett).

The geochemistry of precious metal mineralization in post-emplacement ophiolitic terrains, Ingall's ophiolite complex, Washington (Phillip C. Nisbet).

Reconnaissance trace element geochemistry of the Loon Lake batholith, northeastern Washington (Adolphus A. Afemari).

Vertical geochemical variations in granodiorites associated with porphyry molybdenum-copper deposits at Mount Tolman, Ferry County, Washington (Danelle D. Elder).

## GRAYS HARBOR COLLEGE

### Faculty Research Projects

The effects on the water quality of Grays Harbor of sediment generated during hopper dredging. (James B. Phipps and John M. Smith).

## PACIFIC LUTHERAN UNIVERSITY

### Faculty Research Projects

Geology of the Indian Creek gneiss and related rocks, Rimrock Lake area, Yakima County (Brian Lowes).

Origin of vivianite in Pleistocene sediments of the Olympic coastal strip (Steven Benham).

Pleistocene stratigraphy of the Olympic coastal strip (Steven Benham).

## TACOMA COMMUNITY COLLEGE

### Faculty Research Projects

Guide to the roadside geology of Mount Rainier National Park, Washington (Jack H. Hyde).

## UNIVERSITY OF WASHINGTON

### Geologic Research Projects

Cenozoic geology of the White Pass Goat Rocks area (Geoff Clayton).

Fission track dating of early and middle Cenozoic rocks in Washington State (Joseph Vance).

Geologic maps of Mount Baker and Mount Shuksan 15-minute quadrangles, north Cascades (Peter Misch).

Imbricate zone below Shuksan thrust sheet, northwest Cascades, and several other tectonic/petrologic projects in north Cascades (Peter Misch).

Lahars on the Toutle River generated during the May 19, 1980 eruption of Mount St. Helens (Lee Fairchild).

Mesozoic and Cenozoic tectonics of the Washington Cascades (Joseph Vance).

Mineralization, deformation, and diagenesis of the upper Yellowhead deposit, Pend Oreille mine, Metaline Falls, Washington (Tom Colligan).

Paleomagnetic study of Jura-Cretaceous and Permian rocks in the San Juan Islands (Scott Bogue and Darrel Cowan).

Petrogenesis of metalliferous metasediment in the Shuksan/Easton assemblage (Claudia Owen).

Petrology and structural geology of the Wenatchee Ridge area, north Cascades, Washington (Jerry MacLoughlin).

Petrology of Big Jim Mountains and related rocks, Chiwaukum Mountains, Washington (Peter Kelemen).

Quaternary geology, geomorphology, and sedimentology of the Puget Lowland, Washington (Stan Chernicoff).

Rheology and flow dynamics of the Toutle River debris flows from Mount St. Helens (Mark Wigmosta).

Sedimentary and tectonic significance of the Lummi Formation, San Juan Islands (Joanne Bourgeois, Darrel Cowan, and John Garver).

Sedimentation and tectonics in the Methow Basin, Washington (Joanne Bourgeois, James Trexler, Jr., John Rosenthal, and Linda Reinen).

Shelf-storm deposits — Processes and products (Joanne Bourgeois, J. D Smith, and Elana Leithold).

Stratigraphy and petrology of the Island Mountain volcanics and their relation to the Pasayten fault. (Patricia White).

Storm and flood sedimentation near river mouths on wave-dominated continental shelves (Elana Leithold).

Structural and depositional setting of the Eocene Klondike Mountain Formation, Okanogan County, northeastern Washington (Cynthia Pridmore).

Structural relationship between the Thompson assemblage and the high-grade gneisses of Kettle and Okanogan Domes (Kris Orr).

Structure and tectonic history of San Juan Islands and surrounding areas (Mark Brandon).

Tectonic and sedimentological significance of the Lummi Formation (Jura-Cretaceous) in the Decatur terrane, San Juan Islands, Washington (John Garver, Joanne Bourgeois, and Darrel Cowan).

Thermodynamics of gold-bearing hydrothermal systems (James Wells).

## WASHINGTON STATE UNIVERSITY

### Faculty Research Projects

Bonneville and Missoula flood gravels in the lower Snake River (G. D. Webster).

Geologic mapping of the Anatone 15-minute quadrangle (G. D. Webster, P. R. Hooper, and Steve Reidel).

Geologic mapping of the Clarkston 15-minute quadrangle (G. D. Webster and P. R. Hooper).

Lineaments and seismicity of western Washington (R. Thiessen).

Sedimentology of Eocene nonmarine strata in the Washington Cascades (S. Johnson).

Synthesis of the structure, strain, and metamorphism in the Kootenay Arc, northeast Washington (A. J. Watkinson).

The Lewiston structure and Lewiston basin, Columbia River basalt (P. R. Hooper).

### Student Research Projects

Bonneville flood deposits along the Snake River near Lewiston, Idaho (Eric Swanson).

Digital techniques for structural geologic analysis of topography (Jay R. Eliason).

Distribution and mode of occurrence of trace elements in the Smith coal seam, Centralia mine, Centralia, Washington (Sara E. Kohn).

Geology and structural analysis of the southern Metaline district, Pend Orielle County, Washington (Glenn R. Wiedenhoeft).

Geology of the Swauk Formation in the Lion Gulch area, central Cascades, Washington (Stephen B. Taylor).

Igneous activity in a portion of northeast Washington with implications for Eocene tectonics (Diane Carlson).

Intrusive rocks in the Nespelem and Grand Coulee Dam quadrangles, Washington — The relation of composition and texture to the emplacement of plutons (Diane Carlson).

Petrology and geologic structure of a portion of the Seventeen Mile Mountain quadrangle, Ferry County, Washington (Wade Holder).

Porphyry copper deposit at McCoy Creek, southern Cascades (abandoned by Utah Mines); comparison between Cascade porphyry copper desposits and other known porphyry coppers in the Southwest (John Link).

Sedimentology, stratigraphy, and structure of the Swauk Formation in the Scotty Creek area, central Cascades, Washington (Greg Fraser).

Strain and structural morphology in Arc plus strain studies in the Kootenay Arc, Kettle and Okanogan Domes (Mike Ellis).

Stratigraphy, sedimentology, and structure of the Swauk Formation, Tronsen Ridge, Washington (James W. Roberts).

Structure, stratigraphy, and sedimentation of the Swauk Formation, Mount Lillian area, central Washington Cascades (Darrell Peoples).

The Manila Pass fault (Washington) — An example of large- and small-scale structures developed in a three-dimensional strain field (Diane Carlson).

## WESTERN WASHINGTON UNIVERSITY

### Faculty Research Projects

Chronology of glaciations in the Pacific Northwest using fission-track, K-Ar, amino acid, radiocarbon, and paleomagnetic dating methods (Don J. Easterbrook).

Glacial and volcanic history of Mount Baker (Don J. Easterbrook).

Glaciomarine sediments of the northern and central Puget Lowland (Don J. Easterbrook).

Paleomagnetic reversals in Pleistocene sediments of the Puget Lowland and Columbia Plateau (Don J. Easterbrook).

Paleomagnetism and tectonics of late Mesozoic and early Tertiary rocks in and east of the north Cascades (Russell F. Burmester).

Paleomagnetism, correlation and tectonics of late Precambrian rocks in northeastern Washington, northern Idaho, and northwestern Montana (Russell F. Burmester).

Paleomagnetism of Tertiary volcanic and sedimentary rocks of the Olympic Peninsula and their tectonic significance (David C. Engebretson).

Structure and petrology of the north Cascades Range (Edwin H. Brown).

### Student Research Projects
### (partial listing)

A paleolimnological study of Lake Whatcom, Bellingham, Washington (Al Moore).

A paleomagnetic study of the Eocene Ohanapecosh Formation north and south of Mount Rainier, Washington (David Abbott).

Description and origin of the January 10, 1983, debris torrent event in the Smith Creek drainage, western Whatcom County, Washington (Tim Syverson).

Depositional environment and provenance of the Clallam Formation, Olympic Peninsula, Washington (Kurt Anderson).

Depositional environment, sedimentary petrology, and tectonic setting of the Hoko River Formation, Olympic Peninsula, Washington (Jennifer DeChant).

Economic geology of the 15 Mile Creek area, Stevens County, northeast Washington – A volcanogenic massive sulfide deposit? (Bert Hyde).

Fission track dating of the Chilliwack Group, north Cascades, Washington (Mary Sleeper).

Geology and genesis of the Excelsior mine, Whatcom County, Washington (Russ Franklin).

Geology of the Little Deer Creek area, Skagit Valley, Washington (Greg Reller).

Glacial geology of a portion of the central Okanogan lowland, Okanogan County, Washington (Keith Pine).

Hydrothermal alteration and geothermal potential of the Gamma Ridge rocks, Glacier Peak, Washington (Rick Waldron).

Kitsap County, Washington, net shore drift (Bruce Taggart).

Paleomagnetism of the Tertiary sediments of the northwest Olympic Peninsula, Washington (Ron Moyer).

Petrology of xenoliths in pumice and dome rock from the 1980-81 eruptions of Mount St. Helens (Christina Heliker).

Quaternary geology and geomorphology of the Wishkah River valley and lower Chehalis River valley, Grays Harbor County, Washington (Steve Bubnick).

Sedimentary petrology and depositional environment of the Aldwell Formation, northern Olympic Peninsula, Washington (Keith Marcott).

Sedimentary petrology and depositional environment of the Quimper Sandstone and related tectonic implications (Bill Rauch).

Sedimentary petrology and depositional environment of the unnamed middle Eocene sandstones of Scow Bay, Indian and Marrowstone Islands, northwest Washington (Leslie Melim).

Stucture and mineralization of the Lone Jack mine area, north Cascades, Washington (Lief Christenson).

Structure and petrology of the Lookout Mountain-Teebone Ridge area east of Marblemount, Washington (Edwin Hill).

Structure and petrology of the Swift Creek area, north Cascades, Washington (Chuck Ziegler).

The depositional framework and regional extent of the West Beach silt and its significance in pre-late Wisconsin stratigraphy of the Puget Lowland, Washington (Jeff Sprague).

The petrology, stratigraphy, and basin tectonics of the Montesano Formation, southwestern Washington (Phil Bigelow).

## WHITMAN COLLEGE

### Research Projects
### (partial listing)

Quaternary and environmental geology of the eastern Olympic Peninsula (R. J. Carson).

Sedimentation in glacial lakes (Dean Heizer and R. J. Carson).

## YAKIMA VALLEY COLLEGE

### Faculty Research Projects

Geologic mapping of the Yakima East and Black Rock Springs 15-minute quadrangles (Newell Campbell with Robert Bentley of Central Washington Univer-

sity).

Structural geology along the Columbia River basalt margin, northwest Columbia Basin (Newell Campbell).

## SCIENTISTS REPORT ON MOUNT ST. HELENS MONITORING EFFORTS

Monitoring efforts of Mount St. Helens by scientists of the U.S. Geological Survey (USGS) and the University of Washington geophysics program at the Cascades Volcano Observatory, Vancouver, Washington, were described in a series of eight articles in the September 30, 1983, issue of *Science Magazine*. Subjects ranged from earthquakes occuring beneath the volcano, ground measurements on the crater floor and lava dome, to daily gas emissions from the crater. Some highlights:

Fifteen eruptions have taken place in the horseshoe-shaped crater of Mount St. Helens since the catastrophic events of May 18, 1980. Since late October 1980, the eruptions have been predominantly non-explosive dome-building events. Since early February 1983, the 750-ft.-high lava dome in the middle of the crater has been growing continuously, extruding lava high on its northeast flank. This marks the longest dome-building eruption to date.

Information from six seismometers on the cone and 10 others in the surrounding area is radioed to the University of Washington in Seattle and analyzed and interpreted by seismologists. Seismic data provide information about the location, depth and frequency of earthquakes, times of degassing events for the dome, and rockfalls associated with dome growth. Each of the eruptions in 1981-82 was preceded by an increase in earthquake activity which was used to anticipate the time of the eruptions, particularly 1-2 days before an expected event.

Unlike previous dome-building eruptions, the March 19, 1982 eruption that began with minor explosive activity, was preceded by a significant number of deeper earthquakes between 5-11 km. The previous dome building eruptions were preceded by earthquakes less than 3 km deep.

Measurements inside the crater by USGS scientists using precise surveying equipment and simple tape measures show that the crater floor becomes deformed prior to an eruption, as magma rises upward from a deeper source. In late 1980, cracks often appeared on the crater floor before eruptions and extended outward from the dome like spokes of a wheel. Measurements show that the cracks widen with time, expecially just before an eruption. Other parts of the crater floor often become slightly wrinkled several weeks before an eruption. A few of these wrinkles develop into features called thrust faults, sometimes growing from less than 1 ft. high, to as high as 10-15 ft. The movement of the crater floor along these faults increases before eruptions, and by measuring the rate of movement scientists have been able to predict eruptions one to three weeks in advance.

Electronic tiltmeters specifically designed for use at Mount St. Helens are used to measure small changes in slope of the crater floor, much like a carpenter's level. These tiltmeters, installed within several hundred feet of the dome, show rapid changes hours to days before an eruption and send information by radio to the USGS Cascades Volcano Observatory in Vancouver.

Monitoring the shape of the dome is also used to anticipate eruptions one to three weeks in advance. Measurements between points on the dome and crater floor show that the dome grows or swells as magma moves upward into the dome before it is evenually erupted on the surface of the dome to form a new lobe. Repeated surveys to targets placed on the dome reveal movements that speed up as the eruption nears. Before the May 14, 1982, eruption, for example, a target placed on the west side of the dome was moving roughly 1 in. per day two weeks before the eruption; this movement increased to about 7 ft. per day two days before the eruption. This increase in the rate of movement before the eruption is the key for predictions.

In addition to these ground measurements, gases are collected and measured from the lava dome and crater fumaroles, and carefully analyzed for changes. The emission of sulfur dioxide, measured frequently by aircraft-mounted equipment, decreased rapidly in late 1980 and has remained low through the present. This pattern corresponds to a change in eruptive style from the explosive eruptions during the summer of 1980, to the predominantly non-explosive dome building eruptions that have occurred since late Ocotober, 1980.

The lava-dome eruptions have each added a new flow of sticky viscous dacite magma to the composite lava dome. The major-element chemical composition of the dome has remained essentially constant at 62-63 percent $SiO_2$, suggesting that no new material has been added to the shallow magma system since the summer of 1980. An increase in the crystallinity of the dacite suggests that a deeper, gas-poor, crystal-rich layer is now being tapped rather than a gas-rich magma as during the explosive eruptions of 1980.

On March 19, 1982, a dome-building eruption began with an explosive phase and, owing to winter snowpack, a snow avalanche was initiated. Heat from the eruptive products swiftly melted snow that resulted in a destructive flood in the North Fork Toutle River valley. Had the eruption occurred in the summer, destructive effects of the relatively small explosive eruption would have been confined to the crater and upper flanks of the volcano.

– USGS *News Release*

## RECENTLY PUBLISHED REPORTS BY THE DIVISION OF GEOLOGY AND EARTH RESOURCES NOW AVAILABLE

Copies of these publications may be obtained by writing to the Department of Natural Resources, Division of Geology and Earth Resources, Olympia, WA 98504.

**Please send $1 to cover our Handling and Distribution charge for your total publication order.**

Manson, Connie J., 1984, Index to geologic and geophysical mapping of Washington, 1899-1983: Washington Division of Geology and Earth Resources Information Circular 77, 56 p., 14 pls. Price $6.00.

Livingston, Vaughn E., Jr., 1984, A guide for the preliminary evaluation of rock for road surfacing: Washington Division of Geology and Earth Resources Information Circular 78, 8 p. Free.

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## DIVISION OF GEOLOGY AND EARTH RESOURCES RELEASES OPEN-FILE REPORTS

The following open-file reports may be purchased from the Department of Natural Resources, Division of Geology and Earth Resources, Olympia, WA 98504; they are also available for inspection in our Division library. ***Note the Handling and Distribution charge at the end of the listing.**

Hammond, P. E., Korosec, M. A., 1983, Geochemical analyses, age dates, and flow-volume estimates for Quaternary volcanic rocks, southern Cascade Mountains, Washington: Washington Division of Geology and Earth Resources Open-File Report 83-13, 36 p., 1 plate. Price $2.00.

Holmes, Jenny; Waugh, Kathleen, 1983, Targeting geothermal exploration sites in the Mount St. Helens area using soil mercury surveys: Washington Division of Geology and Earth Resources Open-File Report 83-10, 26 p., 2 plates. Price $2.50.

Korosec, M. A., 1983, The 1983 temperature gradient and heat flow drilling project for the State of Washington: Washington Division of Geology and Earth Resources Open-File Report 83-12, 11 p. Price $1.00.

Stoffel, K. L., Widness, Scott, 1983, Geophysical logs of selected wells in eastern Washington: Washington Division of Geology and Earth Resources Open-File Report 83-14, 83 p. Price $3.00.

Stoffel, K. L., Widness, Scott, 1983, Fluid-temperature logs for selected wells in eastern Washington: Washington Division of Geology and Earth Resources Open-File Report 83-15, 351 p. Price $5.00.

Walsh, T. J., Phillips, W. M., 1983, Rank of Eocene coals in western and central Washington State – A reflection of Cascade plutonism?: Washington Division of Geology and Earth Resources Open-File Report 83-16, 23 p. Price $1.50.

Widness, Scott, 1983, Low temperature geothermal resource evaluation of the Moses Lake-Ritzville-Connell area, Washington: Washington Division of Geology and Earth Resources Open-File Report 83-11, 27 p. Price $1.00.

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*** Please add $1.00 to cover a Handling and Distribution charge for your total publication order.**

## RECENT U.S. GEOLOGICAL SURVEY PUBLISHED REPORTS ADDED TO OUR DIVISION LIBRARY

The following reports are now available for inspection in our division library. If you wish to purchase any of these published reports, please contact the U.S. Geological Survey, Public Inquiries Office, Room 678, U.S. Court House, 1020 Riverside, Spokane, WA 99201; (509) 456-2524.

Church, S. E.; Frisken, J. G.; Tabor, R. W.; Iverson, S. R., 1983, Mineral resource potential of the Wonder Mountain roadless area, Mason County, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF-1418-F, 10 p., 1 sheet, scale 1:62,500.

Fouch, T. D., 1983, Petroleum potential of wilderness lands, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I-1546, 5 p., 1 sheet, scale 1:1,000,000.

Marsh, S. P.; Kropschot, S. J.; Dickinson, R. G., editors, 1984, Wilderness mineral potential – An assessment of mineral-resource potential in U.S. Forest Service lands studies 1964-1984: U.S. Geological Survey Professional Paper 1300, 1183 p. (in 2 volumes) (NOTE: Includes studies of 16 Washington areas.)

Miller, B. M., editor, 1983, Petroleum potential of wilderness lands in the western United States: U.S. Geological Survey Circular 902-A-P, 1 volume (NOTE: Part L is "Petroleum potential of wilderness lands in Washington," by T. D. Fouch.)

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## THESES ADDED TO OUR DIVISION LIBRARY

We have recently acquired the following theses in our Division library where they are now available for reference work.

Blackwell, D. L., 1983, Geology of the Park Butte-Loomis Mountain area, Washington (eastern margin of the Twin Sisters dunite): Western Washington University Master of Science thesis, 253 p., 4 plates.

Blankenship, D. G., 1983, Net shore-drift of Mason County, Washington: Western Washington University Master of Science thesis, 172 p., 6 plates.

Bush, T. A., 1983, Hydrothermal alteration and copper mineralization at Copper Glance, Okanogan County, Washington: Washington State University Master of Science thesis, 155 p.

Cruver, J. R., 1983, Petrology and geochemistry of the Haystack Mountain unit, lower Skagit Valley, Washington: Western Washington University Master of Science thesis, 149 p., 1 plate.

Goff, F. E., 1977, Vesicle cylinders in vapor-differentiated basalt flows: University of California at Santa Cruz Doctor of Philosophy thesis, 181 p.

Harms, T. A., 1982, The Newport fault — Low-angle normal faulting and Eocene extension, northeast Washington and northwest Idaho: Queen's University [Kingston, Ont.] Master of Science thesis, 157 p., 3 plates.

Haviland, Terrance, 1983, A structural and petrographic analysis of the Cedar Lake area, Stevens County, Washington and a review of the controversy surrounding the timing of deformation within the Kootenay Arc: Washington State University Master of Science thesis, 93 p., 1 plate.

## RECENT PERMITS FOR OIL AND GAS DRILLING

| Operator | Permit no. | County | Well name | Location | Ground elevation (feet) | Estimated total depth (feet) | Spud date | Date permit issued |
|---|---|---|---|---|---|---|---|---|
| Shell Oil Co. | 340 | Grant | BN 1-9 | 965 FWL and 1,869 FNL* sec. 9 (15-25E) | 2,400 | 20,000 | 12-21-82 | 5-22-81 |
| AMOCO Prod. Co. | 354 | King | Enumclaw Mill No. 1-34 | 1,430 FNL and 1,370 FWL sec. 34 (20-7E) | 1,447 | 2,500 | | 5-16-83 |
| | | | | **Oil and Gas Stratigraphic Tests** | | | | |
| AMOCO Prod. Co. | 356 | Pierce | Buckley No. 1 | 1,990 FWL and 2,033 FSL sec. 11 (19-6E) | 755 | 1,800 | | 7-26-83 |
| AMOCO Prod. Co. | 360 | King | Fall City Twin No. 1 | 1,217 FNL and 925 FEL sec. 7 (24-8E) | 975 | 1,500 | | 7-26-83 |
| AMOCO Prod. Co. | 361 | Pierce | National No. 1 | 968 FSL and 2,228 FEL sec. 28 (15-6E) | 1,610 | 2,000 | 11-23-83 | 7-26-83 |
| AMOCO Prod. Co. | 362 | King | Snoqualmie Mill Offset No. 1 | 1,489 FNL and 1,297 FWL sec. 25 (24-7E) | 842 | 1,500 | | 7-26-83 |
| AMOCO Prod. Co. | 363 | King | Snoqualmie Mill Twin No. 1 | 1,779 FWL and 601 FSL sec. 19 (23-8E) | 2,190 | 1,500 | | 7-26-83 |
| AMOCO Prod. Co. | 364 | Lewis | Storm King Twin No. 1 | 2,005 FSL and 2,569 FEL sec. 23 (14-5E) | 1,835 | 1,500 | | 7-26-83 |
| AMOCO Prod. Co. | 365 | Lewis | WC-83-12 | 488 FWL and 2,212 FSL sec. 7 (14-5E) | 1,515 | 2,000 | | 12-15-83 |
| AMOCO Prod. Co. | 366 | Pierce | WC-83-11 | 347 FSL and 330 FWL sec. 11 (19-6E) | 752 | 2,000 | | 12-29-83 |
| AMOCO Prod. Co. | 367 | Pierce | WC-83-13 | 964 FNL and 1,015 FWL sec. 10 (15-6E) | 3,260 | 2,000 | | 12-29-83 |
| AMOCO Prod. Co.** | 368 | King | WC-83-14 | 265 FSL and 2,144 FEL sec. 14 (23-7E) | 1,100 | 1,752 | 1-20-84 | 12-29-83 |
| AMOCO Prod. Co | 369 | King | WC-83-15 | 1,104 FSL and 704 FWL sec. 35 (25-7E) | 310 | 2,000 | | 12-29-83 |
| AMOCO Prod Co.** | 370 | Pierce | WC-83-27 | 1,704 FNL and 663 FWL sec. 28 (19-6E) | 900 | 2,000 | 2-18-84 | 2-2-84 |

* Land description indicates that the location is 965 ft from the west line and 1,869 ft from the north line of sec. 9, township 15 north, range 25 east, Willamette meridian.

** Plugged and abandoned.

## RECENT PERMITS FOR OIL AND GAS DRILLING

| Operator | Permit no. | County | Well name | Location | Ground elevation (feet) | Estimated total depth (feet) | Spud date | Date permit issued |
|---|---|---|---|---|---|---|---|---|
| | | | | **Oil and Gas Stratigraphic Tests - Continued** | | | | |
| AMOCO Prod. Co. | 371 | King | WC-83-31 | 114 FSL and 1,194 FEL sec. 15 (25-8E) | 1,125 | 2,000 | | 2-2-84 |
| AMOCO Prod. Co. | 372 | King | WC-83-32 | 739 FNL and 2,032 FEL sec. 26 (26-7E) | 620 | 2,000 | | 2-2-84 |
| AMOCO Prod. Co. | 373 | Pierce | WC-83-26 | 40 FSL and 609 FEL sec. 17 (16-4E) | 725 | 2,000 | | 2-2-84 |
| AMOCO Prod. Co. | 374 | King | WC-83-17 | 847 FSL and 1,460 FWL sec. 13 (22-6E) | 645 | 2,000 | | 2-2-84 |
| AMOCO Prod. Co. | 375 | King | WC-83-16 | 2,254 FNL and 562 FEL sec. 4 (20-7E) | 1,246 | 2,000 | | 2-2-84 |
| AMOCO Prod. Co. | 377 | King | WC-83-20 | 696 FSL and 123 FWL sec. 1 (24-6E) | 435 | 2,000 | | 2-22-84 |
| AMOCO Prod. Co. | 378 | King | WC-83-21 | 216 FSL and 1,131 FEL sec. 33 (21-6E) | 675 | 2,000 | | 2-15-84 |
| AMOCO Prod. Co. | 379 | Pierce | WC-83-23 | 1,073 FSL and 1,130 FEL sec. 24 (19-5E) | 820 | 2,000 | | 2-15-84 |
| AMOCO Prod. Co. | 380 | Lewis | WC-83-24 | 2,244 FSL and 2,356 FWL sec. 1 (14-4E) | 1,635 | 2,000 | | 2-15-84 |
| AMOCO Prod. Co. | 381 | Lewis | WC-83-25 | 1,023 FNL and 752 FEL sec. 29 (13-4E) | 1,540 | 2,000 | | 2-15-84 |
| AMOCO Prod. Co. | 382 | Pierce | WC-83-28 | 2,335 FNL and 661 FEL sec. 19 (19-6E) | 520 | 2,000 | | 2-15-84 |
| AMOCO Prod. Co. | 383 | Pierce | WC-83-29 | 1,144 FNL and 1,183 FEL sec. 32 (18-6E) | 1,695 | 2,000 | 3-11-84 | 2-15-84 |
| AMOCO Prod. Co. | 384 | Lewis | WC-83-33 | 1,107 FNL and 1,243 FEL sec. 33 (13-4E) | 1,355 | 2,000 | | 2-15-84 |
| AMOCO Prod. Co. | 385 | Pierce | WC-83-34 | 700 FNL and 2,346 FEL sec. 25 (16-3E) | 725 | 2,000 | | 2-15-84 |

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