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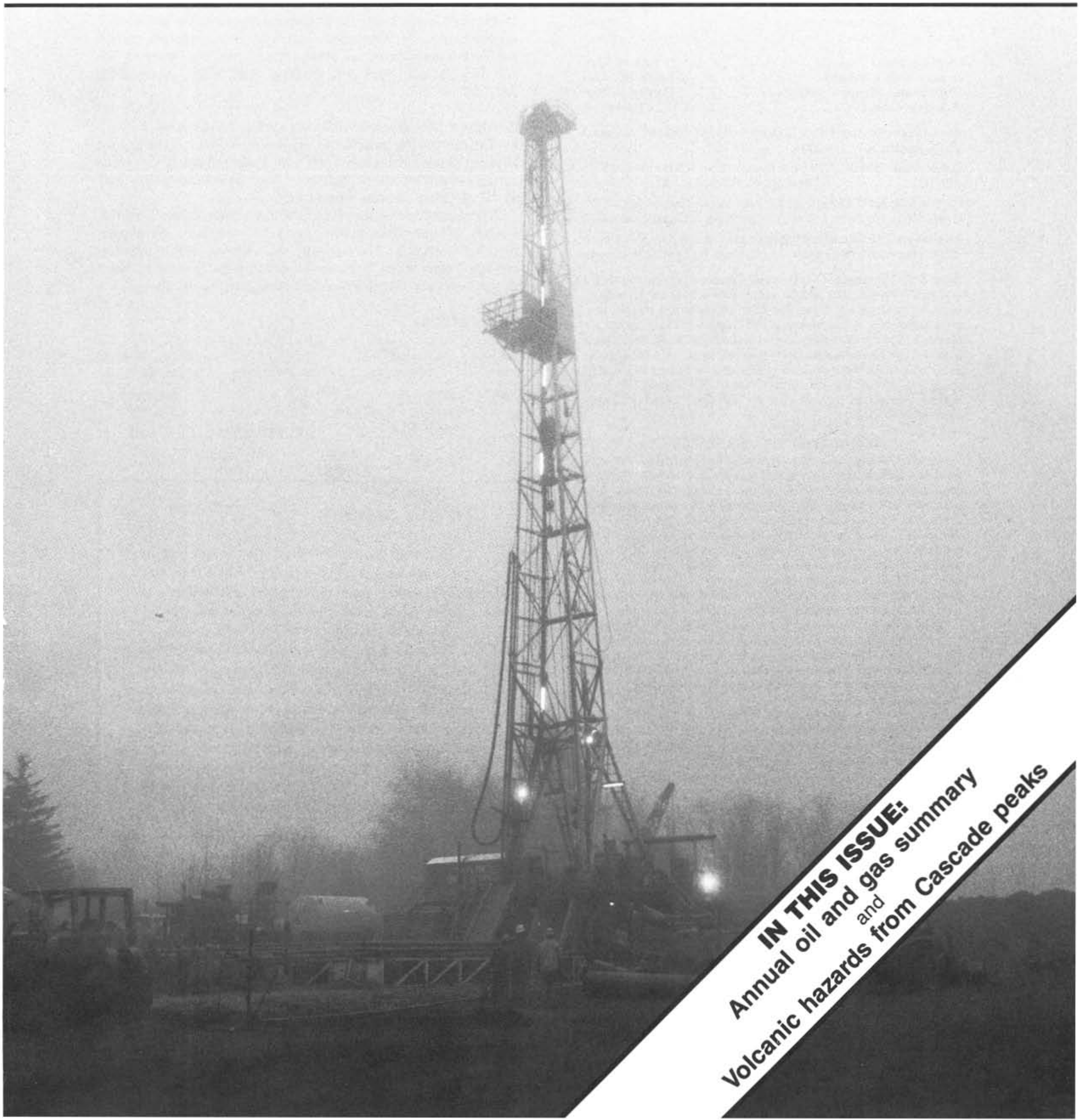

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Annual oil and gas summary
and
Volcanic hazards from Cascade peaks

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Information for contributors

Oregon Geology is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Manuscript contributions are invited on both technical and general-interest subjects relating to Oregon geology. Two copies of the manuscript should be submitted, typed double-spaced throughout (including references) and on one side of the paper only. If manuscript was prepared on common word-processing equipment, a file copy on 5¼-in. diskette may be submitted in addition to the paper copies. Graphic illustrations should be camera-ready; photographs should be black-and-white glossies. All figures should be clearly marked, and all figure captions should be typed together on a separate sheet of paper.

The style to be followed is generally that of U.S. Geological Survey publications (see the USGS manual *Suggestions to Authors*, 6th ed., 1978). The bibliography should be limited to "References Cited." Authors are responsible for the accuracy of the bibligraphic references. Names of reviewers should be included in the "Acknowledgments."

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of DOGAMI.

COVER PHOTO

Preparations to flow-test the well ARCO Foster 42-30-65, one of the seven new natural gas producers of 1987 in the Mist Gas Field, Columbia County, Oregon. Annual summary of oil and gas exploration and development in Oregon in 1987 begins on next page.

OIL AND GAS NEWS

MMS offshore conference

The Minerals Management Service (MMS) will hold a conference in Portland on May 23-25, 1988, to discuss recommendations for environmental studies prior to the scheduled 1992 Lease Sale No. 132. The MMS is conducting several studies as part of its Environmental Studies Program in preparation for the scheduled 1992 lease sale off Oregon and Washington. The conference will enable participants to hear about ongoing studies and to recommend further studies. For information and registration materials, contact Bio/Tech Communications, MMS-OCS Conference Planners, 600 SW 10th Avenue, Suite 418, Portland, OR 97205, phone (503) 245-7377.

Northwest Petroleum Association spring symposium

The oil and gas potential of southwestern Washington and the adjacent Outer Continental Shelf will be the subject of this year's spring symposium of the Northwest Petroleum Association, May 18-20, at Ocean Shores, Washington.

The symposium begins with a field trip on May 18 from Portland, Oregon, to Ocean Shores, Washington, and concludes with another field trip on May 20. The field trips will examine Eocene reservoir sands and other strata. For more information see the announcement of the Northwest Petroleum Association later on in this issue.

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
406	ARCO Columbia Co. 44-27-65 36-009-00240	SE¼ sec. 27 T. 6 N., R. 5 W. Columbia County	Application; 2,150.

□

To our readers

This issue is a historic first: It is the first regular two-month issue of *Oregon Geology* which from now on will appear every other month. For the rest of volume 50, the numbering of the issues will indicate this by double numbers: 5/6, 7/8, 9/10, 11/12.

The size of the issue corresponds to that of two monthly issues—24 instead of 12 pages; the amount of information you receive is the same as before, more, in fact, if you consider that of the 24 pages only two pages take up our list of available publications, compared to four pages in two separate issues.

If the longer interval between issues affects your need for prompt information, please feel free to write or call the Department with your requests.

CONTENTS

Oil and gas exploration and development in Oregon, 1987

by Dan E. Wermiel, Petroleum Geologist, and Dennis L. Olmstead, Petroleum Engineer, Oregon Department of Geology and Mineral Industries

ABSTRACT

Oil and gas leasing in Oregon in 1987 remained at about the same level as during 1986. During 1987, nearly 700,000 federal acres were terminated or relinquished, leaving 762,521 acres in 1,045 parcels under lease at year's end. Counties with the most activity were Umatilla, Crook, and Morrow. There were 160,000 state acres terminated during the year, leaving 109,107 acres under lease at year's end, with the majority of that acreage located in Clatsop County.

Twenty applications for permits to drill were issued during 1987. Nine exploratory wells, one reentry of a suspended well, one redrill, and five gas-storage wells were drilled by four operators, about the same level of drilling activity as during 1986. Of these wells, all but the reentry were in the Mist Gas Field in Columbia County. There were seven new gas completions, all drilled by ARCO Oil and Gas Company.

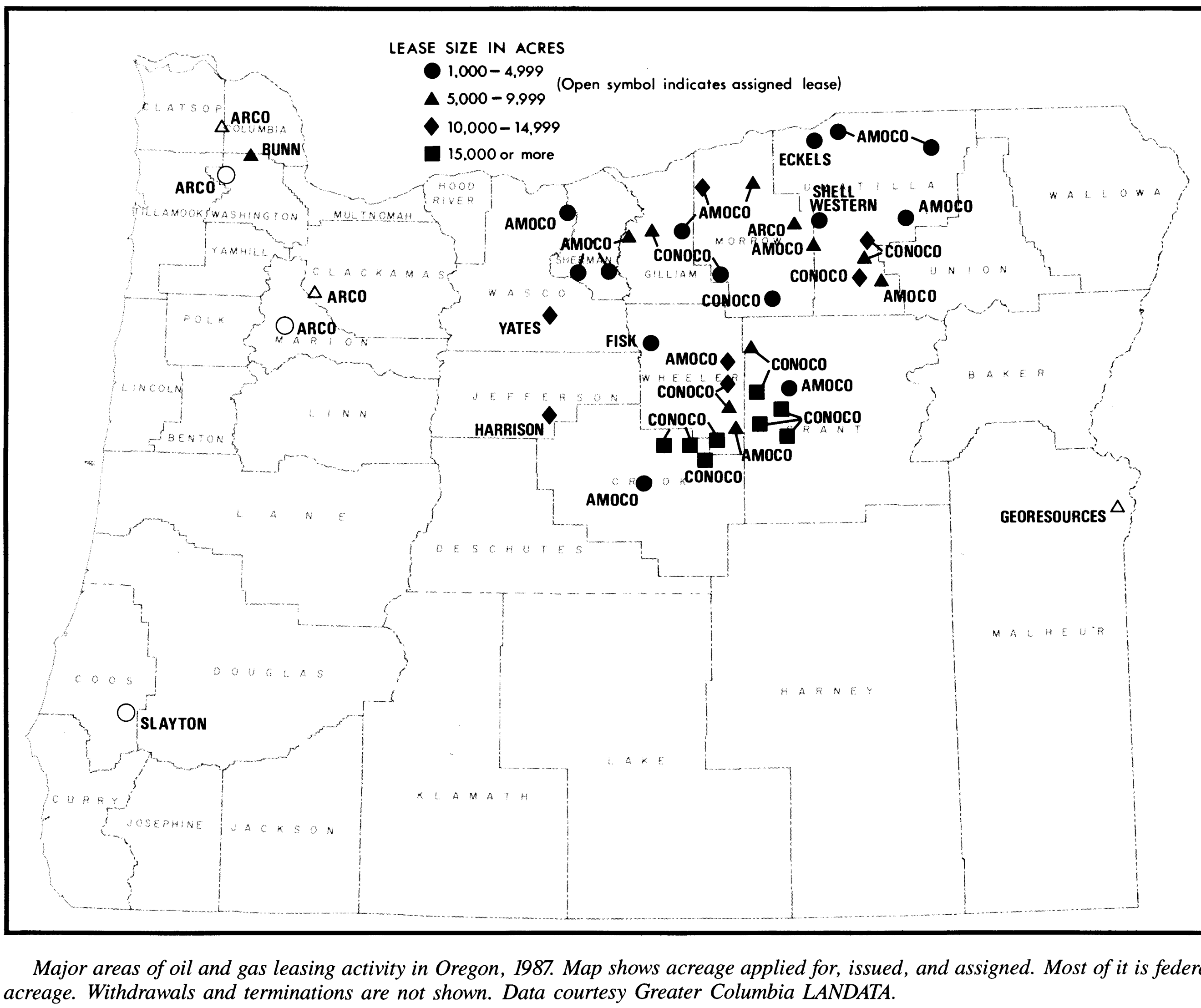
Production in 1987 totaled 3.8 billion cubic feet (Bcf) of gas, down from 4.6 Bcf produced during 1986. Total value for the gas produced was $5.5 million.

Oregon Natural Gas Development Corporation continued drilling at the natural-gas storage project at Mist Gas Field, where the depleted Bruer and Flora Pools are being used for gas-storage purposes. A total of 4 Bcf was injected during 1987.

The Oregon Department of Geology and Mineral Industries (DOGAMI) will conduct a review of permitting, drilling, and development rules during 1988.

LEASING ACTIVITY

During 1987, leasing in Oregon remained at a low level, following a similar year in 1986. Applications were filed for about 93,000 acres of federal land, mostly in the Simultaneous Oil and Gas (SOG) program, which reoffers previously relinquished leases. Of this total, 2,000 acres were in the Over-the-Counter program. The oil-and-gas leasing map shows this acreage as well as 245,000 acres for which Conoco applied in the December 1987 SOG filing and 118,500 acres for which Amoco applied. During the year, leases on 102,732 acres (58 parcels) were issued. Some of this acreage is from 1987 filings, and some was from 1986 or earlier filings. Counties with the most activity were Umatilla, Crook, and Morrow. In 1987, nearly 700,000



Major areas of oil and gas leasing activity in Oregon, 1987. Map shows acreage applied for, issued, and assigned. Most of it is federal acreage. Withdrawals and terminations are not shown. Data courtesy Greater Columbia LANDATA.

Table 1. *Oil and gas permits and drilling activity in Oregon, 1987*

Permit no.	Operator, well, API number	Location	Status, depth (ft) TD=total depth PTD=proposed TD RD=redrill
180 Rework	Oregon Nat. Gas Dev. IW 32d-10 36-009-00082	NE¼ sec. 10 T. 6 N., R. 5 W. Columbia County	Completed, service well; TD: 2,171.
358D	Damon Petroleum Corp. Stauffer Farms 35-1 Deepening 36-047-00020-80	NW¼ sec. 35 T. 4 S., R. 1 W. Marion County	Abandoned, dry hole; TD: 2,752.
364	Oregon Nat. Gas Dev. OM 12c-3 36-009-00201	NW¼ sec. 3 T. 6 N., R. 5 W. Columbia County	Completed, service well; TD: 3,156.
367	Oregon Nat. Gas Dev. OM 14a-3 36-009-00204	SW¼ sec. 3 T. 6 N., R. 5 W. Columbia County	Completed, service well; TD: 3,200.
372	Oregon Nat. Gas Dev. OM 32b-11 36-009-209	NE¼ sec. 11 T. 6 N., R. 5 W. Columbia County	Completed, service well; TD: 3,205.
373	Oregon Nat. Gas Dev. IW 33c-3 36-009-00211	SE¼ sec. 3 T. 6 N., R. 5 W. Columbia County	Completed, service well; TD: 2,772.
377	ARCO Oil and Gas Co. Longview Fibre 11-31-64 36-009-00214	NW¼ sec. 31 T. 6 N., R. 4 W. Columbia County	Completed, gas; TD: 1,745.
378	ARCO Oil and Gas Co. Columbia County 24-26-65 36-009-00215	SW¼ sec. 26 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 2,400.
379	ARCO Oil and Gas Co. Columbia County 11-7-65 36-009-00216	NW¼ sec. 7 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 3,800.
380	ARCO Oil and Gas Co. Columbia County 11-34-65 36-009-00217	NW¼ sec. 34 T. 6 N., R. 5 W. Columbia County	Completed, gas; TD: 1,950.
381	ARCO Oil and Gas Co. Columbia County 23-18-65 36-009-00218	SW¼ sec. 18 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 3,600.
382	ARCO Oil and Gas Co. Columbia County 32-26-65 36-009-00219	NE¼ sec. 26 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 2,200.
383	ARCO Oil and Gas Co. Columbia County 42-9-65 & Redrill 36-009-00220 36-009-00220-01	NE¼ sec. 9 T. 6 N., R. 5 W. Columbia County	Abandoned, dry hole; TD: 2,850, RD: 2,840.
384	ARCO Oil and Gas Co. Columbia County 24-26-65 36-009-00221	SW¼ sec. 26 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 2,000.
385	ARCO Oil and Gas Co. Columbia County 22-27-75 36-009-00222	NW¼ sec. 27 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 2,300.
386	ARCO Oil and Gas Co. Columbia County 31-34-65 36-009-00223	NE¼ sec. 34 T. 6 N., R. 5 W. Columbia County	Completed, gas; TD: 2,344.
387	ARCO Oil and Gas Co. Columbia County 31-27-65 36-009-00224	NE¼ sec. 27 T. 6 N., R. 5 W. Columbia County	Completed, gas; TD: 6,700.
388	LEADCO, Inc. CC-Jackson 22-17 36-009-00225	NW¼ sec. 17 T. 5 N., R. 4 W. Columbia County	Abandoned, dry hole; TD: 2,318.
389	LEADCO, Inc. CC-Jackson 23-17 36-009-00226	SW¼ sec. 17 T. 5 N., R. 4 W. Columbia County	Permit issued; PTD: 2,500.
390	ARCO Oil and Gas Co. CFI 31-1-65 36-009-00227	NE¼ sec. 1 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 2,100.
391	ARCO Oil and Gas Co. Columbia County 34-4-65 36-009-00228	SE¼ sec. 4 T. 6 N., R. 5 W. Columbia County	Completed, gas; TD: 3,382.
392	ARCO Oil and Gas Co. Longview Fibre 32-20-65 36-009-00229	NE¼ sec. 20 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 2,850.
393	ARCO Oil and Gas Co. Columbia County 21-35-65 36-009-00230	NW¼ sec. 35 T. 6 N., R. 5 W. Columbia County	Completed, gas; TD: 1,924.
394	ARCO Oil and Gas Co. Foster 42-30-65 36-009-00231	NE¼ sec. 30 T. 6 N., R. 5 W. Columbia County	Completed, gas; TD: 2,658.
395	Hutchins and Marrs GP 1 36-011-00024	SW¼ sec. 14 T. 30 S., R. 10 W. Coos County	Permit issued; PTD: 6,000.

Wellhead at the ARCO Columbia County 31-27-65, which was drilled to a total depth of 6,700 ft, making it the deepest well drilled during 1987.

acres were terminated or relinquished, leaving 762,521 acres in 1,045 parcels under lease at year's end. Rental income during the year on federal land was $581,107.

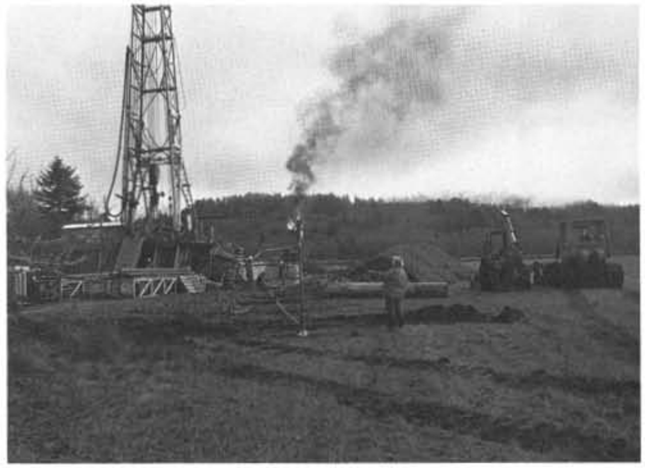
The SOG lease program was ended in December, and Over-the-Counter leases were changed to include a competitive bidding process in 1988.

The Division of State Lands held no lease sales of state land during 1987 and had only one application, which was for 800 acres. Nearly 160,000 acres were terminated during the year, leaving 109,107 acres under lease on December 31. Clatsop County has more state land under lease than any other county.

No counties held lease sales in 1987; however, 14,000 acres taken during the July 1986 Columbia County lease sale were assigned to ARCO Oil and Gas Company.

DRILLING

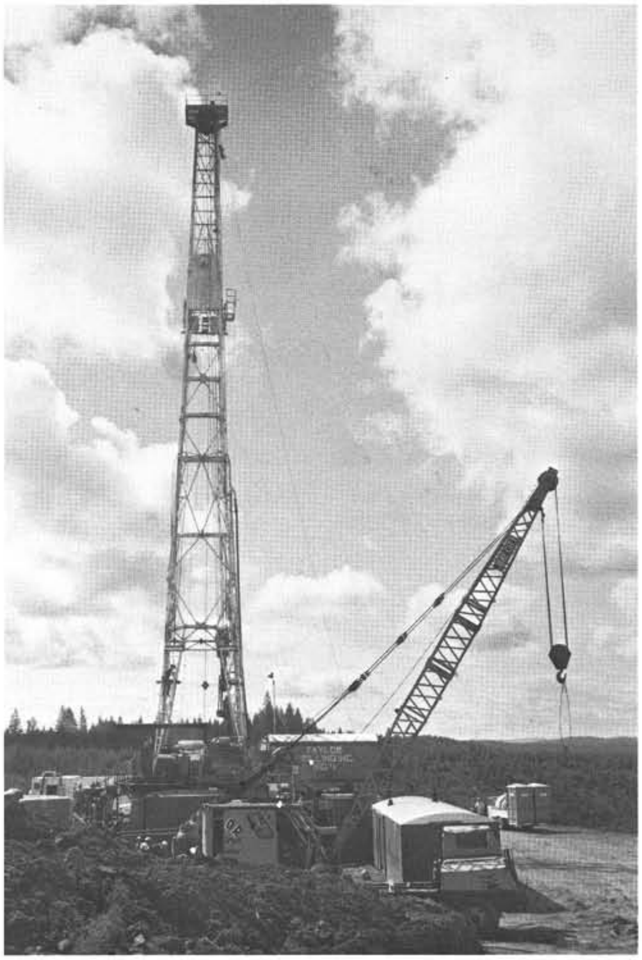
Nine exploratory oil and gas wells, one reentry of a suspended well, one redrill, and five gas-storage wells were drilled in the state in 1987. This amount of drilling is similar to the level of drilling activity during 1986. All but one of the wells were drilled within



Dorothy Foster, royalty owner, lighting the flare at the flow test of the ARCO Foster 42-30-65 well.

Table 2. *Canceled and denied permits, 1987*

Permit no.	Operator, well, API number	Location	Issue date	Cancellation date	Reason
297	Hutchins and Marrs GP 1 36-011-00021	NE¼ sec. 14 T. 30 S., R. 10 W. Coos County	7-25-85	7-25-87	Permit canceled; expired.
298	Tenneco Oil Company Columbia County 11-28 36-009-00144	NW¼ sec. 28 T. 6 N., R. 10 W. Columbia County	6-11-85	6-11-87	Permit canceled; expired.
300	Tenneco Oil Company Columbia County 33-28 36-009-00146	SE¼ sec. 28 T. 6 N., R. 5 W. Columbia County	6-11-85	6-11-87	Permit canceled; expired.
302	Tenneco Oil Company Columbia County 42-28 36-009-00148	NE¼ sec. 28 T. 6 N., R. 5. W. Columbia County	-	-	Permit denied; irregular location.
314	ARCO Oil and Gas Company Scherf 41-21 36-009-00160	NE¼ sec. 21 T. 6 N., R. 5 W. Columbia County	6-20-85	7-1-87	Permit canceled; expired.
346	ARCO Oil and Gas Company CFI 23-9 36-009-00187	SW¼ sec. 9 T. 5 N., R. 4 W. Columbia County	1-31-86	1-31-87	Permit canceled; expired.
352	ARCO Oil and Gas Company Columbia County 44-27 36-009-00191	SE¼ sec. 27 T. 6 N., R. 5 W. Columbia County	3-11-86	3-12-87	Permit canceled; expired.
353	ARCO Oil and Gas Company Longview Fibre 43-4 36-009-00192	NE¼ sec. 4 T. 5 N., R. 5 W. Columbia County	3-28-86	3-28-87	Permit canceled; expired.
354	ARCO Oil and Gas Company Columbia County 44-6 36-009-00193	SE¼ sec. 6 T. 6 N., R. 5 W. Columbia County	3-28-86	3-28-87	Permit canceled; expired.
355	ARCO Oil and Gas Company Columbia County 31-7 36-009-00194	NE¼ sec. 7 T. 6 N., R. 5 W. Columbia County	3-28-86	3-28-87	Permit canceled; expired.
359	ARCO Oil and Gas Company CFI 21-22 36-009-00196	NW¼ sec. 22 T. 5 N., R. 4 W. Columbia County	5-20-86	5-20-87	Permit canceled; expired.
363	Oregon Natural Gas Dev. OM 44d-3 36-009-00200	SE¼ sec. 3 T. 6 N., R. 5 W. Columbia County	7-3-86	7-7-87	Permit canceled; expired.
370	ARCO Oil and Gas Company CFI 12-5 36-009-00207	NW¼ sec. 5 T. 6 N., R. 5 W. Columbia County	7-18-86	7-18-87	Permit canceled; expired.



Rigging up in preparation to spud the ARCO Longview Fibre 11-31-64 well.

the boundaries of the Mist Gas Field, a pattern that has continued since the field discovery in 1979. The other well was an unsuccessful attempt by Damon Petroleum Corporation to reenter and deepen a previously drilled well in the Willamette Valley near Hubbard in Marion County. Although the operator experienced mechanical difficulties and the well was plugged before deepening was accomplished, it indicates a continued interest in the Willamette Valley, where wells have been drilled each year since 1979.

Twenty permits to drill were issued in 1987 (Table 1), down from thirty in 1986. Twelve expired permits were canceled, and one permit was denied during the year (Table 2).

Four operators were active in the state last year. ARCO Oil and Gas Company was most active, drilling eight exploratory wells and one redrill, with seven successful completions at the Mist Gas Field. Oregon Natural Gas Development Corporation drilled five wells as part of the natural-gas storage project at Mist Gas Field. LEADCO, Inc., drilled a dry hole at Mist Gas Field, and Damon Petroleum reentered its 1986 Marion County well.

Total footage drilled for the year, including the gas-storage wells, was 42,665 ft, which is an increase from 39,740 ft in 1986. The average depth for exploration and development wells was 2,896 ft, 11 percent deeper than the 2,600-ft average depth in 1986. The deepest well drilled during the year was a 6,700-ft well drilled by ARCO Oil and Gas Company at Mist Gas Field. This was a relatively rare test of the deeper sediments at Mist. The well was dry at total depth but productive from the Clark and Wilson sand, which remains the only producing reservoir at the field.

DISCOVERIES AND GAS PRODUCTION

The Mist Gas Field experienced seven new producers, which sets a record for the number of new pool discoveries in a single year at Mist. ARCO Oil and Gas Company is the operator of these wells, which include Columbia County 11-34-65, Columbia County 21-35-65, Columbia County 31-27-65, Columbia County 31-34-65, Columbia County 34-4-65, Foster 42-30-65, and Longview Fibre 11-31-64. The cumulative initial flow rate for these seven wells is 10 to 12 million cubic feet (MMcf) of gas per day. This brings the number of completed wells at Mist Gas Field to twenty wells, all operated by ARCO Oil and Gas Company, of which ten were producing gas, four were shut-in, and all but one of the new wells were awaiting connection to gas pipeline at year's end. One producing well, Tenneco Columbia County 41-28, was plugged during the year due to gas depletion.

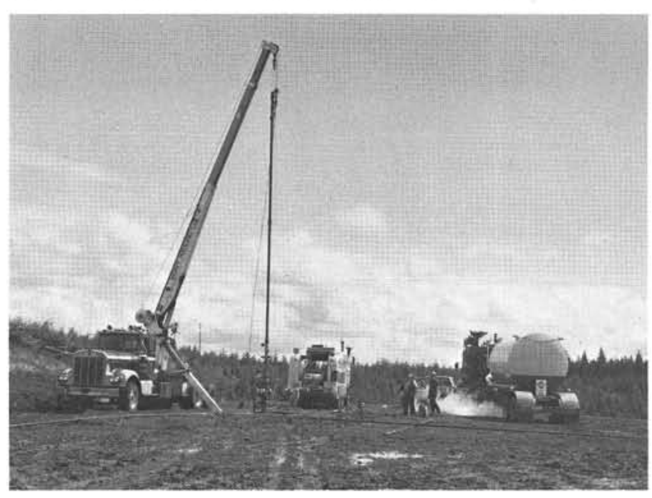
Gas production for the year totaled 3.8 Bcf, a decrease from the 4.6 Bcf produced in 1986. The cumulative field production through the end of 1987 was 31.7 Bcf. The seven new gas wells add an additional 11 to 14 Bcf of reserves to the field. The total value for the gas produced for the year was $5.5 million, down from the $9.2 million produced during 1986. Gas production should increase for 1988 with the connection to gas pipeline of the new producers discovered during 1987. ARCO estimates that daily production at Mist should increase from the 1987 rate of 10 MMcf of gas per day to about 15 MMcf of gas per day upon connection of the new wells.

STORAGE PROJECT

Oregon Natural Gas Development Company began drilling at the natural-gas storage project at Mist Gas Field during 1986. This drilling continued in 1987 with the drilling of three additional observation-monitor wells and two injection-withdrawal wells. Pipeline gas will continue to be injected and stored in the depleted Flora and Bruer Pools. Observation-monitor wells are used to monitor the gas levels and pressures in the storage reservoir, and injection-withdrawal wells are used to add gas to and remove gas from the storage reservoir. During 1987, a total of 4 Bcf was injected at the natural-gas storage project, 1.6 Bcf into the Flora Pool and 2.4 Bcf into the Bruer Pool. Stored gas will be withdrawn for sale later this year.

OTHER ACTIVITY

The Northwest Petroleum Association (NWPA) remained active during 1987, with membership standing at 140 at year's end. At the monthly meetings, papers covering oil and gas-industry-related subjects such as leasing, geology, and economics were presented. A symposium, including a field trip, was held in Bend to discuss the hydrocarbon potential of central Oregon's pre-Tertiary rocks.



Preparations to flow-test the ARCO Longview Fibre 11-31-64 well.

The Oregon Department of Geology and Mineral Industries (DOGAMI) did not undertake law or rulemaking in 1987 but will conduct a triannual rule review during 1988.

Last year, two offshore planning bills, Senate Bill 606 and Senate Bill 630, passed the legislature. SB606 provides for hard-mineral exploration in state waters under the direction of the Division of State Lands. SB630 establishes the Oregon Ocean Resource Management Task Force and requires the group to write a master plan to manage Oregon's ocean resources. DOGAMI is a member of the task force and a consultant to the Division of State Lands.

The Mist Gas Field map (Open-File Report O-88-2) has been updated to January 1988 and is available from DOGAMI for $5. Other publications in the Oil and Gas Investigations Series are also available, including OGI-16, *Available Well Records and Samples of Onshore and Offshore Oil and Gas Exploration Wells in Oregon.* A publication list is presented on the last page of this issue of *Oregon Geology.*

ANTICIPATED 1988 ACTIVITY

The coming year appears to have some significant activity in store for Oregon.

ARCO Oil and Gas Company has received a drilling permit for a proposed 9,000-ft wildcat well in eastern Oregon's Columbia Basin, about 6 mi northeast of Heppner in Morrow County. This well will drill through the rocks of the Columbia River Basalt Group to test underlying Tertiary rocks, which are interpreted to have favorable conditions for hydrocarbon generation and entrapment. ARCO Oil and Gas Company also plans to continue its drilling program at Mist Gas Field.

Oregon Natural Gas plans to drill five more wells, four injection-withdrawal wells and one observation-monitor well, at the natural-gas storage project at Mist Gas Field.

NWPA will hold its annual symposium on the central Washington coast during May. Details may be obtained from the NWPA, P.O. Box 6679, Portland, OR 97228-6679. □

State and counties receive share payments from BLM

For the fiscal year ending September 30, 1987, Oregon counties have received a total of $2,885,470 as their share of "Payments in Lieu of Taxes" distributed by the U.S. Bureau of Land Management (BLM) to offset fiscal impacts of tax-exempt federal lands within local government boundaries.

BLM Oregon-Washington State Director Bill Luscher said that Malheur County was the largest Oregon recipient with $641,084, trailed by Lane County with $325,379, Harney County with $305,539, and Lake County with $212,463.

BLM administers the payment program because it is the largest single federal land management agency, with responsibility for more than 300 million acres of public lands across the nation. BLM manages 15.7 million acres in Oregon.

Tax-exempt federal lands include many different types of land that can have fiscal impacts on the governmental units surrounding them. These payments help local government provide fire and police protection, search-and-rescue operations, road construction, and other vital services. The recipients may use the funds for any governmental purpose.

—BLM News

BLM presents the Badlands

There are places in the U.S. Bureau of Land Management's (BLM) Prineville district where hiking is possible all year. Particularly in winter, when a lot of people head west from Bend to Mount Bachelor to ski, a few head east to the Badlands.

The Badlands is a 32,000-acre area in the High Lava Plains province and is located 12 mi from Bend, just north of U.S. Highway 20. It is readily accessible regardless of weather conditions, according to Berry Phelps, recreation planner. The area contains rolling hills of western juniper and deeply fractured basalt outcroppings that look like giant lava blisters.

The Badlands is not only a place to go to escape but also a good place to get lost. Once you are out in the Badlands, the entire area looks very much the same, and it is easy to become disoriented. Even though the area is not extremely large, it is still a good idea to carry a map and a compass. Maps of the Badlands are available at BLM's Prineville district office (P.O. Box 550, 185 East Fourth Street, Prineville, OR 97754, phone (503) 447-4115).

Much of the area is very sandy. An attempt to drive off established roads and getting stuck could turn a visit into more of an outdoor experience than originally planned. That is why BLM recommends hiking rather than driving.

BLM has studied the Badlands area to determine its suitability for wilderness. Because of the unique natural values in the area, BLM plans to recommend it for wilderness designation.

—Adapted from Brian Cunninghame, BLM News

Historic China Ditch remembered

The U.S. Bureau of Land Management's (BLM) Roseburg district and the National Advisory Council on Historic Preservation are working together to protect the China Ditch, a hydraulic-mining feature in the North Myrtle Creek area.

The China Ditch was dug during the early 1890's to bring water from the Cavitt Creek drainage to hydraulic-mining operations. The name comes from the Chinese laborers who worked on the project. Although the developers promised substantial economic benefits for the area, the results fell far short of their predictions. The project was abandoned in 1894, after approximately 26 mi of the ditch was built.

BLM currently manages 10 mi of the ditch. The immediate focus is on lessening logging impacts. Future goals include an inventory of associated historic sites and development of an interpretive plan.

—Isaac Barner, BLM News

EOMA offers scholarship

Eastern Oregon Mining Association (EOMA), the Baker-based miners' advocate organization, is now accepting scholarship applications from college students whose field of study is mining, announced EOMA President Chuck Chase.

Available this year, as in previous years, is a $500 scholarship to a student who lives in eastern Oregon, a region determined by EOMA directors to be east of the Cascade Mountains and north and south to the state's boundary lines.

Eligible, said Chase, are students starting their third or fourth year in a college or university which offers a degree in a mining-related field. The student must have declared his or her major field of study in a mining-related subject.

The financial award will go to the individual who has demonstrated an aptitude for excelling in the field of mining. The $500 will be awarded to the selected student at a fall meeting of EOMA.

Deadline for applications is June 1. Those interested should contact EOMA, Attention Scholarship, P.O. Box 932, Baker, OR 97814.

—EOMA news release

Volcanic hazards from High Cascade peaks

by John Eliot Allen, Emeritus Professor of Geology, Portland State University, 97207-0751

INTRODUCTION

My interest in High Cascade volcanoes began while I climbed most of them during college. At Berkeley, I studied under the pioneer volcanologist Howell Williams, and my first job out of school was as Ranger Naturalist at Crater Lake, where I wrote my first professional paper on the domes around the north rim of the lake (Allen, 1935). For six months after June 1980, I served at the request of the U.S. Geological Survey (USGS) as chairman of a committee that validated the scientific credentials of visitors into the Mount St. Helens "Red Zone."

When in 1981 the Smithsonian Institution's Tom Simkin and others published *Volcanoes of the World: A regional directory, gazetteer, and chronology of volcanism during the last 10,000 years,* I was fascinated with the different kinds of information that could be extracted from it, and this paper eventually resulted. Unless otherwise noted, statistical data given here were derived from that work (Simkin and others, 1981).

VOLCANIC HAZARDS

Most volcanoes that cause hazards to human affairs occur above zones where a plate of oceanic crust is being "subducted," or shoved down, beneath a continental plate to a depth where its contained water causes melting of formerly solid rock to produce magma (gas-charged molten rock) that then works its way to the surface. These magmas contain large amounts of water vapor and are hence highly explosive. Oceanic volcanoes, such as those that eventually formed Hawaii and Iceland, although much more numerous, are mostly submarine, and their very liquid lavas do not produce explosive activity.

Subduction zones surround the Pacific Ocean and have produced the "Ring of Fire" chains of volcanoes in the Philippines, Japan, Kamchatka, the Aleutian Islands, Alaska, the Cascades, Mexico and central America, and the Andes in South America. An eastward "loop" in the chain supports the volcanoes in the West Indies, and another series of loops off the main line in the western Pacific has produced the volcanoes in the East Indies.

North and Middle Sisters, in the central Oregon High Cascades. View is to the southeast. Foreground is covered by lava flows. Photo courtesy Oregon State Highway Division.

South side of Mount Rainier and Reflection Lake, Washington. This lake was formed about 5,000 years ago when a mudflow formed a natural dam.

The United States is the third most volcanically active country in the world, containing 58 volcanoes that have erupted 471 times since 1700 A.D. Around the Pacific "Ring of Fire," only Japan and Indonesia can boast (or lament!) more.

Of the 58 active volcanoes in the United States, the Aleutian Islands contain the largest number, with 26 volcanoes that have erupted 200 times. The rest of Alaska comes in second, with 17 volcanoes that have erupted 117 times. Since 1750, there is only one period of 10 years (1854 to 1864) when a volcano did not erupt somewhere in the Aleutians or in Alaska.

The Hawaiian islands have only four volcanoes that have been active during historical time, but they have erupted 114 times. Since 1732, there have been only three periods of six years each when one of the Hawaiian volcanoes did not erupt. Fortunately for most of us, the "lower 48" comes in a poor third in the number of volcanoes, with nine that have erupted a total of 40 times since 1750.

EXPLOSIVITY OF VOLCANIC ERUPTIONS

The violence of an eruption can be indicated by the Volcanic Explosivity Index (VEI) (Simkin and others, 1981; Newhall and Self, 1982), which is calculated by measurements of the volume of ejecta; the height of the cloud column; and adjectival terms used by the observers, such as "gentle," "explosive," "severe," "violent," and "cataclysmic." On the VEI scale, 1 is small, 2 is moderate, 3 is moderate to large, 4 is large, and 5 is very large. The scale continues on up to 8, but no eruption in the last 10,000 years has been assigned a VEI of 8, and only one has been assigned a VEI of 7: the Tambora eruption of 1815.

The rest of the 471 eruptions in the U.S. during the last 10,000 years have VEI's of less than 4. This does not include dozens of small cinder cones in Oregon, California, Nevada, and New Mexico, many of which have given off basaltic lava flows covering up to 20 or more square miles.

Table 1. *Casualties and VEI's for some selected historic volcanic eruptions (partly from Simkin and others, 1981, and New York Times, 1969)*

Date	Volcano	VEI	Comments	People killed
79	Vesuvius	5	Pompeii and Herculaneum (ash)	2,000+
1669	Etna	3	Catania (lava)	20,000+
1783	Laki	4	Iceland (gases)	⅕ of population
1815	Tambora	7	Indonesia (tsunamis)	12,000
1883	Krakatau	6	Sunda Straits (tsunamis)	36,000+
1902	Pelee	4	Martinique (nuee ardente)	30,000+
1963	Agung	4	Bali (nuee ardente)	1,500+
1980	St. Helens	3	Washington (nuee ardente)	60?
1985	Ruiz	3?	Colombia (mud flow)	15,000

Table 2. *Rating of U.S. volcanoes according to explosivity. Eruptions during the last 10,000 years. In eruption dates, a minus sign means B.C.*

VEI 6	Crater Lake (-4650) White River, Alaska (525) Novarupta, Alaska peninsula (1912)	13 other eruptions worldwide from 11 volcanoes
VEI 5	White River, Alaska (310) St. Helens, Washington (-1900?, 1500, 1980)	31 other eruptions worldwide from 25 volcanoes
VEI 4	Rainier, Washington (-300?) Newberry Volcano, Oregon (big obsidian flow) (315) Mono Craters, California (810) Inyo Craters, California (910, 1240) Pogromni, Aleutian Islands (1795) Isanotski, Aleutian Islands (1825) Augustine, Alaska (1883, 1976) Spurr, Alaska (1953)	121 other eruptions worldwide from 54 volcanoes

The dating of Holocene but prehistoric eruptions is usually by means of carbon-14 radioactive dating of organic material within the ash layers or beneath lava flows. Such work has been done at only a few volcanoes, so there must have been many more eruptions of less well-studied volcanoes than are listed in Simkin and others (1981).

There are more than 3,000 volcanoes in the Cascade Range that have erupted during the last five million years (Hammond, personal communication, 1987). The greater Portland area contains nearly 50 volcanoes which erupted probably more than half a million years ago (Allen, 1975).

During the 17 years between 1843 and 1860, there was a burst of activity in the Cascades with 21 eruptions; during only six years (three periods of two years each) were there no eruptions. Some geologists have speculated that we may now be entering another such spell of activity.

Mount Tabor, one of the many small extinct volcanoes in the Portland area. This excavated cinder cone serves as an outdoor theater.

Few of the 14 High Cascade volcanoes in the United States are extinct, although such eroded matterhorns as Three Fingered Jack, Mount Washington, and Mount Thielsen might be so considered.

It is no wonder that since the eruption of Mount St. Helens in 1980 the team of USGS geologists at the Cascades Volcano Observatory in Vancouver, Washington, has been working overtime to explore and monitor Mount St. Helens, with some work also being done at the other volcanoes in the range.

PREDICTION

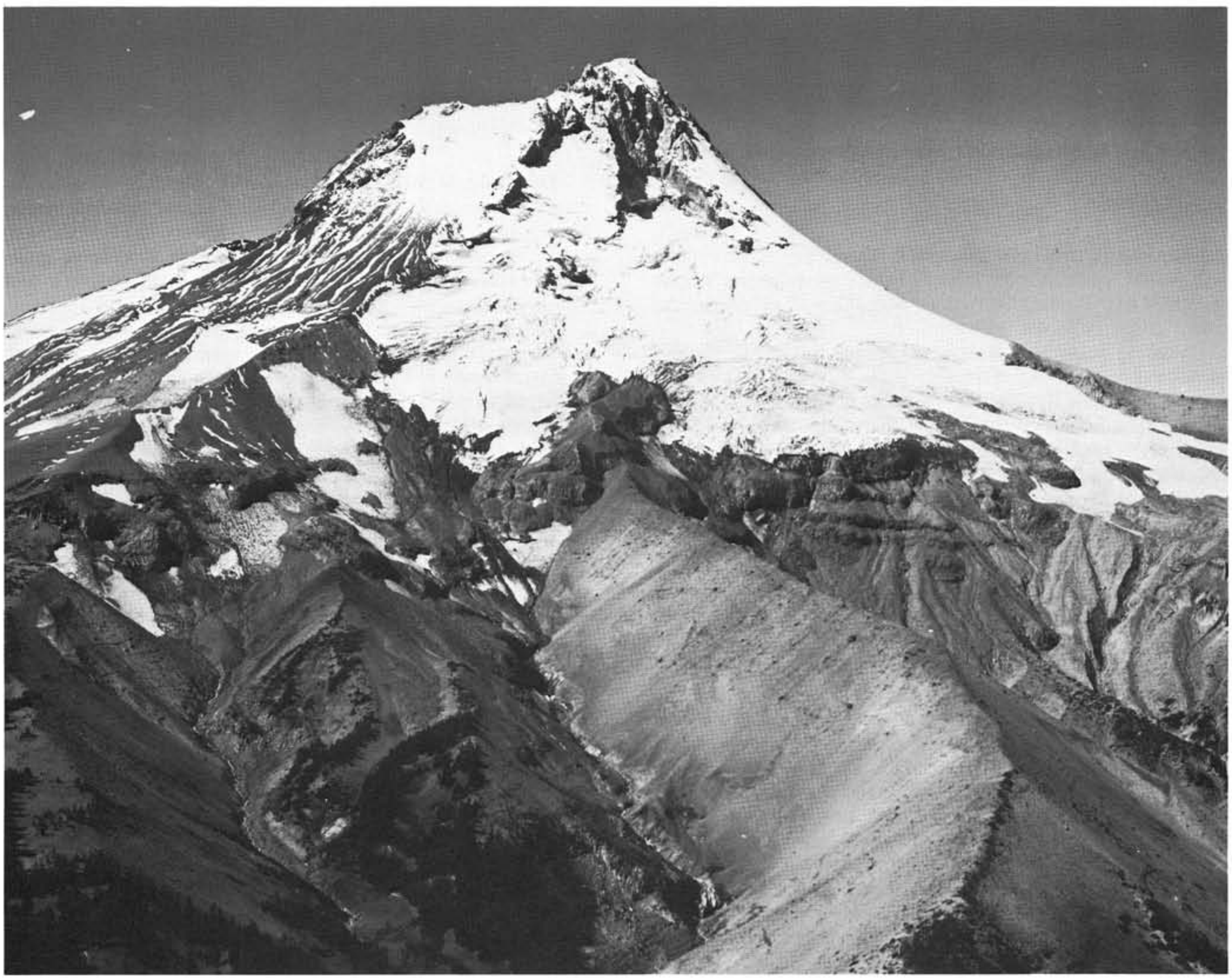
In retrospect, the catastrophic eruption of Mount St. Helens, disastrous as it was, has still had some positive results, since it led to the establishment of the volcano observatory at Vancouver. The extensive USGS program includes mapping and monitoring the Cascade volcanoes that are judged to be most likely to erupt.

Detailed mapping of the geology results in information as to what happened in the past, which, in turn, can result in predictions as to what may happen in the future. Networks of seismographs or tiltmeters have been deployed around several of the Cascade peaks—the seismographs to detect small earthquakes caused by movements of magma and the tiltmeters to detect possible swelling caused by intrusion of magma below the surface. On Mount St. Helens, gravity changes and gas emissions are also being monitored.

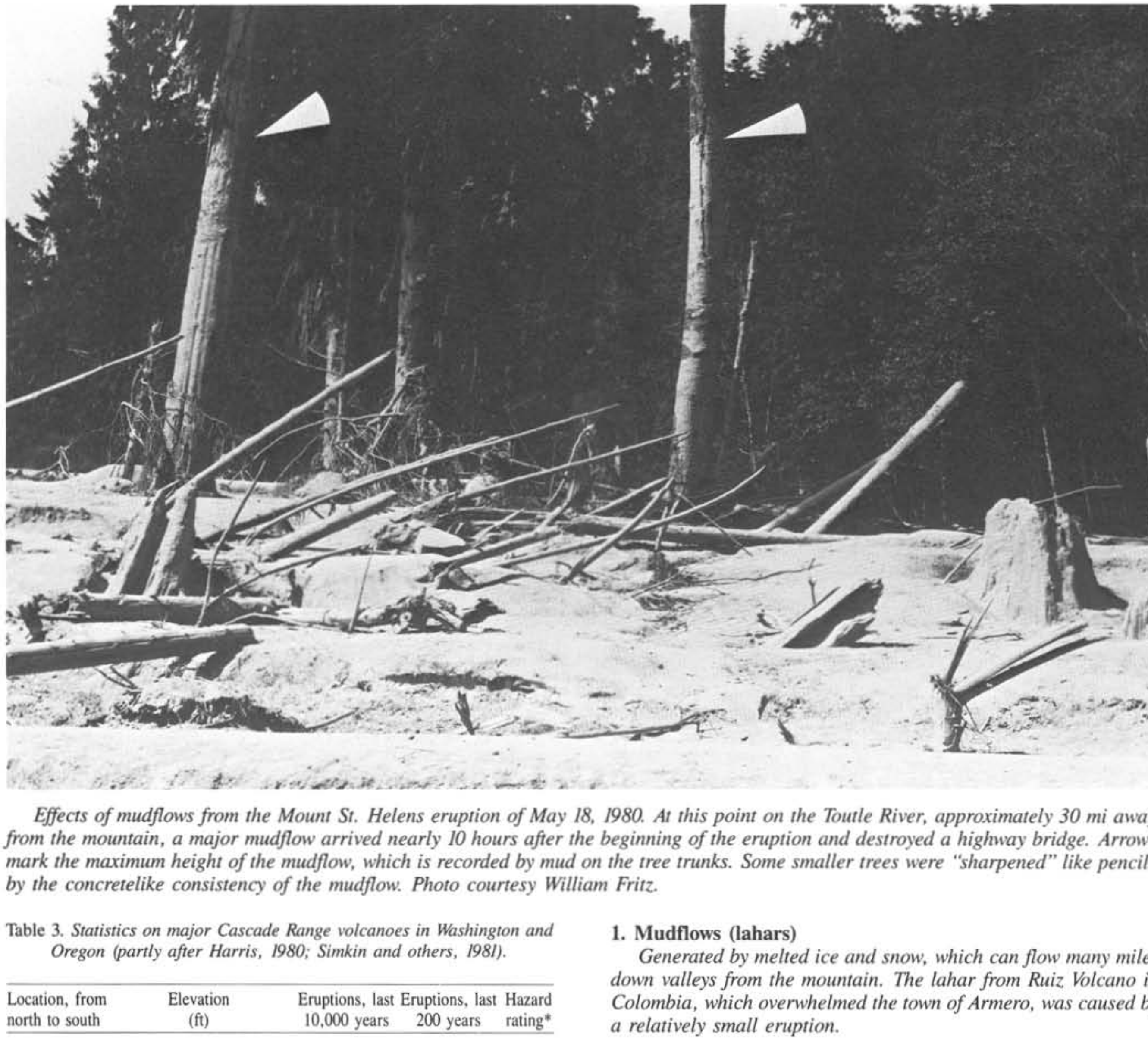
An important but often overlooked consideration for communities near potentially active volcanoes is the development of plans to be activated in the event of an eruption. Such plans include decisions on evacuation of residents; transportation routes; emergency housing, food, water, and sanitation; and ways of dealing with interruptions in communication, transportation, power, and other essential services. Concerned residents should encourage civil authorities to develop appropriate plans.

The USGS geologists may be able to provide a few weeks' or days' warning, but this is not time enough to develop a well-organized plan involving all the government agencies that could help cope with such a disaster. When Mount St. Helens erupted, there was nearly two months' warning, only because the great blast was preceded by numerous earthquakes and small eruptions. We might not be so lucky again!

Work done since 1981 by USGS scientists (Driedger and Kennard, 1986) has shown that most of the larger peaks contain more ice and snow than did Mount St. Helens. They are, therefore, even more susceptible to large mudflows in case of a volcanic eruption. The method of determining the amounts of snow and ice on the four volcanoes studied consists of mapping the areas of snow and ice with aerial photographs and then measuring the depth of the snow and ice at selected locations with a backpack radar unit so that volumes could be estimated.



Mount Hood, seen in late September from the east, showing canyons deeply eroded into volcanic deposits below Newton Clark Glacier. Photo courtesy Oregon State Highway Division.



Effects of mudflows from the Mount St. Helens eruption of May 18, 1980. At this point on the Toutle River, approximately 30 mi away from the mountain, a major mudflow arrived nearly 10 hours after the beginning of the eruption and destroyed a highway bridge. Arrows mark the maximum height of the mudflow, which is recorded by mud on the tree trunks. Some smaller trees were "sharpened" like pencils by the concretelike consistency of the mudflow. Photo courtesy William Fritz.

Table 3. *Statistics on major Cascade Range volcanoes in Washington and Oregon (partly after Harris, 1980; Simkin and others, 1981).*

Location, from north to south	Elevation (ft)	Eruptions, last 10,000 years	Eruptions, last 200 years	Hazard rating*
Baker, Wash.	10,750	12	9	B
Glacier Peak, Wash.	10,436	5	0	C
Rainier, Wash.	14,410	18	7	A
Adams, Wash.	12,307	?	2	D
St. Helens, Wash. (post-1980)	8,364	33	11	B
Hood, Oreg.	11,245	9	6	A
Jefferson, Oreg.	10,495	2	0	B
North Sister, Oreg.	10,094	4	0	B
South Sister, Oreg.	10,354	1	0	B
Newberry Crater, Oreg.	7,984 (Paulina Peak)	13	0	A
Mazama, Oreg.	(11,000?)	1	0	B
McLoughlin, Oreg.	9,510	1	0	C
Shasta, Calif.	14,163	19	1	A
Lassen Peak, Calif.	10,457	4	1	C

*According to population living within 20 mi: A = >2,500, B = 1,500-2,500, C = 500-1,500, D = <500

TYPES OF VOLCANIC HAZARDS

Hazards are discussed in the order of probable extent of risk to the populace, as follows:

1. Mudflows (lahars)

Generated by melted ice and snow, which can flow many miles down valleys from the mountain. The lahar from Ruiz Volcano in Colombia, which overwhelmed the town of Armero, was caused by a relatively small eruption.

Mount Rainier: About 5,700 years ago, the Osceola mudflow came 65 mi down the White River Valley from Mount Rainier and inundated 125 mi² of the Puget lowlands now occupied by the cities of Kent, Auburn, Sumner, and Puyallup to a depth of up to several hundred feet (Harris, 1980).

Glaciers on Mount Rainier cover more than 35 mi² and contain 156.2 bcf of ice and snow (34 times that of Mount St. Helens) that would make a cube slightly more than a mile on a side. Mudflows caused by melted snow and ice came 70 mi down the valley beyond Auburn about 6,000 years ago and 30 mi to Orting about 500 years ago. In historic times, mudflows have occurred most often in the valleys of the White, Nisqually, and Mowich Rivers and in Tahoma and Kautz Creeks.

The present population of the area once covered by mudflows from Mount Rainier now numbers in the hundreds of thousands, and another Osceola-type event would have even more disastrous effects than the recent overwhelming of the town of Armero by mudflows from Ruiz Volcano in Colombia that killed 20,000 people.

Mount St. Helens: Since 2500 B.C., mudflows have come down the various valleys around the mountain at least 10 times. During the 1980 eruption, an estimated 4.6 bcf of that volcano's snow and glacier ice was melted. This would make a cube measuring 1,663 ft on a side that would cover 64 average-size city blocks!

The melting of the snow and ice produced the large mudflows that caused havoc and destruction for many miles down the Toutle and Cowlitz Rivers and into the Columbia River, where shipping was prevented from reaching Portland for several weeks while six dredges cleaned out the filled channel at a cost of many millions of dollars. Several years of dredging in the Cowlitz Valley was necessary in order to prevent future flooding from the filled river channel.

Mount Hood: For two reasons, Mount Hood in Oregon is now perhaps our riskiest volcano: (1) it has a record of repeated activity, and (2) mudflows could affect thousands of people living in the upper Hood River Valley and along 30 mi of the Sandy River. The 12.3 bcf of ice and snow of the nine glaciers on Mount Hood (nearly three times that of Mount St. Helens) covers about 5.2 mi^2 and would make a cube 2,302 ft on a side. This is equal to more than half the water normally stored behind Bonneville Dam. Most of the topography on the lower slopes and down the valleys is the result of a series of mudflows and pyroclastic flows that occurred during an eruptive period about 12,000-15,000 years ago.

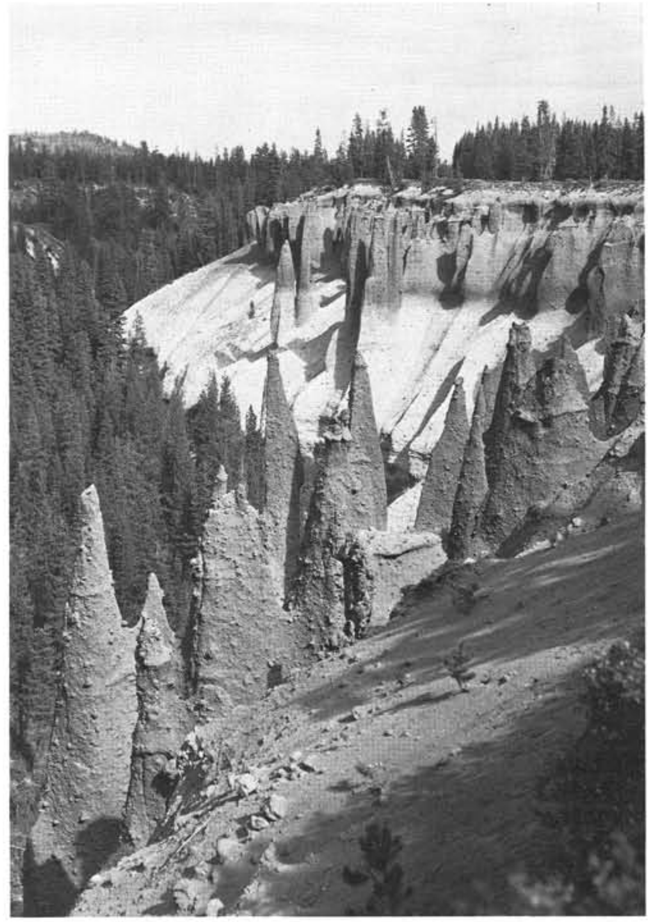
During the last half million years, at least six mudflows from the mountain have come all the way down the Sandy River to the Columbia River, and mudflows have repeatedly poured into the upper Hood River Valley. It is fortunate that Portland is protected from mudflows from Mount Hood by the deep canyon of the lower Sandy River gorge. The upper Sandy and Hood River Valleys are not so protected.

The Three Sisters: The Three Sisters (North, Middle, and South Sisters) contain 5.6 bcf of ice and snow, a cube 1,775 ft on a side. This is about a quarter of the water normally held behind Bonneville Dam. There are five major glaciers covering 3.2 mi^2. The towns of Sisters, Redmond, and Bend (population 20,000) lie less than 25 mi away.

Mount Shasta: Mount Shasta contains 4.7 bcf of ice and snow, a cube 1,675 ft on a side, slightly more than Mount St. Helens. About 80 percent of the ice on Mount Shasta is in the headwaters of Mud, Ash, Whitney, and Bolam Creeks and the McCloud and Shasta Rivers. In the past, mudflows have traveled as much as 16 mi down these drainages. The towns of Weed and Mount Shasta (population 6,000) lie within 10 mi of the volcano.

Table 4. *Volumes of ice and snow on selected High Cascade volcanoes. Volumes are given in billions of cubic feet (bcf). After Driedger and Kennard, 1986.*

Mount Rainier	156.2 bcf
Mount Hood	12.3 bcf
Three Sisters (North, Middle, and South Sisters)	5.6 bcf
Mount Shasta	4.7 bcf
Mount St. Helens	4.6 bcf



The Pinnacles, remnants of pyroclastic flows (mainly ash flows) that filled the drainages surrounding Mount Mazama during its climactic eruption. In this hot ash deposit, vapor phase alteration from hot gases escaping to the surface through fumaroles locally crystallized the ash to create these resistant pinnacles (Bacon, 1983). Artifacts discovered beneath deposits show that human beings were inhabiting this region prior to the eruption. Photo courtesy Oregon Highway Division.

Lassen Peak: The main eruption of Lassen Peak in 1915 was a similar "burning cloud" that came down the north slopes of the mountain and devastated several square miles of forest.

Mammoth Lakes: Prehistoric eruptions produced the caldera at Mammoth Lakes, California, depositing the Bishop Tuff to a depth of several hundred feet. In recent years, the caldera has been showing signs of renewed magmatic activity (swarms of small earthquakes).

2. Pyroclastic flows (nuees ardentes)

Blasts containing hot gas and ash, advancing at more than a hundred miles per hour, that may travel for tens of miles and cover areas of more than 100 mi^2 near the volcano.

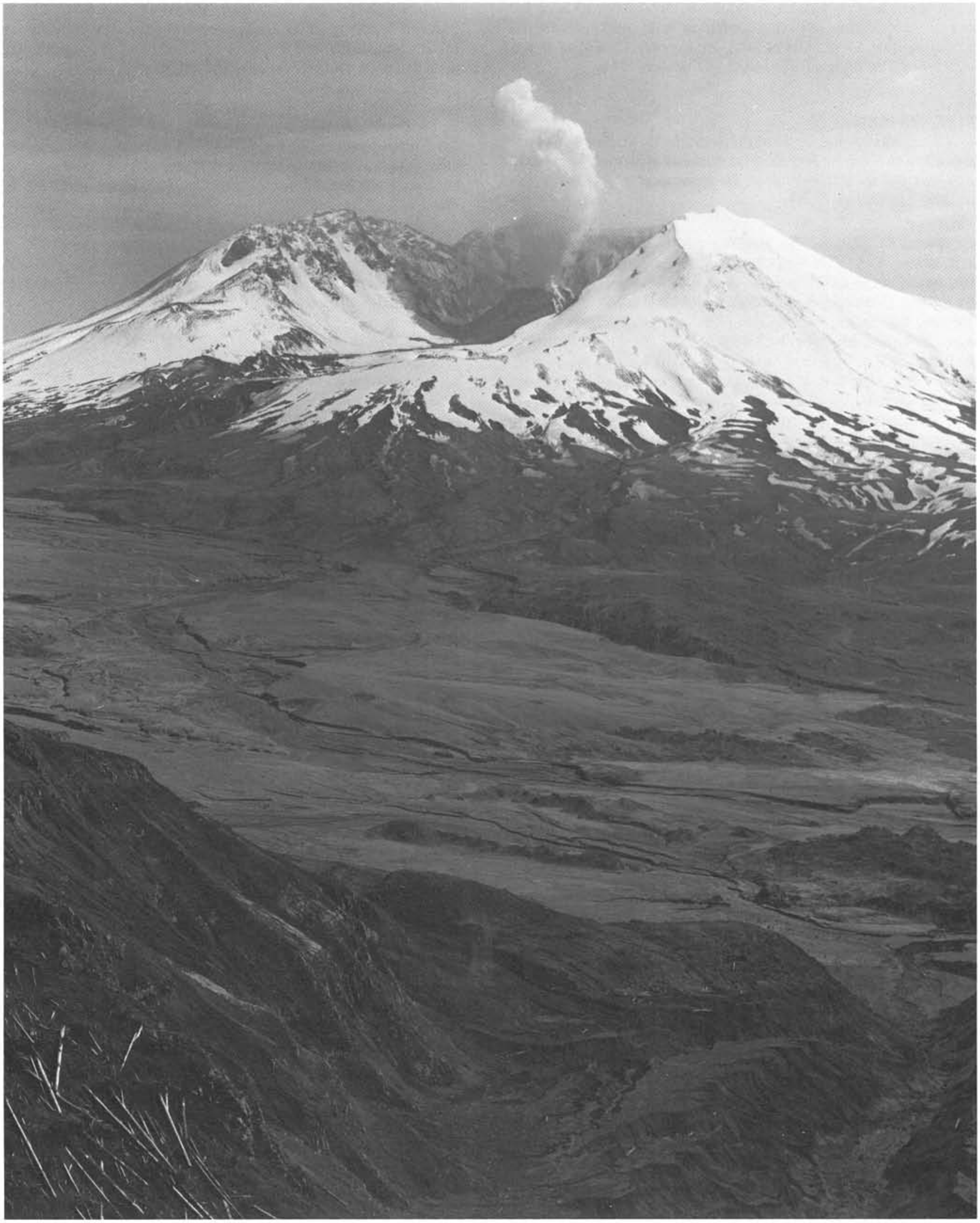
Mount St. Helens: On May 18, 1980, at 8:32 a.m., a cloud of hot gas and ash burst from the north flank of the mountain and raced north, west, and east to level 125 mi^2 of primeval forest. Even though earlier rumblings and small explosions had led to restrictions on access to the area, some 60 people lost their lives in this eruption.

Mount Mazama (Crater Lake): The largest pyroclastic eruption in Oregon within the last 10,000 years occurred about 6,800 years ago, when the top of Mount Mazama collapsed after the outpouring of cubic miles of pumice and ash (Bacon, 1983).

3. Debris avalanches (landslides)

Gravity falls and flows induced by earthquakes accompanying a volcanic eruption. They may travel down a valley for several miles, burying all before them to depths of several hundred feet.

Mount St. Helens: The 1980 eruption of Mount St. Helens was initiated by an earthquake that started a landslide on the north side of the mountain. The landslide, in turn, exposed the magma vent below and turned into a debris avalanche containing two thirds of a cubic mile of debris that came down the mountain at nearly 170 mi/h and eventually covered more than 21 mi^2 for as much as 13 mi down the Toutle River valley. Only half a dozen of the world's more than 75 identified debris avalanches are known to exceed this volume (Lipman and Mullineaux, 1981).



Mount St. Helens, the dome, and the May 18, 1980, debris avalanche, as seen from Coldwater Ridge. Photo courtesy of Lyn Topinka, U.S. Geological Survey, David A. Johnston Cascades Volcano Observatory.

Mount St. Helens is composed largely of domes of very viscous dacite. Some other Cascade volcanoes are composed of andesite, which is less viscous. The most fluid lava is basalt, which frequently flows down valleys like water and poses little hazard to life, even in the Hawaiian Islands, since the flows progress slowly enough to be avoided, and the general area of potential hazard can be deduced from the topography in time for evacuation.

All of the relatively recent flows in North America, with the exception of Paricutin, Mexico, are prehistoric. In the western United States, many of the flows were erupted less than 3,000 years ago, as at the Craters of the Moon, Idaho, and the McCartys and Carrizozo flows in New Mexico. In the Cascades, young rhyodacites were erupted at South Sister, Newberry Crater, and Medicine Lake, and basalts were erupted at McKenzie Pass (Belknap Crater) and near Santiam Junction. The Parkdale lava flow in the upper Hood River Valley is about 7,000 years old.

WHAT SHOULD BE DONE BEFORE A VOLCANO ERUPTS

By geologists and geophysicists:

1. Study the volcano and map hazardous zones and rate them as to degree of potential danger.

2. Monitor the potentially active volcano for such preliminary warning signs as earthquakes, swelling, tilting, and gas emissions.

By local, county, state, and federal authorities:

1. Discourage development within identified hazardous zones.

2. Plan ahead for possible volcanic activity: (A) Establish detailed plans for evacuation, rescue, hospitalization, and emergency housing. (B) Coordinate local, county, state, and federal plans. (C) Review and update these plans at regular intervals.

3. When the volcano shows signs of activity, set up "Red" and "Blue" zones to restrict the public access. Upgrade or enlarge these zones as potential activity becomes more hazardous, and notify the public so people can prepare to evacuate.

By the media:

1. Publicize hazard zones and emergency plans.

2. Publicize escape routes and means of dealing with damage (ash fall, especially).

GLOSSARY (Adapted from Foxworthy and Hill, 1982, and Bates and Jackson, 1987)

Ash fall-----Volcanic ash (fine pyroclastic material, sometimes including larger pumice fragments) that has fallen through the air from an eruption cloud.

Debris avalanche-----A rapid and usually sudden sliding or flowage of unsorted masses of rock and other material. In the 1980 eruption of Mount St. Helens, that included fragmented cold and hot volcanic rock, water, snow, glacier ice, trees, and some hot pyroclastic material.

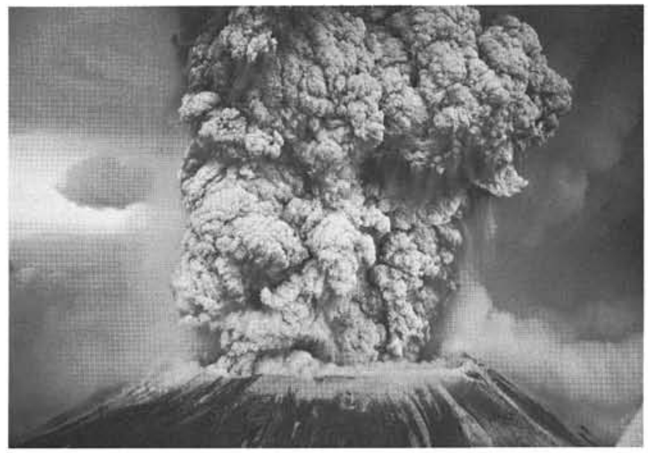
Lahar-----Mudflow originating on the flank of a volcano.

Mudflow-----A flowage of water-saturated earth material with a high degree of fluidity during movement. A less saturated and fluid mass is often called a debris flow.

Nuee ardente (French for "glowing cloud")-----A swiftly flowing, turbulent gaseous cloud, hot and sometimes incandescent, with the characteristics of a pyroclastic flow in its lower portion and capable of very high speed. Sometimes used synonymously with "pyroclastic flow," "ash flow," or "glowing avalanche."

Pyroclastic-----Pertaining to fragmented (clastic) rock material formed by a volcanic explosion or by ejection from a volcanic vent.

Pyroclastic flow-----Lateral flowage of a turbulent mixture of hot gases and unsorted pyroclastic material (volcanic fragments, crystals, ash, pumice, and glass shards). Often used synonymously with "ash flow" and "nuee ardente."



Mount St. Helens in eruption on May 18, 1980. Photo courtesy of Austin Post, U.S. Geological Survey, David A. Johnston Cascades Volcano Observatory, Glaciology Project.

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A satellite radar study of the structures in the Madras area, Jefferson County, Oregon

by D.H. Vice, Consulting Geologist, 449 Hart-Albin Building, Billings, Montana 59101

One of the new remote-sensing techniques developed in the past ten years is satellite radar imagery. Because of this technique's newness and the limited access, most geologists are not familiar with its advantages and disadvantages. One of the advantages is that the imagery provides a synoptic view of a large area, such as the Madras-Hay Creek area of central Oregon. This synoptic view can indicate structures that have not been recognized in standard or high-altitude air photos or in Landsat images.

A study of Seasat satellite radar imagery covering the Madras-Hay Creek area of central Oregon (see facing page) shows several lineaments that suggest the presence of regional structures. Some of these structures have been described previously (Peck, 1964; Swanson, 1969). Others have not been noted on published maps and reports of the area and may not have been recognized because of the stratigraphic discontinuity and lack of marker beds within the Clarno Formation.

The Seasat radar imagery (SAR Revolution 595) has an approximate scale of 1:500,000 (1 in. = 7.89 mi). This ascending revolution traverses Oregon from south-southeast to north-northwest.

The major lineaments visible within the Seasat radar imagery include a possible extension of the Mitchell fault (Little Willow Creek lineament) and a series of anticlines in the Hay Creek area. Other lineaments present in the radar imagery are the Dry River, Gateway, and Axehandle-Horse Heaven features.

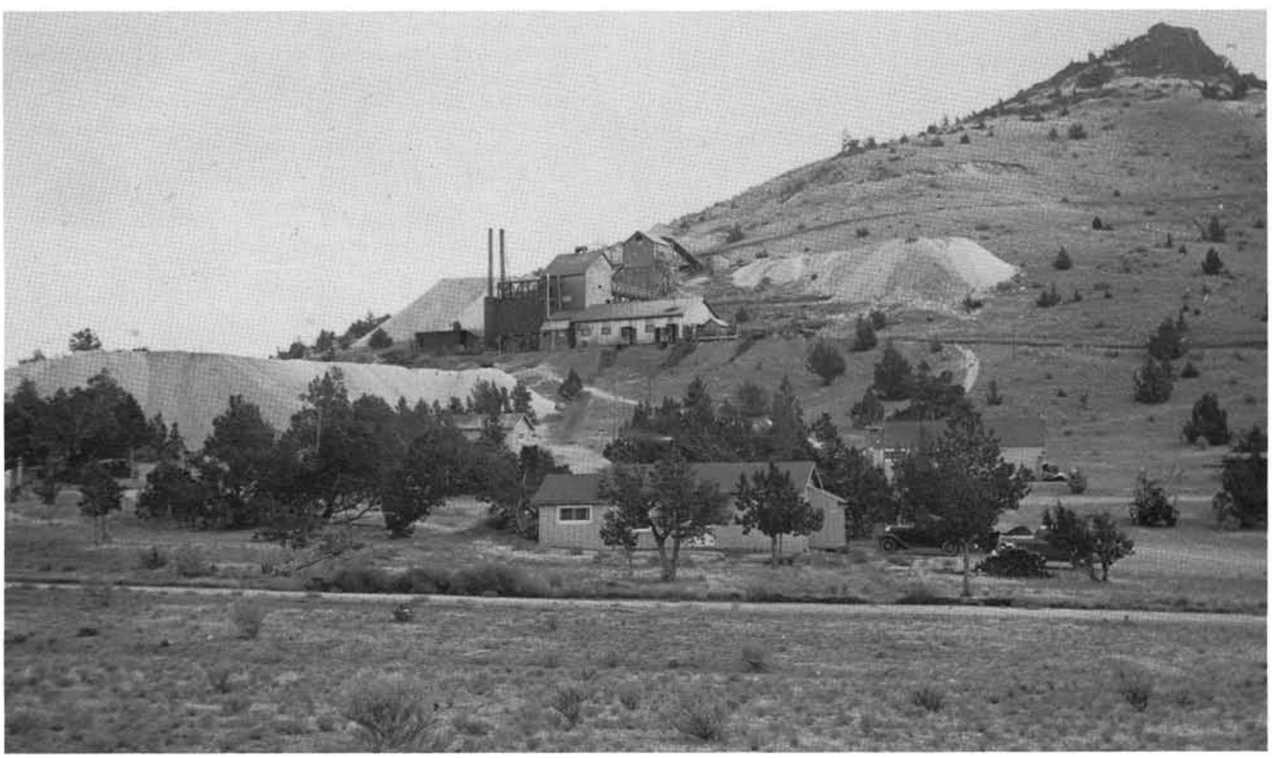
The Little Willow Creek lineament is a discontinuous east-west-trending feature that follows segments of the Deschutes River. The eastern segment of this lineament follows the lower Little Willow Creek and includes short portions of the Trout Creek drainage to the east. The western segment follows the lower portion of Seekseequa Creek. The significance of the lineament is uncertain, because no faults that correlate with the lineament have been mapped in the area.

In the Hay Creek area, the Little Willow Creek lineament appears to offset a secondary, north-trending linear feature that follows Hay Creek. This Hay Creek lineament has a distance of approximately 1½ mi (8,000 ft), separating segments on either side of the Little Willow Creek lineament. If this later feature represents a fault, then considerable movement has occurred along the structure.

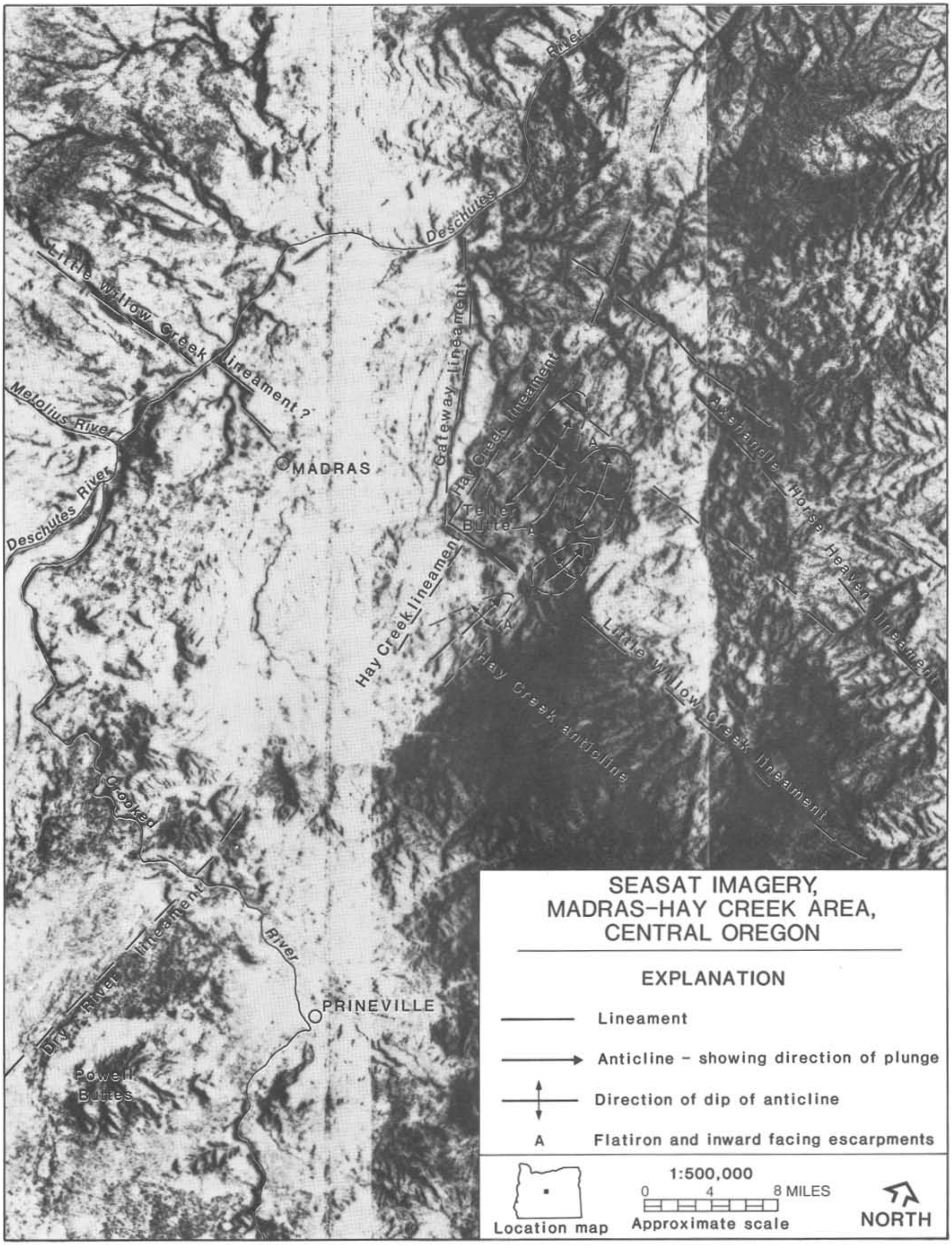
Four anticlines are present in the Hay Creek area. Three of these anticlines occur north of the Little Willow Creek lineament. These structures have a northerly trend. The one structure south of the Little Willow Creek anticline has a north-northeasterly trend. These structures are identifiable within the radar as anticlines because of the presence of steep, inward-facing escarpments and flatirons. Swanson (1969) mapped the structure south of the Little Willow Creek lineament.

The Axehandle-Horse Heaven lineament is poorly defined by the alignment of a series of short drainage segments. The Oregon King Mine, the Axehandle Mine, and the Horse Heaven Mine are all located along this lineament. Swanson (1969) shows a broad zone of silicic and andesitic domes and small intrusives along the same trend.

*(Continued on page 66, **Seasat**)*



Historical photograph of the Horse Heaven mercury mine, east of Madras, Oregon, where mercury was mined and retorted between 1934 and 1944 and between 1955 and 1958. This is one of several mines located along the Axehandle-Horse Heaven lineament.



Deschutes River
Little Willow Creek lineament ?
Metolius River
Deschutes River
MADRAS
Gateway lineament
Hay Creek lineament
Teller Butte
Hay Creek lineament
Hay Creek anticline
Little Willow Creek lineament
Axehandle-Horse Heaven lineament
Crooked River
Dry River lineament
PRINEVILLE
Powell Buttes
SEASAT IMAGERY, MADRAS-HAY CREEK AREA, CENTRAL OREGON
EXPLANATION
Lineament
Anticline - showing direction of plunge
Direction of dip of anticline
A Flatiron and inward facing escarpments
Location map
1:500,000
0 4 8 MILES
Approximate scale
NORTH

(*Seasat, continued from page 64*)

The Dry River lineament is based on the straight segment of its drainage from the Powell Buttes to its mouth at the Crooked River.

The five lineaments shown in the Seasat satellite radar suggest the presence of regional structures. This is particularly true with the Little Willow Creek and Hay Creek lineaments that are associated with four anticlines. The suggestion of regional structure is also true with the Axehandle-Horse Heaven lineament that is associated with several mercury mines and one base-metal mine. The large size of these lineaments often makes them difficult to recognize in standard or high-altitude air photos, because this type of imagery does not have a synoptic view. Although Landsat imagery provides a synoptic view, the color and tonal changes can often mask regional lineaments. Also, Landsat imagery does not emphasize relief the way satellite radar does. In summary, Seasat radar provides an inexpensive tool for regional structural studies. This technique can provide an alternative to Landsat imagery.

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ABSTRACTS

The Department maintains a collection of theses and dissertations on Oregon geology. From time to time, we print abstracts of new acquisitions that we feel are of general interest to our readers.

A STRATIGRAPHIC-GEOCHEMICAL STUDY OF THE TROUTDALE FORMATION AND SANDY RIVER MUDSTONE IN THE PORTLAND BASIN AND LOWER COLUMBIA RIVER GORGE, by Rodney Duane Swanson (M.S., Portland State University, 1986)

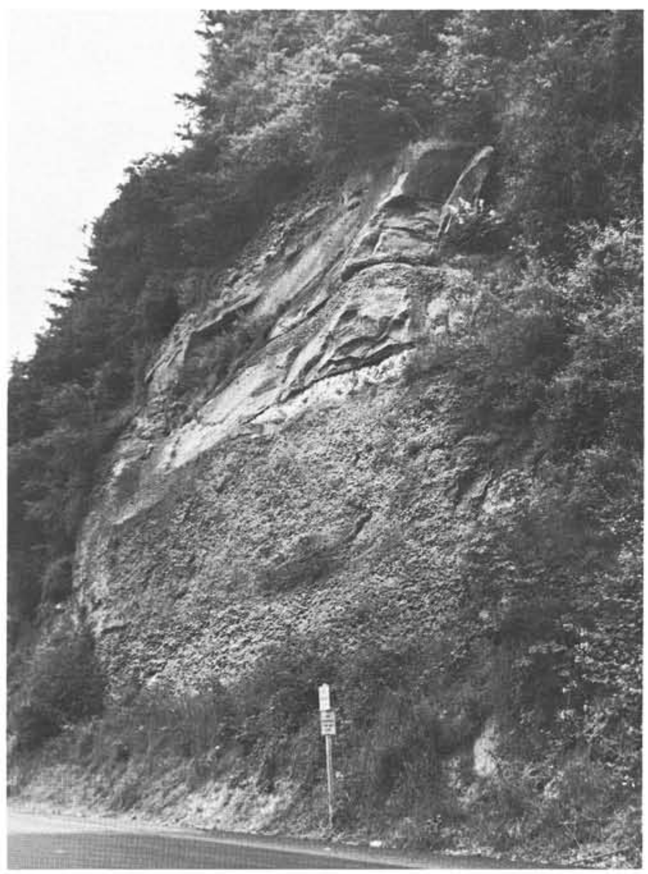
Hyaloclastic sediment forms an identifiable stratigraphic interval within the Troutdale Formation that can be traced from the Bridal Veil channel to the Portland basin. Hyaloclastic sediments, penetrated by wells in northeast Portland and composed chiefly of vitric sands interbedded with muds, sandy muds, and gravels, correlate with the upper member of the Troutdale Formation. These beds are characteristic of the informal upper member of the Troutdale Formation in the Bridal Veil channel of the ancestral Columbia River and the type area of the Troutdale Formation exposed along the Sandy River. Fluvially deposited hyaloclastic beds within the upper Troutdale Formation are interpreted to be the result of interaction of Cascadian basaltic lavas with an ancestral Columbia River. Glass clasts taken from well and outcrop samples have nearly identical trace and minor element geochemical content as determined by instrumental neutron activation analysis.

Based on similar major oxide geochemical content, the upper member Troutdale Formation hyaloclastic sediment is derived from Pliocene (5-2 m.y. B.P.) High Cascades high-alumina basalts found between the Hood River Valley and the Bull Run area. Trace and minor element data for High Cascade group basalts along the Washington side of the Columbia River area show a similarity between basalts near Underwood Mountain and hyaloclastic separates. Vitric material from a gravel 100 m below the main body of upper Troutdale Formation hyaloclastic sediment is tentatively correlated with basalts of the Simcoe Volcanics in south-central Washington, based on major oxide content. Age dates for the Simcoe basalts range from 2(?)-7.5 m.y. B.P. The latest Pliocene and early Pleistocene Boring Lavas, K-Ar dated at 1.3 and 2.5 m.y. B.P., which intrude and overlie the Troutdale Formation in the Portland area, are not source rocks for Portland area Troutdale Formation hyaloclastites, based on differing trace and minor element concentrations.

In the Portland basin, hyaloclastic beds are interbedded with intervals of nonhyaloclastic sediment. Upper Troutdale Formation exposed in the lower Columbia River Gorge is dominated by hyaloclastic sands and gravels. In the Portland basin, up to 900 ft of Troutdale Formation basaltic gravel overlies the hyaloclastic interval that defines the base of the upper Troutdale Formation.

Trace element contents of Sandy River Mudstone and lower Troutdale Formation sediment are similar. Addition of High Cascades lava-derived sediment to the upper Troutdale Formation is indicated by higher Cr, Co, Fe, and Sc concentrations. Q-F-L plots show a similarity between the Sandy River Mudstone and the lower Troutdale Formation and a higher amount of lithic material in upper Troutdale Formation sediments in the well area. Modern lower Columbia River sediment plots within the range of the upper and lower Troutdale Formation in a Q-F-L plot.

Formation of the Portland basin was in progress at the time of Columbia River basalt deposition. Deformation probably continued through deposition of the post-Columbia River basalt Pliocene sediment in the basin. Along the eastern margin of the Portland basin, the Troutdale Formation appears to be gently dipping toward the west. Locally, however, upper Troutdale Formation hyaloclastic sediment is offset approximately 150 m downward from Prune Hill, Washington, to the Blue Lake area, 2 mi to the southwest, on the Oregon bank of the Columbia River.



Upper member of the Troutdale Formation, consisting of conglomerate and sandstone. Outcrop at Stark Street bridge in Portland, Oregon.

THE STRATIGRAPHY AND STRUCTURE OF THE COLUMBIA RIVER BASALT GROUP IN THE SALMON RIVER AREA, OREGON, by Martin Stuart Burck (M.S., Portland State University, 1986)

Approximately 16 km² of Columbia River basalt are exposed in the Salmon River area to the south and to west of Mount Hood, Oregon. A maximum composite basalt section composed of 15 flows and totaling 461 m is exposed in discontinuous areas of outcrop.

The Columbia River basalt in the Salmon River area belongs to the Grande Ronde Basalt and the Frenchman Springs Member of the Wanapum Basalt. The Grande Ronde Basalt section (six flows) was mapped as two chemically distinct units referred to as low-MgO (older) and high-MgO (younger) Grande Ronde Basalt. At least one interfingered flow of the Prineville chemical type occurs within the low-MgO section. The Prineville flow represents the oldest Columbia River basalt exposed in the Salmon River area.

The Frenchman Springs section (eight flows) is represented by four distinct chemical units referred to as the basalt of Ginkgo, the basalt of Silver Falls, the basalt of Sand Hollow, and the basalt of Sentinel Gap.

Stratigraphic division of the Columbia River basalt units was based on geochemistry determined by INAA for trace elements and by X-ray fluorescence spectrometry for major oxides. The definition of geochemical units was aided by stratigraphic position, texture, and phenocryst/glomerocryst abundance.

The Grande Ronde Basalt and the Frenchman Springs Basalt originated in the Columbia Plateau and flowed westward through the Cascade Range along a 72-km-wide tectonic depression. The Prineville flow is chemically similar to flows that originated near the Bowman Dam (formerly the Prineville Dam) located 70-80 km to the southeast.

The distribution of Columbia River basalt in the Salmon River area was controlled by structures that developed gradually. The formation of these structures began during the incursion of the Grande Ronde Basalt and consisted of northeast-trending folds and a northwest-trending fault zone that displays components of strike-slip and vertical displacement. This approximately N 30° W-trending fault zone extends the entire length (30 km) of the Salmon River area.

The Ginkgo intracanyon flow may have passed through the Salmon River area within the projected continuation of the Mount Hood-The Dalles syncline. Rapid infilling by subsequent flows restored the low relief nature of the basalt surface by the end of Frenchman Springs time.

Persistent north-south compressional stresses resulted in the development of large-scale folds that were imprinted by the existing, continually developing small-scale folds. Continual length-shortening resulted in northeast-trending thrusts and high-angle-reverse faults along the weakened limbs of anticlinal structures. Thrust faults are associated with extensive breccias and may show up to 122 m of stratigraphic displacement.

The northwest-trending (predominantly N 30° W) fault zone exists along the western edge of the Salmon River area. Northeast-trending structures appear to terminate against it. The regional, right-lateral, strike-slip sense of motion along this zone is masked in the Salmon River area, where terminated anticlines and synclines create a vertical sense of displacement. The N 30° W structural zone was active throughout the history of structural development in the Salmon River area and has a complimentary relationship with the northeast-trending structures. The prominent overall northwest trend of the basalt outcrop pattern in the Salmon River area is related to the presence of the northwest-trending structures located along its western edge.

Northeast-trending normal faults are the youngest structures recorded by the tectonic history of the Columbia River basalt in the Salmon River area. This relationship was determined where normal faults cut previously formed thrust breccias. The late-forming normal faults are not related to the predominant, northeast-trending structures and indicate a fluctuation in the regional compressive-stress pattern that may exist today. Normal faulting may also be related to the emplacement of semidiscordant sills of silicic volcanic material observed within the basalt section and other intrusive features such as the Still Creek pluton located 1.5 km to the northeast.

THE ENGINEERING GEOLOGY OF THE FOUNTAIN LANDSLIDE, HOOD RIVER COUNTY, OREGON, by Susanne L. D'Agnese (M.S., Portland State University, 1986)

The Fountain Landslide, located along I-84, 5 km east of Cascade Locks, Oregon, has moved periodically for over thirty years. Aerial photographs taken prior to recorded movement of the landslide show the headscarp of a large preexisting landslide. In 1952, a cut was made into the toe of the landslide to straighten Highway 30. The recorded movement history begins at this time. Stabilization procedures in the late 1950's focused on dewatering the slide mass. Movement had nearly stopped by 1957. A deeper cut was made into the toe of the landslide in 1966 to widen the highway to the four-laned I-80N (later renamed I-84). Accelerated movement resulted. The Oregon State Highway Division removed 264,000 m³ of material from the head of the movement zone. Accelerated movement continued. The Oregon State Highway Division then began intense research of the landslide. Research included core logs, slope inclinometers, and the ground-water data. The western portion of the slide mass was unloaded more extensively in 1970 (1.2 million m³). This later unloading slowed down the movement, but it continues periodically.

The oldest unit found in the area is a volcaniclastic unit. It is found only in core logs in the southwest portion of the slide. The basalts of the Columbia River Basalt Group are found intact and as talus in the study area. Quartz diorite intrusives younger than the Columbia River Basalt Group are found at the surface and at depth along the entire length of the toe of the landslide. Wind River lava crossed from Washington, dammed the Columbia River, and was deposited within the study area.

The slide mass consists primarily of Columbia River Basalt Group talus and Wind River lava talus. The slip plane consists primarily of rocky mudstone. The ground-water table is elevated over the intrusive at the toe of the landslide and over the volcaniclastic unit at the head. Surface cracks and scarps indicate that the slide mass moves northward, drops at the head, and heaves at the toe.

A slope-stability analysis of the Fountain Landslide showed that the instability here is the result of elevated ground-water and the removal of material at the toe for highway construction. It also showed that the eastern portion is more stable than the western portion. The differences in the stability result from the addition of fill at the toe and a lower ground-water table in the eastern portion. The development of the prehistoric slide resulted when the dam of Wind River lava was removed, and lateral support for the deposit was lost.

This study shows that it is essential to have adequate geologic information prior to construction or remedial design for any preexisting landslide to avoid stability problems.

PETROGRAPHY AND PROVENANCE OF SANDSTONES FROM THE OTTER POINT FORMATION, SOUTHWESTERN OREGON, by Robert W. Goodfellow (M.S., University of Oregon, 1987)

The Otter Point Formation of southern Oregon is a melange consisting of sheared mudstones and sandstone with included coherent blocks of sandstone and mudstone, chert, pillow basalt, glaucophane schist, and serpentinite. The formation is exposed in both the Gold Beach and Sixes River tectonostratigraphic terranes. Petrographic study of Otter Point sandstones was carried out to determine provenance of the sandstones and to investigate differences and similarities in compositional modes of sandstones in the two terranes.

Sandstones from the Otter Point Formation in the Gold Beach terrane are predominantly quartz-poor lithic wackes. Mean framework compositional modes for Otter Point sandstones are Q7-F17-L36 at the type locality, Q12-F19-L48 at Cape Blanco, and Q7-F17-L46 at the Miller Creek locality. Source rocks for Otter Point sandstones are interpreted to be primarily basalts and andesites that were derived from an island arc. Sediments were probably deposited in a back-arc basin within a marginal sea located between the arc and the North American continent.

Otter Point sandstones from the Sixes River terrane are predominantly quartz-rich, feldspathic wackes that have mixed sources including volcanic, plutonic, and metamorphic rocks. Sediments were derived from both continental and magmatic-arc source areas. Otter Point sandstones in the Sixes River terrane were deposited within, or adjacent to a subduction complex at the North American continental margin.

Collision of the arc with the continent resulted in chaotic mixing of sediments and the formation of a melange, as well as juxtaposition of both terranes. Chert and oceanic basalt were incorporated into the melange of both terranes during the collision event.

PETROGRAPHIC AND GEOCHEMICAL CHARACTERISTICS OF BEDDED CHERTS WITHIN THE JURASSIC OTTER POINT FORMATION, SOUTHWESTERN OREGON, by Sheila A. Monroe (M.S., University of Oregon, 1987)

Bedded cherts of the Late Jurassic Otter Point Formation of southwestern Oregon crop out as erosional remnants. The chert bodies consist of chert beds 2-5 cm thick interbedded with thin (0.1-1.0-cm) shale partings. The cherts are commonly dark reddish brown or pale green. They are composed primarily of radiolarian tests and micro₆crystalline quartz. Radiolarians are best preserved in the argillaceous, dark reddish-brown cherts.

Otter Point cherts are interpreted to have formed at intermediate water depths. Absence of calcareous debris, relatively high concentrations of impurities when compared to DSDP cherts and porcellanites, low Ce anomalies, and intermediate MnO/TiO_2 ratios in the cherts suggest that they were deposited at a moderate distance from shore, possibly in a marginal sea. This nearshore basin was located about 30° north of the Late Jurassic/Early Cretaceous paleoequator.

U/Pb GEOCHRONOLOGIC AND PETROLOGIC STUDIES IN THE BLUE MOUNTAINS TERRANE, NORTHEASTERN OREGON AND WESTERNMOST-CENTRAL IDAHO: IMPLICATIONS FOR PRE-TERTIARY TECTONIC EVOLUTION, by Nicholas Warren Walker (Ph.D., University of California, Santa Barbara, 1986)

Numerous erosional inliers in the extensive Cenozoic-age volcanic and sedimentary blanket of northeastern Oregon and west-central Idaho reveal a lithologically diverse and structurally complex assemblage of Late Paleozoic to Late Mesozoic age rocks of oceanic affinity.

This assemblage includes tectonically juxtaposed, variably deformed and metamorphosed Permo-Triassic volcanic-plutonic complexes and related sedimentary rocks, ultramafic-mafic-silicic igneous suites, polymict melange tracts, and thick sequences of Upper Triassic to Upper Cretaceous volcaniclastic sediments. Numerous undeformed mesozonal gabbroic to granodioritic plutons of Late Jurassic to Early Cretaceous age cross-cut these older rocks, indicating that juxtaposition of the older components took place prior to emplacement of the plutons.

Field, petrologic, and U-Pb geochronologic investigation of igneous and metamorphic components of this region demonstrate that the Permo-Triassic Seven Devils Group was constructed, at least in part, within and upon a Late Carboniferous basement whose protolith was plutonic. Geochemical data suggest this basement is of oceanic origin.

Commencing in the Early Permian and continuing sporadically through the Late Triassic, the basement was penetrated by plutons and dike swarms ranging in composition from gabbronorite to trondhjemite. Geochemical evidence indicates these plutonic bodies were generated from a source depleted in LIL elements and are of oceanic affinity.

Together, the metamorphic basement and plutons compose the crystalline infrastructure to the stratigraphically and structurally overlying Seven Devils Group. A Late Triassic ductile shear zone of unknown displacement affecting these rocks records translation in the thermally softened arc infrastructure.

Regional U-Pb geochronologic data from pre-Jurassic igneous and meta-igneous components throughout this region reveal an age range of plutonic activity of 279 Ma to 215 Ma. This fact, considered in concert with field evidence, paleomagnetic evidence, and paleontologic data, supports the conclusion that, although there are distinct structural/stratigraphic blocks within this region, they are vestiges of a single, ensimatic convergent margin system that was magmatically and tectonically active intermittently from Early Permian to Early Cretaceous time. This kindred assemblage is collectively referred to as the "Blue Mountains Terrane."

Structural telescoping of this convergent margin system took place prior to the emplacement of undeformed Late Jurassic-Early Cretaceous plutons. Accretion to the continental margins occurred subsequent to pluton emplacement and was accomplished by translational movement during the Cretaceous.

GEOCHEMISTRY OF THE EUREKA-EXCELSIOR GOLD-LODE DEPOSIT AND ASSOCIATED GREENSTONES AND METASEDIMENTARY ROCKS, CRACKER CREEK DISTRICT, BAKER COUNTY, OREGON, by Craig Paul Calder (M.S., Eastern Washington University, 1986)

Sixty-seven samples of altered and unaltered metasedimentary rocks, greenstones, and quartz-carbonate vein collected from Cracker Creek district, Oregon, were analyzed for Ag, Au, Cu, Rb, Tl, and Zn. Data on major and minor oxides, SiO_2, Al_2O_3, Fe_2O_3, FeO, MgO, CaO, Na_2O, K_2O, TiO_2, MnO, P_2O_5, H_2O, and CO_2, were obtained for altered and unaltered rocks. In addition, unaltered greenstones were analyzed for Ba, Cr, Sr, Y, and Zr. The metasedimentary rocks include upper Paleozoic to Mesozoic cherts and argillites, whereas greenstones are low-K tholeiites in composition.

The elements K, Rb, and Tl are enriched in hydrothermally altered greenstones by factors of 11, 18, and 24, respectively, in comparison to unaltered greenstones. These enrichment trends demonstrate that Tl is concentrated more in hydrothermal fluids than either Rb or K. Enrichments of H_2O, CO_2, and MgO, with depletions of SiO_2 and Na_2O, are noted in the chloritic alteration zone of the greenstones. The cherts and argillites are less prone to alteration than the greenstones due to their high silica content. Increase in mean Tl contents by factors of 2.6 and 1.8 for argillites and cherts respectively occur in the hydrothermally altered metasedimentary rocks.

The $K/Tl \times 10^4$ and Rb/Tl ratios are more effective than the abundances of individual elements for separating the unaltered and altered rocks. These ratios show a decrease in values from unaltered to altered samples, with the lowest values in the quartz-carbonate vein. The $K/Tl \times 10^4$ ratio shows a more significant depletion in comparison to the Rb/Tl ratio. The enrichment of Tl over K and Rb in hydrothermally altered wall rocks and vein samples is demonstrated in

Tl-Rb-K plots, with unaltered samples clustering near the K apex and altered rocks and vein samples plotting closer to the Tl apex.

Thallium is enriched with respect to K and Rb in the paragenetically later carbonate sulfide-rich phase, which contains the highest concentrations of Au and Ag. The Au/Ag ratios of the sulfide-rich ore range from 1:2 to 1:30, with higher base metal values associated with the lower ratios.

The vein and hydrothermally altered wall rocks contain abundant carbonate. The most common and pervasive alterations are carbonatization, sulfidization, and sericitization. The narrow argillic shear zone in contact with the vein is occasionally of ore grade, with the highest gold values most commonly observed in the footwall. The vein is composite with quartz deposition predominating in the early stages, followed by greater proportions of carbonate, muscovite, and disseminated sulfides in the later stages. Ore minerals include pyrite, chalcopyrite, a mineral of the tetrahedrite-tennantite series, and electrum.

STRATIGRAPHY, PETROLOGY, AND PROVENANCE OF THE CRETACEOUS GABLE CREEK FORMATION, WHEELER COUNTY, OREGON, by Stephen W. Little (M.S., Oregon State University, 1987 [compl. 1986])

The Mitchell inlier in north-central Oregon contains the largest exposure of Cretaceous marine sedimentary rocks in this region. Nearly 9,000 ft of Albian-Cenomanian rocks are exposed along the flanks of the Mitchell anticline. The Cretaceous section rests unconformably on Permian(?) metasedimentary rocks and is unconformably overlain by Tertiary volcanic rocks. The Cretaceous rocks have previously been divided into the Hudspeth and Gable Creek Formations. The Hudspeth Formation consists of thick sequences of hemipelagic mudstone that contain subordinate siltstones and thin beds of turbiditic sandstone. The Gable Creek Formation is composed of numerous isolated sequences of coarse conglomerate, pebbly sandstone, and sandstone. This study concentrates on the stratigraphy and petrologic composition of the Gable Creek conglomerates.

The Gable Creek conglomerates are composed of a heterogeneous assemblage of volcanic rocks, chert, plutonic rocks, and lesser amounts of sedimentary and metamorphic rocks. The petrologic composition of the conglomerates can be accurately reflected by means of pebble-count analysis. Pebble counts provide a valuable tool for quantifying conglomerate composition and documenting compositional variations within the 70-mi^2 Cretaceous outcrop area. Cluster analysis of the pebble count data confirms the presence of two major conglomerate petrofacies within the inlier. The striking compositional contrasts between the two petrofacies may be due to primary differences in sediment composition or secondary, post-depositional changes. Statistical correlation values reveal that conglomerate composition is fairly uniform within each of the two petrofacies. Petrologic composition also remains nearly constant within each of the major conglomerate units but exhibits random variations upward through the stratigraphic section.

The Cretaceous rocks at Mitchell were deposited in a deep marine basin sometimes referred to as the Ochoco basin (Odiorne, written comm., 1985). The Ochoco basin may have extended into southwestern Oregon, where Cretaceous rocks of the Hornbrook Formation are exposed. Several small Cretaceous inliers in central Oregon represent nonmarine and shallow marine environments of deposition that flanked the basin margins.

This study supports the interpretation of the Cretaceous rocks at Mitchell as submarine turbidites as suggested by Kleinhans (1984). The Gable Creek rocks were deposited in submarine channels by various sediment gravity-flow processes in a base-of-slope or proximal-fan setting. The Gable Creek units are arranged into thinning- and fining-upward sequences that may be the result of progressive channel abandonment. The correlative Hudspeth rocks are

Cliff-forming member of Gable Creek Formation at Mitchell, Oregon. Light-colored streaks are lenses of channel sands within conglomerates.

interpreted as submarine levee, overbank, and interchannel deposits associated with the Gable Creek channels. The geometry of the Cretaceous rocks is defined by a series of stacked channel-levee-interchannel sequences.

Paleocurrent data from the Cretaceous section yield a dominant southwesterly direction of sediment transport and a subordinate northwesterly trend. Variations in paleocurrent orientation may reflect several directions of sediment input, overbank deposition, and channel abandonment. The Gable Creek conglomerates have source areas located to the southeast, east, and northeast of Mitchell within the late Paleozoic and early Mesozoic accreted terranes in eastern Oregon. The provenance of the conglomerates is widespread and includes the island-arc rocks of the Seven Devils Group, rocks of the dismembered oceanic crustal terrane, forearc strata of the John Day inlier, and the Jurassic plutons in northeastern Oregon. A previously undescribed tuffaceous unit within the Gable Creek Formation probably marks a short-lived episode of mid-Cretaceous volcanic activity in the source area.

THE GEOLOGY AND PETROLOGY OF THE CHETCO COMPLEX, KLAMATH MOUNTAINS, SOUTHWESTERN OREGON, by Karla Louise Urbanowicz (M.S., University of California, Davis, 1986)

The Chetco Complex forms part of the Western Jurassic Belt of the Klamath Mountains in Oregon. The complex contains ultramafic and mafic plutonic rocks that are chemically and mineralogically consistent in both northern and southern exposures. Ultramafic plutonic rocks commonly exhibit porphyroclastic textures, and gabbroic to dioritic rock types show massive to foliated textures. Whole-rock chemistry for the suite indicates differentiation with an early Fe enrichment during cumulate crystallization, followed by silica and alkali enrichment along calc-alkaline trends. The cumulate assemblage includes olivine, pyroxene, plagioclase, and spinel. Plutonic rocks include two-pyroxene gabbros, hornblende quartz diorites, minor tonalites, and a late-stage hornblende anorthite pegmatite.

Evidence exists for high-grade subsolidus reactions involving the cumulate assemblage, with amphibole as an important phase.

(Continued on page 70, ***Abstracts****)*

Geologist named Reed College president

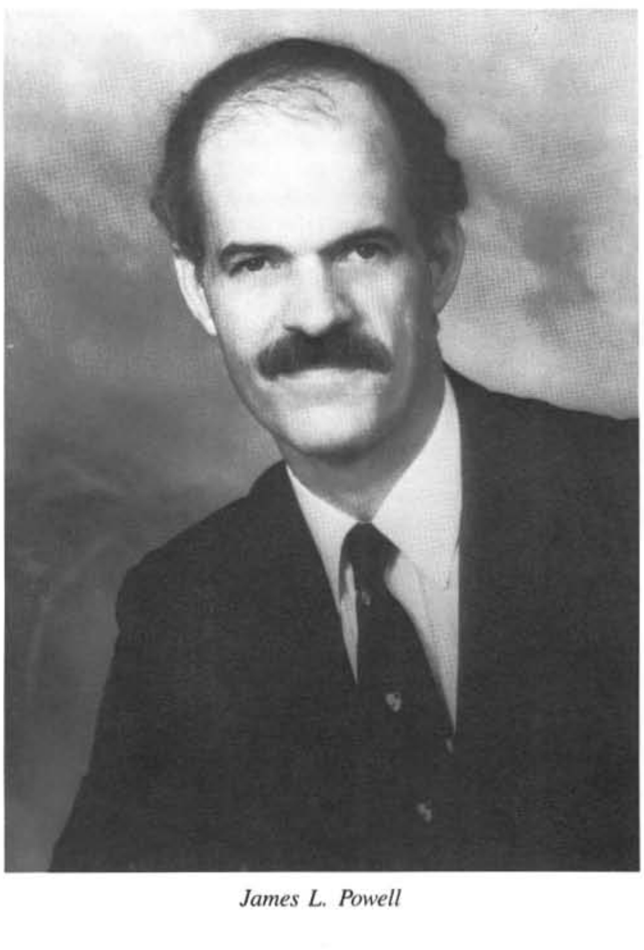
The Board of Trustees of Reed College in Portland, Oregon, has announced the selection of 51-year-old geologist James Lawrence Powell as the next president of this private college.

Powell is currently the president of Franklin and Marshall College in Lancaster, Pennsylvania, where he has served in that function since 1983. He will assume his new responsibilities in August 1988, succeeding Paul E. Bragdon, who leaves the presidency to become Oregon Governor Neil Goldschmidt's Assistant for Education.

A nationally respected scholar in the area of science education, Powell has published in the field of geochemistry over a period of nearly 25 years. He also has delivered recent papers and presentations on computing in liberal education, computer-intensive campuses, prudent college management, and the tenure system.

Powell earned his doctoral degree in geochemistry at the Massachusetts Institute of Technology in 1962 and served as teacher and administrator at Oberlin College before he joined Franklin and Marshall College. Among the awards and honors he has received are an LH.D. (doctor of humane letters) degree from Tohoku University, Japan, in 1986 and an Sc.D. (doctor of science) degree from Oberlin College in 1983.

Powell currently serves the cause of higher education on a national level by actively participating in a significant number of educational organizations. He is, among other things, the only representative from a liberal arts college on the National Science Board, the policy-making body of of the National Science Foundation; he is a director of EDUCOM, a university group for advancing the uses of technology in higher education; and he serves on the board of governors of the Institute for European Studies.



James L. Powell

Powell is married to Joan Hartman, who has taught political science at the Claremont Graduate School, at Oberlin, and at Franklin and Marshall. She has worked at the Congressional Research Service and the U.S. Department of the Interior, which she still serves as a consultant. Powell is the father of three children, Marla, 20; Dirk, 17; and Joanna, 1; and enjoys the music of Mozart, reading biographies and mysteries, running, backpacking, and fly-fishing.

—Reed News

Northwest Petroleum Association announces symposium

The oil and gas potential of southwestern Washington and the adjacent Outer Continental Shelf (OCS) will be examined at the annual spring symposium held by the Northwest Petroleum Association on May 18-20, 1988, at Ocean Shores, Washington.

The purpose of the meeting will be to summarize current stratigraphic and structural models as well as recent drilling, seismic, and leasing activity. There will be a full day of talks on May 19 and pre- and post-meeting technical field trips.

Attention has recently been drawn to the area considered for study because of the Washington State lease sale, the proposed upcoming OCS sale, the regional seismic project of the U.S. Department of Energy, and the search for another Mist Gas Field.

For further information on lodging, recreation, and car rental and to obtain the necessary registration form, contact Gay Preator, Weyerhaeuser Company PC 2-31, Tacoma, WA 98477, phone (206) 924-2624; or Ocean Shores Chamber of Commerce, Ocean Shores, WA 98569, phone (206) 289-2451.

—NWPA news release

(***Abstracts**, continued from page 69*)

Mineral assemblages and textures indicate that initial crystallization occurred at water-undersaturated conditions at temperatures $>1,300°$ and pressures <10 kb, followed by deformation and crystallization under hydrous conditions, with amphibole as part of the stable assemblage.

Gneissic rocks containing primarily hornblende and plagioclase are abundant around the perimeters of the complex. The foliated rock is chemically similar to massive gabbroic and dioritic plutonic rocks in TiO_2, CaO, FeO*, and MnO contents, but trends toward lower Al_2O_3 and higher MgO, Na_2O, and $^{87}Sr/^{86}Sr$ values. Amphibole compositions in gabbroic and gneissic portions of the complex are magnesio-hornblendes, with Al^{IV} contents indicating similar crystallization temperatures. Higher temperatures are indicated for amphiboles in the cumulate portions of the complex. Lamprophyre dikes containing the high-temperature amphibole kaersutite are found crosscutting ultramafic units. The foliated portions of the complex containing hornblende plagioclase gneiss are probably derived from the gabbrioc to dioritic sequence during an episode of deformation with increased water activity. Similar trends in element depletions are noted in oceanic environments, where hydrothermal metamorphism and deformation affects upper and lower portions of the crust.

Values for TiO_2 are consistently low (<1 percent) for the plutonic suite, except for anomalous amphibolite rocks entrained below the Josephine Peridotite sheet. Initial $^{87}Sr/^{86}Sr$ ratios for the nongneissic rocks in the suite are in the range found for volcanic-arc rocks. The chemical trends in the Chetco Complex indicate affinities to calc-alkaline island-arc tholeiites. However, similar mineral assemblages and highly deformed rock textures are also found in modern oceanic transform faults and back-arc basins, which should also be considered as a possible analogue for the Chetco Complex. □

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