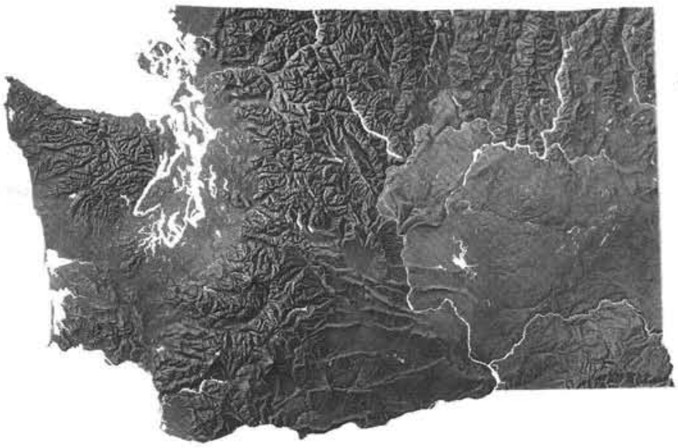
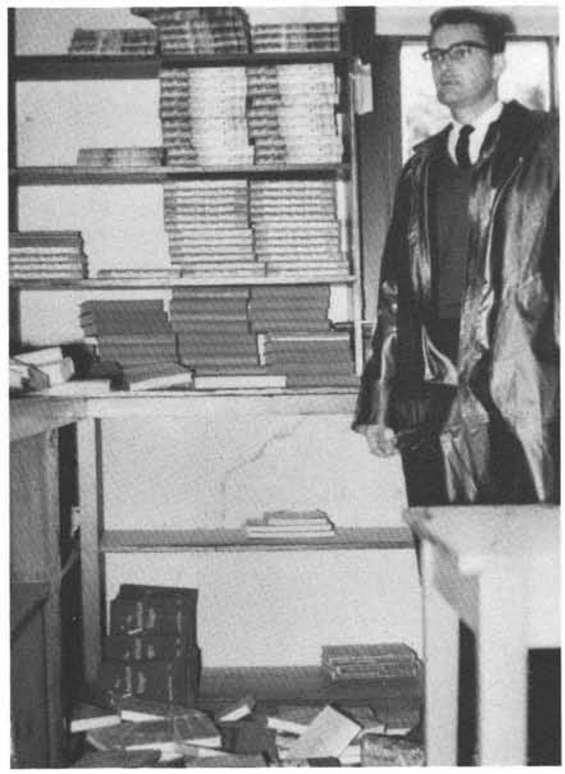
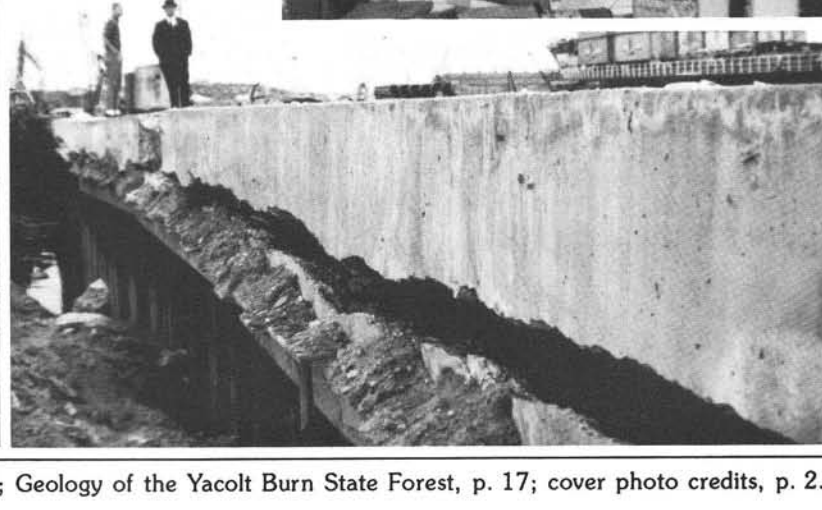


WASHINGTON GEOLOGY

formerly
WASHINGTON GEOLOGIC NEWSLETTER

Washington Department of Natural Resources, Division of Geology and Earth Resources Vol. 19, No. 2, June 1991





In This Issue: Washington seismicity, p. 3-15; Geology of the Yacolt Burn State Forest, p. 17; cover photo credits, p. 2.

WASHINGTON GEOLOGY

Washington Geology (formerly the Washington Geologic Newsletter) is published four times a year by the Washington Division of Geology and Earth Resources, Department of Natural Resources. This publication 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.

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Seismic Safety Advisory Committee

by Raymond Lasmanis

Records show that Washington state has been subject to documented damaging earthquakes since before the first settlers arrived here over the Oregon trail. Although the cause of Washington earthquakes was not fully understood prior to 1980, geologists have been informing appropriate decision makers about how to mitigate losses for a good many years. For example, a report dated October 30, 1925, by consultant Henry Landes (Washington State Geologist 1901-1921) to the Washington Surveying and Rating Bureau in Seattle provided information on earthquakes in Washington and potential mitigation measures. (See article, p. 8.) Landes wrote, "It is a matter of observation that the destructive effects of earthquakes on buildings are much less severe when they are erected upon bedrock as a foundation than upon soil alone. Especially is it true when the soil represents an artificial fill..."

The issue of seismicity in our state continues to be before us. During the 1989-90 session of the legislature, an act was passed to create a seismic safety advisory board. The legislative mandate reads as follows:

"The Department shall create a seismic safety advisory board to develop a comprehensive plan and make recommendations to the legislature for improving the state's earthquake preparedness. The plan shall include an assessment of and recommendations on the adequacy of communications systems, structural integrity of public buildings, including hospitals and public schools, local government emergency response systems, and prioritization of measures to improve the state's earthquake readiness. The Department shall report to the Senate and House of Representatives Committees on Energy and Utilities by December 1, 1991. An interim report shall be made to the Committees by December 1, 1990."

To implement the mandate, the Department of Community Development, Division of Emergency Management, formed a Seismic Safety Advisory Committee. Committee co-chairmen are Raymond Lasmanis, State Geologist, and Bob Lewis, General Manager of Cellular One. Other members are listed on page 31.

(Continued on p. 31)

Cover Photos: Damage in Seattle caused by the 1965 earthquake.

Top left: Brick veneer has become separated from the frame building in the Alki Point area.

Top right: Books were dislodged from classroom shelves at the Alki School; note the cracked wall.

Bottom left: This house was left with a twisted chimney.

Bottom right: The concrete in the dock broke, and the top portion was shifted to the right in this view.

All photos courtesy of K.V. Steinbrugge, consulting geologist (retired).

Modified Mercalli Intensity VI and Greater Earthquakes in Washington State, 1928-1990

by Stephen P. Palmer

INTRODUCTION

During the past four years, the National Earthquake Hazards Reduction Program has provided funds to the Division of Geology and Earth Resources for earthquake hazard studies. Data collection and analysis of historic earthquakes provide a basis for evaluating the state's earthquake hazards. The purpose of this article is to offer an overview of significant earthquakes in Washington state that occurred from 1928 through 1990. The areas affected by these earthquakes can be expected to experience similar, and perhaps larger, earthquakes in the future. Additionally, other areas that lack historical seismicity may also be subject to damaging earthquakes.

In 1928, the U.S. Coast and Geodetic Survey (USC&GS) seismological branch began systematic reporting of earthquake activity in the United States. This record is in the form of summaries of observations of damage and other phenomena associated with felt earthquakes from 1928 through 1984. The USC&GS established and incorporated the modified Mercalli intensity (MMI) scale (Wood and Neumann, 1931) in its reports starting in 1931. (Excerpts of this intensity scale are given in Table 1 of the article by R. Ludwin and A. Qamar in this issue, p. 13). The MMI data are summarized in publications by the seismological staff at the USC&GS and its functional successor, the U.S. Geological Survey (USGS). These publications are the primary sources of data used in preparing this article. Catalogs of pre-1928 Washington earthquakes are available (e.g., Bradford, 1935; Townley and Allen, 1939; Rasmussen, 1967; Coffman and von Hake, 1973), but these catalogs are not based on data collected by an organized reporting system—none was in place at the time of these earthquakes. Examination of the pre-1928 earthquake record will provide valuable information for evaluating earthquake risk in Washington. (See also Ludwin and Qamar, this issue, and the letter by Landes and Glover, p. 8.)

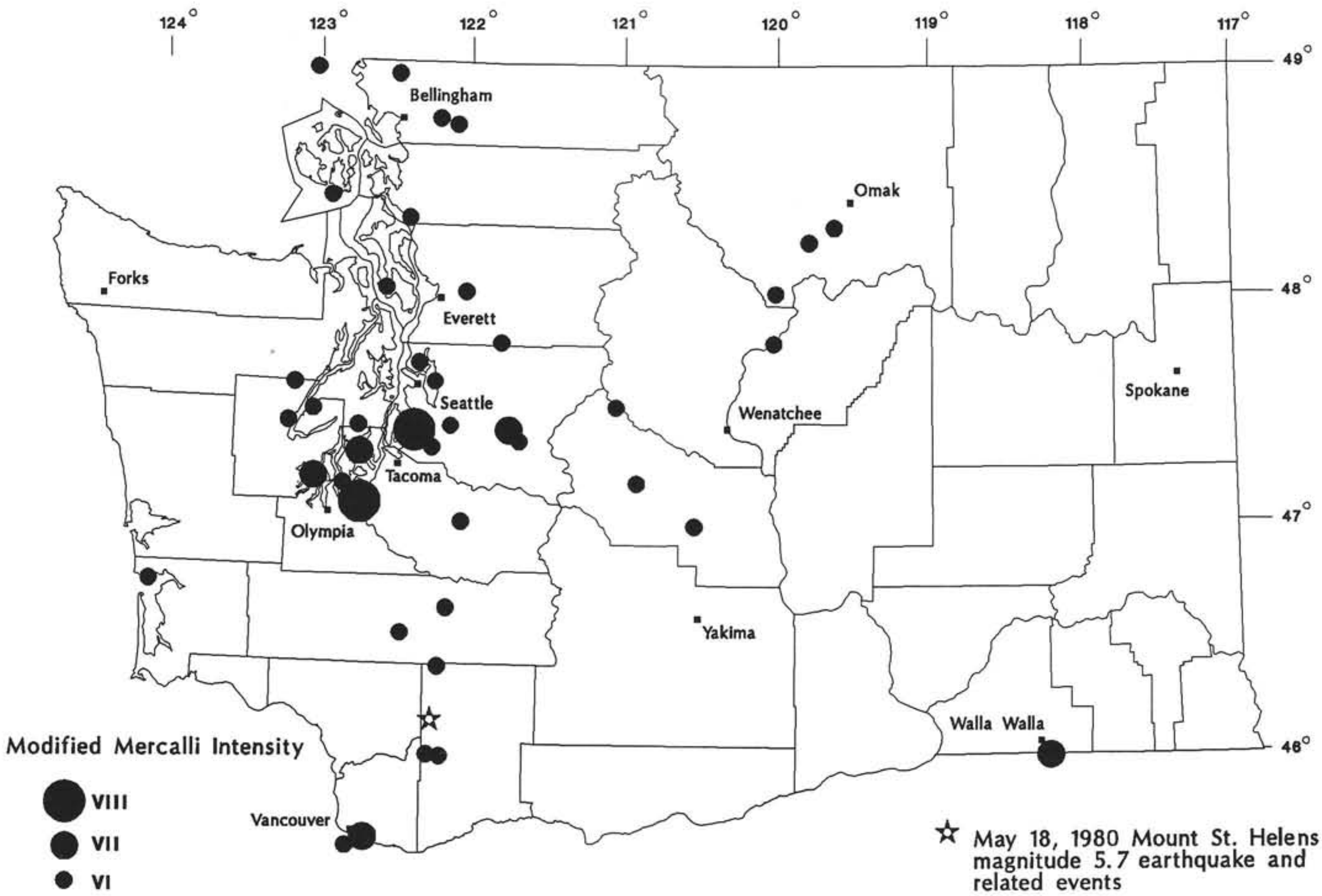

Figure 1. Approximate locations of modified Mercalli intensity VI or greater earthquakes during the period 1928-1990.

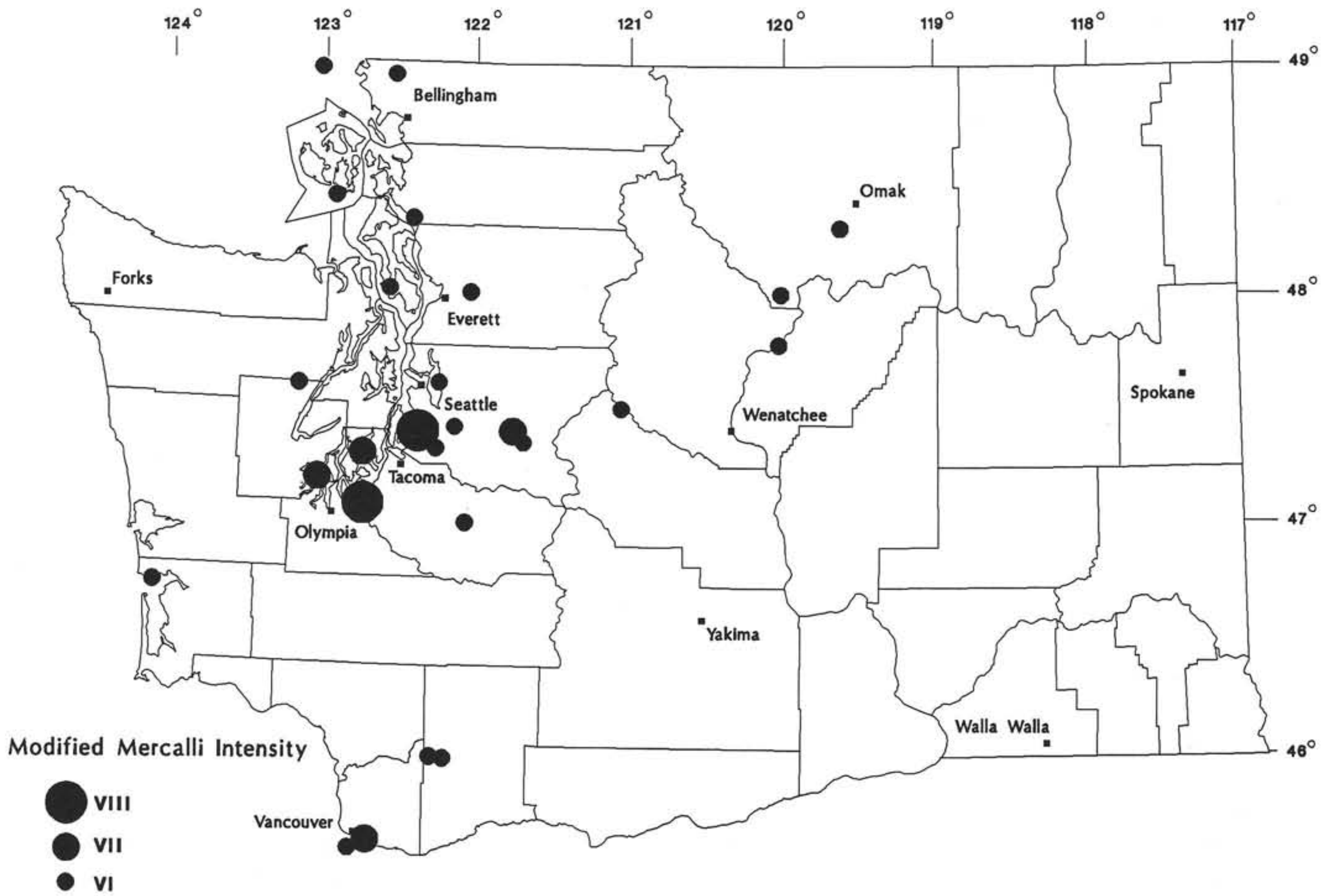

Figure 2a. Approximate locations of modified Mercalli intensity VI or greater earthquakes during the 27 years from 1939 to 1965.

MODIFIED MERCALLI INTENSITY REPORTS

The modified Mercalli intensity reported at a particular site depends on a multitude of factors, including earthquake magnitude (or energy release), distance of the site from the fault rupture, near-surface amplification of the seismic waves, and the type of building construction and interior furnishings typical of the site. Most important is that the site must be inhabited—people's observations of the earthquake phenomena provide the basic data used in assigning a modified Mercalli intensity.

From a regional perspective, the distribution of Mercalli intensities will be governed primarily by the magnitude and focal depth of the earthquake. A small magnitude, near-surface earthquake may produce MMI VI effects within a small area (perhaps only one town). However, a deeper, larger magnitude earthquake would produce MMI VI effects over a larger area, although in both of these hypothetical earthquakes, MMI VI is the highest intensity experienced. I have used the maximum reported Mercalli intensity, whether it was reported at only one site or at a number of sites distributed over a large area, and have not attempted to distinguish specific events based on the area of maximum reported intensity.

An MMI rating of VI was chosen as the threshold intensity of "significant" earthquakes for the following reasons:

- observed phenomena associated with intensities of V and VI are easily distinguished (Table 1 in Ludwin and Qamar),
- earthquakes at the MMI VI level are memorable because of the relative severity of the ground shaking, and
- earthquakes at the MMI VI level are perceived as significant because of the damage to and loss of personal items, the cracking of plaster and masonry, and the expense of repairing this damage.

The USC&GS and its functional successor at the USGS have provided the longest, most consistent reporting of earthquakes in Washington. Although instrumental data would be preferable because they provide an unbiased estimate of earthquake size, a complete instrumental record does not exist for pre-1960 earthquakes in Washington. The MMI scale was the most widely employed method of evaluating earthquake size in the U.S. until the late 1950s; by this time enough seismographs were operating nationally to allow instrumental measurement and location of most strongly felt

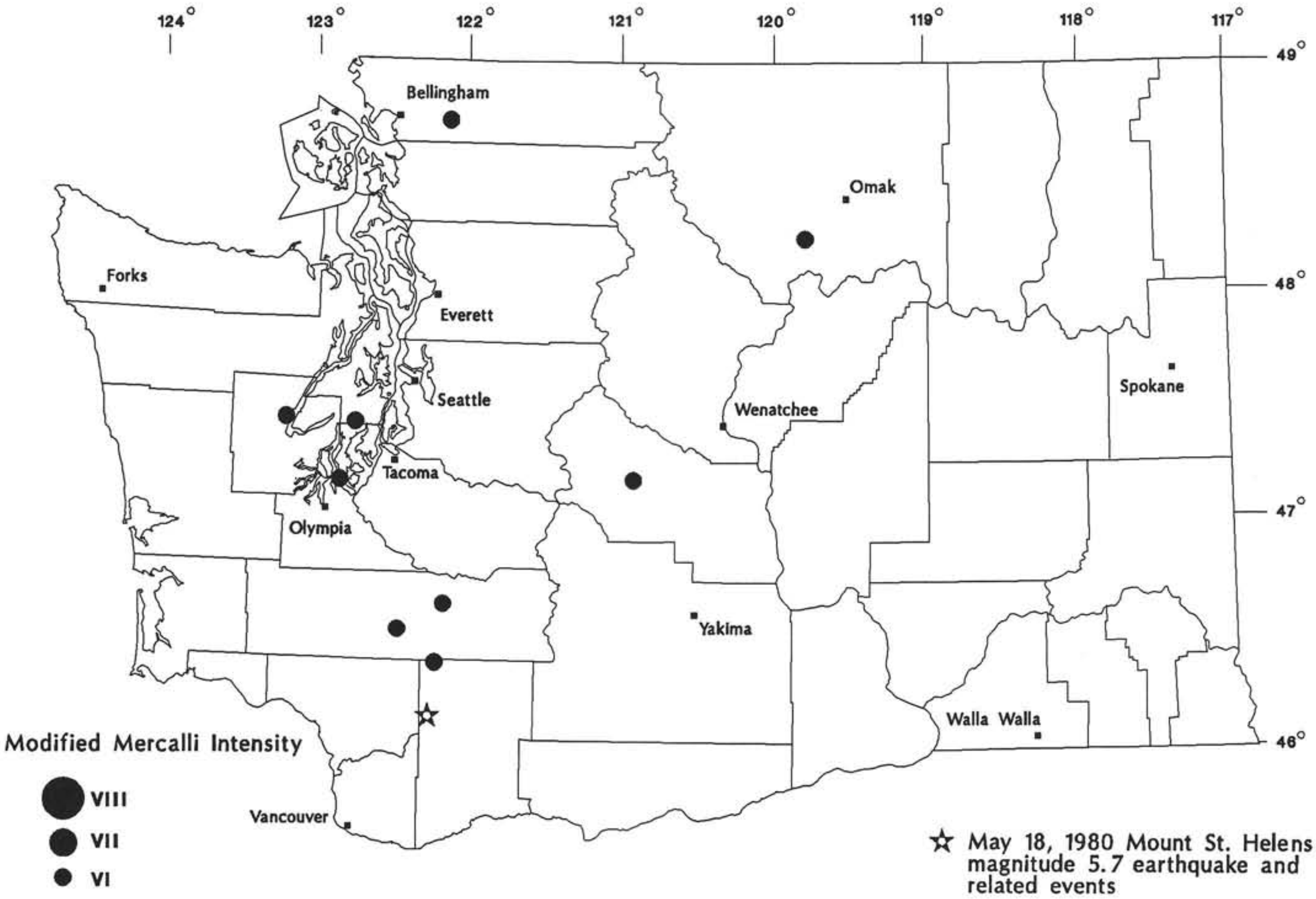

Figure 2b. Approximate locations of modified Mercalli intensity VI or greater earthquakes during the 26 years from 1966 to 1990. Note the much lower level of seismicity statewide in comparison to the 1939-1965 map.

earthquakes. Since 1970, Washington earthquakes have been well documented, both instrumentally and observationally, by researchers at the University of Washington and the USGS.

TEMPORAL AND SPATIAL PATTERNS OF SEISMICITY

I reviewed earthquake damage reports and intensity ratings provided in the cited references and other data sources and determined final intensity ratings for events of intensity VI and greater. Note that my list includes only earthquakes that occurred (had epicenters) within the state; some earthquakes in British Columbia and in nearby states have produced MMI VI effects in Washington, but are not included in this study. My intensity ratings are substantially in agreement with those given in Coffman and von Hake (1973) for earthquakes between 1928 and 1970.

Locations of all earthquakes rated as MMI VI or greater for the period 1928-1990 are plotted on Figure 1. For pre-1960 earthquakes, these locations should be considered only approximate; post-1960 epicenters were instrumentally determined and consequently are better located. Specific locations for earthquakes associated with the 1980 eruption of Mount St. Helens are not included on this map. These events occurred in response to transient local strain associated with the subsurface movement of magma and steam, not long-term strain caused by regional tectonic forces.

Earthquake locations are plotted in Figures 2a and 2b for the periods 1939-1965 and 1966-1990 respectively. A number of observations can be made from these seismicity maps. Between 1939 and 1965 there were 26 MMI VI or greater earthquakes in Washington. From 1966 to 1990 there were only nine MMI VI or greater earthquakes, excluding events directly related to the 1980 eruption of Mount St. Helens. Thus, the rate of earthquake occurrence during the later period is approximately one-third the rate from 1939 to 1965. Further, from 1939 to 1965, 17 intensity VI or greater earthquakes were located in the 11 counties adjacent to the Puget Sound; these counties have contained the majority of the state's population during this century. From 1966 to 1990 only four intensity VI earthquakes were located in this 11-county area, and no MMI VI earthquakes occurred in the Puget Sound region from 1966 to 1974 or from 1979 to 1989. Finally, no earthquakes of intensity VII or greater occurred statewide between 1966 and 1990, although there were four intensity VII and two intensity VIII earthquakes during the period 1939-1965.

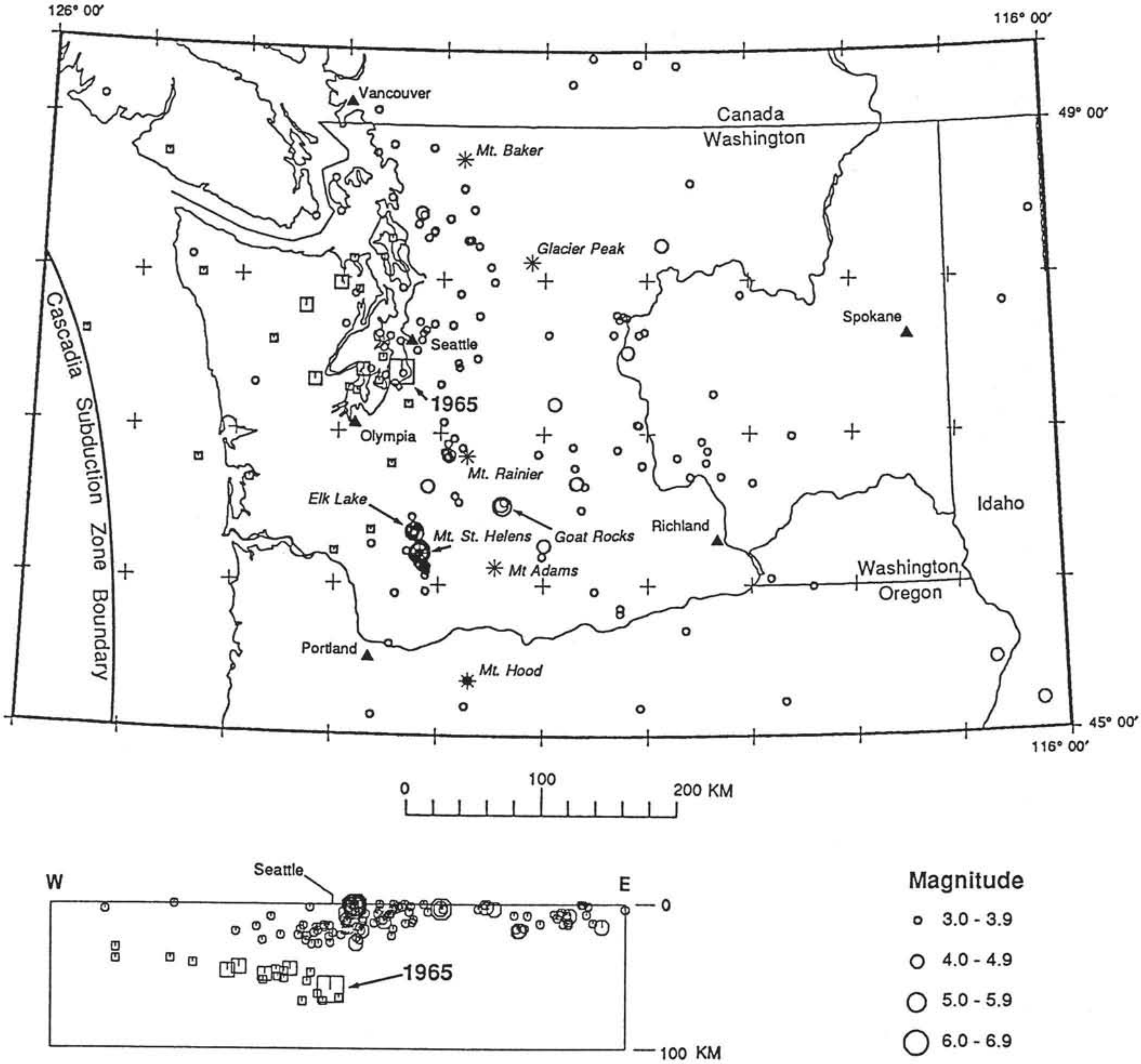

Figure 3. Epicenters of earthquakes of Richter magnitude 3.0 and greater for the period 1980-1989. The location of the 1965 Seattle-Tacoma earthquake (magnitude 6.5) is also shown. Epicenters of shallow earthquakes are shown as circles; epicenters of earthquakes having foci deeper that 30 km are depicted as squares. Stars indicate prominent volcanoes. An east-west cross-section is shown in the lower left corner of the figure.

Figure 3 shows the epicenters of Washington earthquakes of Richter magnitude 3.0 or greater during the period 1980-1989. Most of the intensity VI and greater events shown on Figure 1 fall within the areas of elevated seismicity delineated on this map.

CONCLUSIONS

The observational reports of the USC&GS and USGS are an important source of data for evaluating Washington's earthquake hazards. Earthquakes with a modified Mercalli intensity of VI or greater were identified using these data, as well as data from other sources. A map of MMI VI and greater earthquakes for the period 1928-1990 (Fig. 1) shows that they broadly fall within many of the areas of elevated seismicity that have been identified in recent years using records from Washington's high-quality seismograph network. The rate of occurrence of significant earthquakes (MMI VI or greater) in the Puget Sound region during the last 26 years (1966-1990) (Fig. 2b) is only one-third of the rate experienced during the preceding 27 years (1939-1965). In addition, there were no earthquakes in the

Puget Sound region greater than intensity VI from 1966 to 1990, but there were three MMI VII and two MMI VIII earthquakes in this region between 1939 and 1965.

The recent historic record makes it clear that the level of seismicity in the Puget Sound region during the past 60 years has been quite varied. The relative seismic quiescence of the last quarter century may have some important effects on the public's perception of the risk from earthquakes in this region. The only population group that has experienced the higher level of seismicity typified by the 1939-1965 period are adults over the age of 35 who resided in the Puget Sound region prior to 1966. Because of the rapid population growth in the area during the last quarter century, this "earthquake experienced" group represents only a fraction of the present population. I surmise that because most of the population has not experienced significant earthquakes during their residence in the Puget Sound region, their perception is that the region is at relatively low risk from earthquakes. Effective mitigation of earthquake or other natural hazards depends to a large extent on the acknowledgment of the hazard by the affected communities.

REFERENCES CITED

Bradford, D. C., 1935, Seismic history of the Puget Sound basin: Seismological Society of America Bulletin, v. 25, no. 2, p. 138-153.

Coffman, J. L.; von Hake, C. A., editors, 1973, Earthquake history of the United States: U.S. National Oceanic and Atmospheric Administration, Publication 41-1, Revised Edition (through 1970), 208 p.

Qamar, Anthony, 1990, Earthquakes in Washington and Oregon 1980-89—A decade of discovery: Washington Geologic Newsletter, v. 18, no. 2, p. 12-14.

Rasmussen, N. H., 1967, Washington state earthquakes 1840 through 1965: Seismological Society of America Bulletin, v. 57, no. 3, p. 463-476.

Townley, S. D.; Allen, M. W., 1939, Descriptive catalog of earthquakes of the Pacific coast of the United States 1769 to 1928: Seismological Society of America Bulletin, v. 29, no. 1, p. 1-297.

Wood, H. O.; Neumann, Frank, 1931, Modified Mercalli scale of 1931: Seismological Society of America Bulletin, v. 21, no. 4, p. 277-283.

U.S. Geological Survey Launches New Generation of Earthquake Detectors

New state-of-the-art earthquake detectors in West Virginia and North Carolina, the first of nearly 100 stations of the new U.S. National Seismic Network (USNSN), were scheduled to come on line April 3, 1991, as part of the new satellite age of earthquake monitoring. A dedication ceremony for the event was held in Golden, CO, at the U.S. Geological Survey (USGS) National Earthquake Information Center facility.

The USNSN was designed by the USGS with support in the eastern United States from the U.S. Nuclear Regulatory Commission (NRC). It is scheduled for completion in 1993.

The upgraded equipment will deliver earthquake signals faster and provide a broader range of information than has been previously available nationwide.

"Where seismologists once had to read paper records available hours to years after an earthquake occurred, they now have digital records available seconds to minutes after the earthquake happens," said Dallas Peck, Director of the USGS.

The NRC has funded numerous other earthquake studies, ranging from investigations of small-to-moderate earthquakes in the East to major studies such as the probabilistic seismic hazard assessment of the eastern United States.

The USGS, under the National Earthquake Hazards Reduction Program (NEHRP), is evaluating the earthquake potential of seismically active areas throughout the nation. At its center in Golden, the USGS provides round-the-clock monitoring of earthquake occurrences worldwide.

Stations in the new network are being strategically placed around the country to allow for detection and subsequent determination of location and magnitude of earthquakes as small as magnitude 2.5. The network also enhances the ability to assess the likely extent of damage to the region affected by the earthquake.

Each new site contains a satellite communication system and a comprehensive computer processing system. The seismometers measure a broader band of earthquake energy than existing equipment and provide undistorted signals. Recorded data will be transmitted via satellite to the USGS center in Golden. Access to data from the USNSN will be available in real-time through satellite transmission from the USGS center and in near-real-time through a high-speed, dial-up capability into the database at the center.

By the end of 1991, a total of 42 stations will be on line with new equipment and satellite communication dishes. An existing station in Newport, WA, will be upgraded to become part of the USNSN sometime in 1991.

(Modified from a USGS press release dated March 29, 1991)

Seismicity in Washington—A 1925 Perspective

Note: This letter was written many years before the concepts of earthquake seismology were well understood. Nonetheless, these two former State Geologists rightly identified the relation of soil type and severity of ground shaking, and they understood the relation of faulting and earthquakes. Lacking knowledge of plate subduction, the authors could not recognize the potential for intermediate-depth earthquakes now known to be a significant hazard in western Washington. It is noteworthy that Landes and Glover did not consider Washington seismically active, although they were aware that large earthquakes had occurred in areas that had no record of such events. They include Holden's earthquake catalog for 1833 to 1896, which does not mention the 1882 earthquake discussed by Ludwin and Qamar (this issue). The omission of this event, which was comparable to the 1939 Olympic earthquake, demonstrates the importance of reviewing all possible sources of data when attempting to define Washington's earthquake hazards. Fourteen years after this letter was written, the Puget Sound region entered a 27-year period that produced five moderately damaging earthquakes.

LANDES AND GLOVER, GEOLOGISTS
375 Colman Building
Seattle, Washington

October 30, 1925

Washington Surveying and Rating Bureau
Seattle, Washington

Dear Sirs:

We have lately had a request from you for a letter setting forth the facts and probabilities regarding the occurrences of earthquakes in the state of Washington in general and around Seattle in particular. In giving you a reply, it seems desirable to set forth some of the common observations that have been made on earthquakes and their effects and whatever information as we have at hand concerning local phenomena of this character.

Earthquakes are primarily due to breaks or cracks which have been produced in the earth's crust and where there is more or less movement taking place along these fractures. The crust is evidently broken into great blocks and any readjustment in position among these blocks produces earthquakes from time to time.

The slipping along such fissures or faults may, in any one readjustment, involve a movement of only an inch or less, but that may be enough to produce a thorough shaking up of the loose materials on the earth's surface. The shock from an earthquake, or its effects as noted on the surface, will vary chiefly with the amount of dislocation along the fracture plane below, the depth to this break or fissure, the kind of materials that the earthquake waves must pass through, and the character of the buildings and other works of men that are located on the ground.

It is one of the most common observations among geologists that the upper or visible part of the earth's crust is always broken by craks [sic] or fissures, trending in various directions, whereby the rock is broken into great blocks of an infinite variety of forms. Whenever slipping takes place between two blocks so that there is a slight change in the relative position of each, the fissure between them is then called a fault plane, or simply a fault

While faults are well-nigh universal, it is recognized that they are more common in mountainous and semi-mountainous regions where the upheaval of the rock has been the greatest and the readjustment among the blocks of the most common occurrence. Whenevere [sic] any faulting motion occurs in the rocks below, a shock is unqustionably [sic] felt at the surface above.

Faults are recognized as both active and passive. Active faults are those where readjustment of the crustal blocks is now going on, as in the regions of growing mountains or where changes of level of the earth's surface is now taking place. Passive faults are those, found mostly on the plains or in the older mountains, where there is no evidence of any motion in historic or late geological times. Probably no fault ever becomes wholly passive, but it is so-called when the slips along it produce only tremors or slight shocks which cause no damage at the surface. It is likely that an active changes into a passive fault by slow degrees, so that after a long interval of repose a slip may occur which produces a earthquake in a region where in human history shocks had been unrecorded before.

The world over, certain areas are generally regarded as earthquake centers, or regions where shocks are of very common occurrence, such as southern California, the Mediterranian [sic] countries, Japan, the Chilean coast, Central America, etc. etc. Such localities are those where readjustment of the crustal blocks is now prominent and where the faults qualify in the active class. There are no doubt many more areas where earthquakes are of such rarity or minimum intensity that the faults that underlie the surface are for the time at least in a passive condition.

In the State of Washington we have striking evidences of the upheaval of mountains and of elevations and depressions of the land as regards the level of the sea. Faults are of very common occurrence and they may be observed wherever any extensive areas of bedrock are exposed. In our coal mines there are faults in the strata where the dislocations have been often many hundred feet. In the coal mines nearest to Seattle, such as at Renton, faults are to be found, and they no doubt extend under most parts of the city. But we have no proof from human experience or from geological evidence that these faults are any other than passive ones. As far as we can determine, the great blocks of the earth's crust, not only around Seattle but over the entire state, are in a condition of such adjustment that no slipping of any significance is under way at the present time.

It is a matter of observation that the destructive effects of earthquakes on buildings are much less severe when they are erected upon bedrock as a foundation than upon soil alone. Especially is it true when the soil represents an artificial fill or made ground. The foundation for all buildings in Seattle, and for nearly all within the State, is a rather deep stratum of soil. Under all of Seattle, except the southern end of the city, the depth of soil must range from 500 feet to probably more than 1000 feet. The soil or material overlying bedrock is composed of variable layers of hardpan, gravel, sand, and clay. These formations, brought into place by natural means, afford a better foundation for all purposes than is true of the usual fill made by human agencies, but in resisting tremors and earthquake vibrations they are not as resistant as bedrock. In other words, that part of Seattle which is built upon filled ground would suffer most in the case of a violent earthquake, and the remaining portions, built upon a great thickness of natural soil would be more damaged than would be true if the foundations were all laid upon bedrock, or where only a thin mantle of soil covered the solid rock below.

It goes without saying that the amount of damage also depends upon the type of construction employed in building. Those structures that are best tied together throughout are least injured by an earthquake. Walls stand best when all corners are securely dovetailed and where separation is not easy. Buildings built of steel, or re-inforced concrete are usually the least damaged. On the other hand, if such a building is faced with brick or terra-cotta, the veneer usually separates from the inner wall and collapses on the ground below. In Seattle all the late buildings of large size are about as well adapted to resist earthquakes as one will find in any of the newer cities. Other things being equal, the tall buildings will suffer more than the lower ones, and those of solid masonry will be less damaged than the veneered ones.

It is true of the modern city, as in San Francisco, that following a severe earthquake the damage by fire is often unusually heavy. In the destruction which goes on it is never possible to say what was due to the earthquake alone and what was due to fire. With that in mind, the fire-fighting abilities of a city or town should always be taken into account in considering earthquake insurance.

It was noted above that in many parts of the world the faults in the bedrock have reached a passive state, and there is no movement except in a mild way or after a long interval of time. We have several instances of a violent earthquake occurring in such a region where none had been recorded in human history and where the general locality was supposed to be immune. There is no way known of anticipating or forecasting such a seismic disturbance, and such earthquakes come as a bolt from the blue. Such earthquakes were those of Charleston, South Carolina, on August 31, 1886, and of New Madrid, Missouri, on December 16, 1811. At Charleston, in a population of 55,000 people, 27 persons were killed with a property loss of 5 millions of dollars. Around New Madrid no shocks of consequence were reported prior to the big one of 1811, and only very minor ones have occurred since. To this day the marked changes made in the topography around New Madrid, due to the severity of the earthquake, may be seen.

Attached to this letter there are certain appendices whose titles are self-explanatory. The first appendix, A, gives the scale of intensity which has been generally adopted in describing earthquake shocks. In appendices B, C, and D the earthquakes felt in Washington from 1853 to 1921 are listed, except for the years from 1906 to 1911. In all, 87 shocks were noted, all of which were slight and in no instance apparently was any damage done. In a region as sparsely settled as Washington Territory and state have been, it might be truthfully said that more shocks have gone unrecorded than have been listed in the formal catalogues. On the other hand the shocks as a rule have been of such minor intensity that observers may occasionally have been deceived as to whether or not an earthquake had actually occurred. In the vicinity of Seattle the most pronounced earthquake of which we have any record occurred at 6:40 a.m. on December 25, 1913. At that time windows rattled, lights were sometimes extinguished, but no serious damage was done.

As a summary it may be stated that according to the geological evidence the blocks of the earth's crust seem to be in a stable equilibrium about Seattle and throughout Washington, as far as the present time is concerned; that the earthquake shocks observed by people have been of low intensity and infrequent occurrence; and that our buildings as a rule are well constructed and our facilities for the control of fire are good. On the other hand it should be pointed out that most of our buildings rest upon a deep mantle of soil and not bedrock; that some of our city buildings are very tall and many are faced with a veneer of brick or terra-cotta; and that following the experiences of Charleston, New Madrid, and other places, without any warning and like a lightning stroke there may some time come an earthquake of such marked intensity that a great deal of damage will result. The probabilities of the latter are very hard to calculate.

Very truly yours,
LANDES & GLOVER
By (signed) Henry Landes

APPENDIX A

The Rossi-Forel Scale of Earthquake Intensities

(This scale from I to X is very generally used in describing the relative intensity of any particular earthquake.)

I. Microseismic shock.- Recorded by a single seismograph or by seismographs of the same model but not by several seismographs of different kinds; the shock felt by an experienced observer.

II. Extremely feeble shock.- Recorded by several seismographs of different kinds; felt by a small number of persons at rest.

III. Very feeble shock.- Felt by several persons at rest; strong enough for the direction or duration to be appreciable.

IV. Feeble shock.- Felt by persons in motion; disturbance of movable objects, doors, windows; cracking of ceiling.

V. Shock of moderate intensity.- Felt generally by everyone; disturbance, furniture, beds, etc., ringing of swinging bells.

VI. Fairly strong shock.- General awakening of those asleep; general ringing of bells; oscillation of chandeliers; stopping of clocks; visible agitation of trees and shrubs; some startled persons leave their dwellings.

VII. Strong shock.- Overthrow of movable objects; fall of plaster; ringing of church bells; general panic without damage to buildings.
VIII. Very strong shock.- Fall of chimneys; cracks in walls of buildings.
IX. Extremely strong shock.- Partial or total destruction of some buildings.
X. Shock of extreme intensity.- Great disaster; ruins, disturbance of strata, fissures in the ground, rock falls from the mountains.

APPENDIX B

A Catalogue of Earthquakes on the Pacific Coast

1769-1896 - Smithsonian Miscellaneous Collections, 1087. By Edward S. Holden, Lick Observatory, University of California, December 31, 1896.

(Earthquakes Reported in Washington Only)

Date	Place	Intensity	Remarks
1833 June 29	Fort Nisqually	II	
1856 Dec. 26	Port Townsend		
1857 Sept.	Birch Bay		
1868 May 30	Mukilteo & Tulalip		Severe
1871 May 19	"Shocks in Washington Territory and on Mt. Rainier during the whole month; shocks on the coast."		
1872 Dec. 14 9:20-9:40 pm	Olympia		
1872 Dec. 14 21 h. 40 m.	Puget Sound		1 shock
1872 Dec. 14 21 h. 46 m.	Puget Sound	VII	3 shocks
1872 Dec. 14 22 h.	Puget Sound		Several
1872 Dec. 14 23 h.	Puget Sound		Several
1872 Dec. 15 3 h.	Puget Sound		Several
1872 Dec. 15 5 h.	Puget Sound		1 shock
1872 Dec. 16 9 h. 17 m.	Puget Sound	VIII	1 shock
1872 Dec. 16 to 1873 Jan. 4	Walla Walla		"Light shocks almost daily"
1873 Jan. 9	Tacoma	II	
1873 Oct. 19	Seattle	IV	"Slight shock"
1873 Nov. 22	Tacoma	III	"Very severe in W.T."
1873 Dec. 17(?)	Olympia		3 shocks
1874 (?)	Tacoma	II	
1878 Mar. 18	Tacoma	III	
1880 Aug. 22	So. part of Vancouver Is. & N.W. part of W.T.		
1880 Dec. 7(?) 6(?)	Olympia; also Bainbridge Island	IV	
1880 Dec. 10	Bainbridge Island	IV	
1880 Dec. 14	Bainbridge Island	III	
1880 Dec. 20	Bainbridge Island	IV	
1880 Dec. 29	Bainbridge Island	III	
1881 Jan. 5	Bainbridge Island	III	
1881 Jan. 6	Bainbridge Island	III	
1881 Jan. 7	Bainbridge Island	III	
1881 Jan. 16	Bainbridge Island		Slight shock
1881 Jan. 30	Bainbridge Island	III	
1881 Mar. 14	Bainbridge Island	III	
1883 June (?)	Tacoma	III	
1884 Sept. 1	Tacoma	III	
1885 May 3	Olympia	II	
1885 June 27	Olympia	IV	
1885 Dec. 8	Tacoma; Puget Sound	V	
1885 Dec. 18	Tatoosh Island	III	
1887 April 29	Walla Walla Valley		
1888 Feb. 1	Point No Point Light House		Slight
1889 March 16	Point No Point Light House		Slight
1889 Oct. 20	Point No Point Light House		Slight
1889 Autumn	Puyallup	II	Several shocks
1890 Feb.1	Admiralty Head Light House		Slight
1890 Mar. 8	Olympia	III	
1890 Mar. 15	Roslyn	III	
1890 Mar. 29	Roslyn	III	
1891 Mar. 7	Admiralty Head Light House		Slight
1891 Sept. (?)	Tacoma	II	Several Shocks
1891 Sept. 21	Port Angeles, Port Townsend	VI	
1891 Nov. 29	Seattle, Pysht, Port Townsend, Tacoma	II to VII	
1892 April 17	Tacoma, Olympia	II	"Severe"
1893 Feb. 16	Sydney	II	
1893 Aug. 14	Toutle River, Green River Mines	IV	
1894 Jan. 14	Olympia	I to II	
1894 April 15	Ellensburg	III	
1894 May 23	Tacoma	II	
1894 Nov. 21	Tacoma, Mt. Rainier		
1894[sic] April 16	Port Townsend	VI(?)	
1896 Jan. 8	Turn Point Light House		"A shock"
1896 Feb. 6	East Clallam; Neah Bay	V (?)	

(Extracts from the above report by Prof. Holden)

The number of earthquakes recorded in California, Oregon, and from nearby points on the Pacific Coast for the years 1850 to 1887 was 768.

As regards the wet and dry seasons, the probability of earthquakes is about the same at one time as the other. In San Francisco the shocks are considerably more frequent in the rainy season, contrary to the rule of the state at large.

The average number of shocks per month in San Francisco is 2 1/37. The total number of earthquakes in that city from 1850 to 1887 was 254.

The records show that the light earthquakes common in California are usually rather local than general and widespread phenomena. A curious example of this is the exemption of Santa Barbara from shocks in the years 1860-1872. Before 1860 and after 1872 Santa Barbara was subject to shocks precisely as other places in the same region.

APPENDIX C

Bulletin of the Seismological Society of America, 1911-1922

(List of Washington Earthquakes)

Date	Place	Intensity	Remarks
1911 Sept. 28	Victoria, B.C., Bellingham	VII(?)	
1912 Mar. 11	Seattle	I(?)	
1912 Nov. 24	Seattle	II(?)	
1913 June 29	Lewis, "Eatonville," etc.	V-VI	
1913 Dec. 25	Seattle	IV	
1914 Sept. 5	Tacoma, Olympia	III-IV	
1915 April 22	Seattle, Tacoma		Slight
1915 Aug. 18	Seattle		Slight
1916 Jan. 1	Seattle & Tacoma		Slight
1916 Feb. 22	N.W. Washington		Slight
1918 Feb. 28	Yakima	IV	
1918 Mar. 11	Spokane	IV	
1918 April 18	White Bluffs	III-IV	
1918 Nov. 1	Corfu	IV	
1919 June 5	Seattle		Slight
1920 Jan. 24	B.C., also noted in Bellingham and Anacortes	VIII(?)	
1920 Nov. 28	Seattle and east	III	
1921 Sept. 14	Dixie		Slight

APPENDIX D

Catalogue of Earthquakes on the Pacific Coast. 1897-1906

By Alexander G. McAdie, 1907, Smithsonian Miscellaneous Collections 1721, Part of Vol. XLIX

(Those from Washington listed below)

Date	Place	Intensity	Remarks
1897 Sept. 27	Olympia		"Light shock"
1897 Dec. 15	Waterville, Lakeside		"Severe"
1897 Dec. 16	Lakeside		"Light shock"
1897 Dec. 17	Lakeside		"Light shock"
1897 Dec. 20	Lakeside		"Light shock"
1904 Mar. 16	Seattle	III	
1906 Jan. 2	Spokane		"Light shock"

In the above catalogue 706 tremors were listed from 1897 to 1906, at least 700 having been felt in California. In addition to these earthquakes there were 21 shocks, in San Francisco and vicinity, on April 18, 1906.

New Minerals Publication

Mineral-resource activities and information are reviewed quarterly in the new U.S. Geological Survey Ore-Minerals Resources Newsletter. All USGS minerals-related programs, research results, issues and news are covered in this free newsletter. To be included on the mailing list, contact MIO, USGS, DOI MS2647MIB, 1849 C St NW, Washington, DC 20240; 202/208-5512.

(From Geotimes, May 1991)

Earthquake Preparedness

Taken from a flyer prepared by the Washington State Department of Community Development

Persons affected by a serious trembler need to be prepared to take care of themselves for at least 72 hours. Many safety measures cost very little. The following tips are offered to help Washington residents prepare for—and survive—a major earthquake.

Learn what to expect in an earthquake. During an earthquake, one may hear loud noises, feel the ground shake, and see objects fall and break. Earthquakes may also trigger fires, hazardous material incidents, landslides, and tsunamis.

Learn how to avoid injury. Most earthquake injuries are caused by objects that fall or are sent flying by ground shaking. Avoid injury during a quake by taking the following measures:

- If inside, crouch under a desk or table or stand in a doorway. Turn away from windows, and move away from dividers, unsecured cabinets, shelves, or items suspended from the ceiling. Protect your head and neck with your hands.
- If outside, move away from buildings and heavy overhanging objects, trees, and telephone and electric lines. Drop to the ground and protect your head and neck with your hands.
- If on the road, drive away from underpasses and overpasses, stop in a safe area, turn off the engine, and stay in the vehicle.

Make a family preparedness plan. Family members should know how and where to shut off electricity, gas, and water supplies if lines are broken. Shut off gas only if you suspect a leak. Learn first aid. Develop a plan to reunite if separated. Have a list of telephone numbers for police, fire, and medical personnel, but avoid using the phone unless absolutely necessary. And stock up on these supplies:

- A first-aid book and basic medical supplies.
- Simple emergency equipment, including a fire extinguisher, battery-powered radio and flashlight, spare batteries, matches, heavy leather gloves, pry-bar and shovel.
- A gallon of water per person for at least three days. An undamaged water heater is a good source of water in homes.
- A minimum of three days' supply of canned and dry foods for each member of the family (including babies and pets), a non-electric can opener, and a portable stove for cooking.

Reduce earthquake hazards. Injuries and property damage can be reduced by taking the following steps:

- Place heavy objects, glass, china, and other breakable items on lower shelves; anchor shelves to a wall. Brace and anchor top-heavy items.
- Anchor overhead lights, hanging plants, heavy artworks, and mirrors.
- Bolt or strap water heaters and gas appliances to the wall. Use flexible connections whenever possible.

For more information, contact Joel Aggergaard, Department of Community Development, MS PT-11, Olympia, WA 98504. The office is located at 4220 E. Martin Way.

1882 Earthquake Rediscovered

by R. S. Ludwin and A. I. Qamar
University of Washington

During a recent review of newspaper accounts of earthquakes in Washington and Oregon, we found several references to an earthquake that occurred on April 30, 1882, at 10:48 p.m. local time (or May 1, 6:48 GMT). This event was widely felt in Oregon and Washington Territory and on southern Vancouver Island. It made a considerable impression on the populace, even though, apart from a few broken chimney tops and window panes in Olympia and damage to crockery and glassware there and elsewhere, no really severe damage was reported.

The following paragraphs were selected from newspapers published within the "felt area".

From the Portland *Oregonian*, May 1, 1882:

> At 12 minutes to 11 o'clock last night a slight earthquake was felt, lasting probably two seconds. This was followed about three seconds later by a more severe shock, accompanied by a low rumbling, which lasted from five to seven seconds. Every building in the city was shaken and sleepers were generally aroused. In the Oregonian office it seemed as though the big press was sinking through the floor, pulling the walls in in its descent. In the larger buildings, particularly the Clarendon hotel, New Market theater and Union block, the shock was more keenly felt, and residences in the western portion of the city shook as though they must fall.

From the Portland *Oregonian*, May 2, 1882:

> It was about the only topic of conversation yesterday. Every one had a very interesting story of how badly he was scared, and the accounts told by three hundred or four hundred paterfamilie of how their wives, snatching the youngest child, rushed en dishabille to the front door, had just sufficient variety to prove that one man had not repeated the other's experience.

From the Olympia *Washington Standard*, May 5, 1882:

> The tall shade trees were violently agitated, their branches thrashing in a manner produced by no other natural means, the buildings creaked like ships at sea, and everything movable swayed to and fro in obedience to a force irresistibly grand and peculiar. The feeling of awe induced by the strange phenomena was dispelled by the scenes which followed immediately afterwards, when half-clad women and crying children poured forth into the streets like bees from a great hive, to be reinforced by stalwart men who showed scarcely less trepidation.

The 1882 earthquake was included in the catalogs of both Holden (1887) and Townley and Allen (1939). Later catalogs, however, generally omitted this earthquake, although mention of its single felt aftershock appeared in reports by Berg and Baker (1963) and Rasmussen (1967).

Descriptions of the effects of the 1882 earthquake in newspaper accounts allow us to sketch approximate intensity contours. (See Table 1 [on following page], Fig. 1). The positions of the intensity 5 and 6 contours

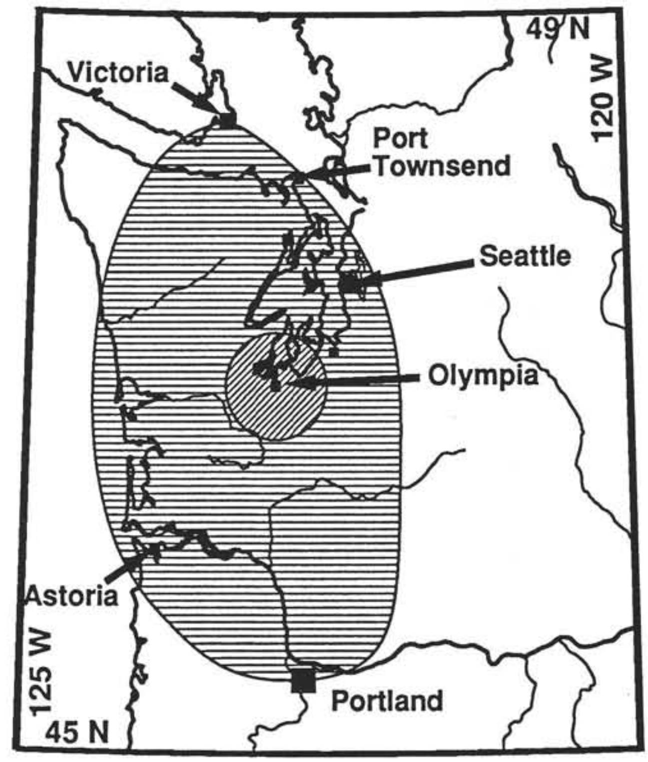

Figure 1. Approximate areas of reported modified Mercalli intensities V (horizontal lines) and VI (diagonal lines) for the April 30, 1882, earthquake. Very few data points were available for constucting this map. The estimated Richter magnitude of this event was ≈6.

for this earthquake appear to be very like those for the 1939 "Olympic" earthquake. This similarity of isoseismal contours suggests that the two earthquakes were of similar magnitude and depth. The 1939 earthquake is considered to have been subcrustal, its epicenter probably at a depth of 40 to 70 km, within the subducting Juan de Fuca plate. The magnitude of the 1939 earthquake, which occurred before instrumentation, has been estimated at from 5.75 to 6.2.

In the southern Puget basin, only three other subcrustal earthquakes of moderate magnitude are known: the 1939 event, the 1949 magnitude (m_s) 7.1 event, and the 1965 magnitude (m_b) 6.5 event. Because all three events were close together in time and space, the potential for recurrence and the recurrence interval for such earthquakes were difficult to estimate. By extending the history of south Puget basin subcrustal events, the 1882 earthquake improves our ability to evaluate the likelihood of similar events in the future.

There are a great number of sources of information on historic Washington earthquakes yet to be studied. Review of other catalogs and data sources will no doubt improve upon our understanding of the 1882 earthquake as well as other historic events.

References Cited

Berg, J. W., Jr.; Baker, C. D., 1963, Oregon earthquakes, 1841 through 1958: Seismological Society of America Bulletin, v. 53, no. 4, p. 95-108.

Holden, E. S., 1887, List of recorded earthquakes in California, Lower California, Oregon, and Washington Territory: Regents of the University of California [Sacramento, CA], 78 p.

Rasmussen, N. H., 1967, Washington state earthquakes 1840 through 1965: Seismological Society of America Bulletin, v. 57, no. 3, p. 463-476.

Townley, S. D.; Allen, M. W., 1939, Descriptive catalog of earthquakes of the Pacific Coast of the United States, 1769 to 1928: Seismological Society of America Bulletin, v. 29, no. 1, p. 1-297.

Wood, H. O.; Neumann, Frank, 1931, Modified Mercalli scale of 1931: Seismological Society of America Bulletin, v. 21, no. 4, p. 277-283.

Table 1. Extract from the Modified Mercalli Intensity scale developed by Wood and Neumann (1931) with references to the older Rossi-Forel scale. (See p. 9-10.)

IV. Felt indoors by many, outdoors by few.
- Awakened few, especially light sleepers. Frightened no one, unless apprehensive from previous experience.
- Vibration like that due to passing of heavy, or heavily loaded trucks.
- Sensation like heavy body striking building, or falling of heavy objects inside.
- Rattling of dishes, windows, doors; glassware and crockery clink and clash.
- Creaking of walls, frame, especially in the upper range of this grade.
- Hanging objects swung, in numerous instances.
- Disturbed liquids in open vessels slightly.
- Rocked standing motor cars noticeably.
- *Equivalent to V on the Rossi-Forel scale.*

V. Felt indoors by practically all, outdoors by many or most; outdoors direction estimated.
- Awakened many, or most.
- Frightened few—slight excitement, a few ran outdoors.
- Buildings trembled throughout.
- Broke dishes, glassware, to some extent.
- Cracked windows—in some cases, but not generally.
- Overturned vases, small or unstable objects, in many instances, with occasional fall.
- Hanging objects, doors swing generally or considerably.
- Knocked pictures against walls, or swung them out of place. Open or closed doors, shutters, abruptly.
- Pendulum clocks stopped, started, or ran fast, or slow.
- Moved small objects, furnishings, the latter to slight extent.
- Spilled liquids in small amounts from well-filled open containers.
- Trees, bushes, shaken slightly.
- *Equivalent to V-VI on the Rossi-Forel scale.*

VI. Felt by all, indoors and outdoors.
- Frightened many, excitement general, some alarm, many ran outdoors.
- Awakened all.
- Persons made to move unsteadily.
- Trees, bushes, shaken slightly to moderately.
- Liquid set in strong motion.
- Small bells rang—church, chapel, school, etc.
- Damage slight in poorly built buildings.
- Fall of plaster in small amount.
- Cracked plaster somewhat, especially fine cracks chimneys [sic] in some instances.
- Broke dishes, glassware, in considerable quantity, also some windows.
- Fall of knick-knacks, books, pictures.
- Overturned furniture in many instances.
- Moved furnishings of moderately heavy kind.
- *Equivalent to VI-VII on the Rossi-Forel scale.*

VII. Everybody runs outdoors.
- Damage negligible in buildings of good construction; slight to moderate in well-built ordinary structures.
- Considerable damage in poorly built or badly designed structures. Some chimneys broken.
- Noticed by persons driving cars.
- *Equivalent to VIII⁻ on the Rossi-Forel scale.*

VIII. Damage slight in specially designed structures, considerable in ordinary substantial buildings with partial collapse, great in poorly built structures.
- Panel walls thrown out of frame structures.
- Fall of chimneys, factory stacks, columns, monuments, walls.
- Heavy furniture overturned.
- Sand and mud ejected in small amounts.
- Changes in well water.
- Persons driving cars disturbed.
- *Equivalent to $VIII^{+}$-IX on the Rossi-Forel scale.*

Workshop on Oregon Earthquake Source Zones

by Stephen P. Palmer

This workshop, convened on March 18, 1991, at Oregon State University, was sponsored by the Oregon Department of Geology and Mineral Industries and Oregon State University to examine the latest evidence regarding potential earthquake sources in Oregon. Because Oregon and Washington share many of these earthquake sources, a brief review of the highlights of this workshop follows.

A number of presentations concerned the potential for great (Richter magnitude 8+) plate interface earthquakes in the Cascadia subduction zone:

- Heat flow analyses presented by Dave Blackwell suggested that the potential width of a "locked zone" along the Cascadia subduction zone is limited by the high temperature and rheologic properties of the subducting slab. He suggested moment magnitudes of 8.0 to 8.5 as an upper value for this earthquake source.
- Ray Weldon presented his recent work using leveling and tide gauge data. His estimates show uplift rates along the Oregon coast ranging from 1.5 to 4.3 mm/yr. These rates are consistent with rates predicted from modeling of elastic strain due to a locked Cascadia subduction zone.
- Chris Goldfinger demonstrated the presence of WNW-trending left-lateral Holocene faults off the Oregon coast using SEABEAM imagery and high-resolution seismic reflection profiles. These faults offset Holocene sediments on the Juan de Fuca plate, and they appear to continue through the accretionary wedge and onto the continental shelf.
- Ray Wells presented paleomagnetic and geologic evidence of progressive clockwise rotation of Eocene to Miocene crustal blocks in western Oregon. He infers that this rotation is due to right-lateral shear caused by the oblique convergence of the Juan de Fuca-North America plate system. The left-lateral faulting discussed by Goldfinger is consistent with this oblique convergence model.

Many of the day's presentations focused on shallow seismicity and Quaternary faulting in Oregon:

- Ian Madin summarized Quaternary faulting in the Portland region based on his analysis of borehole and outcrop data, and he reviewed the concept that the Portland Basin is a pull-apart structure bounded by the left-lateral Portland Hills–Frontal fault system. Active faulting along the Portland Hills–Frontal fault system, which was discussed by Tom Yelin in connection with the 1962 Portland earthquake and recent microseismic activity, is of particular significance to evaluation of earthquake hazards in southwestern Washington, especially in the Vancouver area.
- Robert Yeats presented a detailed study of Quaternary faulting in the Willamette Valley, drawing on deformation of Pliocene(?) gravel deposits along the course of the ancestral Willamette River. He also discussed potentially active faults near Mount Angel, identified using sub-surface geologic data and fault-related seismicity.
- Silvio Pezzopane reviewed his recent work on Basin and Range faulting in southeast Oregon and speculated on the existence of a zone of large right-lateral shear that extends from Nevada through central Oregon and that may cross the Cascades toward the Portland Hills–Frontal fault system.

The panel discussion at the end of the workshop was focused on the Cascadia subduction earthquake potential. There was general agreement that the Cascadia subduction zone is seismogenic and, further, that earthquakes with moment magnitudes of 8.0 to 8.5 are credible. The dating of the most recent event, which can be traced stratigraphically for about 50 km in southwestern Washington, is based on tree-ring analysis by David Yamaguchi and Brian Atwater. These dates indicate that the earthquake occurred sometime between 1690 and 1700. Dating of earlier subduction earthquakes by radiocarbon methods is subject to large uncertainties caused by both analytical and geological limitations. These dating uncertainties greatly restrict our ability to (1) determine a mean recurrence interval of events emanating from the Cascadia subduction zone earthquake source, and (2) estimate the reliability of characterizing this earthquake source using a mean estimate of the recurrence interval.

Workshop Papers

Overview of Oregon seismicity. *George Keller, Oregon State University/Seismic Safety Policy Advisory Commission for Oregon*

Heat flow analysis of the Cascadia subduction zone—How wide is the locked zone? *Dave Blackwell, Southern Methodist University*

Preliminary results from the 1989 central Oregon onshore/offshore seismic experiment. *Ann Trehu, Oregon State University*

Neotectonics and strike slip faulting in the Cascadia subduction zone. *Chris Goldfinger, Oregon State University*

Deformation of the Oregon coast from geodetics and tidal records. *Ray Weldon, University of Oregon*

Coastal paleoseismicity, Oregon continental margin. *Curt Peterson, Portland State University*

Neogene segmentation of Oregon-Washington convergent margin by transverse fault zones. *Ray Wells and Park Snavely, USGS*

Offshore neotectonics of the Cascadia subduction zone, Gorda segment. *Sam Clarke, USGS*

Onshore paleoseismicity of the Cascadia subduction zone, Gorda segment. *Gary Carver, Humboldt State University*

Potentially active faults and folds of the Willamette Valley. *Robert Yeats, Oregon State University*

Neotectonics of the Portland area. *Ian Madin, Dept. of Geology & Mineral Industries*

Neotectonics of central Oregon. *Silvio Pezzopane, University of Oregon*

Poster Session:

Deformed terraces on the Oregon coast. *Rob Ticknor, Western Washington University*

Tomographic imaging of the subducted Juan de Fuca slab. *Gene Humphreys, University of Oregon*

Tidal-marsh microfossil assemblages—A tool for deciphering the great earthquake histories of seismic zone coasts in Oregon and Chile. *Alan Nelson, Anne Jennings, and Kaoru Kashima, USGS*

Stream incision rates and Quaternary deformation in the Oregon Coast Range. *Steve Personius, USGS*

Milton-Freewater neotectonics. *Kevin Pogue, Whitman College*

Gravity analysis of the Portland basin. *Ansel Johnson, Portland State University, and Paul Beeson, PTI Environmental Services*

The re-discovered pre-instrumental earthquake of 1882. *Ruth Ludwin, University of Washington*

Crustal temperatures above the subducting Juan de Fuca plate. *Trevor Lewis, Geological Survey of Canada*

Geothermal constraints on rock rheology under Vancouver Island. *Kelin Wang, Geological Survey of Canada (visiting fellow)*

Oregon accretionary wedge neotectonics. *Vern Kulm, Mary Mackay, Casey Moore, Greg Moore, and Chris Goldfinger, Oregon State University*

Broadband analysis of the recent earthquakes in Oregon. *John Nabelek, Oregon State University*

Geodetic strain studies in coastal Oregon and northern California. *Mike Lisowski and Mark Richards, USGS*

USGS Deep Continental Studies Program, FY 1991 work plan. *Craig Weaver, Walter Mooney, and Wendy Grant, USGS*

Seismicity and neotectonics of northeastern Oregon with emphasis on the Brownlee Dam and Milton-Freewater areas. *Gary Mann, USGS*

Seismotectonic studies in Oregon for dam safety evaluation. *Fred Hawkins, U.S. Bureau of Reclamation*

A limitation on the occurrence of large subduction zone earthquakes by thermal conditions. *Roy Hyndman, Geological Survey of Canada*

Earthquake sources in Washington—Correlation to the inferred thermal regime. *Bob Crosson, University of Washington*

Western Oregon Seismic Hazards Workshop

by Stephen P. Palmer

The Oregon sections of the American Society of Civil Engineers, the Association of Engineering Geologists, and the American Public Works Association held two simultaneous workshops on April 2, 1991, at the Oregon Convention Center in Portland. One of these sessions was concerned with western Oregon seismic hazards, and the other dealt with the problem of stormwater management. Division staff members attended the seismic hazards workshop.

This workshop reviewed the situation in western Oregon regarding earthquake sources, hazards, and engineering issues. The earthquake potential for Oregon was thoroughly reviewed by George Priest (speaking for Bob Yeats), Curt Peterson, and Ian Madin. Matthew Mabey and Ivan Wong summarized the site-specific effects of Oregon earthquakes such as liquefaction and ground motion amplification. Roger McGarrigle, chairman of the Governor's Seismic Safety Policy Advisory Commission, discussed the recommendations of the commission. These included revision of the state's seismic risk map to classify the area of Oregon west of the Cascades as a Uniform Building Code Risk Zone 3 and obtaining a legislative mandate for the commission. Grant Davis, Raymond T. Miller, and Don Eggleston gave talks covering various structural design issues, including a history of Oregon's seismic design code, a case study of the seismic retrofit of the Oregon Capital Building, and the seismic upgrading of buildings with historical value.

The panel discussion following the presentations gave the impression that the proposed change in the building code was an acceptable proposition to the Oregon engineering community. If adopted, this would result in an interesting dichotomy: buildings constructed in Portland would be designed for a Seismic Risk Zone 3, whereas buildings constructed across the Columbia River in Vancouver would require only a Zone 2B design.

Workshop Papers

Earthquake sources and magnitudes. *Robert Yeats, Oregon State University [presented by George Priest, Dept. of Geology & Mineral Industries]*

Evidence for great subduction zone earthquakes along the Oregon coast. *Curt Peterson, Portland State University*

Portland area earthquake geology. *Ian Madin, Dept of Geology & Mineral Industries*

Policies and legislative issues. *Roger McGarrigle, Van Domelen/Looijenga/McGarrigle/Knauf*

Assessment of liquefaction potential in the Portland area. *Matthew Mabey, Dept. of Geology & Mineral Industries/Portland State University*

Site-specific estimates of ground motion. *Ivan Wong, Woodward-Clyde*

Structural engineering issues in seismic design. *Grant Davis, KPFF Consulting Engineers*

Case study of Capitol Building upgrade, Salem, Oregon. *Raymond T. Miller, R.T. Miller Engineering*

Seismic upgrade and architectural issues. *Donald Eggleston, Sera Architects*

Staff Notes

David Clark, our Cartographic Technician, left us in May for a position with the Department of Natural Resources' Information Management Division.

Bob Derkey will be moving to Spokane this summer to take up the leadership of the Division's field office. Bob's primary duties will be overseeing the activities of the Spokane office and continuing to update the Washington minerals inventory.

Venice Goetz has become our newest Geologist 2. She has a B.S. in geology from Sonoma State University and an M.S. in geology from the University of Idaho. Venice, who started work with the Division in mid-May, was recently employed by Echo Bay Exploration in Reno, NV, and Republic, WA. She will be assisting with compilation of the northwest quadrant of the state geologic map and continue working in economic geology.

Chuck Gulick has joined the Division as Geologist 2 in the Spokane office. Initially, Chuck will be compiling geologic maps of the Yakima, Connell, and Pullman 1:100,000-scale quadrangles and co-compiling the geologic map of the state's southeast quadrant. Chuck received his bachelor's degree from Emory University and a master of science degree from Eastern Washington University. He is a registered professional geologist with 14 years' experience with Century Geophysical Corp., St. Joe American Corp., Clayton Silver Mines Inc., CSS Management, and Steelhead Resources Inc., as well as an industrial mineral consultant. Chuck has previously worked for the Division in temporary positions for geologic compilations for the northeast quadrant of the state geologic map. He most recently served as Groundwater Program Coordinator for the Spokane County Water Quality Management Program.

Sheryl Hayes is our new temporary receptionist. She comes to us with several years' experience as a computer operator for private businesses and as a bank teller in a local bank. She replaces **Mary Anne Shawver**, who has taken on the duties of secretary for the Division's regulatory program.

Pat Pringle has recently been promoted to Geologist 3. He steps into the position previously held by **Josh Logan**. Pat will continue to conduct research and mapping of a broad spectrum of geologic hazards (slope failures, volcanic hazards, features susceptible to failure during strong ground motion, liquefaction, Quaternary faulting). New duties include coordinating Quaternary mapping for the state geologic map project. Pat is working on field guides for Mount St. Helens and Mount Rainier and will be responsible for the Bellingham quadrangle for the geologic map of the state's northwest quadrant.

Jari Roloff joined our staff May 6 as Editorial Assistant. Jari brings with her a B.S. in geology from WSU and a B.A. in journalism from the University of Hawaii, as well as strong experience in publication design and desktop publishing. She was formerly Publications Specialist for the YWCA of Seattle-King County.

Renee Snider has been promoted to Word Processing Specialist.

Geologists and the Canada–USA Free Trade Agreement

Effective mid-January 1991, all necessary operational procedures were in place at U.S. Immigration and Naturalization Service Offices for Canadian geologists to obtain entry into the USA as professionals under the terms of the Free Trade Agreement. The legislation provides for U.S. geologists to enter Canada under the same preferential terms.

Canadian geologists can now take advantage of the streamlined procedures associated with the Treaty Canada classification for temporary admission into the U.S. to work as a professional. To qualify, an individual must meet the minimum qualification to engage in the profession, normally a university degree, and must have a bona fide offer of employment in the U.S. that requires his or her professional skills.

To obtain Treaty Canada status, which is valid for one year and permits multiple entries into the USA, application is made to the nearest office of the U.S. Immigration and Naturalization Service. For this you should submit a letter of application, together with a bona fide letter from the U.S. organization requiring your professional skills, evidence (university graduation certificates, etc.) of your professional qualification, evidence of Canadian citizenship or landed immigrant status, and U.S. $50.00 processing fee. Practical experience has shown that Treaty Canada status can be granted in three to five working days.

For further information, please contact the nearest office of the U.S. Immigration and Naturalization Service.

(From the Northwest Mining Association Bulletin, March 1991, p. 6.)

Geology of the Yacolt Burn State Forest

by William M. Phillips
University of Arizona

Editor's note: A map of this state forest is in preparation by the Department of Natural Resources. When available, it can be obtained free from the Division of Engineering's Photo and Map Sales office at 1065 S. Capitol Way, Olympia, WA 98504 (MS EV-11; 206/753-5338).

INTRODUCTION

In September 1902, a series of catastrophic fires burned more than 238,000 acres of forest and farm land in Skamania, Clark, and Cowlitz Counties in southwestern Washington. Public outcry following the inferno was the impetus for some of the first forest fire protection legislation in Washington. In 1955, about 175,000 acres of state-owned land in the burned region was officially designated the Yacolt Burn State Forest.

Today, the forest is managed by the Department of Natural Resources (DNR) primarily for its timber resources. However, a number of other natural features, such as wildlife, rare plants, and diverse geologic features, including several mineral occurrences, make the Yacolt Burn an interesting place to visit.

This article summarizes the geology of the Yacolt Burn State Forest and can be used in conjunction with a road and topographic map of the area (now in preparation by DNR). While not a field guide, it provides more information on the geology of the region than will be printed on the DNR map.

Data for this article were compiled during production of the geologic map of the southwest quadrant of Washington published in 1987. Further details of the Yacolt area's geology can be found in the recommended reading listed at the end of this article.

TRAVEL IN THE YACOLT STATE FOREST

The Yacolt Burn State Forest lies between the Columbia River and Mount St. Helens in the rugged Cascade Range of southern Washington (Fig. 1). Many visitors will approach the Yacolt region from the west—Interstate Highway 5 and State Route 503 (Fig. 1). Access to the forest is via a complex network of mostly unpaved logging roads that, although steep, are generally passable for two-wheel-drive vehicles in good weather. *Caution:* Signs for the logging roads are not always obvious, and it is fairly easy to become lost in the maze of routes. In addition, visitors are urged to avoid areas of active logging; logging trucks driven at high speeds are a source of danger.

Visitors should have the DNR Yacolt map and a U.S. Forest Service map of contiguous and nearby Gifford Pinchot National Forest lands. Information about the National Forest can be obtained at the Pine Creek Information Station on U.S. Forest Service road 90 or at the Mount St. Helens National Volcanic Monument headquarters near Amboy.

GEOLOGIC SETTING

The Yacolt Burn State Forest lies in the heart of the Cascade Range, a volcanic mountain chain stretching from Mount Garibaldi in British Columbia to Lassen Peak in California. In the Yacolt area, the Cascades consist dominantly of lava flows and tuffs erupted between about 38 million and 17 million years ago, during the latest Eocene, Oligocene, and part of the Miocene (Fig. 2). The lavas and tuffs are locally intruded by plutons of granodiorite and diorite of middle Miocene age (about 20 million years old). Quaternary stratovolcanoes such as Mount St. Helens surround the Yacolt region, but are not present in the state forest.

Volcanism has occurred in the Cascades because part of the Pacific Ocean floor, the Juan de Fuca plate, is being subducted beneath the North American continental plate in this region. At depths in excess of 60 miles (100 km) beneath the Cascade Range, the subducted rocks begin to melt. A small portion of the resultant magma occasionally invades the upper part of the crust of the Cascades, solidifying to form plutons or more rarely erupting through the surface as a volcano.

While subduction has occurred beneath the Cascades for more than 35 million years, production of volcanic rocks in the Yacolt area, as in most of the Cascades, has not been a steady process. Instead, vol-

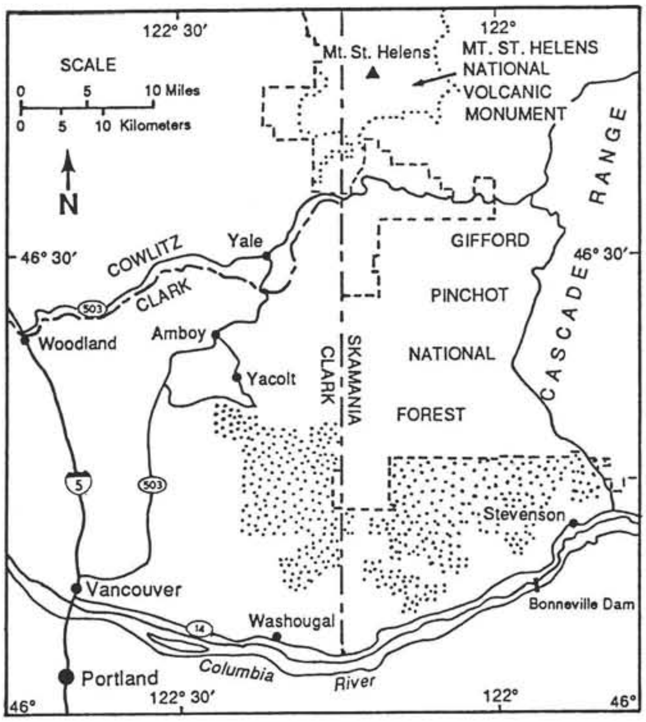

Figure 1. Location of Yacolt Burn State Forest. Stipple pattern indicates approximate forest limits; see Fig. 2.

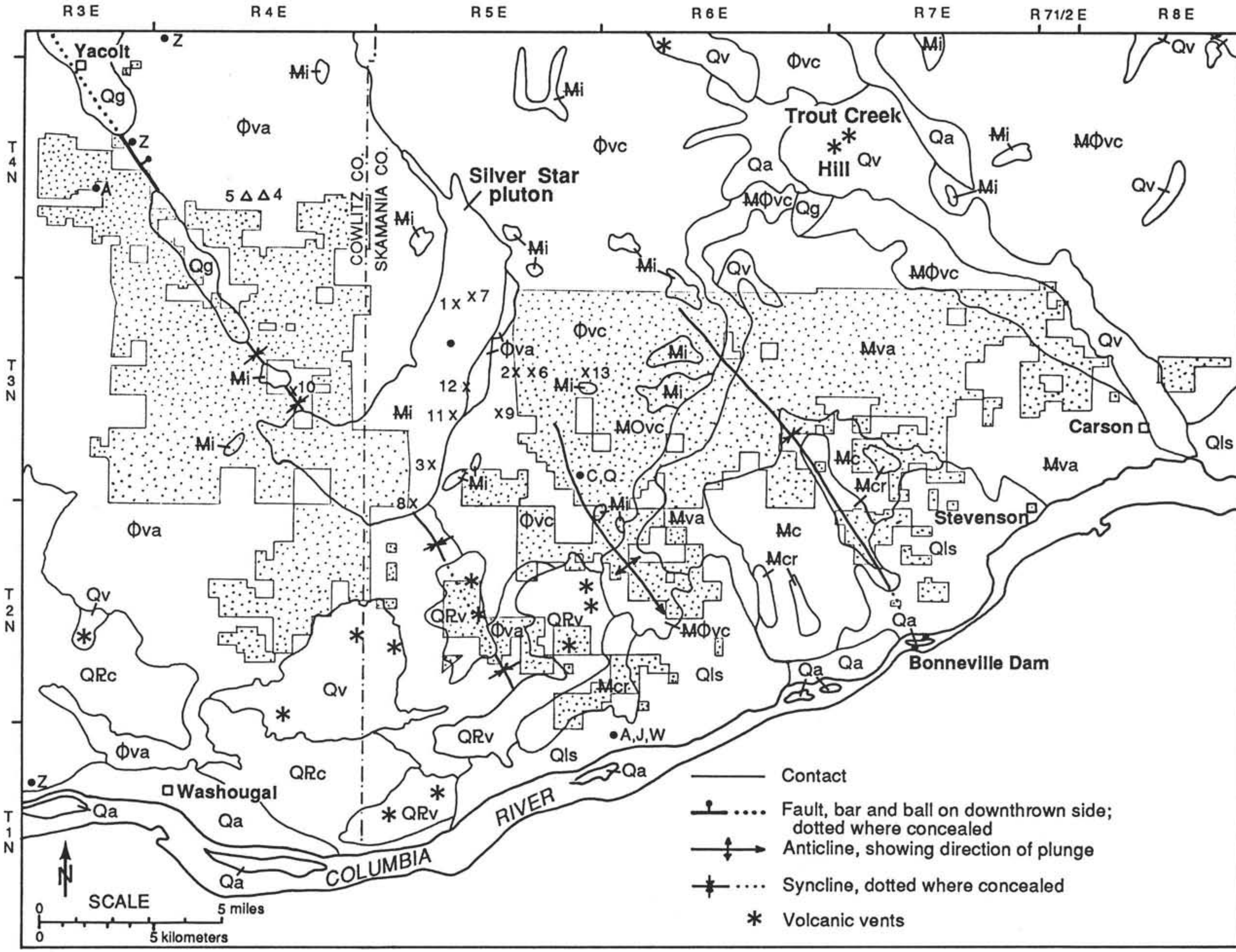

Figure 2. Generalized geologic map of the Yacolt Burn State Forest (modified from Walsh and others, 1987). Stippled areas are state forest lands.

MAP EXPLANATION

Mineral Localities

- A Agate
- C Chrysocolla
- Q Quartz
- J Jasper
- W Petrified wood
- Z Zeolites

Map Units

Quaternary

- Qa Alluvium
- Qls Landslide deposits
- Qg Glacial deposits
- Qv Basalt and andesite lava flows

Quaternary and Pliocene

- QRv Boring Lava
- QRc Troutdale Formation

Miocene

- Mcr Lava flows of the Columbia River Basalt Group
- Mc Eagle Creek Formation
- Mva Lava flows of Three Corner Rock
- Mi Intrusive rocks

Miocene and Oligocene

- MΦvc Pyroclastic and volcaniclastic rocks

Oligocene

- Φvc Volcaniclastic rocks
- Φva Andesite lava flows

Table 1. Major mineral deposits in the Yacolt Burn State Forest

Locality	Property name	Commodity	Ore minerals	Deposit type	Location
1	Black Jack	Cu, Mo, Ag, Au	chalcopyrite, bornite, chalcocite, molybdenite, sphalerite, galena	breccia pipe prophyry system	center, sec. 4, T3N, R5E
2	Blue Bird	Cu, Ag	minor pyrite, chalcopyrite, malachite	quartz vein	SE1/4NE1/4 sec. 15, T3N, R5E
3	Last Change	Cu, Ag	chrysocolla, malachite, bornite, pyrite, azurite, chalcocite, chalcopyrite, descloizite	quartz vein	S1/2SE1/4 sec. 29, T3N, R5E
4	Lewis River	Au	gold	placer	W1/2 sec. 22, T4N, R4E
5	McMunn	Au	gold	placer	E1/2 sec. 21, T4N, R4E
6	Maybee	Cu, Zu, Ag	chalcopyrite, bornite, pyrite, sphalerite	quartz vein	NE1/4NW1/4 sec. 14, T3N, R5E
7	Miners Queen	Cu	chalcopyrite, magnetite, pyrite, pyrrhotite, molybdenite	tourmaline - bearing breccia	center, NE1/4 sec. 4, T3N, R5E
8	Rainbow	Pb	galena	quartz vein	S1/2S1/2 sec. 32, T3N, R5E
9	Silver Creek	Pb, Zu, Cu	galena, sphalerite, chalcopyrite, pyrite	quartz vein and fault breccia	center, sec. 22, T3N, R5E
10	Silver Star	Au, Ag, Cu, Pb, Zn	galena, chalcopyrite, pyrite, sphalerite, gold, bornite, specularite, malachite	quartz vein and fault breccia	W1/2 sec. 23, T3N, R4E
11	Skamania	Cu, Au, Ag	chrysocolla, azurite, malachite, pyrite, bornite, chalcocite, chalcopyrite, covellite	quartz vein	NE1/4SW1/4 sec. 21, T3N, R5E
12	Yellow Jacket	Cu, Ag, Au	chalcopyrite, bornite, azurite, malachite	quartz vein	SW1/4NE1/4 sec. 21, T3N, R5E
13	Zinc Creek	Zn, Cu, Pb	sphalerite, galena, chalcopyrite, pyrite	fracture zone, quartz vein	SW1/4NE1/4 and NW1/4SE1/4 sec. 13, T3N, R5E

canism has been highly episodic. In addition, magma chemistry and eruptive behavior have changed over time. The reasons for these changes are not well understood and are the subject of current research by geologists.

The convergence of the North American plate and the Juan de Fuca plate has also caused deformation of this part of the Cascades. Volcanic rocks originally deposited more or less horizontally are now bowed into a series of northwest-trending anticlines and synclines (Fig. 2). Inactive faults also mark places where strata broke during ancient earthquakes.

The most significant structure of the Yacolt area bedrock is far more subtle, however. Volcanic rocks retain a record of the direction of the Earth's magnetic field at the time they cooled and crystallized. In all rocks about 12 million years and older in southwest Washington and western Oregon, the paleomagnetic directional records indicate rotation about a vertical axis in a clockwise direction. The magnitude of the rotation is varied but can exceed 30 degrees for rocks in the Yacolt area. In general, the upper crust of the western part of the North American plate in the Cascade region was distended to the north and south while expanding westward at the same time. Geologists theorize that oblique subduction between the North American and Juan de Fuca plates plus asymmetric internal extension of North America cause the rotation. If the oldest rocks of the Cascades were rotated back into the positions in which they were formed, the Eocene to early Oligocene coastline of Washington would be trending northwest, and it would be situated considerably closer to the pre-Cenozoic terrains of northeastern Oregon and Idaho.

REGIONAL STRATIGRAPHY

The volcanic stratigraphy of the Yacolt area is not well understood, and a number of formation names have been applied to the same rocks by various geologists.

To the north, in the Mount Rainier area, a much-studied rock section of upper Eocene to Oligocene age consists of grey-green andesitic tuffs and volcaniclastic sedimentary rocks called the Ohanapecosh Formation. Quartz-rich dacitic tuffs of the Oligocene and Miocene Stevens Ridge Formation and andesitic lavas of the Fifes Peak Formation overlie the Ohanapecosh. The Mount Rainier area strata and the Yacolt volcanic rocks cannot be directly correlated. Eocene and Oligocene Yacolt strata lack many of the features of the Ohanapecosh Formation. Specifically, lava flows, which are rare in the Ohanapecosh, dominate many parts of the Yacolt section. Quartz-rich dacitic tuffs are only locally present in the Yacolt area, and these appear to represent a variety of Oligocene or Miocene events and therefore cannot be equivalents of the Stevens Ridge Formation, the age of which is more restricted.

Because of the local variations in stratigraphy, geologists working in the Oregon Cascades apply more general nomenclature to the volcanic rocks of similar age and character. Units older than about 5 million years are assigned to the Western Cascade Group, younger rocks to the High Cascades Group. Informal and a few formal formation names are used locally to further differentiate the Oregon section.

Using the Oregon approach, the Yacolt volcanic rocks are here assigned to the Western Cascade Group. Because relations with surrounding strata are not well understood, only a few formation names are used in this article.

GEOLOGIC HISTORY OF THE YACOLT BURN STATE FOREST

Earliest Volcanism of the Cascade Range

The oldest rocks of the Yacolt region are of late Eocene age (about 38 million to 35 million years old) and represent some of the oldest known rocks in the entire Cascade Range. These rocks are exposed along State Route 503 from Interstate 5 to near Amboy, just outside the forest boundary. Before these rocks were formed, the Cascades did not exist as a mountain chain or volcanic arc, presumably because subduction was not occurring beneath this part of northwestern North America.

In southwestern Washington during the Eocene, a large delta was built up where sands derived from the erosion of mountains in northern Washington and Idaho were deposited into the Pacific Ocean. Early Cascade volcanoes destroyed this delta by disrupting drainages. Rivers flowing from the north or northeast were diverted and blocked by eruptions of late Eocene to early Oligocene andesitic and basaltic lava. These lava flows may have formed a few shield volcanoes with gentle slopes, but most seem to have come from fissure or rift vents. Topographic relief was low, and towering stratovolcanoes like present-day Mount St. Helens were either entirely absent or lay farther to the east. Judging

Figure 3. View north from Gumboot Mountain (R. 5 E., T. 4 N.); Mount St. Helens, upper right, and Mount Adams, center. Bedrock of the State Forest area in the foreground consists of Oligocene andesitic lava flows and tuffs intruded locally by small middle Miocene diorite plugs and sills. Photo taken August 1985.

from the lack of sedimentary rocks between these lava flows and from available radiometric age determinations, eruption rates were high. The great Eocene delta was destroyed and buried beneath as much as a mile of lava in perhaps one million years or less.

Mid-Tertiary Cascade Volcanism

Volcanism continued to generate massive amounts of material into the middle Tertiary. The thousands of feet of volcanic rocks forming the bulk of the Yacolt region date from the Oligocene and early Miocene, about 35 million to 20 million years ago. These rocks are more diverse than the oldest Cascade rocks and consist of andesitic lavas interbedded with tuffs and volcaniclastic sedimentary rocks (map units Φva, Φvc, and MΦvc Fig. 3). Rather than being well-bedded and regularly arranged into neat packages of alternating lithologies, the mid-Tertiary section tends to possess a devilishly complicated geometry. In most places, it is impossible to trace an individual volcanic unit for more than a quarter mile. The complex architecture of these volcanic rocks reflects the style of eruption that produced them. Volcanoes built eruptive edifices of considerable relief. Both large shield volcanoes and steep-sided stratovolcanoes were probably present—the simpler rift-type volcanism recorded by the earliest Cascade rocks apparently did not recur. The large, steep-sided mid-Tertiary volcanoes were dynamic, producing lavas, pyroclastic flows, and lahars or debris flows, all intermixed near the vent. Farther from the vent, volcaniclastic sedimentary rocks and tuff accumulated in river or lake basins. Plant fossils are fairly common in these sedimentary rocks in the Yacolt area.

Figure 5. Basaltic andesite sill intruding Oligocene tuff, Canyon Creek area, NW1/4 sec. 3, T. 5 N., R. 5 E. Photo taken in August 1985 by Matt McClincy.

Lava flows are more numerous in the western part of the Yacolt mid-Tertiary section; in contrast, volcaniclastic rocks dominate the eastern part. This probably reflects the presence during the Oligocene and early Miocene of an arc-front of flow-dominated shield volcanoes and a back-arc basin in which a thick volcaniclastic section accumulated. Figures 4 and 5 show some of the intrusive and volcaniclastic units of the area.

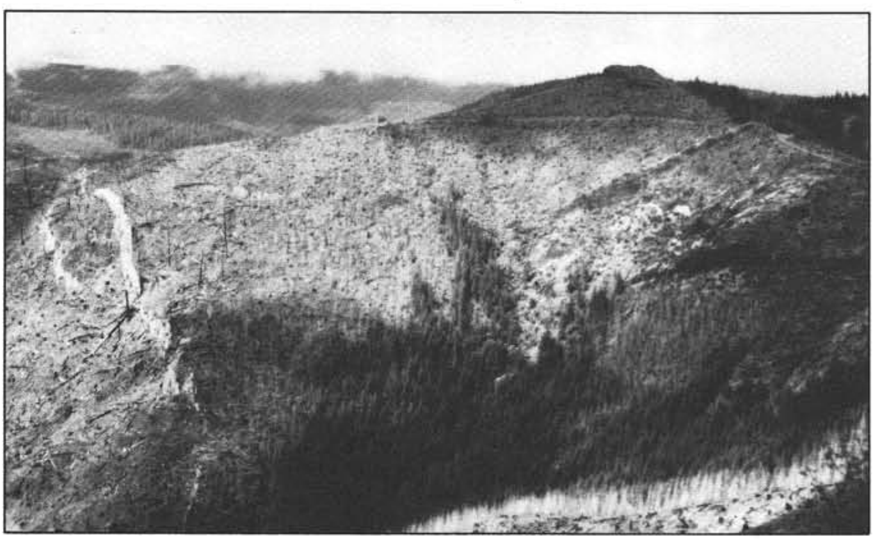

Figure 4. Andesite dikes cutting Oligocene volcaniclastic rocks in the Yacolt Burn State Forest area (sec. 9, T. 5 N., R. 5 E.). Photo taken in August 1985 by Matt McClincy.

Middle Miocene Cascade Plutonism

Numerous granodiorite to diorite plutons invaded the upper part of the crust of much of the southern Washington and northern Oregon Cascade Range during the middle Miocene, about 20 million years ago. In the Yacolt area, a large intrusive body known as the Silver Star pluton (part of unit Mi, Fig. 2) typifies these rocks. The pluton is of special interest because most of the region's metallic mineral resources are closely associated with it. During intrusion, heat from the invading magma baked and altered surrounding rocks. Hot fluids from the magma and ground water moved through fractures, precipitating quartz, feldspar, calcite, and, very rarely, gold and sulfide minerals containing copper, zinc, and other metals.

Because of later erosion, it is unclear if magma from the Silver Star pluton or similar intrusive bodies in the Yacolt region produced volcanic eruptions. The lack of widespread 20-million-year-old dacitic tuffs in the region suggests that most of the magma cooled beneath the surface.

Middle Miocene Cascade Volcanism

During this period, from 20 million to 17 million years ago, thick andesite lava flows were erupted northwest of Stevenson and Carson (unit Mva, Fig. 2). Unlike earlier mid-Tertiary Cascade volcanism, little pyroclastic material was produced by these eruptions. Flow after flow of dark-grey pyroxene andesite piled up to form shield and composite volcanoes. Between volcanic vents, bouldery lahars, and other fluvial deposits accumulated to form the Eagle Creek Formation. The Eagle Creek Formation (unit Mc, Fig. 2) is well exposed along the Columbia River Gorge near Bonneville Dam.

Columbia River Basalt Group Volcanism

Most volcanoes in the Cascade Range were inactive at about 15.5 million years ago. However, in southeast Washington and adjacent Idaho and northeast Oregon, remarkable volumes of basalt and basaltic andesite erupted at this time from long, narrow, south-trending fissure systems. Enormous floods of lavas of the Grande Ronde Basalt filled the Columbia Basin and spilled out down the ancestral Columbia River Gorge to the Pacific Ocean. Several Grande Ronde flows cover the southern portion of the Yacolt Burn State Forest near the gorge (unit Mcr, Fig. 2).

Late Miocene Quiescence

Geologists know little about the period between 15 million and 5 million years ago for much of the Yacolt area because few rocks of this age are present. Uplift of the Cascade Range probably began, and erosion stripped off whatever rocks may have been previously deposited. Volcanoes in this part of the Cascade Range may have been inactive. Several other Columbia River Basalt Group lava flows again filled the ancestral Columbia River Gorge to the south of the Yacolt area.

Pliocene to Early Quaternary Uplift and High Cascade Volcanism

Uplift and erosion of the Cascades from about 5 million to 1.5 million years ago caused large amounts of rock to be stripped from the region and exposed for the first time the intricate details of the lower levels of the Oligocene and Miocene Cascade volcanoes and the Silver Star pluton. Thick deposits of gravel, sand, and silt derived from eastern Washington and deposited by the Columbia River cover extensive areas of the lowlands near the Yacolt region on the south and west. These deposits are called the Troutdale Formation (unit QRc, Fig. 2).

Basaltic volcanism typical of the High Cascades Group began southwest of the Yacolt region. Numerous small cinder cone vents and shield volcanoes produced lava flows that were locally voluminous enough to fill drainages and even temporarily dam the Columbia River. The lavas are typically light grey and vesicular and contain prominent plagioclase and olivine crystals. In the Columbia River Gorge–Portland area, these flows are called the Boring Lava (unit QRv, Fig. 2) and are locally interbedded with the Troutdale Formation.

Pleistocene Glaciation

From about 1.5 million to 10,000 years ago, the regional climate oscillated between cold, wet glacial periods and moderate conditions much like those of today. About 120,000 years ago, a large ice sheet occupied the Lewis River basin of the Yacolt region. The glacier deposited unsorted mixtures of boulders, sand, and clay (known as till) called the Amboy Drift over much of the highlands. Outwash from the glacier filled the valleys of the northwest part of the state forest (unit Qg, Fig. 2).

Between 20,000 and 12,000 years ago, a less intense glaciation occurred. Till and outwash were again deposited in upper Lewis River drainages and on the highlands around Silver Star Mountain. These deposits are called the Evans Creek or Canyon Creek Drifts.

Between 15,000 and 12,000 years ago, several tremendous floods of water released by the failure of glacial dams near Spokane rushed through the Columbia River Gorge to the south of the Yacolt area. No flood deposits are within the forest boundaries, but the topography of the area just to the south was profoundly affected by the floods.

High Cascade Group volcanism continued. A large, basaltic composite cone was built at Trout Creek Hill. Basalt lava from this cone reached the Columbia River (unit Qv, Fig. 2).

Holocene Erosion and Uplift

During the last 10,000 years, uplift and erosion of the Cascade Range has continued. Cascade stratovolcanoes are still active to the north (Mount St. Helens) and south (Mount Hood), but the smaller ones of the Yacolt area are quiet. Along the Columbia River Gorge in the Bonneville Dam area, several very large landslides occurred during this span of time (unit Qls, Fig. 2).

MINERAL DEPOSITS

Metallic Minerals

In 1892, prospectors discovered copper and gold deposits associated with the Silver Star pluton and related rocks. Despite much prospecting, including a modern drilling and geochemical sampling effort by a major mineral company in the 1970s, few profitable deposits have been found in the Yacolt Burn State Forest area. To date, metallic mineral production totals only about $26,000. Major deposits of the Yacolt area (Washougal mining district) are shown on Figure 2 and listed in Table 1.

Metallic mineral deposits in the Yacolt area are of three types: quartz fissure veins (by far the most common); tourmaline-bearing breccia pipes; and placer deposits. The veins and breccia pipes are concentrated along the eastern edge of the granodiorite pluton at Silver Star Mountain.

The quartz fissure veins range from stringers less than 1 in. thick to massive veins 6 ft thick. Most are composed of thin bands of quartz, brecciated wall rock, and fault gouge. The chief ore minerals are pyrite, chalcopyrite, bornite, pyrrhotite, magnetite, galena, and sphalerite. The quartz fissure veins typically contain about 1 percent copper and trace amounts of gold. Richer veins, with as much as 20 percent copper and several ounces per ton of gold, are rare.

A tourmaline-bearing breccia pipe, called the Black Jack breccia pipe, is associated with the quartz diorite dikes and plugs of the Silver Star pluton. The breccia pipe is about 500 ft wide, 800 ft long, and 800 ft deep. Reserves identified on the basis on drilling are 2.9 million tons of rock containing 1.62 percent copper, 0.035 percent molybdenum, and 0.35 oz of gold per ton.

Gold placer deposits have been reported along the East Fork Lewis River.

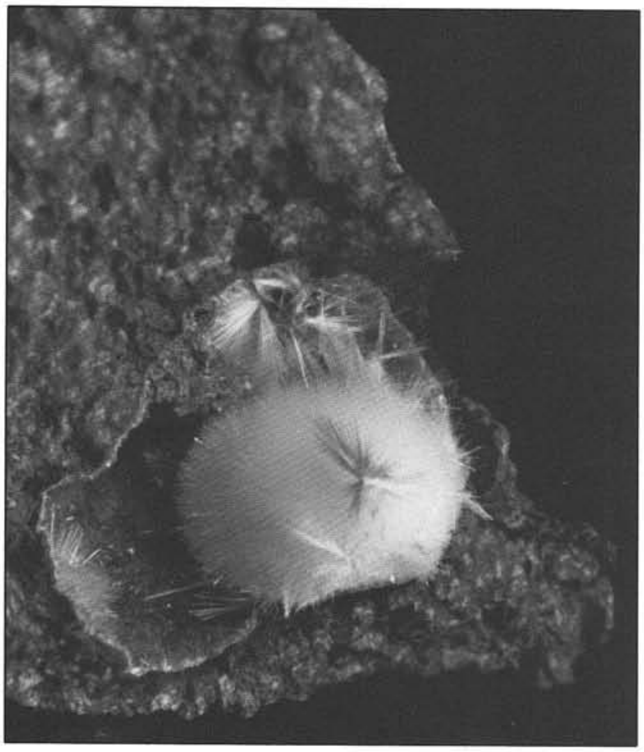

Figure 6. Scolecite on heulandite (top) and gonnardite with smectite, zeolites that can be found in the State Forest area. Photos courtesy of Donald Howard, Portland State University.

While the metallic mineral deposits described above offer some opportunities for mineral collecting, many are on patented claims or active mining claims or are no longer accessible due to collapse of prospects and adits.

Nonmetallic Minerals

Nonmetallic minerals offer the best potential for mineral collecting in the Yacolt area. The locations of several occurrences of agate, chrysocolla, quartz, jasper, petrified wood, and zeolites are shown on Figure 2. Collectors should contact local rock and mineral clubs for information about numerous additional localities.

Zeolites found in the Yacolt area include mordenite, heulandite, cowlesite, epistilbite, stilbite, scolecite, laumontite, gonnardite, garronite, phillipsite, levyne, thompsonite, mesolite, and chabazite (Fig. 6). The zeolites are typically found in greenish, clay- and chlorite-lined vesicles or vugs of mid-Tertiary andesite lava flows.

ACKNOWLEDGMENT

Carl Harris (DGER) provided much helpful information concerning mineral collecting in the Yacolt area.

RECOMMENDED READING

The first two references are available from the Department of Natural Resources, Division of Geology and Earth Resources, MS PY-12, Olympia, WA 98504. Include $1.00 for postage and handling for each order. All orders must be prepaid.

Walsh, T. J.; Korosec, M. A.; Phillips, W. M.; Logan, R. L.; Schasse, H. W., 1987, Geologic map of Washington-Southwest quadrant: Washington Division of Geology and Earth Resources Geologic Map GM-34, 28 p., 1 pl., scale 1:250,000, accompanying explanatory sheet. ($5.57 + .43 [tax for WA residents only] = $6.00).
A basic document for exploring the geology of southwest Washington.

Phillips, W. M., 1987, Geologic map of the Vancouver quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 87-10, 27 p., 1 pl., scale 1:100,000 ($1.39 + .11 [tax] = $1.50).
A technical report containing many details of the geology of the Yacolt region; the map is not colored and is difficult to read in places.

Moen, W. S., 1977, St. Helens and Washougal mining districts of the southern Cascades of Washington: Washington Division of Geology and Earth Resources Information Circular 60, 71 p.
Out of print, but can be viewed in many libraries. Highly recommended for prospectors or mineral collectors.

Tschernich, R. W., 1988, The occurrence and origin of silica rich and silica poor zeolites at Big Tree Creek, Yacolt, Clark County, Washington: Micro Probe, v. 6, no. 7, p. 6-19.
Hard-to-find reference, but vital for serious zeolite collectors. The Division of Geology and Earth Resources library has a copy.

USGS Mineral Resources Activities, Spokane Field Office

by U.S. Geological Survey staff, Spokane

In recent years the U.S. Geological Survey, through the Office of Mineral Resources, has enlarged the staff at the Spokane Field Office. The objective of increasing the staff is to promote better interaction and working relationships with the public, industry, academia, and local, state, and federal governmental agencies. USGS staff in Spokane represent three branches, each with somewhat different functions. The Branch of Western Mineral Resources (WMR) has the largest staff in Spokane. The Branch of Resource Analysis also participates in mineral resource activities and staffs the Minerals Information Office (MIO). Personnel of the Branch of Western Regional Geology undertake geologic mapping projects.

Specific goals of WMR in its Spokane office are:

- to develop recognized expertise with the mineral resources of the Inland Northwest (east of the crest of the Cascades of Washington and Oregon to the foreland of the Rocky Mountain thrust belt in Montana) at regional and district scales,
- to apply this expertise to the assessment of the nation's mineral wealth, appraising the potential for undiscovered conventional and unconventional mineral deposits, estimating metal endowment, and designing future resource research,
- to disseminate information and serve the public and scientific community.

The centerpiece project of the Branch effort in Spokane is titled "Metallogenesis associated with continental margin evolution in the Inland Northwest—The Cretaceous-to-Eocene transition from convergent to extensional tectonism". This project serves to unite the expanded office staff by undertaking a coordinated study of the mineral resources of the Pacific Northwest. The focus is on the youngest of the three main metallogenic episodes in the Inland Northwest region and on the structural and magmatic setting unique to the evolution of convergent continental margins. The project seeks to clarify the plutonic, volcanic, structural, and metallogenic evolution of the continental margin during the transition from east-west convergence to east-west extension.

District- or deposit-scale investigations of mining districts, as well as petrologic, isotopic, and geochronologic studies, will be essential elements of this project. Some effort will be given to characterizing the nature of pre-Cretaceous features, such as older magmatic events and pre-existing crustal weaknesses, that influenced the late igneous or tectonic activity. The project builds on mapping for recent CUSMAP and Idaho Wilderness studies, recent Canadian Geological Survey geochronologic and geologic studies in the Okanogan region in British Columbia, and recent USGS and university mapping and geochronologic studies in the Cascade Range. Industry is actively exploring areas where mineralization of this age is present in central Idaho, the Republic graben, and the Chiwaukum graben near Wenatchee; several deposits are being developed.

Ronald G. Worl is the chief of the Spokane office. His expertise lies in economic geology and methods of mineral resource assessment. His project activities include CUSMAP work in the Hailey, Idaho, area, Idaho Wilderness studies, and regional ore controls.

Below is a list of WMR personnel in Spokane. Areas of expertise (in italics) and project activities follow:

Arthur A. Bookstrom: *Economic geology*; Climax-type molybdenum deposits and Coeur d'Alene- and Metaline-type ores.

Stephen E. Box: *Structural geology and basin analysis*; Idaho Wilderness studies, examination of kinematics of rift structures and core complexes in northeastern Washington, regional ore controls and nature of accreted terranes.

James G. Evans: *Mineral resources studies and quadrangle mapping*; Baker terrane, Wallowa-Seven Devils terrane, areas in eastern Oregon that contain volcanic-hosted gold deposits.

Thomas P. Frost: *Igneous petrology and geochemistry*; Idaho Wilderness studies, examination of Mesozoic to Eocene plutonic rocks and related ore deposits in northeastern Washington, nature and timing of plutonism and metamorphism between the Okanogan and Pasayten faults.

Bruce R. Johnson: *Metamorphic petrology and computerized databases*; Development of geographic information systems, Idaho Wilderness studies, examination of ore deposits related to contact and regional metamorphism.

Thor H. Kiilsgaard: *Economic geology*; Regional ore control and trans-Challis fault system.

James R. Lindsay: *Research chemistry*; Studies of chemistry of surfaces using laser fluorescence methods, development of analytical methods for rare-earth and platinum-group elements and other elements thought to be of interest to advanced technologies.

Cole L. Smith: *Geochemistry*; CUSMAP work near Hailey, Idaho; vapor-transport processes, re-examination of geochemically evolved granites and rhyolites in Idaho and Washington, geochemistry of ore-forming solutions, and geochemical databases.

James W. Whipple: *Sedimentology and stratigraphy*; Sedimentology, stratigraphy and mineralogy of the Belt Supergroup, stratabound and sediment-hosted ore deposits, and stratigraphic controls on ore deposition.

Michael L. Zientek: *Economic geology*; Platinum-group-enriched ore deposits in the Stillwater Complex, Custer-Gallatin National Forest resource assessment, mineral deposits associated with alkaline igneous rocks, and platinum-group commodity maps and specialty and high-tech metals.

The MIO in Spokane serves as a contact through which industry, the public, and other government agencies can obtain information concerning mineral deposits and mineral resources. One of the tools used by the MIO staff to answer requests is a database containing information about more than 80,000 mineralized localities around the world. Most MIO services are free of charge. To make a request, please contact Kate Johnson at 509/353-3113 or stop by Room 651 of the U.S. Courthouse at West 920 Riverside Avenue.

Geological Activities during the Hiatus, 1892-1901

by J. Eric Schuster

Editor's note: This is the last in a series of articles describing the history of Washington's "geological survey".

For most of the time between 1892 and 1901 there was no State Geologist, and the Mining Bureau was inactive and/or unfunded. Nevertheless, the science of geology was being advanced, mainly on two state college campuses, the University of Washington and Washington Agricultural College and School of Science (now Washington State University). Barksdale (1974, p. 8-9) describes the founding of the Department of Geology at the University of Washington and the background of its first professor:

> President Gatch proposed and the regents voted November 28, 1893, to establish a School of Mining. An outline of courses proposed for the new enterprise appeared in the catalogue for 1894, but the school was not activated until 1901.
>
> On second thought, the regents in 1894 established a Department of Geology and Mineralogy in preparation for the move to an enlarged facility on the present campus site. It was activated as planned.
>
> Henry Landes, M.A., Harvard, was appointed Professor of Geology and Mineralogy at a salary of $1,200 upon the recommendation of President David Starr Jordan of Stanford. He arrived in September, 1895, to take up his duties in the new Administration Building (now Denny Hall), an imposing brick and stone structure reminiscent of a Norman Castle. Its generous proportions allowed expansion of the University that had become impossible in the cramped downtown building.

Henry Landes. Photo from the Special Collections Division, University of Washington Libraries.

> Who was this first professor of geology and mineralogy who was to give inspiration and direction to the department, the University, and the community for forty-one years? Henry Landes was born in Carroll, Indiana in 1867. Educated in the country schools he also taught there three years before entering Indiana State University in 1888 as a major in geology. He completed three years at Indiana and went to Harvard, receiving his B.A. from Harvard in 1892; Indiana granted him a B.A. degree at the same time. After another year on a Harvard scholarship he received an M.A. in 1893. During the summers he worked for the U.S. Geological Survey and for the New Jersey State Survey, and in the autumn of 1893 was asked to arrange the geological collection for the State Museum of New Jersey. With job in hand he married Bertha Ethel Knight of Worcester, Massachusetts, on January 2, 1894. The year 1894-95 was spent as principal of the high school in Rockland, Maine. When the call came from Seattle he was ready.
>
> Professor Landes began his courses in 1895-96 in the not quite completed Administration Building. Classes were held on the first floor; the mineralogy laboratory was a partly finished room in the basement. Assaying was given in a construction shack left behind by the builders.

The next year a chair of geology and mineralogy was established at the Washington Agricultural College and School of Science. This event and Solon Shedd's appointment are described briefly by Bryan (1928, p. 174):

> At the meeting of the Board of Regents which occurred at the commencement period a chair of geology and mineralogy was established, and on June 26 [1896] Solon Shedd of Stanford University was elected as assistant professor. Professor Shedd had for some years been a teacher in the Monmouth, Oregon, Normal School and had taken his bachelor's degree at Stanford University, where he studied under the celebrated Professor (afterwards President) Branner. Doctor Branner wrote me, "Shedd is the best mineral analyst at Stanford," and strongly recommended his appointment, which was made, and we never had cause to regret it.

Jenkins (1942, p. 187-188) adds the following background information:

> Solon Shedd was born in Preemption, Mercer County, Illinois, May 25, 1860. His parents were Captain Frank Shedd and Emily Louise (Olin) Shedd. In 1864, the family moved by prairie scooner [sic] from Preemption to Linn County, Oregon, the journey taking 5 months. Today, in the Willamette Valley, is the town of Shedd, which memorializes the early settlement of this pioneer family.
>
> Doctor Shedd was married on June 4, 1907, to Jeannette Bell Wimberly...
>
> Teaching was a very early profession of Solon Shedd, for it started in grammar school work in Oregon, after he attended the Oregon State Normal School at Monmouth and received the degree of B.S. in 1889.

Solon Shedd. Photo from Proceedings Volume of the Geological Society of America Annual Report for 1941, p. 7.

His leaning toward his later chosen subject of geology is indicated by the fact that he was a natural science instructor at Oregon State Normal School from 1890 to 1894.

Later, he came to Stanford University, where Dr. John Casper Branner had a profound and lasting influence on his life.

With an A.B. degree in geology from Stanford University...Professor Shedd moved to Pullman, Washington, where he was appointed assistant professor of geology. He saw the first 4-year class graduate from the State College of Washington and in 1901 was made professor and head of his department.

While the University of Washington and Washington Agricultural College and School of Science were dealing with geology in an academic setting, the state government in Olympia was almost silent on the subject. However, two official actions are known. First, in March, 1896, Henry Landes was appointed unpaid State Geologist by Governor McGraw via the following proclamation:

The State of Washington
J. H. McGraw, Governor

To all to whom these Presents shall Come Greeting.

Whereas, Harry [sic] Landes, of King County, has been appointed by the Mining Bureau as State Geologist

Now, Therefore, I, J. H. McGraw, Governor of the State of Washington, by virtue of authority vested in me by law, do hereby commission him the said Harry Landes as State Geologist of the State of Washington for the term ending January 14, 1897.

Said appointment is made and accepted upon the express understanding and agreement that the state shall not be liable for any salary or expenses herein, and until his successor is duly qualified, and, I do authorize and empower him to execute and fulfill the duties of that office according to the law, with all the powers, privileges, ~~and emoluments~~ appertaining thereto.

In Testimony Whereof I have hereunto set my hand and caused the Seal of said State to be affixed at Olympia, this twenty fourth day of March A. D. one thousand eight hundred and ninety six.

By the Governor:
[signed] J. H. Price, Secretary of State
[signed] J. H. McGraw (McGraw, 1896)

Second, in 1899 the legislature appropriated $1,500 for traveling and other expenses of the Mining Bureau (Jenkins, 1899, p. 194), but there is no indication that this appropriation was ever used.

After Landes' brief term as unpaid State Geologist expired, inquiries were still received about the geology and mineral resources of Washington, as evidenced by the following letters between Governor Rogers' private secretary and Mr. G. H. Raymond, a grain elevator operator (City of Buffalo, 1899) in Buffalo, New York. The letters are reproduced here because they help to document the lack of an official person or organization in Olympia with the responsibility of addressing the state's mineral resources and geology and because Mr. Raymond's letter includes a still-pertinent argument for states to have state geologists:

July 8, 1899.
G. H. Raymond, Esq.,
57 Chapin Block, Buffalo, N.Y.
Dear Sir:-

Your letter of June 23rd, has been handed to me for answer.

In reply thereto permit me to state that there is no State Geologist in this state, the legislature having refused, some six years ago, to appropriate for that department.

I send you in this mail copies of reports of the old State Geologist which may contain the desired information.

Yours respectfully,

Governor's Private Secretary. (Governor's Staff, 1899)

And Raymond's reply:

G. H. Raymond,
57 Chapin Block,
Buffalo, N.Y.
July 13, 1899.
Hon. J R Rogers.
Olympia Wash.

Dear Sir. A little time since I addressed a letter to the State Geologist of your state. The letter was returned with the notation "No such officer in state named." Not understanding what it meant I sent the letter to you and am to-day in receipt of your letter that for six years past your legislature had refused to make appropriations for the Department of Geology.

Had I been advised by you that the great state of Washington had seceded or that a Washington regiment in the Phillipines [sic] had rfused [sic] to obey orders I could hardly have been more surprised than to receive such a report.

It seems to me utterly inexplicable and when one thinks of the great possibilities in the line of minerals which your state possesses the action of your legislatures seem simply unaccountable.

That state or that people makes the most rapid growth financially, socially and every way that makes the most of its natural advantages. In no other way can a state even ascertain intelligently what its natural advantages are in the direction of mineral wealth except through the best efforts of a first class geologist.

The world is not standing still and new matters are continually coming up which make natural advantages of a state which previously may have been unavailable, not only available but of the greatest value. When parties write to a state and are unable to ascertain what it possesses in certain lines of minerals and from another state ascertains fully what it has and its prospects the latter state of course is the one that first reaps the benefits of new orders of things and frequently gets a start which the sleepy state may never have.

It is perhaps not my province to find fault with your legislatures but simply wish to show in one direction only what is being done in certain lines and that information can be obtained from some states in fact every state in the Union except Washington which will at once enable those states to take advantage of progressive ideas and the unprogressive state is passed over neccessarily [sic].

The state of Texas has vast deposits of iron ore. It has however no way of using them on account of expensive fuel. Texas has vast fields of lignite and Brown Coals which heretofore have not been possible to use for practically any purpose. A new process of fuel burning has just recently come to the writers notice which will make it possible to use the lignites and Brown Coals of Texas to make Iron.

Application to the State Geologist of Texas at once brings out all the facts both as to Iron and Coal. The state of California has great deposits of precious metals which cannot now be worked on account of expense of fuel. That state also has a very heavy Oil which cannot now be used for fuel purposes satisfactorily.

The process of fuel burning for lignite coals and Brown Coals will make possible the using the heavy oils of California to smelt the ores noted. This new process of fuel burning makes it possible to use peat, green wood, tar, asphaltum, poor coals, and heavy oils in all smelting operations and so that smelters can be started on a small scale directly at the mines.

There must be many places in your state that would welcome such an opportunity but when the effort is made to ascertain just where these places are the answer is that there is no one in the great state of Washington able to give the information.

In Missouri the RailRoads carry the State Geologist free of charge. Any party in the state having discovered something that he cannot make out in the line of mineral or other deposits has simply to write the Geologist and offers to pay his expenses while away from home and the investigation is made free of cost.

In your own state a man might for years see a slight film on a little stream and be ignorant of what it means. Had he a state Geologist to apply to he might find out that this film meant the presence of Natural Gas and possibly Petroleum. A particluar [sic] style of rock formation and color might show the presence of metals in your state not now dreamed of but without any opportunity to have the matters investigated it might remain for years and perhaps always unknown. These are but samples of the possibilities that arise from a business like treatment of the natural advantages of your state.

Trust you will not think that I am interfereing [sic] in matters that are none of my business but the fact that your state had no Geologist has constrained me to write that you might see how such a condition of things strikes a purely disinterested party. Whatever affects one person must affect others to a greater or less degree and the backwardness of your state in this direction should be checked and from your vigorous efforts in other directions I feel that your succeeding legislatures will feel the results of your efforts in this particular direction.

Trust that you will pardon me if I seem to be going too far and with the greatest respect remain, my dear sir,

Very respectfully,

[Signed] G. H. Raymond. (Raymond, 1899)

Fortunately, the legislature re-examined the need for an agency to deal with Washington's geological resources, and in 1901 it established a state geological survey (Nichols, 1901, p. 334-336). The survey they established, first headquartered at the University of Washington Department of Geology and led by State Geologist and Department Head Henry Landes, endures today.

References Cited

Barksdale, J. D., 1974, Geology at the University of Washington 1895-1973: University of Washington Publications in Geological Sciences, no. 4, 109 p.

Bryan, E. A., 1928, Historical sketch of the State College of Washington, 1890-1925: Published by the Alumni and the Associated Students, Spokane, WA, 556 p.

City of Buffalo, 1899, City Directory of 1899: Buffalo, NY.

Governor's Staff, 1899, [Letter] July 8, to G. H. Raymond: Washington State Archives (Olympia, WA), Governors' files, 1 p.

Jenkins, O. P., 1942, Memorial to Solon Shedd: Proceedings Volume of the Geological Society of America Annual Report for 1941, March, 1942, p. 187-191.

Jenkins, W. D., compiler, 1899, Session laws of the State of Washington, Session of 1899, Compiled by Will D. Jenkins, Secretary of State: Gwin Hicks, State Printer, Olympia, WA, 466 p.

McGraw, J. H., 1896, Certificate dated March 24 proclaiming Harry [sic] Landes State Geologist: University of Washington Archives (Seattle, WA), Accession 75-70-53, Henry Landes papers, 1 p.

Nichols, S. H., compiler, 1901, Session laws of the State of Washington, Seventh session, 1901, Compiled in chapters, with marginal notes, by Sam H. Nichols, Secretary of State: Gwin Hicks, State Printer, Olympia, WA, 466 p.

Raymond, G. H., 1899, [Letter] July 13, to J. R. Rogers: Washington State Archives (Olympia, WA), Governors' files, 4 p.

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

February 1991 through April 1991

THESES

Belcher, Wayne R., 1988, Assessment of aquifer heterogeneities at the Hanford nuclear reservation, Washington, using inverse contaminant plume analysis: Colorado School of Mines Master of Engineering thesis, 54 p.

Bickel, Sonja, 1990, Geochemical and stratigraphic analysis of the Crescent basalt transition zone, Olympic National Forest, Washington: University of Puget Sound Bachelor of Science [thesis], 42 p.

Bittenbender, Peter Edwin, 1991, Mid-Cretaceous orogenesis in the Huckleberry Mountain area, North Cascades, Washington: University of Texas at Austin Master of Arts thesis, 137 p., 2 plates.

Bodvarsson, Gudrun M., 1975, Ocean wave-generated microseisms at the Oregon coast: Oregon State University Master of Science thesis, 83 p.

Bruemmer, Jerry L., 1964, Gravity models for peridotite injection and local metamorphism along north-northeast-trending zones of tectonism, southwest Oregon: University of Oregon Master of Arts thesis, 124 p.

Cary, J. A., 1990, Petrology and structure of the Lookout Mountain–Little Devil Peak area, North Cascades, Washington: Western Washington University Master of Science thesis, 164 p., 3 plates.

Crum, Steven V., 1987, The mechanics of subduction zone topography—A study of age effect in the Pacific Northwest: Pennsylvania State University Master of Science thesis, 58 p.

Finn, Carol Ann, 1988, Structure of the Washington convergent margin, implications for other subduction zones and for continental growth processes: University of Colorado Doctor of Philosophy thesis, 145 p.

Gless, James Douglas, 1989, Slope stability as related to geology at Rainier, Columbia County, Oregon: Portland State University Master of Science thesis, 104 p.

Hagen, T. A., 1988, Ponderosa pine tree rings—Variability of response to precipitation in space and time: Washington State University Doctor of Philosophy thesis, 74 p.

Hill, Roderic P., 1975, Structural and petrological studies in the Shuswap Metamorphic Complex near Revelstoke, British Columbia: University of Calgary Master of Science thesis, 147 p

Jones, T. L., 1989, Simulating the water balance of an arid site: Washington State University Doctor of Philosophy thesis, 201 p.

Li Jing, 1989, Strength characteristics of unsaturated Palouse loess: University of Idaho Doctor of Philosophy thesis, 288 p.

Min, K. W., 1986, A geochemical study of granitic rocks from the Turtle Lake quadrangle and vicinity, northeastern Washington: Colorado School of Mines Doctor of Philosophy thesis, 120 p.

Nazy, David John, 1987, A seismic refraction study of a portion of the northeastern margin of the Tualatin Valley, Oregon: Portland State University Master of Science thesis, 81 p.

North, William Benjamin, 1964, Coastal landslides in northern Oregon: Oregon State University Master of Science thesis, 85 p.

Pelto, M. S., 1988, The mass balance and climatic sensitivity of North Cascade, Washington and Coast Range, southeast Alaska glaciers: University of Maine Master of Science thesis, 115 p.

Phadke, Suhas, 1988, Imaging crustal diffraction zones and seismic tomography: University of Alberta Doctor of Philosophy thesis, 183 p.

Rinehart, Verrill Joanne, 1964, Investigation of twelve earthquakes off the Oregon and northern California coasts: Oregon State University Master of Science thesis, 41 p., 1 plate.

Smith, Moira Tracey, 1990, Stratigraphic, structural and U-Pb geochronologic investigation of lower Paleozoic eugeoclinal strata in the Kootenay arc, NE Washington and SE British Columbia: University of Arizona Doctor of Philosophy thesis, 262 p., 2 plates.

Souza, Manuel Edward, 1927, Physiography and structure of the Oregon Coast Range province: University of Oregon Master of Arts thesis, 73 p.

Trebing, Harry Evan, 1988, Chromite compositional variation in the Twin Sisters dunite, Washington State: Michigan State University Master of Science thesis, 74 p.

Tuxhorn, G. L., 1989, Estimating transport parameters for pesticides in soils of the Columbia Basin of Washington: Washington State University Doctor of Philosophy thesis, 116 p.

Wiberg, Erik James, 1990, The probability distribution of snowmelt in clearcuts from a rain-on-snow event in the central Cascades of Washington: Ohio State University Master of Science thesis, 210 p.

Zervas, Chris Eugene, 1988, A finite element investigation of topographic variation at mid-ocean ridges spreading at the same rate: University of Washington Doctor of Philosophy thesis, 189 p.

U.S. GEOLOGICAL SURVEY REPORTS

Published Reports

Booth, D. B., 1990, Surficial geologic map of the Skykomish and Snoqualmie Rivers area, Snohomish and King Counties, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I-1745, 2 sheets, scale 1:50,000, with 22 p. text.

Good, E. E.; Slack, J. F.; Kotra, R. K., editors, 1990, USGS research on mineral resources—1991 program and abstracts; seventh annual V.E. McKelvey Forum on Mineral and Energy Resources, Reno, Nevada, February 11-14, 1991: U.S. Geological Survey Circular 1062, 99 p.

Switzer, J. C.; Porcella, R. L., 1990, Catalogue of U.S. Geological Survey strong-motion records, 1988: U.S. Geological Survey Circular 1057, 28 p.

U.S. Geological Survey, 1986, Strong-motion program report, January-December 1983: U.S. Geological Survey Circular 971, 57 p.

U.S. Geological Survey, 1990, The national gazetteer of the United States of America—United States concise 1990: U.S. Geological Survey Professional Paper 1200-US, 526 p.

Williams, S. J.; Dodd, Kurt; Gohn, K. K., 1990, Coasts in crisis: U.S. Geological Survey Circular 1075, 32 p.

Open-File reports and Water-Resources Investigations reports

Berge, P. A., 1985, Teleseismic P-wave traveltime residuals across the Cascade Range in southern Oregon: U.S. Geological Survey Open-File Report 85-622, 2 sheets microfiche [104 p.].

Chleborad, A. F.; Schuster, R. L., 1990, Ground failure associated with the Puget Sound region earthquakes of April 13, 1949, and April 29, 1965: U.S. Geological Survey Open-File Report 90-687, 136 p., 5 plates.

Clarke, S. H., Jr.; McClellan, P. H., 1989, Multichannel seismic-reflection profiles collected in May 1981, between latitudes 40 degrees 40′ and 45 degrees 00′ North, offshore of northern California and southern Oregon: U.S. Geological Survey Open-File Report 89-222, 4 p., 2 plates.

Cline, D. R.; Knadle, M. E., 1990, Ground-water pumpage from the Columbia plateau regional aquifer system, Washington, 1984: U.S. Geological Survey Water-Resources Investigations Report 87-4135, 32 p., in folder with 1 plate.

Cotton, J. A.; Catchings, R. D., 1989, Data report for the 1983 U.S. Geological Survey east-central Oregon seismic refraction experiment: U.S. Geological Survey Open-File Report 89-124, 30 p.

Dion, N. P.; Sumioka, S. S., 1991, Extent and source of organic solvents in ground water in the Argonne Road area near Spokane, Washington: U.S. Geological Survey Water-Resources Investigations Report 89-4121, 39 p.

Jones, M. A., 1991, Selected references for the Puget–Willamette Lowland regional aquifer-system analysis, Puget Sound lowland, Washington: U.S. Geological Survey Open-File Report 90-584, 55 p.

Miller, F. K., 1990, Preliminary geologic map of the Orwig Hump area, Washington and Idaho: U.S. Geological Survey Open-File Report 91-24, 20 p., 1 plate.

Selner, G. I.; Taylor, R. B., 1988, GSDRAW and GSMAP version 5.0—Prototype programs, level 5, for the IBM PC and compatible microcomputers, to assist compilation and publication of geologic maps and illustrations: U.S. Geological Survey Open-File Report 88-295A (Documentation and tutorial), and, 88-295B (Executable program disks), 130 p., 2 disks.

Stanley, R. G., 1991, Geologic basis for petroleum resource assessment of onshore western Oregon and Washington (province 72): U.S. Geological Survey Open-File Report 88-450X, 29 p.

GEOLOGY AND MINERAL RESOURCES OF WASHINGTON

(and related topics)

Gaylord, D. R.; Stoffel, K. L.; Joseph, N. L., 1990, Regional geology of northeastern Washington—Implications for Republic district mineral exploration: [Privately published by the authors for the Northwest Mining Association, 96th Annual Convention], 25 p., 1 plate.

Griffin, Jeff, 1990, Surface mining in Whatcom County: Whatcom County Planning Department, 1 v.

Haagen, Edward; and others, 1990, Soil survey of Skamania County area, Washington: U.S. Soil Conservation Service, 430 p., 38 fold-out plates.

Jackson, Bob, 1987, The rockhound's guide to Washington, volume 4: Jackson Mountain Press [Renton, WA], 1 v.

Perry, R. W.; Lindell, M. K., 1990, Living with Mount St. Helens—Human adjustment to volcano hazards: Washington State University Press, 205 p.

Stanford University Department of Geophysics, 1989, Stanford Crustal Geophysics Project, 1988 Columbia plateau seismic program data release: Stanford University Department of Geophysics, 106 p.

Thomas, Jim; Le Mieux, Rachel; Simmonds, Joe; Lin, Peter, 1991, Mineral taxation in Washington State; [final draft]: Washington Department of Revenue, 28 p.

U.S. Army, 1990, Final environmental impact statement for the Yakima Firing Center proposed land acquisition, Yakima Firing Center, Washington, July, 1990: U.S. Army [Fort Lewis, WA], 1 v.

U.S. Nuclear Regulatory Commission, 1991, Draft safety evaluation by the Office of Nuclear Reactor Regulation relating to geology and seismology, Washington Public Power Supply System Washington nuclear project no. 3 (WNP-3), docket no. 50-508: U.S. Nuclear Regulatory Commission, 31 p.

University of Washington Geophysics Program, 1990, Quarterly network report 90-D on seismicity of Washington and northern Oregon, October 1 through December 31, 1990: University of Washington Geophysics Program, 24 p.

Walker, David; Walker, Clois, 1991, Panning for gold and gemstones in Washington: [Privately published by the authors, Fort Smith, AR], 58 p.

Williams, Sara, 1986, Handbook for geophysical survey operators for Washington's offshore and inland marine waters: Washington Department of Ecology, 96 p.

GEOLOGY OF ADJACENT AREAS

British Columbia Geological Survey Branch, 1990, Geological fieldwork 1990—A summary of field activities and current research: British Columbia Geological Survey Branch Paper 1991-1, 437 p.

British Columbia Geological Survey Branch, 1991, British Columbia mineral exploration review 1990: British Columbia Geological Survey Branch Information Circular 1991-1, 80 p.

Commission of Inquiry into Fraser Valley Petroleum Exploration, 1991, Report of the Commission of Inquiry into Fraser Valley Petroleum Exploration: Commission of Inquiry into Fraser Valley Petroleum Exploration [Victoria, BC], 211 p.

Geological Survey of Canada, 1990, Principal mineral areas of Canada; 40th edition: Geological Survey of Canada Map 900A, 1 sheet, scale 1:7,600,000.

Geological Survey of Canada, 1991, Current research, Part A—Cordillera and Pacific margin: Geological Survey of Canada Paper 91-1A, 407 p.

MISCELLANEOUS TOPICS

Krinitzsky, E. L.; Slemmons, D. B., editors, 1990, Neotectonics in earthquake evaluation: Geological Society of America Reviews in Engineering Geology, v. VIII, p. 29-46.

Naeser, N. D.; McCulloh, T. H., editors, 1989, Thermal history of sedimentary basins—Methods and case histories: Springer-Verlag, 319 p.

Ward, P. L., 1990, The next big earthquake in the Bay Area may come sooner than you think—Are you prepared?: U.S. Geological Survey, 24 p.

Washington Department of Ecology, 1990, Shoreline management guidebook: Washington Department of Ecology, 1 v.

Waxman, R. N., 1991, Landslide and subsidence liability; Supplement April 1991: California Continuing Education of the Bar, California Practice Book 65 Supplement, 200 p.

RECENTLY ACQUIRED JOURNAL SUBSCRIPTIONS

Earth. Kalmbach Publishing Co. [Waukesha, Wisc.] v. 1, no. 1, Jan. 1991 - .

Journal of Petroleum Geology. Scientific Press, Ltd., v. 13, no. 1, Jan. 1990 - .

Oil and Gas Drilling Activity—December 1989 to June 1991

The tabulation below brings up to date information about drilling activity in Washington since the last report in this publication.

Company; permit no.	Well name	Location	Total depth (estimated)	Status
Sharon Resources, Inc.; 426	Sharon-Palmer Black Diamond #13-1	NW1/4 sec. 13, T12N, R6E, King County	(3,500')	Cancelled
Sharon Resources, Inc.; 427	Sharon-Palmer Black Diamond #14-1	SW1/4 sec. 14, T21N, R6E, King County	(3,500')	Cancelled
Sharon Resources, Inc.; 428	Sharon-Palmer Black Diamond #14-2	SW1/4 sec. 14, T21N, R6E, King County	(3,500')	Cancelled
Palo/Eagle Joint Venture; 429	Palo/Eagle Joint Venture (PEJV) Carbonado 33-1	2000' FSL, 1000 FWL (approx.), sec. 33, T19N, R6E, Pierce County	(2,500')	Cancelled
Sharon Resources, Inc.; 430	Sharon-Palmer Black Diamond #14-3	NE NE1/4 sec. 14, T21N, R6E, King County	(3,500')	Cancelled
American Hunter Exploration Ltd.; 431	Terrell No. 1	NW1/4 sec. 23, T39N, R1E, Whatcom County	(6,000')	Pending

Seismic Safety

(Continued from p. 2)

Dick Bullock - Washington State Assoc. of Counties
James Carpenter - Structural Engineers Assoc. of Washington
Laura Clark - Washington State Emergency Management Assoc.
John Conrad - Washington Dept. of Transportation
Janet Griffith - Washington Dept. of Health
Maris Grobins and Mike Levenson - Washington Dept. of General Administration
Linda Groce - Washington Hospital Assoc.
Kate Heimbach - Washington Dept. of Community Development
Bob Jones - Fire Protection Policy Board
Thomas Kinsman - Washington Assoc. of Building Officials
Terrance Michaelson - Washington Superintendent of Public Instruction office
Ron Schirman - Disaster Assistance Council
William Wiester, Jr. - Washington Assoc. of Sheriffs and Police Chiefs
Stanley Wu - Assoc. of Washington Cities

The mission of the committee is to assess the current status of seismic vulnerability, risk mitigation, preparedness, and response in the state of Washington and to develop specific state strategies and initiatives to address these.

The goals of the committee are:

- Assess the seismic risk in the state
- Determine the state of risk mitigation, preparedness, and response capabilities
- Clarify and determine federal, state, and private roles with respect to each strategy and initiative
- Identify needs for additional information, mitigation, preparedness, and response capabilities
- Develop and prioritize state strategies and initiatives
- Propose and prioritize policy-level actions.

Meetings

First International Symposium on "Volcanic Ash and Aviation Safety"
July 9-11, Westin Hotel, Seattle, WA

Theme: Detection, tracking, and warning of volcanic ash and the effects of ash on aircraft

Information: Helen Weston/Genice Morgan, Air Transport Assoc. of America, 1709 New York Ave. N.W., Washington, DC 20006-4060 202/626-4060, FAX 202/626-4149

SEPM First Annual Theme Meeting
August 15-18, Red Lion Inn
Jantzen Beach, Portland, OR

Theme: Continental margins—Sedimentation, tectonics, eustasy, climate

Information: SEPM 1991 Theme Meeting, PO Box 4756, Tulsa, OK 74159-0756

Canadian Dam Safety Association
Sept 16-19, Whistler Resort, British Columbia

Theme: Natural hazard risk reduction as applied to dam safety

Information: Dave Cattanach, B.C. Hydro, 970 Burrard St., Vancouver, BC V6Z 1Y3, Canada, 604/663-3126, FAX 604/663-1887

LOCATION OF MAIN OFFICE

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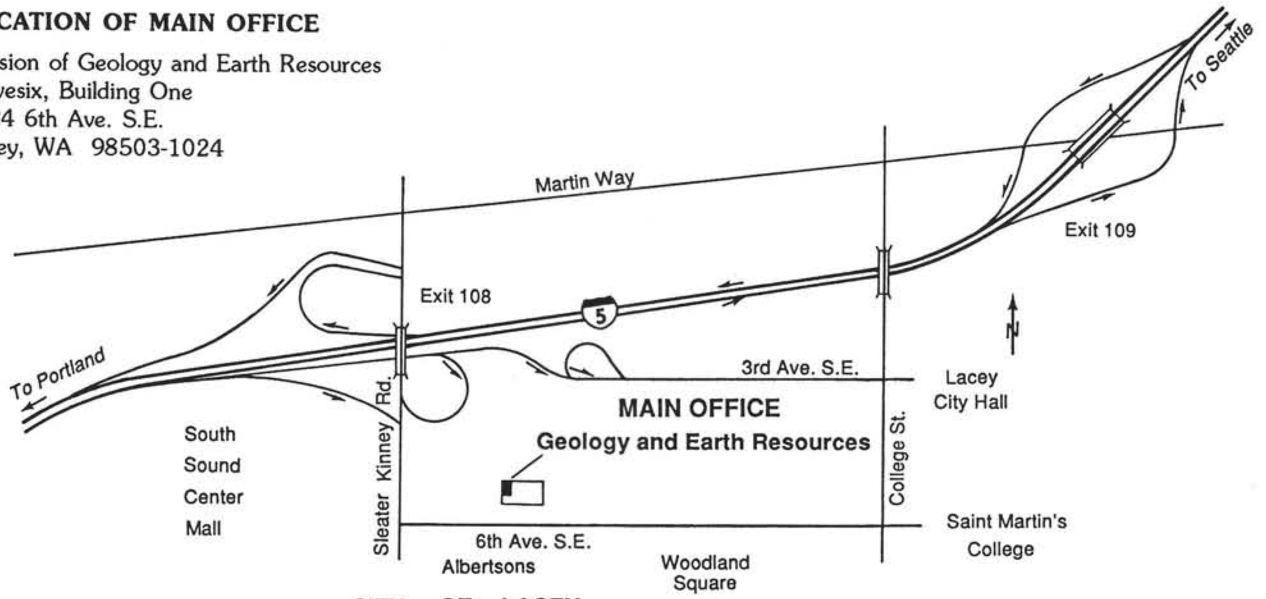

New Division Releases

The Division of Geology has released five new county bibliographies of geologic information in support of the Growth Management Act, bringing the total number issued to 23. These new bibliographies *(size of disk file in parentheses)* are for: **Benton County** (281 k), **Douglas County** (33 k), **Franklin County** (56 k), **Kittitas County** (102 k), and **Walla Walla County** (26 k). Copies are available on paper or disk (IBM-compatible). Paper copies are free, but please include $1 *with each order* for postage and handling. To obtain disk copies, send us enough 5.25-in. or 3.5-in. formatted disks to hold the files. *(Check the size of the files above)*. We will copy the files and return your disks. Please specify whether you want WordPerfect 5.0 or 5.1 or ASCII files. ASCII files will work with any word processing program. ASCII file users may want to order a paper copy as well, since it shows formatting lost in the conversion to ASCII.

The three sheets and accompanying pamphlet for the **Geologic map of Washington—Northeast quadrant of Washington** at 1:250,000 scale (**GM-39**) and the topographic base map (**TM-2**) have been sent to the printer. We expect copies to be available for sale in mid-July. Each copy of GM-39 (folded sheets, in a thumb-notched envelope) will cost $7.42 + .58 (tax for Washington residents only) = $8.00. A limited supply of unfolded copies of the sheets that make up the publication will also be available. The flat version of GM-39 will cost $9.28 + .72 = $10.00, and the three sheets will be mailed in tubes with the pamphlet. The topographic map is available separately: folded ($1.86 + .14 = $2.00) or flat ($3.25 + .35 = $3.50).

The Division has recently released:

Open File Report 91-2, **Coal maturation and the natural gas potential of western and central Washington**. This report was prepared by Timothy J. Walsh and William S. Lingley, Jr., and it describes five depocenters in western and central Washington. Coal rank, sandstone porosity, and thermal maturation data suggest that natural gas should be present in pre-middle Miocene structural traps. The report consists of 26 pages and 1 plate. The price is $1.62 + .13 (tax for Washington residents only) = $1.75.

Open File Report 91-3, **Preliminary bibliography and index of the geology and mineral resources of Washington, 1990**. This 128-page report covers the 975 journal articles, theses, abstracts, maps, and other reports added to the Division library in 1990 and was compiled by Connie J. Manson. The price is $3.71 + .29 (tax for Washington residents only) = $4.00.

Open File Report 91-4, **Geologic strip map of the Ninemile Creek–Wilmont Creek–Hunters Creek area, Ferry and Stevens Counties, Washington**. This report by Moira T. Smith focuses on the structure and stratigraphy of the Lower Paleozoic Covada Group across strike at its widest extent. The report has 9 pages and 1 plate (1:24,000 scale). The price is $1.39 + .11 (tax for Washington residents only) = $1.50.

Please add $1 to each order for postage and handling. Our mailing address is given on p. 2 of this publication. We would appreciate having your Zip Code and the four-digit extension for your address with your correspondence.

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