WASHINGTON GEOLOGIC NEWSLETTER

Volume 18 Number 3 August 1990

Washington State Department of Natural Resources Division of Geology and Earth Resources

Sediment retention structure on North Fork Toutle River (see article starting on page 2)

IN THIS ISSUE

Liquefaction Analysis, Puyallup 3
Agricultural Chemicals and Ground Water 8
NEHRP Workshop Summary 12
Mount St. Helens Symposium Summary..... 19

WASHINGTON GEOLOGIC NEWSLETTER

The Washington Geologic Newsletter is published quarterly 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, reports of investigations, geologic maps, and open-file reports. A list of these publications will be sent upon request.

DEPARTMENT OF NATURAL RESOURCES	Brian J. Boyle *Commissioner of Public Lands* Art Stearns *Supervisor*
DIVISION OF GEOLOGY AND EARTH RESOURCES	Raymond Lasmanis *State Geologist* J. Eric Schuster *Assistant State Geologist*
Geologists (Olympia)	Matthew J. Brunengo, Robert E. Derkey, William S. Lingley, Jr., Robert L. (Josh) Logan, Stephen P. Palmer, William M. Phillips, Patrick T. Pringle, Weldon W. Rau, Katherine M. Reed, Henry W. Schasse, Timothy J. Walsh
(Spokane)	Nancy L. Joseph, Stephanie Z. Waggoner, Keith L. Stoffel
Librarian	Connie J. Manson
Library Technician	Gwen F. Crain
Research Technician	
Editor	Katherine M. Reed
Cartographers	Nancy A. Eberle, Carl F.T. Harris, Keith G. Ikerd
Editorial Assistant	Jack Sareault
Administrative Assistant	Jo Roller
Clerical Staff	Naomi Hall, Mary Ann Shawver, J. Renee Snider
Regulatory Clerical Staff	Barbara A. Preston

Mount St. Helens Sediment Retention Structure

by Raymond Lasmanis

As erosion has proceeded around the base of Mount St. Helens, some of the terrain is acquiring the appearance of badlands. And as streams continue to cut through the pumice, blast, and lahar deposits of the May 18, 1980, eruption, they transport huge amounts of sediment down the Toutle River into the Cowlitz River and eventually to the Columbia River. In 1984 the U.S. Army Corps of Engineers estimated that by 2030, if no controlling measures were taken, the Cowlitz-Toutle river system would deposit 319 million yd^3 of sediment (sand) in the Columbia. At that time, choked river channels were posing the threat of flooding at the communities of Castle Rock and Longview, and the Columbia River shipping channel required continuous dredging.

In order to reduce the sediment load and its consequences, the Corps selected a single sediment retention structure (SRS) in 1984 as the preferred option. Its location, on the North Fork Toutle River above its confluence with the Green River, was chosen to provide a large area for this settling sediment upstream of towns and shipping facilities. Construction of the SRS began in December 1986, and by November 1987, sediment was already being trapped behind the partially completed earthworks dam. The SRS was completed in December 1989. On May 19, 1990, it was dedicated. (See cover photo.)

Specifications for the SRS are:

Dam Structure:
- Dam crest height – 184 ft (el. 999 ft)
- Dam crest length – 1,800 ft
- Dam crest width – 70 ft
- Spillway crest height – 125 (el. 940 ft)
- Spillway crest width – 400 ft

Outlet works:
- Conduits – 30 3-ft diam. (6 rows, 5 per row)

Storage volume and retention area:
- Maximum area – 3,200 acres
- Maximum volume – 285 million yd^3 (est.)

(Continued on page 21)

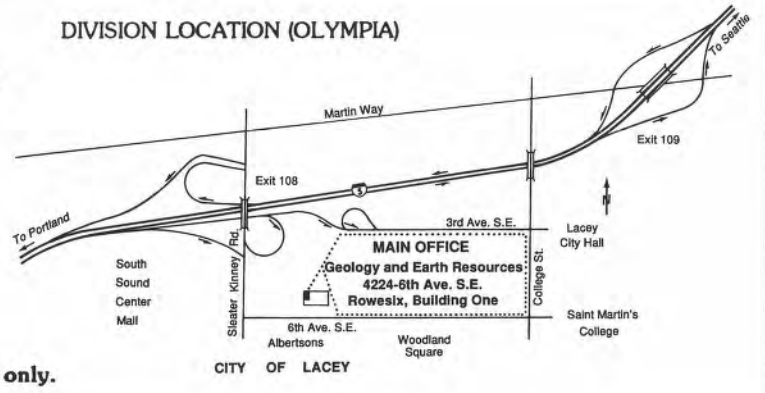
MAILING ADDRESSES

Main Office
Department of Natural Resources
Division of Geology and Earth Resources
Mail Stop PY-12
Olympia, WA 98504
Phone: (206) 459-6372
FAX: (206) 459-6380

Field Office
Department of Natural Resources
Division of Geology and Earth Resources
Spokane County Agricultural Center
N. 222 Havana
Spokane, WA 99202
Phone: (509) 456-3255

NOTE: Publications available from Olympia address only.

DIVISION LOCATION (OLYMPIA)



Geotechnical Analysis of Liquefaction in Puyallup During the 1949 and 1965 Puget Sound Earthquakes

by Stephen P. Palmer

Liquefaction is a process in which a water-saturated granular (sandy) soil layer loses strength because of vibratory shaking most commonly caused by an earthquake. A liquefied layer and its overlying soil mass are subject to large lateral displacements, which can result in the disturbance of building and road foundations, failure of earth-filled dams, and disruption of underground utilities. Liquefaction of a near-surface soil layer is often expressed by the eruption of a sand-water slurry, termed a sand blow, which forms a conical deposit on the ground around the vent. Lateral spreading occurs when blocks of the soil mass overlying a liquefied stratum slide down shallow slopes (0.5° - 3°) toward a free face, such as a river channel or manmade cut. Fracturing and differential settlement of the moving blocks can severely damage structures or pipelines situated in this material. Sand blows and lateral spreading caused by the 1949 magnitude 7.1 and 1965 magnitude 6.5 earthquakes (Fig. 1) were widely reported in the Puget Sound region.

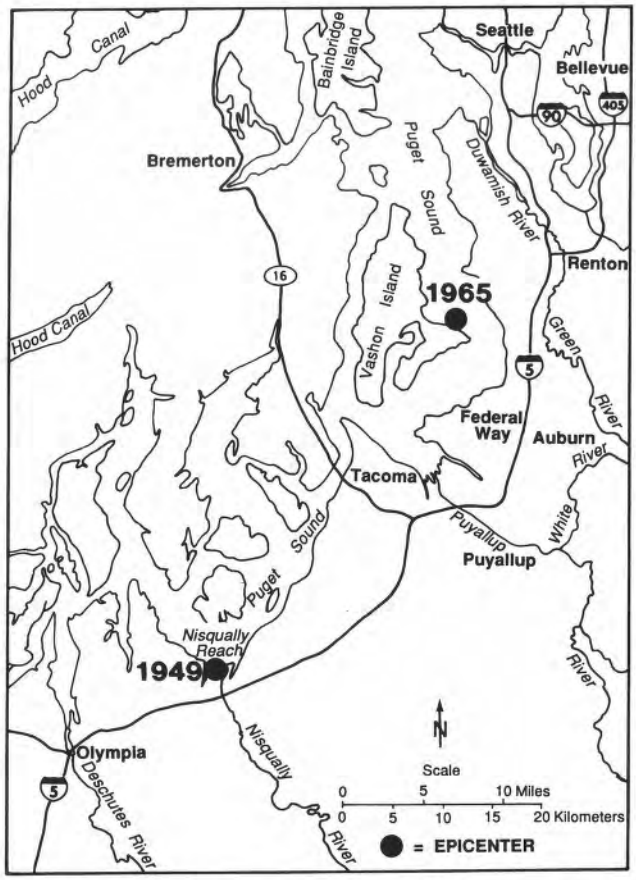


Figure 1. Epicenters of the 1949 magnitude 7.1 and 1965 magnitude 6.5 Puget Sound earthquakes. The hypocentral distance from both of these earthquakes to the city of Puyallup is 65 ± 2 km.

The precise locations of liquefaction phenomena that occurred in the city of Puyallup are now available through the efforts of John Shulene (Shulene, 1990). These locations, shown in Figure 2, provide important data for the evaluation of liquefaction hazards in the Puget Sound area. Geotechnical boring data in the area of Richard Six's photographs (Shulene, 1990) were obtained from Ben Peterson of the City of Puyallup Engineering Division. Three potentially liquefiable soil units, described in Figure 3, were identified in these borings using sample descriptions, sieve analyses, and Standard Penetration Test (SPT) data. Two of these units are described as loose, black, fine to coarse clean sands; this is consistent with the description of the material that erupted as sand blows at the Puyallup sites during the 1949 earthquake (Edwards, 1951; John Shulene, U.S. Geological Survey volunteer and retired Puyallup earth science teacher, oral commun., 1990).

Liquefaction typically occurs in loosely packed, sandy soils that lie below the ground-water table (and consequently are saturated). The geotechnical properties most important in determining a soil's liquefaction capability are the relative density and the amount of the silt-sized fraction. Relative density is a measure of consolidation in a soil. Soils that have a high relative density are tightly packed and have little liquefaction potential. Soils of low relative density are loose and have a high potential for liquefaction during an earthquake. The SPT is the most commonly used method of measuring *in situ* soil density during drilling of a geotechnical boring. In the SPT, a standardized core barrel (a 2-in. outer diameter split-spoon sampler) is driven into the soil mass by a 140-lb hammer falling 30 in. The sampler is driven 6 in. to be properly seated, and then driven another 12 in. The number of hammer blows to drive the sampler this final 12 in. is counted, and this number is termed the SPT blow count. SPT blow counts in the range of 1 to 4 indicate a very loose soil of low relative density; blow counts over 30 indicate a very dense soil which has little susceptibility to liquefaction.

Sandy soils in which the grain size is quite uniform (poorly graded) will liquefy more easily than well-graded sandy soils of equal relative density. The grading of a soil is measured by passing a soil sample through sieves of various mesh sizes. A cumulative percentage by weight of grains passing through each of the sieves is graphed as shown in Figure 4 (p. 6). Typically, sandy soils containing more than 40 percent silt fraction (passing a 200 mesh, or grains smaller than approximately 0.075 mm) are considered to have little potential for

liquefaction. The liquefaction potential is further decreased if the silt fraction contains a significant amount of clay minerals.

Liquefaction during an earthquake is dependent on the magnitude of the ground acceleration, the duration of strong shaking, and the depth to the ground-water table, as well as the relative density and size grading of the soil. Ground acceleration and duration of strong shaking generally increase with increasing earthquake magnitude and decreasing hypocentral distance. By happenstance, Puyallup was at the same hypocentral distance (65 km ± 2 km) for both the 1949 and 1965 earthquakes (Fig. 1). Thus, the difference in acceleration and duration of shaking in Puyallup during these two earthquakes depended, to a first approximation, only on the difference in magnitude of these two events.

The depth to the ground-water table is an important factor in assessing liquefaction potential, as liquefiable soils must be saturated. The elevation of the unconfined ground-water table in the Puyallup valley is governed by seasonal recharge and discharge (Walters and Kimmel, 1968). During April, the month in which both the 1949 and 1965 earthquakes occurred, the ground-water levels are primarily determined by the amount of rainfall during the previous wet season. Precipitation records from the Puyallup Experimental Station indicate that the rainy seasons preceding these earthquakes were similar, and that precipitation was somewhat above normal. Thus, the elevation of the unconfined ground-water table during these two earthquakes probably was quite similar.

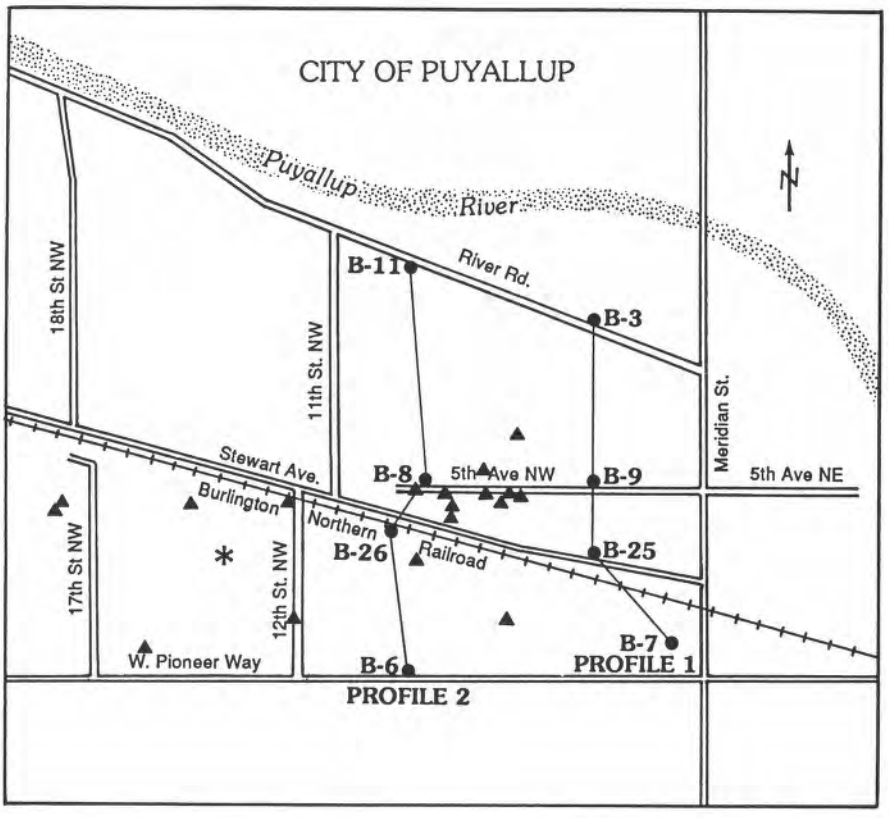


Figure 2. Locations of reported liquefaction phenomena in Puyallup during the 1949 (triangles) and 1965 (asterisk) earthquakes. Most of these reports described sand blows and "gushers" (Shulene, 1990) during the earthquakes. Note that there was only one reported instance of liquefaction during the 1965 event. The geotechnical borings (designated as B-xx) and alignment of profiles 1 and 2 are also shown.

I postulate that the difference in the magnitudes of the 1949 and 1965 earthquakes appears to be the most important parameter controlling the extent of soil liquefaction in Puyallup. Liquefaction-related phenomena were commonly reported only during the 1949 earthquake. This suggests that the smaller magnitude 1965 earthquake did not produce the ground acceleration and duration of strong shaking necessary to cause significant liquefaction in Puyallup.

To verify this interpretation, the critical acceleration required to cause liquefaction for a magnitude 7.1 earthquake was calculated using the method of Seed and others (1983). This is an empirically based method that uses SPT blow count data to determine the critical stress at which a soil will liquefy. This critical stress is compared to the stress imparted by the acceleration of the soil mass during an earthquake. If these stresses are equal, the factor of safety is unity (equals 1) and the soil is just "on the edge" of liquefying. Calculation of the critical acceleration was based on the SPT and soils data obtained from the borings shown in figures 5a and 5b (p. 6-7). In order to account for seasonal discharge, ground-water elevations in these borings were assumed to have been 5 ft higher during the April earthquakes than during September 1978 when they were measured.

Analysis of profile 1 (Fig. 5a) indicates that the critical accelerations range from 0.10 g to 0.20 g for soil units 4 and 6, and that no other soil units could liquefy. A recently developed relation, specific to the Puget Sound, between earthquake magnitude, hypocentral distance, and focal depth predicts a mean peak ground acceleration (PGA) of 0.17 g at Puyallup during the 1949 event (C. B. Crouse, Dames and Moore, oral commun., 1990). Using this 0.17 g as the PGA in Puyallup, significant near-surface liquefaction would occur only in boring B-9, which has more than 15 ft of soil that is liquefiable at accelerations of 0.16 g or less (Fig. 5a). Boring B-9 is located just east of the densest occurrence of liquefaction phenomena reported during the 1949 event (Fig. 2).

Soil unit	Description	γ (pcf)	γsat (pcf)	% fines	Liquefiable
1	Fill, consisting of dense brown, silty, sandy gravels with scattered cobbles and asphalt blocks	130	140	>35	NO
2	Loose, brown to gray, silty, fine to medium sand with scattered gravel and organic material	90	105	35	YES
3	Very soft to medium stiff, gray-brown, clayey or, in places, sandy silt with organics	100	110	65	NO
4	Very loose to medium dense, black, clean, fine to medium sand with some lenses of silty fine sand and sandy silt	100	120	5	YES
5	Medium dense, gray, silty fine sand and sandy clayey silt with scattered organic material	110	130	>35	NO
6	Loose to medium dense, black, fine to coarse sand with scattered gravel	110	130	5	YES

Figure 3. Descriptions and material properties for the six soil units encountered in the geotechnical borings used in this study. γ is the *in situ* unit weight (bulk density) of the soil unit measured in pounds per cubic foot (pcf); γsat is the saturated unit weight of the soil unit.

In the borings shown in profile 2 (Fig. 5b), only soil unit 2 has a significant thickness of potentially liquefiable material. Most soil units along this profile are silts and clays and are consequently not liquefiable. Oddly, this profile is near the reported area of most intense liquefaction during the 1949 earthquake. Trenching during underground utility installation has shown that the continuity of these soil units is quite varied over short distances (typically 50 ft). Interfingering of these silty/clayey soils with the liquefiable black sands (Fig. 5a) may explain the pattern of liquefaction reports. Alternatively, the sand blows reported in the area adjacent to profile 2 may have resulted from liquefaction of soil unit 2.

The estimated mean PGA at Puyallup during the 1965 earthquake is 0.11 g, only 65 percent of the mean PGA for the 1949 event (C. B. Crouse, oral commun., 1990). The 1965 earthquake is estimated to have had only 75 percent of the number of cycles of strong ground shaking in comparison to the 1949 event (Seed and Idriss, 1982). Using a PGA of 0.11 g and a magnitude of 6.5, virtually no liquefaction would be expected in the soils shown in profiles 1 and 2, and indeed there was only one report of sand blows during the 1965 event. Thus, difference in earthquake magnitude appears to have been the controlling factor in the liquefaction response of soils in Puyallup during the 1949 and 1965 Puget Sound earthquakes.

A significant result of this study is that application of the method of Seed and others (1983) to liquefaction assessment of shallow, flat-lying soils in the Puget Sound area seems a valid approach. Further, plausible PGA values can be estimated at identified liquefaction sites for the 1949 and 1965 Puget Sound earthquakes through back calculation using the methodology of Seed and others (1983). Geotechnical analysis of other identified sites of liquefaction that occurred during these earthquakes is planned. An ongoing sedimentological study of these liquefiable black sand units shows that they are primarily composed of fragments of Mount Rainier andesite, and may have been deposited as a hyperconcentrated flow (P. T. Pringle, DGER, oral commun., 1990).

References Cited

Edwards, H. H., 1951, Lessons in structural safety learned from the 1949 Northwest earthquakes; 1st installment. *Reprinted in* Thorsen, G. W., compiler, 1986, The Puget Lowland earthquakes of 1949 and 1965—Reproductions of selected articles describing damage: Washington Division of Geology and Earth Resources Information Circular 81, p. 3-7.

Seed, H. B.; Idriss, I. M., 1982, Ground motion and soil liquefaction during earthquakes: Earthquake Engineering Research Institute, 134 p.

Seed, H. B.; Idriss, I. M.; Arango, I., 1983, Evaluation of liquefaction potential using field performance data: Journal of Geotechnical Engineering, ASCE, v. 109, no. 3, p. 458-482.

Shulene, J. A., 1990, Evidence of liquefaction in the Puyallup valley: Washington Geologic Newsletter, v. 18. no. 2, p. 15-16.

Walters, K. L.; Kimmel, G. E., 1968, Ground-water occurrence and stratigraphy of unconsolidated deposits, central Pierce County, Washington: Washington Department of Water Resources Water Supply Bulletin 22, 428 p., 3 plates.

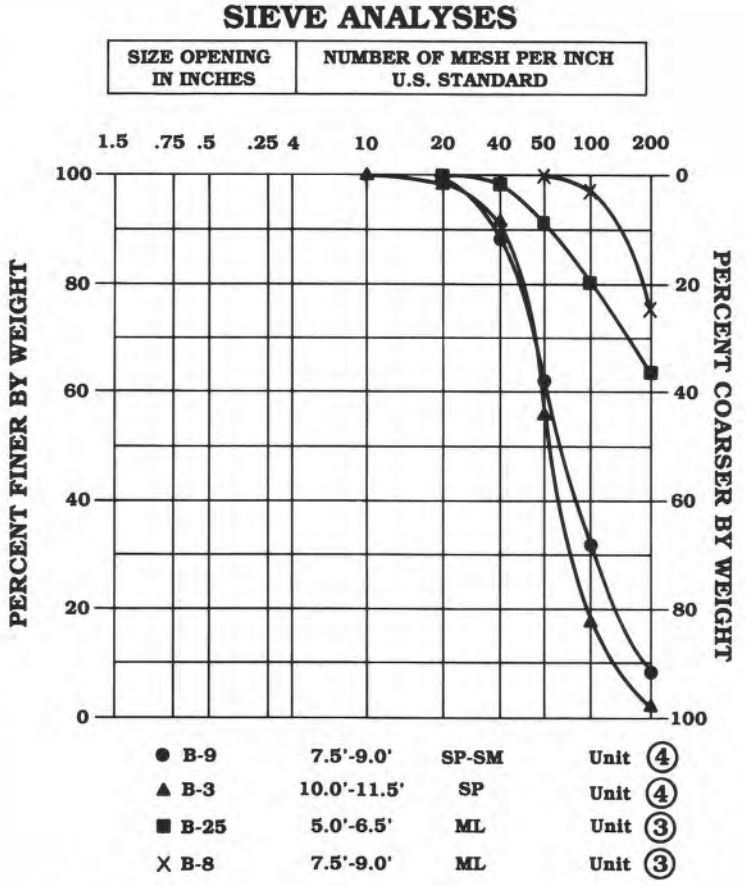
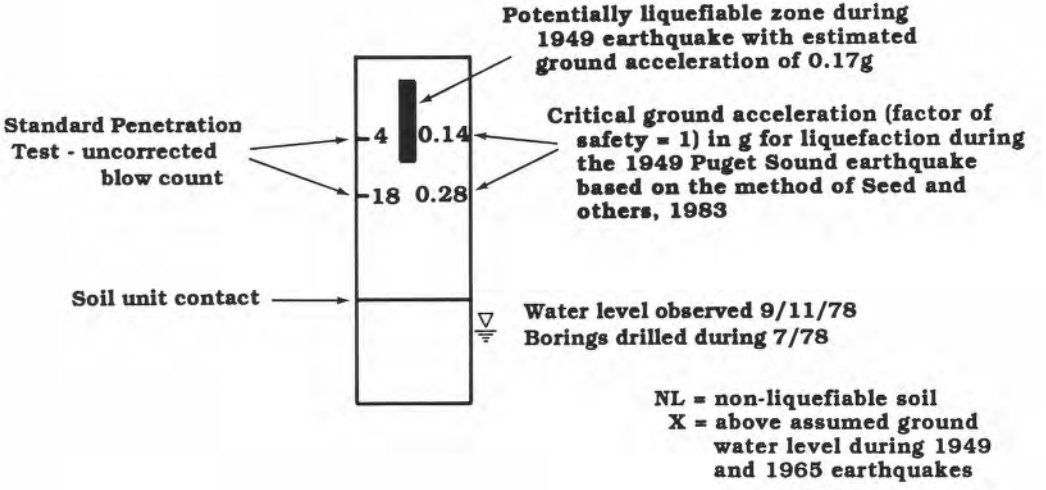


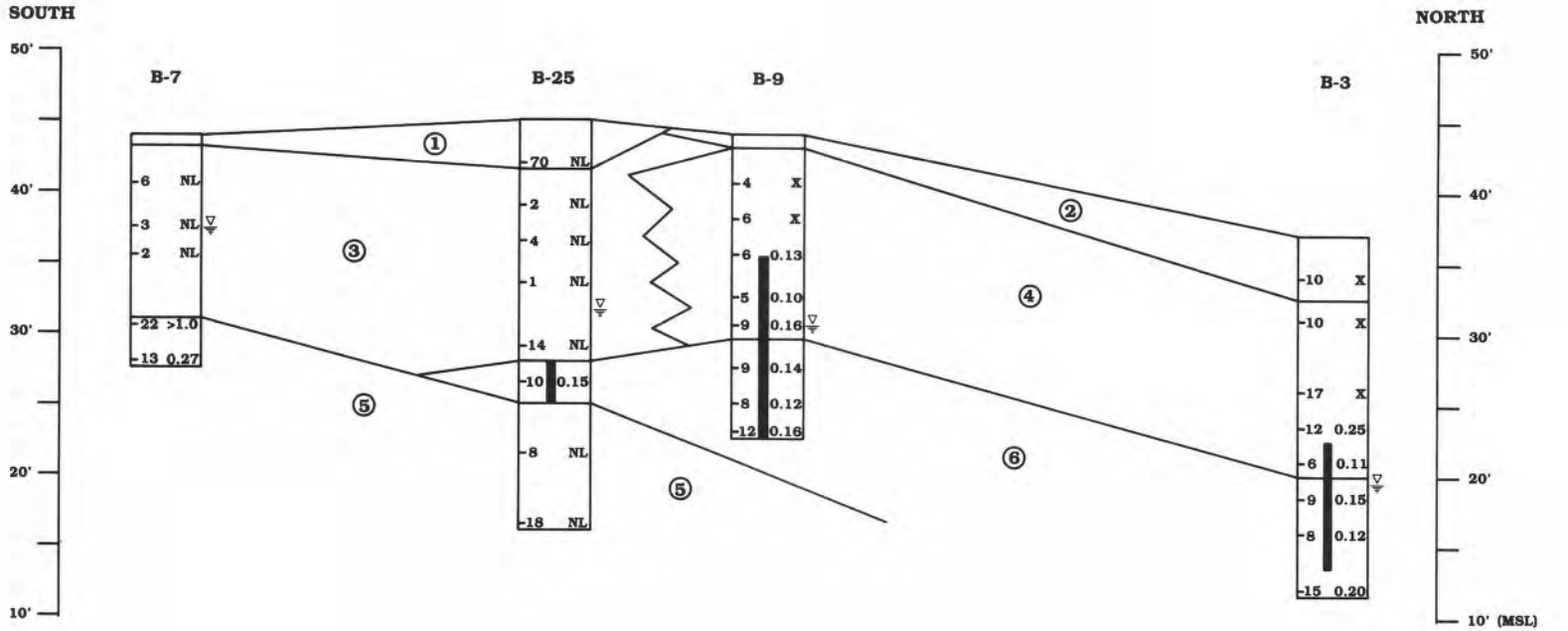
Figure 4. Sieve analysis of four samples from the borings shown in Figure 2. The two samples from soil unit 3 contain more than 60 percent silt fraction and are unlikely to liquefy during an earthquake. The two samples from soil unit 4 are poorly graded and contain less than 10 percent silt fraction. This unit has a high liquefaction potential where SPT blow count data indicate a low relative density.

The second column from left shows the depth interval of the soil sample; third column is the soil classification, using the Unified Soil Classification System. In this system, soil types beginning with the letter S are sands (less than 50 percent silt fraction); those beginning with the letter M are silts (greater than 50 percent silt fraction).

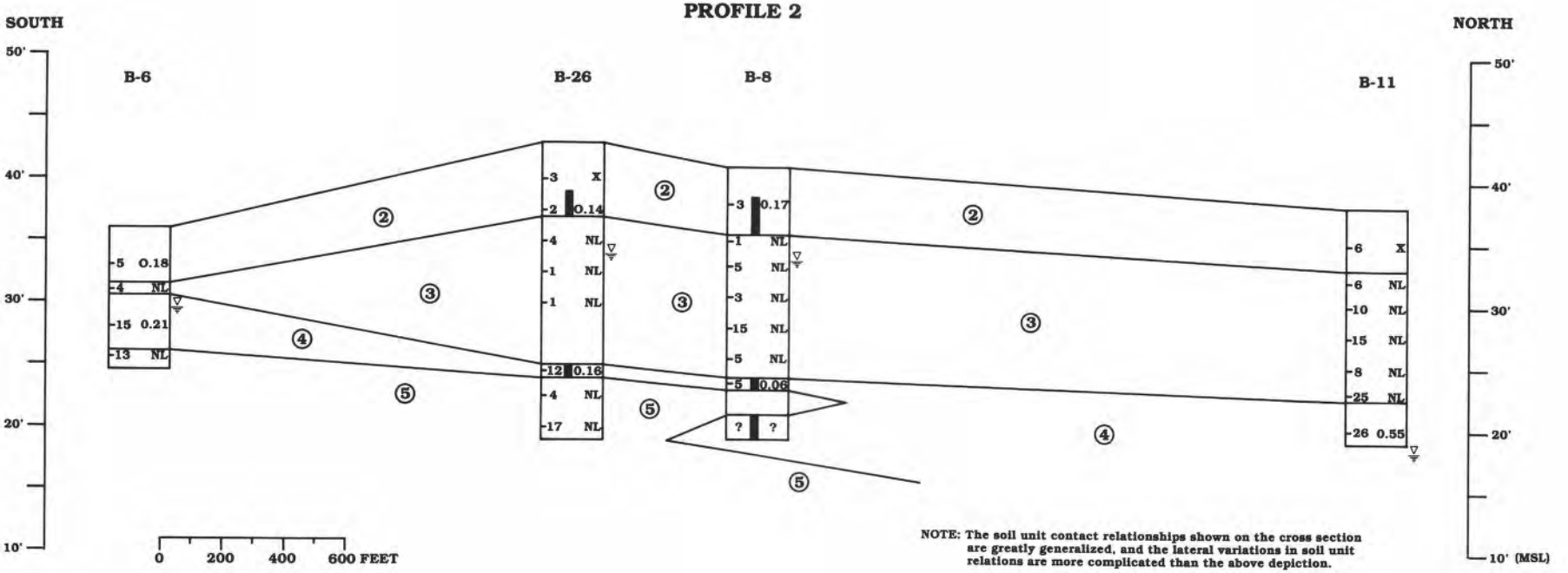
Figure 5. (a) **Profile 1** below (location shown in Fig. 2) shows a thick section of liquefiable black sand (units 4 and 6) that is the likely source of the sand blows observed in this area of Puyallup. Note that this profile is slightly east of the most intense area of liquefaction reported during the 1949 earthquake. (b) Most soil units along **profile 2** below are silts and clays, and are consequently not liquefiable, although this profile is in the area of most intense reported liquefaction. Trenching performed during underground utility installation has shown that the continuity of these soil units is varied over short distances. An explanation of boring log data is presented below.



PROFILE 1



PROFILE 2



NOTE: The soil unit contact relationships shown on the cross section are greatly generalized, and the lateral variations in soil unit relations are more complicated than the above depiction.

Agricultural Chemicals Pilot Study Interim Report

by Denis Erickson
Washington State Department of Ecology
Environmental Investigations and Laboratory Services
Toxics Investigation/Ground Water Monitoring Section
Olympia, Washington 98504-6811

The use of agricultural chemicals in Washington is widespread. As of 1986, 17 pesticides had been found in the ground water of 23 states, including Washington, as the result of agricultural uses (Cohen and others, 1986). However, the effects of these chemicals on the state's ground-water quality are largely unknown. In 1987 the State Legislature funded the Department of Ecology (hereafter Ecology) to begin investigating these effects in the state. The Agricultural Chemicals Pilot Study is an initial step toward defining the effects.

The primary objective of the pilot study is to provide reconnaissance-level information on the presence and concentration of pesticide residues in ground water of selected areas of Washington. Secondary objectives are (1) to evaluate the effectiveness of potential indicator parameters (nitrate/nitrite; total phosphorous, organic carbon, and organic halogens; potassium; and dissolved solids) in identifying wells to be tested for pesticides, and (2) to correlate, where possible, site conditions and pesticide usage with any observed ground-water contamination.

Ecology released a preliminary report of the results of the first sampling round for pesticides and nitrate/nitrite in August 1989. This article is a summary of the findings.

Study Area Selection Process

On a statewide basis, general locations for potential study areas were identified using U.S. Environmental Protection Agency (EPA) Designation of Areas Vulnerable to Pesticide Contamination (EPA, 1986). Refinement of study area locations was based on review of statewide, regional, and local geologic and hydrogeologic reports, county soil reports, well log reports, as well as information from local health departments, regional Ecology offices, and the Washington State University Cooperative Extension Service. The three study areas selected are located in Whatcom, Franklin, and Yakima Counties (Fig. 1).

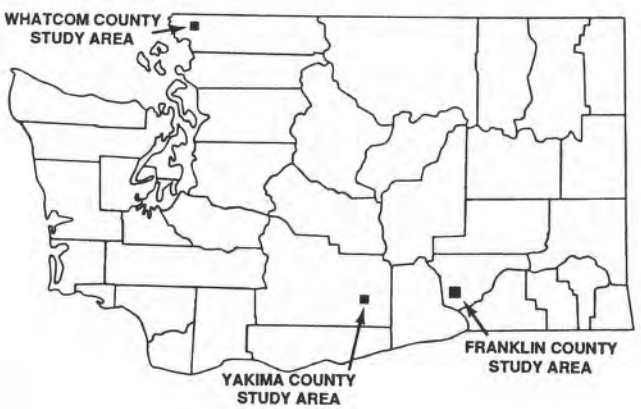


Figure 1. Location of the pilot study areas.

The study areas are characterized by having (1) irrigated agriculture, (2) a variety of crops, (3) ground water at less than 50 ft, (4) an unconfined aquifer with porous media flow, (5) permeable, well-drained soils, and (6) an adequate number of shallow wells for sampling. Two areas had known occurrences of ground-water contamination from agricultural chemicals.

Twenty-seven wells were selected for sampling in each study area. The selected wells are distributed so that data fairly represented shallow ground-water quality for the study area. Each is near some type of agriculture practice, and well construction information and stratigraphic logs are available. The preferred wells are shallow and of fairly new construction and small diameter. Further, wells are not included in the study if potential point sources such as pesticide mixing areas were identified nearby.

Sampling and Analysis

The initial round of sampling took place between August and October 1988. Eighty-one wells were sampled, of which 67 were domestic wells, two were public water supply wells, seven were irrigation wells, and five were piezometers originally constructed for water-level measurements. Samples were obtained from private and public wells using existing installed pumps and piping. Samples from the piezometers were obtained using decontaminated Teflon® bailers.

Forty-six pesticides were targeted for analysis; 33 of these were derived from EPA's list of leachable pesticides, which have properties conducive to migration through soil to ground water (Cohen, 1985). Eight pesticides are on the target list because laboratory test methods can identify them with little additional effort or cost.

Pesticide analyses were conducted by Montgomery Laboratories Inc, of Pasadena, Calif. Quality assurance (QA) procedures included analysis of field replicates, transport blanks, transfer blanks, standard samples, and laboratory duplicates and spikes. Standard samples, consisting of known concentrations of selected pesticides, were prepared by Oregon State University. For pesticide analyses, the level of effort (the ratio of QA samples to total samples) for replication, precision, and accuracy

was about 30 percent. An independent quality assurance review of all pesticide data was conducted by Ecology and Environment, Inc. of Seattle, Wash. All data presented in this report are considered acceptable for use.

In addition to pesticides, other parameters were also studied. The results, which will be presented in the final report, will be used to define the general ground-water quality of the study areas or will be evaluated as potential indicators of pesticide contamination.

Six wells in each study area were tested for major cations/anions and trace metals. Metals (except for mercury) were analyzed by Columbia Analytical Services, Inc., of Longview, Wash. Nitrate/nitrite and total phosphorous analyses were made by Aquatic Research Incorporated of Seattle. All other laboratory tests were conducted at the Ecology/EPA Region X Laboratory in Manchester, Wash.

Data Limitations

The pilot study water-quality results have some limitations:

- The relative vulnerability of the ground water of Washington has not been defined in a comprehensive or consistent manner. It is not known to what extent the study areas are representative of ground-water vulnerability for other areas of the state.
- Information about pesticide use for each of the study areas was limited or unavailable, preventing optimal selection of sampling wells.
- Water-supply well intakes are commonly installed in the most productive portions of aquifers. This may not be the portion of the aquifer most susceptible to contamination. Further, pumps used for water supply can be responsible for altering water-quality (for instance, stripping volatile organics or increasing concentrations of some metals).
- Samples probably represent water quality only near the well intake.
- Sampled wells were not selected on the basis of specific agricultural practices.
- Ground-water quality is likely to change seasonally and over the long term.

Study Area Characteristics

Whatcom County Study Area

The Whatcom County study area (Fig. 1) covers 6.5 mi^2. It is underlain by an unconfined, sandy outwash aquifer having an average thickness of about 35 ft (Easterbrook 1971, 1976; Creahan and Kelsey, 1988). Surficial soils are generally sandy and permeable (Poulson and Flannery, 1953), providing moderate to low attenuation for potential organic contaminants. The water table is normally at a depth of less than 10 ft. Regionally, ground water flows south toward the Nooksack River. However, the ground-water flow pattern is locally affected by surface water and by pumping and irrigation practices. The main drainages and ground water are hydraulically interconnected. About 200 water supply wells are completed in the shallow outwash aquifer, and most serve either to supply water for domestic uses or for irrigation (Black and Veatch, 1986; Creahan and Kelsey, 1988).

The study area boundaries coincide with those of an "Area B" previously defined on the basis of detection of ethylene dibromide (EDB) contamination in ground water (Washington Department of Social and Health Services, 1985: Black and Veatch, 1986).

Franklin County Study Area

The Franklin County study area is in the southern part of the county (Fig. 1) and occupies an area of about 34 mi^2. In this area 200 to 400 feet of unconsolidated and semi-consolidated gravel, sand, silt, and clay deposits overlie basalt flows (Walters and Grolier, 1960; Drost and Whiteman, 1986). Surficial soils consist of permeable sand that provides only moderate to low attenuation of potential organic contaminants. Depth to ground water ranges from about 7 to 100 ft and is usually less than 50 ft. Hydraulic properties of the shallow aquifer are highly varied due to variations in grain size, texture, and packing of the aquifer materials. Regional ground-water flow in the sediments is to the southeast and south toward the Columbia River (Bauer and others, 1985). Flow patterns vary seasonally due to pumping and irrigation. Since the 1950s, the water table has risen locally tens of feet because of irrigation.

Virtually all the approximately 100 identified wells are for either domestic supplies or irrigation. Five wells provide public water supplies. About 30 of the private wells are completed in the shallow, unconfined water-bearing parts of the sedimentary units. Eleven of these shallow wells are observation wells installed by the Bureau of Reclamation in the 1950s to monitor water table responses to irrigation.

Elevated nitrate concentrations have been reported in and near the study area (Turney, 1986; Washington Department of Social and Health Services, 1988; J. Ebbert, U.S. Geological Survey, written commun., 1988). The U.S. Geological Survey (USGS) is conducting a ground-water quality assessment of affected portions of Benton and Franklin Counties; the Ecology Franklin County study area is in the north-central part of the USGS study area. Recent sampling by the USGS has identified low concentrations of aldicarb sulfone, atrazine, dicamba, picloram, and 2,4,5-T (J. Ebbert, USGS, written commun., 1989).

Yakima County Study Area

The Yakima County study area is in the southeastern part of the county and occupies an area of about 10 mi^2. Here, about 200 feet of unconsolidated gravel, sand, silt, and clay overlie basalt (Campbell, 1979; Drost and Whiteman, 1986). Surficial soils are generally sandy and permeable (Lenfesty and Reedy, 1985) and provide moderate to low attenuation of organic contaminants. The upper saturated parts of these sediments are the target aquifer for the pilot study. Depth to ground water ranges from about 6 to 30 ft. Hydraulic properties of the target aquifer vary widely because of the heterogeneity of the sediments. Regional ground-water flow in the sedimentary deposits is south and southeast toward the Yakima River (Bauer and others, 1985; Kinnison

Table 1. Summary of pesticides detected in the Agricultural Chemicals Pilot Study

Study area	Number of detections	Detection frequency (percentage)	Concentration mean (µg/L)	Concentration range (µg/L)
Whatcom County:				
1,2-Dichloropropane	9	33.0	6.9	0.3-24
Dibromochloropropane	1	3.7	0.36	---
Ethylene Dibromide	2	7.4	1.5	0.02-2.95
Carbofuran	1	3.7	2.4	---
Prometon	2	7.4	0.55	0.5-0.6
Franklin County:				
Dacthal (DCPA and metabolites)	7	26.0	0.7	0.26-1.08
1,2-Dichloropropane	2	7.4	0.6	0.4-0.8
Bromacil	1	3.7	11	---
Yakima County:				
Atrazine	1	3.7	0.4	---

Table 2. Classification, use, and status of detected pesticides

Pesticide Name	Classification	Use	Status
1,2-Dichloropropane	Halogenated hydrocarbon	Fumigant	Cancelled*
Atrazine	Triazine	Herbicide	Restricted**
Bromacil	Uracil	Herbicide	Restricted**
Carbofuran	Carbamate	Insecticide	Restricted**
Dacthal (DCPA and metabolites)	Benzoic acid	Herbicide	
Dibromochloropropane	Halogenated hydrocarbon	Fumigant	Cancelled*
Ethylene dibromide	Halogenated hydrocarbon	Fumigant	Cancelled*
Prometon	Triazine	Herbicide	Restricted**

* Use of these pesticides has been cancelled in the United States.

** Can be applied only by certified applicators or by persons under their supervision.

and Sceva, 1963). Flow patterns vary seasonally due to pumping and irrigation.

About 50 of the 80 identified wells in the area are completed in the target aquifer. Most of the wells supply water for domestic use or irrigation.

Turney (1986) reported nitrate (as N) concentrations in the lower Yakima River basin ground water ranged from 1 to 5 mg/L, but no previous occurrences of pesticides in ground water have been reported.

Results of the Preliminary Study

Pesticides

Eighty-one wells were sampled during initial sampling. In 23 of these 81 wells (27%), at least one pesticide was detected. Eight pesticides were identified. Pesticide results are summarized in Table 1. The classification, uses, and regulatory status of the eight pesticides are listed in Table 2.

In the Whatcom County study area,15 pesticide occurrences were observed in 12 wells. 1,2-dichloropropane, detected in eight wells, was the primary pesticide found in samples from that study area; concentrations ranged from 0.3 to 24 µg/L, and the mean was 6.9 µg/L. Ten occurrences of pesticides were observed in the Franklin County study area in ten wells. Dacthal (DCPA and metabolites), the primary pesticide detected in that study area, was detected in seven wells. The concentrations ranged from 0.26 to 1.08 µg/L, and the mean was 0.7 µg/L. In contrast, only one pesticide occurrence was observed in the Yakima study area. Atrazine was the only pesticide observed there; its concentration was 0.4 µg/L. No pesticides were detected in the two public wells sampled.

Maximum Contaminant Levels (MCLs) have not yet been established by EPA for any pesticides found during this study. However, health advisories and/or proposed MCLs have been calculated by EPA. These are listed in Table 3. MCLs are enforceable public drinking water standards. They are the maximum permissible concentration of a contaminant in water which is delivered to any user of a public water system. MCLs are established by considering health effects, treatment technology, national costs, and limitations of laboratory methods.

None of the observed concentrations exceeded those that would cause non-carcinogenic adverse health effects. However, concentrations exceeded the proposed MCL in five wells for 1,2-dichloropropane, in one well for dibromochloropropane, and in one well for ethylene

Table 3. EPA Proposed Drinking Water Standards and Health Advisories for pesticides detected in the pilot study. The number of occurrences exceeding the listed concentration is in parentheses. MCL, Maximum Contaminant Level (From EPA, 1989a, 1989b)

Pesticide	Proposed MCL (µg/L)	Lifetime Health Advisory (µg/L)	10-6 Cancer Risk* (µg/L)
Atrazine	3	3	---
Bromacil	---	90	---
Carbofuran	40	40	---
Dacthal (DCPA)	---	3500	---
Dibromochloropropane	0.2(1)	---	0.03(1)
1,2-Dichloropropane	5(5)	---	0.6(6)
Ethylene dibromide	0.05(1)	---	0.0004(2)
Prometon	---	100	---

* EPA estimates that if an individual drinks water containing this pesticide at the indicated concentration over his or her entire lifetime, that individual would theoretically have no more than a one-in-a-million additional chance of developing cancer as a result of drinking this water.

Table 4. Summary of nitrate/nitrite (as N) results for the Agricultural Chemicals Pilot Study

Study area (county)	Number of detections	Detection frequency (percentage)	Concentration Mean (Range) (mg/L)	Number of wells with >10 mg/L
Whatcom	26	96	7.0 (0.28-24.4)	7
Franklin	27	100	8.6 (0.5-18.8)	11
Yakima	8	30	3.0 (0.10-6.2)	0

dibromide. All wells in which concentrations exceeded proposed MCLs are in the Whatcom County study area.

Nitrate

Nitrate in ground water can result from multiple sources including natural processes. The presence of nitrate in ground water does not necessarily mean that ground water is being contaminated from agricultural practices. Nitrate/nitrite (reported as N) was detected in 61 of the 81 wells tested (Table 4).

Eighteen wells had levels of nitrate/nitrite that exceeded the Primary Drinking Water Standard of 10 mg/L. Detectable concentrations of nitrate/nitrite were present in nearly all wells in the Whatcom and Franklin County study areas, whereas eight wells in the Yakima County study area had detectable concentrations. In the Whatcom County study area seven wells exceeded the 10 mg/L standard, and in the Franklin County study area 11 wells exceeded the standard. However, in the Yakima County study area, all concentrations were below 10 mg/L.

Concluding Remarks

The interim report presents the pesticide and nitrate/nitrite results of only the first round of sampling for the Agricultural Chemical Pilot Study. All wells in which pesticide residues were detected were resampled in June 1989. The second sampling confirmed the initial results in 20 of the 23 wells. A final report, to be released this summer, will describe and evaluate (1) the first and second round of water-quality samples, (2) land use in each study area and its correlation with pesticide and nitrate/nitrite occurrences, and (3) analysis of indicator parameters and pesticide occurrence.

References Cited

Bauer, H. H.; Vaccaro, J. J.; Lane, R. C., 1985, Maps showing ground-water levels in the Columbia River basalt and overlying materials, spring 1983, southeastern Washington: U.S. Geological Survey Water-Resources Investigations Report 84-4360, 4 plates, scale 1:500,000.

Black and Veatch, 1986, Phase I Investigation—Ethylene dibromide sites, Whatcom County: Washington Department of Ecology Remedial Action Division, 90 p.

Campbell, N. P., 1979, Surficial geologic map of the Yakima quad, Washington: Washington Division of Geology and Earth Resources Open File Report 79-15, 1 sheet, scale 1:250,000.

Cohen, S. Z., 1985, Revised list of analytes for the National Pesticide Survey, U.S. Evironmental Protection Agency, Office of Drinking Water, memorandum to Herb Brass Aug. 2, 1985.

Cohen, S. Z., Eiden, C.; Lorber, M. N., 1986, An evaluation of pesticides in ground water: American Chemical Society Symposium Series, 26 p.

Creahan, K.; Kelsey, H. M., 1988, Hydrogeology and groundwater flow near Lynden, Washington: Western Washington University [under contract to] Washington State Department of Ecology, 74 p.

Drost, B. W.; Whiteman, K. J., 1986, Surficial geology, structure, and thickness of selected geohydrologic units in the Columbia Plateau, Washington: U.S. Geological Survey Water-Resources Investigations Report 84-4326, 11 sheets.

Easterbrook, D. J., 1971, Geology and geomorphology of western Whatcom County: Western Washington State College Department of Geology, 68 p.

Easterbrook, D. J., 1976, Geologic map of western Whatcom County, Washington: U.S. Geological Survey Miscellaneous Geologic Investigations Series Map I-8548, 1 sheet, scale 1:62,500.

Kinnison, H. B.; Sceva, J. E., 1963, Effects of hydraulic and geologic factors on streamflow of the Yakima River basin, Washington: U.S. Geological Survey Water-Supply Paper 1595, 134 p., 3 plates.

Lenfesty, C. D.; Reedy, T. E., 1985, Soil survey of Yakima County area, Washington: U.S. Soil Conservation Service, 345 p., 87 plates.

Poulson, E. N.; Flannery, R. D., 1953, Soil survey of Whatcom County, Wash.: U.S. Soil Conservation Service Series 1941, no. 7, 153 p.

Turney, G. L., 1986, Quality of ground water in the Columbia Basin, Washington: U.S. Geological Survey Water-Resources Investigations Report 85-4320, 172 p., 5 plates.

U.S. Environmental Protection Agency, 1986, Use of pesticides in vulnerable groundwaters of Washington State; Draft report: U.S. Environmental Protection Agency Region X Pesticides Section, 15 p.

U.S. Environmental Protection Agency, 1989a, Drinking water standards and health advisories; Draft: U.S. Environmental Protection Agency Office of Drinking Water, 10 p.

U.S. Environmental Protection Agency, 1989b, National Primary and Secondary Drinking Water Regulations; Proposed Rule, 40 CFR Parts 141, 142, and 143: Federal Register, Monday, May 22, 1989, p. 22,062-22,160.

Walters, K. L.; Grolier, M. J., 1960, Geology and ground water resources of the Columbia Basin Project area, Washington, Volume I: Washington Division of Water Resources Water Supply Bulletin 8, 542 p., 3 plates.

Washington Department of Social and Health Services, 1985, Results and implications of the investigation of ethylene dibromide in ground water in western Washington: Washington Department of Social and Health Services Water Supply and Waste Section, 32 p.

Washington Department of Social and Health Services, 1988, Public water supply listing database: Washington Department of Social and Health Services. [Data as of February 9, 1988; database maintained by Environmental Investigations and Laboratory Services, 7171 Cleanwater Lane, Olympia, WA]

The Summer of 1890 — Bethune in the Field

EDITOR'S NOTE — This is the second in a series dealing with George A. Bethune, Washington's first State Geologist. The following account, written after Bethune had been State Geologist for several months, is a summary of Washington's mineral resources directed, in the form of a letter, to the secretary of the State Senate. It is quoted here verbatim.

State of Washington, Office of State Geologist
Address Geo. A. Bethune, State Geologist, Rooms 605, 606, Sixth Floor, Barlow-Catlin Block, Pacific Avenue, Tacoma

Sept 28, 1890

C. M. Barton Esq.
Secretary Senate
Olympia Wash.

Dear Sir:

In reply to your letter of the 17th inst. will say concerning the mineral deposits of the State of Washington that, in my opinion there is no section of this country where there are such promising indications of mineral wealth.

There are a number of gold silver and lead districts throughout the state which are in every sense flourishing mining camps in spite of the lack of transportation facilities. I am firmly convinced that as soon as railroads are extended to the heart of these districts the output of ore bearing these metals will be enormous. The district of most importance is the Okanogan country which embraces an area of 30 miles long and 10 miles wide. This belt may be subdivided into the following districts—Ruby, Salmon River, Galena, Chloride, Oosyos [sic] and Smilkimeen [sic]. The most important of these is the Ruby district where much development work is being done. Fahlerg [fahlore, or tetrahedrite] a grey copper ore, stephanite or brittle silver, cerargyrite or silver chloride, pyrargyrites, argentites and a number of rich veins of free gold are both found in the Ruby mines.

Samples of stromeyrite, a silver copper sulphide from the Galena district assayed by me showed 4000 ounces of silver per ton with 10 per cent of copper. A general assay from the Ruby district would give from $75 to $100 in gold and silver to the ton.

Along the Peshastin, Swauke [sic] and Wenatchee rivers which have their source in the eastern spurs of the Cascade Mountains there are at present over 100 men employed on quartz and placer mines. Nuggets—to the value of from $500.00 to $750.00 have been taken from the Swauke, and $6000 was the earnings of two industrious prospectors last season.

The Colville mining district in Stevens County embracing an area of 90 miles by 40 miles comes next. Rich ore is being shipped to Puget Sound for reduction at the rate of 50 tons per day. The rock of this district resembles that from the Okanogan mines.

There are 200 men employed in the Silver Creek mines in Snohomish County. The formations of this camp are granite, porphyry, and diorite. The indications are extensive. A shipment of ore from these mines recently gave an assay of 125 ozs of silver and 20 per cent of lead per ton. A mill assay from the "Morning Star" mine gives an average of 23 ozs of silver and 23 per cent of lead per ton. The veins average from 4 to 6 feet in width.

At the head waters of the Skagit River about 400 miners and prospectors are at work on a high grade galena ore.

Several companies are working prospects near Snoqualmie Falls with reported good results. I have no authentic data concerning this locality.

In the Cle Elum district a one stamp mill is at work on some rich free gold ore.

Copper has been discovered in the Cle Elum district, where there are veins of from 4 to 6 feet in width showing native copper, and cuprite (a red oxide) which assays as high as 60 per cent metalic [sic] copper, malachite or green copper as high as 42 per cent and azurite or blue copper and chalcopyrite or copper pyrite as high as 22 per cent. These coppers carry from 5 ozs to 40 ozs of silver and 1/2 oz of gold per ton.

In the Okanogan district there are several veins of chalcocite or copper glance found in lime formations which assay as high as 40 per cent of metalic copper with 90 ozs of silver to the ton.

One copper mine is now being developed near Snoqualmie Falls.

In Mason County at the foot of the Olympic Mountains are rich and extensive croppings of native and carbonate copper ores.

Iron is found on the Skagit River where there are large veins of hematites, limonites and carbonates of iron. An average sample of one vein gave 60 per cent metalic iron and 8 per cent of silica.

On the Steilaguamish [sic] and Snoqualmie rivers, embracing a large area in Snohomish and King Counties are found hematites, carbonates and silicates. At Ryan's

Hill in Snohomish County specimens of iron ore have assayed as high as 63.95 per cent of metalic iron. Hematite ores from the vicinity of Bellingham Bay have given results of 65.80 per cent of metalic iron and 3.10 of silica per ton with little or no phosphorus or sulphur. On the west side of Puget Sound on both sides of the Olympic range exceedingly rich specimens of iron ore have been discovered and brought to my office for treatment, but the character of the country has offered so much impediment to prospectors that comparatively little data as to the width and extent of the veins has been furnished me.

On the east side of the Cascade range in Kittatas [sic] County is the Cle Elum district, where great reefs of iron ore are being developed by the Moss Bay and other iron mining companies. The principal ores are hematites, limonites, carbonates and magnites [magnetites]. An analysis of hematite ore made by me gave 46.13 per cent of metalic iron, and another assay of magnetic iron ore from the same district resulted in 69.11 per cent of metalic iron with 5.30 per cent of silica, 0.13 sulphur and 0.06 of phosphorus.

Limestone is quarried extensively on San Juan Island which assays 98.34 per cent of carbonate of lime, 1.30 water and a trace of phosphates. An assay of limestone from the Snoqualmie quarries gives: Carbonate of lime 94.77, and magnesia 1.08. In the Olympic range at the back of Union City there are immense deposits of this mineral which assays 97.17 per cent of Carbonate of lime. On the Wenatchee and Columbia Rivers limestone is being quarried which assays 98.00 per cent of Carbonate of lime. In the Cle Elum district there is a considerable quantity of limestone showing 97.50 per cent of carbonate of lime. The same may be said of a deposit on the upper Columbia river

In Skagit County and near the Snoqualmie Falls are large areas of marble, although none has yet been quarried.

There are extensive deposits of potters clay and clay for making ordinary brick, tileing [sic] and terra cotta, but so far no clay has been discovered that is refractory enough for fire brick.

Specimens of cinnabar, molybdum [molybdenum] sulphide, nickle [nickel], and manganese ores have been sent to this office but I am, at present unable to furnish any reliable data.

I am extremely sorry that I cannot more fully give you a more complete and comprehensive report as to the mineral resources of the state, but my time has, since my appointment as State geologist, been so fully taken up with preparations for the thorough establishment of a bureau of information as to our mineral wealth, which is not yet completed that I can scarce find time to attend even to most urgent correspondence.

Very truly yours

Geo. A. Bethune

Mine Quest Theme of 1991 Metals Sessions

Mine Quest - Diversification for the 90s, the Pacific Northwest Metals and Minerals Conference, will be hosted next spring in Spokane by the AIME-SME Columbia Section.

The conference is scheduled for May 1-3, 1991, in the Sheraton-Spokane Hotel. Technical sessions will include more than 50 papers covering international mining and exploration activity in addition to base metal, gold, platinum, and non-metallic ventures. Environmental issues and metal processing will be investigated during special sessions.

The conference will be preceded by eight two-day field trips April 30 and May 1 to metal mines and processing facilities. Options will include trips to the Stillwater complex, northeastern Washington gold properties, Montana copper and gold mines, Idaho silver mines, and several refineries and smelters.

Additional information may be obtained from Mine Quest, c/o U.S. Geological Survey, W. 920 Riverside, Spokane, WA 99201.

Mining Group to Repeat Popular Drilling Course

Management of mineral drilling projects will be the subject of a short course presented immediately preceding the 96th annual convention of the Northwest Mining Association convention in Spokane.

The course will be offered Dec. 2-4 at the Spokane Sheraton Hotel, the convention headquarters. The course, last offered in 1981, is considered the most successful presented by the Association.

The convention itself is scheduled for Dec. 5-7. The theme of the convention will be recognition of the accomplishments of the minerals industry in the field of environment protection, and the balance between added increments of improvement and the value/cost relations of those increments.

Convention program chairpersons will be Linda Thorstad of Interaction Resources Ltd, Vancouver, B.C., geology; Marshall Koval of Golder Associates, Redmond, Wash., environment; and Doug Halbe of Met-Tek, Inc., Salt Lake City, operations.

After last year's record 3,622 attendance, additional meeting space will be made available in the Inn at the Park, directly across the Spokane River from the Sheraton.

Highlights of the Fourth Annual NEHRP Workshop for Puget Sound and Portland Areas

by Patrick Pringle, Stephen P. Palmer, and R. L. (Josh) Logan

The 1990 National Earthquake Hazards Reduction Program (NEHRP) workshop, sponsored by the Washington Division of Geology and Earth Resources (DGER), Washington Division of Emergency Management, Federal Emergency Management Agency (FEMA), and the American Society of Civil Engineering Technical Council on Lifeline Engineering, was held April 17-19 in Seattle. The workshop consisted of two field trips, 29 oral presentations, two panel discussions, and a poster session. The sessions integrated wide-ranging topics relating to earthquake studies, from seismologic research to sociological studies. Welcoming addresses were delivered by **Brian Boyle**, Washington Commissioner of Public Lands, **Gary Johnson**, Chief of Earthquakes and Natural Hazards Programs Division of FEMA, **Ray Williams**, Region X Director of FEMA, and **Craig Weaver** of the U.S. Geological Survey (USGS).

Keynote speaker **Brian Boyle** noted that earthquake policy implementation was difficult because the issue generates little pressure on political leaders. He questioned the preparedness of Washington, pointing out that the State has no direct expenditure for earthquake readiness—unlike California, which spends more than $3 million annually for geologic studies alone. At the same time, the need for preparedness has been demonstrated: 200,000 children attend schools the Superintendent of Public Instruction thinks would not survive a major earthquake; 65 bridges and freeway ramps are obsolete; and numerous other buildings, such as hospitals, prisons, nursing homes, and office buildings, need seismic evaluation. Boyle further noted that California has 75 state-supported strong motion accelerometers; Washington has only a handful. These instruments provide detailed information about seismic motion, and Boyle suggested this kind of information should be available to every building designer in the state. He stressed the importance of added training and organizational work to coordinate and improve readiness of vital communication links throughout the state.

Tectonic Framework of the Pacific Northwest

The first morning of the workshop opened with a session concerning the tectonic framework of the Pacific Northwest. **Robert Crosson** of the University of Washington provided an overview of seismicity in the Pacific Northwest as it relates to the structure and geometry of local tectonic plates. He suggested that the angle of the subducting plate (deviation from the horizontal) may have profound effects on the nature of uplift and on the distribution of earthquakes in the Pacific Northwest. He concluded that the uplift of the Olympic Mountains may be associated with the shallow dip (10° to the east) of the Juan de Fuca plate as it is subducting beneath the North America plate. The low angle is the result of a flexure or "arching" of the slab beneath western Washington noted by previous researchers. (See Weaver and Baker, 1988.) This geometry offers one explanation for the development of the Olympic Mountains. Because the previous large intraplate earthquakes of 1949 and 1965 seem to be focused in the arched portion of the slab, other areas overlying arched portions of a subducting slab could be similarly vulnerable to large intraplate earthquakes.

Curt Petersen of Portland State University summarized evidence of stacked peat horizons as proxy indicators of tectonic subsidence associated with subduction zone earthquakes in Oregon and Washington. He reviewed his own research, the pioneering work of Brian Atwater, Wendy Grant, Gary Carver and others, stratigraphic evidence for earthquake-generated tsunamis noted by Mary Reinhart and Joanne Bourgeois, as well as archeological research, recent investigations of turbidites near Vancouver Island by John Adams, and geodetic evidence of strain noted by Mike Lisowski and Herb Dragert (using the Global Positioning Satellite to measure across the Strait of Juan de Fuca) and by Paul Vincent (who used first-order levelling near Tillamook, Ore.). Petersen's presentation included an updated compilation of radiocarbon ages associated with the stratigraphic evidence that suggest apparently contemporaneous subsidence in Washington and Oregon.

Thomas Heaton, Scientist in Charge of the USGS seismological laboratory in Pasadena, compared subduction zones and their respective earthquake types in the Pacific Rim to the inferred configuration of the subduction zone in the Pacific Northwest. In particular, he distilled the work of Ruff and Kanamori (1980), who compared the systematics of subduction zones with the magnitudes of earthquakes. (See also Heaton and Hartzell, 1987.) Characteristics that can be used in comparing various subduction zones include plate collision velocity, age of the subducting slab, and the presence of back-arc spreading. Using these characteristics, Heaton suggested that the subduction zones in Japan, Colombia, and Mexico are those most similar to the Cascadia subduction zone. Of these, only the Cascadia subduction zone has not experienced moment magnitude (M_w) 8+ thrust-rupture earthquakes in the 20th century. Heaton also discussed the scale and nature of ground motion and response spectra typically associated with great subduction zone earthquakes. These earthquakes cause very strong shaking over a long period (often greater than 2 min). He also noted that ground motions from subduction zone earthquakes seem to persist over longer distances than those from strike-slip earthquakes of a similar magnitude.

Craig Weaver, USGS seismologist, focused his discussion on shallow crustal earthquakes. The occurrence of a damaging magnitude 5.0 crustal earthquake in the Deming area (northwestern Washington) the week before the NEHRP meeting made his choice of topic all

the more relevant. He summarized the historic record of shallow-crustal seismicity in the Pacific Northwest (or lack of it in some areas) and related the foci of those earthquakes to geologic structures at depth. Drawing on his previous work, he related the locations and configuration of the northwest-trending St. Helens Seismic Zone (SHSZ) and a similarly trending fault zone west of Mount Rainier to the edge of an inferred underlying crustal block at 12 km depth. He speculated that a magnitude 6.3-6.8 earthquake could occur on the SHSZ between Elk Lake and Spirit Lake, depending on whether a hypothesized 7- or 12-km segment of this strike-slip fault were to rupture. Such an earthquake could have significant impact on the Portland area. (See Weaver and Shedlock, 1989.)

Following Weaver's presentation, **Stewart W. Smith** of the University of Washington, who chaired the opening session, led a panel discussion of the participants.

Richard Eisner, Director of the Bay Area Regional Earthquake Preparedness Project (Governor's Office of Emergency Services, California), delivered a luncheon slide presentation showing some of the damage caused by the October 17 Loma Prieta earthquake. He noted that the California Department of Transportation (Caltrans) had spent more than $50 million on seismic retrofitting (phase 1) before the Loma Prieta earthquake, but that $300 million had been required for clean up to date (not including replacement of damaged or destroyed structures). The money invested in phase 1, specifically for the installation of joint restrainers, apparently prevented many bridge spans from collapsing, according to testimony submitted by Caltrans to the Governor's Board of Inquiry to the Loma Prieta earthquake. However, in the case of the ill-fated Cypress structure, the joint restrainers were not enough to prevent collapse, and column retrofitting would have been necessary to mitigate this hazard because column abutments were so far apart. (See Thiel and others, 1990.)

Ivan Wong of Woodward-Clyde Consultants discussed the role of site-specific and regional effects in strong ground shaking. He summarized recent methodologies for predicting strong ground motions and applied them to modeling the spectral response at sites in the Puget Sound and Portland areas for earthquakes of various magnitudes and epicentral distances. These simulation methods are particularly important because of the scarcity of strong-motion data in the region.

Stephen Palmer of DGER reviewed the phenomena of seismically induced liquefaction and ground settlement, using examples from the 1949 and 1965 Puget Sound earthquakes. Liquefaction studies presently being performed by the USGS and other NEHRP-funded researchers in the Pacific Northwest were described. (See related article in this issue.)

Ralph Archuleta of the University of California at Santa Barbara stressed the importance of impedance contrasts and resonance peaks in analysis of amplification of strong ground motion. He summarized work at McGee Creek, Calif., where he and Sandra Seale measured the influences of local geology (glacial drift overlying hornfelsed bedrock) on amplification of seismic waves. Major amplification effects at the surface of their test site were caused by resonance effects brought about by the impedance contrast of soil compared to bedrock.

S. T. (Ted) Algermissen of the USGS reviewed the methodology used to generate probabilistic earthquake ground-motion maps. Such maps are often used by engineers to estimate seismic lateral forces during design of buildings, dams, bridges, and other major structures. These maps are revised to "custom-fit" the various parameters used in these analyses to the regional tectonic and seismologic history.

Jerald LaVassar, an engineer with the Dam Safety Section of the Washington Department of Ecology, discussed some of the shortcomings of the probabilistic approach to estimating earthquake ground motions. A major problem in dam safety evaluation is determining the liquefaction potential of older earth-filled dams. Liquefaction depends on both the level of ground acceleration and the duration of strong shaking. Probabilistic acceleration maps provide only an estimate of the maximum probable acceleration and give no indication of the expected duration of shaking. As a rule, larger earthquakes are accompanied by strong shaking of longer duration, which results in a greater potential for liquefaction. Also, it appears that many probabilistic acceleration maps may overemphasize the contribution of earthquakes of smaller magnitude, especially maps for events of long return periods.

Derek Cornforth of Landslide Technology in Portland, Ore., provided an overview of mass movements related to earthquakes. He discussed three broad categories of mass failures: movements from marginally stable slopes, block-slide movements, and movements resulting from liquefaction. Cornforth stressed that liquefaction-induced movements are the most important group of earthquake-induced landslides because they are the most common and cause the most damage to engineered structures.

John Hooper of Ratti, Swenson, Perbix, and Clark in Seattle discussed the philosophy of seismic design of the Uniform Building Code (UBC), including the intent and limitations of its provisions. The basic design philosophy is to insure the safety of the inhabitants. Hooper noted that minimum standards have been set to safeguard structures against major failures and loss of life due to ground shaking. However, no UBC provisions have been made for earth conditions other than basic soil types that are generally not genetically related to geologic parent material. These soil types are used only in characterizing the ground motion and do not take into account behavior of the soil during the shaking. In light of the significance of liquefaction in causing damage to engineered structures, Hooper believes this is an area where improvements to the UBC could be made.

Addressing the importance of geologic parent material, **Thomas Bodle** (Univ. of Washington) related Seattle-area intensities of the 1965 and 1981 Puget Sound earthquakes and 1981 Elk Lake event to surficial geology and elevation. He found significant association

between intensity and postglacial surficial deposits at elevations less than 100 ft, and between intensities and all surficial units except till for elevations between 0 and 200 ft. Previous studies had plotted intensities against USDA soils maps; many mapped soil units are only incidentally related to surficial geology.

Evening Poster Session

William J. Perkins and **W. Paul Grant** (Shannon and Wilson, Inc., Seattle) and **T. Leslie Youd** (Brigham Young University) displayed their maps of liquefaction susceptibility for the Seattle North and Seattle South quadrangles. The maps were prepared using estimated thicknesses of critical liquefiable units as determined from standard penetration test data.

Mark Holmes presented single-channel seismic reflection data recorded in Elliott Bay by the Department of Oceanography of the University of Washington. These data show that slumping and turbidity flows are the two primary mass-wasting phenomena controlling sediment movement in this area of Puget Sound. These two processes have severely modified the spoils pile deposited in Elliott Bay during Seattle's Denny regrade projects. Also, seismic reflection data clearly show an underwater pipeline that had been uncovered during slumping of overlying mud and evidence of turbidity flows in the deeper channels of Puget Sound.

Stephen Palmer and **John Shulene** presented their work on liquefaction in the Puyallup valley caused by the 1949 and 1965 Puget Sound earthquakes. (Their results are published in this issue and the previous issue of this newsletter.) Although the 1949 magnitude 7.1 earthquake caused widespread liquefaction in Puyallup, the 1965 magnitude 6.5 earthquake did not produce ground acceleration and duration of strong shaking sufficient to trigger liquefaction.

Ian Madin of the Oregon Department of Geology and Mineral Industries and **Silvio Pezzopane** of the University of Oregon summarized results of recent mapping in which investigators have identified fault offsets in Pliocene-Pleistocene Boring Lavas near Portland. Madin and Pezzopane also documented paleoliquefaction features (clastic dikes and sand blows) in silts and fine sands deposited in the Portland area by catastrophic Pleistocene floods from glacial Lake Missoula. Strong ground shaking during local or distant earthquakes and rapid loading during catastrophic floods provide possible explanations for these features.

Earthquake-hazard maps of the Portland area were also displayed by **Ian Madin**, who used geologic mapping, geotechnical boring, and water-well data to compile the maps. These maps show the distribution of a variety of liquefiable sediments, as well as the locations of numerous faults.

Mark Darienzo and **Curt Petersen** of the Geology Department at Portland State University showed evidence for small-scale (>1 m) tectonic subsidence in Alsea Bay, Ore., associated with Cascadia Subduction Zone earthquakes. This subsidence is less than the 1-2 m of sudden subsidence observed in estuaries of northern Oregon and southern Washington. The smaller subsidence could be attributed to Alsea Bay being farther from the axis of subsidence or to separate, smaller magnitude subduction zone earthquakes. The first hypothesis is supported by the position of an offshore fold belt that is seaward of and parallels the subducting trench. Since this fold belt comes onshore near Coos Bay, Darienzo and Petersen suggest evidence of uplift may be found between Coos Bay and Alsea Bay. Alternatively, the latter hypothesis could imply segmentation of the Cascadia Subduction Zone.

Brian Cohee, **Paul Sommerville**, and **Norman Abrahamson** of Woodward-Clyde Consultants presented the results of their computer simulation of ground motions from Cascadia subduction zone earthquakes. They computed the ground motion for a hypothesized M_w=8 thrust earthquake on rock and soil sites in the Puget Sound and Portland regions. These computations show that for periods less than 1 sec, the estimated spectral velocities would be as much as twice those recorded during the 1949 Olympia and 1965 Seattle earthquakes, and that durations of strong shaking would be significantly longer (40-60 sec versus 10-20 sec).

Tammi Baier of the Department of Geography and Regional Planning at Western Washington University summarized her study of the public's attitudes toward and response to earthquake hazards in the Tacoma and Puyallup areas of Washington. Because more than half the replies to her questionnaire were returned on or before the October 17, 1989, Loma Prieta earthquake, she has been able to compare those attitudes with later replies which may have been influenced by the earthquake. Although her statistical analysis of the data is not yet finished, Baier observed that perceptions of dread were noticeably more common among those whose replies were postmarked after the Loma Prieta earthquake. A greater percentage of the post-Loma Prieta replies also indicated persons intended to take more precautions about earthquake hazards.

Harry Halverson, retired vice president and cofounder of Kinemetrics (manufacturer of seismometers), provided a photographic display of Namazu-e, colorful woodblock prints reflecting Japanese folklore that a great subterranean catfish (Namazu) produced earthquakes. The creation of the prints was a result of the Edo (Tokyo) earthquake of 1855, although the prints contain references to other earthquakes. The Namazu-e reflect conflicting ideas about earthquakes that existed at that time. Earthquakes were seen as punishment of various classes of people in some instances, and at other times, the Namazu were thought to assist carpenters and other laborers who might benefit from the effects of an earthquake. (See Bolt, 1976.)

Structural Engineering Session

For geologists, one of the most rewarding aspects of the NEHRP workshop was the opportunity to interact with engineers, architects, and planners. This session demonstrated that new information on the nature and magnitude of anticipated forces generated by earthquakes must be accounted for in structural design and retrofitting older buildings.

Todd Perbix of Ratti, Swenson, Perbix, and Clark provided an introduction to earthquake engineering of buildings, including a history of design code applicability in the Seattle area. He summarized the typical problem areas: gable failures, parapet failures, and general problems with unreinforced masonry. He showed various examples of anchorage mechanisms and techniques for securing parapets and the installation of ductile frames and diaphragms to allow increased redundant transfer of shear forces.

John Hooper (Ratti, Swenson, Perbix, and Clark) talked about retrofitting the Heritage Building in Pioneer Square. (See field trip below.) This building has a long-aspect ratio problem and had a "soft story" (a lower, open floor not able to accommodate shear forces). The soft story was corrected by adding a center brick shear wall to resist north-south lateral forces, anchoring of the wood floor structure to this wall, and devising drag strut connections. Anchorage rosettes were used to secure brick and sandstone faces of the building. Elsewhere, beam and column tie plates were used, and additional concrete shear walls were constructed.

Thomas Kinsman, building official for the City of Seattle, discussed the nature of the retrofit problem in the Seattle area. He noted that each building is unique, that there are no "cookbook" methods for dealing with retrofitting. Retrofitting regulations are enforced when a hazard is observed, a building is being substantially renovated, there is a change in occupancy, or the building is re-occupied after more than a year of vacancy. A case history of the Franklin High School in South Seattle was presented by **John Desalvo** of Mayan and Desalvo to demonstrate how a local landmark was preserved and expanded as it was upgraded to meet current seismic safety standards. Major shear wall structures in the original building were strengthened by the application of shotcrete veneer and by the addition of steel ties at the roof and floor levels. Additional lateral strength was supplied by the new addition to the original structure.

Field Trips

The day before the meeting's opening, **Robert Bucknam** (USGS) led a field trip to Bainbridge Island (5 km west of Seattle) to show evidence of abrupt uplift in the last 1,700 years. An intertidal platform cut into the Blakeley sandstone has been uplifted about 7 m (Fig. 1), and Bucknam postulates that the uplift was caused by an earthquake.

On the second day of the meeting, **Todd Perbix** led a field trip to the Pioneer Square area in downtown Seattle, where the Heritage Building and Union Station were visited. The trip was designed to introduce participants to rapid visual screening of buildings for seismic hazards and to provide an opportunity to view retrofit techniques first hand. Many of the retrofit features described during the Structural Engineering Session were observed during the trip.

Lifelines Session

To begin the final day of the meeting, **Keith Eldridge** of KOMO News narrated a slide presentation

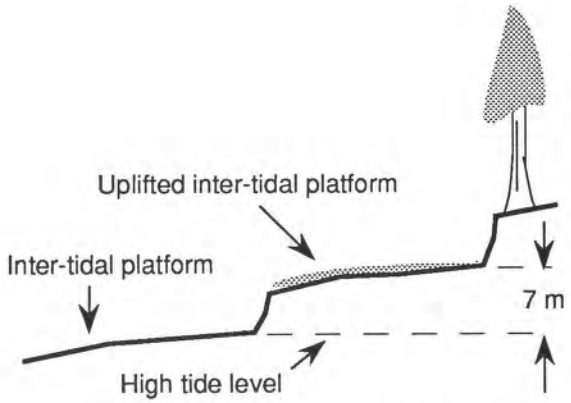


Figure 1. Platform and uplift in the Blakeley sandstone, Bainbridge Island.

showing damage caused by the Loma Prieta earthquake. The presentation was prepared by the Lifeline Session chairman, **Don Ballantyne**. Eldridge was raised in the San Francisco area, and thus had more than casual interest in this earthquake. KOMO News dispatched him to California within hours of the main shock. Ballantyne discussed the importance of insuring that lifeline functions, such as power supply, communications, water and sewer services, can be restored quickly and easily after a major earthquake. He stressed that this can only come about with adequate preparation before the event.

A panel composed of **Walter Anton** (Seattle Water Department), **Allan Walley** (Washington Department of Transportation), **J. D. Cattanach** (B.C. Hydro), **William Elliott** (Portland Water Bureau), and **Ken Sullivan** (FEMA) discussed four issues:

- Marketing an earthquake mitigation program to decision makers who control the lifeline's budget
- Assessing the vulnerabilities of a lifeline system
- Estimating potential losses to a lifeline system
- Planning to reduce losses to a lifeline system

Elliott discussed the inventory and seismic loss estimation model for the Portland, Ore., water and sewer systems. He noted that credible expert opinion is the most important first step in marketing an earthquake mitigation program. Walley noted that 3,000 highway bridges would be in jeopardy in Washington State if a major earthquake were to occur. Of these, 70 would be vulnerable to tension failure, and 85 would have lesser vulnerability. He estimated that $30 million would be needed to retrofit existing bridges to current standards. Anton described the operation of the Seattle water-supply system and said that the most vulnerable part of this system would be the pipeline west of Lake Washington which carries water to Mercer Island. He noted that a $16 million seismic upgrade program has funded a new dam, reservoir lining, improved transition pipeline supports, strengthening of elevated tanks and standpipes, and other improvements. Sullivan explained the broad spectrum of FEMA's earthquake mitigation efforts with regard to five types of lifelines. He noted

that FEMA has published volumes relating to each of the categories of lifelines and a final summary volume, *Abatement of seismic hazards to lifelines–An action plan*. The information has been distilled into an agency plan. Sullivan briefly discussed ongoing and planned FEMA projects for lifelines for the upcoming year.

Luncheon Festivities

Professors **Bekhzad Yulgashev** (particle physicist) and **Tursun Rashidov** (seismic engineer) representing the Uzbek Academy of Sciences (USSR) were distinguished guests at the luncheon on the third day of the workshop. State Geologist Ray Lasmanis presented the Uzbeks with a copy of *Engineering Geology in Washington*, published by DGER in 1989. Yulgashev gave a slide presentation about the impacts of the 1988 Armenian earthquake and his work on the design (using seismodynamic theory) of seismic-resistant underground structures.

Edward Wolfe, Scientist-in-Charge of Cascades Volcano Observatory (CVO) in Vancouver, Wash., followed with an assessment of volcanic hazards in the Pacific Northwest, which he had compiled with C. Dan Miller of CVO. Wolfe summarized the postglacial eruptive activity of Cascade Range volcanoes, described the nature of the volcanic processes, and discussed methods of monitoring and volcanic hazards analysis now being conducted by the observatory.

Loss Estimation Session

Bruce Olsen, independent consulting engineer, chaired the Loss Estimation Session. The first speaker, **Peter May** of the University of Washington, differentiated two types of loss estimates: region-wide dollar estimates of prospective losses and vulnerability assessments. He summarized implications and usefulness of these estimates. Noting that there were few examples of loss estimates being put to practical use, May stressed that we should focus more attention on "vulnerabilities of key elements of our physical and social systems than [on] region-wide dollar losses." The result would be an increased emphasis on priorities for upgrading facilities and lifeline systems to reduce their vulnerability. May stated that loss estimates are highly uncertain and that policy actions, such as research priorities and planning monies, linked to them are potentially flawed.

W. Paul Grant of Shannon and Wilson, Inc., discussed the impact of poor soil conditions on building damage during earthquakes. His slides detailed typical damage caused by the 1949 Olympia and 1965 Seattle earthquakes.

Chris Arnold of Building Systems Development focused on the economic aspects of architectural design as they relate to potential earthquake losses. He discussed hidden costs, such as those associated with damage to a new Hyatt hotel by the Loma Prieta earthquake. The hotel sustained $7 million damage outright, but it lost an additional $1 million per month revenue because it could not be opened until repairs were made. He demonstrated how difficult it is to define loss because of the revenue increases in some businesses and the increasing "velocity of money" following an earthquake.

Roger McGarrigle of Van Domelen, Looijenga, McGarrigle, and Knauf discussed seismic design and loss estimation in areas of low historical seismicity. He noted that upgrading structural components is generally a minor component (about 2-5 percent) of the total cost of a new building and that it is much more expensive to retrofit.

Craig Taylor of Dames and Moore in Seattle examined the complicated relation of earthquake losses to lenders and the insurance industry. He analyzed the types of risks that lenders and insurers incur, the nature of loss estimation, and stressed the need for financial models that can quantify the degree to which lenders and insurers, respectively, bear losses, as opposed to losses borne by others.

This Fourth Annual NEHRP Workshop for the Puget Sound and Portland areas was probably one of the more successful in presenting not only geotechnical data, but also engineering information to planners, architects, and emergency response managers and specialists. Likewise, geoscientists were able to learn a great deal about mitigating structural damage, estimating losses, and protecting lifelines. Evidently, not all the aftershocks of the Loma Prieta earthquake were seismic in nature because new data and numerous insights regarding earthquake damage and effects, in a large part related to the recent studies of this event, have provided an impetus for anticipating and solving similar earthquake problems in the Northwest. Mitigation of earthquake hazards will have much greater success with the kind of strong interdisciplinary approach that characterized this meeting.

Proceedings of the meeting will be published as an open-file report by the meeting sponsors as part of a continuing USGS series of earthquake hazard conference proceedings.

References Cited

Bolt, B. A., 1976, Namazu-e: Pacific Discovery, v. 29, p. 10-13.

Heaton, T. H.; Hartzell, S. H., 1987, Earthquake hazards on the Cascadia subduction zone: Science, v. 236, no. 4798, p. 162-168.

Ruff, Larry; Kanamori, Hiroo, 1980, Seismicity and the subduction process: Physics of the Earth and Planetary Interiors, v. 234, p. 240-252.

Thiel, C. S; and others (eds.), 1990, Competing against time—Report to Governor George Deukmejian from the Governor's Board of Inquiry on the 1989 Loma Prieta Earthquake: State of California, Office of Planning and Research, 264 p.

Weaver, C. S.; Baker, G. E., 1988, Geometry of the Juan de Fuca plate beneath Washington and northern Oregon from seismicity: Bulletin of the Seismological Society of America, v. 78, no. 1, p. 264-275.

Weaver, C. S.; Shedlock, K. M., 1989, Potential subduction, probable intraplate, and known crustal earthquake source areas in the Cascadia Subduction Zone. *In* 3rd annual workshop on "Earthquake hazards in the Puget Sound, Portland area": U.S. Geological Survey Open-File Report 89-465, p. 11-26.

Mount St. Helens Anniversary Symposium

by Patrick Pringle

On May 18, a symposium titled "Mount St. Helens–Ten Years Later" was held in Kelso. This tenth anniversary event was jointly sponsored by Weyerhauser Company, Federal Emergency Management Agency, U.S. Army Corps of Engineers, U.S. Forest Service (USFS), U.S. Geological Survey (USGS), Washington Departments of Natural Resources, Transportation, and Wildlife, and the Washington State Division of Emergency Management.

Robert Christiansen, USGS, and **Peter Frenzen**, Monument Scientist at the Mount St. Helens National Volcanic Monument (USFS), gave introductory overviews of the Mount St. Helens eruption and its ecosystem impacts, respectively. The general session was followed by six concurrent sessions: ecosystem responses, emergency management, construction response, geologic impacts, fish and wildlife recovery, and forest and watershed recovery. This article summarizes presentations from the geologic impacts session.

Dwight "Rocky" Crandell, retired USGS geologist, opened the geologic impacts session with a detailed discussion of updated geologic evidence obtained during the last decade of volcano studies. Crandell, synthesizing his work with that of other researchers, characterized the sizes, types, and durations of the Mount St. Helens eruptive events of the past 500 years and compared those events with the eruption that began in 1980. In particular, he summarized the stratigraphic and petrologic investigations by Richard Hoblitt and John Pallister (both USGS) which have taken on new significance thanks to the tree-ring studies of David Yamaguchi (Univ. of Colorado, Inst. of Arctic and Alpine Research). Yamaguchi has precisely dated major eruptions of 1480, 1482, and 1800, as well as smaller later eruptions (Yamaguchi, 1983, 1985).

Crandell noted that the Wn eruption in 1480, which began the Kalama Eruptive Period (1480-late 1700s), produced about six times the volume of tephra (fallout including ash and larger particles) produced in 1980 (Table 1). Even the smaller We tephra eruption of 1482 was about 20 percent larger than the 1980 eruption. These eruptions were followed by pyroclastic flows and construction of a lava dome during the 1490s and, at about 1500, by an explosive andesitic eruption that produced the X tephra. Minor amounts of andesite tephra were deposited after the X tephra, and andesite lava and pyroclastic flows during the early to mid 1500s produced the sinuous Worm Flows visible on the south and southeast flanks of the cone. From the late 1500s to late 1700s, silica content increased as dacite pyroclastic flows accompanied construction of the volcano's summit dome.

Apparently, Mount St. Helens was dormant for only a few decades after the Kalama Eruptive Period. Crandell observed that the Goat Rocks Eruptive Period commenced in 1800 with the eruption of the T tephra, and, as suggested by a recent study (Yamaguchi and others, 1990), the Floating Island Lava Flow (a high-silica andesite) was extruded within a few months of this tephra eruption. Silica content of the magma increased again from the 1840s to about 1857, when the Goat Rocks dacite dome was constructed.

Table 1. Data for Mount St. Helens eruptive products of the last 500 years. PF, pyroclastic flow.

Eruptive period	Tephra	Volume, (km^3)	Misc. activity	Date	Silica (%)
	Wn	2	...	1480	68-65
	We	0.4	...	1482	67
	...	...	PFs; Dome	1490s	65
Kalama	X	...	...	≈1500	58
	...	...	Minor tephra	pre-1505	58
	...	...	Lava; PFs	≈1505 to mid 1500s	57-58
	...	...	Dome; PFs	late 1500s to late 1700s	61-64
	Dormant for several decades				
	T	0.5	...	1800	64
Goat Rocks	...	0.1	Floating Island Lava Flow	1800	60
	...	...	Goat Rocks Dome	1840s to 1857	63
	Dormant for 123 years				
1980 to ?	18 May	0.34	...	1980	64-62
	...	...	Dome, PFs	1980 to 1986	61-63

A dormant period of 123 years then preceded the most recent eruptive sequence.

Crandell noted that, like the Kalama and Goat Rocks Eruptive Periods, the post-May 1980 eruptive products also show a decrease in silica content and then an increase. He suggests that the 1980-1986 activity resembles the pattern of the Goat Rocks eruption and speculated that, if it follows this Goat Rocks "cycle", we will have continued intermittent lava extrusion, possibly over the next 30 years or so, and then a dormant period before yet another explosive eruption. Considering the explosive eruptions that have occurred at Mount St. Helens over the past 500 years, Crandell estimated a 10 percent probability per decade of similar eruptions in the future.

Thomas Pierson of the Cascades Volcano Observatory (CVO) in Vancouver, Wash. (USGS), talked about the nature of the geologic and hydrologic processes associated with the Mount St. Helens May 18, 1980, eruption and explained that effects of similar processes can be observed and continue to be hazards at other volcanoes in the Cascades Range. He summarized the physical aspects and extent of the individual processes, such as the lateral blast, pyroclastic flows, lahars, and the debris avalanche, processes which have been measured and analyzed in more detail than ever before. The 300°F lateral blast, for example, reached the speed of sound and had devastating impacts as far as 27 km from the volcano. Pierson also reviewed the histories of other volcanoes in the Northwest. Noting that a relatively small eruption at Nevado del Ruiz volcano in Colombia melted 10-20 million m^3 of ice and snow and that this event resulted in a lahar that killed at least 23,000 people, he warned that the vast areas of ice and snow on Cascades volcanoes such as Mount Baker (52 km^2) and Mount Rainier (91 km^2) could feed similar lahars during an eruption.

Edward Wolfe, Chief Scientist at CVO, spoke about monitoring Cascades Range volcanoes. (See review of NEHRP meeting, this issue.)

Steven Brantley, Public Information Scientist at CVO for seven of the last ten years, talked about the sensitive process of providing volcano information to the public. He reviewed the diverse range of questions raised by the media and public during a volcanic crisis and the kind of information that would be made available when such a crisis occurs at another Cascade volcano.

Thomas Casadevall of the USGS Volcanic Hazards Program in Denver closed the geology session with a discussion of three topics that constitute new frontiers in volcanology: restless calderas, international volcanology, and jet aircraft.

A volcanic caldera is a large depression whose diameter is many times larger than its volcanic conduit, and a restless caldera is one that is experiencing earthquake swarms, deformation, or anomalous fumarolic activity that may portend volcanic activity. Crater Lake and Newberry Caldera in Oregon are the two calderas closest to Washington. Casadevall talked about three calderas that have been notably restless in the 1980s: Phlegraean Fields Caldera (Italy), Rabaul Caldera (Papua New Guinea), and Long Valley Caldera (California). The geologic record indicates that these calderas have had catastrophic eruptions in the relatively recent past. Each area now supports a large human population. Casadevall noted that, for this reason, calderas demonstrate the difficulties of dealing with a volcanic eruption. Because of the uncertainty caused by the wide range of eruptive possibilities at calderas, large-scale social disruption is possible when they become restless. Much of the updated information on calderas has been compiled in Newhall and Dzurisin (1989).

According to Casadevall, the 1980s were the most disastrous decade since the early 1900s in terms of human impacts caused by volcanoes, but not in terms of the severity of eruptions. The severity of these impacts is a direct result of increasing populations on or near volcanoes. On an international scale there were 336,000 evacuees and 26,000 volcanic fatalities during the 1980s (compared to an estimated 250,000 volcano fatalities in historic times). On the other hand, Casadevall pointed out that the decade had some remarkable success stories, such as the smooth evacuation of 10,000 people from Banda (Spice Islands, Indonesia) in 1988.

Near-disastrous interactions of jet aircraft with eruption ash plumes have occurred at least six times during the 1980s. One incident involved a flight from Portland to Seattle during the May 18, 1980, eruption of Mount St. Helens, and another interaction occurred during the May 25 eruption. Other incidents included two aircraft-ash interactions during the 1982 eruption of Galunggung and one during the 1985 eruption of Soputan, both in Indonesia, and the December 15, 1989, incident in which a KLM (Royal Dutch Airlines) 747 inbound to Anchorage, Alaska, from Europe encountered the eruption plume from Redoubt volcano. The aircraft climbed to 28,600 ft in an attempt to avert the plume, but lost power in all four engines and plummeted to 12,000 ft before the engines could be restarted. Although no lives were lost, the engines of the 747 had to be replaced at a cost of $5-7 million each.

These costly near-disasters have demonstrated the need for improved tracking of eruption plumes from volcanoes. Ash plumes from volcanic eruptions commonly generate lightning. Using this characteristic, Thomas Murray and Richard Hoblitt of CVO have been working with the Bureau of Land Management in Alaska to refine a lightning detection system to track ash plumes. Fortuitously, the initial system had been set up on February 14 and was able to detect lightning strikes along the path of the plume from the February 15 eruption of Redoubt south to Homer, Alaska.

The presentations by the researchers at the Ten-Year Symposium indicated that they carried a genuine spark of enthusiasm about their areas of specialty. The hundreds of symposium participants, who included government officals, many educators, and the general public, crowded conference rooms to standing-room-only levels during most sessions. There was a consensus that a tragic natural disaster had been turned into a valuable learning experience not only for scientists, but for the region as a whole.

References Cited

Newhall, C. J.; Dzurisin, Daniel, 1989, Historical unrest at large calderas of the world: U.S. Geological Survey Bulletin 1855, 1,108 p. [2 v.]

Yamaguchi, D. K., 1983, New tree-ring dates for recent eruptions of Mount St. Helens: Quaternary Research,v. 20, no. 2, p. 246-250.

Yamaguchi, D. K., 1985, Tree-ring evidence for a two-year interval between recent prehistoric explosive eruptions of Mount St. Helens: Geology, v. 13, no. 8, p. 554-557.

Rockhounding in the National Forests

The National Forests of Washington and Oregon are rich with deposits of collectable rocks, gemstones, and fossils. Recreational mineral collecting and rockhounding appear to be increasing on National Forest Land administered by the Forest Service in the two states. As a result, public inquiries about the Region's policy for administering such activities are becoming more frequent.

Recreational collecting involves removal of minerals found on the surface of the ground, or panning of present-day stream gravels. The collecting is accompanied by only very minor digging and the loosening of soil material. No significant vegetation removal is done, no explosives are used, and no power equipment is used for excavating. Typically, the activity is conducted infrequently, and disturbance to the environment is nominal.

In most cases, rockhounds, mineral collectors, and fossil collectors may remove small quantities of rocks, minerals, gemstones, and invertebrate fossils from Forest Service administered lands. If the amount is small and the material will be used for private collection, scientific, or educational purposes, permits and fees usually will not be required. If the material is used for commercial purposes, sold, or bartered, a permit and fee are normally required before the collecting is done.

There are exceptions to this policy, however. If the removal of even small quantities would cause significant disturbances or would disturb especially sensitive resources, prior approval from the local Forest Service office must be obtained.

Some areas may be closed to collecting activities, so check with the local Ranger Station before you collect. Examples of areas that may be closed include research natural areas, historical/archaeological sites, outstanding natural areas, campgrounds, environmentally sensitive areas, or roadbanks. In some areas the cumulative impacts of many years of collecting have become so significant that the area has been closed to collecting, or "withdrawn" from use).

If the area is withdrawn, permits for panning, sluicing, dredging and collecting may or may not be issued; so you should ask about that. Many areas are encumbered by unpatented mining claims, so to prevent any misunderstanding with a claimant, you should avoid collecting in those areas. The corners of mining claims typically are marked and may be signed.

If more than a small amount of material will be collected, the material collected will be sold or used for commercial purposes, or if the area is withdrawn from mineral entry, you must ask the local District Ranger's office whether permits are required and what fees must be paid.

If you are not sure about the status of the area, district personnel will also be able to tell you if the area is actually open to collecting and if sensitive resources may be impacted. Contact with district offices before you collect may prevent any later misunderstanding.

The Forest Service encourages public recreation on National Forest lands. However, visitors must be sensitive to their impacts on the environment. Fish habitat and water quality are of special concern when gold panning or suction dredging takes place. Rockhounds should refill and revegetate any small excavations they have made.

The best way to ensure a bright future for rockhounding on the National Forests is to carefully comply with Federal and State laws and regulations. If you have questions or concerns, please contact the Forest Service office nearest your collecting area.

From a June 29, 1990, news release by J. D. Simmons, Wenatchee National Forest, 301 Yakima St. (P.O. Box 811), Wenatchee, WA 98801.

Sediment Retention (From page 2)

The total cost of the SRS, including fish bypass facilities and dredging and levee improvements, will be about $229 million. The State, Cowlitz County, and diking districts agreed in 1986 to contribute $32 million toward the 50-yr life of the project.

During Water Year 1989 (Oct. 1988-Sept. 30, 1989) measurements showed that 8.8 million yd^3 of suspended sediment was transported into the impound ment area. Of that amount, 6.8 million yd^3 settled out behind the SRS. Sediment loads below the SRS have now declined dramatically. (See Mount St. Helens - A ten-year Summary, Washington Geologic Newsletter, v. 18, no. 2, p. 4).

The Mount St. Helens SRS provides a unique opportunity to view, from State Route 504, our attempts to control the dynamic forces of nature.

Seismicity at Mount St. Helens, 1989 to mid-1990

by Patrick Pringle

While volcanoes like Hawaii's Kilauea and Alaska's Redoubt continue to capture headlines, Mount St. Helens quietly grumbles here in Washington State. Minor earthquakes continue under Mount St. Helens, although the activity does not seem to be building toward an eruptive event (Fig. 1). Because trends in earthquake activity are one of the most useful tools for monitoring a volcano, scientists continue to scrutinize even the most subtle seismic events.

Seismicity at Mount St. Helens remained at "background" levels for over two years following the latest dome building episode (October 21-24, 1986). Earthquake activity increased by a factor of four at the volcano during 1989, typically occurring as swarms of small earthquakes (less than magnitude 3 on the Richter Scale) that lasted for hours or several days. The earthquake hypocenters mostly were shallow (<6 km) during the first few episodes, but by October, earthquakes were occurring throughout the magma conduit. (See Fig. 2.)

The first significant earthquake swarm since the October 1986 extrusion began on February 17, 1989. Most of the earthquakes had foci at about 2.5 km depth, and the largest event was a magnitude 2. On February 18 and 19, additional events were recorded, all less than 1 km deep. Minor earthquake activity continued from March through July 1989, but no deformation of the lava dome accompanied the events.

A large increase in activity occurred on August 24. It began with a 95-second signal similar to that associated with ash/gas emission events observed in 1986. This event was followed by volcanic tremor, hundreds of small, closely spaced earthquakes, during the next several hours. Seismic activity continued for at least 8 hours at one crater seismic station. Tiltmeters on the north and west sides of the lava dome showed a minor response to the August 24 event, but no new ash deposits were discovered. Minor earthquakes and two smaller seismic events similar to those of August 24 also took place on August 25 and 31.

Sporadic seismic events continued throughout September and October. However, during mid-October the rate of earthquake occurrence increased markedly, as did the range of focal depths. Unlike the previous episodes of 1989, these hypocenters extended from the surface down to 11 km. The two largest events of October had magnitudes of 1.6 and 1.5. On December 7, a 5-hour episode of increased seismicity was recorded, and minor amounts of ash were discovered on the crater floor. The west side of the dome deformed several tens of centimeters as a result of that explosion.

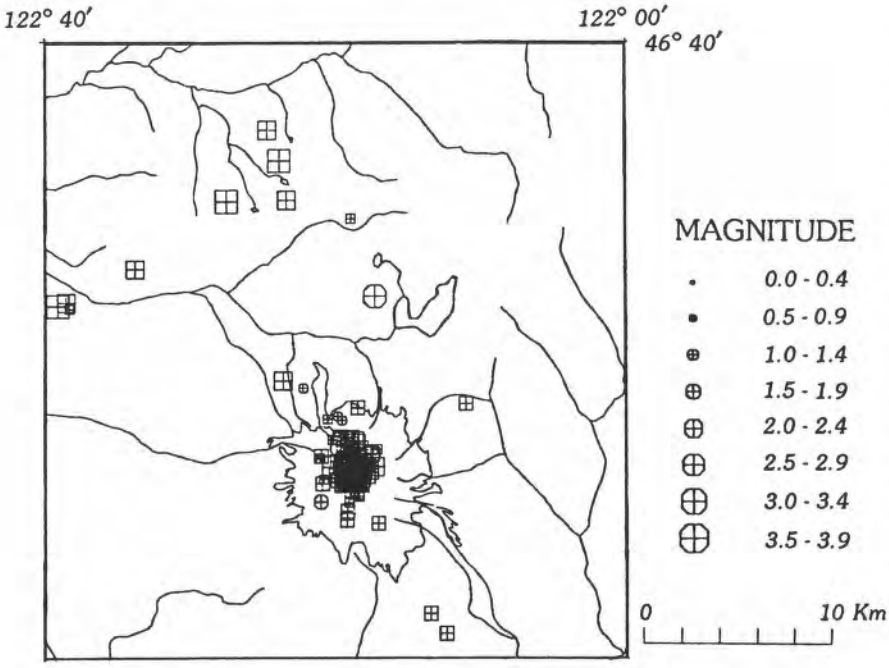


Figure 1. Earthquake epicenters at Mount St. Helens, Jan. 1-Feb. 28, 1990. Square symbols represent earthquakes at depths >3 km. Data from Chris Jonientz-Trisler, Univ. of Washington Geophysics Program.

The largest event in the series occurred early in the morning on January 6, 1990. Once again, a high-amplitude signal was followed by tremor for several hours. A small explosion generated an avalanche that destroyed one tiltmeter and a magnetometer station on the north side of the dome. Residents of Yakima and Toppenish reported a light dusting of ash, although no "juvenile" (new) pumice was discovered in the deposits. Geologists later noted that part of the lava dome's north sector moved down nearly 2 m to the north in response to the explosion. This deformation apparently occurred suddenly (as a slump) and not incrementally, as it would have if it were caused by new magma slowly pushing into the dome. Deformation of the dome following the slump event was negligible. Another smaller explosion occurred on April 25 and was followed by several hours of increased seismicity. No ashfall was reported.

Geologists at the Cascades Volcano Observatory and the University of Washington thus far have seen no evidence that the current seismic activity is building systematically toward a major eruptive event. The earth-

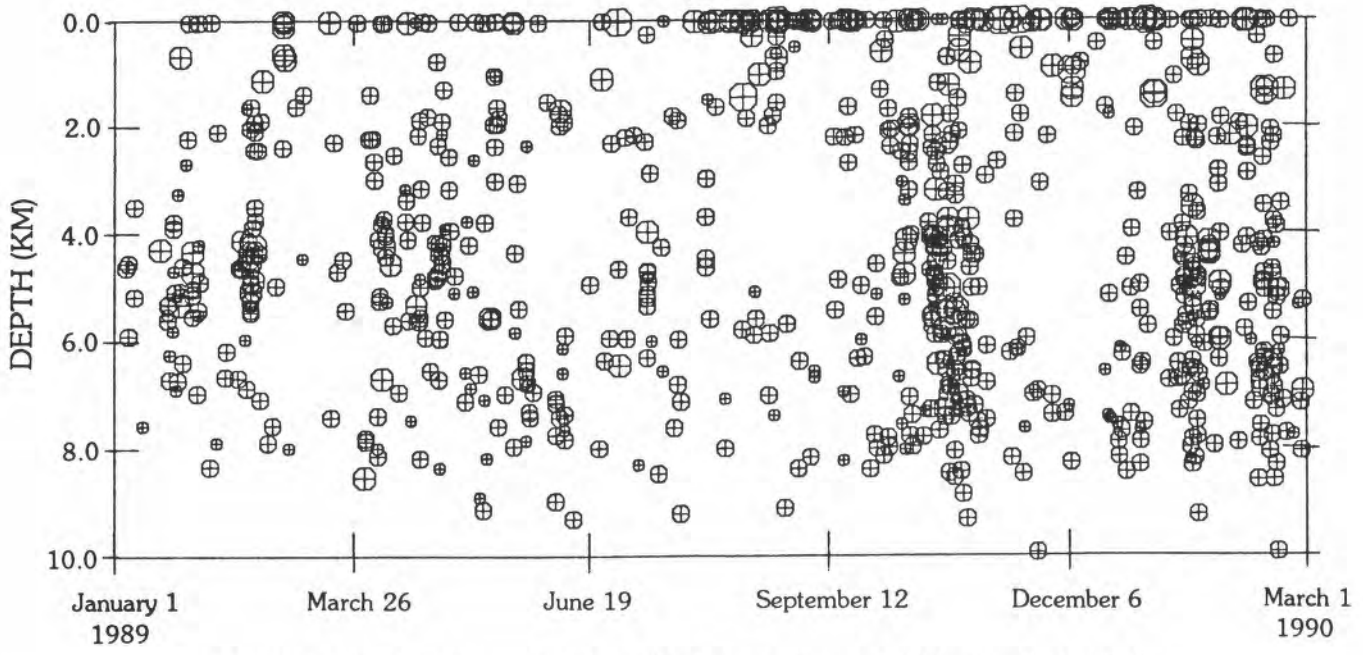


Figure 2. Earthquakes under Mount St. Helens, Jan. 1, 1989 - March 1, 1990.

quakes may have been caused by movement of fluids (gases) through the conduit. The cumulative seismic-energy release since the 1986 extrusion is lower than that before each previous eruptive event. This sluggish release of seismic energy suggests that the subvolcanic magma body may have released much of its volatiles and/or is becoming more crystalline.

Not all recent seismic activity at Mount St. Helens has been caused by volcanic or tectonic earthquakes. Numerous rockfall and snow avalanche events have generated seismic signals as well. A gradual-onset, low-amplitude signal of at least 30 minutes was recorded only on the HOA and PAK seismometers during the evening of January 10, 1990, and apparently was caused by a mudflow. These two seismometers are on the apron of pyroclastic debris several kilometers north of Mount St. Helens. A geologist working in the area observed that a relatively low-gradient portion of the debris avalanche had failed at Carbonate Springs (8 km [5 mi] NNW of the crater) and flowed as a mudflow at least 9 km (5.6 mi) down the North Fork Toutle River. The terminus of the mudflow deposit was located downstream of the Coldwater Lake outlet channel. Several severe rainstorms in early January apparently saturated the Carbonate Springs area and triggered the failure. The January 10 seismic signal was apparently caused by this rainfall-induced mudflow.

Rock Fracture Short Course Slated in Victoria

The University of Victoria's Division of University Extension and Community Relations will present a short course in Rock Fracture Mechanics Sept. 4-7, 1990, in the new Victoria Conference Centre in Victoria, British Columbia.

The course will provide a review of fundamentals, then go on to explore new and diverse applications of rock fracture mechanics. Topics covered will include problems of elasticity, laboratory testing, rock dynamics, numerical techniques, and new initiatives.

Instructors will be Joanne Wegner, a University of Victoria engineering professor, and Hans Peter Rossmanith, a guest lecturer from the Technical University of Vienna.

Additional information can be obtained from Jeanette Muzio, program coordinator, Computer Based Information Systems, Division of University Extension and Community Relations, Box 1700, Victoria, B.C. V8W 2Y2 (604 721-8459).

Staff Notes

Jo Roller, who has been with the Department of Natural Resources for nearly 10 years, became the Division's Administrative Assistant 2 on July 9. She was a Human Resource Assistant 2 with the Central Region in Chehalis for the last six years. Prior to that, she was a Clerk Typist 3 with the Fire Control Division in Olympia and the Timber Sales Division, also in Olympia. She began State service in February 1980 as a Clerk Typist 3 with the Utilities and Transportation Commission in Olympia. She transferred to the Department of Natural Resources eight months later.

Roller, the former Jo Ann Noonan, has a strong background in personnel and fiscal matters.

Arnold Bowman

Arnold Bowman has retired as the Division's Natural Resource Research Technician after completing 22 years of State service. He served under three State Geologists: M. T. Huntting, V. E. Livingston, Jr., and Raymond Lasmanis. Bowman (as he is called by his co-workers) joined the Division after 20 years of U.S. Army duty. He ended his military career as a Medical Specialist.

Bowman started his "second career" in 1967 as a Lab Helper. During his years with the Division, he acquired a reputation as a master maker of thin sections. He provided many other laboratory services, including micropaleontological sample processing and specimen mounting, emission spectrophotometry, X-ray diffractometry, X-ray fluorescence, and sieve analysis.

Bowman plans to spend his retirement playing golf, traveling with his wife, Stacey, and continuing his hobby of woodworking.

Michael A. Korosec left the Division in May to run his own business. Mike started work with the Division in July 1978 as a Geologist 2; he became a Geologist 3 a year later. He spent considerable time evaluating the eruptive events at Mount St. Helens and developing explanatory information for the media and the public. He also conducted several federally funded geothermal exploration projects involving drilling to determine heat flow and temperature gradients in the Cascade Range and evaluating low-temperature geothermal resources statewide. Many of Mike's publications were related to his geothermal work; these include GM-25, a 1:500,000-scale map of geothermal resources in Washington, and Open File Reports (OFR) 82-3 and 83-7, as well as several National Technical Information Service reports. Mike compiled geologic maps of two 1:100,000-scale quadrangles (OFRs 87-5, 87-6, for Mount Adams and Hood River, respectively) in the southwest quadrant of the state and collaborated on preparation of three quadrangles in the northeast quadrant (OFR 90-6, Banks Lake quadrangle; 90-9, east half of the Twisp quadrangle; and the 90-12, Omak quadrangle). He is also an author of GM-34, Geologic map of Washington—Southwest quadrant.

We also have said goodbye to **Susan P. Davis**, our Administrative Assistant 2 for nearly 5 years. Susan came to the Division from a similar position in the Department of Fisheries. She supervised the day-to-day

Mike Korosec

Susan Davis

business support functions, including clerical services, telephones and mail, and publication sales during a period when demand for such support grew tremendously but when the fraction of the Division's budget devoted to this support remained nearly static. Susan left us in May for an opportunity in the private sector.

USGS Engaged in Southeast Mapping Update

A 1,300-mi^2 area of agricultural country in southeastern Washington is being mapped this summer by surveyors, cartographic technicians and field assistants with the U.S. Geological Survey.

The USGS crew is collecting and field-checking data that will be used to update 25 7.5-minute, 1:24,000-scale maps of an area that includes Benton, Franklin, and Walla Walla counties in Washington and a thin strip of Umatilla County in Oregon.

The Snake River Revision Project, as designated by the USGS, is being done at the request of the U.S. Army Corps of Engineers. The mapping project is strictly a government effort to update standard topographic maps, according to USGS district cartographer Bill Olson in Denver, and is not concerned with any commercial development.

The original 7.5-minute maps of the area that were produced in 1966 have not been updated since 1973. The new maps will be available in about three years.

Members of the mapping crew, while they are in the Tri-Cities area, are available to talk to groups and interested individuals about the Snake River project and the USGS mapping program. Gary Bohren, the project supervisor, can be reached by dialing (206) 696-7904. Or inquiries can be directed to Olson at the USGS Rocky Mountain Mapping Center, Mail Stop 509, Box 25046, Denver Federal Center, Denver, CO 80225, phone (303) 234-5812.

1990 Geological Projects, Washington Colleges and Universities

This list is taken from material submitted, by press time, by the geology departments of the state's colleges and universities. Names in parentheses with the faculty projects are student collaborators; with student projects, these are faculty collaborators unless otherwise noted. Affiliations other than with the pertinent college or university are bracketed. Some projects involve areas outside Washington.

Eastern Washington University

Faculty Projects:

Mineralogy of the Golden Horn batholith, North Cascades, Washington—*Russell C. Boggs*

Structural states of feldspars as an indicator of sedimentary provenance—*Russell C. Boggs*

Mineralogy of the Sawtooth Batholith, Idaho—*Russell C. Boggs*

Geomorphic mapping of Blue Creek to evaluate the potential for enhancing fish habitat—*John P. Buchanan*

Geomorphic study of Cee Cee Ah Creek, Pend Oreille County, Washington—*John P. Buchanan*

Hydrogeology of Deer Lake, Stevens County, Washington—*John P. Buchanan*

Hydrogeology of Long Lake, Spokane and Stevens Counties, Washington—*John P. Buchanan*

Radon gas distribution in cave systems in the Pacific Northwest—*John P. Buchanan*

Survey of karst features in the Pryor Mountains, Montana—*John P. Buchanan*

Mineral inventory of Jewel Cave, Black Hills, South Dakota—*John P. Buchanan*

Permian bryozoans of the carbonate units of the Mission Argillite, northeastern Washington—*Ernest H. Gilmour*

Biostratigraphic studies of Pennsylvanian and Permian bryozoans in North America and Pakistan—*Ernest H. Gilmour*

Carbonate petrology and paleoecology of the Antler Peak Limestone, northeastern Nevada—*Ernest H. Gilmour*

Rare earth element geochemistry of gold deposits—*Mohammed Ikramuddin*

Distribution of immobile trace elements in hydrothermally altered rocks associated with various types of gold deposits—*Mohammed Ikramuddin*

Thallium--a potential guide to mineral deposits—*Mohammed Ikramuddin*

Geochemistry of sediment-hosted precious metals deposits—*Mohammed Ikramuddin*

Development of new analytical methods by inductively coupled argon plasma and electrothermal atomic absorption—*Mohammed Ikramuddin*

Geochemistry of granitic rocks of northeastern Washington—*Mohammed Ikramuddin*

Hydrogeochemical and biogeochemical methods of exploration for gold and silver—*Mohammed Ikramuddin*

Geochemistry of platinum group elements—*Mohammed Ikramuddin*

Geochemistry of volcanic rocks and its relationship to gold-silver mineralization—*Mohammed Ikramuddin*

Use of cesium as a guide to mineral deposits—*Mohammed Ikramuddin*

The use of boron in gold exploration—*Mohammed Ikramuddin*

Reconnaissance lithogeochemical survey of northwest Pakistan—*Mohammed Ikramuddin*

Study of toxic elements in environmental samples—*Mohammed Ikramuddin*

Chemical analysis of ultrapure electronic materials—*Mohammed Ikramuddin*

Glacial and catastrophic flood history of eastern Washington—*Eugene P. Kiver*

Quaternary map of northeastern Washington east of the Okanogan River—*Eugene P. Kiver*

Geology of national parks—*Eugene P. Kiver*

Structure and stratigraphy of the Middle Paleozoic Antler Orogen in northwestern Nevada—*Linda B. McCollum*

Stratigraphy, sedimentology, and paleontology of the Cambrian System of the Great Basin—*Linda B. McCollum*

Paleozoic continental margin sedimentation in western U.S.—*Linda B. McCollum*

Transcurrent faulting and suspect terranes in the Great Basin—*Linda B. McCollum*

Alkaline igneous rocks and related precious metal deposits—*Felix E. Mutschler*

Compilation of computer data base of whole-rock chemical analyses of igneous rocks—*Felix E. Mutschler*

Space-time tectonic and magmatic maps of the Cordillera—*Felix E. Mutschler*

Styolites in igneous rocks—*James R. Snook*

Geologic map of the Inchelium quadrangle, Washington—*James R. Snook*

Petrology of the Quartz Hill molybdenum deposit, Alaska—*James R. Snook*

Paleomagnetic investigation of glacial Lake Missoula flood deposits—*William K. Steele*

Use of remanent magnetization direction to correlate airfall ash deposits from Cascade volcanoes—*William K. Steele*

Mechanism of acquisition of remanent magnetization by airfall ash—*William K. Steele*

Student Projects:

Depositional interpretations of quartzite units in the middle part of the Precambrian Prichard Formation, western Coeur d'Alene mining district, Idaho—*Eugene N. J. St. Godard*

Microfacies study of the Antler Peak limestone, northern Nevada—*D. Chad Johnson*

The petrology and paleoecology of the Toroweap Formation, southeastern Nevada—*Laleh Mansoury*

Effects of hillslope development on quantity and quality of recharge to the Spokane Aquifer, Spokane, Washington—*Tammy L. Hall*

Saturated zone chemistry down-gradient from mine tailings ponds near Twisp, Washington—*Robert H. Lambeth*

Abundance of Te in selected gold deposits from western United States—*Mohammad Zafar*

Water budget analysis of the Deer Lake basin, Stevens County, Washington—*Bruce L. Siegmund*

Reconnaissance lithogeochemical survey of Chitral area, northwestern Pakistan—*Abdul G. Afridi*

Abundance and behavior of boron in some selected gold deposits—*David L. Payne*

Thallium in volcanic-hosted hot spring gold-silver deposits—*David A. Scorgie*

Geology along the Centennial Trail, Spokane County, Washington—*Cheery E. Arquero*

Fenestrate bryozoans of the Toroweap Formation, Muddy Mountains, Nevada—*Miriam E. McColloch*

Groundwater geochemistry down-gradient from a uranium mill tailings pond—*Ronald A. Stone*

Origin and mineralization of Colorado Plateau uranium-copper-bearing breccia pipes—*J. Michael Faurote*

Alkaline igneous rocks and related metal deposits—*Thomas C. Mooney*

Gold deposits in the alkaline rock igneous centers of Colorado—*Daniel W. Fears*

Biogeochemical methods of exploration for Archean gold deposits—*Richard B. Lestina*

Geology of the McCullough Creek area, Douglas County, Oregon—*Allen V. Ambrose*

Bryozoan biostratigraphy of the Phosphoria Formation, southeastern Idaho—*Robert C. Walker*

Sedimentation and mineralogical composition of the Latah Formation (Miocene), eastern Washington—*John D. Robinson*

FERROS--a computerized data base for Precambrian auriferous banded iron-formations and related rocks—*Glen R. Carter*

Geochemistry of igneous rocks from Newport and adjacent areas, northeastern Washington—*L. Christine Russell*

Upper Cambrian carbonate section in the Toano Range near Wendover, Nevada—*Joseph Drumheller*

Abundance and behavior of cesium, and selected trace elements in rock, soil and water samples from the Republic area, northeast Washington—*Wilfred H. Little*

Granite-molybdenite systems—North American Cordillera—*Curtis A. Hughes*

Mineralogy and geology of tungsten, molybdenum vein systems in northeastern Washington—*Dean G. Heitt*

Grays Harbor College

Faculty Project:

Recent coseismic subsidence events in Grays Harbor—*James B. Phipps*

Pacific Lutheran University

Faculty Projects:

Palynology and depositional environments of Pleistocene sea cliff deposits north of Kalaloch, Washington—*S. R. Benham*

Origin and chemical analysis of vivianite from the Kalaloch area, Olympic Peninsula, Washington—*S. R. Benham and F. L. Tobiason (M. J. Thielman)*

Petrology of rocks in the White Pass (Cascade Mountains) area, Washington—*B. L. Lowes (Kenneth Gardner)*

Tacoma Community College

Faculty Project:

Roadside guide to the geology of Mount Rainier National Park—*Jack H. Hyde*

University of Washington, Geophysics Program

Faculty Projects:

Geomagnetic induction, magnetotellurics, inverse theory, geophysical fluid dynamics—*John R. Booker*

Experimental and theoretical mineral and rock physics—*J. Michael Brown*

Seismology and geophysical inverse theory—*Kenneth C. Creager*

Seismology, structure and tectonics, earthquake hazards—*Robert S. Crosson*

Processes of lithosphere generation and consumption using seismology, gravity, and magnetics—*Brian T. R. Lewis*

Seismicity of Mount St. Helens, the Cascade volcanoes, and eastern Washington; computer applications in seismic network analysis—*Stephen D. Malone*

Geomagnetism, geophysics of solids, rock magnetism—*Ronald T. Merrill*

Earthquakes associated with volcanoes and glaciers, earth-structure and earthquake hazards—*Anthony Qamar*

Seismology, earthquake risk, seismotectonics—*Stewart W. Smith*

Washington State University

Faculty Projects:

Geochemical evolution in shallow groundwaters of the interior plains—*C. Kent Keller*

Exploration targets for the next century – metals in the metasomatic environment—*Lawrence D. Meinert*

Geologic and geohydrologic site characterization studies, Hanford site, Washington—*David R. Gaylord and Eileen P. Poeter*

Eolian morphology, sedimentology, and paleoclimatic significance, Hanford site, Washington—*David R. Gaylord*

Sedimentology and stratigraphy of middle Eocene volcanogenic deposits, northeastern Washington and southern British Columbia—*David R. Gaylord*

Biostratigraphic analysis of three potential mid-Carboniferous boundary stratotypes in the Great Basin—*Larry E. Davis with Gary D. Webster.*

Project ERUPT – Educational Resources for Understanding Plate Tectonics—*Larry E. Davis with Donald C. Orlich*

The significance of orogen-parallel lineations—*A. John Watkinson*

Refold geometries observed in the Loch Monar region, Scotland—*A. John Watkinson*

Refold analysis of multiply deformed mines and mining districts—*Richard L. Thiessen*

Geophysical investigations of the cratonic margin in the Pacific Northwest—*Richard L. Thiessen*

Structural analysis of the central Columbia Plateau utilizing radar, Landsat, digital topography, and magnetic data bases—*Richard L. Thiessen*

A three-dimensional computer analysis of modelling system for remote sensing-structural geologic problems—*Jay R. Eliason*

Application of Geologic Spatial Analysis to gas exploration in West Virginia—*Richard L. Thiessen*

Deformation along the Olympic-Wallowa lineament, Oregon and Washington—*Peter R. Hooper*

The Columbia River basalts in the Lewiston Basin and along the Blue Mountains uplift (Oregon and Washington)—*Peter R. Hooper*

Primitive basalt flows in the Pacific Northwest—*Peter R. Hooper (David G. Bailey and Richard M. Conrey)*

Paleomagnetism of volcanics in the Pacific Northwest—*Peter R. Hooper, William K. Steele* [Eastern Washington Univ.] *(David G. Bailey, Richard M. Conrey, Kevin M. Urbanczyk and Sandra P. Lilligren*

Alkali basalts and ultramafic nodules of eastern China—*Fan Qicheng [Institute of Geology, Beijing, China] and Peter R. Hooper*

Alkali basalts of the Harrats of Saudi Arabia—*Victor E. Camp [USGS] and Peter R. Hooper*

Deccan basalts—*Peter R. Hooper, John Mahoney [Univ. of Hawaii] (John E. Beane)*

Student Projects:

A hydrogeologic investigation of a fractured bedrock aquifer near Lyons, Colorado—*John A. Rohde (C. Kent Keller)*

Geologic controls on carbon dioxide flux and the carbon mass balance in two vadose zones—*Brian D. Wood (C. Kent Keller)*

Geologic controls on numbers and diversity of microbes in two vadose zones—*Karen J. Severson (Don L. Johnstone and C. Kent Keller)*

Mass flux and fate of agricultural nitrate in groundwater as a function of slope position—*Debi J. Farnsworth (C. Kent Keller, Jeffrey L. Smith, soil chemist, and Don L. Johnstone)*

Vertical hydraulic conductivity of Palouse loess as a function of slope position—*George E. Johnson (C. Kent Keller)*

Gold skarn mineralization at the Buckhorn prospect, Okanogan County Washington—*Robert J. Hickey III*

Geology and geochemistry of gold skarn mineralization in the McCoy mining district, Lander County, Nevada—*Jeffrey W. Brooks*

Geology of the Tillicum gold skarn camp, British Columbia—*Dean M. Peterson*

Gold mineralization in skarn and carbonate replacement bodies, New World mining district, Park County, Montana—*Todd W. Johnson*

Gold skarn mineralization in the Fortitude deposit, Lander County, Nevada—*Greg L. Myers*

Gold skarn mineralization in clastic host rocks, Beal mine, Montana—*Kurt M. Wilkie*

Regional stratigraphy and sedimentology of the upper Sanpoil Volcanics and Klondike Mountain Formation in the Republic, First Thought, and Toroda Creek grabens, Washington and southern British Columbia—*James D. Suydam*

Sedimentology and stratigraphy of upper Sanpoil Volcanics and the Klondike Mountain Formation, Republic mining district—*Scott M. Price*

Sedimentology, stratigraphy and paleoclimatic implications of eolian deposits on the Hanford site, Washington—*Larry D. Stetler*

Sedimentology and geoarchaeology of eolian deposits on the Hanford site, Washington—*Grant D. Smith*

Stratigraphy and sedimentology of the O'Brien Creek Formation, northeastern Washington and southern British Columbia—*Jeffrey M. Matthews*

Stratigraphy, sedimentology, and depositional history of the Upper Cretaceous Beaverhead Conglomerate, McKnight Canyon, southwest Montana—*Holly J. Corner*

Kinematics and strain in the Lincoln gneiss dome, northeast Washington—*Jay P. Busch (A. John Watkinson)*

Refold geometries at the Richmond Hill mine, northern Black Hills, South Dakota—*Erik D. Weberg*

Fracture patterns and fold related strain using examples from the Yakima Fold Belt, Washington, and the Montana fold and thrust belt—*Sarah M. Koerber (A. John Watkinson)*

Geologic analysis of a portion of the Weatherbee Formation, northeastern Oregon—*Rebecca Myers*

Correlation of fractures observed using a televiewer in the Cajon Pass DOSSEC drill hole with ones determined from Geologic Spatial Analysis applied to topographic data bases—*Mark Ader*

Structural analysis of the West Idaho Suture Zone—*David E. Blake*

Identification of range front fault scarps using digital topography data bases and application to the Wasatch Front, Utah—*Douglas S. Neves*

Determination of the three-dimensional orientation and location of faults using earthquake foci and application to the Puget Sound—*Eric Rieken*

Mt. Jefferson and the Oregon Cascades—*Richard M. Conrey*

The Powder River Volcanics, Oregon—*David G. Bailey*

Syenites around the Idaho Batholith, Idaho—*D. Kate Schalck*

Colville Batholith and Sanpoil Volcanics—*Charles M. Knaack and Laureen J. Wagoner*

The volcanic rocks of the eastern Clarno—*Kevin M. Urbanczyk and Sandra P. Lilligren*

Western Washington University

Faculty Projects:

Granitoid composition and tectonic setting in the crystalline core of the North Cascades—*R. Scott Babcock*

Chemistry of the Skagit migmatites—*R. Scott Babcock (Donna Whitney, Univ. of Washington)*

Geochemistry, paleomagnetism, and paleotectonics of the Crescent Formation and related mafic igneous rocks in the Washington and Oregon Coast ranges—*R. Scott Babcock, David C. Engebretson, and Russell F. Burmester (Andrew Warnock)*

Metamorphic and structural geology of the Cascade River area, North Cascades—*E. H. (Ned) Brown*

Thermoluminescence dating of Pleistocene sediments—*Don J. Easterbrook and Glenn W. Berger*

Chronology of early Pleistocene glaciations in Washington—*Don J. Easterbrook*

Revision of Quaternary chronology in the Puget Lowland—*Don J. Easterbrook*

Causes of debris torrents in northern Washington—*Don J. Easterbrook*

Estimating ancient stream discharges of paleofloods—*Don J. Easterbrook*

A new determination of Pacific-Kula relative motions—*David C. Engebretson (Harold Cashman)*

Student Projects:

Relative sea-level changes for the late Holocene determined from salt marsh stratigraphy at six Puget Sound sites—*Harriet G. Beale*

The geochemical significance of coeval mafic potassic and calc-alkaline plutonism within the Similkameen batholith, north-central Washington, south-central British Columbia—*Andrew M. Buddington*

Tidal flushing characteristics of the proposed Lummi Bay Marina, Whatcom County, Washington—*William M. Watts*

Paleogeographic reconstruction of the Crescent terrane on the Olympic Peninsula—*Andrew C. Warnock*

Whitman College

Faculty Projects:

Glacial geology of the Elkhorn Mountains, northeastern Oregon—*Robert J. Carson (Bradley W. Thurber)*

Glacial geology of the Medicine Bow Mountains, Wyoming— *Robert J. Carson (Caleb H. Thompson)*

Quaternary geology of the Hood Canal area, western Washington—*Robert J. Carson*

Small mammal fauna from the Touchet beds, Walla Walla Valley, Washington—*Patrick K. Spencer*

Pre-late Wisconsin catastrophic glacial flood deposits, Walla Walla Valley, Washington—*Patrick K. Spencer (Amanda Vrooman)*

Small mammal fauna from Mount Mazama tephra, southeastern Washington—*Patrick K. Spencer*

Contact metamorphism around the Wallowa Batholith, Aneroid Lake, Oregon—*John D. Winter (Emily Sklar)*

Geochronology, deformational history, and metamorphic conditions of the Archean rocks of northern Labrador—*John D. Winter*

Geologic evolution of the Archean rocks of the Angmagssalik area, East Greenland—*John D. Winter*

Current Academic and Federal Projects

Annette B. Tucker and *Rodney M. Feldman* of the Geology Department at Kent State University in Ohio are studying late Eocene-early Miocene deep-water decapods from the Twin River Group of Washington. Tucker plans to complete her dissertation in 1992.

Terrance M. Gerlach, of the U.S. Geological Survey (Denver), has started a 6-year study of the role of volatiles in volcanic and shallow magmatic systems. He will use geochemical data to develop and test hypotheses for the mechanisms, thermodynamics, and rates of processes in mass and transport of volatiles in these systems. Further, he will develop and evaluate gas-based methods for volcano monitoring and eruption forecasting. Study results should assist in interpreting the formation of geothermal systems and ore deposits, the role of degassing as a source of volatiles for biogeochemical cycles, and environmental changes. Samples from Mount St. Helens will be included in the study.

Selected Additions to the Division of Geology and Earth Resources Library

April 11, 1990 through June 18, 1990

THESES

Anderson, James Lee, 1987, The structural geology and ages of deformation of a portion of the southwest Columbia Plateau, Washington and Oregon: University of Southern California Doctor of Philosophy thesis, 283 p.

Bradley, Jeffrey Brent, 1986, Hydraulics and bed material transport at high fine suspended sediment concentrations: Colorado State University Doctor of Philosophy thesis, 140 p.

Brown, B. J., 1987, Sediment transport in hyperconcentrated flows in sand-bed streams of volcanic origin: Colorado State University Doctor of Philosophy thesis, 169 p.

Cupp, Creth Edward, 1989, Identifying spatial variability of stream characteristics through classification: University of Washington Master of Science thesis, 92 p.

Echelmeyer, Keith Alan, 1983, Response of Blue Glacier to a perturbation in ice thickness—Theory and observation: California Institute of Technology Doctor of Philosophy thesis, 342 p., 1 plate.

Kok, Hans, 1989, Freeze-thaw induced variability of soil shear strength: University of Idaho Doctor of Philosophy thesis, 183 p.

McGroder, Michael F., 1988, Structural evolution of the eastern Cascades foldbelt—Implications for late Mesozoic accretionary tectonics in the Pacific Northwest: University of Washington Doctor of Philosophy thesis, 140 p.

Reneau, Steven Lee, 1988, Depositional and erosional history of hollows—Application to landslide location and frequency, long-term erosion rates, and the effects of climatic change: University of California at Berkeley Doctor of Philosophy thesis, 328 p.

U.S. GEOLOGICAL SURVEY REPORTS

Published Reports

Doukas, M. P., 1990, Road guide to volcanic deposits of Mount St. Helens and vicinity, Washington: U.S. Geological Survey Bulletin 1859, 53 p.

Carter, L. M. H., editor, 1990, USGS research on energy resources—1990, program and abstracts; Sixth V. E. McKelvey forum on mineral and energy resources: U.S. Geological Survey Circular 1060, 99 p.

Peddie, N. W.; Zunde, A. K., 1990, Magnetic models for the United States for 1985: U.S. Geological Survey Circular 1039, 26 p.

Porcella, R. L.; Switzer, J. C., compilers, 1989, Catalogue of U.S. Geological Survey strong-motion records, 1987: U.S. Geological Survey Circular 1044, 44 p.

Walker, G. W., editor, 1990, Geology of the Blue Mountains region of Oregon, Idaho, and Washington—Cenozoic geology of the Blue Mountains region: U.S. Geological Survey Professional Paper 1437, 135 p.

Yeend, Warren; Shawe, D. R.; Wier, K. L., 1989, Gold in placer deposits: U.S. Geological Survey Bulletin 1857-G, 19 p.

Open-File Reports

Bargar, K. E., compiler, 1990, Publications of the Volcano Hazards Program, U.S. Geological Survey, 1986-1989: U.S. Geological Survey Open-File Report 90-277, 18 p.

Driedger, C. L., 1988, Geology in action--Jokulhlaups on Mount Rainier: U.S. Geological Survey Open-File Report 88-459, 2 p.

Orndorff, R. C.; Dodd, Kurt; Gunnells, G. B.; Sakss, Yula, 1989, Computer programs released as U.S. Geological Survey publications through August 1989: U.S. Geological Survey Open-File Report 89-681, 70 p.

Yount, J. C.; Vick, G. S.; McCoy, Gail, 1990, Geotechnical drill-hole logs from the southern Seattle area, Washington: U.S. Geological Survey Open-File Report 90-90, 143 p., 1 plate.

REPORTS ON WASHINGTON GEOLOGY, SOILS, HYDROLOGY, AND MINERAL RESOURCES

Earth Sciences Associates; Geo Recon International, 1986, Geologic and seismic investigations of Oregon offshore dredge disposal sites: U.S. Army Corps of Engineers, 63 p.

Geological Survey of Canada, 1989, Program and abstracts/programme et sommaires—Cordilleran geology and exploration roundup/Forum sur l'exploration et la géologie de la cordillère: Geological Survey of Canada, 1 v.

Geomatrix Consultants, Inc.,1990, Seismotectonic evaluation, Walla Walla section of the Columbia Plateau geomorphic province; final report: Geomatrix Consultants, Inc. [under contract to] U.S. Bureau of Reclamation, 1 v., 6 plates.

James, L. G.; Ley, T. W.; Sonnichsen, R. P.; Butcher, W. R.; Whittlesey, N. K., 1989, Irrigation water use efficiency demonstration project; Phase I--State-wide evaluation of irrigated areas: Washington Water Research Center Report 75, 116 p.

Juul, S. T. J.; Funk, W. H.; Moore, B. C., 1990, The effects of nonpoint pollution on the water quality of

the west branch of the Little Spokane River: Washington Water Research Center Report 76, 156 p.

Klungland, M. W.; McArthur, Michael, 1989, Soil survey of Skagit County area, Washington: U.S. Soil Conservation Service, 372 p., 67 plates.

Landry, M. R.; Hickey, B. M., editors, 1989, Coastal oceanography of Washington and Oregon: Elsevier Science Publishers Oceanography Series 47, 607 p.

Maley, T. S., 1990, Mining law from location to patent—Cumulative supplement, 1990: Mineral Land Publications [Boise, ID.], 156 p.

Maley, T. S., 1990, Mineral title examination—Cumulative supplement, 1990: Mineral Land Publications [Boise, Id.], 68 p.

Manson, C. J., compiler, 1990, Bibliography and index of the geology and mineral resources of Washington, 1981-1985: Washington Division of Geology and Earth Resources Bulletin 79, 484 p.

McCord, J. T.; Moore, B. C.; Searcy, C. C., 1989, Hydrological and limnological study of Ken Lake, Washington: Washington Water Research Center Report 74, 27 p.

McMillan, N. J.; Embry, A. F.; Glass, D. J., editors, 1988, Devonian of the world—Proceedings of the Second International Symposium on the Devonian System: Canadian Society of Petroleum Geologists Memoir 14, 3 v.

Northern Miner Press, Ltd., 1990, American mines handbook, 1990: Northern Miner Press, Ltd., 312 p., 1 plate.

Okanogan County Planning Department, 1990, Okanogan County, draft environmental impact statement, land use regulations and wildlife plan and guidelines: Okanogan County Planning Department, 1 v.

Robinson, Lee, compiler and editor, 1990, Proceedings of the 1990 annual symposium on engineering geology and geotechnical engineering (no. 26): Idaho Department of Transportation, 1 v.

Scott, J. W.; Vasquez, C. R.; Newman, J. G.; Sarjeant, B. C., 1989, Washington—A centennial atlas: Western Washington University Center for Pacific Northwest Studies, 155 p.

Stoffel, K. L., compiler, 1990, Geologic map of the Oroville 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 90-11, 58 p., 1 plate.

Stoffel, K. L., compiler, 1990, Geologic map of the Republic 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources Open-File Report 90-10, 62 p., 1 plate.

U.S. Bureau of Land Management, 1990, [Mining claims of Washington and Oregon]: U.S. Bureau of Land Management, 55 sheets microfiche.

U.S. Environmental Protection Agency, 1990, Progress in ground-water protection and restoration: U.S. Environmental Protection Agency EPA 440/6-90-001, 52 p.

U.S. Forest Service, 1988, Earth's heat—Geothermal energy on the national forests of the Pacific Northwest: U.S. Forest Service, 12 p.

University of Washington Geophysics Program, 1990, Quarterly network report 90-A on seismicity of Washington and northern Oregon, January 1 through March 31, 1990: University of Washington Geophysics Program, 23 p.

Watters, R. J., editor, 1989, Engineering geology and geotechnical engineering—Proceedings of the 25th symposium on engineering geology and geotechnical engineering: A. A. Balkema [Rotterdam], 420 p.

Watters, T. R.; Golembek, M. P., editors, 1989, MEVTV workshop on tectonic features on Mars: Lunar and Planetary Institute [Houston, Tex.] Technical Report 89-06, 126 p.

Mineralogists Slate NW Symposium

Ore Minerals will be the theme of the 16th annual Mineralogical Symposium of the Pacific Northwest Chapter, Friends of Mineralogy, September 28-30 at Alderbrook Inn near Union on Hood Canal.

The gathering will include dealers and exhibits. Lectures will be presented by such renowned collectors as Gilbert Gauthier of Paris, France (cobalt minerals from Shaba); Wayne Leicht of Laguna Beach, Calif. (gold); Bob Jones of Scottsdale, Ariz. (copper minerals of the world); and Ray Lasmanis (lead minerals).

Additional information can be obtained from Lasmanis, 910 Sleater Kinney Rd. S.E., Suite 155, Lacey, WA 98503.

New Division Releases

Two more reports covering 1:100,000-scale quadrangles in the northeast quadrant of Washington have been released:

Open File Report 90-12, Geologic map of the Omak 1:100,000 quadrangle, Washington, compiled by C. W. Gulick and M. A. Korosec. 52 pages, 1 plate. The price is $2.78 +.22 sales tax (Washington residents only) = $3.00.

Open File Report 90-13, Geologic map of the Colville 1:100,000 quadrangle, Washington-Idaho, compiled by Nancy L. Joseph. 78 pages, 1 plate. The price is $3.25 + .25 tax = $3.50.

Also available from the Division is the current edition of **Publications of the Washington Division of Geology and Earth Resources**. The 36-page guide lists annual reports, bulletins, reports of investigation, information circulars, reprints, geologic map series, topographic maps, general information pamphlets, regulatory information and open-file reports published by the Division. Also included is an author index. The guide is available free of charge.

Please add $1 for each order. The open-file reports and guide can be obtained from the Division's main office. (See page 2 of this Newsletter.)

Leasehold Tax Refunds for State Mineral Leases

The Washington Department of Revenue has recently changed its interpretation of RCW 82.29A.020 and ruled that the leasehold tax charged in the state of Washington does not apply to leases held for extractive purposes. The Department of Revenue is prepared to refund all leasehold tax paid on such leases since January 1, 1986. If you held a state mineral prospecting lease during that time period, and you paid leasehold tax, you may collect your refund by contacting Lennard Ball at the Department of Revenue at (206) 586-2082.

Keep Us Posted

If your address on this Newsletter is not exactly as you want it, please drop us a letter or card with the correct version. Thank you.

WASHINGTON STATE DEPARTMENT OF
Natural Resources

Division of Geology and Earth Resources
Mail Stop PY-12
Olympia, WA 98504

BULK RATE
U.S. POSTAGE
PAID
Washington State
Department of Printing