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BOISE, IDAHO GEOTHERMAL SYSTEM

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ABSTRACT

Geologic mapping and data from geothermal-water wells have provided information to delineate late Cenozoic geologic units and structures important to understanding the geothermal system of Boise as it is currently being developed. The main geothermal aquifer is a sequence of rhyolite layers and minor arkosic and tuffaceous sediments of the Miocene Idavada Group. The aquifer is confined by a unit of impermeable basaltic tuffs. The aquifer has sufficient fracture permeability to yield 150-170 °F hot water at a rate of 600 to 1200 gpm from wells drilled in the metropolitan area north of the Boise River. In this area the rhyolite lies at a depth of 900 to 2000 ft.

A conceptual model of recharge assumes percolation to a depth of 7000+ ft beneath the granitic highlands northeast of the city driven by the topographic head. Heated water convects upward through the NW-trending range-front faults.

INTRODUCTION

Geothermal groundwater has been used in the Boise, Idaho area for direct heating and hot water supply for more than 90 years. Hot springs formerly issued at four or more locations at the boundary between the foothills and the plain at the northeast edge of the city (Lindgren, 1898; Wells, 1971; Burnham and Wood, 1983). The original two wells of the Boise Warm Springs Water District (BWSWD #1 and 2, Table 1 and fig. 2) have pumped water at an average rate of about 500 gpm for the 7-month cold season. Several hundred homes and the old Natatorium have been supplied by these wells since 1891. Billing rates to users have always been on orifice size. About 244 homes have been served by the district: in 1971, the charges for heating an average size home was about $200 (Wells, 1971).

In 1975 and 1976 exploratory wells were drilled with support from the U.S. Department of Energy in the Military Reserve Park area (Table 1). Two wells obtained artesian flow of 165 - 170°F water.

Although it had long been known that the hot springs and successful hot water wells are somehow directly related to obvious fault features at the base of the Boise foothills, it was not until the late 1970's that a concerted effort was applied to determining the geology and hydrology of the geothermal system. Geologic mapping by Wood and Vincent (1980), interpretation of seismic reflection data by Wood and others (1981) and the collection of good geologic and hydrologic data during drilling (Anderson, 1981; Wood and others, 1982; and Burnham and Wood, 1983) have produced a much clearer understanding of the geothermal aquifer system.

In 1980 the State of Idaho drilled the Capitol Mall #1 (CM#1) well as an exploratory hole to test the availability of geothermal water beneath the state office building complex and away from the mountain front fault. At a depth of 1750 ft the well drilled into a dark-green glassy rhyolite and was completed to a depth of 2150 in the Idavada Group. This was the first well to demonstrate the presence of the rhyolite aquifer. It was also the first well drilled with good geological supervision and logged with a set of geophysical logs useful for distinguishing volcanic rocks. The well flowed 153°F water at a rate of 200 gpm.

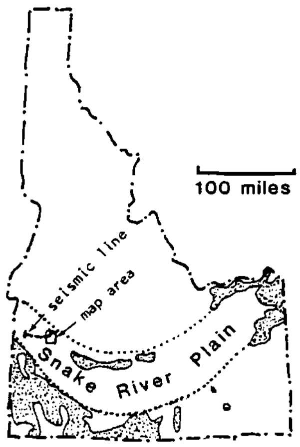


FIGURE 1. Location map of the Boise geothermal area showing seismic section and the geologic map area. Outcrop areas of silicic volcanic rocks of late Cenozoic age are stippled.

Capitol Mall #2 well was drilled in 1981 to a depth of 3010, and completed in the Idavada Group with an artesian flow of 960 gpm of 160°F water. The Capitol Mall heating system uses CM#2 as the producing well and CM#1 as a re-injection well. The heating system designed by CH2M-Hill utilizes the greater artesian head of the CM#2 well to drive the water through the distribution system

Table 1. Geothermal Wells in the Boise, Idaho area

well name	date	location	elevation (feet)	total depth (ft)	perforated or uncased interval (ft)	temp. (oF)	static** water depth (ft)	flow-rate during test (gpm)	draw-down (ft)	test time (hrs)	formation
D.Harris	1981	SW NW 20 3N 2E	2860	800(?)		190(?)	-40	small			
BWSWD#1&2	1890	SE SW 12 3N 2E	2764	410	160-410	172		1200	160	24	Idavada
BWSWD#3	1980	SE SW 12 3N 2E	2790	595	215-595	145	-113 to -32*	150	83	3	Idavada
Kanta	1983	SW NE 13 3N 2E	2786	1015	640-1015	162	-23	640	179	8+	Idavada
St.of Idaho	1965	SW NE 13 3N 2E	2780	875	220-862	139	-73	630	150	5	Idaho & Idavada
St.of Idaho	1953	SW SE 12 3N 2E	2765	487	89-131 438-490	82	-103	18	149	72	Idavada
BHW	1976	NW NE 11 3N 2E	2747	1281	823-1279	170	+13 to +23	380	112	27	?
BEH	1975	NE NW 11 3N 2E	2742	1224	780-1223	165	+12 to +22	120	169	72	Basaltic tuff
BGL#1	1980	SW NE 11 3N 2E	2749	2000	830-2000	170	+11 to +21	not tested			Idavada
BGL#2	1980	NE NW 11 3N 2E	2749	880	642-880	172	+11 to +21	900	20	168	Idavada
BGL#3	1981	NE NW 11 3N 2E	2770	1897	680-901 1050-1897	170	+11 to+21	2000+	50		Idavada
BGL#4	1981	NW NE 11 3N 2E	2749	1103	720-1040	170	+11 to +21	400	3	47	Idavada
CM#1	1980	NE NE 10 3N 2E	2716	2152	1750-2152	153	+35	750	238	18	Idavada
CM#2	1981	SE SE 3 3N 2E	2709	3030	1260-3030	164	+42	930	42	38	Idavada
Koch	1972	NW SW 2 3N 2E	2755	1143	630-670 1065-1105	121	-52 to-63	5(?)	30(?)	1/4	?
Edward's	1926	SW NE 29 4N 2E	2660	1195	?	118	+50	140	20	24	?

* seasonal variation produced by pumping from BWSWD#1 & 2.
**water level is based on a hot column of water and before significant pumpage. Positive values are pressure head in feet of flowing-artesian conditions.

and plate heat exchangers in each of 7 buildings and then down the re-injection well (CM#1). Total investment in this system is $1,925,000 with a projected pay back of 9 years as a cost savings over the previous and projected costs of natural gas heating (Worbois, 1982). In a newly constructed building this system is a considerable savings over large gas-fired boilers because of the small space requirement and cost of the plate heat exchangers and the lower operating and maintainance costs.

The Boise Geothermal, Inc. system utilizes 3 production wells (BGL nos. 2, 3, & 4, Table 1) drilled in 1981 by a private partnership, Boise Geothermal, Ltd. These three wells produce 2000 gpm of water at 170oF, and and are capable of delivering 4000 gpm with 2,000,000 BTU/hr available for heating. The 4.5-mile distribution system has been completed through downtown Boise. The distribution system is a major cost in the development. The specially constructed, insulated asbestos pipe for the main 12-inch trunk line costs about $55 per foot, and another $20 to $30 for underground installation mostly beneath city streets. Pipeline costs and the cost of drilling wells nearer to the utilization site need to be considered. Total costs for the drilling and completion of most of the large production wells (12 inch) during 1980 - 1981 have ranged from about $165 to $200 per foot.

The price for hot water from the BGL and the BWSWD systems is reported to be $0.35 to 0.40 per therm (1 therm = 100,000 BTU). Tentative contracts as of July 1982 were based on a charge per therm discounted by 30 per cent from the price charged to a commercial user by the largest supplier of natural gas in Idaho (Worbois, 1982).

Geologic and hydrologic data gathered during the 1980-81 drilling progam has shown that the main geothermal aquifer is a sequence of layered silicic volcanic rocks of the Idavada Group that has fracture permeability. This confined aquifer system lies beneath most of north Boise at depths of 850 to as deep as 2000 feet. Testing of the CM and BGL wells by Anderson and Kelly, Inc. indicate that the aquifer to the southwest of the foothills faults has transmissivity values of the order of 100,000 gpd/ft and storativity of 0.001. Near and within the foothills fault zone, the BGL wells indicate higher transmissivities of about 1,000,000 gpd/ft from fault-fracture permeability during the early response part of draw down tests. Tests also show a no-flow boundary immediately to the northeast. The aquifer has a dip of about 4 degrees to the southwest. Geophysical data suggest that south of the Boise River it may be downfaulted to considerable depth, possibly beyond the reach of economical drilling. No deep wells have been drilled south of the Capital Mall wells (fig.2).

GEOLOGY

The Boise geothermal area lies along the northern margin of the western Snake River Plain, a deep structural depression and physiographic lowland about 30 miles wide. The western plain has the appearance of a large northwest-trending graben, bounded on the north and south sides by terrain underlain by granitic rocks. Hot springs and hot water aquifers are common along the margins of the plain and appear to be associated with NW-SE-trending normal faults of late Cenozoic age (Applegate and Donaldson, 1977; Brott and others, 1978; Lewis and Young, 1982; Arney and others, 1982; and Burnham and Wood, 1983). Downwarping and faulting of the plain area probably began in middle Miocene, and the lowland has continued to be downfaulted, downtilted, and filled by volcanic and sedimentary material. Late Cenozoic sediments and volcanic rocks have been drilled to a depth of 14,000 ft in the center of the western plain (Wood and Anderson, 1981). The foothills north of Boise and the subsurface beneath the city contain most of the late Cenozoic stratigraphic units defined by Malde and Powers (1962),although misidentification of volcanic rocks and the lack of detailed geologic mapping by earlier workers led to considerable confusion over the geology of the geothermal system during the exploration activity in the 1970's.

Granitic Rocks and Porphyry Dikes

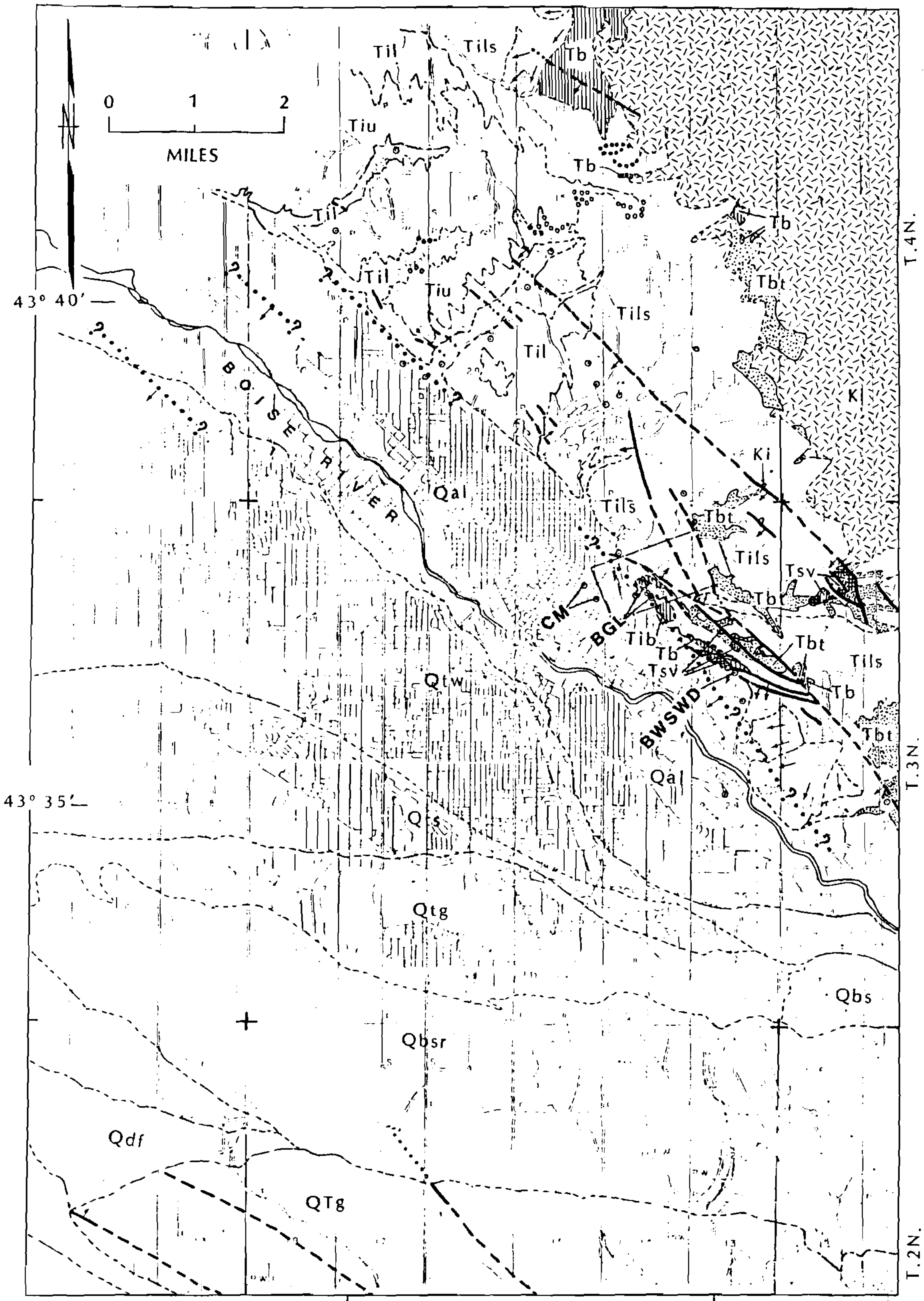
Boise Ridge dominates the high country northeast of the city. It is underlain throughout its length by the intrusive rocks of the Idaho Batholith which are mostly biotite quartz monzonite described by Anderson and Rasor (1934). The batholith rocks are invaded by a variety of dikes rocks. Most common in the Boise Ridge area are rhyolite porphyries associated with hydrothermal alteration and minor gold-quartz mineralization probably associated with the Challis volcanic and plutonic episode of Eocene age (Armstrong, 1974; Wood and others, 1982) and not Miocene as originally indicated by Anderson (1954). These dikes predate all of the layered volcanic rocks of the Boise foothills.

Idavada Group: Silicic Volcanic Rocks and Sediments

Silicic volcanic rocks and arkosic and tuffaceous sediments of the Miocene Idavada Group rest upon or are faulted against the granitic rocks in the foothills. The Idavada Group is a regionally significant group of rhyolitic rocks that probably cover more than 60,000 km2 in southwest Idaho and adjacent parts of Nevada and Oregon. The unit was defined by Malde and Powers (1962) and has been shown by Armstrong and others (1975) to represent time-transgressive silicic volcanism associated with the formation of the plain. The age of volcanism becomes younger to the east. Ages of rhyolites from the Oregon-Idaho border to 116oW longitude range from 9.5 to 14 m.y., and are middle to late Miocene (Armstrong and others, 1980). Individual flow units are very widespread, and Ekren and others (1981) have suggested that many units that appear to be flow rhyolites may have originally been emplaced as very hot ash flows that remelted and flowed as lavas. No centers of rhyolite volcanism have been identified north of the plain (Wood and Gardner, 1983), and Ekren and others (1981) indicate that many must have erupted from an areas now beneath the plain.

Two rhyolite lithologies exposed in the eastern Boise foothills are encountered in geothermal wells drilled beneath the city. A quartz-plagioclase porphyritic rhyolite occurs in the canyon of Cottonwood Creek (Sec. 6 and 7, T3N, R3E) where it is faulted against granitic rocks. The 300-ft thick flow is composed of both pinkish- gray stony rhyolite and gray perlite with about 3 per cent quartz phenocrysts (1-4 mm in diameter) and about 3 per cent feldspar phenocrysts, and small opaque grains of magnetite. Exposures of the base are poor in Cottonwood Canyon, but the rhyolite appears to overlie an air-fall pumice unit. The rhyolite is overlain by tuffaceous sediments of the Basaltic Tuff Unit. In the subsurface beneath Boise, the deeper of two thick rhyolite layers is also quartz-phenocryst bearing, and is quite similar to the unit in Cottonwood Canyon. It was encountered in the BWSWC#3 well, in the bottom 300 feet of the CM#2 well, and several of the BGL wells. In the subsurface it is overlain and underlain by arkosic sandstones and conglomerate interbedded with silicic tuff.

The other rhyolite lithology forms the rocky outcrop northwest of the old State Penitentiary, locally known as Castle Rock (Sec. 12, T3N, R2E). The rock is a plagioclase-porphyritic yellowish-brown stony rhyolite or a greenish-black vitrophyre in its unaltered forms. The rock contains 15 to 20 per cent chalky-white plagioclase phenocryst 0.2 to 2 mm in size and minor microphenocrysts of clinopyroxene and magnetite. Because of its dark color and mineralogy this rock has been mistakenly called andesite or basalt in the literature. Hydrothermally altered forms of the rock in well cuttings have been called both altered basalt and blue clay in the past, but the blocky white phenocrysts are quite distinctive, and even when the matrix is altered to a gray clay, the relict white phenocrysts can be seen. It is this rhyolite lithology that forms the main geothermal reservoir rock. In outcrop the unit has a fine jointing similar to sheeting that is parallel to flow banding. The upper part of the unit is also crudely jointed into vertical columns with dimensions of 1 to 3 ft. All productive geothermal wells are completed in this unit. The CM#2 well penetrated a total thickness of 400 feet of this unit where it is underlain by arkosic sediments and the quartz-bearing rhyolite (fig. 2). In the Kanta well, this rhyolite was overlain by about 40 feet of interbedded sandstone and hard white silicic tuff. Above this is the basaltic tuff unit such as encountered in most of the other wells. Fracture permeability seemed to be best developed in the upper part of this unit in the



GEOLOGIC MAP OF BOISE , IDAHO

EXPLANATION

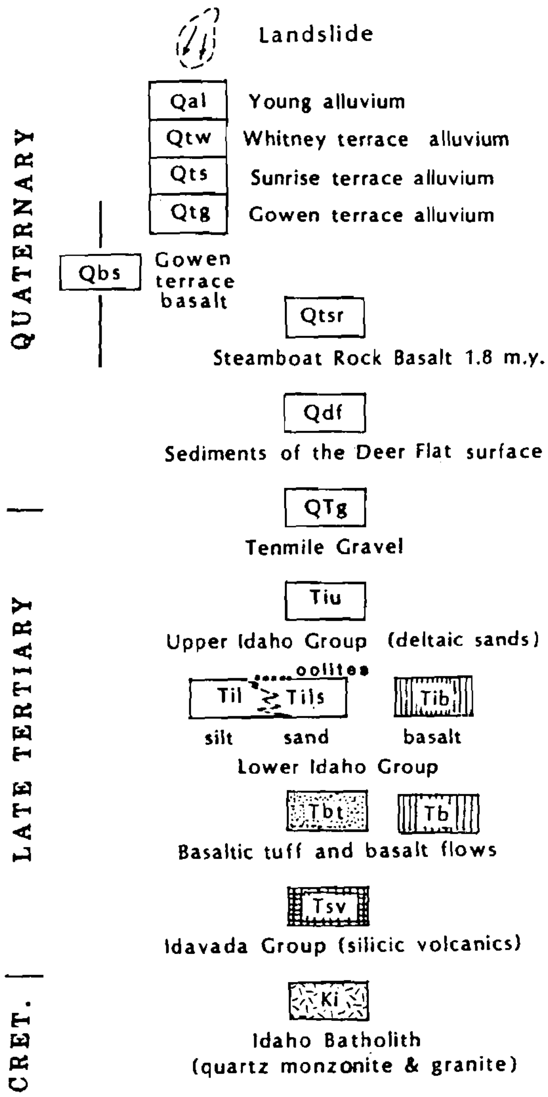


FIGURE 2. Geologic map of the Boise, Idaho area, and location of the principal producing wells of the geothermal system. Faults are shown with a solid line where the trace can be mapped from surface exposure and offset beds. Exposed fault planes where dip can be measured are shown with a small arrow indicating dip direction. All faults have normal displacement. Dashed line indicates inferred location of fault where exposures are poor. Dotted line indicates a buried fault trace located by seismic reflection surveys , by ground magnetometer surveys, from well logs, or a location inferred by extending a surface outcrop beneath a younger depositional unit. Question mark indicates a projection of the fault trace beyond geophysical or other subsurface control.

CM#1 and 2 wells and in the Kanta well. In these three wells we do not think that fault related fractures provide the permeability because the wells are not located on a major fault. Rather, it seems that the fractures are original cooling joints, flow breccia, or from weathering in the upper parts of the flow. In the BGL wells and the BWSWC 1 and 2 wells, the fractures are almost certainly related to the faults.

Basaltic Tuffs and Flows

Silicic volcanic rocks of Idavada Group are overlain by a unit of basaltic tuffs and flows and minor arkosic and tuffaceous sediment. The lower part of the unit near the contact with the granitic rocks contains sandy and clayey mudstone with interfingering lenses of bouldery debris derived from the granitic highlands. Beyond a mile from the contact, the unit is mostly basaltic ash and scoriaceous lapilli commonly altered to yellowish or olive brown palagonite clay. Some layers are entirely bedded basalt lapilli and ash. Several basalt flows occur in the upper part of the unit. Porphyritic basalt laps against the rhyolite at Castle Rock (sec. 12, T3N, R2E.). In the valley of Warm Springs Creek (Sec.7, T.3N, R.3E) a distinctive cumulophyric-plagioclase basalt overlies the basaltic tuffs and laps upon the granitic rocks to the northeast.

In the subsurface beneath Boise, this unit is about 600 ft thick. The basaltic tuff material is identified in well cuttings by its dark olive or yellowish-brown colors, or by cuttings of scoria. The tuffs have a distinctive appearance on natural gamma ray logs, for they have the same low gamma radiation as the basalt flows. Basalt flows can be distinguished by their high velocity on sonic logs or by their high densities on formation- density or porosity logs, whereas the tuffs have low velocities and high porosity, and low density.

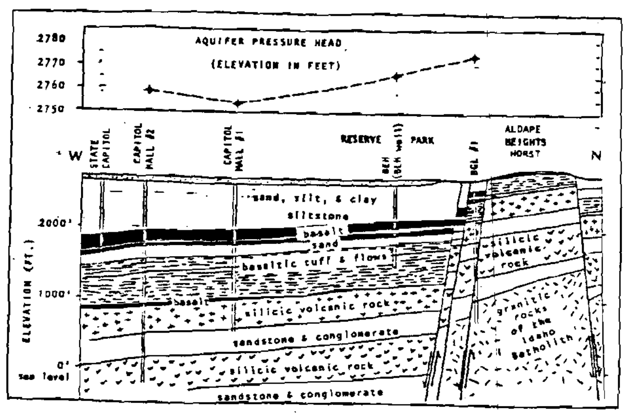


FIGURE 3. Geologic structure section across the main reservoir of the geothermal system constructed from well logs. Shown above the section is the piezometric level of the reservoir rock. Aquifer pressure is for a column of hot water, and prior to significant production. Section is true scale--no vertical exaggeration.

The basaltic tuffs overly an eroded topography on the rhyolitic rocks. Some of the tuffaceous mudstones contain scattered rhyolite pumice lapilli and thick layers of water-laid white rhyolite ash. Occurrence of minor amounts of rhyolitic pyroclastic materials in a dominantly basaltic unit indicates that rhyolite volcanoes elsewhere were shedding airfall debris into the drainage basin of depostional area. This observation is consistant with the view of Armstrong and others (1975) that centers of silicic volcanism have migrated east across the plain. Airfall debris from explosive rhyolite eruptions would have been transported by air and water into the depositional environment of the basaltic tuffs.

The basaltic tuff unit is probably correlative with the Banbury Basalt of Stearns (1936), and if so, probably has an age of about 9 m.y.(Armstrong and others, 1980). An angular unconformity occurs between the basaltic tuff unit and arkosic sediments of the lower Idaho Group in the Boise foothills. For this reason, we are reluctant to place the unit in the lower Idaho Group as was done by Malde and Powers (1962). The unit may be time-transgressive, becoming younger to the east in the same manner as the underlying Idavada Group. More detailed geochronology and paleomagnetic study than presently available should ultimately refine the stratigraphic position of this unit.

Older reconnaissance maps of the Boise area have incorrectly shown the basaltic tuff as the Payette Formation. The so called "Payette Formation" is not a useful term in this area since it probably refers to older rocks associated with the middle Miocene Columbia River Basalt Group or with the Sucker Creek Formation, both of which should be older than the Idavada Group.

The basaltic tuff unit acts as a confining seal on the geothermal reservoir rock. This has been clearly demonstrated during drilling, for the temperature and static water level both rise abruptly at the lower contact of this unit with the underlying rhyolite. In outcrop the basaltic tuff contains moderately expansive clays both as alteration of the tuffaceous material and also as sandy blue-and-maroon-colored clay layers. Surface distribution of the basaltic tuff unit is important because the unit contains weak clay layers that are prone to landsliding. Weathering of the unit also produces a moderately expansive brown clay soil.

Idaho Group Sediments and Basalt

The basaltic tuff unit is unconformably overlain by sediments of the Idaho Group. We have divided the Idaho Group into an upper and lower part in the Boise foothills based on an abrupt lithologic contact of a thick sequence of coarse deltaic sands overlying the lake-margin facies of the lower Idaho Group (fig.2 and 4). The lower Idaho Group also contains deltaic sands, but they grade into a siltstone facies to the west. The uppermost regressive sand may correlate with the lower part of the Glenns Ferry Formation, but the seismic section from the foothills to Caldwell (fig.6) indicates that most of the units in the foothills are the lowermost part of the Idaho Group that filled the basin between Boise and Meridian.

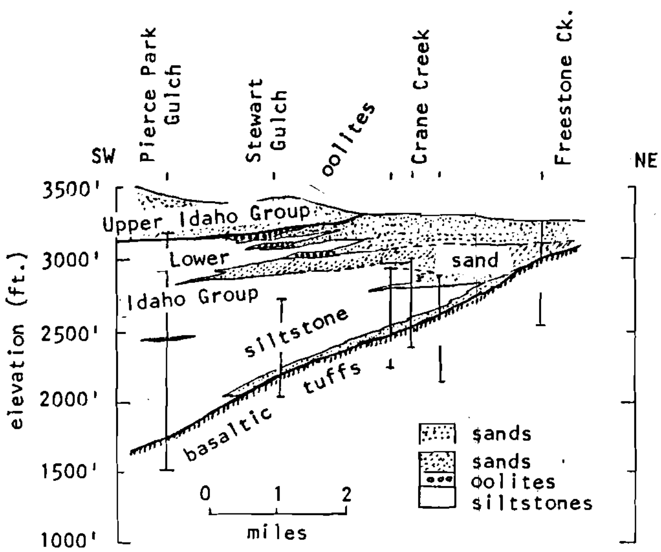


FIGURE 4. Stratigraphic section of the Idaho Group sediments in the Boise foothills compiled from water-well logs and geologic mapping. Vertical lines are locations of wells. Section illustrates the facies relationships of lake-margin sediments and the boundary between the upper and the lower Idaho Group.

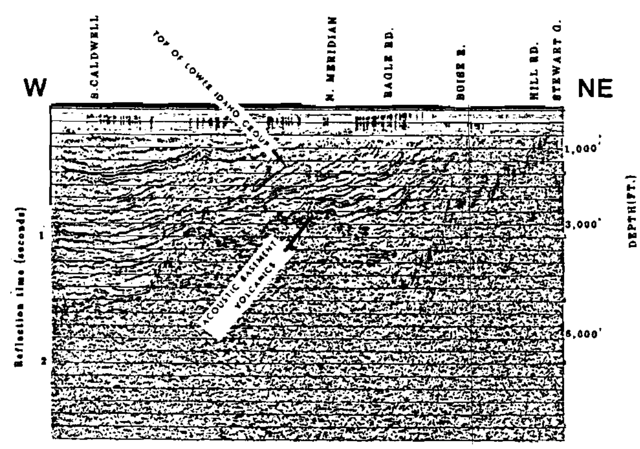


FIGURE 5. Seismic reflection section from the Boise foothills in Stewart Gulch to Caldwell, Idaho (35 miles). About 16X vertical exaggeration. Location of section is shown on figure 1. Reflections above the acoustic basement are from sediments within the Idaho Group. Acoustic basement beneath the Meridian area is the top of a 7000-ft sequence of Miocene basalt described by Wood and Anderson (1981). Acoustic basement beneath Boise may be rhyolite or basalt.

Tenmile gravels, Boise River terrace deposits, and intercanyon basalt flows

A blanket of fluvial gravel and sand was deposited upon the Idaho Group over much of the plain in the Boise area. The deposit heads in the foothills just south of Lucky Peak Dam, about 5 miles east of Boise, where it is up to 500 ft thick. The deposit extends to the Oregon border. Remnants are found over much of the area to the west of Boise where the gravels are 10 to 50 feet thick. These gravels were called the Tenmile Gravels by Savage(1958). The Tenmile Gravels are downfaulted to the north, and this faulting may have produced the graben like valley in which the present Boise River is confined (fig.2). During the Quaternary the river has occupied at least 6 successively lower flood-plain levels now preserved as the broad terraces occupied by the southern part of the city of Boise. An intercanyon basalt flow from the upper Boise River drainage spread out on one of the oldest of these ancient floodplains. We have tentatively correlated this level with the Steamboat Rock Basalt of Howard and Shervais (1973) which is dated by Howard and others (1983) at 1.8 million years. Another basalt occurs at the level of Sunrise Terrace, but data from driller's logs in the area suggest that this basalt may be older, and simply an erosional remnant that actually underlies the Steamboat Rock basalt, and its stratigraphic position is not resolved.

STRUCTURE

Structural deformation of the Cenozoic rocks in the foothills is limited to normal faulting, local associated drag folding, and tilting of fault blocks. Deformation of the granitic rocks is difficult to document, nevertheless a number of major drainages have northeast trends, as do most of the thin porphyry dikes suggesting an early Cenozoic trend of extensional fracturing. Thirty miles north of the Boise area, the granitic rocks are broken by a system of NS-trending, down to the east, normal faults that experience a moderate degree of active seismicity (Meissner, 1983). Late Cenozoic faulting in the Boise area has been dominated by NW-SE trending normal faults, although some branching faults have strikes of N 10o W to N 75oE. Dip on fault planes typically ranges from 60o to vertical.

The fault pattern along the foothills is quite complex where the older rocks are exposed in the eastern part of the map area (fig.2). The subsurface is apparently broken into many wedge-shaped fault blocks, and flow testing of the BGL wells showed a number of permeability barriers exist at different distances from the well. Faults shown on figure 3 with solid or dashed lines have been located with reasonable certainty. Faults shown with a dotted line have uncertain orientation and are identified only by a few crossings with geophysical surveys.

The largest documented offset occurs between the fault block immediately northeast of the BGL wells and the CM wells (fig. 2 and 3). The offset of the rhyolite here is about 800 feet. At the BWSWD wells, the rhyolite is offset about 1000 feet between the outcrop and the Kanta well. Fault offset of the Idavada Group rocks is greater than that of the Idaho Group although a fault with several hundred feet of displacement has downdropped the Table Rock area (SW 1/2 of section 8, T.3N.,R.3E.) to the south. Fault offset in the upper Idaho group appears to be slight, perhaps less than 100 feet. Many faults are covered by unbroken upper Idaho Group. Faulting of the Tenmile Gravel can be observed in several gravel pits south of Boise, but offsets are probably less than 100 feet.

THE GEOTHERMAL SYSTEM

The southern Idaho batholith and the Snake River Plain are situated in a region of abnormally high heat flow generally in the Basin and Range

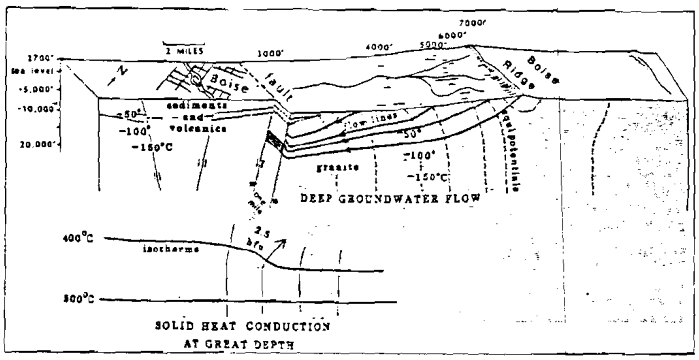


FIGURE 6. Conceptual model of the Boise geothermal system showing deep percolation of water in the granitic rocks driven by the regional topographic head of the mountains to the northeast. Solid conduction heat flow from great depth is refracted into the more conductive granite. Heat flow values are typically 2.5 HFU along the edge of the granitic highlands, and the gradient is typically 30oC/Km. Groundwater flow net is sketched using topography for equipotentials. Water must be driven to a depth of at least 2 km (7000 ft) in order to reach 75oC. This constraint indicates a flow path of about 10 miles and a slope of 0.1 to 0.03. Using a 7000 yr age (Mayo,1983) and a flow path of 50,000 ft implies a flow rate of about 7 ft/yr, and a permeability of the granite 2 to 3 km deep of the order of 0.1 darcy. Discharge from a flow tube 2000 ft thick and one mile wide along the front would be about 1000 gal/min per linear mile along the front. Major objection to this kind of model is that it requires relatively high rock permeabilty of 0.1 darcy at a depth of 2 km. Permeablities of crystalline rocks deeper than 1300 feet are more typically of the order of 0.001 darcy (Davis, 1981), but no data exists for the granitic rocks of the southern Idaho Batholith.

geologic province (Lachenbruch and Sass, 1977; Brott and others, 1978). Focusing of heat flow and hot springs at the margins of the plain may be caused both by convective heat transfer by upward-moving hot water along fault zones and by the refraction of heat flow that diffuses by solid conduction at the interface of more conductive granite with the less conductive layered sediments and volcanics (figure 6). Origin of the thermal water has never been fully explained, yet an understanding of the recharge system will become important as development of the resource in the Boise area continues. Young and Lewis (1982) have suggested a conceptual model to explain geothermal water on the south side of the Snake River Plain where heating of the waters takes place in the Idavada reservoir rock at a depth of about 5000 ft. We propose a somewhat different model for the Boise area whereby the waters are heated in the granitic rocks, realizing that neither model is unique or closely constrained by existing data.

Mayo (1983) and John Mitchell (Idaho Department of Water Resources, personal communication, 1983) have obtained radiocarbon activities of the geothermal waters in the Boise area and report ages ranging from 6000 to 12000 years. We have used that data in a conceptual model of a recharge system driven by the regional topographic head between the plain and the adjacent highlands (figure 6). Calculations outlined in the caption produce reasonable numbers for the supply of water to the geothermal aquifer along the mountain front; however, we wish to emphasize that the calculated 1000 gpm per mile along the front could be changed either way by an order of magnitude using different assumptions in the model.

The calculations also implie a permeability of 0.1 darcy for deep percolation in the granitic rocks. This value is higher than usually advocated, but not impossible for granitic rocks with numerous fracture zones. We suggest that the fractures associated with NS-and-NE-trending lineaments in the batholith may provide conduits for deep percolation, and NW-trending fault systems at the margin provide conduits for upward convecting hot waters. Late Cenozoic fault activity has maintained zones of open fractures through which water can indeed percolate to depths of 2 to 3 km. The discharge flow of hot water along edge of the granitic highlands certainly requires upward percolation of thermal waters through such zones. These hot waters have a moderate artesian head (Table 1) which drives them into layered, confined aquifer units adjacent to faults along the margins of the Snake River Plain.

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