OREGON GEOLOGY

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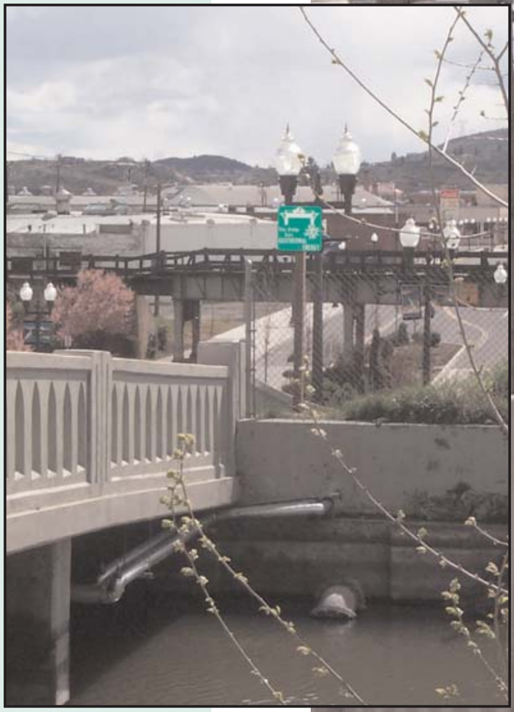

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On the Cover

In Klamath Falls, the Esplanade Bridge over the "A" Canal uses a geothermal heating system for pavement de-icing. The geothermal heating system keeps the bridge deck relatively snow free even when outside temperatures drop to -10ºF and a snowfall up to 3 inches per hour. Several government, commercial, and educational buildings in Klamath Falls also use geothermal energy for heating, as do hundreds of private homes. Photos by Margi Jenks.

Oregon Geology (ISSN 0164-3304) is published in Spring and Fall by the Oregon Department of Geology and Mineral Industries on its web site http://oregongeology.com. (Volumes 1 through 40 were entitled *The Ore Bin*.)

Introduction

BY VICKI S. MCCONNELL, DEPUTY STATE GEOLOGIST
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Geothermal energy is "back on the radar screens" as a viable energy source. As a matter of fact, Oregon was one of the western states recently identified by the Bush Administration's alternate energy strategists as containing geothermal energy resources. This issue of Oregon Geology provides a compilation of nearly fifty reports that DOGAMI and others have prepared documenting Oregon's geothermal potential.

Oregon has the desirable distinction of being a state where geothermal resources are available in many areas. Our geothermal resources are suitable for many different types of uses but are commonly divided into two categories: high and low temperature. High temperature resources (>150° C) are suitable for electrical generation with conventional cycles (steam), low temperature resources (<150° C) are employed for direct heat uses and electricity generation using a binary fluids cycle.

Right now in Oregon, lower temperature geothermal energy is used for space heating in several locations across the state. For example, the city of Klamath Falls, Klamath County, Oregon, began to tap into its geothermal energy in 1981. The city has since developed a heating district that supplies geothermal water for heating government and downtown buildings and road de-icing. Also, there are hundreds of geothermal wells in Klamath Falls equipped with downhole heat exchangers. These are used by single homes, shared by several homes, and provide heat to schools and apartment buildings.

Oregon does not generate commercial electricity from geothermal energy. The potential is there because of the geologic processes that formed the High Cascades. Active or recently active volcanoes, such as the Cascade volcanic chain, give off heat from cooling magma chambers. For example, we know from heat flow measurement studies of the ground in Oregon that high temperature gradients cover the full length of the Cascades. These thermal gradients, when projected to the usual geothermal well depth of 7,000-10,000 ft, indicate adequate heat for commercial power generation. We also know that there are a number of excellent targets for geothermal exploration in locations around the state outside of Wilderness Areas or the National Parks.

High heat flow also occurs in southeastern Oregon. There the geologic structure is considered part of the Basin and Range, a series of mountains and valleys stretching from New Mexico north. Water that circulates in the deep faults and fractures that make up the Basin and Range is heated up to temperatures that make it applicable for geothermal energy production.

Geothermal energy has a number of positive features making it competitive with conventional energy sources and some renewable sources. These features include:

- As a local energy source, it can reduce demand for imported fossil fuels.
- It has a large positive impact on the environment by displacing combustion of CO_2 and fossil fuels.
- It is efficient and competitive with conventional commercial power generation, in part by population distribution and because of recent energy price trends.
- Geothermal plants can operate continuously, without constraints imposed by weather conditions, unlike other renewable sources.
- It has an inherent storage capability and is best suited to base-load demand.
- It is a reliable and safe energy source, which does not require storage or transportation of fuels.

Learn more about DOGAMI's oil, gas, and geothermal program by logging on to: www.oregongeology.com

Geothermal Resource Publications of the Oregon Department of Geology and Mineral Industries

COMPILED BY JL CLARK

Oregon Department of Geology and Mineral Industries, 800 NE Oregon Street, #28, Portland OR 97232

Short annotations and summaries on the major findings of these publications are included. Please note that all time references in the summaries (for example, "This project will be completed soon") refer to the period of the original report.

Publications can be purchased from the department.

"On file" and "Out of print" publications can be inspected at the department library in Portland. We are in the process of scanning these publications, and they will be re-released on CDs as they become available. Check the website (www.oregongeology.com) for updates.

STATEWIDE

OPEN-FILE REPORT O-79-03 — **Chemical analyses of thermal springs and wells in Oregon, 1979**

by USGS and DOGAMI

171 p.

Chemical analyses contained in this report were derived from specific samples collected of water, condensate, or gas from thermal surface springs or wells in Oregon.

SPECIAL PAPER 4 — **Heat flow of Oregon, 1978**

by D.D. Blackwell, D.A. Hull, R.G. Bowen, and J.L. Steele

42 p.

1 pl., 1:1,000,000

An extensive new heat-flow and geothermal gradient data set for the State of Oregon is presented on a contour map of heat-flow at a scale of 1:1,000,000 and is summarized in several figures and tables. The 1:1,000,000-scale heat-flow map is contoured at 20 milliwatts per meter square (mW/m^2 [0.5 HFU]) intervals. Also presented are maps of heat-flow and temperature at depth of 1 km averaged for $1^o \times 1^o$ intervals. Histograms and averages of geothermal gradient and heat-flow for the State of Oregon and for the various physiographic province within Oregon are also included.

One group of provinces with the greatest potential for geothermal development occupies the southeastern third of the state and includes the High Lava Plains, Basin and Range, Owyhee Upland and Western Snake River Basin provinces. The mean heat-flow is 98.4 ± 3.8 mW/m^2 (2.34 ± 0.08 HFU) and the mean gradient is 89.1 ± 3.4^o C/km. These values are extremely high. In the past, extensive volcanism and tectonism characterized these provinces and now hydrothermal convection systems are common, resulting in a large scatter in the observed heat-flow values. Large scale crustal effects on the heat-flow are also observed. Because of the high geothermal gradient and high heat-flow, this area of the state probably has the greatest potential for geothermal development for both high and moderate temperature geothermal systems.

The fourth area of the state includes the High Cascades Range. Reliable heat-flow data are not available for the central and eastern parts of this

Issues of *Oregon Geology* also contain short articles, and news and statistics of pertinence to Oregon's geothermal resources. An index to geothermal articles and information in *Oregon Geology* can be found on page 26.

area of extensive young volcanism; however, heat-flow values along the northwestern boundary average 105.1 ± 8.5 mW/m^2 (2.51 ± 0.20 HFU) and the geothermal gradient averages 61.3 ± 3.4° C/km. More data are needed for the High Cascade Range in order to properly evaluate its heat-flow and geothermal potential. However, based on the heat-flow data along the northwestern boundary, the young volcanism, and the existence of many hot springs along the western boundary, the geothermal potential of this province is undoubtedly large.

The overall heat-flow pattern in the state consists of subnormal heat-flow values in the western one-third of the state separated from slightly high to very high heat-flow values in the eastern two-thirds of the state by the High Cascade Range. The pattern is related to the effect of Cenozoic plate tectonic activity in the Pacific Northwest and to subduction of the Juan de Fuca plate beneath the Pacific Northwest during the past few tens of millions of years.

MISCELLANEOUS PAPER 19 — Geothermal exploration studies in Oregon, 1977

by R.G. Bowen, D.D. Blackwell, and D.A. Hull

50 p.

This report presents a compendium of geothermal data. Geothermal gradients were measured in 86 predrilled holes. The data are divided into a group for the Western Snake River Basin and a group for the remainder of Oregon. In the Western Snake River Basin, 35 heat-flow values were obtained including five values from holes drilled for the study. Outside the Western Snake River Basin, 36 heat-flow values were obtained in 13 different areas. The data gathered so far have resulted in the identification of seven areas of anomalously high heat-flow.

The geothermal data indicates that the portion of Oregon within the Basin and Range physiographic province shares the high heat-flow characteristic of the region. The low thermal conductivity of the extensive lacustrine sedimentary deposits of the region causes the geothermal gradient to be higher than normal, the median being 88° C per km, with many readings above 100° C per km. This indicates that outside of recharge areas temperatures in the range of 75-150° C will be nearly ubiquitous at depths of 1 km (0.6 miles). If suitable traps and circulation systems are present, the area should be extremely favorable for the occurrence of higher temperature geothermal waters.

MISCELLANEOUS PAPER 18 — Proceedings, Citizens' Forum on Potential Future Energy Sources, 1975

by K. Dittmer, R. Foleen, E. Hewson, A. Meinel, M. Meinel, R. G. Bowen, J. Middleton, and A. Forney

62 p

Temperature increases with depth at an average rate of about 30° C/km (1.6° F/100 ft). This gives a lot of heat in storage, but because of its relatively low temperature it is quite diffuse and not very usable. But in possibly 10 percent of the land surface, the gradient is about 60° C/km (3.2° F/100 ft). It is believed that most of Oregon from the west edge of the High Cascades to the eastern border of the State falls within this zone, and it is here that our high-temperature geothermal resources lie. From our present state of knowledge, it seems reasonable to believe that within about 10 percent of the high-heat-flow zone, or 1 percent of the land surface of the earth, the geothermal gradient is in the neighborhood of 80° C/km (4.4° F/100 ft), and throughout eastern Oregon we have found many readings of this order or greater.

In Oregon, we have about 200 hot springs, or 1/6th of those known in the

United States, and in addition we have recent volcanism. This illustrates there is a great amount of heat underlying our State. It is reasonable to estimate that we could expect to find at least 20,000 Mwe of dry-steam geothermal energy in Oregon.

OPEN-FILE REPORT O-75-07 — **Geothermal studies and exploration in Oregon, 1975**

by R.G. Bowen, D.D. Blackwell, and D.A. Hull

65 p.

Included in the study are data from six monitor wells located in areas with differing geographic, geologic, and climatic conditions. Temperatures were recorded at depths ranging from 1 to 25 m for periods of time sufficiently long to show the patterns of seasonal variations. Graphs from these six locations show changes in temperature with depth and changes of temperature with time. A total of 140 shallow (3-8 m) holes were drilled to show the shallow-temperature field over an anomaly identified by deeper (62-152 m) drilling. Shallow-temperature conditions are also shown for several areas in southeastern Oregon. Eighty geothermal gradients were measured in pre-drilled holes. Thirty-one heat-flow determinations are reported, including those from five bore holes drilled as a part of the study. Geothermal data gathered has so far resulted in the identification of six areas of anomalously high heat-flow.

EASTERN OREGON

OPEN-FILE REPORT O-96-04 — **Geothermal resources of SE Oregon, 1996**

by I.P. Madin, M.L. Ferns, R. Langridge, A. Jellinek, K. Priebe

41 p.

Eleven areas were studied with indirect methods including satellite imagery and photogeologic mapping of faults. Success was limited. At best, these techniques can eliminate some areas, including Guano and Catlow.

The three areas which may have the greatest geothermal energy potential are Christmas Lake-Summer Lake, Antelope Valley, and Drewsey.

OPEN-FILE REPORT O-80-10 — **Alvord Desert area, 1980**

by N.V. Peterson and D.E. Brown

57 p.

2 maps, 1:250,000

This reconnaissance study of the Alvord Valley has defined two geothermal systems worthy of further investigation. Those are (1) the Mickey Hot Springs area in the northern end of the Valley, and (2) the Alvord-Hot Borax Lake area in the central and southern end of the Valley. Surface indications are that both of these areas have high estimated reservoir temperatures and may represent the surface manifestations of a system at depth which has temperatures high enough for direct utilization and possibly electrical power production.

OPEN-FILE REPORT O-80-09 — **Lakeview area, 1980**

by N.V. Peterson, D.E. Brown, and G.D. McLean

108 p.

2 maps, 1:62,500

The geothermal system at Lakeview has been used for heating, greenhouse therapeutics, and recreation since before the turn of the century. The resource for direct utilization appears to be of large enough volume and high enough temperature to warrant exploration by Northwest Geothermal Corporation for a local heating district. Active exploration and drilling is, at the writing of this report, ongoing. Understanding of the actual geothermal system is, however, at a low level of confidence.

OPEN-FILE REPORT O-80-07 **Southern Harney Basin, 1980**

by D.E. Brown, G.D. McLean, and G.L. Black

90 p.

8 maps, geologic maps 1:62,500

The reconnaissance study performed for the southern Harney Basin has tentatively identified two geothermal resource areas based on geology, geophysics, geochemistry, and sparse geothermal gradient data. They are (1) the area surrounding the town of Crane (Plate II) and (2) the area immediately surrounding Harney Lake (Plates I, III, and IV). Preliminary results indicate both of these areas may have reservoir temperatures in the moderate range of 100-150° C.

OPEN-FILE REPORT O-80-06 **Northern Harney Basin, 1980**

by D.E. Brown, G.D. McLean, and G.L. Black

52 p.

4 maps, geologic map 1:62,500

The reconnaissance study performed for the northern Harney Basin has tentatively defined two low-temperature resource areas within piping distance of Burns which merit further investigation. They are (1) the area near the Soldier Creek shear zone (Plate I) and (2) the area immediately south, west, and east of the city of Burns.

OPEN-FILE REPORT O-80-05 **Western Snake River plain, 1980**

by D.E. Brown, G.D. McLean, and G.L. Black

114 p.

4 maps, geologic maps 1:62,500

With its high population density and large agricultural industry the Western Snake River Plain is one of the most important moderate-temperature geothermal resource areas in Oregon. And, with the possibility of a high temperature component (over 150° C), it may prove to have electrical generation potential. At present the rate of geothermal activity in the area is high with a deep (3 km) hole just completed by Ore-Ida, Inc. in the Ontario area.

The rate of activity is high; however, in attempts to locate a resource for utilization, failure is more common than success, and with the high expense of drilling $15-30/ft., failures can be very costly. The reason for most exploration failures is poor understanding of the physical nature of the resource system.

OPEN-FILE REPORT O-80-04 **Craig Mountain-Cove area, 1980**

by D.E. Brown, G.L. Black, and G.D. McLean

68 p.

1 map, 1:250,000

The area with the greatest potential geothermal resource base is the Craig Mountain-Hot Lake fault zone and extensions of that zone to the north and south. The La Grande area may lie on an extension of that zone, but these data are inadequate to evaluate this possibility. Shallow (152 m) drill holes for this study were inadequate to evaluate heat-flow patterns which might show thermal waters beneath La Grande. Intermediate-depth (2,000 ft) wells should be drilled along extensions of the Craig Mountain fault and similar fault zones within the city of La Grande. Such wells should be drilled with techniques capable of overcoming caving and lost-circulation problems associated with loose basin sediments and shattered bedrock. Such techniques will inevitably lead to unusually high drilling costs, but are justified by the potential resources.

Direct utilization by La Grande of known resources at the Hot Lake should be investigated. The Hot Lake hot spring (measured temperature = 85° C; possible reservoir temperature = 100-125° C; flow = 1,700 gpm) lies only 11.7 km (7.3 mi) southeast of La Grande. Intermediate depth (2,000 ft) holes should be drilled around the Hot Lake springs to define the details of that geothermal system for siting of possible production wells. A detailed engineering study of the cost effectiveness of direct utilization of the resources at Hot Lake should be made to guide decisions on the viability of exploitation.

OPEN-FILE REPORT O-75-08

An estimate of SE Oregon's geothermal potential, 1975

by D.M. Fisher

9 p.

In the petroleum industry, estimates of oil reserves are based on the concepts of resource base, estimated s\reserves, and proven reserves. Estimates of geothermal reserves can also be viewed in terms of total amount of heat stored within a reasonable depth (resource base), amount of the resource which may be recoverable (estimated reserves), and actual measured energy to be derived from a reservoir (proven reserves). The following table illustrates the use of the concept for The Geysers, California and southeastern Oregon (Table 1).

Table 1: The Geysers, California and southeastern Oregon

Area	Resource Base[1]	Estimated Reserves
The Geysers	1.42 x 10^{18} BTU	
SE Oregon	6.59 x 10^{20} BTU 1.14 x 1014 bbls of oil	6.59 x 1015 BTU 1.14 x 109 bbls of oil

[1] Assuming a maximum temperature of 500º C in Oregon and at The Geysers, a minimum useable temperature of 90º C, density of 2.6 gm/cm3, specific heat of 0.25 cal/gmº C in Oregon and 0.2 at The Geysers, and a gradient of 100º C at The Geysers, with 80º C/km gradient in Oregon.

CASCADE RANGE/CENTRAL OREGON

OPEN-FILE REPORT O-94-07

Geothermal electrical power generation potential of Newberry volcano and Oregon Cascade Range and A summary of deep thermal data from Cascade Range and analysis of the "rain curtain" effect, 1994

by G.L. Black and D.D. Blackwell

131 p.

Thermal data in this report includes temperature-depth data from 17 wells; thermal conductivity measurements from 8 wells; and heat-flow values calculated for 5 wells.

Throughout most of the Cascade Range, exposure to temperatures of 30 to 50º C results in a drastic decrease in the permeability of the mafic volcanic rocks. The results in a predominance of conductive heat transfer over depths of at least hundreds of meters. The electricity resistivity generally decreases by a factor of 50 to 100 percent in association with the alteration. Therefore resistivity soundings can be a good indication of the depth required to drill a geothermal gradient test well to obtain useful thermal data.

OPEN-FILE REPORT O-92-03

Geology and geothermal resources of Santiam Pass area of Oregon Cascade Range, Deschutes, Jefferson, and Linn Counties, 1992

by B.E. Hill, *editor*

61 p.

1 map, 1:62,500

The 929-m-deep Santiam Pass well in its completed state is characterized by downflow of cold groundwater in the bore that prevents accurate determination of the true rock thermal conditions below 160 m depth. Average thermal conductivity of the 400 to 927 m interval is 1.66±0.07

W/m/K. The calculated gradients for the 410-718, 718-920, 912-928 and 919-928 m depth intervals are 16, 52, 115.8±0.9, and 103.6±23° C/km, respectively. The gradients in the first two intervals are based on the bottom-hole temperature data. The heat-flow values for the bottom three intervals of the well are 86, 175 and 204 mW/m^2 respectively. These values bracket the regional average for the High Cascades of 105±5 mW/m^2. The increase of heat-flow with depth is controlled by regional groundwater flow. The effect of such flow on the thermal field diminishes with depth due to decreases in permeability as the rocks become progressively more altered. Hot springs and other thermal features along the McKenzie River are probably related to upwardly focused, gravity-driven regional groundwater flow along faults bounding the west side of the High Cascades graben. The focusing is related to the fault-bounded termination of the relatively more permeable rocks of the High Cascades graben against the less permeable rocks of the Western Cascades. The heat-flow at the bottom of the well is equal to or higher than the true heat-flow; examples from other Cascade Range wells are illustrated to demonstrate the basis for this conclusion. The results demonstrate that heat-flow along the Cascade Range axis in an area between active stratovolcanoes is equal to or higher than that along the west edge of the High Cascades as described by Blackwell and others (1982, 1990).

OPEN-FILE REPORT O-88-05

Geology and geothermal resources of Breitenbush-Austin Hot Springs area, Clackamas and Marion Counties, 1988

by D.R. Sherrod, *editor*

91 p.

1 map, 1:24,000

Part of the area lies within a regional of heat-flow in excess of 100 milliwatts per square meter (mW/m^2). Mariner and others (1980) listed Breitenbush Hot Springs as one of the top ten areas of geothermal potential in the state, on the basis of chemical geothermometers.

The report includes a geologic cross section showing topography, stratigraphy, structure, isotherms, heat-flow, gravity, and hydrology. The picture emerges of an igneous-related conductive thermal regime with heat-flow of 100 mW/m^2 beneath the High Cascades. The conductive gradient decreases to 40 mW/m^2 in the Western Cascades but is locally perturbed by convective anomalies arising from the migration of heated ground water in fracture zones (Austin Hot Springs) and along the top of impermeable barriers in altered Oligocene and lower Miocene volcaniclastic rocks (Breitenbush Hot Springs).

This model differs from interpretations that extend the igneous-related heat source from the High Cascades into the Western Cascades and thus narrows the area of prime interest for geothermal exploration. Though not fully tested, the model is compatible with the information presently available.

SPECIAL PAPER 15

Geology and geothermal resources of central Oregon Cascade Range, 1983

by G.R. Priest and B.F. Vogt, *editors*

123 p.

3 pl, 1:62,500

This paper summarizes investigations of the geology and geothermal resources of the central Cascade Range of Oregon conducted by the Oregon Department of Geology and Mineral Industries from 1977 through 1982.

Heat Flow

Heat-flow data from 170 holes, most of them located in the Willamette Valley, Western Cascade, and High Cascade physiographic provinces, are tabulated. The data indicate that a zone of low heat-flow averaging 43±1 mW/m^2 occupies the Willamette Valley province and most of the Western Cascade province. A zone of higher heat-flow averaging 104±9 mW/m^2 occupies the High Cascade province and extends about 10 km (6 mi) into the Western Cascade province. The transition between the two zones is very narrow, averaging less than 10 km (6 mi) in width throughout most of its length in Oregon. Heat-flow in the Willamette Valley and Western Cascade provinces is primarily conductive.

In the High Cascade province, high lateral permeability makes the measurement of meaningful heat-flow values virtually impossible at depths of less than 300 m (984 ft). A 25-mgal negative gravity anomaly which is superimposed on a regional negative trend occurs at the heat-flow transition zone. Thermal modeling of the heat-flow data and gravity modeling indicate that temperatures as high as 700º C may underlie the High Cascade province and that it is possible that molten rock underlies large portions of the high heat-flow zone. Three conceptual models that may explain the origin of the north-south line of hot springs paralleling the High Cascade-Western Cascade boundary are described. Finally, numerical estimates for the geothermal potential of the Cascade Range of Oregon are made. The estimates are based on the heat-flow data base and thermal modeling.

Geothermal Exploration

Exploration in the central Oregon Cascades should be focused within the High Cascade heat-flow anomaly. In the volcanic rocks of the Western Cascade episode, geothermal aquifers are most likely to occur where thick sections of brittle intrusive or holocrystalline flow rock have been recently fractured by tectonic deformation. In the younger rocks of the High Cascade episode, exploration should be focused on unusually thick sequences within large grabens or calderas; the Waldo Lake-Lookout Mountain area and High Cascade province 20 km (12 mi) north of Breitenbush Hot Springs are probably examples. Areas of youthful silicic volcanism, such as Mount Jefferson, Crater Lake, and South Sister, are particularly attractive targets, because they may be underlain by shallow plutonic heat sources. A high priority target is the silicic highland around the Three Sisters. Because most of this area is in the Three Sisters Wilderness, however, the only portion that may be exploited is in the Devils Lake-Sparks Lake area.

OPEN-FILE REPORT O-83-03

Survey of potential geothermal exploration sites at Newberry volcano, Deschutes County, 1983

by G.R Priest, B.F. Vogt, and G.L. Black, *editors*

174 p.

Because no new drilling data are available, it is not possible to advance any new electrical power generation estimates for Newberry volcano from data examined in this study. On the basis of data from Newberry and other analogous areas, the USGS has estimated that the electrical power production potential of the caldera of the volcano is about 740 MWe for 30 years (Brook and others, 1979). The USGS discovery of fluids at 265º C (Sammel, 1981) prompted DOGAMI, at the request of the Pacific Northwest Utilities Conference Committee (PNUCC), to update the USGS estimate. Utilizing 265º C rather than the 230º C used in the 1979 USGS calculation, DOGAMI estimates that the electrical generation potential of the caldera is 1,116 MWe for 30 years (Black, 1982).

Both of the above estimates are very optimistic because they assume that most of the caldera block is saturated with fluid. On the other hand, both are somewhat conservative in that neither considers the possibility of hydrothermal fluids outside of the caldera.

In order to put an upper limit on the potential resource at Newberry, Black (1982), utilizing the most optimistic estimate of the size of the underlying heat source, estimates that a maximum of 13,430 MWe for 30 years could be present at the volcano. This estimate includes the caldera and large areas on the flanks.

The present study investigated the source of heat for the geothermal systems at Newberry by analysis of geologic, teleseismic, gravity, aeromagnetic, and heat-flow data (Chapters 2, 7, and 8). These geologic and geophysical data indicate that a large, relatively shallow, mostly solidified magma body could underlie the summit of the volcano. However, none of these analyses conclusively proves this hypothesis. Under the most pessimistic interpretation of the data, only a few small silicic magma bodies may be present at shallow depths. These small bodies may have been the feeders to the Big Obsidian Flow and the young silicic domes on the uppermost southeast flank.

A soil-mercury survey conducted on the flanks and in the caldera of the volcano (Chapter 6) revealed that there is a very high probability that hydrothermal systems occur well outside of the caldera. The survey indicated that about 32 km^2 of the flanks and about 8 km^2 of the caldera possess anomalous soil mercury. The anomalies tend to correlate with concentrations of volcanic centers (Chapter 3) and major caldera faults and fracture zones. Soils near the discovery well in the caldera do not possess anomalous soil mercury, indicating that lack of a mercury anomaly does not preclude the presence of hydrothermal fluids at depth. Although the results of the mercury survey cannot yield quantitative estimates of the electrical generation potential of the volcano, they do indicate that thermal fluids may underlie large areas accessible to exploration on the east and south flanks of the volcano.

SPECIAL PAPER 14

Geology and geothermal resources of Mt. Hood area, 1982

by G.R. Priest and B.F. Vogt, *editors*

100 p.

Overview

Geothermal exploration should be concentrated in the High Cascade heat-flow anomaly and the somewhat higher Mount Hood heat-flow anomaly where permeable rocks are present in thermal zones. Permeable rocks and hydrothermal circulation systems are most probably where Columbia River basalt or phaneritic plutonic rocks occur and where fracture permeability has been enhanced by faulting. North-south-trending normal faults and "pressure shadows" in northwest-trending faults with strike-slip motion are probably the most favorable structures for fracture permeability. Intersection of these structures with the Laurel Hill and Still Creek plutons and areas near youthful volcanic vents on the north and east sides of Mount Hood are very favorable exploration targets, especially where the Columbia River Basalt Group is present at depth.

Old Main Flat Area

Two deep drill holes, OMF-1 (1,220 m [4,002 ft]) and OMF-7A (1,837 m [6,027 ft]) were drilled into open-fractured basalt of the Columbia River Basalt Group near a late Pliocene fault with a probably dip-slip offset of at least 400 m (1,300 ft). Although temperatures near or in excess of 100º C were encountered in both holes, no significant quantities of thermal water were found. These results suggest that further drilling at Old Main Flat may have low probability of success.

Heat Flow

Geothermal data from 25 wells within a 20-km radius of Mount Hood stratovolcano in north-central Oregon are described. The wells range in depth from 65 m to 1 km. There are two holes 1.2 km in depth, eight holes in the depth range of 250-600 m, and the rest in the depth range of 100-250 m. Thermal conditions are a complicated function of position around the volcano. As a general rule, there is an increasing resistance to fluid flow with increasing age of the rocks, so that (1) generally conductive heat-flow measurements are observed in Miocene and older units, and (2) increasingly convection-dominated measurements are seen in younger units. An exception to this generalization occurs in the southwest corner of the mountain, where two quartz diorite plutons have a high fracture permeability, and temperatures are affected by a forced ground-water system in this fractured granitic rock. Heat-flow values range from 65 to 150 mW/m^2. As the volcano is approached, there is a general increase in heat-flow from regional values of approximately 80 mW/m^2 at a distance of 12 km or greater from the volcano, to heat-flow values on the order of 130-150 mW/m^2 at a distance of 5-8 km from the apex of the mountain. No holes were drilled closer than 5 km to the apex.

No geothermal systems of electrical grade have been outlined by the present studies; however, the heat-flow values are high enough that temperatures suitable for space heating exist at reasonable depths, and in at least one place, the holes may be used for such an application. Large areas of the mountain are as yet untested, and some attractive regions remain to be explored.

Heat Flow and Geophysical Log Analysis for Geothermal Test Well

Geothermal test well OMF-7A is located in NE¼SE¼ sec. 15, T. 2 S., R. 8 E., in northwestern Oregon. This hole was the first deep geothermal test hold drilled in the High Cascades of Oregon, and extensive logging, cutting analyses, and core measurements have been carried out in order to evaluate as completely as possible the physical and chemical properties of the rocks encountered in the drill hole.

The overall geothermal gradient in the hole decreases with depth from a surface value of over 70º C/km to a value at the bottom of the hole of approximately 50º C/km. On the other hand, thermal conductivity rises with depth at least proportionally to the decrease in gradient. The terrain effect also contributes to the higher gradients observed at the shallow depths. The mean heat-flow in the hole is 114 mW/m^2, and there is some suggestion from the data that the heat-flow actually increases with depth, in spite of the decrease in gradient.

SPECIAL PAPER 9 — **Geology of Breitenbush Hot Springs quad, 1980**

by C.M. White

26 p.

1 pl, 1:62,500

The purpose of this study is to provide geological information that can be used in the evaluation of the Oregon Cascades as a potential geothermal resource. The Breitenbush Hot Springs area was selected because it includes the boundary between the Tertiary rocks of the Western Cascades and the Quaternary lavas of the High Cascade crest. The fact that the contact is marked by a line of hot springs along about 200 km of its length has led geologists to speculate that it may be the site of a major fault system.

OPEN-FILE REPORT O-80-08 **Powell Buttes area, 1980**

By D.E. Brown, G.L. Black, G.D. McLean, and J.R. Petros

117 p.

1 map, 1:62,500

The Powell Buttes area is located within economic piping distance of the industrial districts of three of the major communities in central Oregon; Bend (10 mi), Prineville (5 mi), and Redmond (5 mi). Our preliminary evaluation, based on geology, geophysics, geochemistry, probing of existing water wells, drilling and probing of eight 152 m (500 ft) gradient holes, and the drilling and probing of one 460 m (1510 ft) gradient hole, indicates the potential exists for 100º C (212º F) temperatures at depths of approximately 1000 m (3,300 ft.). The existence of these elevated temperatures and usable fluids has not, however, been proven.

OPEN-FILE REPORT O-80-03 **Willamette Pass area, 1980**

by D.E. Brown, G.D. McLean, N.M. Woller, and G.L. Black

65 p.

1 map, 1:62,500

Owing to the highly complex nature of the geology of the Willamette Pass, no preliminary geothermal model is presented with this report. Several areas, however, exhibit characteristics which appear to be favorable for geothermal development. They are the Eugene-Denio lineament, the Hills Creek Reservoir-Flat Creek shear zone, and the North Fork shear zone - a geophysical and geological lineament found at the northern boundary of the map. All of these areas show intense faulting and hydrothermal alteration, geophysical anomalies, and, in the case of the Eugene-Denio lineament, some indication of association with present-day active geothermal systems. Of the presently active geothermal systems, McCredie and Kitson Hot Springs are the most economically attractive for low-temperature exploitation, owing to their proximity to the city of Oakridge.

OPEN-FILE REPORT O-80-02 **Belknap-Foley area, 1980**

by D.E. Brown, G.D. McLean, G.R. Priest, N.M. Woller, and G.L. Black

58 p.

1 map, 1:62,500

During the course of this investigation, two major north-south lineaments were found to have close correlation with the distribution of thermal springs and areas of increased heat-flow. Geological mapping revealed that both lineaments are the result of major north-south-trending fault zones and that these fault zones must, to a certain extent, control the flow of geothermal waters.

The available analyses indicate that the thermal waters may be separated into two compositional groups based on total ionic content, ionic rations, and calculated reservoir temperatures. These two groups show a one-to-one correlation with the aforementioned fault zones: the hotter springs (i.e., Bigelow, Belknap, and Foley) being associated with the McKenzie-Horse Creek fault zone which forms the western margin of the High Cascade graben; and the cooler springs (Cougar and Terwilliger) being associated with the Cougar Reservoir fault zone which lies west of the High Cascade graben margin. This correlation is also seen in heat-flow measurements, with the higher values associated with the McKenzie-Horse Creek fault zone and the lower numbers associated with the Cougar Reservoir fault zone.

This preliminary data analysis indicates that the McKenzie-Horse Creek fault zone may control a higher temperature geothermal resource than the Cougar Reservoir fault zone. Both zones, however, contain geothermal resources which warrant further study.

OPEN-FILE REPORT O-79-08 — Geothermal-resource assessment of Mount Hood, 1979

by J.F. Riccio, *editor*

273 p.

Overview - Temperature Gradients

DOGAMI, in late 1978, successfully completed the drilling of eleven temperature gradient holes in the Mt. Hood area to depths ranging from 76 to 152 m.

The only geothermal anomaly discovered from the temperature gradient investigation was from a hole in Hood River Valley (1S/10E-9bc) northeast of Mt. Hood. The temperature-depth curve is characteristic of a shallow aquifer flow when the aquifer temperature is much above background temperature. Thus, water flowing in the aquifer heats the rock above and below the aquifer, resulting in the characteristic shape. Chemical analyses of the water from this hole suggest that the water may in fact be a geothermal fluid with a much higher geothermal temperature implied than is observed.

It appears that the low-temperature water (24º C) is probably related to the intrusion that resulted in the lava flow. These results are of sufficient interest that additional geologic-geophysical studies should be carried out to investigate the geothermal implications of the anomaly. The proximity to major energy consumption centers in Hood River Valley and The Dalles is also a favorable feature of the anomaly.

OPEN-FILE REPORT O-77-03 — Heat-flow study of Brothers fault zone, 1977

by D.A. Hull, D.D. Blackwell, R.G. Bowen, and N.V. Peterson

38 p.

During 1975 and 1976, 38 holes were drilled in central and eastern Oregon to obtain data for calculation of heat-flow along the Brothers fault zone and a possible eastward extension of the zone. The holes were drilled to variable depths with the majority of holes in the depth range of 60-150 m (197-492 ft). Geothermal gradients and estimated heat-flow values were also obtained from 15 water wells and mineral exploration holes.

Heat-flow is variable along the zone and many of the values appear to be influenced by ground water movement. Most of the heat-flow values in the fault zone between Pine Mountain on the west and Riley Junction on the east are 1.9 HFU or greater whereas values north of the zone are approximately 1.6 HFU. The systematic decrease in the age of silicic volcanism from east to west along the fault zone is not reflected by a systematic variation in heat-flow values. Anomalously high heat-flow at Glass Buttes and several localities in the west of Harney Basin outlines a broad area, parallel to the fault zone, which deserves further study. At Glass Buttes high heat-flow coincides with an area of intensive hydrothermal alteration and low electrical resistivity and these features collectively define a promising exploration target.

Heat-flow values of 1.7-2.0 HFU in three holes along the eastern border of Oregon limit the western extend of the Battle Mountain heat-flow high.

BULLETIN 89 — Geology and mineral resources of Deschutes County, 1976

by N.V. Peterson, E.A. Groh, E.M. Taylor, and D.E. Stensland

66 p.

4 pl, 1:24,000

Recent interest in Oregon for geothermal resources is high and our studies show a favorable geologic environment for parts of Deschutes County. The potential for the future development of this type of earth energy appears to be considerable.

Intense volcanic and tectonic activity has been the geologic history of Deschutes County. Volcanic activity in the Quaternary (2 million years to the present time) has been especially pronounced within the County. This is shown in the building of the great Newberry Volcano, a shield complex, and the continuation of volcanic activity of this feature essentially to the present time. It is also evident in the Quaternary volcanism of the High Cascades, particularly the Three Sisters-Broken Top area, the Mount Bachelor-Sheridan Mountain chain, and the Kiwa Butte area.

Silicic volcanism near Glass Buttes, just south of the eastern end of Deschutes County, has an age of about 5 million years. Westward are scattered younger silicic eruptions, and in Newberry Caldera the youngest silicic rock dated so far is about 1,300 years (Peterson and Groh, 1969). Still farther to the west, young silicic eruptions in the South Sister-Broken Top area are only a few thousand years in age. MacLeod and others (1975), reporting on the significance of geothermal potential in southeast Oregon, state: "Most electric-power-producing geothermal fields in the world occur in or proximal to areas of young silicic volcanic rocks."

At the present time, geothermal prospects for the High Cascade range must be considered as speculative. Geologically the volcanicity of the area suggests large sources of heat brought to shallow levels of the crust; however, a great deal of preliminary exploration will be required to assess the geothermal resource potential. Here again, exploration and development of geothermal resources must be compatible with the environmental aspects.

OPEN-FILE REPORT O-76-01 — Electrical resistivity survey and evaluation of Glass Buttes geothermal anomaly, Lake County, 1976

by D.A. Hull

11 p.

A dipole-dipole electrical resistivity survey was made at Glass Buttes, a silicic volcanic dome located along the Brothers fault zone in central Oregon, to evaluate the technique and to study the Glass Buttes geothermal anomaly. An a-spacing of 2,000 ft with separations between electrode pairs ranging from 2,000 to 12,000 ft and a frequency of 0.125 hertz were used. The survey revealed marked resistivity contrasts and outlined a broad area at depth underlain by material having a resistivity value interpreted to be less than 5 ohm meters. A near-surface layer with resistivity values exceeding 300 ohm meters generally coincides with the outline of the silicic volcanic rocks.

OPEN-FILE REPORT O-75-02 — Central Western and High Cascades geological reconnaissance and heat-flow hole location recommendations, 1975

by N.V. Peterson and W. Youngquist

41 p.

Summary of Suggested Drilling Locations

Seven locations are suggested:

Breitenbush area, secs. 16, 21, or 28, T. 9 S., R. 7 E.

Santiam Junction, south center sec. 36, T. 12 S., R. 6 E., or N¼ sec. 1, T. 13 S., R. 6 E.

Sand Mountain, just east or northeast of Sand Mountain which is a few miles southeast of Santiam Junction.
Two Buttes, E¼ sec. 9, or W¼ sec. 9, or W? sec. 10, T. 16 S., R. 7 E.
Deer Creek-Belknap area, NE¼ sec. 2, T. 16 S., R. 6 E., with another possible location on property of John Bigelow, west of Belknap Springs. Bigelow's property is in sec. 10, T. 16 S., R. 6 E.
Foley Springs, E¼ sec. 28, or W? sec. 27, T. 16 S., R. 6 E. Topography limits locations.
Kitson-McCredie area, within a mile or so of McCredie Hot Springs which are in NW¼ sec. 36, T. 21 S., R. 4 E., Lane County.

Additional possibilities are:
Drill an additional hole in the Breitenbush area, with one being put in the valley proper, and one in the surrounding hills, preferably south.
Drill the additional hole recommended in the Deer Creek-Belknap area.
Drill one of the mineralized zones showing hydrothermal activity in the past such as up Christy Creek (off North Fork of Middle Fork of Willamette River), or in the Quartzville Creek area near Detroit.

BULLETIN 66 **Reconnaissance geology and mineral resources of E. Klamath County and W. Lake County, 1970**

by N.V. Peterson and J.R. McIntyre

70 p.

The 6,000-square-mile project area is in eastern Klamath and western Lake Counties.

Mineral resources typical of a region dominated by Cenozoic volcanism are abundant and widespread. The presence of hot springs, hot-water wells, and large areas of anomalously high heat-flow are indications that geothermal energy has a promising future for economic development.

GEOTHERMAL-GRADIENT DRILLING

OPEN-FILE REPORT O-95-03 **Geothermal gradients in Oregon, 1985-1994, 1995**

by D.D. Blackwell

132 p.

OPEN-FILE REPORT O-86-02 **Geothermal gradient data for Oregon (1982-1984), 1986**

by D.D. Blackwell, G.L. Black, and G.R. Priest

107 p.

OPEN-FILE REPORT O-82-04 **Geothermal-gradient data (1981), 1982**

by D.D. Blackwell, G.L. Black, and G.R. Priest

430 p.

OPEN-FILE REPORT O-81-03 **Geothermal-gradient data, 1881**

by D.D. Blackwell, G.L. Black, and G.R. Priest

3 parts

O-81-03-A. Data for 1978, 63 p.
O-81-03-B. Data for 1979, 98 p.
O-81-03-C. Data for 1980, 374 p.

OPEN-FILE REPORT O-80-12 **Geothermal-gradient drilling, N-central Cascades of Oregon, 1980**

by W. Youngquist

47 p.

2 gamma-ray logs

Six wells were drilled during this program.

Well 2 (Twin Meadows) shows an isothermal gradient down to the level of the regional water table (the main stream valley adjacent to the well site on the west) and then shows a linear gradient of about 70º C/km from the regional water table to total depth.

Well number 1 (Fish Lake Creek), which was drilled on a broad interstream divide between the headwaters of the North Fork of the McKenzie River, and the North Santiam River, and is not immediately adjacent to any deep valleys, shows essentially an isothermal gradient in much of the lower part of the well, reflecting cold water saturation of this portion of the drilled section. But the upper part of the wells shows a high gradient (102º C/km) which may be due to the presence at about 655 feet (200 meters) of a fracture which is carrying warm water from a geothermal system in the region. The most probable location of such a system is to the east and northeast, which is topographically up-slope and is a fracture line marked by several young (300 years) volcanic cones (the Sand Mountain, and Nash Crater-Little Nash Crater lineaments). This area should be investigated further.

OPEN-FILE REPORT O-78-04 **Geothermal gradient data,12/76-12/77, 1978**

by D.A. Hull, D.D. Blackwell, and G.L. Black

187 p.

OPEN-FILE REPORT O-77-02 **Geothermal gradient data, 9/75-12/76, 1977**

by D.A. Hull, D.D. Blackwell, R. Bowen, N. Peterson, and G.L. Black

134 p.

OPEN-FILE REPORT O-75-04 **Geothermal gradient data, Vale area, Malheur County, 10/74-6/75, 1977**

by D.A. Hull

17 p.

OPEN-FILE REPORT O-75-03 **Geothermal gradient data (of 75 bore holes, mostly east of Cascades), 1970-1974, 1975**

compiled by R.G. Bowen

133 p.

LOW-TEMPERATURE RESOURCE ASSESSMENT

OPEN-FILE REPORT O-94-09. **Digital data and selected texts from O-94-08, low-temp geothermal database for Oregon, 1994**

by G.L. Black

OPEN-FILE REPORT O-94-08 Low-temperature geothermal database for Oregon, 1994

by G.L. Black

178 p.

5 Location maps

This study identified 1,281 low and intermediate temperature geothermal energy sites. No new geothermal areas were discovered, but findings of earlier studies were reinforced. In particular, the Columbia Plateau appears to be underlain by large volumes of water at 20-25º C, at depths mostly less than 600 m.

OPEN-FILE REPORT O-82-07 Geology and geothermal resources of Cascades, 1982

G.R. Priest and B.F. Vogt, *editors*

206 p.

4 Geologic maps

This report summarizes investigations of the geology and geothermal resources of the central Cascades of Oregon conducted from 1977 through 1982.

A shallow drilling program and geologic mapping project provided data for heat-flow and geologic analysis. In some areas, detailed geologic maps were produced around individual drill sites, so that heat-flow interpretations could be related to local geology. The report contains chapters that address the geology and geothermal resources for the following areas:

Outerson Mountain-Devils Creek , Marion County
Lookout Point, Lane County
Swift Creek, Lane County
Willamette Valley south of the Clackamas River

An important conclusion of this study is that the central Cascade Range is probably one of the most attractive areas for geothermal resources in the western United States. A high heat-flow and premeable reservoir rocks may characterize the volcanic center of South Sister and the Newberry volcano. Also, the central Cascades have a heat-flow anomaly, roughly two and one-half times normal crustal heat-flow. This condition makes the central Cascades a good exploration target for electrical-grade geothermal resources at depths of a few kilometers.

OPEN-REPORT O-82-05 Oregon low-temp resource assessment, final technical report, 1982

by G.R. Priest, G.L. Black, and N.M. Woller

54 p.

Numerous low-temperature hydrothermal systems are available for exploitation throughout the Cascades and eastern Oregon. All of these areas have heat-flow significantly higher than crustal averages and many thermal aquifers. In northeastern Oregon low temperature geothermal resources are controlled by regional stratigraphic aquifers of the Columbia River Basalt Group at shallow depths and possibly by faults at greater depths. In southeastern Oregon most hydrothermal systems are of higher temperature than those of northeastern Oregon and are controlled by high-angle fault zones and layered volcanic aquifers. The Cascades have very high heat-flow but few large population centers. Direct use potential in the Cascades is therefore limited, except possibly in the cities of Oakridge and Ashland, where load may be great enough to stimulate development. Absence of large population centers also inhibits initial low temperature geothermal development in eastern Oregon. It may be that uses for the abundant low temperature geothermal resources of the state will have to be found which do not require large nearby population centers. One promising use is generation of electricity from freon-based biphase electrical generators. These generators will be installed on wells at Vale and Lakeview in the summer of 1982 to evaluate their potential use on geothermal waters with temperatures as low as 80º C (176º F).

The report summarizes low-temperature resource assessment data generated for the following project areas:

- Alvord Desert
- Belknap-Foley Hot Springs
- Corbett-Moffett
- Harney Basin
- La Grande (Craig Mtn.-Cove area)
- Lakeview
- McDermitt
- Milton-Freewater
- Parkdale
- Powell Buttes
- Western Snake River Plain
- Willamette Pass

Open-File Report O-80-14 **Progress report on activities of low-temperature resource assessment program, 1979-80, 1980**

by D.A. Hull

79 p.

The report summarizes low-temperature resource assessment data generated for the following project areas:

- Alvord Desert
- Belknap-Foley Hot Springs
- Harney Basin
- La Grande
- Lakeview
- McDermitt
- Powell Buttes
- Western Snake River Plain
- Willamette Pass

GEOPHYSICAL LOGS

Open-File Report O-81-02 **Geophysical logs, Old Maid Flat 7A, Clackamas County, 1981**

O-81-02-A. 4 logs, (96-1,190 ft)
O-81-02-B. 2 logs, (96-5,952 ft)

Geophysical logs in this report include fracture identification, temperature, variable density, and a Schlumberger directional survey.

Open-File O-81-11 **Engineering and air and mud drilling data, DOGAMI geothermal exploratory well Old Maid Flat 7A, 1980**

by T. Macleod and J. Hill

Includes one logging sheet, folded into 16 pages.

Open-File O-78-06 **Geophysical logs, Old Maid Flat #1, Clackamas County, 1978**

2 p., 7 logs

Geophysical logs in this report include dual induction, compensated density, temperature, drift, fracture, and acoustic velocity.

MAP ONLY PUBLICATIONS

Geologic Map Series GMS-61 Geology and mineral resources of Mitchell Butte quad, Malheur County, 1990, by M.L. Ferns and K. Urbanczyk,1:24,000

Geologic Map Series GMS-58	Geology and mineral resources map of Double Mountain quad, Malheur County, 1989, by L. Ramp and M.L. Ferns, 1:24,000
Open-File Report O-88-03	Newberry Crater Geothermal Resource Area, Deschutes County, 1988, 1 drilling map, by D.L. Olmstead and D.E. Wermiel, 1:24,000
Open-File Report O-84-04	Heat-flow map of Cascade Range of Oregon and index map of mapping in Oregon Cascades, 1984, 2 maps, 1:500,000 and 1:1,000,000
Geologic Map Series GMS-21	Map showing geology and geothermal resources of Vale East quad, 1982, by D.E. Brown, 1:24,000
Geologic Map Series GMS-20	Map showing geology and geothermal resources of south part of Burns 15´ quad, 1982, by D.E. Brown, 1:24,000
Geologic Map Series GMS-11	Preliminary geothermal resource map of Oregon, 1978, by J.F. Riccio, 1:500,000
Geologic Map Series GMS-10	Low- to intermediate-temperature thermal springs and wells in Oregon, 1978, 1 map, by R.G. Bowen, N.V. Peterson, and J.F. Riccio, 1:1,000,000 (Supersedes MP-14 see below)
Miscellaneous Paper MP-14	Thermal springs and wells in Oregon, 1970, 1 map, by R.G. Bowen and N.V. Peterson, 1:1,000,000 (Superseded by GMS-10)

THESIS ABSTRACTS

The Department maintains a collection of theses and dissertations on Oregon Geology. From time to time, we print abstracts of new acquisitions or from contributors that in our opinion are of general interest to our readers. While reserving the right to determine the desirability of each acquisition, the Department is interested in purchasing two copies of each accepted master's thesis or doctoral dissertation, bound, and complete, for the amount of $150 or $200, respectively, if such a thesis or dissertation concerns the geology of Oregon. Part of the acquisition will be the right to publish the abstract in Oregon Geology.

Petrology and geochemistry of silicic volcanics of the Menagerie Wilderness, Western Cascades, Oregon

GEOFFREY WILLIAM COOK, (M.S., Boise State University, 2002)

The early magmatic history of the Cascade Arc is recorded in the Oligocene and early Miocene volcanics of the Western Cascade province. These rocks consist chiefly of silicic tuffs, tholeiitic basalts and basaltic andesites. Although the mafic end of this system has been well studied, the silicic rocks are poorly documented owing to difficulties inherent in dating and chemically analyzing hydrothermally altered pyroclastics. We have addressed this problem by analyzing relatively unaltered samples from a complex of silicic domes and lava flows exposed within the Menagerie Wilderness, north of the South Santiam River. The study area is on the northern edge of a series of rhyolite exposures that define a rough circle approximately 15 km in diameter, and which may represent an eroded caldera complex.

Silicic lavas in the Menagerie area range in composition from medium K rhyolite to trachydacite (high K) and dacite (low K). Three main silicic centers were discovered within the study area and were distinguished mainly through petrographic characteristics. Phenocryst assemblages include plagioclase-hornblende-magnetite (Rooster Rock Rhyolite), plagioclase-quartz-magnetite (Soda Fork Rhyolite) and quartz-plagioclase-biotite-hornblende-magnetite (Moose Mountain Rhyolite). Chondrite normalized REE plots have moderate Eu anomalies and flat MREE-HREE patterns, consistent with fractionation of plagioclase and hornblende. However, trace element modeling indicates that Menagerie area rhyolites can not be related to any likely parent composition by crystal fractionation alone, and instead were crustal melts that have been modified by crystal fractionation.

Differentiation of two Quaternary Mt. Hood lahares by clay mineralogical, quantitative X-ray diffraction and particle size analysis

ROBYN C. COOK, (Senior thesis, Middlebury College, 2002)

Multiple analytical methods have successfully differentiated three similar Quaternary lahar deposits on the northern flank of Mount Hood and in downstream valleys. Theses methods include X-ray diffraction (XRD) of clay mineral content, quantitative XRD of bulk mineral content, and laser diffraction particle size analysis (LDPSA). The best differentiators are clay and bulk mineralogy. QXRD results of bulk samples indicated that the older lahar (older than 425 Ka) contains 16-24 percent plagioclase feldspar and 35-65 percent total dioctahedral clay (predominantly halloysite), whereas the younger lahar (40 to 80 Ka) contains 36-63 percent plagioclase feldspar and 25-36 percent total dioctahedral clay (predominantly expandable smectitic-vermiculitic clay). The intermediate unit (~130 Ka) consists of 33-38 percent clay (more weathered than smectite) and 40-43 percent plagioclase. At most sites, the older lahar is relatively enriched in clay and sand-sized grains as compared to the more silt-rich younger lahar. These preliminary results will prove valuable in determining the spatial variability of lahars and may be used in remote sensing mapping by providing differentiating characteristics.

Geomorphology and failure mechanics of gigantic landslides within Summer Lake basin: implications for seismogenic triggers, Lake County, Oregon

THOMAS C. BADGER, (M.S., University of Nevada, Reno, 2002), 89 p.

Summer Lake basin is located in south-central Oregon in the northwestern Basin and Range. The 40 km-long, Winter Ridge-Slide Mountain (WR-SM) escarpment that bounds the basin on the west and south, respectively,

exposes a kilometer-thick, Neogene sequence of dense volcanic flow rocks overlying very weak tuffaceous sedimentary rocks that dip 10° west. Gigantic landslides scallop the southwestern escarpment and display several kilometer long runouts characteristic of rock avalanches. Geotechnical rock mass characterization and slope stability analyses confirm observations that these landslides generally initiate along shallow, east-dipping, planar failure surfaces within the weak tuffaceous sedimentary rocks, are insensitive to groundwater fluctuations, and are stable under static conditions. Pseudo-static analyses reveal that strong shaking (>1g), resulting from Quaternary dip-skip movement on the WR-SM fault, is required to trigger landsliding. Shaking is also responsible for initiating large flow slides with Quaternary deposits along the base of the escarpment.

Stratigraphy, sedimentation, and geochemistry of Missoula Flood rhythmites in the northern Willamette Valley, Oregon

DAVID H. JAMES, (M.S., Portland State University, 2002),

A detailed stratigraphic, sedimentologic, and geochemical study was performed on Missoula Flood deposits at two sites in the northern Willamette Valley, Oregon: along Greeley Avenue in north Portland and near the town of Dayton, Yamhill County.

The Missoula Floods were a series of late Pleistocene (15,300-12,700 years b.p.) glacial outburst floods that left significant slackwater deposits in the Willamette Valley of Oregon.

The 21.9 m stratigraphic exposure at Greeley Avenue contains at least 25 rhythmite couplets (graded flood beds ranging from 0.007 m to 4.13 m thick (average = 0.91 m ± 0.94 m). Particle size varies from silt to gravelly sand with boulders up to 45 cm in diameter, indicative of a variable and high-energy depositional environment.

The 14.6 m stratigraphic exposure near Dayton, Oregon contains least 30 rhythmite couplets ranging from 0.28 m to 0.97 m thick. Average thickness of the upper 13 beds is 0.34 m ± 0.06 m, and average thickness of the lower 17 beds is 0.60 m ± 0.15 m. Particle size for rhythmite bed bottom sections range in graphic mean from 6.90 ϕ (0.0086 mm) ± 1.77 ϕ to 4.63 ϕ (0.041 mm) ± 1.07 ϕ; Inclusive Graphic Standard Deviation ranges from ± 0.93 ϕ (moderate sorted) to ± 2.23 ϕ (very poorly sorted). Rhythmite bed top sections range in graphic mean from 6.00 ϕ (0.0156 mm) ± 2.01 ϕ to 6.87 ϕ (0.0088 mm) ± 1.70 ϕ; Inclusive Graphic Standard Deviation ranges from ± 1.66 ϕ (poorly sorted) to ± 2.01 ϕ (very poorly sorted).

Instrument Neutron Activation Analysis (INAA) results at Dayton show increases in iron (3.49 % ± 0.04 % to 5.61 % ± 0.05 % by weight), and scandium (13.90 ppm ± 0.05 ppm to 19.25 ppm ± 0.09 ppm) with a corresponding decrease of chromium (71.99 ppm ± 1.78 ppm to 43.72 ppm ± 1.46 ppm) through time.

The chemical transition may represent the stripping of glaciogenic loess of the Palouse Silt Formation and establishment of well-defined Columbia River Basalt Group (CRBG) bedrock flood pathways in the source area of eastern Washington.

Stratigraphy, distribution, and geochemistry of the Newberry volcano tephras

STEPHEN CHRISTOPHER KUEHN, (Ph.D., Washington State University, 2002), 697 p.

Newberry volcano has a long history of silicic pyroclastic volcanism and has produced many extensive tephra deposits. During the last approximately 550,000 years, the volcano has erupted at least 60 rhyolitic and dacitic tephras. These record a range of eruptive styles including plinian, sub-plinian, pyroclastic flows, and pyroclastic surges and both dry and phreatomagmatic activity. Tephra dispersal from individual eruptions ranges from very limited (i.e., small pumice rings a few hundred meters to a kilometer in extent) to extensive (i.e., plinian airfall deposits which have been recognized several hundred kilometers downwind). The most recent plinian eruption, the approximately 1,250-1,450 year old Newberry Pumice, produced an eruption column which reached a height of ~25 km and was dispersed by unusually high velocity winds. Some Pleistocene eruptions, including tephra 9822B, may have sent pyroclastic material to heights of 40 km or more. Several deposits including Evans Well, 9822B, Qat/Abt, 995B, and Qtae are compositionally heterogeneous and probably record the mixing of magmas before or during eruption.

The similarity coefficient and discriminant function analysis have been used to compare electron microprobe determined glass compositions for proximal Newberry tephra deposits and distal ash layers. Newberry Pumice correlates to six distal locations in Oregon and Idaho. Paulina Creek, Ice Quarry, 9912D, 9920C, 984F, 984G5, 9917C, and 9881C correlate to ash layers at Summer Lake, Oregon. Paulina Creek tephra also correlates to several locations in northern California and is the source of the Olema ash bed. Tephra 9917C is highly similar to Pringle Falls tephras K and D. Lava Pass tephra correlates to a distal ash preserved at a depth of 142 m in the Knolls core in the Bonneville basin, Utah. A coarse 0.6 m thick deposit of Wono tephra has been located on the northwest flank of Newberry volcano.

The large number of eruptions and established tephra correlations suggest that additional correlations of Newberry tephra are likely to be made to distal sites, both studied and yet to be studied. The volcano's extensive eruptive history and relatively recent activity also indicate that future large ash and pumice producing eruptions are likely.

Reconnaissance geochemistry of Middle Sister volcano, Central Oregon

JENNIFER P. PÉREZ, (M.S., Baylor University, 2002), 44 p.

Middle Sister volcano (10,047 ft) is a major late Pleistocene composite volcano, located in the Three Sisters area near Bend in Central Oregon. It is part of the High Cascade arc, which extends from British Columbia to Northern California.

Eleven samples of volcanic rock collected from the west flank of Middle Sister range from basaltic andesite to obsidian and represent the types of rock that comprise Middle Sister. Samples from Middle Sister show a transition from the mafic rock of North Sister to the more differentiated silicic rocks of South Sister. Middle Sister trachyandesites appear to be the products of fractional crystallization of basaltic andesite similar to McKenzie Pass magmas with small degrees of assimilation of crustal rocks.

Slope and seismic stability of the Castle Lake Debris Dam, Mount St. Helens National Monument, Washington

JASON M. TAYLOR, (M.S., Portland State University, 2002), 104 p.

The Castle Lake Debris Dam was created by a debris avalanche that flowed down the Toutle River Valley during the eruption of Mount St. Helens on May 18, 1980. The dam is approximately 610 m long by 425 m wide and holds back a volume of 2.34×10^7 m^3 of water. Sources for potential failure are seepage erosion, slope failure, and liquefaction.

Using the slope stability program XSTABL, the dam is found to be stable from slope failure under most climatic events. Earthquakes are the greatest threat to the long-term stability because they increase driving forces and decrease resisting forces that are not normally present, through ground accelerations and pore pressure increases. To determine the dam's earthquake susceptibility, the effects of amplification, liquefaction and earthquake-induced slope failures were analyzed for Mount St. Helens Seismic Zone, Cascadia Subduction Zone and intraslab earthquakes using standard penetration test, shear wave velocities, SHAKE91, and XSTABL. Results show that peak horizontal accelerations can be as high as 0.7 g for crustal earthquakes and 0.5 g for subduction and intraslab earthquakes. Based on the shear wave velocities and SPTs in the debris dam, a minimum Mw 6.3 earthquake with peak horizontal accelerations of 0.5 g is needed in order to cause liquefaction on the dam, though the groundwater would have to be 2 m higher than its present level. Using SHAKE91, liquefaction is susceptible for all the modeled earthquakes. Earthquake induced slope failure start occurring with horizontal acceleration of 0.2 g. Liquefaction and slope failure will likely occur during an earthquake but will not be large enough to initially release the lake. However, if a large enough portion of the dam is removed, it could change the groundwater system in such a way that piping, heave and internal erosion could retrogressively breach the Castle Lake.

After the February 28, 2001, M 6.8 Nisqually intraslab earthquake, approximately 110 km away, a small failure was observed on the debris dam. The cause is attributed to earthquake induce slope failure and not liquefaction based on accelerations too low to cause liquefaction.

Evolution of Volcanism in the Central Oregon High Cascades and its Relation with Yellowstone Plume Magmatism

HEATHER L. WILLIAMSON, (M.S., Baylor University, 2002), 91 p.

682 volcanic vents (7 percent basalt, 75 percent basaltic andesite, 3 percent andesite, 3 percent dacite and rhyodacite, 12 percent rhyolite) were mapped in the Bend and La Pine 30′ x 60′ quadrangles of central Oregon. This region contains the intersection of the two dominant volcano-tectonic features in Oregon: the High Cascades Graben and the Brothers Fault Zone. The dominance of basaltic andesite reflects the general extensional tectonic setting of central Oregon; andesite, dacite, and rhyodacite are concentrated in a few High Cascade centers; rhyolite is concentrated along the Brothers Fault Zone and its extension into the Three Sisters region of the High Cascades.

Recent rhyolite eruptions, the age pattern of migration of silicic volcanism towards central Oregon from southeast Oregon over 10 Ma, and the recently-discovered regional swelling in the Three Sisters area suggest that this region may experience future silicic eruptions.

GEOLOGIC NOTES

Overview of the Kelly Point Park Earthquake, Portland, Oregon

The earthquake near Kelly Point Park, north Portland, of Thursday, April 24, 2003, at 12:26 p.m. (PDT) was a magnitude Mw=3.9 event. The quake caused no injuries or damage, but the quake was strong enough for some residents in the epicentral area to report shaking. In the Portland-Vancouver metropolitan area, a quick jolt was felt based on reports received from residents. Also, people as far away as Mount Hood, Salem, Silverton, and up to La Center, Washington, reported feeling a jolt. Seismographs recorded an aftershock nine minutes after the main event with a magnitude of Mw=1.6, followed by another, at 3:41 p.m., at a magnitude Mw=1.2. So far, seven related aftershocks have been located. These aftershocks were imperceptible without instruments.

As reported by the Pacific Northwest Seismograph Network (PNSN) at the University of Washington, the earthquake's epicenter is about 15 km (9 mi) northwest of Portland at the confluence of the Willamette and Columbia Rivers (Figure 1). The hypocentral depth was placed at a depth of 18 km (11 mi).

PNSN posted the results of a first motion study, often referred to as a fault plane solution, that provided two possible choices for the fault plane. The first choice indicates a right-lateral, strike-slip fault with the following parameters: strike 120°, westerly dip 35°, and rake 139°. A second choice indicates a reverse fault with the following parameters: strike 245°, northerly dip 68°, and rake 62°.

Figure 1. A modified shaded-relief map of the northern part of the Willamette Valley. Star indicates the approximate location of the epicenter for the Kelly Point Park earthquake.

Geologists at DOGAMI believe that the likely fault plane solution is the later given what is known about faulting in the Portland-Vancouver metropolitan area. However, too little is known about the location of faults in the Kelly Point Park area to link the earthquake to a particular fault plane solution or fault. Here faults are entirely hidden by river sediments, vegetation, and urban development. The earthquake could be on part of the Portland Hills fault[1]; it could be on part of the East Bank fault; or it could be associated with deeply buried faults that remain undetected (Figure 2). Even those faults that are mapped at the surface are poorly located at earthquake depths.

In the last ten years, about 20 earthquakes have been recorded and located within a few miles of the Kelly Point Park's epicenter. This activity includes the most recent March 31, 2003, quakes. Within a nine-hour period, three temblors were recorded with magnitudes Mw=2.7, 2.2, and 2.0. And in July 1999, three quakes hit the same site in one day, with a magnitude of Mw=3.2. This quake was reported felt throughout much of the Portland-Vancouver metropolitan area.

The Kelly Point Park earthquake served as a gentle reminder to the residents of the Portland-Vancouver metropolitan area that they live in earthquake country. Also, the quake was the largest to strike the area since a pair of earthquakes struck nearly 40 years ago. The pair happen to be the largest recent recorded earthquakes in Portland. On November 5, 1962, a magnitude Mw=5.5 shook Portland. A year earlier on November 7, 1961, a magnitude Mw=4.7 earthquake struck Portland.

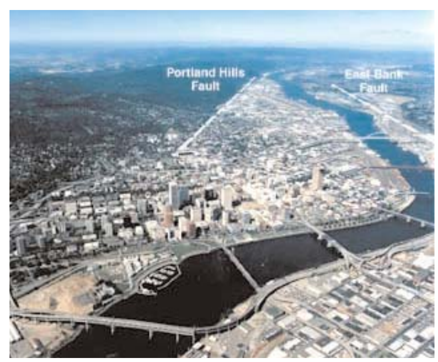

Figure 2. Oblique air photo of Portland and the Portland Hills. The view is looking northwest showing the inferred location of the Portland Hills fault and the East Bank fault.

[1] An article on the Portland Hills fault appeared in Oregon Geology, Spring 2001, Volume 63, No. 2, p. 39-50.

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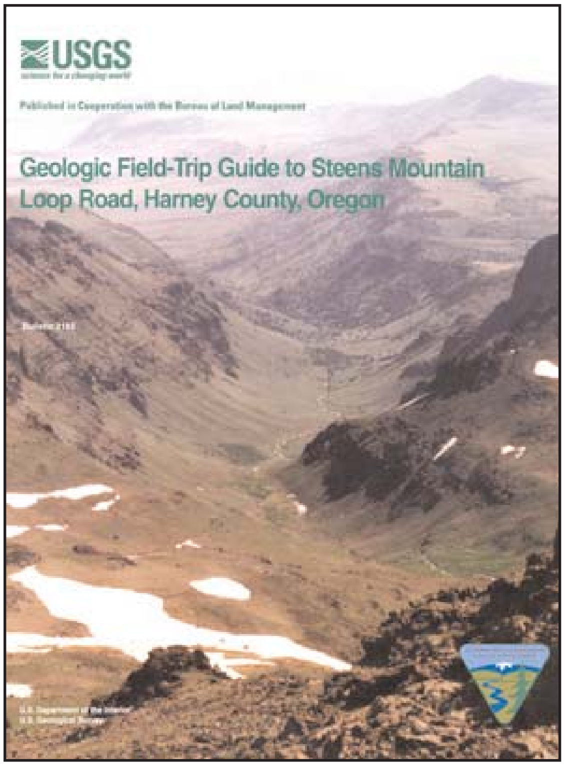

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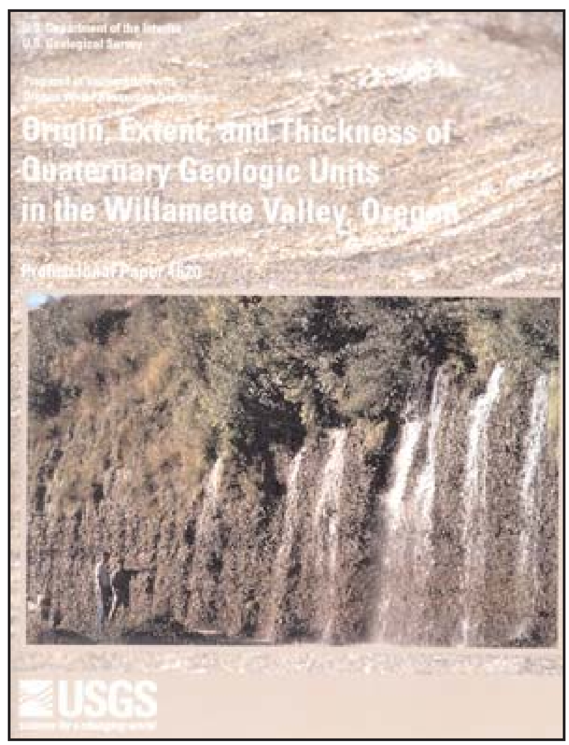

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We believe *Oregon Geology* is an important publication, offering a unique and suitable place to share information about Oregon that is useful for the geoscience community and ultimately for all Oregonians.

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