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THE SEARCH FOR HOT ROCKS

GEOTHERMAL EXPLORATION, NORTHWEST

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Dry volcanic regions in the Pacific Northwest signal potential for geothermal energy sources. Attention is focusing now on exploring known probable sources for development and finding new ones. Northern California's working plant shows an example.

J. ERIC SCHUSTER

Geothermal energy exists in all rocks deep in the earth's crust. Hot igneous rock at moderately shallow depths makes it possible to utilize geothermal energy because these bodies bring high temperatures within reach of the drill.

Heat from the radioactivity of uranium and thorium in the earth's crust rises slowly and constantly to the cooler surface. Ultimately, this heat is radiated into the air. Although the total amount of heat emitted in this way is very large, the amount escaping from an area of a few square feet is usually too small to be measured except with very sensitive instruments.

The temperature difference between the hot interior of the earth and its relatively cool surface produces a thermal gradient — the greater the depth, the higher the temperature. At depths of 15 miles or more, temperatures are so high that rocks lose their strength and become plastic, or begin to melt. If ruptures or dislocations in the earth's upper crust are present, some of this deep molten rock (magma) may be forced upward through these ruptures to form large intrusive rock bodies, or break through the earth's surface to form volcanoes and lava flows. This is currently taking place in Hawaii, Iceland, the Mediterranean, and throughout a volcanic belt encircling the Pacific Ocean. The Pacific Northwest, part of this belt, shows abundant evidence of recent activity in the volcanoes, lava flows, and hot springs of Washington, Idaho, Oregon, and northern California.

For a geothermal reservoir to exist, there are four requirements:

First, a heat source in the form of a cooling igneous rock at shallow depth in the crust — probably within five miles of the surface.

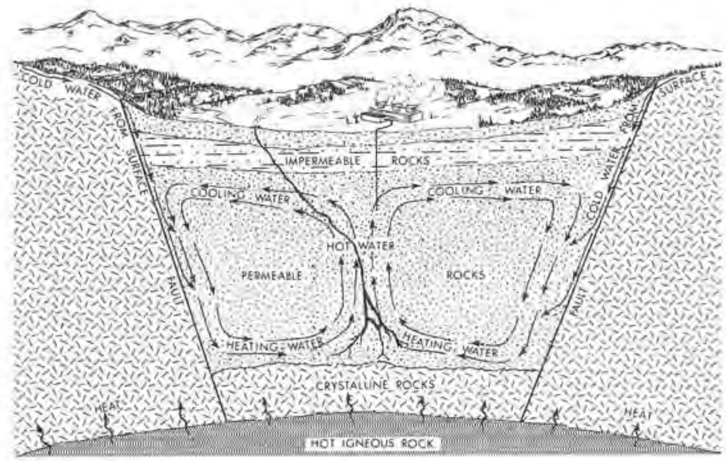
Second, a suitable reservoir rock above the cooling igneous rock to hold and transmit large quantities of fluid. The reservoir rock must, therefore, be porous and permeable.

Third, fluid in the reservoir rock to transfer heat from the cooling igneous rock to a geothermal well. Technically, any hot rock is capable of producing energy, but unless there is a fluid within it to serve as a heat transporting agent, there is no economical way to transfer heat to the surface.

Fourth, a cap rock above the geothermal reservoir to prevent hot fluids within the reservoir rock from escaping rapidly to the surface. Unlike the reservoir rock, it must have low permeability to restrict the flow of fluids. A source of recharge for the reservoir is desirable, to replace the hot fluid lost through leakage (hot springs) or production from drilled wells.

Given these four conditions, the geothermal reservoir may then be either of two general types — dry steam or hot water.

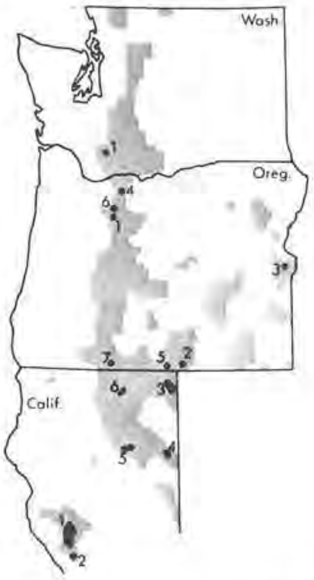
The dry steam type is hotter than the boiling point of water, and the confining pressure is low enough so steam can exist within the reservoir. Therefore, a well drilled into a dry steam reservoir will produce steam with little or no water. This steam can be piped into a turbine to produce electrical power with very little treatment; only the removal of particles is necessary. A hot water geothermal reservoir also has temperatures above the boiling point of water, but the confining pressure on the reservoir is great enough to prevent the water from vaporizing. The water, therefore, exists in the reservoir as a liquid. When a well is drilled into a hot water geothermal reservoir, the confining pressure is removed in the vicinity of the well bore, and the superheated water partially flashes to steam. The flashing of water to steam produces a large increase in volume, causing a mixture of boiling water and steam to rush up the drill hole. At the surface, the water must be separated from the steam before the steam can be fed into a turbine. Since the quantity of steam is typically only about 20 percent of the total volume of flow, production of electrical power from a hot water geothermal reservoir involves disposal of large quantities of hot, often saline, water. For example, generation of one kilowatt of electricity from a dry steam geothermal reservoir requires the disposal of about five pounds of waste water, while generation of one kilowatt of electricity from a typical hot water geothermal reservoir requires the disposal of about 75 pounds of waste water.



Idealized cross-sectional view of a geothermal reservoir. Hot igneous rocks at depth supply heat to the water-filled reservoir rock above. The hot water is less dense and rises until the impermeable cap rock is reached. If fissures are present in the cap rock, part of the geothermal fluid may escape and form hot springs or fumaroles at the surface. When the water reaches the area of the cap rock, it begins to move outward, cool, and become more dense. The greater density or weight causes the cooler water to move downward and be recycled, along with recharge water that might enter the reservoir along faults or fractures. A power plant is shown, drawing steam and/or hot water from the upper part of the reservoir.

California has the greatest potential for geothermal development of any state.

The only geothermal reservoir being used to generate electrical power in the United States is at The Geysers, located in California about 75 miles north of San Francisco. Power generation began in 1960, when a 12-megawatt plant went into operation (one megawatt equals 1000 kilowatts). Since our per capita power requirement is estimated at one kilowatt per day, the original plant supplied the electrical needs of about 12,000 people. Additional facilities are now operating, and the present capacity is



PACIFIC NORTHWEST GEOTHERMAL RESOURCE AREAS

EXPLANATION

Areas valuable prospectively

Known geothermal resource areas

Washington:
1. Mount St. Helens

Oregon:
1. Breitenbush Hot Springs
2. Crump Geyser
3. Vale Hot Springs
4. Mount Hood
5. Lakeview
6. Carey Hot Springs
7. Klamath Falls

Northern California:
1. The Geysers
2. Calistoga
3. Lake City
4. Wendel-Amedee
5. Lassen
6. Glass Mountain

From: U.S. Geological Survey Circular 647, 1971

250 megawatts, or enough power to supply about 250,000 people. By 1975, production should reach 600 megawatts; the ultimate capacity of the geothermal field is judged to be over 1000 megawatts. Within the next two years, The Geysers is expected to become the world's largest power-producing geothermal field. Lardarello, Italy, is presently the world's largest, generating about 350 megawatts.

The Geysers is a dry steam geothermal reservoir so steam can be passed directly from wells to turbines; the only treatment required is removal of rock particles. Steam reaches the turbines at about 100 pounds per square inch pressure and about 350 degrees F. From the turbine, the steam enters a barometric condenser which condenses the steam to liquid water. The marked decrease in volume creates a vacuum at the exhaust end of the turbine, thereby producing greater turbine efficiency. The waste water is then pumped into a cooling tower where large fans evaporate most of the water into the atmosphere. What remains is reinjected into the geothermal reservoir.

The steam at The Geysers contains about one-half of one percent of gases other than steam, including carbon dioxide, ammonia, methane, hydrogen sulfide, and hydrogen. Hydrogen sulfide (rotten egg gas) although present in very minor amounts, causes problems because of its odor; efforts are being made to prevent its escape from the plant.

Over 100 steam wells have been drilled at The Geysers; the largest ones produce about 350,000 pounds of steam per hour. Since generating one kilowatt of electricity requires about 20 pounds of steam, these more productive wells each produce about 17.5 megawatts of electricity.

Geothermal energy is often called a renewable resource — one that cannot be exhausted by use. In the case of The Geysers, this is not true. Heated water, rising from great depth in the reservoir, carries considerable dissolved minerals, particularly silica. When the upper part of the reservoir is reached, the water begins to cool, losing its ability to carry mineral matter in solution. When this happens, the silica and other minerals are deposited in the pores and fractures of the reservoir rock. Eventually the fractures and pores completely close in the upper part of the reservoir, creating a cap rock or seal. This strong, impermeable seal prevents ground water in surrounding rocks from reaching the reservoir. The high confining pressure is thus reduced, so steam can form in the upper part of the reservoir. The seal may also prevent significant recharge from taking place. As production occurs, steam is not replenished by inflow of ground water so the reservoir at The Geysers must eventually become depleted. How soon is unknown, but The Geysers should produce power at least through the end of this century.

The self-sealing type of reservoir is not always present. If it is not, and recharge is possible, the limiting factor is the heat content of the cooling igneous rock. A large, crystallizing body of magma may require several hundreds or thousands of years to cool. In such a case, a geothermal reservoir may be considered a renewable resource within the framework of recorded history, not, of course, in a geologic time scale.

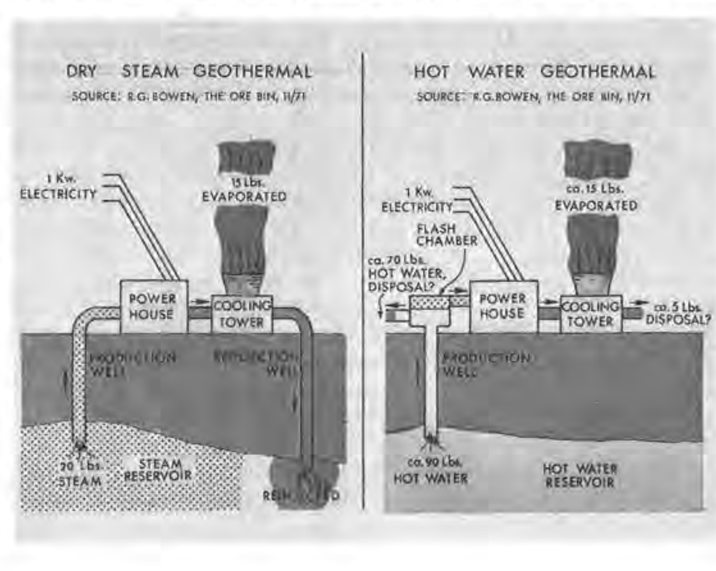
Other areas of geothermal resources in northern California are Calistoga Hot Springs, south of The Geysers, and Lake City, Wendel-Amedee, Lassen and Glass Mountain, all in northeastern California. Although some test wells have been drilled, no power sources have been developed. In southern California, the Imperial Valley has reserves estimated at about 30,000 megawatts and is probably the largest geothermal area in the world with the exception of Yellowstone National Park. Utilization has been slowed because of problems in handling corrosive brines (Imperial Valley is a hot water geothermal reservoir); much work is being done to overcome these problems.

In many parts of southern and eastern Oregon, geothermal energy is used for space heating and irrigation.

Five hundred homes, schools, and businesses are so heated at Klamath Falls, and space heating with geothermal energy is also practiced at Lakeview, Burns, and Vale.

Oregon has more young volcanic rock than any other state;

Typical plant layouts for dry steam and hot water geothermal power. The amounts of dry steam or hot water required by each type of plant to generate one kilowatt of electricity are shown, along with the amounts of effluent that must be reinjected or disposed of in some other way.



the two best known examples are probably Mount Hood and Crater Lake. The U.S. Geological Survey has classified Breitenbush Hot Springs, Crump Geyser, Vale Hot Springs, Mount Hood, Lakeview, Carey Hot Springs, and Klamath Falls as known geothermal resource areas because young volcanic rocks and surface manifestations (hot springs, geysers, and fumaroles) are present in these areas. Breitenbush Hot Springs discharges at least 900 gallons per minute of water with a maximum temperature of 198 degrees F. Several hot springs occur in the Crump Lake area, and Crump Geyser is actually a geothermal well that was drilled in 1959, abandoned, and then blew out as a geyser for more than a year before it was plugged. The Vale area has several hot springs, and a geothermal test well will be drilled to about 6000 feet early in 1973. Mount Hood is a young volcano, but the only known geothermal manifestations associated with it are fumaroles near the top of the mountain. At Lakeview, a zone of hot springs extends for about 50 miles, and an abandoned geothermal test well, drilled in 1959, is used to heat a one-half acre greenhouse. Carey Hot Springs discharges more than 300 gallons per minute of water up to 196 degrees F. At Klamath Falls, hot springs were formerly present, but a lowering of the water table caused them to dry up.

Exploration for geothermal resources in Oregon has involved the detailed geologic mapping of known geothermal resource areas, sampling of thermal water for chemical analysis, and determination of geothermal gradient in shallow drill holes. Most of the Oregon exploration is coordinated by Richard G. Bowen, a geologist with the Oregon Department of Geology and Mineral Industries in Portland.

In Idaho, an area known to be rich in geothermal sources, searching is underway. The young plutonic rocks and intrusive granite, along with 80 to 90 hot springs near the boiling point, mean considerable potential. Geothermal heat is used for space heating in Boise, and farmers along the Snake River use it for irrigation. The Snake River lava flows are basaltic rocks that are younger than those of the Columbia Plateau in Washington and Oregon, and the Craters of the Moon are a very young geologic feature.

In Washington, exploration for geothermal resources has not yet led to known usable resources. The U.S. Geological Survey has classified Mount St. Helens as a known geothermal resource area because of its recent volcanic activity, but Washington has no known geothermal reservoirs. Even though the state has young volcanic rocks and very likely the necessary sources of heat for geothermal energy, there are no hot springs, only warm and mineral springs, and these are considerably fewer than in California or Oregon. Part of the reason may be that although the Cascades are of volcanic origin from Snoqualmie Pass southward, the northern Cascades are mostly older sediments and metamorphic rocks. There is volcanic activity in the northern Cascades, but it is more localized and less widespread than in the south. Then the combination of higher than average rainfall and much porous and broken rock in Washington's Cascades means that surface water seeps down deep and may cool hot springs before they surface. There are, then, fewer clues to explore than for example in California.

Exploration for geothermal energy has always begun in areas where hot springs, geysers, or fumaroles revealed some kind of geothermal resource. Since there are no such target areas in Washington, geologic mapping is needed first to locate suitable heat sources, reservoir rocks, and structures that might allow the existence of a geothermal reservoir. The Washington State Department of Natural Resources is sponsoring a mapping project in the southern Cascade Mountains of Washington that is designed to locate target areas for further exploration. This project is being conducted by Dr. Paul Hammond of Portland State University, and the preliminary results (a geologic map) should be ready for public inspection by mid 1973.

The worldwide average geothermal gradient is about 30 degrees C/km or 87 degrees F/mile. The boiling temperature of pure water would normally be reached at a depth of about two miles. A geothermal gradient several times higher than average would warrant further investigation as a possible geothermal area. The Washington State Department of Natural Resources is making geothermal gradient measurements in an effort to learn more about the distribution of heat in the earth's crust in Washington.

The measurement of geothermal gradients and the flow of heat toward the earth's surface is not likely to lead directly to the discovery of a geothermal reservoir because such reservoirs are probably present under only a tiny fraction of Washington's land area. Therefore, the chance that any randomly located drill hole would hit a geothermal reservoir is quite small. The purpose of making geothermal gradient and heat flow measurements is to better understand the geologic history of the state. Interpretation of geothermal gradient and heat flow values is needed to understand the geology of Washington and to help define areas where the occurrence of valuable geothermal energy is most likely.

Spring and surface waters are being collected for chemical analysis by the Washington Department of Natural Resources. Because elevated temperatures found in geothermal reservoirs promote chemical reactions between water and rock, the concentrations of chemical compounds, silica for example, can sometimes indicate that water has been at high temperature even though it may be cool when it reaches the surface.

A new and potentially promising technique for locating geothermal sources lies in detecting low frequency noise that apparently emanates from the reservoirs. A program of geothermal noise recording was sponsored by the Washington Department of Natural Resources in 1971 and conducted by Dr. Robert Crosson of the University of Washington. This study failed to identify any areas of geothermal activity, partly because the nature of geothermal ground noise is not yet fully understood.

MR. SCHUSTER is a geologist with the Division of Mines and Geology in the Washington State Department of Natural Resources. As part of his duties, he is working on a program of geothermal gradient and heat flow measuring to locate target areas in Washington.