GEOLOGY OF THE BOISE GEOTHERMAL AREA,
GEOLOGIC ROAD LOG (1984); WITH COMMENTS ON GEOTHERMAL GROUNDWATER

by Will L. Burnham
3220 Victory View Drive
Boise, Idaho 83725
and
Spencer H. Wood
Department of Geology and Geophysics
Boise State University, Boise, Idaho 83725

FIELD TRIP ROUTE IS SHOWN ON FIGURE 1.

Distance

0.00 mi (0.00 km)

Parking area at North side of Old State Penitentiary Museum compound, behind the Bishop House. Looking north across the south boundary of Section 12, T. 3N, R. 2E (indistinct fence line) at the ridge slope and the newly refurbished well house for BWSWD (Boise Warm Springs Water District) wells. The well house contains the original two wells drilled in 1890 for hot water at a prominent hot spring, seep, and marsh area (Wells, 1971). The wells were quickly placed in service to provide space heating and domestic hot water for homes and businesses, as well as a Natatorium. Demand for space heating has varied over the years because of the convenience of gas and electric heat, but current records show that the wells service some 200 connections. Both wells were redeveloped and partly reconstructed at various intervals, principally in about 1930. Other wells have been drilled near these from time to time, but none have been as successful as the original. The wells are each about 400-to-410 feet (122-to-125 m) deep, are 31 feet (9 m) apart, and are cased with 12-inch (30.5-cm) steel pipe to a depth of 160 feet (49 m). Below 160 feet (49 m) the wells are about 9 inches (23 cm) in diameter and are uncased. Information about the subsurface materials drilled is sketchy, but it is probable that 160 feet (49 m) marks the base of potentially collapsible sediments and the top of more stable volcanic rock (see attached diagrams and cross-sections, Fig. 2). Borehole television inspection in 1980 indicated hard, fractured rock to about 370 feet (113 m), then coarse conglomerate to the bottom. Geologic mapping and other well data indicate the rock is rhyolite.

The wells are both artesian, and will flow at the well house floor (elev. 2,765 ft., 843 m) if not pumped. They have been in continuous use since 1891 and still yield water at the original temperature of 170-172°F (78°C). To prevent overtopping during summer shutdown, each well casing is tapped near the top by a line that feeds into the distribution pipeline. The best available information indicates that static water level has declined a few feet during the 90-year period—perhaps as much as 18 feet (6 m) (see Lindgren, 1898). Yield of each well is limited by depth of pump setting which is at the 160-foot (49-m) casing base. The west well is slightly the better of the two, and will yield at least 1,200 gpm (gallons per minute) or 4543 liters per minute when pumped alone. Drawdown interference between wells is large, and maximum yield with both pumps operating is only slightly greater than 1,200 gpm (4543 lpm). Average
Figure 1. Route Map for Boise Geothermal System Field Trip.
discharge during the peak of the winter heating season is about 1000 gpm (3028 lpm). Average for the season is nearer 500 gpm (1893 lpm). Well tests in 1980 prior to installation of the present pumps gave indicated aquifer transmissivity and storativity values of about 15,000-25,000 gpd/ft. (56,781-94,635 lpd/m) and 1.5 x 10^{-4}, respectively. In an attempt to increase yield and number of service connections a cable-tool hole was drilled to a depth of 595 feet (181 m) (from elev. 2,785 ft, 849 m) about 650 feet (198 m) northwest of these wells in 1982. This latest well (BWSWD #3) penetrated a fault plane at about 315 feet, (96 m), then was drilled in hard, dense rhyolitic rock to 471 feet (144 m). A white clay occurs to 487 feet (148 m), then pinkish, quartz-rich rhyolite to the bottom at 595 feet (181 m). Insufficient yield and water temperature of about 145°F (63°C) makes the well unusable for planned purposes. It is presently equipped with a water-level recorder to monitor annual trends and the effect of pumping at the producing wells (see attached hydrograph, Fig. 3).

The attached sketch and cross-section of the ridgeslope (Fig. 2), and the stratigraphic chart (Fig. 4) identify the principal geologic features of this geothermal site. The wells are in, or very near, at least one of three distinct fault planes that strike along the ridge base (Fig. 5) and dip 65° to 80° south. The northernmost fault is immediately north of BWSWD #3 and is the one cut by the well at about 315 feet (96 m). The middle fault trace is sub-parallel and trends about through the production wells. The third, and apparently largest, fault offset is on a plane again sub-parallel and trending just behind the old penitentiary, beneath the parking area. The tabular blocks between the faults are tilted to the northwest about 12°, forming ramps on the down-dropped sandstone surfaces as seen to the right of the well house. The ridge face behind the well house is a moderately eroded fault scarp, exposing sandstone and siltstone along the crest, resting on a thin greenish-gray claystone, all sediments of the lower Idaho Group (see stratigraphic chart attached, Fig. 4). The claystone is unconformable on porphyritic basalt that, in turn, laps unconformably against the higher of the two rhyolitic rock outcrops to the west, or left (locally referred to as Castle Rock). Large (several centimeters) phenocrysts of feldspar occur in the basalt, as well as zeolite, calcite, and opaline secondary deposits. The basalt occupies the same stratigraphic position as basalt flow units at the base of the basaltic tuff unit (Tbt) found in outcrops throughout the area and in the geothermal wells at Military Reserve and Capitol Mall. The remainder of the scarp face is composed of two distinctive rhyolitic rock types (Tsv1 on stratigraphic chart, Fig. 4,5), best seen in and around the two prominent outcrops of "Castle Rock." The higher and larger mass is a stoney rhyolite flow, or densely welded rhyolite tuff, displaying well-developed sheet jointing, the orientation of which suggests a tight asymmetrical anticlinal fold whose axis plunges gently north. This is the outcrop described as a laccolith by Lindgren in his 1898 report, and argued over by geologists ever since. There is now good evidence to indicate that the exposure represents only the draping of the lower Idaho Group sandstone (Til) over the rhyolite, with a large erosional unconformity between.

The core of the nearer, smaller outcrop is the same stoney rhyolite,
Figure 2. Sketch and generalized Cross-Section across east end of ridge behind old State Penitentiary and BWSWD wells showing geologic units and fault displacement.
Figure 3. Boise Warm Spring Water District #3 well. Record of water levels for 1981.
### Figure 4. Stratigraphic and lithologic sequence of the principal rock units seen in outcrop within the foothills, and in the geothermal wells near Boise.

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<th>CRET.</th>
<th>Granitic Rocks (K1) Monzonitic and granitic rock of the Idaho Batholith.</th>
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<td>MIocene and Pliocene</td>
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<td>Rhyolitic Lava or Welded Tuff (Tsv) Pinkish to purplish-gray, stoney, well-jointed at some places, massive, flow-banded and perlite at others. Quartz-rich.</td>
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<td>Sandstone (Tss 2) Very coarse to medium sand with siltstone streaks. Arkosic, no volcanics.</td>
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<td>Course-Medium Sandstone (Tss 1) Arkosic sand, gray, grades to fine sand and silt. Moderate cementation locally.</td>
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<td>Silicic Flow or Welded Tuff (Tsv) Rhyolitic flow and ash-flow tuff. Light gray to pink, stoney, highly jointed. Secondary phase is dark green to black, glassy matrix, with imm plagioclase. No quartz.</td>
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<td>Basaltic Tuff (Tbt) Medium brown to tan tuff with flow basalt at top and bottom at some locations. Thick, white ash beds at some places. Laps on or is faulted against the granitic rocks, and laps on and around the rhyolitic flow rocks.</td>
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<td>Sand (Ts) Mostly arkosic, light gray, medium texture. Some cross-bedding.</td>
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<td>Basaltic Lava (Tba and Tb) Two or more flow units with thin sand separations. In Aldape Heights Tba is non-porphyritic.</td>
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<td>Quaternary</td>
<td>Alluvium Sand, silt, clay</td>
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<td>Idaho Group sediments Sand, silt and clay with thin layers of gravel in the upper part, becoming mostly blue clay and shale with siltstone in the lower. Largely arkosic with minor volcanics. Most of section is in the Lower Idaho Group (TIl)</td>
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Figure 5. 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 indicated 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.
although the jointing is oriented more to the northwest and the fold upside down. Surrounding this outcrop is a dark green or brown to nearly black, porphyritic rhyolitic vitrophyre. Plagioclase phenocrysts in the glassy matrix are about 1 to 1.5 mm (.04 to .06 in.) in size. The rock displays large hexagonal joint columns, oriented perpendicular to the plane of faulting.

Fragments that appear to be derived from the stoney rhyolite may be seen near the contact with that rhyolite as inclusions in the vitrophyre. An excellent exposure of hydrothermally altered and leached rhyolitic rock occurs along the northernmost fault plane immediately north of BWSWD #3. Also, the two stoney rhyolite outcrops are separated by a north-trending zone of hydrothermal alteration and silicification.

Finally, the fault group displayed here marks the southern boundary of a triangular horst block that underlies most of the Foothills East Subdivision area, across the ridge to the north of this locality, and extends northwestward beyond Military Reserve Park. Displacement of the rhyolitic rocks across this fault group is indicated to be at least 800 feet (243 m), down to the south. A recent well drilled in the down-thrown block (the Kanta well at the SE corner of the old prison compound) reached rhyolite at about 790 feet (241 m) below elevation 2,765 ft. (843 m), which matches closely the log of a second well to the southeast (State Old Pen well). A second new well drilled for Boise City Parks Dept. in the open flat about 600 ft. (183 m) south of "Castle Rock" also reached top of rhyolite at 700 ft. (213 m) below land surface elevation, 2,735 ft. (834 m). Although this shows a rhyolite offset of at least 800 ft. (243 m), the top of the overlying basaltic rock sequence is offset only about 550 to 600 ft. (168 m to 183 m).

In this structural block, faulted down at least 800 ft. (243 m) below "Castle Rock", the maximum temperature of water from the three known hot-water wells in the block is at least 10 degrees F (-12°C) less than that of the BWSWD wells. The reason may be both because of mixing with cold near-surface water, and because of lateral distance of the wells from major fault planes.

Stop sign. Intersection with Warm Springs Avenue (Hwy 21), turn right. The subsurface trace of the principal Boise Front Fault (Foothills Fault of Hollenbaugh) is believed to pass at about this point and trend about parallel to Warm Springs Avenue to the left. This fault further displaces the rhyolite down to the south.

Trolley House Restaurant and School on left. Immediately behind is a Boise City swimming pool. This is the site of the Natatorium, which was a major user of BWSWD well water until the 1950's. Continue on Warm Springs Avenue.

Locust Street. Turn right toward foothills. At least 200 homes along Warm Springs Avenue and the first two blocks here on the north side use the BWSWD well water for space heat and for domestic hot water. The water is delivered through either a meter or an adjustable orifice. Spent water is discharged to the sewer or to canals leading to the Boise River (See map; BWSWD distribution system, Fig. 7). Recently some spent water
### GROUPS AND FORMATIONS

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*New stratigraphic names
**Old stratigraphic names, redefined

**Figure 6. Upper Cenozoic stratigraphic units of the western Snake River Plain proposed by Malde and Powers (1962), and as adapted for the Boise geothermal area.**
Figure 7. Distribution and service areas for the three separate geothermal systems in place in Boise. The Boise City and Boise Warm Springs Water District systems are inter-tied. The Capitol Mall system serves State of Idaho facilities, and is a separate closed system.
has been diverted for use in experimental prawn culture before final discharge.

1.45 mi.  
(2.33 km)  
Locust Street crosses the principal faults of the Boise Front about here. Cross onto the horst block. Immediately ahead is thin aluvium on basalt at the base of the basaltic tuff unit.

1.60 mi.  
(2.57 km)  
Turn right onto Shenandoah and enter Foothills East Subdivision.

1.80 mi.  
(2.89 km)  
The knob on the left is capped by lower Idaho Group Sandstone (Til) overlying porphyritic basalt. Sandstone overlies flow basalt under the ridge coming into view on the right, leading up to "Castle Rock." The horst block is broken in this vicinity by internal normal faults, with displacements of a few feet to tens of feet. The faults trend mainly NW and dip steeply. Continue around Shenandoah St.

2.10 mi.  
(3.38 km)  
Intersection with Rimrock Street on left. The multiple dwelling units ahead on the right are about on one of the northeast boundary faults of the horst block. Several sub-parallel normal faults, down to the northeast, are present in this vicinity and trend SE through the large depression on the right. The faults bring lower Idaho Group sediments down against basaltic tuff, flow basalts, and older lower Idaho Group sediments.

2.30 mi.  
(3.70 km)  
Turn right on Shaw Mtn. Road. Immediately after the turn, Shaw Mtn. Road crosses the trace of the principal northeast boundary normal fault of the horst block. The fault trace is covered by unfaulted terrace gravel here, but strata of the block immediately ahead (NE) are down, relative to those of this block. The down-faulted, graben-like block is narrow at this southeast end, and widens to the northwest. It is tilted several degrees northwest.

2.50 mi.  
(4.02 km)  
Bear left on Shaw Mtn. Road.

2.60 mi.  
(4.18 km)  
Descending the south wall of Cottonwood Creek Canyon. A good view of the nearly flat-lying, brown, basaltic tuff unit, overlain by light gray sand, is ahead just beyond the ranch house in the canyon on the left. Just ahead, the road crosses a second main zone of normal faults of the Boise Front zone of faulting. Although not well exposed along the road here, these faults are clearly traced both to the northwest and southeast, and mark the northeast boundary of the graben block just crossed. Trend of the faults is about N38°W with a steep SW dip. Throw is down to the SW, such that the basaltic tuff exposed beyond the house is found in wells this side of the fault at greater depths.

3.00 mi.  
(4.82 km)  
Cross cattleguard, then Cottonwood Creek. On ridge point at northeast side of tributary from the right, basaltic tuff is overlain by white sand (Ts), which in turn is unconformably overlain by Quaternary bouldery terrace alluvium (Qg). The white sand is Tertiary and everywhere in this vicinity marks the contact between basaltic tuff (Tbt) and the lower Idaho Group sediments. The Quaternary gravel above is a terrace deposit and is not known to be faulted within the foothills, and marks an ancestral Cottonwood Creek drainage system. It is traceable from terraces at the
present mouth of Cottonwood Creek, to an elevation of about 3,500 ft. (1067 m) in upper Picket Pin Creek ahead.

3.20 mi.  
(5.15 km)  
Cross 100-ft. (30 m) offset in top of basaltic tuff, down to SW.

3.30 mi.  
(5.31 km)  
Good view of basaltic tuff unit in canyon wall on south side of creek.  
Tuff on both sides of canyon and in the roadcuts on the left. Here the tuff is overlain by red-brown arkosic sand and silt, without the distinctive gray-to-white sand separator.

3.70 mi.  
(5.95 km)  
Road crosses onto outcrop of purplish-gray, glassy, flow-banded, welded rhyolite tuff (Tsv2). Basaltic tuff, overlain by lower Idaho Group sandy sediments, laps onto and over the rhyolite in the ridge on the left. Across the creek the basaltic tuff appears to lap onto the rhyolite. The rhyolite here is a dark vitrophyre of the lower (Tsv2) unit shown on the stratigraphic chart.

3.80 mi.  
(6.11 km)  
Stop 1. Confluence of Cottonwood Creek and Picket Pin Creek. Purplish-gray perlitic rhyolite on the point between the creeks is characteristic of similar outcrops near and surrounding the base of the Tsv2 unit. The west edge of the rhyolite outcrop here between the creeks is beveled to a uniform, flat, bench surface some 20 or 30 ft. (6 or 9 m) above the creeks. The red-brown fluvial deposit above the bench is in the lower Idaho Group and the basaltic tuff is missing. Thus this contact marks a large erosional unconformity at this locality. The top of the basaltic tuff unit appears at, or just above, road level in the canyon wall on the north side of Cottonwood Creek, yet about 2,000 ft. (610 m) up Picket Pin Creek the top of basaltic tuff is more than 500 ft (152 m) above this point. There, as here and to the west, the tuff is nearly horizontal. The rhyolite flow of Rocky Canyon is at least 200 feet (61 m) thick, and may be as much as 400 ft. (122 m) thick. The rock is complexly flow-banded and highly fractured, varying in color from dark and glassy gray-brown to a stoney lavender-gray. It contains euhedral quartz and phenocrysts of both plagioclase and alkali feldspar. Mafic minerals are not conspicuous, but careful examination is yet to be done. Flow features suggest it may be either a densely welded ash-flow tuff or rhyolite flow. It is known to occur in the subsurface in Freestone Creek, 1.5 miles (2.4 km) northwest.

Continue up Rocky Canyon Road.

4.00 mi.  
(6.44 km)  
Note sudden offset in height of canyon walls, then immediately the near-vertical fracture patterns in the rhyolite on either wall.

4.30 mi.  
(6.92 km)  
Stop 2. At upstream margin of rhyolite. On the left, north of the road in thick bushy growth, the granite of the Idaho Batholith (Ki) is in fault contact with basaltic tuff. These red-brown deposits give the color to the saddle-like swale in the contact zone between the granite and the
rhyolite. South of the creek (to the right) the basaltic tuff is clearly evident in the lower part of the canyon wall; and appears to lap against the rhyolite. A few hundred feet upstream, an old mine adit follows a fault contact between granite and basaltic tuff. The contact zone here has not been studied sufficiently to determine just how the granite, rhyolite, and basaltic tuff occur. It appears, however, that the basaltic tuff overlies or laps against the rhyolite, and that both are faulted against the granite on a contact that trends N52°W and dips toward the southwest about 72 degrees. (See geologic map sections.)

The road bends sharply left, then back 90° right. The granitic rock here is biotite bearing, but much of the rock is hydrothermally altered so it contains no visible mafic minerals. Originally it was probably a biotite quartz monzonite. In the tributary to the right, there are hydrothermal quartz veins and alteration in the granitic rock. Note the consistent joint sets or extensive fracturing in the area.

Continue up Rocky Canyon Road through the granitic rock exposures, noting the great variability in degree and orientation of jointing and fracturing. Flow basalt caps the south canyon wall ridge, lying unconformably on both the granitic rocks and basaltic tuff. Stratigraphically this basalt overlies unconformably the basaltic tuff, and is equivalent in position to the flow basalts at the top of the basaltic tuff unit at the mouth of Cottonwood Creek. The basalts of the two localities are very dissimilar in texture and mineralogy, however. Unconformably on this basalt, and on the granitic rocks of the north canyon wall, is gravelly alluvial sediment of the lower Idaho Group.

Basalt dikes cutting granitic rocks in roadcuts.

Stop 3. Turn around at mouth of Fivemile Canyon. Numerous old workings for gold in quartz veins occur up this canyon. Large outcrops with prominent jointing are seen ahead in Cottonwood Creek and on the east wall of Fivemile Canyon.

Turn vehicles around and retrace the trip. The intent now is to use this as the beginning point for a trip upward in stratigraphic sequence (and time) across most of the rocks of importance to the geothermal system and the wells. The best conceptual model at present is that recharge to the thermal water flow system occurs here and to the northeast over the jointed, fractured granitic rocks, and through the intense fracturing of the rhyolitic rocks. Consider this concept as we now backtrack through Rocky Canyon and emerge on the basaltic tuff. The tuff is widespread throughout the Boise Front and into the valley. It has very small cross-bed permeability and does not accept recharge readily. It is broken by the faults, but the basaltic composition tends to alter to clay wherever faulting has allowed contact with hydrothermal conditions. Thus, the basaltic tuff and overlying Idaho Group sediments provide a hydraulic cap to the deep circulation system in the granitic and rhyolitic rocks. We climb back out of Cottonwood Creek onto Idaho Group sediments and Qg as we return to the intersection of Shaw Mtn. Road and Shenandoah Street.

Re-set odometer to 0.0 at junction of Shaw Mtn. Road and Shenandoah.
Continue down Shaw Mtn. Road and recall that we are again on the horst block.

0.25 mi. (0.40 km) Fault on right in roadcut bank of cross-bedded yellowish sand. This fault is one of the main internal structural features of the horst block. It strikes NW and dips 62°NE. A second, similar fault is visible again on the right a few hundred feet further on around the curve. The faulted sand belongs near the base of the lower Idaho Group sediments. Basaltic flow units, at the base of the basaltic tuff, outcrop a short distance below the road on the left.

0.60 mi. (0.97 km) Cross contact at base of the uppermost basalt flow units in the area (Tba), designated the basalt of Aldape Heights on the stratigraphic chart. Below the road, on the left, there are exposures of a light gray sand that separates this basalt from the basaltic tuff sequence. Continue around Shaw Mtn. Road on the Aldape Heights basalt (Tba), which dips about 15° southwest.

0.70 mi. (1.13 km) Looking northwest along the toe of the Boise Front and the trace of the principal faults of the Frontal Fault zone. Straight ahead are the four Boise Geothermal Limited wells, BGL-1 thru 4 and test hole BGH-1 (Beard). Three sub-parallel planes of normal faulting are known to occur along or near the break in slope, with a down-to-the-southwest throw of rhyolitic rocks totaling about 900-1,000 ft. (274-305 m) (Fig. 8,9). Throw on the basaltic tuff is about 450 ft. (137 m), and on the basalt of Aldape Heights (Tba) is about 270 ft. (82 m). The fault planes here dip about 80-85°SW. This fault zone trace is the same one noted earlier beneath Warm Springs Avenue near the old penitentiary.

0.90 mi. (1.45 km) Continue left on Reserve Street.

1.10 mi. (1.77 km) Turn right at signal onto Mountain Cove Road. Berms on the right bound flood-control basins for Cottonwood Creek and Freestone Creek drainages. Controlled outflow is through the flume along the road, on left.

1.40 mi. (2.25 km) Cross headgate structure and turn right onto dirt track up the frontal slope. Exposure at base of slope on left and around the ridge into Cottonwood Creek is the uppermost of two distinct basalt flows of the Aldape Heights basalt (Tba).

1.70 mi. (2.74 km) Stop 4. Park in designated area for overlook into Cottonwood-Freestone Creeks. Walk about 200 ft. (61 m) north to picnic shelter and overlook. We are on the Quaternary terrace gravel noted earlier as we crossed Cottonwood Creek heading up to Rocky Canyon gorge. The gravel is in erosional contact here with the Tba unit that is seen in exposure across the canyon, and it caps the ridge between the creeks. This is the youngest deposit known in the area, except for the alluvium of the present stream terraces and channels. It contains cobble layers, as well as large blocks and boulders of the distinctive basalt, overlying granitic rock above the Rocky Canyon gorge, about 2.5 miles (4 km) upstream.

Looking at the north canyon wall above Mountain Cove Road, the upper flow unit of Aldape Heights basalt (Tba) is exposed in the old quarry and...
Figure 8. Generalized location map of the Capitol Mall and Military Reserve Park area, with wells, line of section (Fig. 10), and general geology.
Figure 9. Section from SW to NW through Capitol Mall and Military Reserve to the granite NW of Cottonwood Creek.
Figure 10. Correlation section from the State Capitol to Cottonwood Creek. No vertical exaggeration.
dips about 12°SW. Base of Qg is seen at 'the top of the exposure unconformably on the basalt. Down and to the right near the road is a thin white sand which thickens southward under our vantage point, and separates the two flow units of Tba. Up and slightly right of the sand exposure is an outcrop of sandstone striking NW and dipping only about 3 to 5 degrees SW. The sandstone belongs stratigraphically well above the basalt with which it appears here to be continuous. One of the main faults of the NE side of the horst block passes between the outcrops, trending N58°W and dipping steeply NE. The fault also cuts across the nose of the dividing ridge between the creeks before us and to the right, then can be found in a tributary draw along this side of the canyon about 1,200 ft. (366 m) upstream. Another, and the main NE boundary fault of the horst block, crosses the dividing ridge a few hundred feet farther east, and trends N52°W with a steep NE dip. The two wells noted by Lindgren in his 1898 report as being in Cottonwood Creek about 2 miles (3.2 km) above Boise were located near the south wall of the creek; just upstream (East) of the trace of this NE boundary fault of the horst. The basalt reported in those wells is the down-faulted Tba.

1.90 mi. (3.06 km) On switchback above well BGL-3. (See map, figure 8 for well numbers and locations.) The Tba unit is under soil cover in the roadcut here. The top of basalt is found in well BGL-3, about 80 ft. (24 m) away, at a depth of 270 ft. (82 m). This fault offset of nearly 300 ft. (91 m) is on the middle of the three fault planes along the front, striking N38°W and dipping 85°SW. The first geothermal test hole drilled in 1975 and designated BEH-1 (BLM) is located beside the nearest metal-sided building, across the road and flume toward the west, about 400 ft. (122 m) away. All three fault traces of the frontal fault zone occur between here and that well.

2.00 mi. (3.22 km) Stop 5. At Boise Geothermal Limited Well No. 2 (Fig. 8). Wells are numbered in the order drilled. Number 1 is at the SE without a shelter. The others are in concrete housings, designed for partial burial to blend with park landscaping. Most of the pertinent information on locations, well construction, yield, water temperature and quality; instrumentation, distribution system, and uses is given in accompanying maps, diagrams, and table. A few additional facts on design, construction, testing, and completion follow:

1. Data from test holes BEH-1 (BLM) and BGH-1 (Beard) restricted location to near vicinity of interpreted faults striking NW along the toe of the break in slope of the Boise Front.

2. Right-of-way and access restricted locations to roadways and berm tops within Military Reserve Park between Mountain Cove Road and the south boundary.

3. Planned uses determined a desired peak season yield of 2,000 gpm (7571 lpm) or greater. Test data from the BLM-Beard holes indicated individual well yields of 500 gpm (1893 lpm) with economically feasible drawdown. Consequently, four wells were needed to be fitted into available locations.

79
Figure 11. Typical well construction for Boise Geothermal Limited wells 1 through 4 and Capitol Mall well #2.

1. BGL-1
   - Depth: 2,000'
   - Surface casing to 807'
   - Perforations:
     - 157-1,019
     - 1,020-1,049
     - 1,050-1,090
     - 1,091-1,157
   - Open hole from 1,160-2,000'

2. BGL-2
   - Depth: 980'
   - Surface casing to 692'
   - Open hole from 742-775'

3. BGL-3
   - Depth: 1,897'
   - Surface casing to 680'
   - Perforations:
     - 820-980
     - 981-991
   - Open hole from 1,000-1,897'

4. BGL-4
   - Depth: 1,103'
   - Surface casing to 687'
   - Perforations:
     - 760-860
     - 861-949
     - No open hole

5. CM-2
   - Depth: 3,470'
   - Surface casing to 1,235'
   - Perforations:
     - 1,250-2,750
   - Open hole from 2,750-3,470
Figure 12. Temperature profiles for BGI #3, BLM (BEH-1), Beard (BHW-1) after wells shut in for several months and temperature stabilized.
Representative Water Quality
(Geothermal & Shallow Cold Water)

<table>
<thead>
<tr>
<th></th>
<th>BWSMD (Westwell)</th>
<th>DGL-2</th>
<th>VA Supply</th>
<th>Capitol Mall #2</th>
<th>Barnes (Foothills)</th>
<th>BMCO Centennial (Valley)</th>
<th>Boise River (Barber)</th>
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<tr>
<td>Specific Conductance</td>
<td>378</td>
<td>405</td>
<td></td>
<td>415</td>
<td>157</td>
<td>208</td>
<td>85</td>
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<td>(micromhos/cm)</td>
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<td></td>
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<tr>
<td>pH</td>
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<td>7.7</td>
<td>7.29</td>
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<tr>
<td>Temperature, °C</td>
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<td>74</td>
<td>72</td>
<td>70.5</td>
<td>16</td>
<td>(Cold)</td>
<td>9</td>
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<tr>
<td>Cations (mg/l)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Calcium</td>
<td>3.2</td>
<td>1.9</td>
<td></td>
<td>1.3</td>
<td>16</td>
<td>21</td>
<td>10.4</td>
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<td>&lt;0.1</td>
<td></td>
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<tr>
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<td></td>
<td>79.2</td>
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<td>23</td>
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<tr>
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<td></td>
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<td></td>
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<tr>
<td>Bicarbonate</td>
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<td>138</td>
<td></td>
<td>142</td>
<td>83</td>
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<td>46</td>
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<tr>
<td>Chloride</td>
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<td>5</td>
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<tr>
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<td>22</td>
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<td>10</td>
<td>20</td>
<td>2</td>
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<td>15.7</td>
<td>16.7</td>
<td>16</td>
<td>0.32</td>
<td>0.62</td>
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</table>

Table 1. Representative water quality, Boise area.
4. Spacing to minimize drawdown interference between wells had to be matched to access and right-of-way, and to pipeline costs for the gathering system.

5. State and local laws and regulations related to geothermal wells required pressure grouting of surface casing to protect shallow cold-water aquifers, and blow-out protection when drilling the thermal zone. Such requirements dictated size, type, and capabilities of drilling equipment used. Design, discharge, and drawdown dictated size of pumps required. Size of pump dictated size of hole to be drilled to accept casing and the pressure-cemented annulus needed. Size of surface casing was further dictated by size of the production hole and casing needed, and by the possibility that at least two hole-size reductions might be needed below the surface casing. Such considerations further determined the size and type of drilling equipment.

6. Drilling deep, large diameter holes in or near fault zones anticipates hole-wall instability and loss-of-circulation problems. A carefully designed and controlled drilling mud is required. To minimize drilling mud effects on thermal water production, only bentonite clay mixed with fresh water was used where mud drilling was necessary. Conditioning additives were closely monitored and kept to a minimum. Wherever possible in the thermal water production zones; drilling was done with water only, with compressed air assistance in removing cuttings and maintaining circulation.

7. Only moderate thermal-water formation pressures were encountered, and as a rule the wells did not flow or make a significant amount of water during drilling. Each well was completed by circulating out the drilling fluid with clear water, then air lifting to reduce the column density sufficiently to initiate artesian flow. Flow was continued until the discharge was clear and stable. Well BGL-3 is located such that the wellhead elevation is above artesian pressure head. That well was air-lift pumped for completion.

8. The wells were testflowed or pumped under a variety of procedures, designed to determine both well and aquifer hydraulic characteristics, under planned production schedules and use. Testing included long-term monitoring of water-level changes in the thermal water zones at the Koch well which is drilled in the fault blocks northeast of the Frontal Fault Zone (Fig. 8). Also monitored was BWSWD well #3 (Fig. 3) which is in or near the faults directly connected to the Frontal Fault Zone and the BLM test hole which is on the valleyward side of the Frontal Fault Zone. During flow tests, all wells in the vicinity completed in the thermal water zones were used as observation wells. Additionally, shallow cold-water wells nearby were monitored for possible drawdown effects.

9. Well and aquifer characteristics, as based on testing done to date, may be summarized as follows:

The wells in Military Reserve Park and valleyward in the Capitol Mall area display a seasonal static level fluctuation that matches closely both timing and magnitude of change in cold-water municipal, domestic, and irrigation wells in and near Boise. The Koch well water level fluctuates in a manner completely out of phase with
other wells, and is more in harmony with industrial and municipal supply wells within the foothills toward the northwest. BWSWID well #3 water level follows very closely the pumping times and magnitude at the two production wells near the Old Penitentiary (see attached hydrographs; Fig. 13,14).

The thermal water aquifer system at the BGL wells is well confined, with indicated storage coefficients of $10^{-4}$ to $10^{-3}$. All wells have a barometric efficiency of about 80 to 90 percent. During the early, initial period of a test, the aquifer responds as a fault-fracture system with indicated transmissivity in the $10^6$ gpd/ft. range and no-flow boundary across the faults to the northeast. Toward the southwest, the Capitol Mall and BLM observation wells indicate the aquifer responds more in the character of a granular material with transmissivity values of the order of $10^5$ gpd/ft. and storativity of $10^{-3}$.

There is a regional gradient of the static water level (pressure head) toward the northwest from BGL-1 to BGL-3, within the Military Reserve area. Also, toward the west-northwest between wells in Military Reserve and those at Capitol Mall. The pressure head in the thermal groundwater system is everywhere greater than either artesian or water-table levels in the cold-water aquifers of the lower Idaho Group sediments. It is therefore interpreted that the gradient in the thermal water system reflects lateral migration valleyward from the frontal faults and discharge upward by cross-bed bleeding to Idaho Group deposits at lowerhead.

Continue southeast along the line of wells to Reserve Street.

3.15 mi. Reserve Street. Turn right and proceed toward downtown Boise.
(5.07 km)

3.60 mi. Turn right on Fort Street. Cold-water wells here in the Military Reserve Park area are 400-500 ft. (122-152 m) deep. Monitored water levels in these wells do not reflect drawdown caused when flow-testing the geothermal wells. Idaho Group sediments are more than 600 ft. (183 m) thick in this vicinity.
(5.79 km)

3.80 mi. Turn left on Washington Street.
(6.11 km)

3.90 mi. On the left, the structure in the parking lot houses the State of Idaho Capitol Mall well #1. The field trip will not stop here, as it will return to this site at the end of a walking tour through the State facilities.
(6.28 km)

Continue west on Washington Street.

4.15 mi. State of Idaho parking lot on right. Enter lot and continue around to Capitol Mall well #2 well house near SE corner. This is the final stop.
(6.68 km) Capitol Mall well #2 was drilled by the same equipment and under essentially the same specifications as the four Boise Geothermal Limited wells in Military Reserve Park. The well is 3,030 ft. (924 m) deep and
Figure 13. Boise Geothermal LTD. #3 well. Water level elevations.
Figure 14. Koch "Old" well. Water level elevations.
bottoms in quartz-rich rhyolite (Tsv2). Attached diagrams and correlative sections give the essentials of well construction and stratigraphic relations. Pressure cementing of the 12-inch (31-cm) surface casing was done by Halliburton Oil Well Cementing, and the suite of borehole geophysical logs was made by Schlumberger, both from Evanston, Wyoming. In addition to the geolograph record and log of cuttings, logs were run for Natural Gamma, Caliper, Induction Electrical Resistivity, Borehole Compensated Sonic, Compensated Neutron-Formation Density, and Temperature. These were used to guide production casing, perforation, and completion programs. The drilling was done with fresh water mixed with bentonite mud, and/or just fresh water and air. Artesian flow was controlled by mud until wellhead valving was in place and disposal facilities were in order. Upon purging of mud from the column, flow of at least 950 gpm (3596 lpm) was obtained for initial cleanup and completion. Temperature of discharge water stabilized at 160°F (71°C), and shut-in pressure of the hot water column was about 18 psig. The water quality is similar to that from other wells, and following flow tests for data about aquifer constants, the well was equipped and placed into service for the 1982-83 heating season. Attached information sheets furnish the pertinent information about the well; the heat-exchange equipment in the State buildings, and the equipment for injection of the spent water at Capitol Mall well #1.

After viewing the well facilities, proceed with walking tour through office buildings and to Capitol Mall well #1. This well is equipped for injection of the spent thermal groundwater from well #2. Drilled under a separate State contract with light-duty rotary drilling equipment, the well is 2,153 ft. (656 m) deep and bottoms in sandstone and conglomerate (Tss1) below the upper silicious volcanic rock (Tsv1). The well was drilled primarily as an exploratory well and was not designed sufficiently to meet flow needs for heating the Capitol Mall. It does serve well, though, as an injection well; the receiving aquifer being the upper part of the rhyolite at about 1,700-1,800 ft. (518-548 m) (Fig. 10).

End trip at Capitol Mall #1. Re-board transportation for return.
CAPITOL MALL GEOTHERMAL FACT SHEET

I. Pump Date and Operation (Fig. 15).

a) Production Pump P-5 - Peerless 5 stage vertical turbine, 70 foot (21 m) setting, with 2 speed 40 hp motor, rated for 750 gpm (2839 lpm) at 165 ft. (50 m) TDH on high speed and 500 gpm (1893 lpm) at 75 ft. (23 m) TDH on low speed.

b) Injection Pump P-6 - Peerless 4 stage horizontal centrifugal rated for 750 gpm (2593 lpm) at 360 ft (110 m) TDH.

c) Injection Pump P-7 - Peerless end suction centrifugal rated for 300 gpm (1135 lpm) at 75 ft. (23 m) TDH.

d) Operation
   Pump P-7 - On at temperatures below 60°F (16°C) Off at temperatures above 60°F (16°C)
   Pump P-5 - On at low speed at 200 gpm (757 lpm) On at high speed at 375 gpm (1419 lpm)
   Pump P-6 - On at 500 gpm (1893 lpm)
   Pump P-5 - Discharge pressure controlled to 30 psig on low speed and 50 psig on high speed.
   Pump P-6 & P-7 - Suction pressure controlled to 10 psig

II. Pipeline

a) Buried geothermal supply line is pre-insulated asbestos-cement, 8-inch (20 cm) size for the main line and 4-inch (10 cm) size to the Library.

b) Buried geothermal return line is uninsulated asbestos-cement, 8-inch (20 cm) size for the main line and 4-inch (10 cm) size to the Library.

c) Exposed geothermal piping is welded or screwed carbon steel with field applied 1-1 1/2 inch (2.5-4 cm) fiberglass insulation. Main supply and return lines are 8-inch (20 cm) size. Victaulic fittings were used in mechanical rooms and the pump stations.

III. Building Retrofits

a) Len B. Jordan Building

97,000 sq. ft. (29,566 sq. m), 115 gpm (435 lpm) geothermal design flow, 1.71 x 10^6 Btuh design load. Geothermal water flows directly to stainless steel air coils which were installed upstream of the existing steam coils, which were left intact to provide back-up and peak heating. A 330,000 Btuh heat exchanger uses geothermal return water to heat domestic hot water.
Figure 15. Boise Capitol Mall geothermal space-heating system showing production and re-injection well installations.
b) Hall of Mirrors

145,000 sq. ft. (44,196 sq. m), 80 gpm (303 lpm) geothermal design flow, 1.12 x 10^6 Btuh design load. Geothermal water flows to a plate heat exchanger to heat a new closed building hot water loop. The existing steam coils were removed and replaced by hot water coils. A steam converter was installed in series with the plate heat exchanger to provide back-up and peak heating.

c) Capitol Building

127,000 sq. ft. (38,710 sq. m), 160 gpm (606 lpm) geothermal design flow, 2.32 x 10^6 Btuh design load. Geothermal water flows to a new plate exchanger which was installed in series with the existing steam converter in the existing closed building hot water loop. The steam converter was left intact to provide back-up and peak heating. There are several small, remote air handlers with steam coils that were not retrofitted because it was uneconomical to pipe hot water then.

d) Central Services

43,000 sq. ft. (13,106 sq. m), 60 gpm (227 lpm) geothermal design flow, 0.81 x 10^6 Btuh design load. Geothermal water flows to stainless steel air coils which were installed upstream of the existing steam coils, which were left intact to provide back-up and peak heating.

e) Tower

166,000 sq. ft. (50,597 sq. m), 110 gpm (416 lpm) geothermal design flow, 1.68 x 10^6 Btuh design load. Geothermal water flows to a new plate heat exchanger which was installed in series with the existing steam converter in the existing closed building hot water loop. The steam converter was left intact to provide back-up and peak heating. The heat exchanger was actually sized for 220 gpm (833 lpm) geothermal flow, and will be able to carry the second Tower when it is added to this structure. A 500,000 Btuh plate heat exchanger heats domestic hot water with geothermal return water.

f) Supreme Court Building

66,000 sq. ft. (20,117 sq. m), 60 gpm (227 lpm) geothermal design flow, 0.83 x 10^6 Btuh design load. Geothermal water flows to a plate heat exchanger which heats water in a new closed building hot water loop. The existing steam coils were removed and replaced with hot water coils. A new steam converter was installed in series with the plate heat exchanger to provide back-up and peak heating.

g) State Library

39,000 sq. ft. (11,887 sq. m), 40 gpm (151 lpm) geothermal design flow, 0.52 x 10^6 Btuh design load. A new plate heat exchanger was installed to heat the closed building hot water loop. One air handler had hot water coils, and the steam coils in the other air handler was replaced with hot water coils. The existing steam converter was upgraded to increase its capacity to handle back-up and peak heating for both air handlers.
h) Controls

Water flow to the air coils is controlled by the leaving air temperature, which is on a reset schedule of 75°F (24°C) supply air at 60°F (16°C) outside air temperature, and 100°F (38°C) supply at 20°F (-7°C) outside air temperature.

Geothermal water flow to the plate heat exchangers is controlled by the leaving closed building loop water temperature which is on a reset schedule of 85°F (29°C) and 60°F (16°C) outside air temperature, and 120°F (49°C) at a 20°F (-7°C) outside air temperature.

IV. Experience

The system was started up October 1, 1982. For the winter of 1982-1983 the system operated very well, although start-up problems kept the energy management system from recording as much data as was hoped for. Generally, flows were somewhat less than the design values, injection pump P-6 was not required to be used, and geothermal water return temperatures ranged from 120 to 130°F (49 to 54°C) for buildings with plate heat exchangers and 100 to 110°F (38 to 43°C) for buildings with direct use stainless steel coils.

Following is a table showing degree days and therm usage at the State of Idaho Capitol Mall gas meter.

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
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<tr>
<td></td>
<td>Oct</td>
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<td>Dec</td>
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<td>Degree Days</td>
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Corrected 1982-1983 usage = 103,772 x 4250/3876 = 113,786

% gas usage in '82-'83 = 113,786/277,455 = 41% of '81-'82

The State of Idaho realized a savings of approximately $80,000 on its gas bill in 1982-1983, as compared to the same 6 months in 1981-1982.
REFERENCES


