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PRELIMINARY HEAT-FLOW MAP AND EVALUATION OF OREGON'S GEOTHERMAL ENERGY POTENTIAL

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Introduction

The utilization of Oregon's long-recognized geothermal energy resources has been increasing in recent years as the economic and environmental costs of conventional energy sources have risen. By focusing attention on the depletable nature of fossil fuels, the 1973 petroleum crisis emphasized the importance of finding and developing alternative domestic energy sources. At the same time, a heightened public environmental consciousness led to the consideration of different kinds of energy sources that offered more favorable environmental tradeoffs than those of conventional energy sources.

An initial, but farseeing, overview of Oregon's geothermal resource potential by Groh (1966) was based on geological considerations. Since then, the Oregon Department of Geology and Mineral Industries has been conducting geological, geophysical, and geochemical investigations of the State's geothermal resources. The results of these studies have been published or released to open file. The present article is a summary of Oregon's geothermal energy potential, based on these studies and work by others, especially the U.S. Geological Survey.

Methods

Geothermal energy resources that can be utilized under existing technology and economic conditions occur as localized concentrations of natural steam and hot water in permeable rocks of the earth's crust at depths generally no greater than 3,000 m (about 10,000 ft). The primary tools we have utilized to evaluate geothermal resources on a regional basis are (1) heat-flow calculations based on measurements in drill holes; (2) an inventory of geothermal phenomena such as hot springs, fumaroles, and

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hot-water wells; and (3) geologic mapping to indicate faults and areas of young volcanic rocks. Other geophysical techniques, such as gravity, magnetic, and electrical resistivity surveys, aid in the delineation of geologic structures in potential geothermal resource areas; and geochemical analyses of hot-spring fluids aid in the interpretation of the temperature and fluid quality of individual geothermal reservoirs.

Heat flow

Heat flows from the hot interior of the earth toward the surface. Usable geothermal energy under existing technology is based upon the location of concentrations of hot fluids that may occur either in areas of Quaternary volcanism where subsurface bodies of magma or cooling igneous rocks are present or in areas where favorable structural conditions allow the deep circulation and heating of ground water in faults and permeable rocks. The latter mechanism normally produces geothermal resources only in areas of high crustal heat flow. Heat-flow measurements thus represent a direct means of outlining regions of higher-than-average heat flow where geothermal energy may be expected to occur and then locating concentrations of geothermal resources within these regions.

Heat flow is calculated as the product of the geothermal gradient (the increase in temperature with depth) measured in the drill hole and thermal conductivity (ability of a material to transfer heat by conduction) measured on rock samples taken from the drill hole.

The gradient data are corrected for influence of irregular topography near the drill hole; and the heat-flow value, if necessary, is corrected for the heat produced by natural radioactivity in the earth's crust. Because the solar heat flux at the surface is several thousand times greater than the normal heat flux from depth, reliable values of geothermal heat flow can be obtained only from drill holes deeper than 20 m (65 ft).

The results of the Department's heat-flow studies over the past five years have been given by Bowen (1972, 1975), Bowen and Blackwell (1973, 1975), Bowen and others (1975, 1976, and 1977), Hull (1975), Hull and others (1976, 1977a, and 1977b), and Blackwell and others (1977). Similar work by the U.S. Geological Survey has been reported by Diment and others (1975) and Sass and others (1973, 1976a, 1976b, and 1976c).

Geothermal phenomena

Natural leakage of hot fluids from geothermal systems within the earth's crust to the earth's surface results in hot springs (springs with a temperature 10°C above ambient temperature) and fumaroles (volcanic vents from which gases and vapors are emitted). An inventory of these phenomena in Oregon was made by Bowen and Peterson (1970). Hot springs and fumaroles are not associated with all geothermal resources, however; and other search techniques, such as heat-flow measurements, are desirable in geologically favorable areas.

Geologic mapping

Geothermal energy resources are often found in areas of geologically recent volcanic activity. As geologic mapping and age dating of volcanic rocks are the most efficient methods of locating and outlining these areas, there is a continuing need for detailed geologic mapping as an aid in systematic geothermal resource appraisal.

Geothermal Energy Potential

The heat-flow data, inventory of hot springs, and geologic maps have been combined and interpreted by the authors to give a preliminary regional evaluation of Oregon's geothermal energy potential. Since heat flow and the distribution of hot springs are closely related to the State's geologic history, the evaluation is discussed in terms of Oregon's physiographic provinces, which are shown in Figure 1. A preliminary heat-flow map of the State is included as Figure 2. The preliminary nature of this evaluation should be stressed, because the exact boundaries of the areas of various potential are not yet accurately delineated; and the search by both industry and public groups for resources within the areas of higher potential has barely begun. To date, only four deep production tests (holes deeper than 610 m [2,000 ft]) for geothermal resources have been drilled in Oregon.

The geothermal energy potential of the various provinces is categorized into three subdivisions, based on existing technology and economics: (1) areas of maximum inferred potential, (2) areas of intermediate potential, and (3) areas of low potential. Areas of maximum potential have a geologic environment favorable for the formation of geothermal resources of temperatures that are high enough to be used for electric power generation as well as for lower temperature nonelectric applications such as space heating and industrial-process heating. The exploration for and subsequent development of these resources will be expensive and time consuming. Areas of intermediate potential most likely contain resources suitable for nonelectric applications. Under existing economic conditions and current technology, electric power generation from geothermal energy will be unlikely in regions with intermediate potential. Areas of low potential will not likely produce geothermal energy in substantial quantity in the foreseeable future.

Areas of maximum potential, shown as "High" in Figure 2, have regional heat-flow values ranging from 1.9 to more than 2.5 microcalories per cm^2 sec (heat-flow units or HFU), numerous thermal manifestations in the form of hot springs and fumaroles, and volcanism that occurred within the last 2 million years. Areas of intermediate potential are characterized by scattered hot springs and/or warm-water wells, heat-flow values between 1.5 and 2.0 HFU, and most recent volcanism generally ranging in age from Miocene to Pliocene. An exception is the pattern of heat flow in the Western Cascades which ranges from less than 1.5 HFU at the west margin of the province to about 2.5 at the east margin adjacent to the Holocene volcanism in the High Cascades. Areas shown as "Low" in Figure 2 are considered to have low potential under present utilization technology as they have heat-flow values generally less than 1.2 HFU, volcanic rocks that are Miocene in age or older, and no thermal manifestations.

The interpretation of the potential of some geologic provinces will change as (1) future field studies shed new light on resource occurrence, (2) utilization technology improves, and (3) economic conditions change, with respect to alternate energy sources. It may eventually be possible to transport geothermal energy from areas of resource occurrence to areas of high energy demand, either by conversion to electricity or as hot water via pipelines.

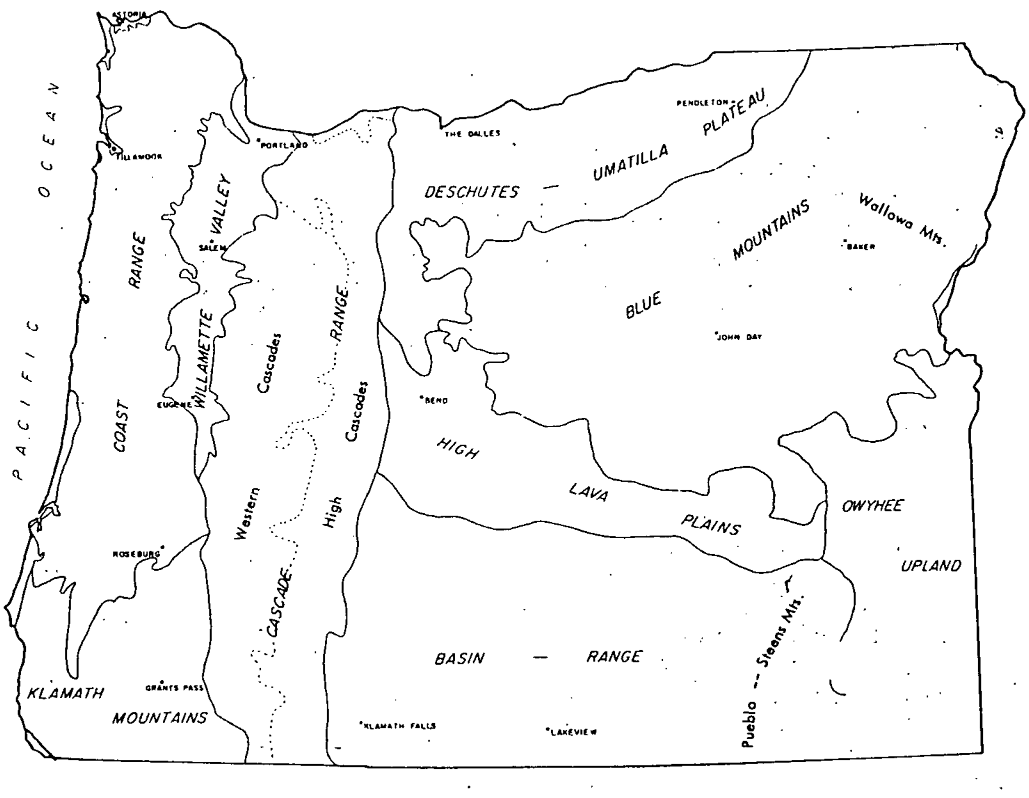

Figure 1. Physiographic provinces of Oregon.

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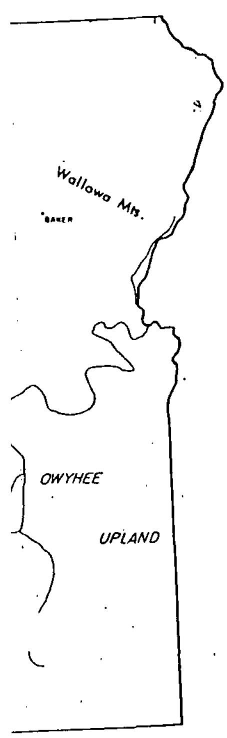

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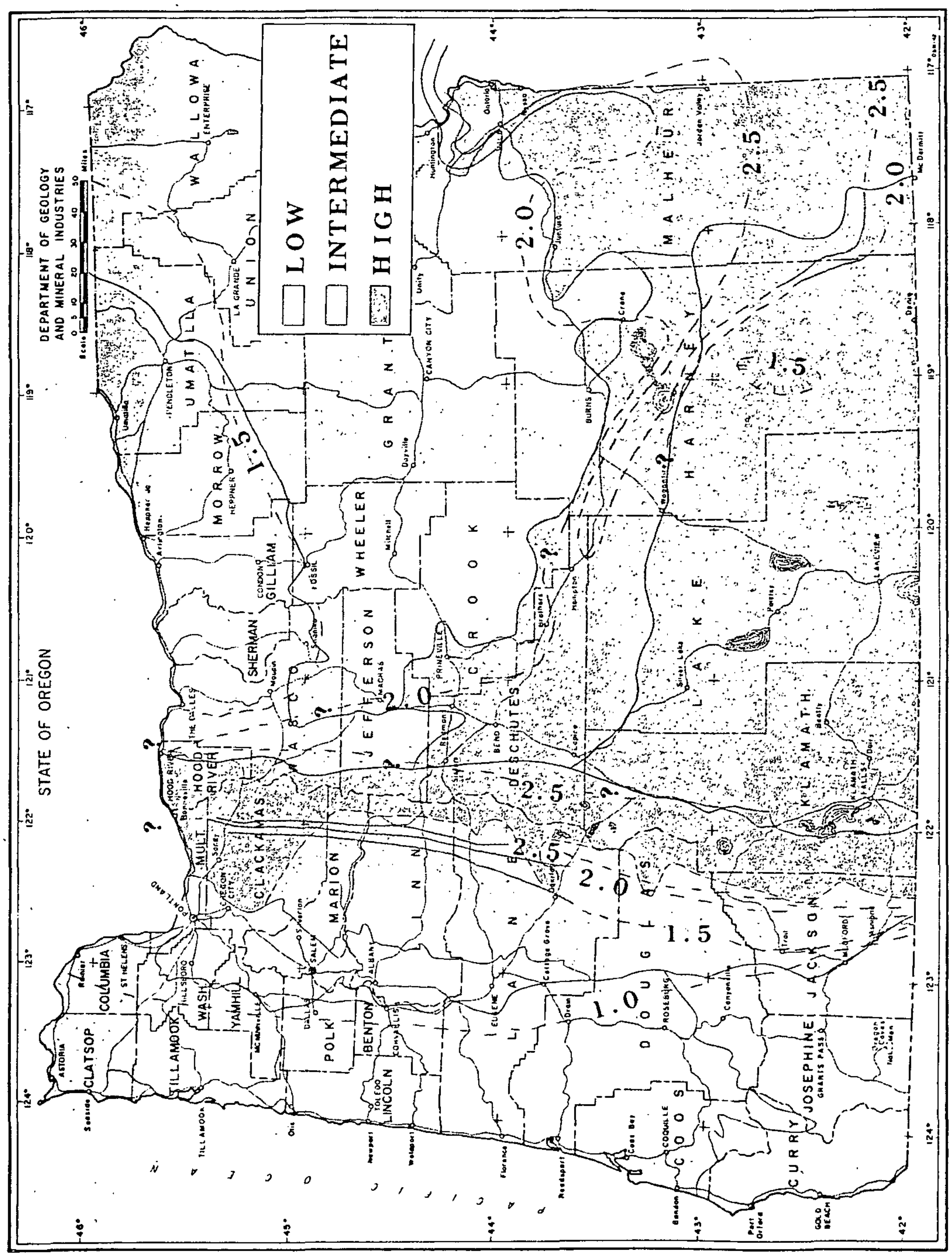


Figure 2. *Preliminary heat-flow map of Oregon showing geothermal energy potential of various physiographic provinces. Heat-flow contours indicate heat-flow units of microcalories per* cm^2 *sec.*

Coast Range

No hot springs are reported in the Coast Range in Oregon, heat flow based on meager data is less than 1.0 HFU, and the youngest volcanic rocks are Miocene in age (more than 12 million years old). Heat flow in the Coast Range, as shown in Figure 2, is based on scattered measurements in shallow wells and on approximate bottom hole temperatures reported for deeper wells drilled for oil and gas. No holes have been drilled for heat-flow data in the province. Existing information, however, suggests that the area has a low potential for geothermal energy resources.

Willamette Valley

Heat-flow values for the Willamette Valley are reported by Bowen and others (1977) and Blackwell and others (1977). Systematic measurement of temperature gradients in predrilled wells in 1976 in the vicinity of Portland, Salem, and Eugene failed to detect any obvious concentrations of geothermal resources (Hull and others, 1977b). There are no known hot springs or other geothermal phenomena in the province. Although most volcanic rocks are Eocene to Miocene in age, the youngest volcanic rocks near Portland may be less than 1 million years old (Allen, 1975). Further work to evaluate the potential near Portland is desirable.

Temperature gradients measured to date in the Willamette Valley are typically 20° to 40°C per km. Extrapolation of these gradients indicates that the 180° to 200°C temperatures required for electricity generation will not likely be encountered at depths less than 4 or 5 km, depths beyond the economic limit of drilling.

Klamath Mountains

The Klamath Mountains geologic province encompasses a broad area of rocks of Mesozoic age (65 to 225 million years). Hot springs are not found in the province except at its eastern border adjacent to the younger rocks of the Western Cascades province. Measured temperature gradients are extremely low, ranging from 10° to 20°C per km; and observed heat-flow values reported by Diment and others (1975) are less than 1.5 HFU. The geothermal energy potential of the Klamath Mountains province is adjudged to be low. The very low temperature gradients indicate that hot fluids would be encountered only at depths too great for economically feasible resource development.

Western Cascades

The Western Cascades province is a belt of volcanic and volcaniclastic rocks of Tertiary age which lie on the western flank of the present Cascade Range. The volcanic rocks of the zone appear to be too old to be a heat source for geothermal resources;

yet there is a north-trending belt of hot springs in the eastern third of the province, and a regional heat-flow study has revealed values ranging systematically from 1.0 HFU in the west to about 3.0 HFU in the east.

The high heat-flow values at the east boundary (Figure 2) are considerably in excess of normal, suggesting either localized heat source(s) at the eastern border of the province, deep circulation of hot fluids from the High Cascades to the east, or lateral effects of crustal heating associated with the volcanism of the High Cascades.

Although the potential of the province is considered to be intermediate, except along the eastern border, it may ultimately prove to be one of Oregon's most important geothermal energy sources because of its proximity to major population centers and energy markets in the Willamette Valley. Additional work is clearly needed in order to define the geologic controls over hot spring systems, to ascertain the nature of the heat source, and to establish more accurately the transition zone between low heat flow at the west edge of the Western Cascades province and the much higher heat flow at the east boundary of the area.

High Cascades

The High Cascades are characterized by numerous Holocene volcanoes, some of which have been active within the past few thousand years. Volcanoes such as Mount Hood and the Three Sisters and their underlying magma are obvious heat sources. No reliable heat-flow values have been reported for the High Cascades, and the only known geothermal manifestations are warm springs and fumaroles on Mount Hood. The paucity of hot springs in the High Cascades is not surprising in view of the abundant precipitation that soaks through the porous rocks to mask the heat that must be underground. The areas surrounding the High Cascade volcanoes are some of the most promising geothermal resource areas in the state, but few factual data are available for this province.

Deschutes-Umatilla Plateau

The northern part of Oregon east of the Cascade Range is a broad plateau underlain by a thick sequence of Miocene flood basalts of the Columbia River Group. There are few hot springs or warm wells, no Quaternary volcanic rocks, and few reliable heat-flow values in the province. Heat flow, based on values reported by Sass and others (1971) and Munroe and Sass (1974) from holes in southern Washington and geothermal gradients measured in Oregon, appears to be approximately 1.5 HFU. The Oregon gradient values, which were measured in relatively shallow holes, are affected by ground-water aquifers in the somewhat permeable basalt. A single heat-flow value of 1.9 HFU was obtained from a hole drilled in a pre-Tertiary granitic intrusive body at the southern boundary of the province. Existing data show typical geothermal gradients of 30° to 40°C per km for the province. The geothermal energy potential of the Deschutes-Umatilla Plateau is considered to be intermediate.

Blue Mountains

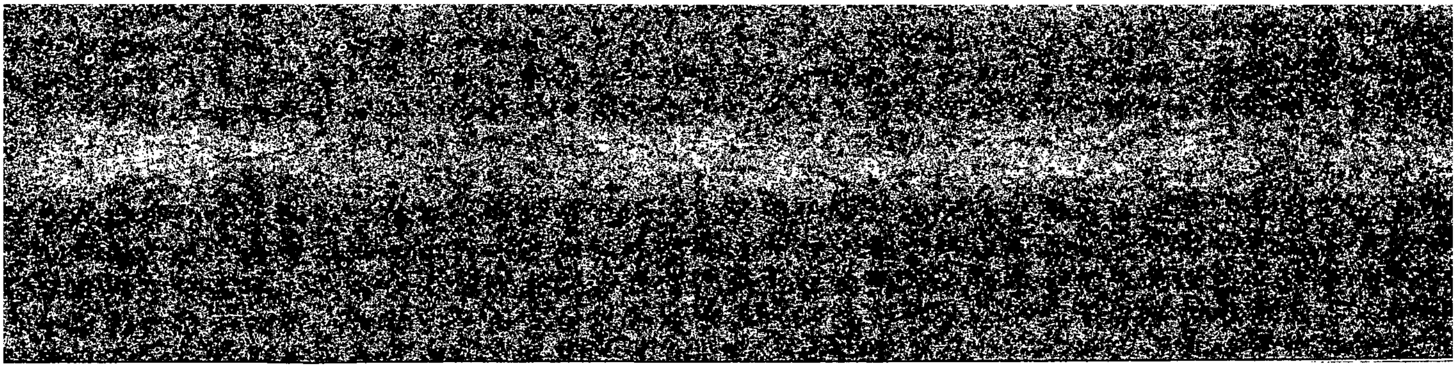
The Blue Mountains province is an area of complex geology, numerous hot springs, and poorly known heat flow. The geology is dominated by Mesozoic volcanic, sedimentary, and intrusive igneous rocks overlain by Tertiary volcanic and sedimentary units. The youngest dated volcanic activity is Pliocene in age, although basalt of Quaternary age was mapped by Brown and Thayer (1966). Heat flow based on a few scattered values appears to be in the range of 1.5 to 2.0 HFU. Several of the hot springs are located near the larger towns of the region, and utilization of the geothermal resources for nonelectric applications may be feasible. The overall potential of the Blue Mountains province is believed to be intermediate.

High Lava Plains

A belt of extensively faulted young volcanic rocks extends across central Oregon from the Cascade Range on the west to Harney Basin on the east. The volcanic rocks, ranging in age from Eocene to Holocene, are a bimodal suite of basaltic and silicic lavas with intercalated sedimentary strata, widespread silicic ash flow tuff, and scattered rhyolite domes. Silicic volcanic activity generally shows a progressive decrease in age from east to west (MacLeod and others, 1975). Basaltic volcanism lacks this pattern, and Holocene basalts are found at both the western and eastern ends of the belt.

Numerous hot springs and wells occur at the east end of the province, but only a few hot springs are found in the western portion where the age of silicic volcanism is youngest. Extensive heat-flow work along the Brothers fault zone, which spans the province, has shown heat-flow values to be higher in the zone than in areas to the north (Hull and others, 1977a). Portions of the zone are characterized by heat flow in excess of 2.5 HFU; and "blind" heat-flow anomalies (anomalies without nearby hot springs or fumaroles) have been found along the zone, for example, at Glass Buttes in northeast Lake County (Bowen and others, 1977; Hull, 1976).

The young volcanism, areas of high heat flow, and scattered hot springs and wells suggest that the High Lava Plains province has a high potential for discovery and future development of geothermal resources (Figure 3). In the Harney Basin near Burns is clear evidence of geothermal fluids with temperatures adequate for nonelectric applications (Hull and others, 1977a). There are no identified systems with temperatures suitable for electric power generation, but the available evidence suggests that higher temperature fluids may be found by future exploration.



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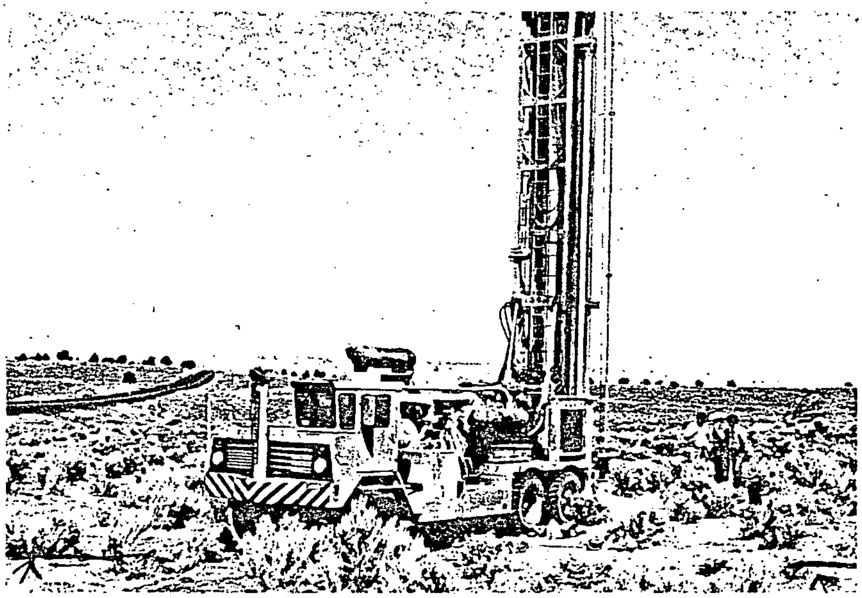

Figure 3. Drilling rig at site of heat-flow hole near Riley Junction in Harney County.

Basin and Range

The geology of the Basin and Range province is generally similar to that of the High Lava Plains to the north. The Brothers fault zone, which crosses the High Lava Plains, marks the northern terminus of the structural style characteristic of the Basin and Range (Lawrence, 1976).

The Basin and Range province, characterized by numerous hot springs, contains areas of established geothermal resource utilization at Klamath Falls (Figures 4 and 5) and Lakeview (Figure 6). Heat-flow studies have shown a wide variation in values, and many individual values appear to be affected by shallow groundwater movement. The average heat flow in the province is between 2.0 and 2.5 HFU (Bowen and others, 1977). Typical geothermal gradients for the province range from 50° to 80°C per km.

Most of the volcanic rocks of the province are too old to represent a direct heat source for geothermal fluids, yet the numerous hot springs and overall high heat flow suggest a high potential. The key unanswered question is whether temperatures sufficiently high for electric power generation are to be found in the region. The presence of hot water at the boiling point is well known at Klamath Falls and Lakeview, and geochemical studies of hot springs indicate that reservoir temperatures of approximately 200°C may be present in the Alvord Valley at the eastern edge of the province (Mariner and others, 1974). The nature of the heat source at Klamath Falls and Lakeview is still unclear, and additional research and deep drilling are needed.

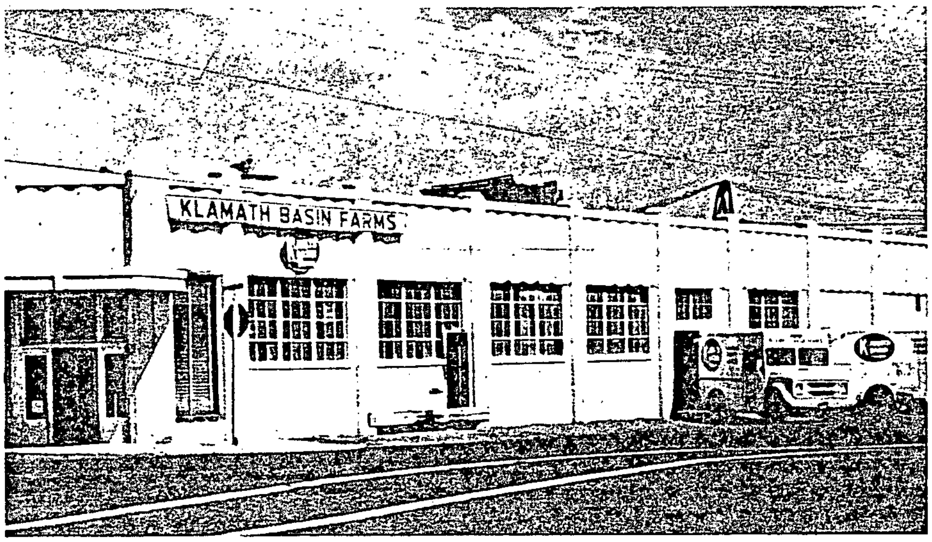

Figure 4. Klamath Falls dairy which uses natural hot water for pasteurization.

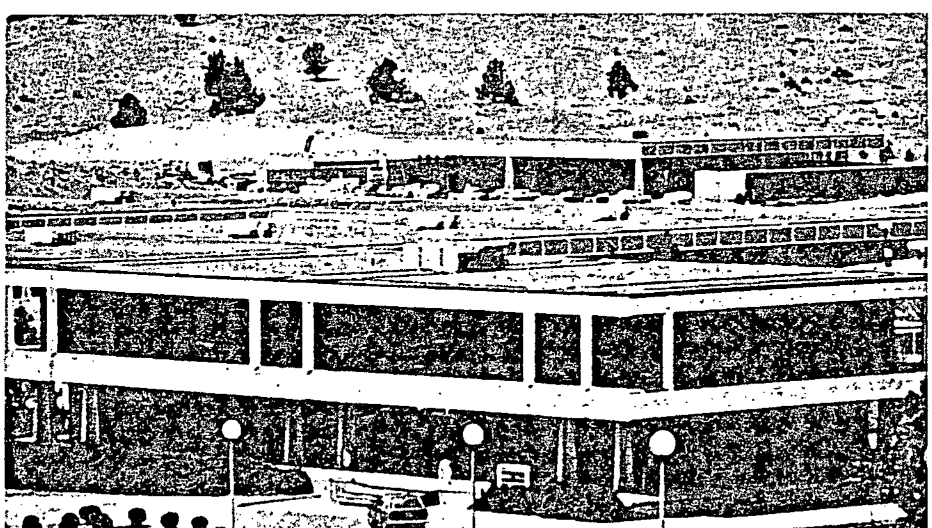

Figure 5. Snell Hall, Oregon Institute of Technology, Klamath Falls. All nine OIT campus buildings are heated by geothermal energy.

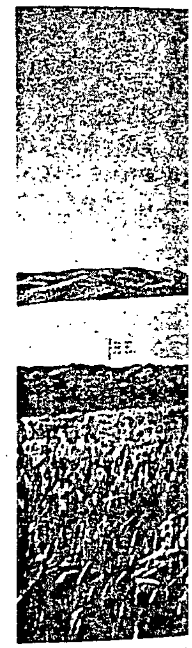

Figure 6.

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Figure 6. Lakeview greenhouse heated by geothermal energy.

Owyhee Upland

The southeastern corner of Oregon lies in the Owyhee Upland province, underlain mainly by Miocene to Holocene volcanic rocks and intercalated sedimentary units. Hot springs are scattered throughout the province. Heat-flow work to date has been concentrated near the Idaho border in the eastern part of the province in the western portion of the Snake River Basin. Hot springs and anomalous heat flow are associated with faults (Bowen and Blackwell, 1975; and Couch, 1977); and detailed heat-flow work has revealed "blind" heat-flow anomalies (Bowen and Blackwell, 1975). Heat flow over much of the province appears to be in excess of 2.0 HFU.

Currently some geothermal resources are utilized at Vale in northern Malheur County, and the overall potential for nonelectric applications of geothermal energy is high. The potential for fluids of sufficiently high temperature for generation of electricity is not known. Estimates based on geochemical studies of the Vale hot springs suggest a reservoir temperature of approximately 160°C (Renner and others, 1975). At Neal (Bully Creek) hot springs, the estimated reservoir temperature is 180°C.

Summary

Available geologic mapping; ages of volcanic rocks; heat-flow measurements; and the distribution and chemistry of fumaroles, hot springs, and wells are collectively utilized to evaluate the geothermal energy resource potential of the various physiographic provinces in Oregon. Provinces having high potential are the High Cascades, High Lava Plains, Basin and Range, and Owyhee Upland. Areas of intermediate potential on a regional basis are the Deschutes-Umatilla Plateau, the Blue Mountains province in northeastern Oregon, and possibly the Western Cascades province. Several provinces in western Oregon appear to have a low potential for geothermal resources under existing economic and technological conditions.

The existing data base is generally insufficient for outlining areas of greater or lesser potential within each province, although the potential of some selected specific sites has been estimated by White and Williams (1975). Exploration has indicated that potentially important geothermal resources may occur in areas lacking nearby surface manifestations such as hot springs, hot-water wells, or fumaroles.

The geothermal energy potential of the Western Cascade and High Cascade provinces is poorly understood. Reliable heat-flow measurements are lacking for the High Cascades, and data for the Western Cascades are sparse. There may be a rather sharp transition between low heat flow in the Willamette Valley (0.8 to 1.0 HFU) and significantly higher heat flow in the Cascade Range (*greater than 1.5 HFU*); and the location of this boundary is important for prediction of the area of geothermal resource potential. An area of low heat flow extends over the western third of the State, although there could be localized exceptions to this pattern in areas of younger volcanic rocks.

Within the High Lava Plains and Basin and Range provinces, heat-flow values vary widely because of complexities in geologic structure and the influence of moving ground water. Detailed hydrologic and heat-flow studies will be required to learn the causes and areal extent of many of these variations. A better understanding of these anomalies will be necessary in order to properly evaluate the geothermal energy potential of these provinces.

This paper is presented as a progress report summarizing a continuing geothermal resource assessment by the Department. It is hoped that the evaluation presented herein will be of value to land use planners, government agencies, and public and private energy research groups.

Acknowledgments

In addition to those noted in the references listed below, a number of individuals and organizations have aided in the collection and interpretation of the data discussed herein. We have had numerous stimulating discussions of Oregon's geothermal resources with Paul Hammond of Portland, Walter Youngquist of Eugene, John Hook of Salem, Paul Lineau and John Lund of Klamath Falls, and Ed Groh and Larry Chitwood of Bend.

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An initial, but farseeing, overview of Oregon's geothermal resource potential by Groh (1966) was based on geological considerations. Since then, the Oregon Department of Geology and Mineral Industries has been conducting geological, geophysical, and geochemical investigations of the State's geothermal resources. The results of these studies have been published or released to open file. The present article is a summary of Oregon's geothermal energy potential, based on these studies and work by others, especially the U.S. Geological Survey.

Methods

Geothermal energy resources that can be utilized under existing technology and economic conditions occur as localized concentrations of natural steam and hot water in permeable rocks of the earth's crust at depths generally no greater than 3,000 m (about 10,000 ft). The primary tools we have utilized to evaluate geothermal resources on a regional basis are (1) heat-flow calculations based on measurements in drill holes; (2) an inventory of geothermal phenomena such as hot springs, fumaroles, and

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ot-water wells; and (3) geologic mapping to indicate faults and reas of young volcanic rocks. Other geophysical techniques, uch as gravity, magnetic, and electrical resistivity surveys, id in the delineation of geologic structures in potential geo-hermal resource areas; and geochemical analyses of hot-spring luids aid in the interpretation of the temperature and fluid uality of individual geothermal reservoirs.

eat flow

Heat flows from the hot interior of the earth toward the urface. Usable geothermal energy under existing technology is ased upon the location of concentrations of hot fluids that may ccur either in areas of Quaternary volcanism where subsurface odies of magma or cooling igneous rocks are present or in areas here favorable structural conditions allow the deep circulation nd heating of ground water in faults and permeable rocks. The atter mechanism normally produces geothermal resources only in reas of high crustal heat flow. Heat-flow measurements thus re-resent a direct means of outlining regions of higher-than-average eat flow where geothermal energy may be expected to occur and then ocating concentrations of geothermal resources within these re-ions.

Heat flow is calculated as the product of the geothermal radient (the increase in temperature with depth) measured in the rill hole and thermal conductivity (ability of a material to trans-er heat by conduction) measured on rock samples taken from the rill hole.

The gradient data are corrected for influence of irregular opography near the drill hole; and the heat-flow value, if nec-ssary, is corrected for the heat produced by natural radioactiv-ty in the earth's crust. Because the solar heat flux at the sur-ace is several thousand times greater than the normal heat flux rom depth, reliable values of geothermal heat flow can be obtained nly from drill holes deeper than 20 m (65 ft).

The results of the Department's heat-flow studies over the ast five years have been given by Bowen (1972, 1975), Bowen and lackwell (1973, 1975), Bowen and others (1975, 1976, and 1977), ull (1975), Hull and others (1976, 1977a, and 1977b), and Black-ell and others (1977). Similar work by the U.S. Geological Sur-ey has been reported by Diment and others (1975) and Sass and thers (1973, 1976a, 1976b, and 1976c).

eothermal phenomena

Natural leakage of hot fluids from geothermal systems with-in the earth's crust to the earth's surface results in hot springs (springs with a temperature 10°C above ambient temperature) and fumaroles (volcanic vents from which gases and vapors are emitted). n inventory of these phenomena in Oregon was made by Bowen and eterson (1970). Hot springs and fumaroles are not associated with all geothermal resources, however; and other search tech-niques, such as heat-flow measurements, are desirable in geo-logically favorable areas.

Geologic mapping

Geothermal energy resources are often found in areas of geo-logically recent volcanic activity. As geologic mapping and age dating of volcanic rocks are the most efficient methods of locat-ing and outlining these areas, there is a continuing need for de-tailed geologic mapping as an aid in systematic geothermal resourc appraisal.

Geothermal Energy Potential

The heat-flow data, inventory of hot springs, and geologic maps have been combined and interpreted by the authors to give a preliminary regional evaluation of Oregon's geothermal energy potential. Since heat flow and the distribution of hot springs are closely related to the State's geologic history, the eval-uation is discussed in terms of Oregon's physiographic provinces, which are shown in Figure 1. A preliminary heat-flow map of the State is included as Figure 2. The preliminary nature of this evaluation should be stressed, because the exact boundaries of the areas of various potential are not yet accurately delineated; and the search by both industry and public groups for resources within the areas of higher potential has barely begun. To date, only four deep production tests (holes deeper than 610 m [2,000 ft]) for geothermal resources have been drilled in Oregon.

The geothermal energy potential of the various provinces is categorized into three subdivisions, based on existing technology and economics: (1) areas of maximum inferred potential, (2) areas of intermediate potential, and (3) areas of low potential. Areas of maximum potential have a geologic environment favorable for the formation of geothermal resources of temperatures that are high enough to be used for electric power generation as well as for lower temperature nonelectric applications such as space heat-ing and industrial-process heating. The exploration for and sub-sequent development of these resources will be expensive and time consuming. Areas of intermediate potential most likely contain resources suitable for nonelectric applications. Under existing economic conditions and current technology, electric power gen-eration from geothermal energy will be unlikely in regions with intermediate potential. Areas of low potential will not likely produce geothermal energy in substantial quantity in the fore-seeable future.

Areas of maximum potential, shown as "High" in Figure 2, have regional heat-flow values ranging from 1.9 to more than 2.5 micro-calories per cm^2 sec (heat-flow units or HFU), numerous thermal manifestations in the form of hot springs and fumaroles, and vol-canism that occurred within the last 2 million years. Areas of intermediate potential are characterized by scattered hot springs ınd/or warm-water wells, heat-flow values between 1.5 and 2.0 HFU, ınd most recent volcanism generally ranging in age from Miocene :o Pliocene. An exception is the pattern of heat flow in the Jestern Cascades which ranges from less than 1.5 HFU at the west ıargin of the province to about 2.5 at the east margin adjacent :o the Holocene volcanism in the High Cascades. Areas shown as 'Low" in Figure 2 are considered to have low potential under)resent utilization technology as they have heat-flow values jenerally less than 1.2 HFU, volcanic rocks that are Miocene in ıge or older, and no thermal manifestations.

The interpretation of the potential of some geologic pro- /inces will change as (1) future field studies shed new light on 'esource occurrence, (2) utilization technology improves, and (3) economic conditions change, with respect to alternate energy ;ources. It may eventually be possible to transport geothermal ɜnergy from areas of resource occurrence to areas of high energy demand, either by conversion to electricity or as hot water via)ipelines.

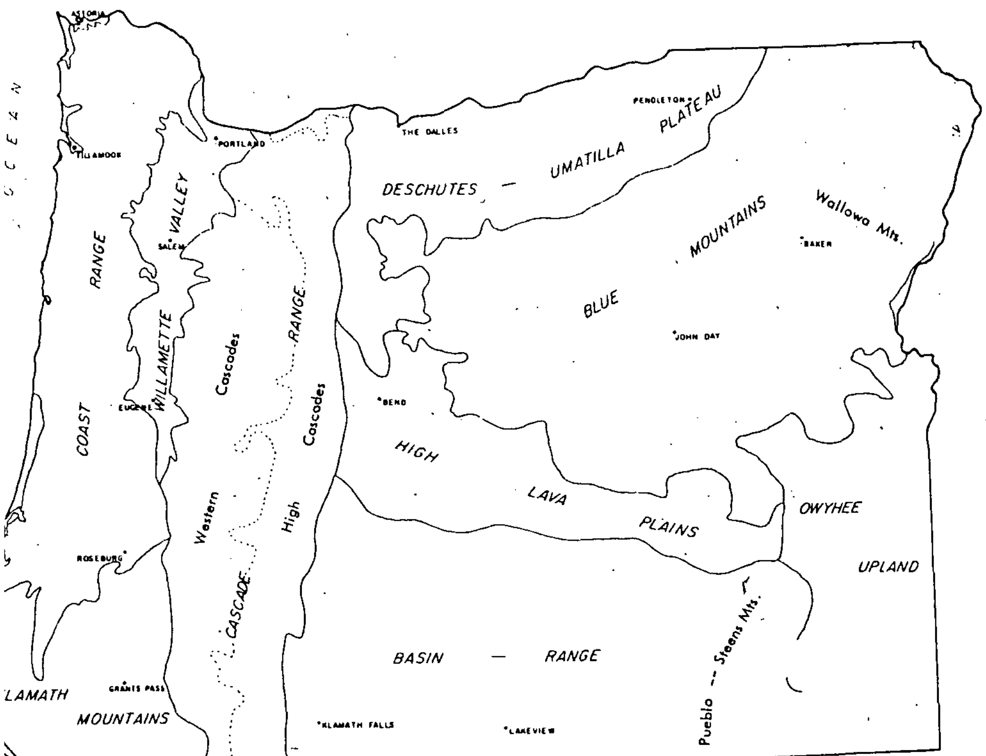


Figure 1. Physiographic provinces of Oregon.

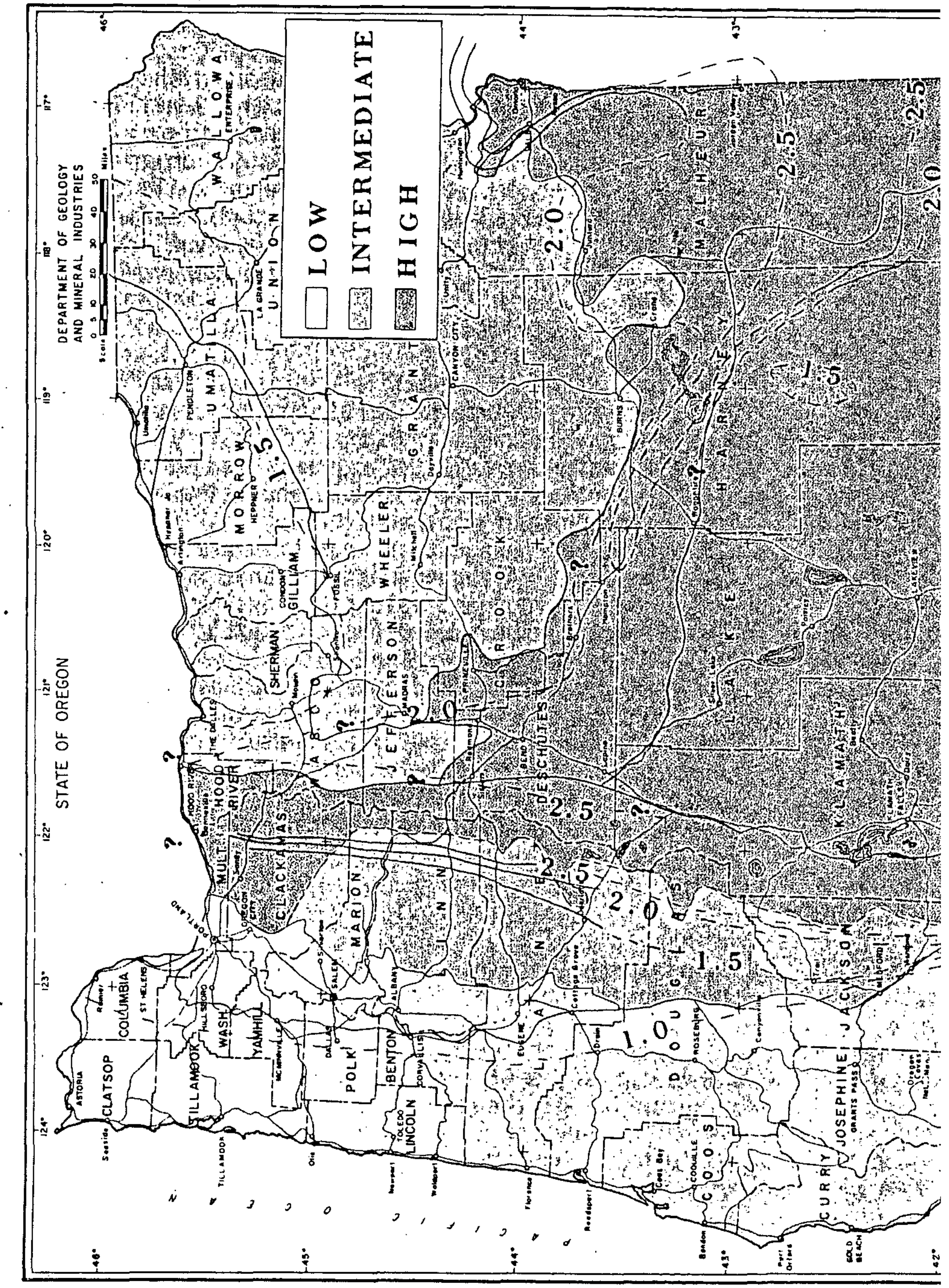


Figure 2. Preliminary heat-flow map of Oregon showing geothermal energy potential of various physiographic provinces. Heat-flo contours indicate heat-flow units of microcalories per cm² sec

ast Range

No hot springs are reported in the Coast Range in Oregon, at flow based on meager data is less than 1.0 HFU, and the ungest volcanic rocks are Miocene in age (more than 12 million ars old). Heat flow in the Coast Range, as shown in Figure 2, based on scattered measurements in shallow wells and on ap- oximate bottom hole temperatures reported for deeper wells illed for oil and gas. No holes have been drilled for heat- ow data in the province. Existing information, however, sug- sts that the area has a low potential for geothermal energy sources.

llamette Valley

Heat-flow values for the Willamette Valley are reported by wen and others (1977) and Blackwell and others (1977). System- ic measurement of temperature gradients in predrilled wells in 76 in the vicinity of Portland, Salem, and Eugene failed to de- ct any obvious concentrations of geothermal resources (Hull and hers, 1977b). There are no known hot springs or other geother- l phenomena in the province. Although most volcanic rocks are cene to Miocene in age, the youngest volcanic rocks near Port- nd may be less than 1 million years old (Allen, 1975). Further rk to evaluate the potential near Portland is desirable.

Temperature gradients measured to date in the Willamette lley are typically 20° to 40°C per km. Extrapolation of these adients indicates that the 180° to 200°C temperatures required r electricity generation will not likely be encountered at depths ss than 4 or 5 km, depths beyond the economic limit of drilling.

amath Mountains

The Klamath Mountains geologic province encompasses a broad ea of rocks of Mesozoic age (65 to 225 million years). Hot rings are not found in the province except at its eastern bor- r adjacent to the younger rocks of the Western Cascades pro- nce. Measured temperature gradients are extremely low, rang- g from 10° to 20°C per km; and observed heat-flow values re- rted by Diment and others (1975) are less than 1.5 HFU. The othermal energy potential of the Klamath Mountains province is judged to be low. The very low temperature gradients indicate at hot fluids would be encountered only at depths too great r economically feasible resource development.

estern Cascades

The Western Cascades province is a belt of volcanic and vol- niclastic rocks of Tertiary age which lie on the western flank the present Cascade Range. The volcanic rocks of the zone pear to be too old to be a heat source for geothermal resources; yet there is a north-trending belt of hot springs in the eastern third of the province, and a regional heat-flow study has revealed values ranging systematically from 1.0 HFU in the west to about 3.0 HFU in the east.

The high heat-flow values at the east boundary (Figure 2) are considerably in excess of normal, suggesting either localized heat source(s) at the eastern border of the province, deep circulation of hot fluids from the High Cascades to the east, or lateral effects of crustal heating associated with the volcanism of the High Cascades.

Although the potential of the province is considered to be intermediate, except along the eastern border, it may ultimately prove to be one of Oregon's most important geothermal energy sources because of its proximity to major population centers and energy markets in the Willamette Valley. Additional work is clearly needed in order to define the geologic controls over hot spring systems, to ascertain the nature of the heat source, and to establish more accurately the transition zone between low heat flow at the west edge of the Western Cascades province and the much higher heat flow at the east boundary of the area.

High Cascades

The High Cascades are characterized by numerous Holocene volcanoes, some of which have been active within the past few thousand years. Volcanoes such as Mount Hood and the Three Sisters and their underlying magma are obvious heat sources. No reliable heat-flow values have been reported for the High Cascades, and the only known geothermal manifestations are warm springs and fumaroles on Mount Hood. The paucity of hot springs in the High Cascades is not surprising in view of the abundant precipitation that soaks through the porous rocks to mask the heat that must be underground. The areas surrounding the High Cascade volcanoes are some of the most promising geothermal resource areas in the state, but few factual data are available for this province.

Deschutes-Umatilla Plateau

The northern part of Oregon east of the Cascade Range is a broad plateau underlain by a thick sequence of Miocene flood basalts of the Columbia River Group. There are few hot springs or warm wells, no Quaternary volcanic rocks, and few reliable heat-flow values in the province. Heat flow, based on values reported by Sass and others (1971) and Munroe and Sass (1974) from holes in southern Washington and geothermal gradients measured in Oregon, appears to be approximately 1.5 HFU. The Oregon gradient values, which were measured in relatively shallow holes, are affected by ground-water aquifers in the somewhat permeable basalt. A single heat-flow value of 1.9 HFU was obtained from a hole drilled in a pre-Tertiary granitic intrusive body at the southern boundary of the province. Existing data show typical eothermal gradients of 30° to 40°C per km for the province. he geothermal energy potential of the Deschutes-Umatilla Plateau is considered to be intermediate.

ue Mountains

The Blue Mountains province is an area of complex geology, imerous hot springs, and poorly known heat flow. The geology is minated by Mesozoic volcanic, sedimentary, and intrusive igne-is rocks overlain by Tertiary volcanic and sedimentary units. ie youngest dated volcanic activity is Pliocene in age, although isalt of Quaternary age was mapped by Brown and Thayer (1966). eat flow based on a few scattered values appears to be in the inge of 1.5 to 2.0 HFU. Several of the hot springs are located ar the larger towns of the region, and utilization of the geo-iermal resources for nonelectric applications may be feasible. ie overall potential of the Blue Mountains province is believed be intermediate.

gh Lava Plains

A belt of extensively faulted young volcanic rocks extends ross central Oregon from the Cascade Range on the west to Har-y Basin on the east. The volcanic rocks, ranging in age from cene to Holocene, are a bimodal suite of basaltic and silicic vas with intercalated sedimentary strata, widespread silicic h flow tuff, and scattered rhyolite domes. Silicic volcanic tivity generally shows a progressive decrease in age from east west (MacLeod and others, 1975). Basaltic volcanism lacks is pattern, and Holocene basalts are found at both the western d eastern ends of the belt.

Numerous hot springs and wells occur at the east end of the ovince, but only a few hot springs are found in the western rtion where the age of silicic volcanism is youngest. Exten-ve heat-flow work along the Brothers fault zone, which spans ie province, has shown heat-flow values to be higher in the ne than in areas to the north (Hull and others, 1977a). Por-ons of the zone are characterized by heat flow in excess of 5 HFU; and "blind" heat-flow anomalies (anomalies without earby hot springs or fumaroles) have been found along the ne, for example, at Glass Buttes in northeast Lake County owen and others, 1977; Hull, 1976).

The young volcanism, areas of high heat flow, and scattered t springs and wells suggest that the High Lava Plains province is a high potential for discovery and future development of geo-iermal resources (Figure 3). In the Harney Basin near Burns is ear evidence of geothermal fluids with temperatures adequate r nonelectric applications (Hull and others, 1977a). There are identified systems with temperatures suitable for electric wer generation, but the available evidence suggests that higher mperature fluids may be found by future exploration.

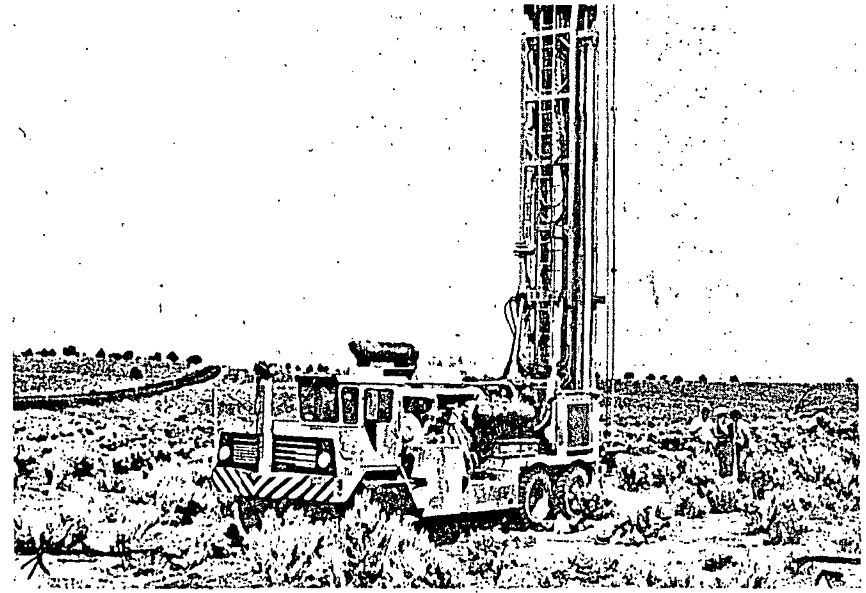


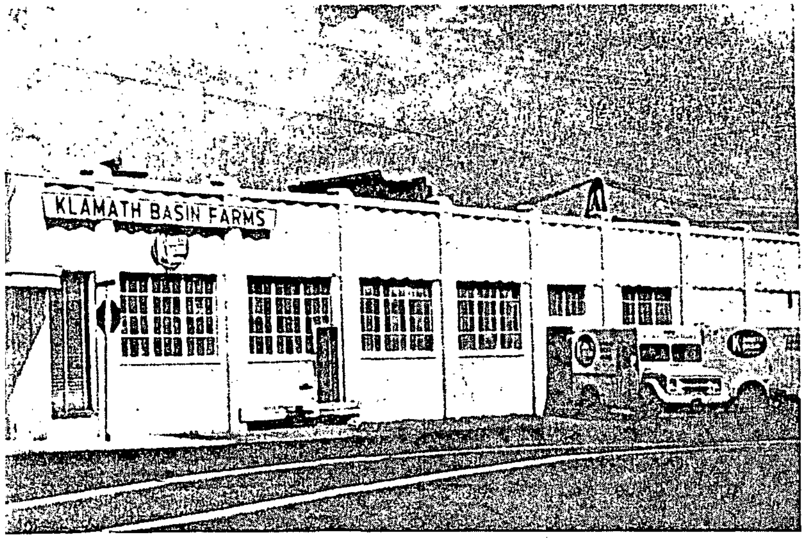
Figure 3. Drilling rig at site of heat-flow hole near Riley Junction in Harney County.

Basin and Range

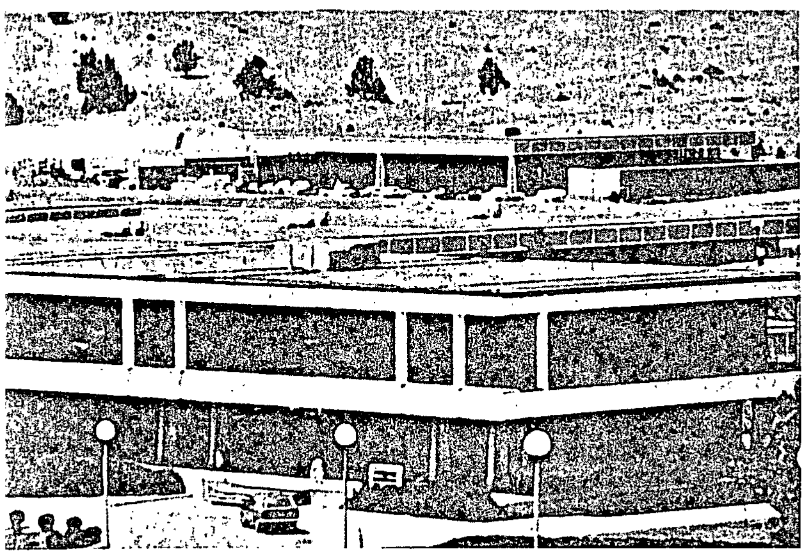
The geology of the Basin and Range province is generally similar to that of the High Lava Plains to the north. The Brothers fault zone, which crosses the High Lava Plains, marks the northern terminus of the structural style characteristic of the Basin and Range (Lawrence, 1976).

The Basin and Range province, characterized by numerous hot springs, contains areas of established geothermal resource utilization at Klamath Falls (Figures 4 and 5) and Lakeview (Figure 6). Heat-flow studies have shown a wide variation in values, and many individual values appear to be affected by shallow groundwater movement. The average heat flow in the province is between 2.0 and 2.5 HFU (Bowen and others, 1977). Typical geothermal gradients for the province range from 50° to 80°C per km.

Most of the volcanic rocks of the province are too old to represent a direct heat source for geothermal fluids, yet the numerous hot springs and overall high heat flow suggest a high potential. The key unanswered question is whether temperatures sufficiently high for electric power generation are to be found in the region. The presence of hot water at the boiling point is well known at Klamath Falls and Lakeview, and geochemical studies of hot springs indicate that reservoir temperatures of approximately 200°C may be present in the Alvord Valley at the eastern edge of the province (Mariner and others, 1974). The nature of the heat source at Klamath Falls and Lakeview is still unclear, and additional research and deep drilling are needed.



.4. *Klamath Falls dairy which uses natural hot water* ɔr *pasteurization.*



. *Snell Hall, Oregon Institute of Technology, Klamath* ls. *All nine OIT campus buildings are heated by geo-* rmal *energy.*

Figure 6. Lakeview greenhouse heated by geothermal energy.

Owyhee Upland

The southeastern corner of Oregon lies in the Owyhee Upland province, underlain mainly by Miocene to Holocene volcanic rocks and intercalated sedimentary units. Hot springs are scattered throughout the province. Heat-flow work to date has been concentrated near the Idaho border in the eastern part of the province in the western portion of the Snake River Basin. Hot springs and anomalous heat flow are associated with faults (Bowen and Blackwell, 1975; and Couch, 1977); and detailed heat-flow work has revealed "blind" heat-flow anomalies (Bowen and Blackwell, 1975). Heat flow over much of the province appears to be in excess of 2.0 HFU.

Currently some geothermal resources are utilized at Vale in northern Malheur County, and the overall potential for nonelectric applications of geothermal energy is high. The potential for fluids of sufficiently high temperature for generation of electricity is not known. Estimates based on geochemical studies of the Vale hot springs suggest a reservoir temperature of approximately 160°C (Renner and others, 1975). At Neal (Bully Creek) hot springs, the estimated reservoir temperature is 180°C.

Summary

Available geologic mapping; ages of volcanic rocks; heat-flow measurements; and the distribution and chemistry of fumaroles, hot springs, and wells are collectively utilized to evaluate the geothermal energy resource potential of the various physiographic provinces in Oregon. Provinces having high potential are the High Cascades, High Lava Plains, Basin and Range, and Owyhee Upland. Areas of intermediate potential on a regional basis are the Deschutes-Umatilla Plateau, the Blue Mountains province in northeastern Oregon, and possibly the Western Cascades province. Several provinces in western Oregon appear to have a low potential for geothermal resources under existing economic and technological conditions.

The existing data base is generally insufficient for outlining areas of greater or lesser potential within each province, although the potential of some selected specific sites has been estimated by White and Williams (1975). Exploration has indicated that potentially important geothermal resources may occur in areas lacking nearby surface manifestations such as hot springs, hot-water wells, or fumaroles.

The geothermal energy potential of the Western Cascade and High Cascade provinces is poorly understood. Reliable heat-flow measurements are lacking for the High Cascades, and data for the Western Cascades are sparse. There may be a rather sharp transition between low heat flow in the Willamette Valley (0.8 to 1.0 HFU) and significantly higher heat flow in the Cascade Range (greater than 1.5 HFU); and the location of this boundary is important for prediction of the area of geothermal resource potential. An area of low heat flow extends over the western third of the State, although there could be localized exceptions to this pattern in areas of younger volcanic rocks.

Within the High Lava Plains and Basin and Range provinces, heat-flow values vary widely because of complexities in geologic structure and the influence of moving ground water. Detailed hydrologic and heat-flow studies will be required to learn the causes and areal extent of many of these variations. A better understanding of these anomalies will be necessary in order to properly evaluate the geothermal energy potential of these provinces.

This paper is presented as a progress report summarizing a continuing geothermal resource assessment by the Department. It is hoped that the evaluation presented herein will be of value to land use planners, government agencies, and public and private energy research groups.

Acknowledgments

In addition to those noted in the references listed below, a number of individuals and organizations have aided in the collection and interpretation of the data discussed herein. We have had numerous stimulating discussions of Oregon's geothermal resources with Paul Hammond of Portland, Walter Youngquist of Euge John Hook of Salem, Paul Lineau and John Lund of Klamath Falls, and Ed Groh and Larry Chitwood of Bend.

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GEOTHERMAL OPEN-FILE REPORT RELEASED

"Heat Flow Study of the Brothers Fault Zone, Oregon," by Don H David Blackwell, Richard G. Bowen, and Norman V. Peterson, ha been issued by the Department as Open-file Report 0-77-3. Th 1975-76 study, which was financed by U.S. Geological Survey E tramural Research Grant 14-08-0001-G-200, covers an area east the Cascades between Burns and Bend.

Heat flow along the Brothers fault zone is characterized a wide range of values. Anomalously high heat flow detected tween Glass Buttes and Harney Basin, near the town of Burns, be evidence of widespread geothermal resources near the east of the Brothers fault zone.

The 101-page report, available at the Portland office, s for $3.00. It includes geothermal data and location maps.

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DEPARTMENT PUBLISHES REVISED REGULATIONS

Miscellaneous Paper No. 4 has been revised as of July 1, 1977 to two parts: Part I, Rules, Regulations and Laws Relating t Oil and Gas Exploration; and Part II, Rules, Regulations and l Relating to Geothermal Resources. The price is $1.00 each or $2.00 per set.

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USGS PRELIMINARY GEOLOGIC MAP ON OPEN FILE

"Preliminary Reconnaissance Geologic Map of Part of Jackson Co Oregon," by James G. Smith and Norman J. Page, is USGS Open-f Map 77-318.

The black-and-white map may be seen in the Department's Po land office, and copies may be ordered for $2.00 each.

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