TEC-13 TDA 301

AMAX EXPLORATION, INC.
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INTER-OFFICE MEMORANDUM

SUBJECT: Geology and Geothermal Potential of the Grand View Area, Idaho

DATE February 7, 1978

TO: H. J. Olson

cc: W. M. Dolan
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FROM: J. E. Deymonaz

SUMMARY AND CONCLUSIONS

The Grand View property lies along the southern margin of the western Snake River Plain. The Plain is a northwest trending complex graben, possibly associated with a crustal rift. Basaltic volcanism continued from Miocene until recent time, in and around the area. Silicic volcanism produced large volumes of rhyolitic and latitic material during Miocene time, and perhaps early Pliocene. To the north and east of the project area, eruptions of silicic material continued well into Pliocene time.

Reservoir rocks would consist of either Cretaceous granite, or a thick sequence of basalts and intermediate volcanic rock. Pervasive fracturing and interflow zones in the volcanic rocks should provide sufficient permeability. Extensive alteration would impair permeability; however, lost circulation zones deep in the Anschutz well suggest that this will not be a major problem. Jointing and pervasive fracturing within the granitic rocks should also provide adequate permeability.

Seismic and gravity data have been interpreted as depicting a large northwest trending rift zone. This zone extends the length of the western Snake River Plain and roughly parallels the AMAX property which is several kilometers to the southwest.

The zone, interpreted as a rift, may be either a true rift, or crustal thinning with mantle material abnormally close to the surface. In either case, this "zone" appears to be the primary heat source. Linear faults and fault intersections provide conduits for deep circulation of fluids in one or more circulation systems.

Thermal gradients and calculated heat flow values are impressive along the southern margin of the Plain. However, most, if not all, of the abnormally high gradients occur near faults. These faults act as conduits for the upward migration of hot water and do not reflect deep heat sources. Warm subsurface waters move along these faults near the edge of the Plain, and enter permeable aquifers dipping toward the center of the Plain. At the intersection of the fault and aquifer, the water is at its nearest proximity to the surface. The result is a surface heat flow that, moving from south to north, increases suddenly at the fault, and decreases gradually towards the Plain. The decrease is controlled by the dip of the aquifer in relation to the surface. Shallow aquifer temperatures range from 38^{o}C to 83^{o}C. Gradients controlled by them should not be used to predict depths to production temperatures. However, areas of high gradients do outline faults having deep circulation, and will be helpful in locating sites for deeper drilling.

Volcanic-rock aquifers in the Plain produce low chloride, high flouride, and high sulfate waters. Chemically similar waters occur in hot springs of the Idaho Batholith. Estimated temperatures for most samples from volcanic rock aquifers based in the silica and Na-K-Ca geochemical thermometers range from 61^{o}C to 199^{o}C and suggest mixing with cooler bicarbonate water. A mixed-water method used, estimated dilutions of 60 to 90%, and temperatures of 180^{o}C to 275^{o}C. The mixed-water method, however, is viewed with skepticism by Frank Dellechaie.

RECOMMENDATIONS

Previous deep drilling, geologic study and thermal gradient data indicate a favorable geothermal potential in the Grand View area. The following recommendations are made to more fully evaluate the area's of geothermal potential.

1. Sufficient shallow temperature gradient data has been collected. Additional shallow drilling would not be cost effective, nor would it significantly add to the knowledge of the resource.

2. Two intermediate depth (600 m) temperature holes should be drilled at the following locations:

   a. SE 1/4, sec. 1, T8S, R4E

   b. NE 1/4, sec. 29, T6S, R2E

   Hole (b) may not be necessary if Earth Power Corp. drills a proposed 460 m hole in the NE 1/4. sec. 30, T6S, R2E.

3. Additional SP data should be collected to help further delineate the structure controlling the movement of geothermal fluids. This could be accomplished by AMAX personnel at a minimal cost.

4. Completion of the SP and MT projects now underway in the area by Terraphysics Inc.

5. Additional geologic and photogeologic mapping to aid in delineating northeast trending structures not previously recognized.

6. A close watch on competitor activity should be maintained. Of particular interest is:

    a. A 2400 m to 3000 m geothermal well being drilled by Phillips Petroleum Company in the NE 1/4, sec. 24, T5S, R1E.

    b. Three proposed 460 m thermal gradient holes to be drilled by Earth Power Corp.

    The above activities should prove the commercial potential of the area by mid-year 1978.

John E. Deymonaz

JED:d

GEOLOGY AND GEOTHERMAL POTENTIAL
OF THE
GRAND VIEW AREA, IDAHO

J. E. Deymonaz
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Denver, Colorado

February 1978

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INTRODUCTION

Location and Description

The Grand View area is in north-central Owyhee County in southwestern Idaho (Fig. 1). The property falls on the western boundary of the Snake River Plain geomorphic province, and is bounded to the south by the Owyhee Uplands.

The Snake River Plain has a gently rolling to hilly profile which has been incised by the Snake and Bruneau Rivers which lie at elevations of 700 m to 760 m (2300 to 2500 feet). From the Snake River, the Plain slopes gently upward to the south-southwest reaching elevations of 1000 m to 1200 m (3300 to 4000 feet) at the base of the Owyhee Uplands and plateau area.

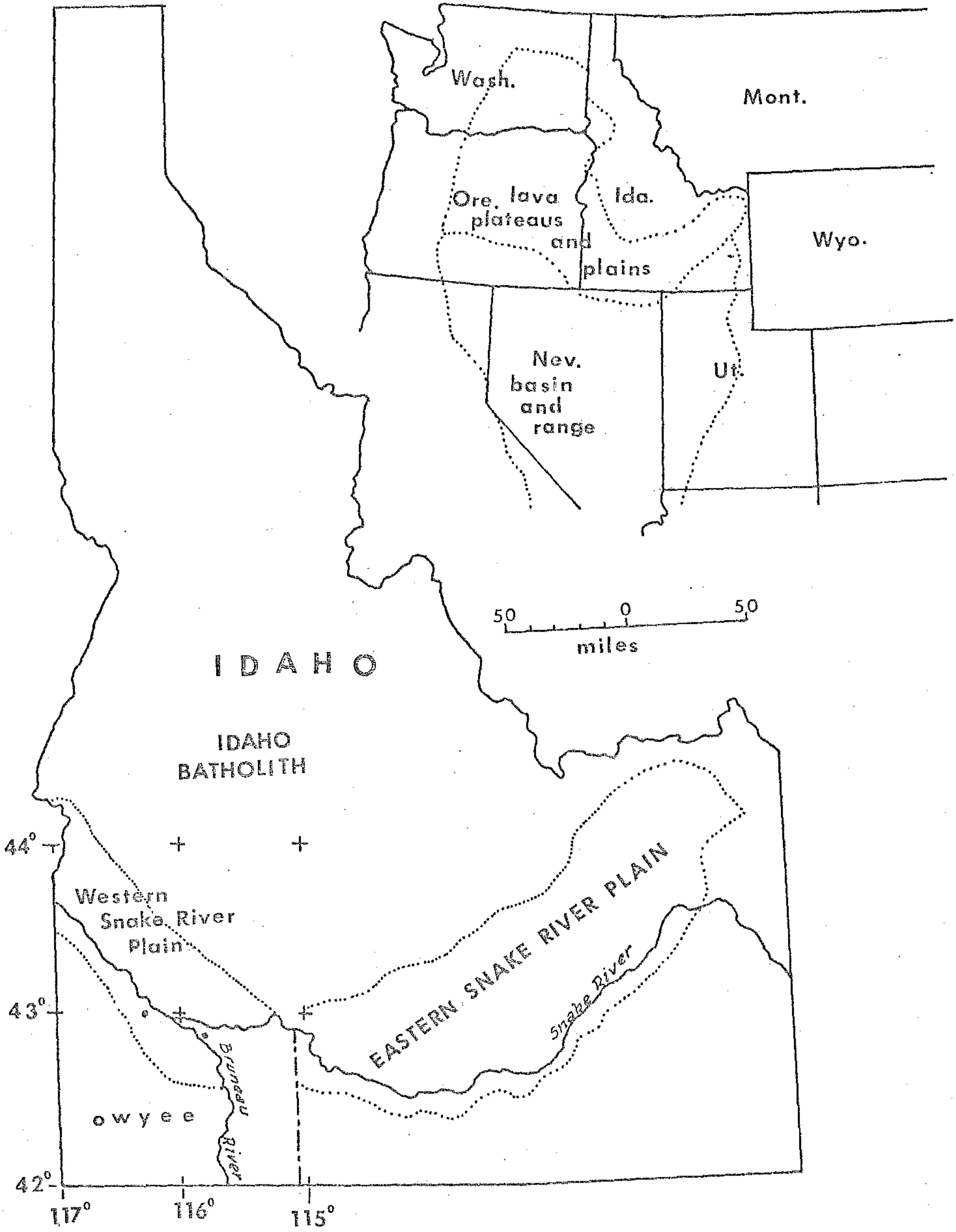
Grand View and Bruneau are the only communities in the area and have a combined population of about 300. Economy of the area centers around farming and ranching. Numerous farms and ranches are located on the Snake River Plain, confined primarily to the major stream valleys with the remainder of the area very sparsely inhabited. Thousands of acres of arid land are irrigated by several hundred producing water wells on the Plain. A substantial number of these wells have been drilled to depths of 300 m to 900 m (1000 to 3000 feet).

The area is arid to semiarid receiving less than 25 cm (10 inches) of precipitation on the Snake River Plain and up to 63 cm (25 inches) in the higher portions of the Owyhee Uplands. Mean annual temperature for the area is about 11°C (52°F) on the Plain, with hot dry summers and cool to very cold winters depending upon the elevation. The coldest months are December and January, averaging -1°C (30°F) on the Plain.

Paved highways provide access across the northern and eastern portions of the area, and well maintained gravel and unimproved dirt roads provide good access to most of the remainder of the area except for portions of the plateau and Owyhee Uplands.

Many gold and silver mines are located in the southwestern portion of the area in the granites of the Owyhee Upland, although only one is actively being worked at the present time.

Idaho Power Company supplies power to the area and has a 83 MW generating station between Bruneau and Grand View and a 10 MW plant at Swan Falls near Grand View, both on the Snake River. Power from these plants is carried to the main transmission system via 138 KV lines.



LOCATION MAP

Figure 1

Physiographic Provinces

The Grand View area may be divided into three physiographic provinces: (1) The Snake River Plain, with a rolling topography ranging from 700 m to 1150 m (2300 to 3800 feet) in elevation and generally underlain by a thick sequence of diverse subareal, lacustrine and fluviatile sediments and interbedded basalt flows collectively known as the Idaho Group (2) the plateau area with altitudes of 900 m to 1200 m (3000 to 4000 feet) and consisting primarily of middle Tertiary porphyritic latitic tuffs of the Idavada Volcanics (Malde and Powers, 1962) dipping gently toward the Plain. The plateau area is often capped by thin flows of blocky olivine basalt of the Banbury Group, and has been deeply incised by several small streams; (3) the Owyhee Upland in the southwestern portion of the project is a rugged, mountainous area which ranges in elevation from 900 m to 2400 m (3000 to 8000 feet) and consists of granitic rocks similar in age and composition to those of the Idaho Batholith.

GEOLOGY

The Anschutz drill hole east of Oreana revealed a 1500 m (5000 feet) thick sequence of Miocene volcanics beneath the Idavada Volcanics which is not exposed at the surface in the Grand View area. Therefore, descriptions of the geologic units include several formations which are not included on the geologic map (Plate 1), or on the geologic cross-sections (plates 4 to 13). Formations included on the geologic map are presented in parenthesis following the formation titles.

Cretaceous Granite (ki)

Location and Distribution

Basement rock in the Grand View area, other than a possible rift zone, is Cretaceous granite. The rock is predominantly granodiorite; however, in previous work the common term granite has been used. Associated with the granodiorites are granites, quartz monzonites, and pegmatite dikes. Within the project area the granitic rocks are restricted to the Owyhee Uplands in the western portion of the area. Similar rocks are exposed to the west in the Owyhee Mountains and were mapped as Silver City Granite by Asher (1968) and McIntyre (1966). The granitic rocks are also similar to, and believed to be correlative with, granites of the Idaho Batholith.

Description

In hand specimen the typical granitic rock has a medium to coarse-grained granular texture. Grains of quartz, orthoclase, plagioclase, biotite, and minor muscovite are of roughly equal size, ranging from 0.2 mm to 1.0 mm in diameter. In some samples, larger than normal orthoclase crystals give the rock a porphyritic appearance. Plagioclase is either dominant or equal in amount to orthoclase.

The granitic rocks in some places have developed a parallel jointing which gives them a bedded appearance when viewed from a distance. Weathering in areas of well-developed jointing or veining produces a hummocky terrain with pinnacles of rock protruding from an otherwise steeply rolling topography. Where the rock is more uniform, the topography is rounded with steep slopes covered with granitic debris.

Age

Granitic rocks in the project area are comparable in age and composition to those of the Idaho Batholith. Most age-dates for granitic rocks of the Idaho Batholith cluster around 100 million years (m.y.). Granitic rocks in eastern Oregon and north-central Nevada (Koenig, 1976) yield similar radiometric ages. However, age-dates of 62 to 66 m.y. have been reported for one graniodiorite pluton in the Owyhee Upland (Pansize, 1972). Portions of the Idaho Batholith have been assigned Tertiary age-dates; however, these abnormally young ages may be due to a powerful thermal shock during Eocene time which reset the K-Ar "clock" rather than various ages of intrusive activity (Koenig, 1976). The thermal shock may have been associated with either volcanism, deep seated intrusions, or both. Some of the more silicic plutons and dike swarms within the batholith may, therefore, be Lower to Middle Tertiary in age.

Basalt-Latite Sequence

Description

West of the project area in the Owyhee Mountains, Asher (1968) describes a basalt-latite sequence which may be correlative, in part, with the 1500 m (5000 foot) sequence of basalts, latites, dacite, and silicic rocks encountered in the Anschutz hole. As described by Asher, the basalts are dark grayish-black to greenish-black, porphyritic olivine basalts with feldspar phenocrysts (An_{50} to An_{75}) in a dense groundmass containing olivine. Weathered rocks are yellowish-brown to brownish-gray.

The latites vary from dark glassy rocks to medium-to dark-gray fine-grained rocks with minor pumaceous tuffs. Porphyritic varieties contain small white feldspar phenocrysts (An_{40} to An_{60}) in a dense groundmass. Weathered surfaces are medium-brown to reddish-brown in color and break into flaggy debris. The glassy latites are black, occasionally porphyritic and have a sub-vitric luster. Fractures are conchoidal, producing subangular to rounded fragments that weather to a grayish-brown.

Thickness

Asher reported 450 m (1600 feet) of basalt, and McIntyre (1966) estimated a maximum thickness of 945 m (3100 feet) in the Reynolds Creek basin (T.2 and 3S., R. 3 and 4W.) northwest of the project area.

Interfingering of the basalt-latite sequence with the fluviatile and lacustrine deposits of the Sucker Creek Formation suggests fairly rugged topography and active tectonism during deposition. The period of eruption appears to have spanned a considerable length of time so that substantial erosion may have occured between eruptions. Together, these events would have resulted in a thick sequence of volcanic and associated sedimentary strata which could have significant variations in thickness and lithology over relatively small lateral distances. Thickness and sequence of events are thus difficult to correlate from the Owyhee Mountains to the project area. However, the Anschutz hole supports the contention that a thick sequence of volcanic and sedimentary rock, similar to those reported by McIntyre and Asher do exist beneath the Idavada Volcanics in the project area.

Age

Sedimentary rocks of the Miocene Sucker Creek Formation have interbedded basalt flows which appear correlative with the basalt-latite sequence (Asher, 1968). Previous investigators have assigned both Upper Miocene or Lower Pliocene (McIntyre, 1966) to the Sucker Creek Formation.

Ross and Forrester (1947) included the basalt-latite sequence within the Columbia River Basalts. Later workers have disregarded this relationship since the basalts are neither flood basalts nor tholeiitic in composition (McIntyre, 1966).

The basalt-latite sequence stratigraphically lies below the Silver City Rhyolite (Owhyee Rhyolite) and above the Cretaceous granite. Therefore, the basalt-latite sequence should be considered Middle Miocene to as young as Upper Miocene.

Sucker Creek Formation

Description

The Sucker Creek Formation consists of altered tuffs, volcanic sandstones, vitric tuffs, arkosic sandstones, granite cobble conglomerate, and carbonaceous volcanic shales (Kittleman and others, 1965). The Sucker Creek Formation has been correlated with the Payette Formation in western Idaho.

Several flows of olivine basalt are interbedded locally near the top and bottom of the formation and a tabular rhyolitic body occurs near the middle of the formation. In Oregon, a 300 m thick lenticular rhyolitic tuff, known as the Leslie Gulch Ash-Flow Tuff Member, occurs near the top of the formation.

Age and Thickness

In the Owyhee Mountains, Asher (1968) noted that strata of the Sucker Creek Formation was interbedded with and overlies portions of the Upper Miocene basalt-latite sequence. Kittleman and others (1965) assigned the Sucker Creek Formation an age of Upper Miocene based on mammalian fossils.

Kittleman estimated a thickness of 490 m (1600 feet) for the Sucker Creek Formation. In the Anschutz well about 300 m of basalts, silicic tuffs, and related sedimentary rocks believed to be of the Sucker Creek Formation were encountered. Lateral extrapolation of thickness in the Sucker Creek Formation is difficult in that it was deposited during a time of structural unrest, and volcanism, together with erosion and deposition. Therefore, estimates of thickness should be used with caution.

Tertiary Rhyolites (Tv)

Description

Rhyolitic rocks occur in the south-central portion of the Grand View area lying stratigraphically between the Idavada Volcanics and Cretaceous granite of the Owyhee Uplift. The rocks are predominantly welded crystal tuffs and porphyritic rhyolite flows rich in quartz and biotite. Silicification is common and some mineralization is evident. Individual flows are of short lateral extent, most pinching out, are buried, or end abruptly within a few kilometers. However, the overall composition of the individual flows is similar enough to suggest a single parent magma.

Distribution

In the project area, the rhyolite outcrops are restricted to the east side of the granitic Owhyee Uplift, and were encountered in a few drill holes immediately adjacent to outcrops. No exposures were located along the north and west margins of the granite; however, southward into the Owyhee Uplands the rhyolitic rocks appear to be more extensive.

In sec. 13, T5S, R1E, the Anshutz hole encountered pumiceous and ashy rhyolite and dacite at between 1430 m and 1740 m (4700 to 5700 feet). The lower portion of this interval includes basalts and sediments.

Thickness

The rhyolitic rocks have been estimated to be 600 m to 900 m (2000 to 3000 feet) thick. As mentioned above, the Anschutz well penetrated about 300 m (1000 feet) of rhyolitic rock below the Idavada Volcanics. On the other hand a deep water well in the southeast portion of the area (sec. 4, T9S, R5E) encountered 460 m (1500 feet) of Idavada Volcanics and then passed into a thick sequence of basaltic and intermediate volcanic rock and sediments similar to the basalt-latite sequence of the Owyhee Mountains.

In the Owyhee Mountains, the Owyhee Rhyolite stratigraphically lies between "welded tuff unit one" (correlative to the Idavada Volcanics) and the basalt-latite sequence. If the interpretation of the units in the above water well is correct, then the Owyhee Rhyolite is not present in this immediate area. This together with the lack of any exposures of rhyolite along the north and west boundaries of the uplifted granite in the area suggests a very uneven distribution of the unit. As with the basalt-latite sequence, the Owhyee Rhyolite may have an aggregate thickness of over a kilometer in some areas while in others it is considerably thinner or absent. In the northwestern portion of the project area, between 300 m and 400 m (1000 to 1300 feet) of rhyolitic rock can probably be expected to lie at depth beneath the Idavada Volcanics in T4 and 5S, R1E, and T6 and 7S, R2E. In the rest of the area data is insufficient for an estimate.

Age

Rhyolitic rocks within the project area have been suggested to be Miocene in age. The Silver City rhyolite of the Owyhee Mountains, although poor in boitite, resembles the rhyolitic rocks in the Grand View area. It lies stratigraphically between the basalt-latite sequence of Asher (1968), and the welded tuffs correlative with the Idavada Volcanics of early Pliocene age.

If the rhyolites in the Anschutz hole are correlative with the same unit, it is stratigraphically between the Idavada Volcanics and the Sucker Creek Formation which interfingers with the basalt-latite sequence. Asher concluded that the Silver City Rhyolite of the Owyhee Mountains was interbedded and correlative with the upper portion of the Sucker Creek Formation, placing it in Upper Miocene or Lower Pliocene. From the relationships observed here, Asher's dates seem acceptable.

Regional Distribution

The rhyolites in the project area and in the Owyhee Mountains are similar to rhyolitic rocks in: the Jarbridge Mountains, Nevada; near the Bruneau River, Owyhee County, Idaho; and near Goose Creek, Cassia County, Idaho. Malde and Powers (1962) state that these units may correlate. If so they would represent a period of regional silicic volcanism.

Idavada Volcanics (Tiv)

Description and Source

A porphyritic tuff of latitic composition is the most prominent geologic unit in the Grand View area. The Idavada Volcanics underlie the plateau area and commonly crop out along the front of the Owyhee Uplift. The Idavada Volcanics consist of a variety of rock types resulting from the violent nature of its emplacement.

The most common unit in the Idavada Volcanics is an intensely jointed, welded, crystal porphyritic tuff. Typically it contains 5 to 15 percent subhedral to euhedral crystals of sodic plagioclase, clinopyroxene, hypersthene, and magnetite set in a light-gray to pinkish-gray aphanitic devitrified groundmass. Such tuffs underlie most of the plateau area. The rocks have been deeply incised by several small streams to form spectacular steep-sided canyons, often over 150 m (500 feet) deep. At least three separate flows can be distinguished in some of the deeper canyons. Occasionally thin contact zones of unconsolidated, devitrified tuff, breccia and vitrophyre are present. Individual flows are commonly over 20 m thick.

A second unit of the Idavada Volcanics is a vitrophyre, often interbedded with vitrophyre breccias or flow breccias. These thick breccias may indicate proximity to a source area or vent for the more widespread devitrified ash-flow tuffs. An example occurs in T7 and 8S, R4E along Little Jacks Creek where about 26 square kilometers (10 square miles) of vitrophyre breccias and interbedded massive flow rocks crop out. The breccias are composed of angular to subrounded fragments of vitrophyre in a white to gray devitrified, poorly consolidated to moderately well indurated tuffaceous matrix. The vitrophyre fragments range from several centimeters to well over a meter in diameter. Except in steep sided canyons, the breccia weathers to a surface of subrounded cobbles and boulders since the tuffaceous matrix is easily eroded.

The breccia and vitrophyre are commonly reported in water wells from Little Valley westward to Mud Flat Road, and from Shoofly Road southward towards the base of the plateau area. This may indicate that a vent area for the tuffs lies within the immediate vicinity.

In the western portion of the project area, west of Castle Creek, two welded tuff units (Tiv_1 and Tiv_2) were mapped and included within the Idavada Volcanics Formation. They appear to be more rhyolitic, containing small amounts of quartz and biotite, but correlate well in stratigraphic position with the silicic latites.

In hand specimen, the rock is generally dark-gray to purplish-red on fresh surfaces and weathers to lighter shades. Phenocrysts of plagioclase (less than 1 mm in length) comprise up to 10 percent of the specimen with lesser amounts of quartz, biotite, and rarely sanidine. The groundmass is aphanitic to glassy devitrified and commonly partly silicified.

As with the silicic latities, the rhyolitic units are massive to platy, with closely spaced joints. They tend to form deep, steep-sided canyons where eroded, with relatively flat and often gravel covered surfaces between canyons. South of Black Butte, portions of a flow contact are exposed, revealing brecciated vitrophyre set in a tuffaceous matrix.

Unit Tiv_1 which extends from Black Butte (sec. 28, T7S, R1W) to the north for about 14 kilometers was confined to a relatively narrow steep sided canyon near Black Butte during its eruption. Now partly eroded by Castle Creek, well developed columns of porphyritic vitrophyre are exposed in the lower 20 m of the unit. The vitrophyre grades upward into a porphyritic rhyolitic rock similar to Tiv_2. The base of the flow is also exposed north of Black Butte along Castle Creek where it overlies Cretaceous granite.

Asher (1968) described a welded tuff unit similar in age and composition to unit Tiv_1 in the Silver City area and designated it "welded tuff unit one". Discontinuous outcrops of this unit can be observed from Ashers area into the Browns Creek area west of Castle Creek.

Beneath the Snake River Plain the Idavada Volcanics dip toward the center of the basin at 1.5 to 2 degrees and are cut by several northwest trending faults. The Idavada Volcanics are buried under the sediments and interbedded basalt flows of the Idaho Group to depths exceeding 900 m (3000 feet) in the vicinity of the Snake River.

Thickness

Malde and Powers (1962) mapped a sequence of Idavada Volcanics at least 900 m (3000 feet) thick to the east of the project area. A 850 m (2800 feet) water well in sec. 4, T9S, R5E which began in Idavada Volcanics passed into a sequence of intermediate volcanics and basalts at 490 m (1600 feet). The 3400 m (11, 120 feet) well drilled by the Anschutz Corporation in sec. 13, T5S, R1E near Castle Creek passed through what may have been a 600 m (2000 feet) thick sequence of Idavada Volcanics. Within the project area it may be assumed that the Idavada Volcanics have a maximum thickness of around 600 m (2000 feet) and may possibly average as little as 450 m (1500 feet).

Eruptions of the Idavada Volcanics apparently took place in rapid succession. The widespread uniform thickness of the flows, and the lack of any pronounced paleotopography along the individual flow contacts, suggests that the interval between successive eruptions was too short for any substantial erosion to occur.

Age

A Pliocene age has generally been assigned to the Idavada Volcanics, however, on the basis of radiometric age-dates from southwestern and south-central Idaho, Armstrong et al. (1975) gave ages of from 9 to 13 million years. Mammalian faunal chronology of the underlying Sucker Creek Formation also tends to support these dates. Based on this, an age of Upper Miocene and Pilocene seems most appropriate.

Idaho Group (QTiu)

In the Snake River Plain of the Grand View area a diverse assemblage of fluviatile and lacustrine sediments, interbedded basalt flows and tuffs of the Idaho Group rest upon the Idavada Volcanics. Within the project area, the Idaho Group probably does not exceed 900 m (3000 feet) in thickness.

Since the Idaho Group does not have much importance in geothermal exploration only a cursory description of the seven major units will be given here

Poison Creek Formation

The Poison Creek Formation consists of clay, silt, ash, and basalts exceeding 200 m (650 feet) in thickness, but with significant local variations. The Poison Creek Formation was probably encountered by the Anschutz hole just above the Idavada Volcanics. Basalts within the formation are difficult to distinguish from younger Banbury Basalts except by radiometric dating, fauna or floral determinations.

Fauna and flora contained within the Poison Creek Formation is of Clarendonian age. Based upon its stratigraphic relationship with the underlying Idavada Volcanics, a Lower Pliocene age is assigned.

Banbury Basalt (Tb)

The Banbury Basalt is composed predominantly of thin flows of olivine basalt and porphyritic basalts. Often the basalts show alteration to greenish-brown saprolite with some residual spheroids of undecomposed rock. Individual flows are usually less than 5 m in thickness and some columnar flows are up to 15 m thick. Overall thickness of the formation ranges from a few meters to over 300 m (1000 feet). Thin lenticular lacustrine and fluviatile deposits of clay, sand, and gravel are a minor feature of the Banbury Basalts.

Based on fauna and flora, the Banbury Basalt spans the Clarendonian-Hemphillian boundary of Middle Pliocene.

Chalk Hills Formation

Lying stragigraphically above the Banbury Basalt, the Chalk Hills Formation consists of fluviatile and lacustrine silt, sand, gravel, and a few thin basalt flows. The predominant rock type is a well-layered, banded brownish-gray tuffaceous silt. A few 1 m to 3 m thick layers of silicic volcanic ash occur within the unit. The ash layers are variegated whites, pink, brown and gray.

Exposed thickness of the Chalk Hills Formation is about 90 m; however, up to 140 m (460 feet) has been reported in water wells.

Glenns Ferry Formation

The Glenns Ferry Formation consists of poorly consolidated detrital material and minor lava flows of olivine basalt. The formation is characterized by abrupt lateral changes in facies. Various facies include: 1) massive layers of faintly bedded silt; 2) evenly layered thick beds of sand, locally cemented to flaggy sandstone; 3) thinly bedded dark clay, silt, and clay; 4) riple marked sand and silt; 5) granitic sand and fine pebble gravel; and 6) quartzitic cobble gravel.

Several thin beds of silicic volcanic ash, and thicker beds of basaltic fragmental material, as well as thin sheet-like olivine basalt flows occur within the various facies. The basalt flows are generally altered to saprolite with spheroids of undecomposed rock, and are difficult to distinguish from flows of Banbury Basalt except by stratigraphic relationships.

The Glenns Ferry Formation attains a maximum thickness of about 600 m (2000 feet) north of the Snake River. In the project area it is probably less than 300 m (1000 feet) thick. Age of the Glenns Ferry Formation is upper Pliocene.

Tuana Gravel

The Tuana Gravel consists of pebble and cobble gravels less than 60 m thick, interbedded with beds of massive brown to gray sand and silt. Most of the gravel was derived from silicic latites of the Idavada Volcanics. South of Bruneau there are significant quantities of quartzitic debris in the gravel. The Tuana Gravel is often capped by a massive caliche layer one or more meters thick. The Tuana Gravel is considered to be Upper Pliocene to Lower Pleistocene in age.

Bruneau Formation

The Bruneau Formation is composed of roughly equal amounts of basalt flows and cinders, and lacustrine and fluviatile sediments.

The dominant detrital material is a series of massive, light colored silt, clay and diatomite beds up to 15 m thick. Thinner beds of reworked iron-stained gravels are dispersed throughout the formation.

Basalt flows of the Bruneau Formation erupted from several vents on the north side of the Plain, and form a series of lava ridges and canyon filling dams. Most prominent are the flows which form the rim-rock along the north side of the Snake River canyon in the Bruneau-Grand View area.

An aggregate thickness of over 600 m (2000 feet) has been measured for the Bruneau Formation. In the project area, the maximum thickness of the Bruneau Formation is about 250 m (800 feet). Age is considered to be Middle Pleistocene.

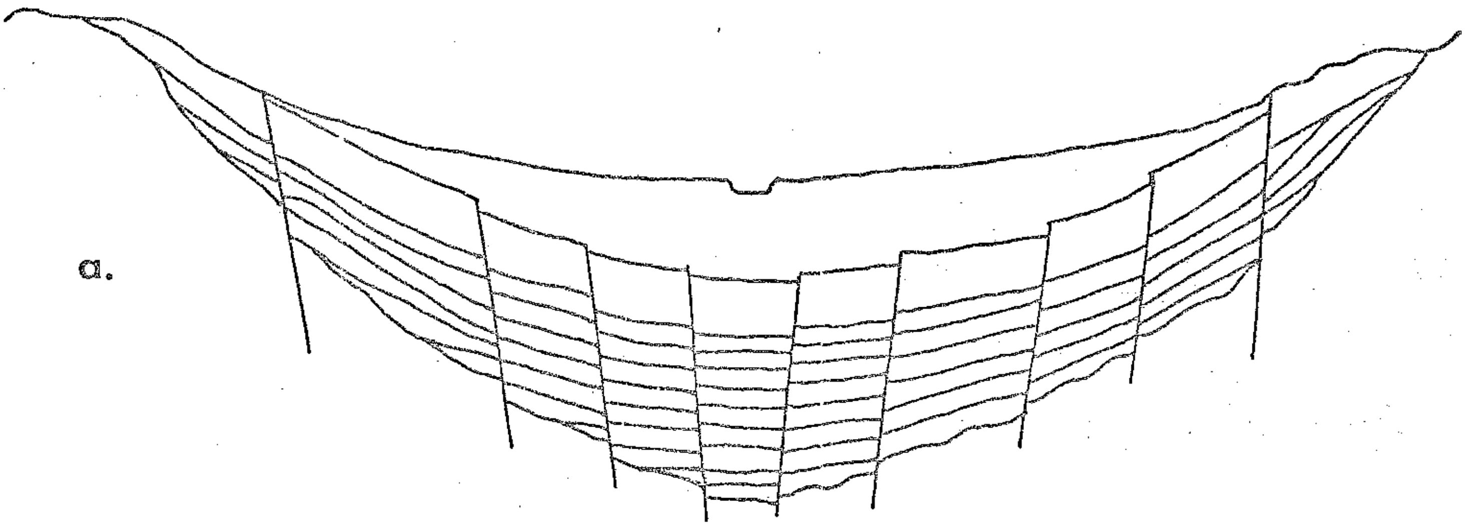
Black Mesa Gravel

Sand and gravel 10 m to 15 m thick, near the Bruneau Canyon and further eastward, comprise the Black Mesa Gravels. Apparently they are preserved remnants of a large pre-existing pediment south of the Snake River and approximately 170 m higher than its present level. Composed primarily of reworked gravels from older formations, the Black Mesa Gravels are often capped by a 1 m to 2 m thick caliche layer. Age of the Black Mesa Gravel is Upper Middle Pleistocene.

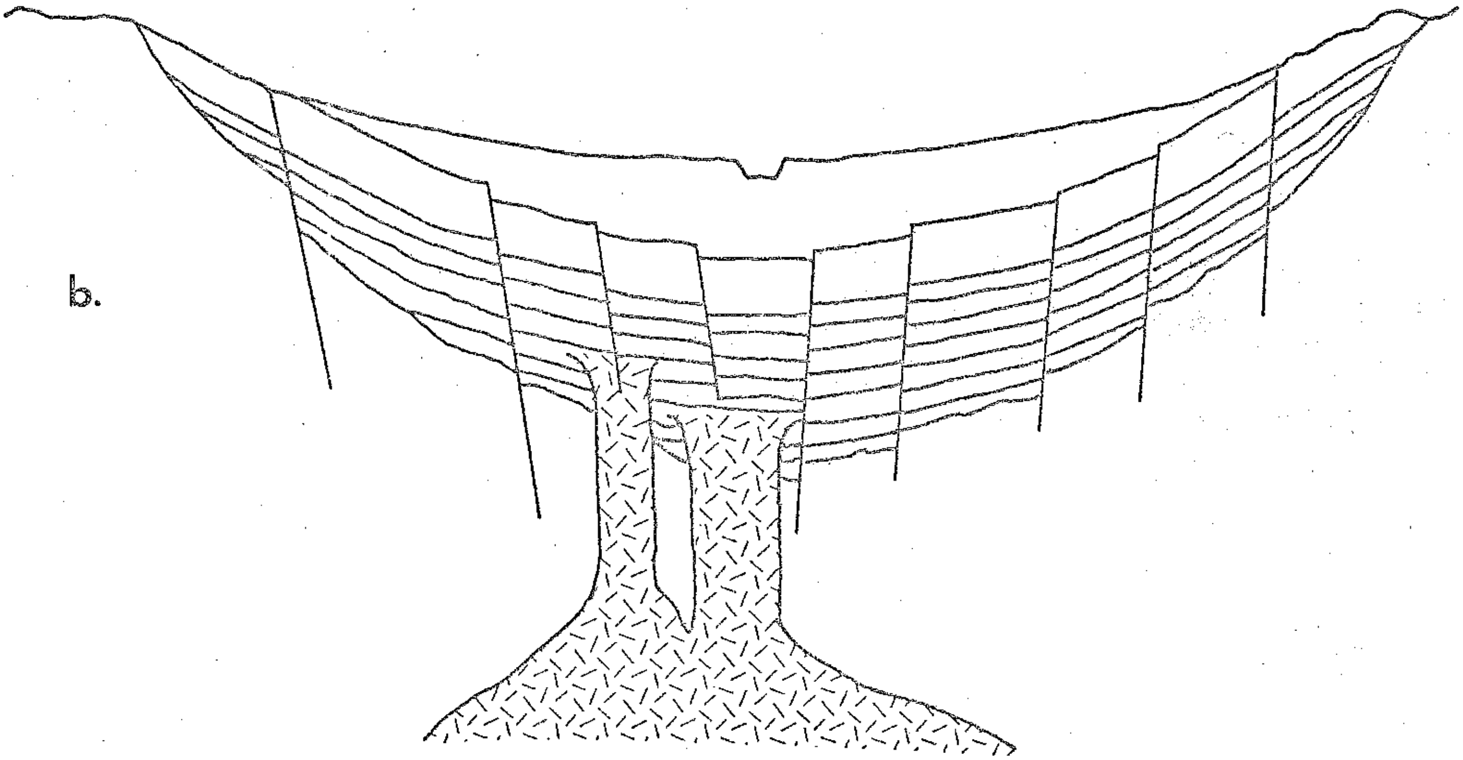
STRUCTURE

The Snake River basin in the Grand View area has been postulated to be either a complex graben or a true rift. (Koenig, 1976). In the case of a rift, the crust would be thinned, pulled apart, and partially replaced with mafic intrusive rock (Fig. 2). Whereas with a complex graben, the crust would be under extensional forces with normal faulting taking place and maximum downward displacement occuring near the center of the basin. The structural interpretation is significant for geothermal exploration. Unfortunately, evidence collected thus far does not definitely support either theory.

Gravity data (Plate 3) may be interpreted to support the rift theory, as is shown in a northeast cross-section across the Plain near the Anschutz well (Fig. 3). It suggests a deep seated body or fissure zone of basaltic rocks underlying the Plain. If this interpretation is correct and the axis of the gravity high is roughly the trace of this fissure zone, the AMAX land would lie slightly to the south of this zone. Assuming this, and taking into consideration previous drilling information, granitic rock could be expected at depths of 3 km (9840 feet) or less within the AMAX lands.



Complex Graben

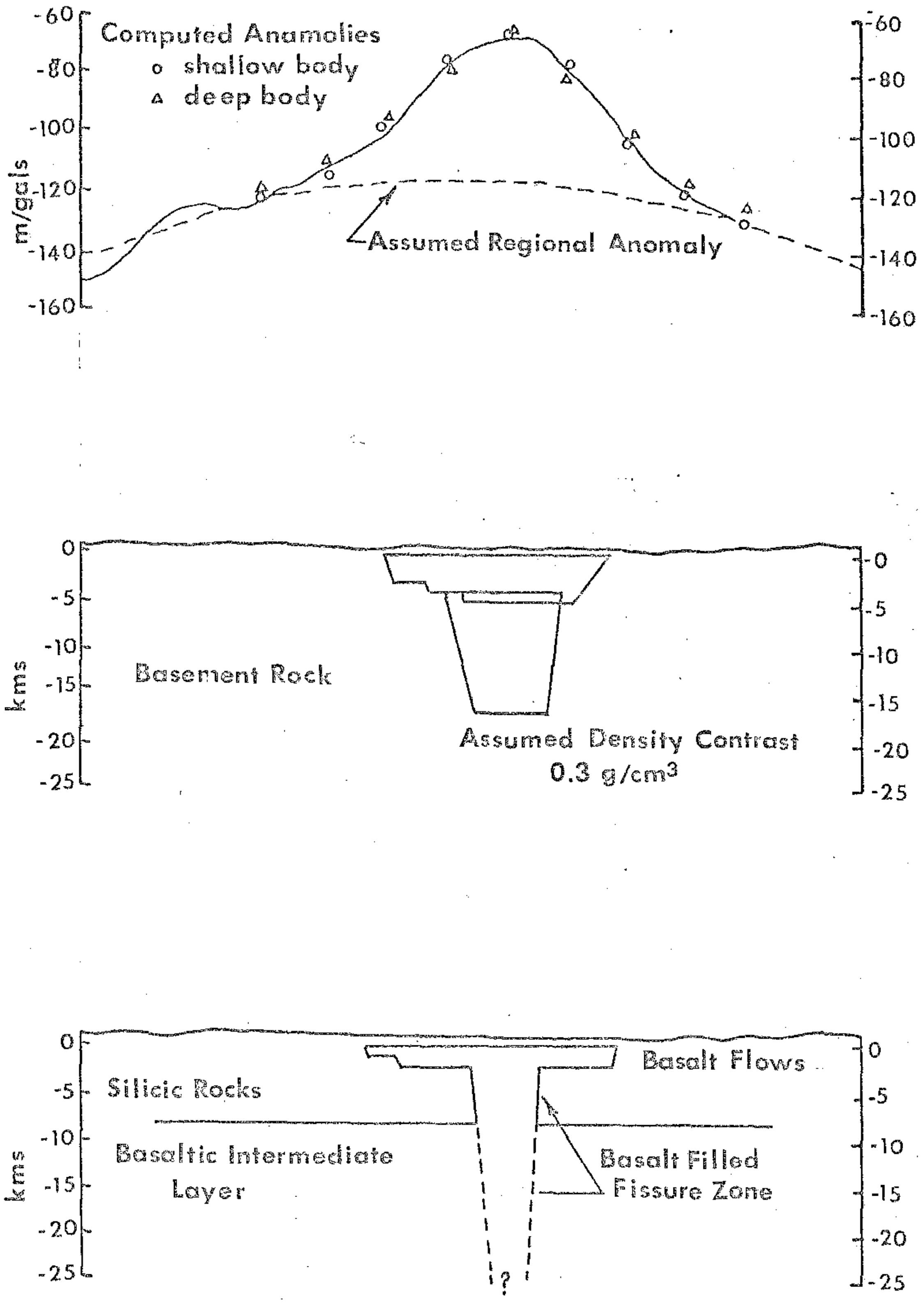


Rift System

IDEALIZED CROSS SECTIONS ACROSS THE SNAKE RIVER BASIN

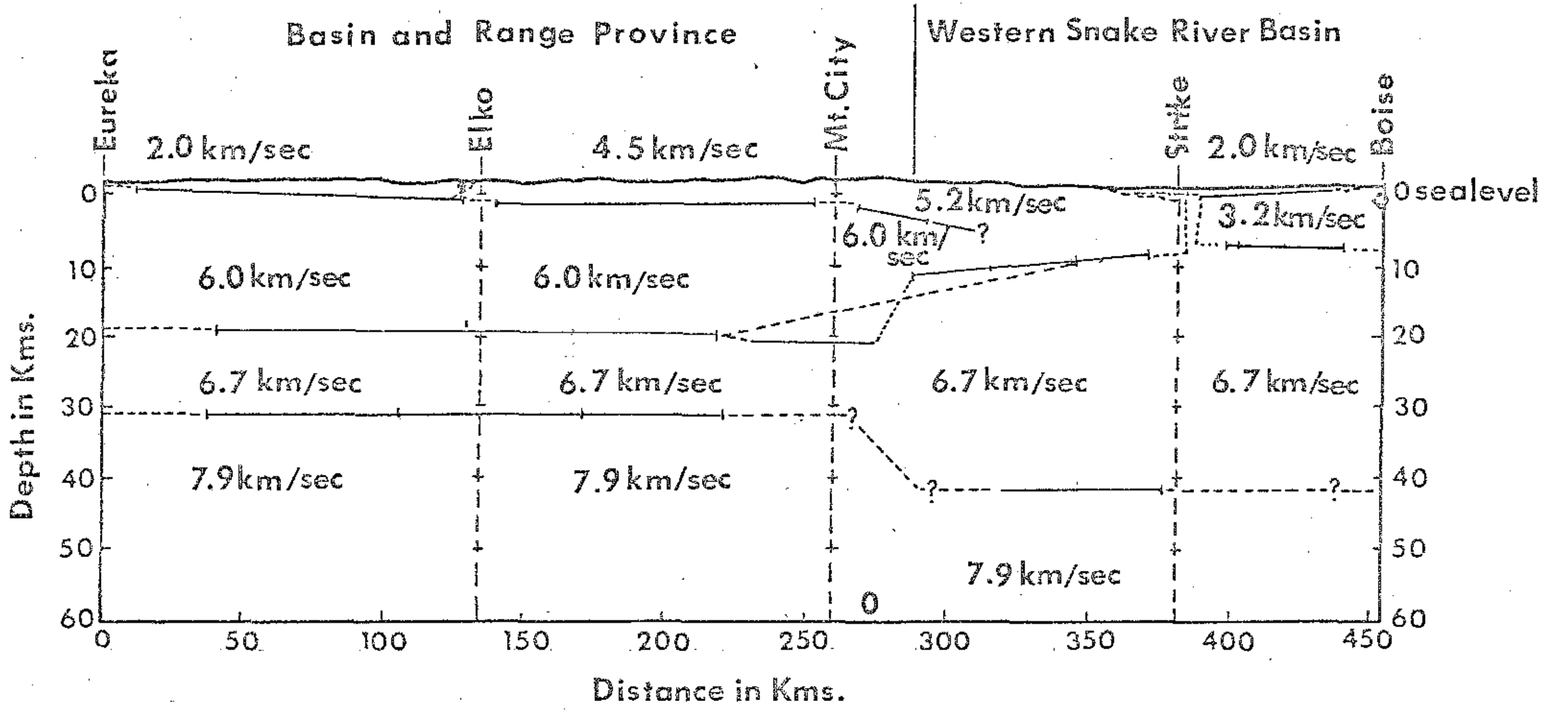
(a.) As a complex graben, and (b.)as a rift system

Figure 2



GRAVITY CROSS SECTION
OF
SNAKE RIVER BASIN

Figure 3



CRUSTAL STRUCTURE OF THE SNAKE RIVER BASIN AND BASIN & RANGE PROVINCES, FROM SEISMIC REFRACTION PROFILES

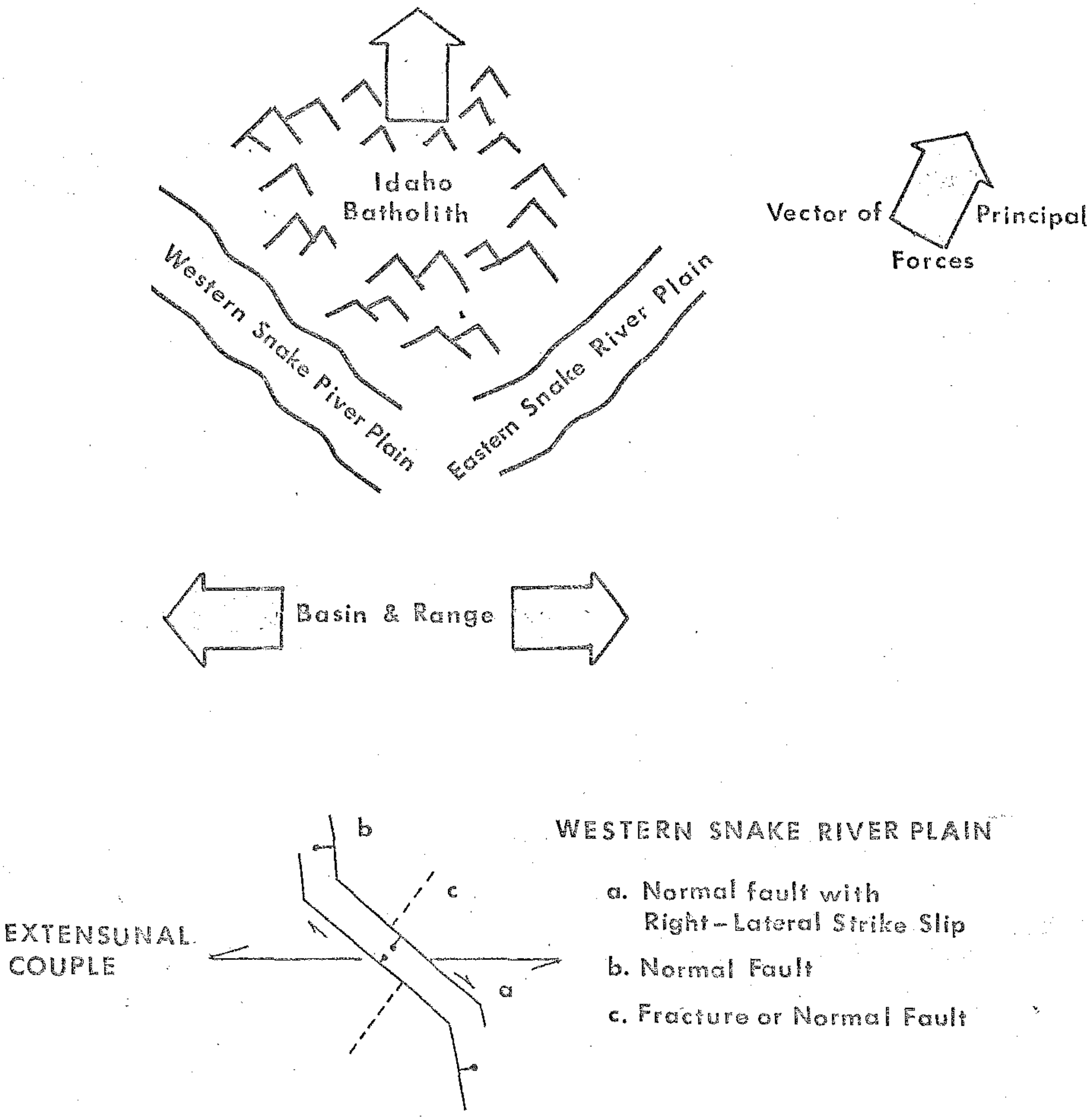
Figure 4

Faulting

The most obvious structural features in the area are a series of high angle, northwest trending (N35W to N60W) normal step faults which bound the Snake River downwarp. At the edge of the basin these faults disappear beneath the sediments of the Idaho Group. However, water well, gravity data, and to some extent surface topography indicate a continuation of this faulting towards the center of the Plain. Minor secondary grabens occur along the edge of the Plain. One such small graben is located south of Little Valley (T7 and 8S, R4E), and has approximately 100 feet of displacement. Within the graben is a thin Pleistocene olivine basalt flow and some lacustrine sediments.

Most faults have relatively small displacement, ranging from a few meters to some which may have more than 200 m (356 feet) of displacement. The faults range in length from 5 to 50 kilometers (3 to 30 miles). Most of the normal faults dip from 70 to 90 degrees toward the Plain, with dips of about 80 degrees appearing to be the most common. No direct measurements of dip were possible, so dips were estimated from drill hole data, however, the estimates seem reliable.

In addition to the northwest trending faults, several northeast trending faults (N30E to N40E) with both strick-slip and normal displacement, occur across the Plain. The combination of these structures suggest that the western Snake River Plain was subjected to an extensional couple (Fig. 5). This would also suggest some right-lateral strick-slip displacement may have occurred along certain northwest-trending faults.



SKETCH OF FORCES
TO
CREATE A NORTHWEST TRENDING RIFT

Figure 5

GEOTHERMAL POTENTIAL

Hydrogeochemistry

Chemistry of thermal waters from wells in the Bruneau-Grand View area varies, depending primarily upon rock type of the aquifer from which it is pumped. Waters eminating from the sedimentary rocks of the Idaho Group are generally high in dissolved solids (greater than 600 ppm), nearly neutral in pH, and low in flouride (less than 2 ppm).

Volcanic rock aquifers consist of Pliocene basalts and minor interbedded sediments of the Banbury basalt group, and the underlying silicic latites of the Idavada Volcanics. Water from the volcanic rock aquifers is generally low in dissolved solids (less than 500 ppm), high in flouride (usually from 8 to 29 ppm), and is alkaline (pH greater than 8.5).

Thermal waters in the area have chloride concentrations of from 2.7 to 79 ppm. Water from volcanic rock aquifers generally have chloride concentrations of less than 20 ppm which is only slightly higher in water from sedimentary rock aquifers (Young and Whitehead, 1975). Sulfate concentrations are generally higher in water from volcanic rock aquifers.

The low chloride, high flouride, and high sulfate waters of the volcanic rock aquifers is similar to other thermal waters eminating from granitic rocks of the Idaho Batholith. An example of these similarities is shown in Table 1. This similarity indicates that rocks of similar mineralogy, to those of the Idaho batholith, may lie beneath the Grand View area. Deep circulation would then bring the water into contact, and chemical equilibrium with these rocks.

TABLE I.

COMPARISON OF DEEP WATER WELLS IN THE GRAND VIEW AREA WITH HOT SPRINGS OF THE IDAHO BATHOLITH

	VOLCANIC-ROCK AQUIFERS		IDAHO BATHOLITH	
	WELL 4S-1E-34ba	WELL 5S-3E-26bc	SUNBEAM HOT SPRINGS 11N-15E-19c	VULCAN HOT SPRINGS 14N-6E-11bd
Depth (m)	902	905		
Temperature (°C)	75.5	83.0	76.0	87.0
Silica (mg/l)	91	110	91	120
Calcium (mg/l)	1.0	2.1	1.5	1.8
Magnesium (mg/l)	0	0	0	0.1
Sodium (mg/l)	99	110	85	94
Potassium (mg/l)	0.8	1.7	2.4	3
Sulfate (mg/l)	40	62	54	43
Chloride (mg/l)	13	15	12	17
Fluoride (mg/l)	13	15	15	24

Other minor elements occur in the thermal waters and are shown in Table 3. No significant concentrations of boron, lithium, mercury, or arsenic were recognized, however, notable variations do occur.

Boron concentrations range from less than 100 to 1,100 ppb in the volcanic rock aquifers, and as high as 1,900 ppb in water issuing from sedimentary rock aquifers. The higher values within the sedimentary rock aquifers probably reflects enrichment from evaporite beds within the Idaho Group. Volcanic rock aquifers with the highest concentrations of boron occur near the center of the Plain near Bruneau and Grand View. These are most likely due to mixing with water from sedimentary aquifers, or enrichment from interbedded sediments in the Banbury basalt.

Lithium concentrations were also highest in sedimentary rock aquifers (less than 1,100 ppb), while water in the volcanic rock aquifers have very low concentrations (less than 30 ppb), typical of water from basaltic rock aquifers.

Arsenic and mercury concentrations are both low in the project area, with the higher values of both in water from volcanic rock aquifers. Mercury concentrations range from 0 to 4.3 ppm, and arsenic from 0 to 78 ppb.

Chemical Geothermometers

Young and Whitehead (1975) sampled water from 94 wells and springs in the Bruneau-Grand View area. Temperatures of these waters ranged from 9.5° to 84°C (Table 2).

Estimated temperatures using the silica geothermometer range from 92°C to 157°C with aquifers in the Idaho Group sediments giving some of the higher values (Table 2). The higher values of the water in the sedimentary rock aquifers probably results from equilibrium between warm water and amorphous forms of SiO_2 in silicic rich sediments.

In waters produced from the volcanic-rock aquifers, estimated temperatures using SiO_2 range from 123°C to 147°C, and are believed to be more reliable than those from shallower sedimentary-rock aquifers.

Using the Na-K-Ca geothermometer, estimated temperatures range from 21°C to 206°C, Values derived from sedimentary-rock aquifers, which contain considerable amounts of volcanic ash and bentonitic clay, are believed to be unreliable due to selective solution of alkali-bearing minerals. Young and Whitehead stated:

> "The chemical quality of the warm water derived from the sedimentary-rock aquifers suggest enrichment of sodium and potassium with smaller enrichment of calcium. This effectively reduces the sodium-to-potassium ratio and tends to increase the estimated aquifer temeratures. Similar interbedded sedimentary rocks in the volcanic-rock aquifers could conceivably have the same effect on the composition of the thermal waters".

Samples from volcanic-rock aquifers are believed to be more reliable, especially where there is good correlation with the silica geothermometer.

Estimated temperatures from waters of the volcanic-rock aquifers using the N-K-Ca geothermometer vary within the project area, and can be separated into several distinct areas.

In the Little Valley area, Na-K-Ca values fall into two distinct ranges, one group of nine wells from 87°C to 94°C and 12 other wells giving estimated temperatures ranging from 180°C to 199°C. Values derived using the silica geothermometer fall between the two groups, and range from 123°C to 137°C.

In the Bruneau River Valley, Na-K-Ca values in the volcanic rock aquifers are low (79°C to 94°C), and do not agree with estimated temperatures of 125°C to 137°C from the SiO_2 geothermometer.

Na-K-Ca values in the Grand View area from volcanic rock aquifers range from 60°C to 106°C, while SiO_2 values range from 123°C to 143°C. East of Oreana, in the vicinity of the deep Anschutz well, water wells yield Na-K-Ca values of 61°C to 96°C and SiO_2 values of 123°C to 132°C.

Mixed-water Geochemical Thermometer

Young and Whitehead used Fournier and Truesdells (1974) mixed-water method for determining the percentage of mixing and the original temperature of the hot water fraction of 48 wells and springs in the Bruneau-Grand View area (Table 2). Maximum temperatures of the hot water component were estimated to range from 150°C to 275°C, and the percentage of cold water to be from 61 to 92 percent. However, estimates of 80 t0 90 percent dilution may be excessive and estimated temperatures of over 220°C are possibly due to enrichment by amorphous silica, and may not represent equilibrium with quartz.

TABLE II.

ESTIMATED AQUIFER TEMPERATURES, MEASURED TEMPERATURES, AND TYPE AQUIFER FROM SELECTED WELLS AND SPRINGS IN THE GRAND VIEW AREA, IDAHO

Well or Spring #	Well Depth Feet	Water Temp. at Surface °C	Major Aquifer	Minor Aquifer	Aquifer Temperatures From Geochemical Thermometers °C			
							Mixed Water Method	
					SiO_2	Na-K-Ca	Temp. Hot Water °C	% Cold Water
3S-1E-35dac	300	20.0	QTiu	---	106	56	---	---
4S-1E-25ccd	?	30.0	QTiu	---	148	86	---	---
26abc	1700	27.0	QTiu	---	135	200	---	---
29ccd	3040	70.0	Tiv	---	127	78	173	64
30bdb	350	16.5	QTiu	---	108	30	---	---
34bad	2960	75.5	Tiv	Tb	132	81	176	61
4S-2E-29dbc	1000+	28.0	QTiu	---	137	175	---	---
32bcc	2704	43.0	QTiu	Tb	143	160	---	---
5S-1E-3aab	1900	32.0	QTiu	---	148	192	---	---
10bdd	2960	64.0	Tiv	Tb	127	61	182	69
21cbc	660	65.0	Tb	---	123	72	169	66
24acd	3120	66.0	Tiv	Tb	131	96	189	70
5S-2E-166c	1800	49.5	Tb	---	123	60	213	82
2cda	2460	36.5	QTiu	Tb	131	187	---	---
5bcd	2009	42.5	QTiu	Tb	143	149	---	---
13ada	1748	23.0	QTiu	---	143	197	---	---
5S-3E-14cbb	2300	58.5	Tiv	Tb	126	62	196	74
15cba	1620	15.0	QTiu	---	153	171	---	---
20ada	2430	60.0	Tiv	Tb	143	73	242	79
20bbb	?	27.0	QTiu	---	143	169	---	---
22aad	1300	25.0	QTiu	---	157	170	---	---
25bbb	1320	18.0	QTiu	---	122	168	---	---
26bcb	2970	83.0	Tiv	Tb	143	91	196	61
26bcb	2970	67.0	Tiv	Tb	137	95	208	72
27bdd	2900	60.0	Tiv	Tb	118	76	170	69
28bcc	2540	65.0	Tiv	Tb	136	106	208	73
35ccc	2570	71.5	Tiv	Tb	137	75	202	68
5S-4E-34ccb	356	27.0	QTiu	---	134	71	---	---
5S-5E-33bbd	250	22.0	QTiu	---	92	62	---	---
34ddd	885	25.0	QTiu	---	130	197	---	---
6S-2W-14cba	?	11.0	QTiu	---	---	---	---	---
6S-1E-32bba	?	25.0	Ki	---	97	21	---	---
6S-3E-2cbc	3050	62.0	Tb	QTiu	137	128	217	75
2ccc	1940	53.0	Tb	QTiu	137	146	244	82
4bcc	1680	48.0	Tb	QTiu	143	167	---	---
5cac	3600	61.0	Tiv	Tb	134	90	212	75
9acc	1425	39.0	Tb	QTiu	153	176	---	---
11dad	1400	34.0	Tb	QTiu	148	162	---	---
6S-4E-14abc	1905	54.0	Tiv	Tb	157	143	---	---
18bcc	455	18.0	QTiu	---	96	44	---	---
25bcc	1750	20.0	QTiu	---	120	92	---	---
35cda	955	32.5	QTiu	---	135	206	---	---

Well or Spring #	Well Depth Feet	Water Temp. at Surface °C	Major Aquifer	Minor Aquifer	Aquifer Temperatures From Geochemical Thermometers °C			
							Mixed Water Method	
					SiO_2	Na-K-Ca	Temp. Hot Water °C	% Cold Water
6S-5E-10ddd	1667	38.5	Tb	QTiu	124	141	220	87
18ccb	2960	27.0	Tb	QTiu	148	169	---	---
20aab	?	43.5	Tb	QTiu	110	151	150	76
24bca	1095	33.5	Tb	QTiu	131	141	---	---
24ddb	1938	32.5	Tb	---	125	94	254	92
29dcc	1560	32.5	QTiu	---	148	161	---	---
35cca	460	22.0	QTiu	---	120	73	---	---
6S-6E-8bc	905	32.0	QTiu	---	---	---	---	---
12ccd	990	37.0	QTiu	---	148	178	---	---
19ccd	913	38.0	Tb	---	130	133	253	90
19dbd	1347	42.0	Tb	QTiu	128	91	223	86
32bdd	1402	34.5	Tb	QTiu	130	132	275	92
6S-7E-1acb	1000+	41.5	QTiu	Tb	120	138	196	84
1dbd	1050+	33.0	QTiu	Tb	120	139	225	90
2cdd	1350	34.5	QTiu	Tb	122	144	228	90
8bba	365	23.0	QTiu	---	130	199	---	---
7S-3E-4acd	804	34.0	QTiu	Tb	134	78	---	---
7S-4E-1acc	1800	40.0	Tiv	Tb	127	182	226	87
3abd	1142	42.0	Tb	---	134	194	250	88
5cca	1040	30.0	Tb	QTiu	135	85	---	---
10bdb	1145	37.5	Tb	---	137	198	---	---
11cbc	1500	36.0	Tiv	Tb	137	92	---	---
12bdd	1105	43.0	Tiv	Tb	135	185	250	87
13bcc	1060+	39.0	Tiv	Tb	134	193	267	90
13dcd	1000	40.0	Tiv	Tb	136	186	270	90
14abc	1146	39.0	Tiv	Tb	135	196	275	90
14cc	950	32.0	Tiv	Tb	---	---	---	---
15acd	1065	38.5	Tiv	Tb	137	88	---	---
22ab	1000	?	Tiv	Tb	---	---	---	---
22ba	800	?	Tiv	Tb	---	---	---	---
23cbb	810	38.5	Tiv	Tb	135	188	275	90
25adc	735	36.5	Tiv	Tb	137	93	---	---
26bcb	867	31.0	Tiv	Tb	132	94	---	---
27bcc	1390	27.0	Tiv	---	123	87	---	---
7S-5E-5dbc	2405	32.0	Tb	---	122	175	248	92
7abb	1625	39.0	Tiv	Tb	132	187	256	89
8ccc	1500	40.0	Tiv	---	132	183	244	88
9ddd	2065	40.0	Tiv	---	131	90	246	88
13aac	150	25.0	QTiu	---	133	91	---	---
13cbb	1954	36.0	Tb	QTiv	127	187	247	90
16acb	1515	39.5	Tiv	Tb	132	180	250	89
19ccc	760	36.5	Tiv	Tb	134	186	---	---
28acd	1003	34.0	Tiv	Tb	134	199	---	---

Well or Spring #	Well Depth Feet	Water Temp. at Surface °C	Major Aquifer	Minor Aquifer	Aquifer Temperatures From Geochemical Thermometers °C			
							Mixed Water Method	
					SiO_2	Na-K-Ca	Temp. Hot Water °C	% Cold Water
7S-6E-6bd	405	26.0	QTiu	---	---	---	---	---
7aac	1086	25.0	QTiu	Tb	137	186	---	---
9bad	910	50.0	Tb	---	137	131	228	82
16cdc	513	42.5	Tb	---	126	91	213	85
21dbc	760	43.0	Tb	---	127	94	213	95
22aad	1410	45.0	Tiv	Tb	129	79	216	84
23cad	1300	44.0	Tiv	Tb	137	93	253	87
26ada	1000	38.0	Tiv	Tb	127	80	232	88
27adb	400	43.0	Tb	---	128	86	219	85
34dcb	?	41.0	Tb	---	127	99	223	86
35bbb	?	40.0	Tb	---	131	86	245	88
8S-1E-20cca	?	9.5	Tiv	---	---	---	---	---
8S-6E-3bdd	?	39.0	Tb	---	130	182	243	89
9S-2E-13cbc	?	11.0	Tiv	---	---	---	---	---

TABLE 3

CHEMICAL ANALYSES OF WATER FROM SELECTED WELLS AND SPRINGS

(Chemical constituents in milligrams per litre except where noted.)

Well or spring identification number	Reported well depth below land surface (feet)	Date of collection	Discharge (cubic feet per second)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Alkalinity as $CaCO_3$	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrite plus Nitrate ($NO_2 + NO_3$)	Phosphorus (P)	Dissolved Solids (calculated)	Dissolved Solids (tons per ac-ft)	Hardness		Percent sodium	Sodium-absorption ratio	Specific conductance (field)	pH (field)	Water temperature (°C)	Chemical constituents in micrograms per litre			
																			as $CaCO_3$	Noncarbonate						Arsenic (As)	Boron (B)	Lithium (Li)	Mercury (Hg)
3S-1E-35dac1	300	73/7/24	–	55.0	43.0	9.9	35.0	6.0	246	0	202	25.0	7.7	2.1	0.01	0.07	305	0.41	150	0	33	1.3	440	7.8	20.0	4	60	30	0
4S-1E-25ccd1	–	73/7/24	0.01	120	25	2.9	310	29	952	0	781	5.5	25	.6	.02	.25	989	1.35	74	0	86	16	1,420	7.3	30.0	4	1,000	810	0
26abc1	1,700	73/6/8	.01	96	13	2.8	250	29	763	0	626	3.6	13	.6	.01	.16	786	1.07	44	0	87	16	1,160	7.3	27.0	14	780	740	0.6
29ccd1	3,040	73/6/5	3.3	83	1.2	0	100	.8	69	51	142	39	12	12	0	.01	333	.45	3	0	98	25	476	9.2	70.0	22	150	10	.2
30bdb1	350	73/7/23	–	57	33	3.2	7.9	3.1	129	0	106	10	2.7	.3	.01	.10	181	.25	96	0	15	.4	220	8.9	16.5	20	20	10	0
34bad1	2,960	73/7/9	–	91	1.0	0	99	.8	72	46	136	40	13	13	0	0	339	.46	3	0	98	27	453	9.2	75.5	29	150	10	0
4S-2E-29dbc1	1,000+	73/7/27	.02	100	21	6.9	330	24	1,010	0	828	4.5	31	.3	0	–	1,020	1.39	81	0	87	16	1,390	7.4	28.0	0	620	630	0
32bcc1	2,704	73/7/9	.05	110	5.8	.7	150	8.5	383	0	314	5.2	17	8.7	.70	.07	499	.68	17	0	92	16	699	8.8	43.0	5	1,000	260	.3
5S-1E- 3aab1	1,900	73/7/24	–	120	27	1.3	260	29	787	0	645	7.2	18	.5	0	.22	853	1.16	73	0	84	13	1,230	7.8	32.0	10	800	700	0
10bdd1	2,960	73/6/5	2.7	83	2.2	0	100	.7	63	49	133	42	13	15	0	.01	336	.46	6	0	97	19	514	9.3	64.0	44	160	10	.3
21cbc1	660	73/6/6	.81	77	1.3	0	100	.7	57	50	130	42	13	15	.05	.02	317	.43	3	0	98	24	468	9.2	65.0	30	170	10	.2
24acd1	3,120	73/7/9	4.5	89	1.1	0	100	1.3	82	39	132	41	14	15	.78	.01	344	.47	3	0	98	26	463	9.3	64.5	29	150	20	.3
5S-2E- 1bbc1	1,800	73/7/9	.06	77	1.7	0	86	.6	46	59	136	7.1	16	15	.36	0	288	.39	4	0	86	18	423	9.8	49.5	1	1,100	10	0
2cda1	2,460	73/6/7	.02	89	9.9	2.0	250	22	675	0	554	3.4	25	6.4	.01	.06	742	1.01	33	0	90	19	1,100	–	36.5	4	1,200	740	.3
5bcd1	2,009	73/6/5	.17	110	5.2	1.1	150	6.7	223	75	308	8.1	20	8.6	0	.04	496	.67	18	0	93	16	648	9.3	42.5	3	990	250	.3
13ada1	1,748	73/6/22	.01	110	13	2.6	260	28	767	0	629	3.2	30	1.5	0	.10	828	1.13	43	0	88	17	1,260	7.6	23.0	5	1,200	830	0
5S-3E-14cbb1	2,300	73/7/23	.14	81	2.4	0	91	.8	66	42	124	10	18	23	0	.05	302	.41	6	0	97	16	419	9.6	58.5	2	1,100	10	0
15cba1	1,620	73/6/21	.01	130	22	5.7	280	20	886	0	727	5.4	36	1.3	0	.17	950	1.29	80	0	86	14	1,260	7.3	15.0	5	1,100	1,100	.2
20ada1	2,420	73/7/13	–	110	1.1	.1	85	.7	27	61	124	6.4	15	19	.09	.01	313	.43	3	0	98	21	396	9.6	60.0	1	780	0	0
20bbb1	–	73/7/23	.01	110	42	3.9	230	19	703	0	577	6.7	30	.5	3.6	.13	806	1.10	120	0	78	9.1	1,330	7.2	27.0	2	790	730	0
22aad1	1,300	73/6/22	.01	140	19	3.4	250	18	683	0	560	4.0	38	.7	.02	.04	812	1.10	61	0	87	14	1,280	7.3	25.0	6	1,200	950	0
25bbb1	1,320	73/6/28	.01	98	30	8.7	200	16	528	0	572	5.5	28	.2	0	.12	733	1.00	110	0	77	8.2	1,120	7.2	18.0	2	800	940	0
5S-3E-26bcb1	2,970	73/6/7	–	110	2.1	0	110	1.7	22	64	125	62	15	15	.01	.02	391	0.53	5	0	97	21	530	9.3	83.0	4	570	40	.3
26bcb2	2,970	73/6/8	–	100	1.5	.1	110	1.5	35	55	120	64	15	14	.03	.01	380	.52	4	0	98	23	529	9.3	67.0	4	550	30	.5
27bdd1	2,900	73/7/13	–		1.4	.1	81	.9	63	39	124	12	17	20	.25	0	279	.38	4	0	97	18	403	9.4	60.0	4	830	0	.2
28bcc1	2,540	73/5/31	–	98	.8	0	97	1.3	27	67	134	9.8	15	21	0	.02	324	.44	2	0	98	30	437	9.4	65.0	5	620	20	.1
35ccc1	2,570	73/5/31	–	100	2.2	0	100	1.1	54	49	126	72	16	15	.01	.03	391	.53	3	0	98	30	551	9.3	71.5	7	560	40	2.7
5S-4E-34ccb1	356	73/7/20	–	94	85	7.8	83	12	227	0	186	240	18	1.7	0	.03	654	.89	240	58	41	2.3	845	8.3	27.0	5	130	140	0
5S-5E-33bbd1	250	73/7/31	–	40	86	66	170	6.9	425	0	349	450	50	.6	5.3	–	1,100	1.50	490	140	43	3.4	1,650	7.2	22.0	28	300	230	0
34ddd1	885	73/7/31	–	87	29	12	190	26	625	0	513	12	24	.6	.33	–	691	.94	120	0	73	7.5	1,100	7.5	25.0	10	700	440	0
6S-2W-14cba1S		73/7/3	0.06	30	5.6	1.4	8.2	2.0	28	0	23	8.5	6.3	.1	2.3	.06	86	.12	20	0	44	.8	91	7.1	11.0	1	30	0	.2

TABLE 3. Chemical analyses of water from selected wells and springs. (continued)

Well or spring identification number	Reported well depth below land surface (feet)	Date of collection	Discharge (cubic feet per second)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Alkalinity as $CaCO_3$	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrite plus Nitrate ($NO_2 + NO_3$)	Phosphorus (P)	Dissolved Solids (calculated)	Dissolved Solids (tons per ac-ft)	Hardness		Percent sodium	Sodium-absorption ratio	Specific conductance (field)	pH (field)	Water temperature (°C)	Chemical constituents in micrograms per litre			
																			as $CaCO_3$	Noncarbonate						Arsenic (As)	Boron (B)	Lithium (Li)	Mercury (Hg)
6S-1E-32bba1S		73/7/12	–	45	37	8.5	22	1.6	126	0	103	35	21	0.5	0.56	0.01	235	0.32	130	24	27	0.8	344	7.2	25.0	5	30	0	0.1
6S-3E- 2cbc1	3,050	73/5/31	–	99	1.2	0	120	2.8	86	52	157	45	19	17	.01	.02	399	.54	3	0	98	30	599	9.1	62.0	2	850	40	0
2ccc1	1,940	73/7/6	1.6	100	1.2	.1	110	4.0	120	37	160	27	18	17	.03	.01	374	.51	3	0	97	26	504	9.2	53.0	3	760	40	.1
4bcc1	1,680	73/6/4	–	110	1.6	0	110	6.4	58	74	171	42	11	12	0	.02	396	.54	4	0	95	24	534	9.4	48.0	2	440	20	.2
5cac1	3,600	73/6/4	–	94	4.6	0	59	3.4	78	12	84	20	9.7	11	.08	.01	253	.34	11	0	89	7.6	320	8.6	61.0	23	150	10	.2
9acc1	1,425	73/6/4	3.7	130	3.6	.1	97	8.1	157	25	170	42	11	9.1	0	.06	404	.55	9	0	91	14	516	8.8	39.0	2	420	80	.2
11dad1	1,400	73/7/25	–	120	5.6	.3	86	6.1	155	0	127	33	11	11	.03	.12	350	.48	15	0	89	9.6	433	8.9	34.0	0	400	50	0
6S-4E-14abc1	1,905	73/5/30	3.3	140	5.0	.1	110	4.7	20	74	140	65	19	24	.02	.06	452	.61	13	0	93	13	583	9.4	54.0	30	540	0	.4
18bcc1	455	73/6/27	2.3	44	58	4.6	38	4.7	220	0	180	58	9.2	.7	1.3	.01	332	.45	160	0	33	1.3	462	7.3	18.0	22	80	30	0
25bcc1	1,750	73/6/26	.20	73	41	2.3	95	13	129	0	106	190	14	3.9	.23	.03	497	.68	110	6	62	3.9	702	7.8	20.0	3	130	90	0
35cda1	955	73/6/26	–	96	4.6	.1	47	8.9	96	0	79	24	9.0	8.0	0	.04	245	.33	12	0	81	5.9	273	8.5	32.5	24	100	20	0
6S-5E-10ddd1	1,667	73/7/5	.01	78	2.6	.3	120	4.3	159	19	162	24	15	29	.04	.02	371	.50	8	0	95	19	508	8.4	39.0	2	690	10	0
18ccb1	2,960	73/6/26	–	120	3.9	.1	100	7.3	93	25	118	52	20	13	.13	.03	388	.53	10	0	92	14	520	7.6	27.0	20	540	40	0
6S-5E-20aab1	–	73/5/30	0.01	59	4.7	0.1	110	5.6	198	18	192	3.7	17	24	0	0.04	341	0.46	12	0	93	14	562	8.8	43.5	8	950	50	0
24bca1	1,095	73/6/25	.01	89	3.6	0	120	4.6	149	21	157	28	13	27	0	.02	380	.52	9	0	95	17	509	9.1	33.5	6	570	10	0
24ddb1	1,938	73/7/25	–	79	2.8	0	99	2.3	127	10	121	35	11	25	0	.05	327	.44	7	0	96	16	418	9.0	32.5	20	380	10	0
29dcc1	1,560	73/7/5	.01	120	7.1	.3	87	6.3	117	4	103	42	15	19	.05	.04	359	.49	19	0	88	8.7	435	8.8	32.5	1	400	70	0
35cca1	460	73/7/19	–	73	38	3.3	54	8.6	166	0	136	66	11	6.9	.17	.02	344	.47	110	0	50	2.3	462	9.1	22.0	18	100	40	0
6S-6E-12ccd1	990	73/7/6	–	120	10	.6	180	15	493	0	404	3.6	19	5.9	3.0	.07	612	.83	27	0	89	15	843	8.2	37.0	1	1,100	220	.3
19ccd1	913	73/5/22	.01	88	3.0	0	93	3.1	94	19	109	38	10	26	.01	.01	327	.44	8	0	95	15	457	9.0	38.0	15	340	0	.2
19dbd1	1,092	73/7/18	–	84	2.3	0	94	1.9	87	24	111	28	10	26	.02	–	314	.43	6	0	96	17	421	9.2	42.0	25	340	10	0
32bdd1	1,402	73/6/25	.06	87	3.1	.1	94	3.1	132	8	122	28	11	27	.01	.02	327	.44	8	0	94	14	413	9.3	34.5	45	350	10	0
6S-7E- 1acb1	1,000+	73/8/1	.01	73	7.0	.6	260	8.0	614	0	504	3.4	62	4.4	0	–	723	.98	20	0	95	25	1,240	8.0	41.0	0	1,500	230	0
1dbd1	1,050+	73/8/1	.02	72	8.1	1.2	250	8.2	585	0	480	3.6	79	3.2	.02	–	716	.97	25	0	94	22	1,170	8.0	33.0	0	1,900	220	0
2cdd1	1,350	73/6/25	.01	75	5.8	.5	210	7.6	524	0	431	2.8	56	7.6	.30	.01	628	.85	17	0	94	22	951	8.0	34.5	1	1,700	20	0
8bba1	365	73/7/26	–	87	26	17	240	31	530	0	435	250	17	.7	.01	.04	931	1.27	140	0	75	9.0	1,210	7.0	23.0	40	280	240	0
7S-3E- 4acd1	804	73/6/8	1.6	94	51	2.8	31	15	214	0	176	36	7.2	1.7	.02	.02	346	.47	140	0	29	1.1	437	7.4	34.0	24	80	50	.3

7S-4E- 1acc1	1,800	73/5/21	1.7	83	6.9	.2	53	6.7	79	10	81	17	8.6	9.7	.29	.02	235	.32	18	0	81	5.4	278	8.6	40.0	3	100	0	.8
3abd1	1,142	73/6/28	3.7	95	5.8	.1	46	7.4	88	5	81	20	8.7	8.9	.12	.01	241	.33	15	0	80	5.2	272	8.4	42.0	17	120	10	0
5cca1	1,040	73/6/27	4.1	96	50	1.4	54	15	154	0	126	130	8.7	2.0	.01	.03	433	.59	130	4	44	2.1	497	7.7	30.0	9	120	60	0
10bdb1	1,145	73/6/11	1.1	99	7.2	.1	47	8.3	106	0	87	24	8.6	9.4	.26	.04	257	.35	19	0	78	4.7	284	8.6	37.5	17	110	10	.1
11cbc1	1,500	73/6/12	4.4	99	16	.3	45	9.0	113	0	93	30	9.3	8.2	1.3	.03	278	.38	41	0	65	3.1	312	8.3	36.0	20	100	20	.2
12bdd1	1,105	73/5/21	–	96	7.0	.1	51	7.0	97	0	80	17	8.4	8.7	.29	.02	244	.33	18	0	81	5.2	293	8.7	43.0	13	100	0	1.1
13bcc1	1,060+	73/7/26	3.3	95	7.3	.2	49	7.8	89	6	83	20	8.0	9.0	.26	.06	247	.34	19	0	79	4.9	289	9.0	39.0	19	100	10	0
13dcd1	1,000	73/5/30	2.8	97	8.7	.1	53	7.5	80	11	84	19	9.0	11	.25	.02	257	.35	22	0	78	4.9	261	8.7	40.0	14	90	10	.4
7S-4E-14abc1	1,146	73/6/12	3.7	96	7.2	0.1	45	7.8	104	0	85	18	8.1	6.0	1.2	.04	245	.33	18	0	85	4.6	275	8.6	39.0	12	110	10	0.1
15acd1	1,065	73/6/12	5.9	100	23	.8	48	9.9	123	0	101	54	9.9	14	.80	.04	323	.44	58	0	60	2.7	359	8.0	33.0	12	110	30	.1
23cbb1	810	73/6/13	7.3	96	12	.2	58	8.7	108	6	99	36	11	10	1.1	0	296	.40	31	0	75	4.5	352	8.4	38.5	–	–	–	–
25adc1	735	73/5/24	6.1	100	6.8	.1	25	6.4	108	0	89	29	11	15	.58	.04	250	.34	18	0	67	2.5	364	8.9	36.5	36	120	10	.1
26bcb1	867	73/7/10	2.9	91	13	.4	45	8.3	103	0	84	22	12	8.2	.82	.05	254	.35	34	0	69	3.4	300	8.2	31.0	15	110	10	4.3
27bcc1	1,390	73/7/10	3.1	76	16	1.3	46	7.7	109	0	89	28	14	6.6	1.9	.06	258	.35	45	0	64	3.0	292	8.0	27.0	15	110	10	2.9
7S-5E- 5dbc1	2,405	73/6/25	.05	75	4.4	.1	63	6.1	87	4	78	48	9.5	8.2	0	.02	261	.36	11	0	88	8.1	332	9.0	32.0	3	170	10	0
7abb1	1,625	73/7/6	7.8	91	8.5	.2	51	7.4	96	0	79	17	9.8	9.7	.95	.04	246	.33	22	0	78	4.7	279	8.5	39.0	21	90	10	.6
8ccc1	1,500	73/5/21	1.8	90	5.9	.1	55	6.9	81	11	85	19	9.3	11	.25	.01	249	.34	15	0	83	6.2	291	8.7	40.0	10	110	0	.1
9ddd1	2,065	73/6/14	2.0	89	12	.5	50	6.8	85	9	85	18	9.0	11	.71	0	250	.34	32	0	73	3.8	290	8.6	40.0	14	60	10	.1
13aac1	150	73/7/17	.78	93	18	2.3	51	9.2	100	0	82	50	10	10	.15	.04	294	.40	54	0	63	3.0	361	8.4	25.0	46	120	20	1
13cbb1	1,954	73/6/21	–	83	6.7	0	50	7.1	86	5	79	19	9.0	11	.13	.04	234	.32	17	0	81	5.3	284	8.7	36.0	27	130	10	.3
16acd1	1,515	73/5/30	–	90	6.7	.1	53	6.5	101	0	87	20	9.8	16	.26	.02	259	.35	17	0	83	5.9	278	8.7	39.5	17	90	10	.3
19ccc1	760	73/7/23	2.6	95	7.7	.1	55	7.6	103	0	84	24	11	12	.24	–	264	.36	20	0	80	5.4	309	8.4	36.5	19	110	10	0
28acd1	1,003	73/5/24	2.5	94	8.3	.3	52	9.2	97	0	80	24	9.5	11	.23	.01	257	.35	22	0	77	4.8	297	8.6	34.0	16	110	0	.4
7S-6E- 7aac1	1,086	73/7/19	–	100	2.8	.1	61	6.8	80	16	92	23	10	10	.01	.03	269	.37	7	0	89	9.8	310	9.2	25.0	30	140	10	0
9bad1	910	73/7/5	–	100	1.6	.3	100	2.8	59	43	120	27	10	24	.06	.04	338	.46	5	0	96	19	461	9.4	50.5	78	210	10	.1
16cdc1	513	73/6/14	–	81	7.4	.4	49	5.1	99	3	86	18	9.0	8.9	.33	0	232	.32	20	0	80	4.8	287	8.5	42.5	17	60	10	.2
21dbc1	760	73/6/14	–	82	5.9	.3	54	4.6	91	7	86	18	9.0	12	.28	0	239	.33	16	0	84	5.9	287	8.5	43.0	16	70	0	.1
22aad1	1,410	73/5/22	5.5	86	16	1.9	40	6.3	124	0	102	15	8.4	3.7	.60	.01	241	.33	48	0	61	2.5	274	8.0	45.0	4	90	20	.1
23cad1	1,300	73/5/22	–	100	12	1.1	53	7.2	126	0	103	17	8.7	8.2	.54	.01	272	.37	35	0	73	3.9	327	8.3	44.0	16	120	20	0
26ada1	1,000	73/5/22	2.3	82	16	2.8	36	6.9	134	0	110	15	8.6	3.1	.66	.02	240	.33	51	0	57	2.2	288	8.0	38.0	7	100	20	1.1
27adb1	400	73/6/19	1.2	84	12	1.1	48	6.2	129	0	106	17	8.6	5.4	.59	.03	249	.34	35	0	71	3.6	287	9.2	43.0	18	80	10	.3
34dcb1S		73/6/19	1.0	83	6.2	.3	55	5.5	103	6	94	18	8.8	8.5	.46	.03	244	.33	17	0	83	5.9	288	9.1	41.0	26	10	0	.2
35bbb1S		73/7/18	–	89	13	1.8	43	6.7	126	0	103	15	8.8	4.5	.60	.03	247	.03	40	0	66	3.0	287	8.5	40.0	19	110	10	1
8S-1E-20cca1S		73/7/2	.01	22	11	2.8	6.0	.7	62	0	51	3.2	2.0	.2	.62	.07	81	.11	39	0	25	.4	100	7.1	9.5	2	20	0	.1
8S-6E- 3bdd1S		73/7/5	1.0	87	6.5	.6	53	6.7	113	5	101	15	9.1	6.0	.66	.06	248	.34	19	0	81	5.3	300	8.3	39.0	18	80	10	0
9S-2E-13cbc1S		73/7/2	.01	39	14	2.9	11	2.1	71	0	58	9.5	6.3	.3	.04	.08	120	.16	47	0	33	.7	130	7.2	11.0	0	40	0	.3

Analyses by: U. S. Geological Survey

Based on the mixed-water method, temperatures in excess of 180°C may be expected at depth in the Bruneau-Grand View area. This is supported by the apparent mixing of cooler bicarbonate water with the thermal waters which would lower the SiO_2 values more than the Na-K-Ca values as it would more than likely be poor in SiO_2 while containing significant alkaline elements in solution. In addition, the Na:K ratio does not vary appreciably among the high and low Na-K-Ca values in the Little Valley-Bruneau Hot Springs area, but contains an overabundance of calcium which would indicate dilution by calcium bicarbonate waters.

Reservoir Rocks

Possible reservoir rocks in the Grand View area include Cretaceous granites, Miocene volcanic rocks, and associated sediments. The permeability of these formations is mainly secondary, being dependent upon faulting and pervasive fracturing. The formations will be discussed from youngest to oldest, as they would be encountered in an idealized drill hole.

Water wells producing from the Idavada Volcanics range from poor to excellent, with the majority in the latter class. Some wells tapping these aquifers produce over 190 l/s (3000 gpm). Generally the rock is moderately to highly fractured and provides a permeable aquifer of large lateral extent. Vertical movement of fluids is restricted to fissure zones or faulted areas. Although the permeability of these rocks is attractive, it is doubtful that they lie at great enough depths to serve as reservoir rocks for fluids of production temperatures.

The tertiary rhyolites in the Grand View area have limited lateral distribution and lack primary permeability. However, in areas of pervasive fracturing the unit would have sufficient permeability to make good reservoir rocks.

The tuffs, basalt flows, and sediments of the Sucker Creek Formation represent poor to moderate reservoir rocks. Sedimentary units are generally of short lateral extent, and basalt flows are often severely altered. Tuff members in the Sucker Creek Formation may have a fairly widespread distribution and areas of pervasive fracturing within the tuffs would produce adequate permeability.

Primary permeability in the basalt-latite sequence is very low except for sedimentary interbeds or cinder zones. However, secondary fracturing and jointing due to cooling would produce adequate permeability resulting in a good reservoir rock. Alteration and clay mineralization will tend to reduce secondary permeability. It may be noted for comparison that Columbia River Basalts which are of similar age to the basalt-latite sequence are often excellent aquifers and many wells produce thousands of gallons-per-minute from these strata throughout the Northwest.

The Cretaceous granites may be an important reservoir rock beneath the AMAX lands. Although doubt has been expressed about whether the permeability in granitic rocks can provide a geothermal reservoir, the experience at Marysville, Montana, and Roosevelt, Utah, should negate most of these fears. Numerous small faults and internal pervasive fracturing and jointing should insure adequate permeability.

Heat Flow

Heat flow refers to the conductive transfer of heat through the crust, as described by the relationship:

$$Q=k\frac{dt}{dx}$$

where Q is heat flow (1 HFU = 1 microcalorie/cm^2-sec); k is thermal conductivity (1 TCU = 1 millicalorie/cm-sec-$^{\circ}$C); and $\frac{dt}{dx}$ is the thermal gradient ($^{\circ}$C/km).

AMAX drilled 46 thermal gradient holes in the Grand View area during 1977-78. Additional thermal gradient data was obtained through data exchanges with competitors in the area, temperature measurements in water wells, and from published thermal gradient and water well information. Sufficient data was obtained to compile a detailed heat flow map.

Along the southern edge of the Snake River downwarp, gradients range from isothermal to over 250°C/km. Conductivities in the area range from 2.5 TCU in sediments to over 7 TCU in the Idavada volcanics and granites (Table 4). The resulting values commonly exceeded 7 HFU. The zones of extremely high heat flow are linear features and are controlled by northwest trending faults and intersections with northeast trending faults. Unfortunately, areas of 7 HFU's and higher reflect convective rather than conductive heat flow. In these areas faults bring hot water (38°C to 83°C) near the surface, where it intercepts shallow aquifers dipping northeastward beneath the Plain. Moving in a northeast direction across one of these anomalies, the heat flow increases rapidly, peaking at the fault. Continuing to the northeast, heat flow declines slowly as the hot water aquifer dips to greater depths beneath the surface.

TABLE IV

Thermal Conductivities of Rocks in the Grand View Area, Idaho

Hole Number	Measured K
844-2	5.37
844-15	6.14
844-18	5.25
844-21	3.60
844-27	3.24
844-30	4.42
844-33	3.42
844-35	4.34
844-37	3.70
844-38	4.37
844-51	5.43
844-58	2.04
844-59	8.10

Thermal gradients obtained in areas of convective heat transfer cannot be used to extrapolate depths to production temperatures. However, the high permeability and vertical movement of fluids along the controlling faults make them attractive drilling targets. At greater depths these faults may serve as conduits for higher temperature geothermal fluids.

Thermal gradient hole 844-30 (sec. 35, T7S, R4E) is a graphic example of convective heat flow. The hole intercepts a $38^{o}C$ aquifer at 54 m, yielding a gradient of $262^{o}C/km$ or 14.6 HFU. From 80 m to 150 m no additional aquifers were encountered and measured temperatures decreased slightly to hole bottom. The hole was drilled near a fault intersection which apparently serves as a conduit for the convective movement of hot water.

Associated with the convective heat flow highs are two more widespread areas with values in excess of 4 HFU (gradients generally greater than 80°C/km). One area in T7S, R2E covers 80 square kilometers (30 square miles), and occurs at the intersection of a major northeast trending fault, and the northwest trending band of high heat flow. The other area is southeast of Little Valley (T8 and 9S, R4 and 5E) and extends over 140 square kilometers (50 square miles). The southern extent of this anomaly is not known.

One zone of low to negative thermal gradients also occurs in the Grand View area. In the vicinity of Little Jacks Creek (T7 and 3S, R3 and 4E) an area of roughly 45 square kilometers (16 square miles) has a heat flow of less than one. Two thermal gradient holes in this area produced negative gradients. Exposures of vitrophyre breccia of the Idavada Volcanics covers much of the area, suggesting an eruptive center may be located in the immediate vicinity which could act as a relatively impermeable "plug". This would block the southward migration of thermal waters at depth, and allow the cooler surface waters flowing out of the plateau area to seep down and northward through the area. Higher temperatures probably occur below the influence of the cooler shallow waters. From the present information the magnitude of this increase is impossible to determine.

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