

# OREGON GEOLOGY

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**THIS MONTH:**  
Geothermal exploration in Oregon, 1986

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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. 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 bibliographic 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

View of Portland from the air. The Willamette River here flows in a generally northerly direction. A new book, *Portland's Changing Landscape*, which was recently published by the Portland State University Department of Geography, is discussed in an article on page 74. Photo courtesy of John V.A.F. Neal.

## OIL AND GAS NEWS

### Mist Gas Field production update

Cumulative gas production for 1987 at Mist Gas Field through April was 1,505,675 million cubic feet of gas. There are currently fourteen producing wells at the field, of which thirteen are operated by ARCO and one by Tenneco Oil Company.

### Recent permits

Permit no.	Operator, well API number	Location	Status, proposed total depth (ft)
388	Leadco, Inc. CC-Jackson 22-17 36-009-00225	NW ¼ sec. 17 T. 5 N., R. 4 W. Columbia County	Application; 2,500.
389	Leadco, Inc. CC-Jackson 23-17 36-009-00226	SW ¼ sec. 17 T. 5 N., R. 4 W. Columbia County	Application; 2,500.
390	ARCO CFI 31-1-65 36-009-00227	NE ¼ sec. 1 T. 6 N., R. 5 W. Columbia County	Application; 2,100.
391	ARCO Col. Co. 33-4-65 36-009-00228	SE ¼ sec. 4 T. 6 N., R. 5 W. Columbia County	Application; 3,000.

## Philip B. King, famed USGS geologist and author, dies

Philip B. King, of Los Altos, Calif., a world-renowned geologist and author, considered one of the preeminent scientists in the history of the U.S. Geological Survey (USGS), died Saturday, April 25, 1987, at the Mt. View Convalescent Hospital in Mt. View, Calif. He was 83.

King, a colorful as well as illustrious figure described as a giant in the field of geology, worked for the USGS for almost half a century. He is perhaps best recognized for the definitive geologic map of the United States, the currently used tectonic map of North America, and the geologic map of North America.

His books, *The Evolution of North America* (1950) and *The Tectonics of Middle North America* (1951), are reputed to be geologic classics and models of regional synthesis. Through his lifetime, Dr. King's books and reports were widely acclaimed for their lucid writing and his own superb illustrations. His total bibliography numbers more than 125 maps, reports, journal articles, and books. His works span a period of 55 years, beginning in 1926.

Up until his death he was working on reports, "pecking at the typewriter like a child," according to his family. He had completed 12 or 13 pages of a new paper on Paleozoic rocks before he died.

For his map work and earlier success in deciphering the geology of the Marathon Basin in Texas and the Great Smoky Mountains in Tennessee, King was awarded the Penrose Medal in 1965, the nation's highest geologic award. In the same year in Moscow, he was presented the Lomonosov medal, the highest equivalent honor bestowed by the Soviet Union.

King was a member of the National Research Council Committee on Tectonics, a Fellow of the Geological Society of America, and a Fellow of the American Association of Petroleum Geologists. Among other high honors, he was awarded the U.S. Department of Interior Distinguished Service Award. □

# Geothermal exploration in Oregon, 1986

by George R. Priest and Neil M. Woller, Oregon Department of Geology and Mineral Industries; David D. Blackwell, Southern Methodist University; and Marshall W. Gannett, Oregon Water Resources Department

## ABSTRACT

The general level of leasing activity was similar to last year's level. Drilling activity increased partly as a result of the U.S. Department of Energy (USDOE) Cascade Deep Thermal Gradient Drilling Program, a cooperative effort between USDOE and industry. Drilling of intermediate-depth (1.2- to 1.5-km-deep) diamond core holes continued to be the dominant form of exploration in 1986. All drilling occurred either at Newberry volcano or in the High Cascades. Holes generally need to be relatively deep to be sure of penetrating the blanket of cold ground water that masks deep heat flow in these two areas. The most exciting news from the drilling programs is the discovery of temperatures of 107.1 °C at 405-m depth in California Energy's MZI-IIA hole on the southeast flank of Mount Mazama (Crater Lake area). Other publicly available data from the Cascade and Newberry drilling programs indicate that, in most cases, the holes could have gotten reliable temperature-depth data at depths of as little as 0.65 km. Drilling through the cold water blanket or "rain curtain" may therefore be somewhat easier than previously thought.

Original permit requirements prompted California Energy Company to elect to suspend drilling on its MZI-IIA hole. Possible alternatives to these requirements are being studied by the U.S. Bureau of Land Management (USBLM). Possible classification of the heat-flow anomalies in the floor of Crater Lake as "significant thermal features" by the federal government may have future regulatory impacts on geothermal development on Mount Mazama.

New age data from the U.S. Geological Survey (USGS) indicate that the silicic volcanic highland west of Bend may be much younger than previously thought. An average K-Ar age of about 0.3 million years (Ma) was obtained on an ash flow that was probably erupted from the highland. The 24-km-wide highland could therefore harbor still-hot magma bodies and associated hydrothermal systems.

Direct use of geothermal fluids continued to expand slowly in 1986, and more expansion is expected in 1987. Most of the activity is occurring at Klamath Falls, La Grande, Lakeview, and Vale. Oregon Trail Mushroom Company, a new \$8.5-million fresh-pack operation, utilized the 107 °C water at Vale for heating. Klamath Falls expanded its district heating system. Use of geothermal heat for a greenhouse and for residential heating continued at Lakeview. New developments are planned at Olene Gap near Klamath Falls.

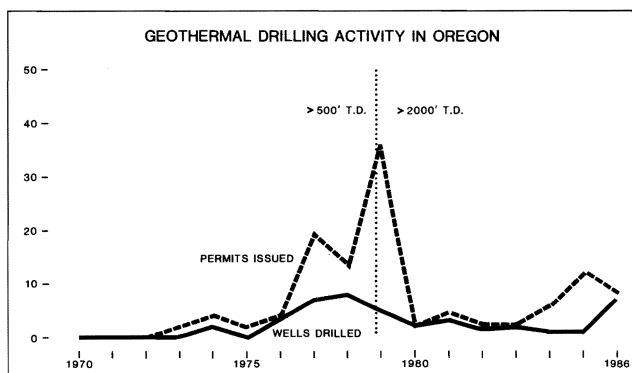


Figure 1. Geothermal well drilling in Oregon. Vertical line indicates time when definition of geothermal well was changed to a depth greater than 610 m (2,000 ft).

## LEVEL OF GEOTHERMAL EXPLORATION

### Introduction

In 1986, geothermal-gradient drilling continued in the young volcanic rocks of the High Cascades and Newberry volcano. The amount of leased land declined on U.S. Bureau of Land Management (USBLM) land but increased on U.S. Forest Service (USFS) land. The total amount of federal land leased for geothermal resources has in general changed by only small amounts over the last two years. The trend toward deeper drilling and more stable leasing patterns is the natural result of industry moving into more advanced phases of exploration.

### Drilling activity

Figure 1 shows the number of geothermal wells drilled and geothermal drilling permits issued in 1986. The number of permits decreased slightly, whereas the number of wells drilled increased. The increase in drilling was caused by two factors: (1) the need for companies to begin testing of leased lands in order to keep their leases and consolidate lease positions, and (2) the influx of U.S. Department of Energy (USDOE) matching funds for temperature-gradient drilling.

The USDOE program was focused on exploration of the High Cascades, Newberry volcano, and Medicine Lake volcano. This

Table 1. Active permits for geothermal drilling in 1986

Permit no.	Operator, well, API number	Location	Status, proposed total depth (m)
116	California Energy Co. MZI-IIA 035-90014	SW¼ sec. 10 T. 31 S., R. 7½ E. Klamath County	Suspended; 413.
117	California Energy Co. MZII-1 035-90015	SE¼ sec. 13 T. 32 S., R. 6 E. Klamath County	Suspended; 148.
124	Thermal Power Co. CTGH-1 36-047-90002	SE¼ sec. 28 T. 8 S., R. 8 E. Marion County	Suspended; 1,463
125	Geo Operator Corp. N-2 36-017-90018	SW¼ sec. 29 T. 21 S., R. 12 E. Deschutes County	Suspended; 1,337.
126	Geo Operator Corp. N-3 36-017-90019	NE¼ sec. 24 T. 20 S., R. 12 E. Deschutes County	Suspended; 1,219.
127	California Energy Co. CE-NB-3 36-017-90020	NW¼ sec. 16 T. 22 S., R. 13 E. Deschutes County	Suspended; 1,325.
128	California Energy Co. CE-NB-1 36-017-90021	NW¼ sec. 16 T. 22 S., R. 12 E. Deschutes County	Permit issued; 1,219.
129	California Energy Co. CE-NB-4 36-017-90022	SE¼ sec. 4 T. 21 S., R. 12 E. Deschutes County	Suspended; 1,225.
130	Trendwest, Inc. Olene Gap 1 36-035-90016	NW¼ sec. 35 T. 39 S., R. 10 E. Klamath County	Permit issued; 914.

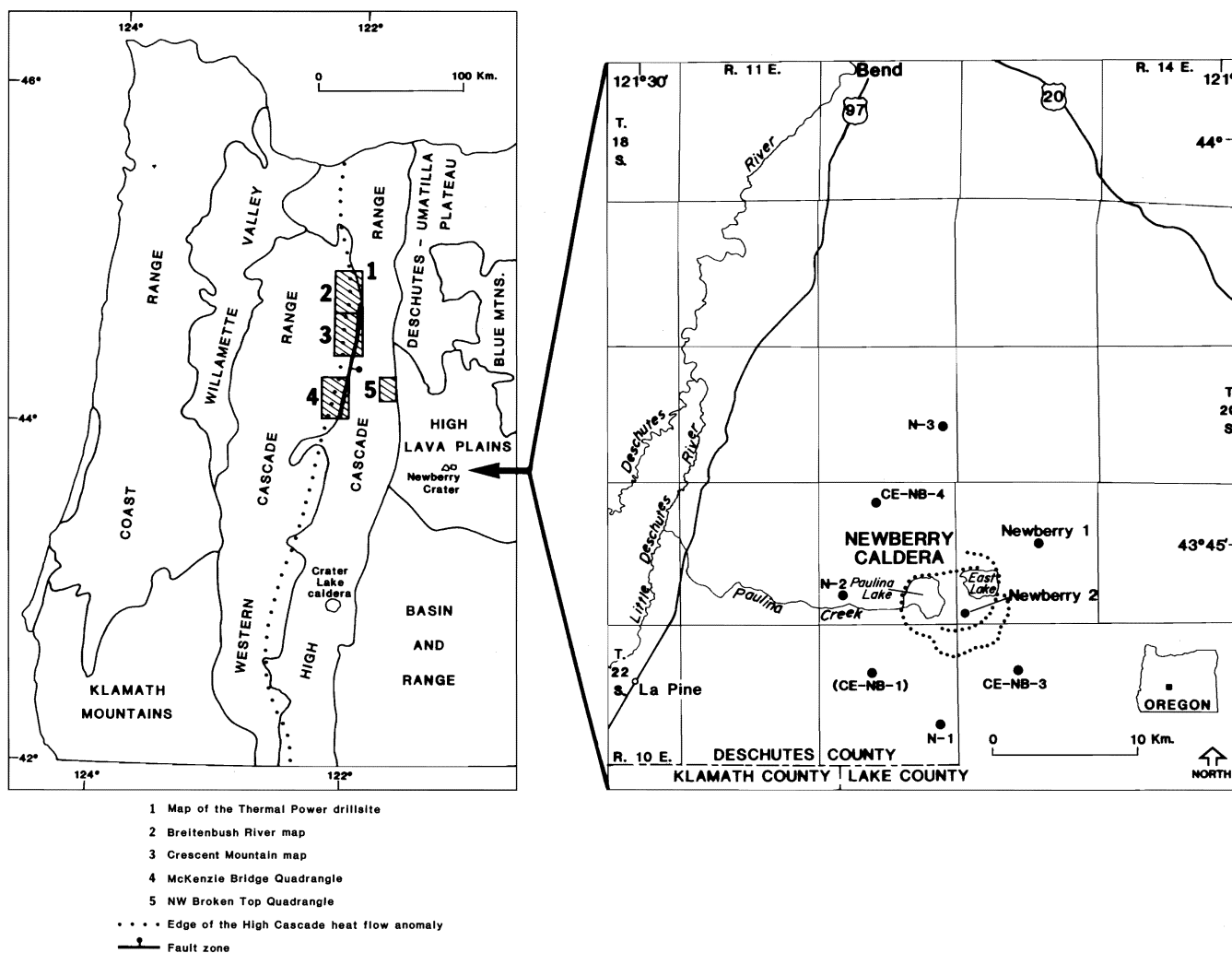


Figure 2. Physiographic provinces of western Oregon (after Dicken, 1950), showing areas of DOGAMI-supported geologic mapping and locations of recently drilled temperature-gradient holes. Also shown is the edge of the High Cascade heat-flow anomaly from Black and others (1983).

focus was partly responsible for the drilling activity in the High Cascades and at Newberry volcano. Temperature-gradient holes were drilled on the flanks of Mount Mazama (Crater Lake area), Newberry volcano (Paulina Lake area), and northwest of Mount Jefferson (Table 1; Figure 2).

Most holes were drilled by diamond coring, continuing a trend established in previous years. The diamond core technique allows the operators to drill through zones of lost circulation that are common in the highly fractured young volcanic rocks of the High Cascades.

The target depth of most of the temperature-gradient holes is about 1.2 km, although the hole drilled by Thermal Power Company northwest of Mount Jefferson was permitted to 1.52 km and drilled to 1.46 km (Table 1). No permits for prospect holes (holes less than 610 m) were issued (Figure 3). The prevailing perception of the industry is that drilling to a depth of about 1.2 km is necessary in order to guarantee that the holes will penetrate the so-called "rain curtain" effect that masks deep heat flow in the High Cascades and Newberry volcano. Temperature-gradient data from many of the holes suggest that drilling to somewhat shallower depths may effectively penetrate the "rain curtain" in most areas (see discussion of the temperature-gradient data below).

### Leasing

The total leased acreage of federal lands decreased only about 4 percent in 1986 (Table 2; Figure 4). This slight decrease in leased lands was the result of a 58-percent decline in USBLM non-competitive leases coupled with a 3-percent rise in USFS non-competitive leases (Table 2). Overall, the amount of leased federal lands seems to have begun to stabilize, although the shift of land positions from the southeast Oregon USBLM lands to the Cascade lands of the USFS is continuing. A continuing slight decrease in leased lands is expected as companies explore and consolidate their land holdings. A major discovery in a new area could easily change this picture, however.

### KGRA SALES

No Known Geothermal Resource Area (KGRA) lands were offered for bid in 1986.

### DIRECT-USE PROJECTS

Direct use of geothermal fluids continued to expand slowly in 1986, and more expansion is expected in 1987. Most of the activity is occurring in the Klamath Falls area, La Grande, Lakeview, and Vale.

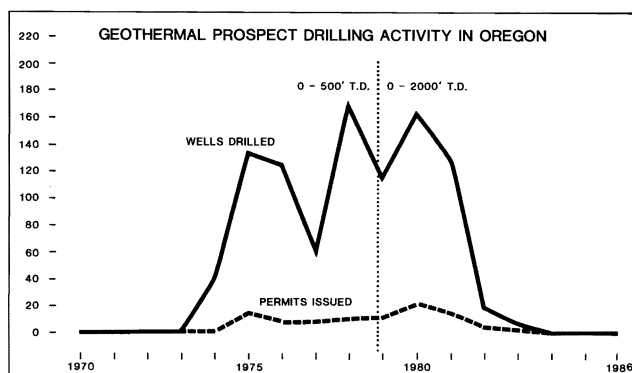


Figure 3. Geothermal prospect-well drilling in Oregon. Vertical line indicates time when definition of prospect well was changed to a depth of less than 610 m (2,000 ft).

Oregon Trail Mushroom Company, a new \$8.5-million fresh-pack operation, utilizes a 107 °C aquifer at Vale for heating and cooling. Geothermal heat is used to maintain a constant temperature for various processes in the 16,728-m<sup>2</sup> facility. The operation employs about 100 people and produces 2.3 million kg of mushrooms per year. Other users at Vale are Ag-Dryers (a grain-drying facility), Hawley Meat Packing (slaughterhouse heating and washing), and a greenhouse operation. More information on this area is given below in the section on activities of the Oregon Water Resources Department (OWRD).

Klamath Falls is pursuing expansion of its district heating project. Whereas the downtown loop is temporarily shut down because of pipe leakage, a new heating loop was added to heat local residences in the Michigan Street area (Kent Colahan, personal communication, 1987). Construction of the new loop was supported by a \$600,000 grant from the U.S. Department of Housing and Urban Development. The same resource is used by the Oregon Institute of Technology (OIT) to heat the campus, although, unlike the City, which reinjects spent fluids, the OIT system discharges to the surface.

Olene Gap, a thermal area east of Klamath Falls, has been the focus of efforts by Trendwest Company to develop a geothermal industrial park. According to an article in the November 12, 1986, Klamath Falls *Herald and News*, Trendwest drilled a test hole to 183 m and encountered a 38,000-lpm aquifer at about 22 °C. The company intended to drill to about 760-910 m but became discouraged when the aquifer was encountered. Bob Kent of Trendwest Company was quoted as stating, "We hit upon a source of water that is so large, it might make it difficult to bring up [hot water] at that location." The article goes on to indicate that Trendwest has been contacted by aquaculture firms interested in utilizing the 22 °C

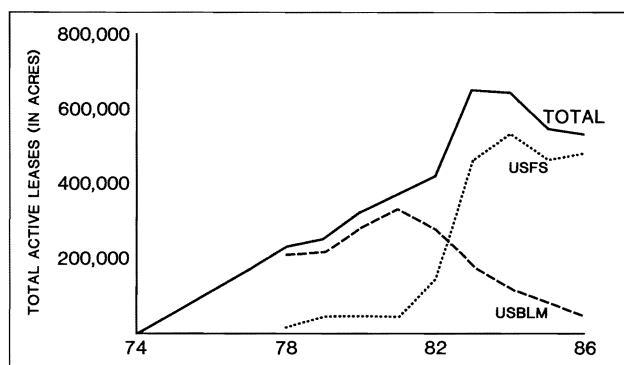


Figure 4. Active geothermal leases on federal lands in Oregon from the inception of leasing in 1974 through December of 1986.

Table 2. Geothermal leases in Oregon in 1986

Types of leases	Numbers	Acres
Federal active leases:		
Noncompetitive, USBLM	22	25,106
Noncompetitive, USFS	256	475,361
KGRA, USBLM	12	26,000
KGRA, USFS	1	360
Changes during 1986:		
Total 1-1-86	294	545,916
Noncompetitive, USBLM	-19	-33,921 (-58%)
Noncompetitive, USFS	+14	+13,935 (+3%)
KGRA, USBLM	+3	+1,938 (+8%)
KGRA, USFS	-1	-1,040 (-74%)
Subtotal	-3	-19,088 (-4%)
Total 12-31-86	291	526,828
Federal leases relinquished:		
Noncompetitive, USBLM	244	381,052
Noncompetitive, USFS	78	175,708
Competitive, USBLM	50	92,308
Competitive, USFS	7	11,565
Federal leases pending:		
Noncompetitive, USBLM	0	0
Noncompetitive, USFS	110	No data
State leases:		
Total active in 1986	No data	No data
Applications pending in 1986	No data	No data
Private leases:		
Total active in 1986	No data	No data

aquifer to raise channel catfish. Exploration will reportedly continue in the area.

No significant geothermal development has occurred recently in Lakeview. The binary cycle electrical generating station set up several years ago remains idle primarily due to economic considerations and low energy demand. Geothermal heat is used at Lakeview by the Greenhouse, a local company, to maintain optimum growing conditions. Geothermal heat is also used to heat residences in a local subdivision and for the municipal pool.

## DOGAMI ACTIVITIES

Oregon Department of Geology and Mineral Industries (DOGAMI) geologists completed field mapping of the McKenzie Bridge 15-minute quadrangle during 1986. Belknap, Foley, Terwilliger, and several unnamed hot springs occur in the area, which encompasses the transition zone between the High Cascades and Western Cascades near South Sister (Figure 2). The map is still being compiled and will not be published until late in 1987 or early 1988.

Two geologic maps, each encompassing the area of a standard 15-minute quadrangle, are scheduled for publication in 1987. These maps cover the transition zone between the High Cascades and Western Cascades from about Breitenbush Hot Springs to just south of the junction of Highways 126 and 20 (Figure 2).

The geologic mapping, which was completed with USDOE support, was aimed at defining the geologic context of major hydrothermal systems in the Cascade Range. The maps delineate a major zone of faulting that starts near the elbow of the North Santiam River and continues south to headwaters of Horse Creek in the McKenzie Bridge quadrangle (Priest and others, 1987b; Black and others, 1987) (Figure 2). The Western Cascades are uplifted relative to the High Cascades at this faulted boundary (Taylor, 1980; Brown and others, 1980; Priest and others, 1982, 1983). Belknap Hot Springs and adjacent unnamed hot springs are on this fault zone (Brown and others,

1980). No major fault has been mapped through Breitenbush Hot Springs. Thermal fluids in the Breitenbush area probably ascend from southeast of the hot springs within a series of gently dipping quartz-bearing ash flows of the Breitenbush Tuff (Priest and others, 1987a,b).

The Department received a grant from USDOE to do a geologic study of the previously mentioned Thermal Power drill hole. Lithologic correlation between the drill core and adjacent areas will be accomplished by (1) geologic mapping of 39 km<sup>2</sup> around the site, and (2) analysis of core from the hole and cuttings from nearby drill holes. Terry Keith and Keith Bargar of the U.S. Geological Survey (USGS) will do complementary studies of the hydrothermal alteration. Temperature and heat-flow data will be analyzed by David D. Blackwell of Southern Methodist University. An open-file report that synthesizes the data in terms of a geothermal model for the Breitenbush-Olallie Butte area will eventually be published.

#### RELEVANT RESEARCH BY OSU

Edward M. Taylor of Oregon State University (OSU) aided DOGAMI staff in mapping the McKenzie Bridge quadrangle. Taylor has also completed a paper on the geology of the northwest quarter of the Broken Top quadrangle. The paper will be published later in 1987 as a DOGAMI special paper and will contain a folded geologic map at a scale of 1:24,000.

Brittain Hill, a doctoral candidate at OSU, is extending his work on the Quaternary ash flows in the Bend area (Hill, 1985). He has acquired new data that support venting of the ash flows from the highland of silicic volcanic rocks west of Bend. His dissertation will be a unique study of the characteristics of small-scale pyroclastic eruptions. The geothermal implications of his work and of research by the USGS in the same area are discussed below.

#### ACTIVITIES OF THE U OF O

Workers at the University of Oregon (U of O) completed magnetotelluric surveys at Newberry volcano and in the central Oregon Cascade Range. The results were reported at the 1986 American Geophysical Union conference in San Francisco (Urquhart and others, 1986; Rygh and others, 1986). The survey at Newberry found a pervasive conductor at a depth of about 1 km (Urquhart and others, 1986). The survey in the central Cascade Range found a pervasive midcrustal conductor under the High Cascades and evidence in support of a graben structure that affects both the High Cascades and adjacent Western Cascades (Rygh and others, 1986). This inferred graben appears to be the same structure that has been interpreted from gravity data and referred to as the "Cascade graben" by Couch and Foote (1983).

#### USGS ACTIVITIES

David Sherrod of the Menlo Park USGS office completed reconnaissance mapping in several areas of the Cascade Range. This work is being done in part to contribute to a project headed by James G. Smith of the USGS aimed at producing geologic maps of the entire Cascade Range in the United States. Compilation of a 1:500,000-scale map of the Oregon part of the range will be one of the map products. Currently completed but unpublished maps by Sherrod include the following:

1. Mount Hood area:
  - a) High Rock 15-minute quadrangle.
  - b) Mount Wilson 15-minute quadrangle.
  - c) 1:50,000-scale composite map composed of the Flag Point, Fivemile Butte, Friend, and Wolf Run 7.5-minute sheets.
  - d) Bonneville Dam 15-minute quadrangle.
  - e) Part of the Hood River 15-minute quadrangle.
2. Breitenbush Hot Springs 15-minute quadrangle (coauthored with Richard Conrey).
3. West half of the Crescent 1° by 2° sheet (coauthored with Norman MacLeod).

4. West half of the Klamath Falls 1° by 2° sheet (coauthored with Norman MacLeod).

George W. Walker and coauthor Norman S. MacLeod have completed their several-year compilation geologic map of the state of Oregon (scale 1:500,000). Work is also underway on a map of the Salem 1° by 2° sheet.

These USGS maps are not yet available, although the mapping in the southern Cascade Range of Oregon is shown in Sherrod's dissertation (Sherrod, 1986). This thesis is a major contribution to the geology of the southern half of the High Cascades and adjacent parts of the Western Cascades. It contains a particularly informative discussion of uplift in the Western Cascades.

Terry E.C. Keith and Keith Bargar continued to pursue hydrothermal alteration studies of holes drilled under the USDOE cost-share program. This work is not complete as yet.

Andre M. Sarna-Wojcicki published a summary of tephra correlation studies that are relevant to the geothermal potential of the Cascades in the Three Sisters-Bend area (Sarna-Wojcicki and others, 1987). The geothermal implications of these data are discussed below.

#### ACTIVITIES OF OWRD

The Ground Water Division of the Oregon Water Resources Department (OWRD) has a Low-Temperature Geothermal Program consisting of two major parts. The first part is a state-wide network of thermal wells and springs where water levels, flow rates, temperatures, and some chemical parameters are measured with a frequency ranging from quarterly to biennially, depending on location. The main purposes for this activity are to monitor the condition of developed resources and to collect baseline data in undeveloped areas. Data collection is focused primarily in areas that have undergone development or that exhibit significant development potential. The observation network includes Klamath Falls, Vale, Lakeview, Olene Gap, the Western Cascade hot springs, the Harney Basin, and the Grande Ronde Valley. An additional area of activity is downtown Portland, where nonthermal water is heavily utilized for the purpose of heating and cooling office buildings.

The second major part of the program is aquifer characterization. This consists of intensive study of individual areas to determine the extent, thickness, hydraulic characteristics, and recharge and discharge rates of the known geothermal aquifers. These studies take at least two years to conduct and typically involve evaluation of geologic, geochemical, geophysical, and hydrologic aspects of the ground-water system. The ultimate purpose of such investigations is to determine as closely as possible the maximum sustainable production capacity of the system and to recommend some management scheme.

OWRD is currently studying the known geothermal area at Vale. To date, the Vale project has included quarterly monitoring of water levels, temperature/depth logging of all wells in the hot-well area (to determine total heat flux and discriminate individual aquifers) with regular, periodic relogging of key wells, geologic reconnaissance, and field checking of published geologic mapping. In addition, OWRD has conducted preliminary sampling and analysis of chloride in the Malheur River area to evaluate the feasibility of calculating the total geothermal discharge in the area through chloride flux measurements.

Future OWRD work includes stream-temperature studies, well-location surveys and leveling, analysis of drill cuttings from wells (if available), and pumping tests.

The area at Vale known to be underlain by hot aquifers at shallow depths is quite small, probably less than 40 acres. However, this flux of 107 °C water represents a significant amount of energy and is important to the local economy. There has been fairly rapid development of this resource in the last five years, including the construction of the previously mentioned mushroom growing plant, and additional development is planned.

The two other major low-temperature geothermal areas in



Oregon are Klamath Falls and Lakeview. The Klamath Falls geothermal system is the largest known and most highly developed low-temperature geothermal resource area in the state and is utilized for domestic, commercial, and institutional space and water heating, as well as for industrial applications. OWRD data indicate that water levels in the Klamath Falls geothermal reservoir have exhibited a modest decline of about 0.3 m per year for the last decade. Investigations by the City of Klamath Falls suggest that this loss in pressure is attributed to the withdrawal of geothermal water without reinjection, with peak withdrawals estimated at about 3,000 gallons per minute. In 1985, to mitigate this decline, the City of Klamath Falls adopted a Geothermal Management Act that requires reinjection of all geothermal effluent by 1990 (with special exceptions). A fairly major aquifer characterization project and extensive aquifer test were completed in 1984 by the USGS and Lawrence Berkeley Laboratories. OWRD has no active research ongoing in the area, and the agency's activities there are limited to semiannual water-level measurements in about 20 wells, tracking of development, evaluation of individual injection proposals (in cooperation with the Department of Environmental Quality), and participation on the local Geothermal Advisory Committee.

### ACTIVITIES OF ODOE

In 1986, geothermal activities of the Oregon Department of Energy (ODOE) focused on research and support for other agencies. ODOE performed economic research into new geothermal power plants. This work was done cooperatively with the Washington State Energy Office for the Bonneville Power Administration (BPA). For another section of BPA, ODOE also provided information on specific steps to take toward geothermal resource confirmation. Direct-use research into district heating was expanded to include all energy sources. That work resulted in a published paper (Siford, 1986) and another to be published by ODOE in 1987.

ODOE continues to respond to inquiries on geothermal energy development from the public. Over 100 such responses were provided in 1986. ODOE also certifies geothermal tax credits. Eighty residential and seven business tax credits were certified in 1986. ODOE continues to provide leadership in the Pacific Northwest Section of the Geothermal Resources Council (GRC). Finally, ODOE reviewed and commented on the geothermal energy aspects of several National Forest Draft Management Plans.

### ACTIONS OF REGULATORY AGENCIES CONCERNING GEOTHERMAL EXPLORATION

California Energy Company stopped drilling on its MZI-IIA hole on the southeast flank of Mount Mazama, because it could not meet the requirements stipulated in the Environmental Assessment (EA) for the Mount Mazama area that have been interpreted to prohibit drilling without circulation. California Energy Company contends that it is not technically feasible to maintain circulation in the hole, given the frequency of lost circulation zones in typical hydrothermal systems. The company requested two changes in stipulations to the EA: (1) that they be allowed to drill without circulation, and (2) that the maximum allowed depth of drilling be extended from 1.2 km to 1.7 km. All potential environmental effects of these proposed amendments to the EA are now being evaluated by USBLM. Edward Sammel (USGS, retired) and Sally Benson (Lawrence Berkeley Laboratory) are collaborating on a study of the ground-water flow system in the vicinity of Crater Lake and the potential effects of introducing drilling mud into this flow system. Sammel is a contractor to USBLM, whereas Benson's work is funded primarily through USDOE. Dennis Simontacchi of USBLM estimates that the environmental review will be complete by the end of April 1987. Proposed amendments will then be available for public comment for 30 days. It is conceivable that an amended EA could be finalized by early June 1987. There would then be a 30-day period for appeals.

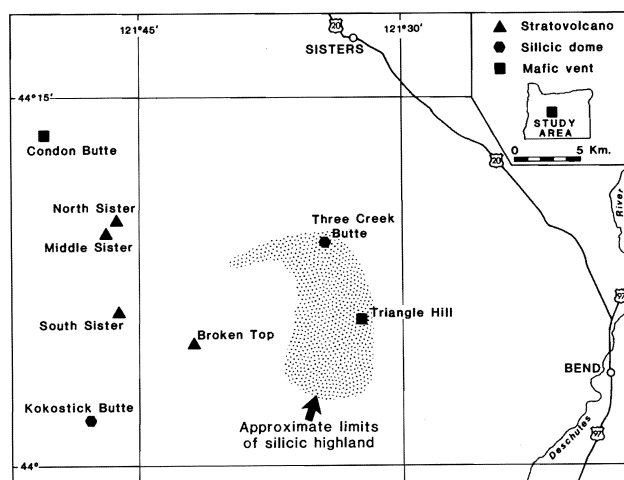


Figure 5. Index map showing the locations of the silicic highland west of Bend relative to various volcanic centers (taken from an unpublished 1987 figure by Brittain Hill, Oregon State University).

The USBLM, in response to an October 15, 1986, Act of Congress, suspended geothermal leasing on federal lands (see Section 115 (2)(a) of the October 15, 1986, *Congressional Record*). The act gave the Secretary of the Interior 120 days to publish a proposed list of "significant thermal features" in the National Park System. After publication of the proposed list, the Secretary was given 60 days to evaluate public comment and send the final list to the Committee on Energy and Natural Resources of the Senate and Committee on Interior and Insular Affairs of the House of Representatives. The proposed list was published on February 13, 1987; the final list is to be sent to Congress in the near future.

The proposed list contained references to the heat-flow anomalies found by the USGS on the floor of Crater Lake (Williams and Von Herzen, 1983). The Department of the Interior is now deciding whether these heat-flow anomalies qualify as "significant thermal features" under the guidelines of the Congressional act.

### SILICIC HIGHLAND WEST OF BEND—NEW DATA ON THE GEOTHERMAL POTENTIAL

New isotopic age data on an ash-flow/air-fall eruptive sequence near Bend suggest that local pyroclastic rocks are much younger than previously supposed. Four new K-Ar analyses from the Tumalo tuff, a rhyodacite ash-flow tuff that crops out west of Bend, yielded an average weighted age of  $0.29 \pm 0.12$  million years (Ma) (A.M. Sarna-Wojcicki and J.K. Nakata, unpublished data cited by Sarna-Wojcicki and others, 1987). Previous ages on this ash-flow and the cogenetic, compositionally identical Bend pumice ranged from  $0.83 \pm 1.5$  Ma (recalculated from Armstrong and others, 1975, by Fiebelkorn and others, 1983) to  $3.98 \pm 1.9$  m.y. (Fiebelkorn and others, 1983). The large analytical errors were the result of large amounts of atmospheric argon contamination in the samples. Reversely magnetized lava flows were thought to overlie the Tumalo tuff, leading previous workers to conclude that the Bend pumice and Tumalo tuff were older than about 0.9 Ma (Armstrong and others, 1975). However, Sarna-Wojcicki and others (1987) could not reproduce the reversed magnetization measurements.

The variation in grain size and distribution of the Tumalo tuff and Bend pumice suggest that they were probably erupted from a 24-km-wide highland of silicic lavas (Taylor, 1978) immediately west of Bend and east of the Three Sisters (Figure 5) (Hill, 1985). Three Creek Butte, one of the silicic domes on the eastern margin of this highland (Figure 5), has rhyodacite lava (74 percent  $\text{SiO}_2$ ) so similar in composition to these two tuff units that it is probably from the same magma chamber (Hughes, 1983; Brittain Hill, in preparation).

Mimura and MacLeod (1978) and Mimura (1984) studied imbrication in the Tumalo Tuff and concluded that the ash flow had a source southwest of the Bend area and about 32 km south of the silicic highland. Hill (1985) pointed out that the data from this study are also consistent with a source on the silicic highland, provided the ash flow traveled in drainage systems similar to the present ones. The current drainage system would cause ash flows to flow northeast, giving an apparent southwesterly source, even for ash flows erupting from the east (Hill, 1985).

Silicic magmas generally reside at relatively shallow levels in the crust and are associated with much of the world's best geothermal resources (Smith and Shaw, 1973, 1975). Smith and Shaw (1973, 1975) suggest that not more than about 10 percent of a silicic magma chamber is erupted during one pyroclastic eruption. The size of the Bend pumice-Tumalo tuff eruption is thought to be greater than 10 km<sup>3</sup> (Hill, in preparation), so a silicic magma chamber greater than 90 km<sup>3</sup> probably existed under the silicic highland about 300,000 years ago. Significant magma chambers and geothermal systems appear to be present in silicic volcanic centers with similar or greater age. Examples are Yellowstone Park, Long Valley caldera, and Valles caldera. Therefore it is likely that similar chambers and geothermal systems still exist under the silicic highland.

#### ENCOURAGING TEMPERATURES AT MOUNT MAZAMA—NEW TEMPERATURE-DEPTH DATA FROM THE USDOE-INDUSTRY DRILLING PROGRAM

USDOE has sponsored geothermal assessment projects in and adjacent to the Cascade Range for the last 10 years. Efforts by the agency to provide reliable temperature-depth and heat-flow data in the High Cascades were generally defeated by the previously mentioned "rain curtain" effect. In 1985, the USDOE Division of Geothermal and Hydropower Technologies initiated the Cascade Deep Thermal Gradient Drilling Program aimed at penetrating the "rain curtain" by cost-sharing drill holes with industry. Temperature-depth curves for four of these drill holes are shown in Figure 6.

The MZI-11A hole, drilled by California Energy on the southeast flank of Mount Mazama, has an anomalously high temperature of 107.1 °C at a depth of only 405 m (Joseph La Fleur, written communication, 1987). The lowest 20 m of the hole had a gradient of about 372 °C/km, well above regional background gradients (Figure 6). Such high temperatures and gradients are evidence that the heat flow at this site has been raised above background by magmatic intrusion and/or upward convection of thermal fluids. This is very encouraging for the geothermal resource potential of the Mount Mazama area.

Three of the holes in Figure 6 have temperature gradients of 74–83 °C/km in the lower, relatively linear part of the curves. These values are typical of areas with normal background heat flow in the regional heat flow high associated with the High Cascades (e.g., see Black and others, 1983; Blackwell and others, 1978). Two of these holes have temperature-depth curves with isothermal zones bounded by gradients that are nearly horizontal (Figure 6). Curves with this shape are generally produced by movement of fluid that disturbs the normal conductive temperature gradient. Fluids in aquifers encountered by the borehole can move laterally across the hole or vertically within the hole. In the latter case, two scenarios are possible: (1) cool aquifers can sink into warmer fluid in the hole, lowering temperatures to the value of the cool aquifer, or (2) fluid from warm aquifers can rise, raising temperatures to the value of the warm aquifer. In each case the part of the hole disturbed by intra-borehole circulation will be nearly perfectly isothermal. The temperature-depth curve at intermediate depths in Geo Operator N-1 looks like case 1, whereas the curve at similar depths in Geo Operator N-3 looks like case 2. If the aquifers in each hole were cased off, the temperature gradients in both would probably be relatively linear below depths of about 400–500 m. Above those depths, the so-called

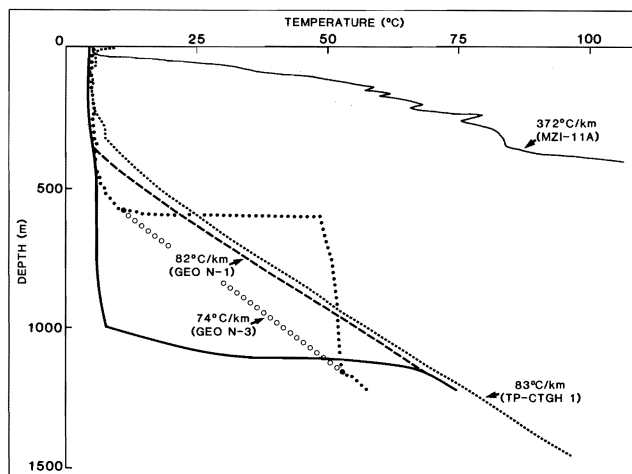


Figure 6. Temperature-depth curves of holes from the USDOE Cascade Deep Thermal Gradient Drilling Program. Dashed lines show the temperature-depth curves as they would be were they not affected by inferred intra-borehole fluid circulation. Inferred temperature gradients are shown in degrees Centigrade per kilometer. Temperature data in hole MZI-11A were taken only 20 hours after circulation of drilling fluids, so hole temperatures had probably not completely stabilized. Temperatures for MZI-11A were measured by Al Waibel of Columbia Geoscience; other measurements are by David D. Blackwell of Southern Methodist University. See Table 1 and Figure 2 for drill-hole locations.

"rain curtain" effect disturbs the heat flow, producing erratic, low temperatures in both Geo Operator N-1 and Geo Operator N-3 (Figure 6). In a hole such as Thermal Power CTGH1, where no significant aquifers were encountered at depth (Joseph Iovenitti, personal communication, 1986), a relatively linear gradient occurs below the shallow (300-m depth) flows of cold ground water. These observations suggest that the "rain curtain" at all of these drill sites extends only to depths of about 300–500 m. Valid temperature gradients could therefore have been found by drilling to only about 650 m. Whether these conclusions can be widely applied to other parts of the Cascades cannot be determined until the geologic and hydrologic context of each hole is studied in more detail.

#### ACKNOWLEDGMENTS

This paper could not have been written without the cooperation of numerous individuals in government and industry. The writers are indebted to Brittain Hill of OSU for sharing his unpublished research on the Quaternary volcanic stratigraphy in the Bend area. David Sherrod of the USGS provided a detailed summary of his many mapping projects. Dennis Simontacchi and Jack Feuer of USBLM shared their information on regulatory issues. Jacki Clark of USBLM provided the federal leasing data. Dennis Olmstead and Dan Wermiel of DOGAMI provided the data on drilling permits. Local residents and city officials at Vale, Lakeview, and Klamath Falls provided current information concerning direct-use projects.

The USDOE Cascade Deep Thermal Gradient Drilling Program is responsible for putting invaluable data in the public domain. The temperature and the lithologic information from the program have greatly increased our understanding of both the geology and geothermal resource potential of Newberry volcano and the High Cascades. Michael Wright of the University of Utah Research Institute helped coordinate the release of the temperatures and other data from the program. Joseph La Fleur of California Energy Company sent copies of his temperature data on hole MZI-11A for public release.



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## Bob Bates re-opens Pandora's Bauxite

Bob Bates, Professor Emeritus of Geology at Ohio State University and author of "The Geologic Column" in *Geotimes*, is the author of *Pandora's Bauxite — The Best of Bates: Selections from the Geologic Column, 1966-1985*, recently published by the American Geological Institute (AGI). Bates has had much to say over the years about the "use and abuse of the language" — particularly when it comes to geology, and this book contains some of his choicest columns. As Bates says:

"My purpose ... has been to choose material that will be of interest and amusement to nongeologists as well as to specialists in the various fields of earth science. The items range in length from a line or two to a page or two; people with a short attention span should feel at home. Those who consider the geological sciences sacred and immune to humor will be happier reading the IUGS classification of igneous rocks or the Stratigraphic Code."

However, if you are interested in such subjects as "The Pterosaur of Ptexas"; "Melanopyxilation" (the study of black boxes); "Wor-dbreaks: bluep-rint for mans-laughter"; "Fiscal obfuscation"; "The unauthorized glossary of geology"; "Abandon *hopefully*, all ye who enter here"; "At the Lulu mine" (a lulu is a three-word expression with an adjective, two nouns, and no hyphens, producing such results as "unexploded bomb expert," "buried pipeline designer," "edible oil refinery," or "waterlogged wood experts"); "Obtaining the unobtainium;" or "The boola-boola concept," you find that this book is a joy to read.

Bates tells about the California dam protected by "heavy riffraff" and the Hari Krishna temple in West Virginia with water faucets made of "an opalescent pink marble called rose quartz." He reveals little-known facts such as the 1881 oil test in Franklin, Pennsylvania, that inadvertently drilled into the underground storage tanks of a brewery, making it the nation's first beer well. When a mine near one of the Great Lakes sprang a leak and water with large numbers of fish entered the mine, Bates explains that the mine workings intersected a "perched water table."

Bates loves puns. For example, a "sinter" is a position played by the tallest person on a southern basketball team, "forsterite" is said of a graduate student grinding out his thesis, or a "harpolith" is a rock with ripple marx. He coins new mineral names such as

(Continued on page 74, *Pandora's Bauxite*)

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## ABSTRACTS

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*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.*

### THE GEOLOGY AND GEOCHEMISTRY OF THIRTEEN CINDER CONES AT CRATER LAKE NATIONAL PARK, OREGON, by Elizabeth M. Prueher (M.S., University of Oregon, 1985)

Major- and trace-element variations exhibit an increase in excluded elements and a decrease in included elements as differentiation increases, indicative of crystal fractionation of olivine, clinopyroxene, orthopyroxene, and plagioclase.

LREE patterns for the rocks are irregular. First, basalt is enriched in LREE relative to other members of the suite. Second, there is a repeated pattern of three pairs of basalt and andesite, with each successive basalt enriched in LREE relative to the preceding andesite. From consideration of the REE data, it is apparent that the cinder cones were derived from more than one partial melt.

Compositional variations in the magmas of the cinder cones support the conclusion that they were generated by more than one partial melting event. Partial melting of a mantle source region with the composition of peridotite could have produced primitive basaltic magmas. Subsequent mixing and fractional crystallization produced the more differentiated basaltic to andesitic magmas.

### BIOSTRATIGRAPHY OF THE COWLITZ FORMATION IN THE UPPER NEHALEM RIVER BASIN, NORTHWEST OREGON, by Neil B. Shaw (M.S., Portland State University, 1986)

Examination of stream and roadcut exposures of the Cowlitz Formation allows the selection of measured representative sections and collection of fossils from an area roughly defined by the intersection of the boundaries of Clatsop, Columbia, Tillamook, and Washington Counties in Oregon. The study defines the features of the local environment of deposition, correlates sections to derive a composite columnar section, and develops a checklist of species for both microfossils and megafossils of the Cowlitz Formation.

A composite columnar section of 720 m based on three stream sections and one roadcut section is presented. Twenty-two selected samples yielded fossil assemblages that included a total of forty-seven species of foraminifera, twenty-seven species of macrofossils, and a small number of terrestrial plant fossils and trace fossils.

Paleoecologically diagnostic species and assemblages indicate that the features of the environment of deposition varied. Water depth varied from upper bathyal or outer neritic in the lower Cowlitz Formation to possibly inner neritic during deposition of the upper Cowlitz sands. Cool bottom temperatures and probably warm, stratified surface waters are also indicated.

The integration of paleontological and sedimentary structural evidence has resulted in several models proposed for the environment of deposition of the Cowlitz Formation. A comparison of these models is made.

The composite section is assigned to the Narizian foraminiferal stage of Mallory. Only one zone, the *Plectofrondicularia* P. *jenkinsi* zone of Rau, is recognized. It is represented by two faunules, the *Plectofrondicularia-Lenticulina* (lower) faunule and the *Cibicides-Lenticulina* (upper) faunule. A narrow overlap of

the teilzones of *Cyclammina pacifica* Beck and *Lenticulina texanus* (Cushman and Applin) permits local correlation.

One measured section, the Sunset Camp section, was continued across the Cowlitz-Keasey contact in order to achieve stratigraphic control. The Narizian-Refugian stage boundary appears to be coincident with this contact in this section. The fossils recovered from the Keasey Formation above the Cowlitz-Keasey contact were assigned to the *Sigmorphina schenki* Zone of Rau. This contact is gradational and poorly defined. A marked reduction in mica characterizes Keasey rocks as well as the disappearance of the foraminiferal species *Cibicides natlandi* Beck, the occurrence of which is considered here to be diagnostic for the Cowlitz Formation.

The Cowlitz Formation in the study area can be correlated with the type Cowlitz Formation in southwest Washington; the Spencer Formation, Yamhill, the Nestucca and the Coaledo Formations of Oregon; the McIntosh Formation of Washington; and the Tejon Formation of California. □

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## Geographers write book about Portland

Approximately 2,600 geographers from all over the country assembled in Portland this April for the 83rd Annual Meeting of the Association of American Geographers. As part of the event, the local hosts, the Portland State University (PSU) Department of Geography, prepared and published a collection of essays on different aspects of Portland. Entitled *Portland's Changing Landscape* and edited by Larry W. Price of the PSU Geography Department, this book contains 13 essays by various authors from PSU, other universities, and the community.

This 220-page book begins appropriately enough with a chapter by Price on Portland's landscape, which is of course determined by the local geology. Price describes the geologic units found in the Portland area, including basalt of the Columbia River Basalt Group, Troutdale Formation, Boring Lava, and the Portland Hills Silt. He discusses the Missoula floods that inundated the Portland area several times about 13,000 years ago. Price notes that "...Portland has been the scene of what are among the largest lava and water floods on the face of the earth."

Succeeding chapters are concerned with other aspects of Portland, such as climate and weather, the riverscape, downtown Portland, neighborhoods, shaping and managing Portland's metropolitan development, transportation, economy, the Port of Portland, the Silicon Forest, and livability. Geologists will note how many of these subjects are influenced by local geology.

Change is the theme of many of the essays—whether it be change in geology, topography, the character of the city and rivers, or human activities. By bringing in a historical perspective and then examining the current status of these various aspects of Portland, the authors are able to present the city in a multidimensional way, "summing up, taking stock of where we have been and where we are going."

*Portland's Changing Landscape* is available at selected local bookstores. It may also be purchased directly from the Department of Geography, Portland State University, Portland, OR 97207, phone (503) 229-3916. The purchase price is \$11.95. □

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### *(Pandora's Bauxite, continued from page 73)*

the Central America copper mineral guatemalachite, the gangue mineral umbilicalcordierite found only in the mother lode, or the Turkish semiprecious stone constantinopal.

This 88-page book is not available in the Oregon Department of Geology and Mineral Industries library. A personally owned copy is floating around the Department but will be hard to find. Copies may be purchased, however, for \$7.95 from AGI, 4220 King Street, Alexandria, VA 22302. Orders must be prepaid. □

## AVAILABLE DEPARTMENT PUBLICATIONS

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