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Geologic framework of the Boise Warm Springs geothermal area, Idaho

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LOCATION

The Boise Warm Springs area is 2 mi (3.3 km) southeast of the Idaho State Capitol building (Fig. 1). Turn north from Warm Springs Avenue onto Old Penitentiary Road. Take the first left turn, about 200 ft (70 m), and proceed west about one block to Quarry View City Park. A major part of the area is a public park administered by the City of Boise and the Idaho Historical Society. A prominent outcrop of rhyolite, locally known as "Castle Rock" is on private land, but at the present time access is not restricted.

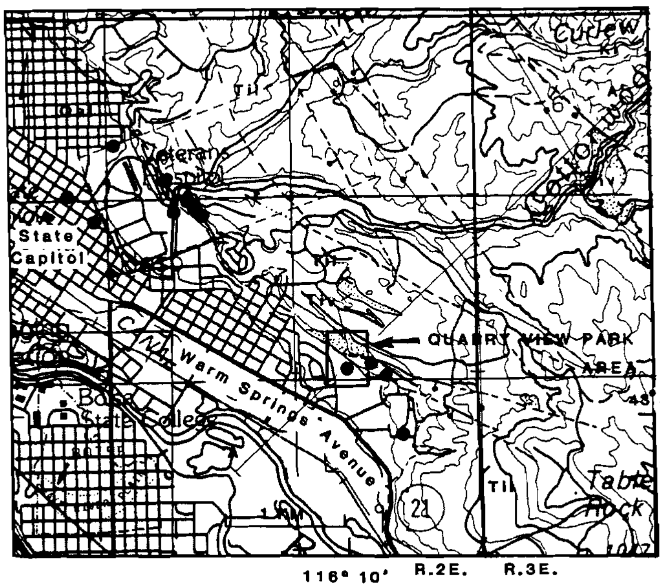

Figure 1. Geologic map of northeast Boise showing location of Quarry View City Park. Ki, granite of the Idaho batholith; Tiv, rhyolite of the Idavada Group; Til, mostly sand and siltstone of the lower Idaho Group, but contains a significant section of basaltic tuff and basalt in its lower part; Qal, alluvium and terrace gravels of the Boise River floodplain. Black dots show locations of geothermal water wells used in heating systems discussed by Wood and Burnham (1983).

SIGNIFICANCE

The hydrogeology of an important geothermal-water resource is well displayed at the Boise Warm Springs area. Late Cenozoic volcanic and sedimentary strata exposed in the hill of an upthrown fault block are the same geologic layers as the subsurface aquifers from which 66°C (172°F) water has been produced from wells for nearly a century. Structure and volcanic stratigraphy at the site is typical of the western Snake River Plain, a 30-mi-wide (50 km) grabenlike basin filled with late Cenozoic silicic and basaltic volcanic rock and fluvial and lacustrine sediments. The fault system of the graben margin is the deep conduit for geothermal groundwater that supplies the oldest geothermal heating district in the United States. On the site are the original 1892 geothermal wells and pump house and the 1870 Idaho Territorial Penitentiary: both are listed on the National Register of Historic Places.

GEOLOGIC FRAMEWORK

The sequence of late Cenozoic rocks on the rocky hillside above Quarry View Park has been downfaulted to the south to a position 850 ft (260 m) deep beneath the park area. A structure section and map are shown in Figures 1 and 2. The stratigraphy of the rocks on the hillside is illustrated in Figure 3. These rocks are underlain by granite of the Idaho batholith, which is well exposed along the road in Cottonwood Creek Canyon, 2 mi (3 km) north of the park (Figs. 1 and 4). The oldest rock at the site is a body of glassy and stony rhyolite of the Idavada Group. The rhyolite is locally onlapped by a sequence of basalt flows, 50 ft (15 m) thick. Unconformably overlying the basalt and rhyolite is a poorly exposed 15 to 30 ft (5 to 10 m) sequence of red-and-green sandy clay of the Idaho Group. At the top of the section is a 20-ft-thick (6 m) bluff-forming sandstone that was extensively quarried in the nineteenth century for building stone. Quarries and rock piles on the hill are a reminder of the prisoners' labor in procuring dimension stone to construct the penitentiary walls.

Main production of geothermal wells in the northeast Boise area is from fractures in subsurface rhyolite. The basalt and clay unit is comparatively thick in the subsurface and serves as a sealing aquitard on the rhyolite aquifer. Prior to uplift and exposure by erosion, the sandstone was also a geothermal aquifer fed by hot water ascending through high-angle faults. It became cemented as these waters travelled laterally through the sandstone and cooled, causing dissolved silica to be precipitated.

The main fault is obscured by talus and colluvium at the base of the hill, but its approximate location is shown in Figure 5. Several minor fault planes cut sandstone outcrops on the hillside. One fault, which dips about 60° south, drops the sandstone stratum down about 80 ft (25 m) to form a wedge-shaped plateau in the area east of the Warm Springs Water District pump house and north of the penitentiary. This fault is one of several within a

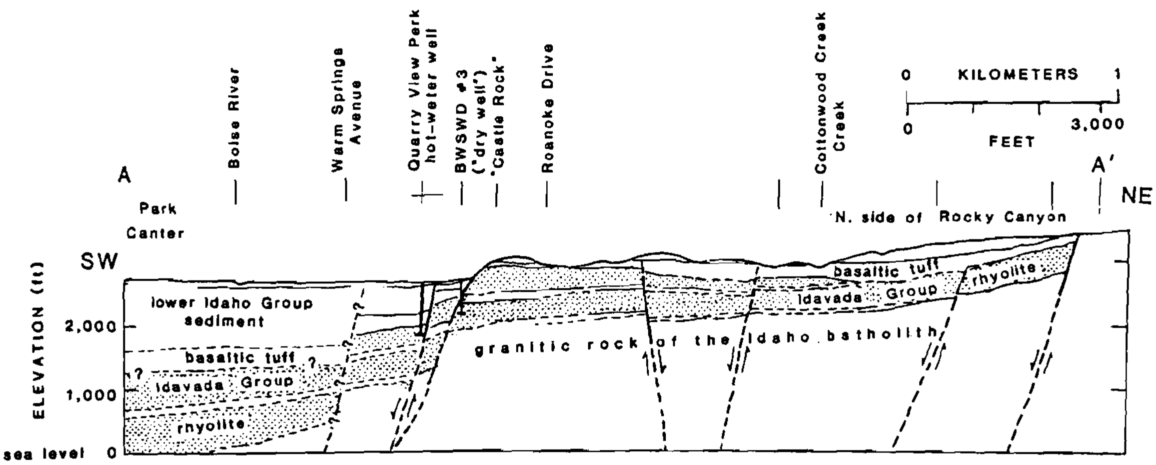

Figure 2. Geologic cross section through the well at Quarry View Park. Location of section is shown along line A–A′ in Figure 1.

complex zone of normal faults that is characteristic of the northeast margin of the western Snake River Plain. The exposed fault zone in the Boise foothills is 2 mi (3 km) wide. Geophysical exploration has found other faults beneath the plain, just south of this area, and the total offset of the volcanic sequence on seismic sections is at least 0.9 mi (1.4 km; Wood, 1984).

LINDGREN'S LACCOLITH

Prior to our work, the only published work on the Boise Warm Springs area was an interpretation of this site by Lindgren (1898a) as a "laccolith in miniature." Lindgren's interpretation that the rhyolite is intrusive requires that it is younger than the sandstone, and a relatively young age for silicic igneous activity. The interpretation is important to understanding the geothermal resource, because the laccolith concept suggests a shallow magma body as the heat source, and our interpretation relies on the deep regional heat flow anomaly. However, his interpretation is interesting from a historical point of view. Laccolith intrusives of the Henry Mountains, Utah, described by G. K. Gilbert in the late 19th century were a relatively new concept that clearly influenced Lindgren.

In our interpretation, faulting and warping can account for the arched sandstone stratum (Fig. 5). The basalt strata clearly lapped upon the rhyolite as shown by a red-brick–colored soil at the bottom of the basalt sequence that was oxidized by the heat of the basalt flow.

Lindgren (1898a, 1898b) recognized faulting and orogenic movement as a process in the region, but he did not recognize faulting at this locality. He attributed the northwest-trending margins of the western plain to early Neogene faulting, which he must have believed to be buried by the deposits at this site. He assigned a late Neogene age to the north-south–trending set of faults that displace Miocene Columbia River basalt in the region north of the plain. In an early paper, H. E. Malde pointed out the

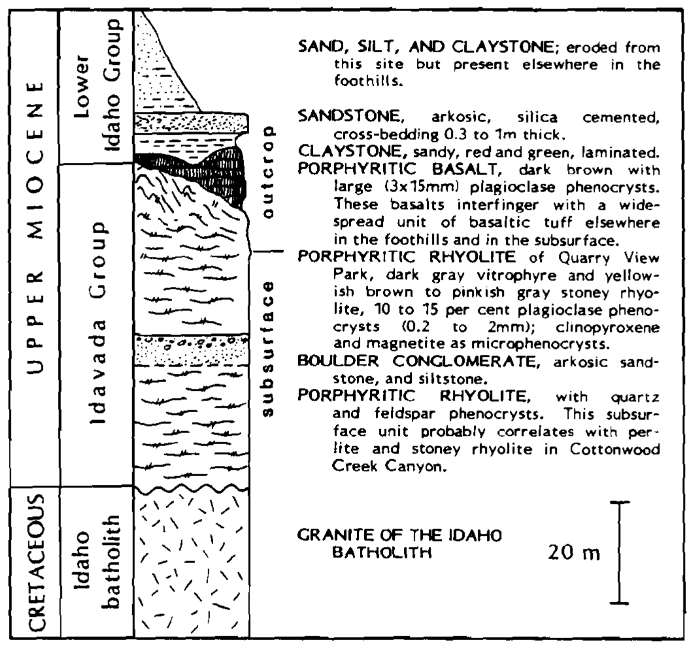

Figure 3. Stratigraphic section of outcrop on hill above Quarry View City Park and subsurface geologic units known from drilling beneath the park.

importance of large-displacement late Cenozoic northwest-trending faults that control the margins of the western plain (cited by Malde, 1987). Such faults apparently truncate the earlier Miocene north-south trend.

REGIONAL STRATIGRAPHY DISPLAYED AT SITE

Stratigraphic names of late Cenozoic rocks of the western Snake River Plain generally follow the work of Malde and his colleagues (cited by Malde, 1987). Interfingering volcanic, flu-

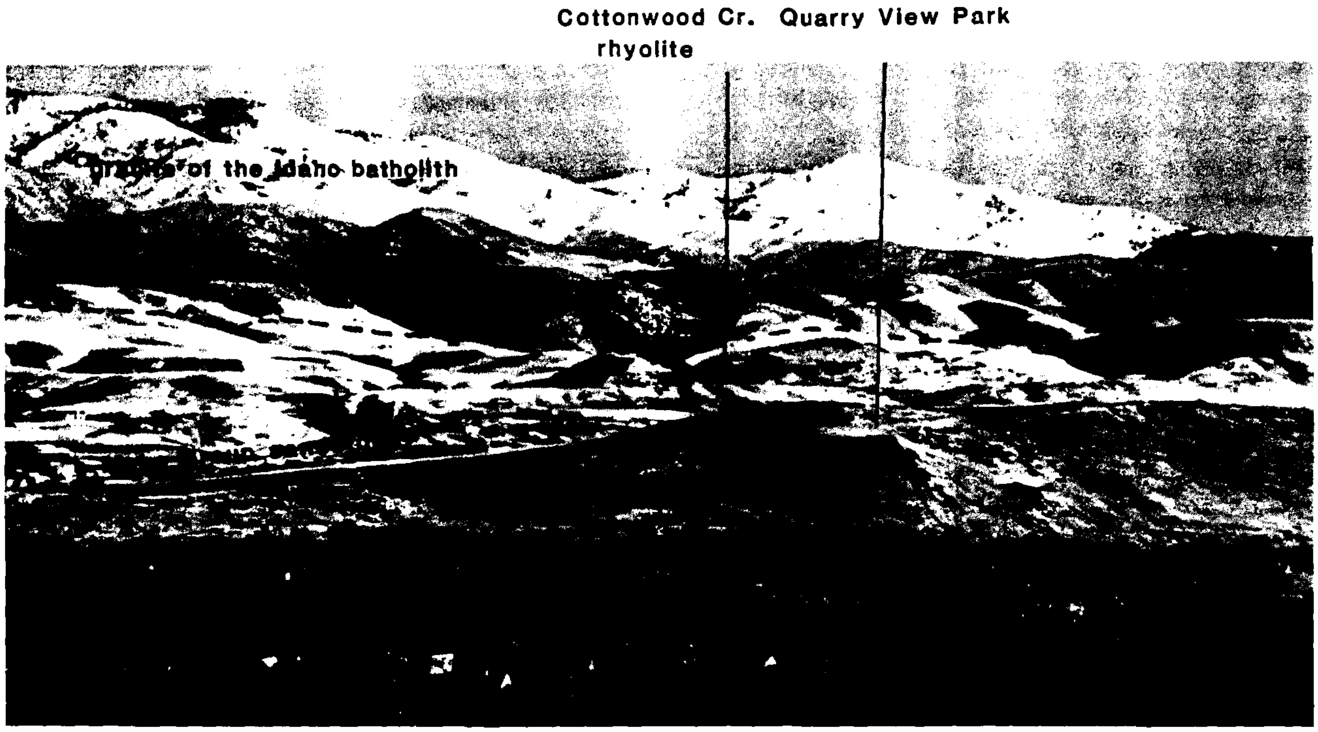

Figure 4. View toward the northeast of the Quarry View and Castle Rock area. It is this view of the sandstone-draped rhyolite mass that suggested the appearance of a laccolith structure to Lindgren in 1898a. Snow covered hills rise to 5,900 ft (1800 m) elevation above the plain, which is about 2,800 ft (850 m) in elevation.

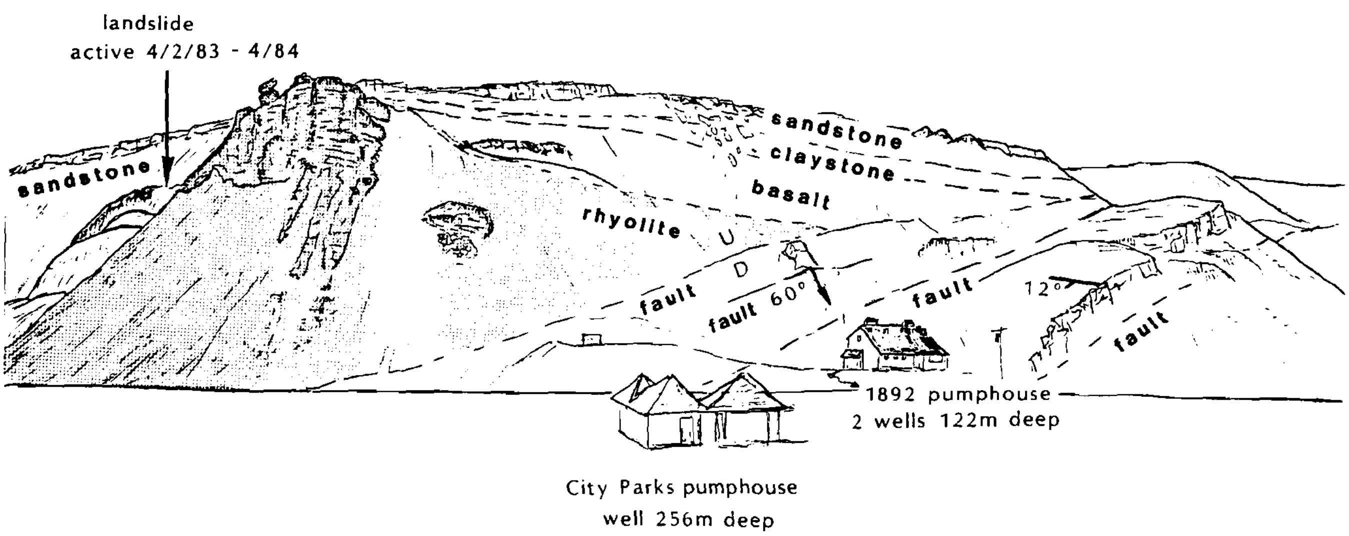

Figure 5. Field sketch of geologic features and the geothermal wells as seen from Quarry View City Park.

vial, and lacustrine facies complicate the assignment of formational names to these rocks. Armstrong and others (1975) described a systematic progression of volcanic and sedimentary facies that has migrated from west to east, showing that at any particular local section one sees (from oldest to youngest): (a) silicic volcanic rocks, mostly as ash-flow tuff deposits with minor basalt and sediment intercalations; (b) basalt flows with minor intercalated sediment and local silicic volcanic rocks; and (c) lacustrine and fluviatile sediments complexly interstratified with basalt flows. Associated with this facies progression is a systematic decrease in age of the rhyolite to the east, which has been interpreted by many as a record of the continental lithosphere sliding over a fixed "hot spot" in the mantle at an average rate of 3.5 cm/yr) (Leeman, 1982).

A similar facies sequence is exhibited on a much-compressed vertical scale in the Boise Warm Springs area (Fig. 3). The oldest rock here is of the upper Miocene Idavada Group of silicic volcanic rocks. The dark outcrops on the hill are a part of a tabular body of rhyolite which is known from recent drilling to be at least 300 ft (90 m) thick. It occurs in drill holes 850 ft (260 m) beneath the park area, and 2,000 ft (610 m) beneath the State Capitol Building, about 1.9 mi (3 km) west of here. The rhyolite has two lithologic variations here: a dark gray flow-banded vitrophyre, and a lighter-colored stoney rhyolite. We believe both lithologies are of about the same emplacement age; the differences are possibly produced by devitrification. Phenocryst mineralogy of the two lithologies is identical. In the stoney rhyolite, plagioclase phenocrysts have decomposed to a soft white chalky material that has washed out along joint surfaces, leaving a pitted surface. The rhyolite is flow banded on large and small scale, and has thin sheeting joints parallel to large-scale flow banding. Large-scale flow banding shows an asymmetric anticlinelike structure about 260 ft (80 m) wide. Drilling shows that the flow-banded rhyolite is part of a widespread flow or a tabular sheet of densely welded ash-flow tuff. However, the flow-banded rhyolite could also be part of a dome marking the source of the tabular flow. It is difficult in this region to distinguish the form of a rhyolite body at one locality, because densely welded tuffs are known to have completely remelted and remobilized as lavas (Ekren and others, 1984). A petrologically different rhyolite body underlies the ones exposed here. It was penetrated by the Boise Warm Springs Water District (BWSWD) no. 3 well (Fig. 2). This underlying rhyolite is distinguished by conspicuous quartz phenocrysts. This type of rhyolite is exposed as perlite and stoney rhyolite in Rocky Canyon about 1.5 mi (2.5 km) northwest of this area (Figs. 1 and 4). This type has a higher content of silica (76 percent), potassium, and sodium than the rhyolite mass exposed here at Quarry View City Park, which is 70 percent silica (S. H. Wood, unpublished analysis).

A tabular body of plagioclase-porphyritic basalt laps upon and, in places, overlies the rhyolite in outcrops on the hillside. Many vesicles and fractures are variously filled with zeolite minerals, calcite, clay, and chalcedony. Much of the basalt is discolored and altered, apparently by geothermal water. Chemical analysis of a little-altered sample is similar in composition to the group of "Snake River olivine tholeites" described by Hart and others (1984).

The overlying sediments are fluvial and lacustrine rocks of the lower Idaho Group. Cross-beds in the sandstone stratum at the crest of the hill indicate deposition under river-bed conditions. A significant thickness of clayey siltstone originally covered this sand unit, but has since been stripped off of the uplifted fault block by erosion. It is preserved in the subsurface beneath the park area where the geothermal wells penetrate about 650 ft (200 m; Fig. 2).

The volcanic and sedimentary rocks on the northern margin of the western plain have not been dated. K-ar ages of the Idavada Rhyolite Group on the south side of the western plain span 9.8 to 13.5 Ma (Armstrong and others, 1975), and this span is certainly reasonable for the rhyolite exposed at this site. Affinity of the basalt to the "Snake River olivine tholeites" is not helpful for age assignment because that geochemical group ranges from late Miocene to early Pleistocene (Hart and others, 1984). The overlying sediments are similar in lithology and setting to the Chalk Hills Formation of the lower Idaho Group on the south side of the Snake River Plain where intercalated volcanic ash layers have been dated by fission-track methods at 6.6 to 8.6 Ma or late Miocene age by Kimmel (1982).

THE GEOTHERMAL GROUNDWATER SYSTEM

This area is the site of the oldest space-heating development using geothermal water in the United States. Several wells were drilled here beginning in 1890. The first two, completed to 394 ft (120 m) and 404 ft (123 m), were strongly artesian and flowed at 170° F (77° C) water temperature at a combined rate of about 550 gallons per minute (35 l/s). In 1896 or early 1897, Lindgren (1898a) noted that the water was under moderate pressure and would rise not more than 50 ft (15 m) above the well mouth, or to about elevation 2,815 ft (858 m). This artesian flow of water was piped to a large natatorium, then to homes and businesses along Warm Springs Avenue; the unused flow was discharged to the Boise River. Credible records of the two producing wells of the Boise Warm Springs Water District are not available, but the present wells are believed to have been constructed in the early 1900s at or near the site of the original wells. The pumphouse (Fig. 5) incorporates the lower part of wooden derricks built to construct these wells. The house is on the National Register of Historic Places and was restored in 1982. The wells are 30 ft (9 m) apart and equipped with turbine pumps. According to owner records, the wells are lined with 16-in-diameter (41 cm) steel casing to 160 ft (49 m), and are an open 9-in (23 cm) hole to approximately 400 ft (122 m) depth. The wells are not capable of being shut in; however, based on tests in 1979, the calculated artesian head at the west well was at about elevation 2,783 ft (848 m), suggesting an artesian head loss of about 32 ft (10 m) since 1896. Both pump intakes are set at about elevation 2,606 ft (794 m), just above the 160-ft-deep (49 m) base of casing. This pump setting limits available drawdown to 160 ft (49 m) and consequently limits maximum available pump discharge. Artesian-head decline is expected to continue, and to be accelerated by post-1980 development of the Boise geothermal system. No change in temperature, or the physical and chemical quality of the water has been documented since the initial well construction of nearly 100 years ago. The water is slightly alkaline, with total dissolved solids of 320 mg/l, typical of the chemical quality throughout the system (Mayo and others, 1984).

The distribution system and pumps were upgraded in 1979–1980 to accommodate additional demand for hot-water service. During the 5-month heating season, the wells are pumped at 850–1,000 gallons per minute (54–63 l/s) creating drawdown to just above the pump intake. For about 5 months in the spring and fall, wells are pumped at about 200–500 gallons per minute (13–32 l/s). In the two late summer months, output is about 200 gallons per minute (13 l/s). The spent water is discharged through ditches and sewers to the Boise River. Precise values of discharge rates are not available because flow-measuring equipment and record keeping have been inadequate over past years. More than 250 homes and several buildings are currently served, those of long standing being billed a flat rate of about $400 per annum. Newer users in the district are on metered service at a present charge of $0.57½ per 100 cubic feet (2.8 cubic meters). This makes the cost of geothermal heat about $0.20 per therm if temperature is dropped 50°F through heat exchangers (1 therm = 100,000 BTU). This cost compares to a current cost of natural gas heat of about $0.36 per therm (based on $2.50 per 1000 cubic feet of natural gas, 70 percent efficiency.)

Much of own knowledge of the Boise geothermal system has been derived from drilling and testing post-1980 wells 1 to 2 mi (2 to 3 km) northwest of the Boise Warm Springs site (Fig. 1). The Boise Warm Springs wells are on the same major fault-fracture zone as are several of the newer wells. At this site the wells are clearly in or very near to fractures of a principal fault (Figs. 2 and 5). All producing wells have been completed in the rhyolite. Wells for the State of Idaho Capitol Mall system, 2 mi (3 km) northwest (Fig. 1), are much deeper and encounter thick rhyolite layers and intercalated sandstone and conglomerate (Wood and Burnham, 1983). The clayey basaltic tuffs, altered basalt, and siltstone of the Idaho Group compose the confining layers for the moderately to well-confined fault-fracture system. The geothermal "aquifer" system is not necessarily a layered unit, it may be more properly visualized as a linearly distributed system of numerous, variously interconnected zones of cracks, fractures, and open work. Hydraulic conductivity within this system of extreme range of permeability has not been determined with reasonable accuracy. Further, data thus far available are not adequate to reasonably characterize aquifer thickness, areal extent, or degree of interconnection between fractured blocks and the boundary fault fractures.

Data gathered from discharge-drawdown tests of several types, from artesian head response to barometric pressure change and from long-term response of artesian head to variable annual

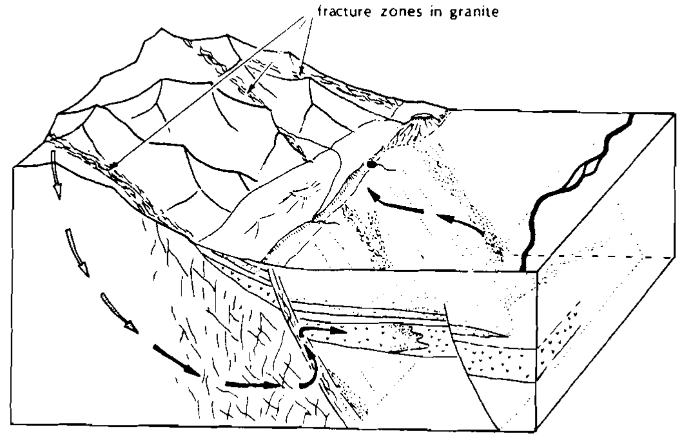

Figure 6. Conceptual model of the groundwater circulation system through fractured granite to the discharge area along the foothills fault zone of Boise and into the permeable rhyolite aquifers beneath the northeastern part of the city.

discharge rates, have been analyzed for engineering-design purposes. Such analyses suggest that within time limits of a few hours to a few days the system responds to a measured discharge-drawdown stress as though the average transmissivity is of the order of 240,000 gal/day/ft (32,000 ft^2/day or 3,000 m^2/day) and storativity is of the order of 5×10^{-4} (dimensionless). Large deviations from these gross engineering estimates occur in parts of the system. Here, near the Boise Warm Springs wells, analysis by C. J. Waag at Boise State University (personal communication, 1986) suggests transmissivities ranging from 3,500 gal/day/ft (43 m^2/day) to 25,000 gal/day/ft (435 m^2/day) and that the aquifer is confined or semiconfined. More exact values of aquifer parameters cannot be obtained until reliable observation wells are in place, discharge and injection activity by other well operators is controlled during testing, and better knowledge of fault locations and aquifer boundaries is in hand.

Several models may be developed to characterize both the heat supply and the areal geothermal groundwater circulation system. The one now thought most likely is a system of circulation to about 1 mi (2 km) depth over a path of about 6 mi (10 km) through north-to-northeast–trending deep fracture zones in the Idaho batholith (Wood and Burnham, 1983). Meteoric-water recharge at high elevations circulates with an indicated residence time (Carbon-14 activity) of 6,700 to 17,000 years (Mayo and others, 1984). Discharge at the western Snake River Plain margin is through seeps, springs, or by lateral migration through fractured silicic volcanic rock (Fig. 6). The regional high heat flow anomaly (>2.5 microcalories/cm^2s of the northern Basin and Range (Lachenbruch and Sass, 1978) apparently extends to the western Snake River Plain and the southern part of the Idaho batholith. Geothermal gradient in the plain and in the region of the geothermal wells is more than 40°C/km (Wood, 1984), which provides opportunity for the observed well-discharge temperatures with relatively shallow circulation. Further, heat flow along the margins of the western Snake River Plain is typically 3.0 microcalories/cm^{2}s, possibly localized by thermal refraction related to the faulted interface of relatively conductive granitic rocks of the margin with the more insulating basin fill deposits of the plain (Brott and others, 1978).

The Boise geothermal groundwater system has many geologic characteristics in common with other fault-related warm springs in the western United States. It is unique in that its potential for heating and culinary water was recognized and developed on a moderate scale nearly one century ago. Because of its proximity to a center of population, demands on the system will presumably increase to its ultimate capacity. Since 1892, the Boise Warm Springs wells have averaged about 700,000 gal/day (2,650 m^3/day) for about 250 days of the year. Since 1981, withdrawals from the system have tripled to about 2,500,000 gal/day (9,500 m^3/day) for this heating season. Of this, about 700,000 gal/day is currently reinjected into the rhyolite aquifer. It is hoped that continued monitoring of the system as it is developed will avert expensive overdevelopment. Studies as the system is stressed will also greatly enhance our knowledge of the broader recharge mechanism of this type of groundwater system.

REFERENCES CITED

Armstrong, R. L., Leeman, W. P., and Malde, H. E., 1975, K-Ar dating of Quaternary and Neogene volcanic rocks of the Snake River Plain, Idaho: American Journal of Science, v. 275, p. 225–251.

Brott, C. A., Blackwell, D. D., and Mitchell, J. C., 1978, Tectonic implications of heat flow of the western Snake River Plain, Idaho: Geological Society of America Bulletin, v. 89, p. 1697–1707.

Ekren, E. B., McIntyre, D. H., and Bennett, E. H., 1984, High-temperature, large-volume, lavalike, ash-flow tuffs without calderas in southwestern Idaho: U.S. Geological Survey Professional Paper 1272, 76 p.

Hart, W. M., Aronson, J. L., and Mertzman, S. A., 1984, Areal distribution and age of low-K, high alumina olivine tholeite magmatism in the northwestern Great Basin: Geological Society of America Bulletin, v. 95, p. 186–195.

Kimmel, P. G., 1982, Stratigraphy, age, and tectonic setting of the Miocene-Pliocene lacustrine sediments of the western Snake River Plain, Oregon and Idaho, *in* Bonnichsen, B., and Breckenridge, R. M., eds., Cenozoic geology of Idaho: Idaho Geological Survey Bulletin 26, p. 559–578.

Lachenbruch, A. H., and Sass, J. H., 1978, Models of an extending lithosphere and heat flow in the Basin and Range Province, *in* Smith, R. B., and Eaton, G. P., eds., Cenozoic tectonics and regional geophysics of the western Cordillera: Geological Society of America Memoir 152, p. 209–250.

Leeman, W. P., 1982, Development of the Snake River Plain–Yellowstone Plateau Province, Idaho and Wyoming; An overview and petrologic model, *in* Bonnichsen, B., and Breckenridge, R. M., eds., Cenozoic geology of Idaho: Idaho Geological Survey Bulletin 26, p. 155–177.

Lindgren, W., 1898a, Description of the Boise Quadrangle, Idaho: U.S. Geological Survey Geologic Atlas, Folio 103, 7 p.

——, 1898b, The mining districts of the Idaho Basin and the Boise Ridge, Idaho: U.S. Geological Survey 18th Annual Report, pt. 3, p. 625–736.

Malde, H. E., 1987, Quaternary geology and structural history of Snake River Plain, Idaho and Oregon: *in* Morrison, R. B., ed., Quaternary Nonglacial Geology: Conterminous United States: Boulder, Colorado, Geological Society of America, The Geology of North America, v. K-2, in press.

Mayo, A. L., Muller, A. B., and Mitchell, J. C., 1984, Geochemical and isotopic investigations of thermal water occurrences of the Boise front area, Ada County, Idaho: Idaho Department of Water Resources Water Information Bulletin 30, pt. 14, 55 p.

Wood, S. H., 1984, Review of late Cenozoic tectonics, volcanism, and subsurface geology of the western Snake River Plain, *in* Beaver, P. C., ed., Geology, tectonics, mineral resources of western and southern Idaho: Dillon, Montana, Tobacco Root Geological Society, p. 48–60.

Wood, S. H., and Burnham, W. L., 1983, Boise, Idaho, geothermal system: Transactions of the Geothermal Resources Council, v. 7, p. 215–225.