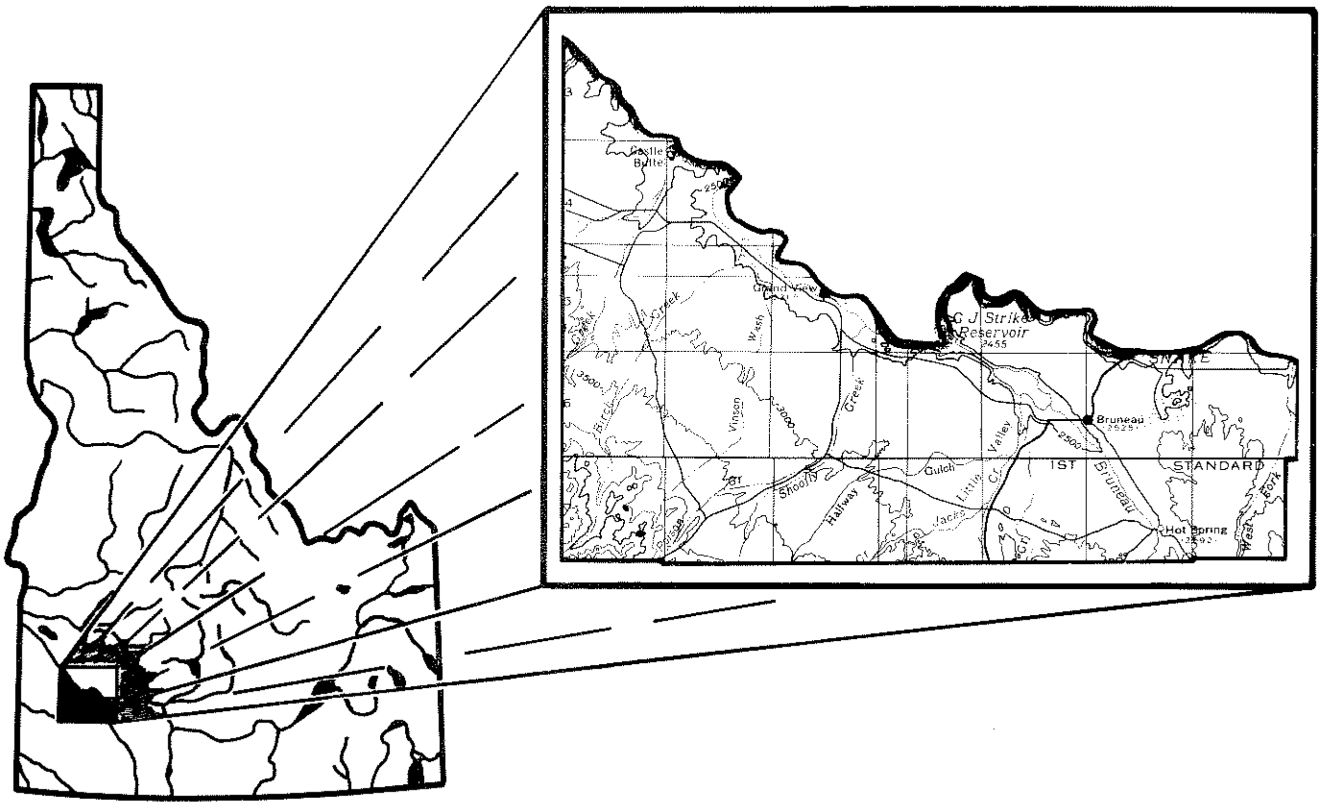
GEOTHERMAL INVESTIGATIONS IN IDAHO

PART 2

AN EVALUATION OF THERMAL WATER IN THE BRUNEAU–GRAND VIEW AREA SOUTHWEST IDAHO



IDAHO DEPARTMENT OF WATER RESOURCES

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An Evaluation of Thermal Water in the Bruneau-Grand View Area, Southwest Idaho

by

H. W. Young and R. L. Whitehead

with a section on A Reconnaissance Audio-Magnetotelluric Survey

by

D. B. Hoover and C. L. Tippens

Prepared by the U. S. Geological Survey

in cooperation with

the Idaho Department of Water Resources
Statehouse
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ABSTRACT

The Bruneau-Grand View area occupies about 1,100 square miles in southwest Idaho and is on the southern flank of the large depression (possibly a graben) in which lies the western Snake River Plain. The igneous and sedimentary rocks in the area range in age from Late Cretaceous to Holocene. They are transected by a prominent system of northwest-trending faults. For discussion purposes, the aquifers in the area have been separated into two broad units: (1) the volcanic-rock aquifers, and (2) the overlying sedimentary-rock aquifers. The Idavada Volcanics or underlying rock units probably constitute the reservoir that contains thermal water.

An audio-magnetotelluric survey indicates that a large conductive zone having apparent resistivities approaching 2 ohm-metres underlies a part of the area at a relatively shallow depth.

Chemical analysis of 94 water samples collected in 1973 show that the thermal waters in the area are of a sodium bicarbonate type. Although dissolved-solids concentrations of water ranged from 181 to 1,100 milligrams per litre (mg/1) in the volcanic-rock aquifers, they were generally less than 500 mg/1. Measured chloride concentrations of water in the volcanic-rock aquifers were less than 20 mg/1.

Temperatures of water from wells and springs ranged from 9.5° to 83.0°C. Temperatures of water from the volcanic-rock aquifers ranged from 40.0° to 83.0°C, whereas temperatures of water from the sedimentary-rock aquifers seldom exceeded 35°C. Aquifer temperatures at depth, as estimated by silica and sodium-potassium-calcium geochemical thermometers, probably do not exceed 150°C. However, a mixed-water geochemical thermometer indicates that temperatures at depth may exceed 180°C.

The gas in water from the volcanic-rock aquifers is composed chiefly of atmospheric oxygen and nitrogen. Methane gas (probably derived from organic material) was also found in some water from the sedimentary-rock aquifers.

The thermal waters in the area are believed to be heated by deep circulation in a zone of high geothermal gradient resulting from thinning of the earth's crust.

INTRODUCTION

Twenty-five areas in Idaho, including the Bruneau-Grand View area, were recommended for further geothermal investigation by Young and Mitchell (1973) in their report describing a preliminary reconnaissance of Idaho's thermal waters. These areas were selected on the basis of their having estimated aquifer temperatures of 140°C or higher, or of having the unique geologic conditions that favor the occurrence of a geothermal anomaly.

The Bruneau-Grand View area was selected for further study because (1) the geochemical data previously collected indicated that water temperatures as high as 190°C occur at depth within a large part of this area, (2) the lithologic and structural data available appeared to indicate that the geologic conditions especially favorable to the occurrence of a geothermal anomaly were present, and (3) a significant amount of the water-quality, well-log, and geophysical data needed to define further any geothermal anomaly present could be readily collected. Accordingly, the U.S. Geological Survey, in cooperation with the Idaho Department of Water Resources, initiated a study whose goal was to further evaluate the potential of the Bruneau-Grand View area as a geothermal prospect.

The Bruneau-Grand View area comprises about 1,100 square miles in northern Owyhee County, which is in the southwestern part of the Snake River Plain (fig.1). The area extends eastward from Oreana to Indian Cove (fig. 4), with the Snake River forming the northern boundary of the area and the township line between T. 9 S., and T. 10 S. forming the southern boundary.

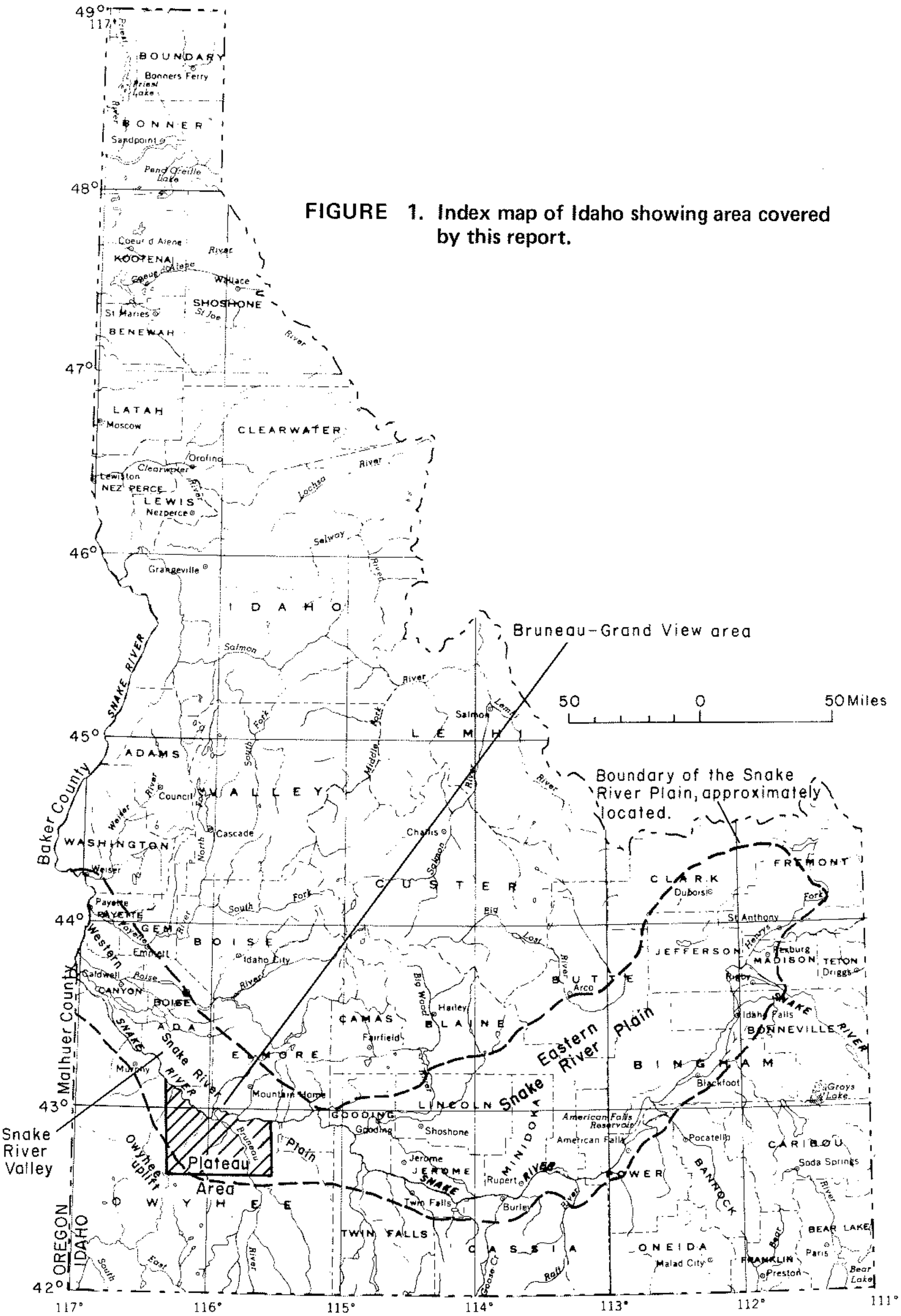
The area has an arid to semiarid climate with cool winters and hot summers. Precipitation averages less than 10 inches annually, and mean annual temperatures range from 10.5° to 13.0°C. (Mundorff, Crosthwaite, and Kilburn, 1964, p. 67).

Purpose and Scope

The purpose of this report is to present (1) a description of the areal extent and chemical character of thermal water in the Bruneau-Grand View area; (2) estimates of water temperature at depth using geochemical thermometers; (3) a description of the geophysical data available for the area; (4) a description of the surficial and subsurface geology utilizing compilations of data from other reports and drillers' logs of wells; and (5) a brief description of the source of the thermal water issuing from springs and wells.

Water samples from 87 wells and 7 springs were collected for standard chemical analyses, including the common ions and silica. Additional samples from the same wells and springs were collected for analyses of the minor elements: mercury, lithium, boron, and arsenic. Also, 15 gas samples were collected for analyses. These data were collected from the majority of operating wells and flowing springs in the Bruneau-Grand View area and are thought to be representative of most of the thermal and nonthermal ground water in the area.

FIGURE 1. Index map of Idaho showing area covered by this report.



For all wells and springs sampled, water temperatures at depth were estimated using the silica, the sodium-potassium-calcium, and the mixed-water geochemical thermometers. Also, ratios of selected chemical constituents in the waters sampled were used to characterize and thereby distinguish water from separate aquifers.

Geophysical data and studies of the Geological Survey were used as an aid to defining the extent of the geothermal system in the Bruneau-Grand View area. Previous reports and drillers' logs were used to prepare a geologic map and geologic sections for the area as an aid to describing the areal hydrology. The geologic data presented were modified from reports by Malde, Powers, and Marshall (1963), Littleton and Crosthwaite (1957), Anderson (1965), Ralston and Chapman (1969), and Ross and Forrester (1947). Correlation of the geologic units shown in the different reports was made by utilizing information presented by Ralston and Chapman (1969).

A preliminary hydrologic analysis was made to identify areas of recharge to the geothermal system and to describe a circulation pattern of the ground water.

Previous Work

Reports by Stearns (1922), Buwalda (1923), Piper (1924), Kirkham (1931a and 1931b), and Russell (1903) contain data on the geology and hydrology of the Bruneau-Grand View area. Although these reports are of limited scope, they provide useful background information on the geology and hydrology of the Bruneau-Grand View area. Pakiser (1963), Hill (1963), and Malde and Powers (1962) give general descriptions of the deep subsurface structures of the area based on geophysical surveys. A map by Malde, Powers, and Marshall (1963) presents detailed geology for the eastern half of the Bruneau-Grand View area. A report by Littleton and Crosthwaite (1957) provided much of the generalized geologic and hydrologic data presented in this report. Anderson (1965) mapped the geology of the Oreana 15-minute quadrangle. A report by Ralston and Chapman (1969) contains hydrologic and geologic data and a correlation of the geologic units reported in the abovementioned reports and maps. A State geologic map at a scale of 1:500,000, compiled by Ross and Forrester (1947), supplied information for areas that lacked detailed geologic mapping.

Acknowledgments

A significant part of the information presented in this report was supplied by residents in the Bruneau-Grand View area. For this reason, the authors wish to express their gratitude to these residents for supplying data on their wells and allowing access to their property. The following Geological Survey employees contributed significantly to this investigation: A. H. Truesdell and K. L. Pering provided gas analyses; D. R. Mabey, D. B. Hoover, C. L. Tippens, D. B. Jackson, and D. L. Peterson conducted and interpreted the geophysical surveys.

Well- and Spring-Numbering System

The numbering system used by the Geological Survey in Idaho indicates the location of wells or springs within the official rectangular subdivision of the public lands, with reference to the Boise base line and meridian. The first two segments of the number designate the township and range. The third segment gives the section number, followed by three letters and a numeral, which indicate the quarter section, the 40-acre tract, the 10-acre tract, and the serial number of the well within the tract, respectively. Quarter sections are lettered a, b, c, and d in counterclockwise order from the northeast quarter of each section (fig. 2). Within the quarter sections, 40-acre and 10-acre tracts are lettered in the same manner. Well 6S-3E-2ccc1 is in the SW¼SW¼SW¼, sec. 2, T. 6 S., R. 3 E., and was the first well inventoried in that tract. Springs are designated by the letter "S" following the last numeral, as in 8S-6E-3bdd1S.

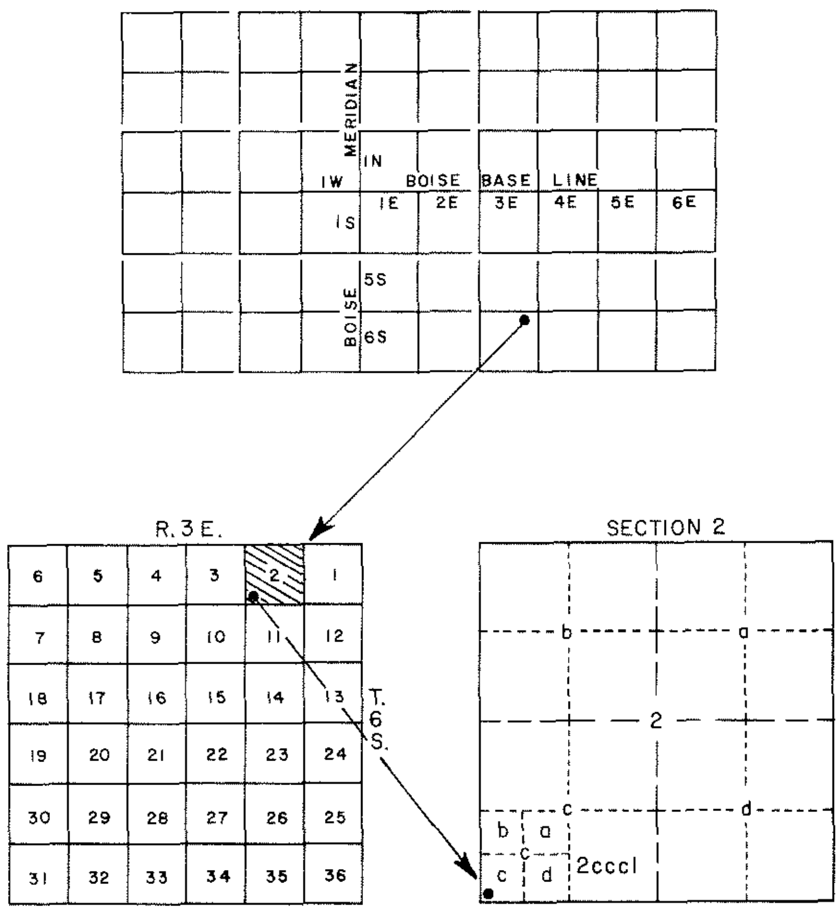


FIGURE 2. Diagram showing the well- and spring-numbering system. (Using well 6S-3E-2ccc1.)

Factors For Converting English Units to International System (SI) Units

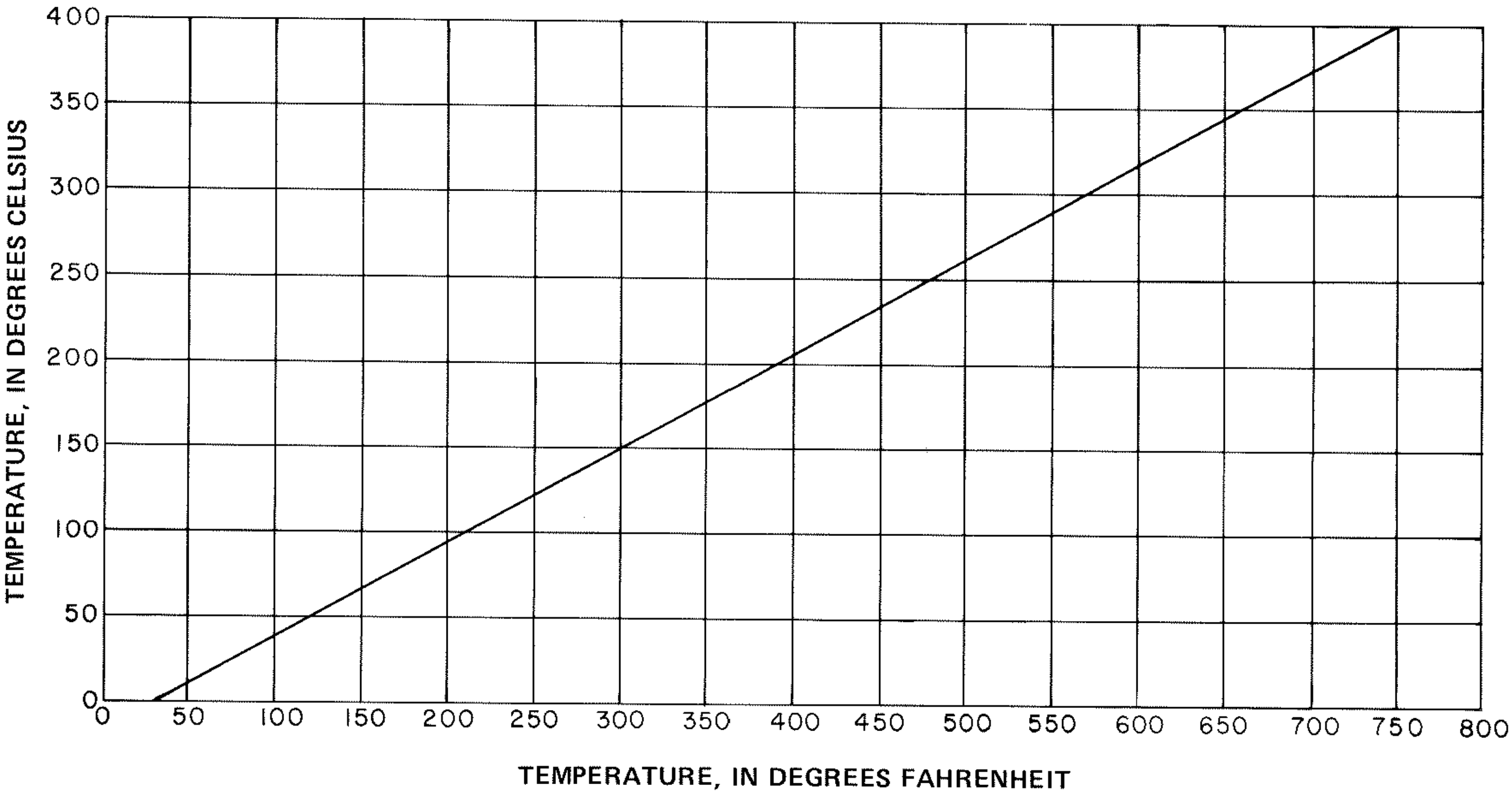
The International System of Units is being adopted for use in reports prepared by the U.S. Geological Survey. To assist readers of this report in understanding and adapting to the new system, many of the measurements reported herein are given in both units. In addition, a graph (fig. 3) and the factors listed below are presented as an aid to conversion from one system of units to another. Chemical data for concentrations are given only in milligrams per litre (mg/1) or micrograms per litre (ug/1) because these values are (within the range of values presented) numerically equal to equivalent values expressed in parts per million, or parts per billion, respectively.

Multiply English units	By	To obtain SI units
	Length	
inches (in)	25.4	millimetres (mm)
	.0254	metres (m)
feet (ft)	.3048	metres (m)
miles (mi)	1.609	kilometres (km)
	Area	
acres	4047.	square metres (m^2)
	.4047	hectares (ha)
square miles (mi^2)	2.590	square kilometres (km^2)
	Flow	
cubic feet per second (ft^3/s)	28.32	litres per second (l/s)
	.02832	cubic metres per second (m^3/s)
gallons per minute (gal/min)	.06309	litres per second (l/s)
million gallons per day (Mgal/d)	.04381	cubic metres per second (m^3/s)

GEOLOGY

The three principal subdivisions in the Bruneau-Grand View area are: (1) The Snake River valley, wherein altitudes range from 2,300 to 3,800 feet. Generally, this subdivision, which is underlain by sediments and basalt, consists of the valley of the Snake River and a series of tributary intermittent stream channels that contain sedimentary rocks of fluviatile origin; (2) the plateau area, wherein altitudes range from 3,000 to 7,000 feet. This area is underlain by volcanic rocks and by sedimentary rocks of fluvial and lacustrine origin. At the higher altitudes, the streams in this area have eroded deep channels into the volcanic rocks; (3) the Owyhee uplift, a rugged, mountainous region in the southwestern part of the area. The uplift is composed of an eroded core of metamorphic and granitic rocks and of younger igneous and sedimentary rocks that are exposed at the surface. Altitudes on the uplift range from 3,000 to 8,400 feet above mean sea level, with most of the higher altitudes occurring to the west and southwest outside the study area.

The rocks in the Bruneau-Grand View area range in age from Late Cretaceous to Holocene. Rocks of the Cenozoic Era have been subdivided into the following four major groups by Malde, Powers, and Marshall (1963): (1) an unnamed sequence of rhyolitic and related rocks, (2) the Idavada Volcanics, (3) the Idaho Group, and (4) the Snake River Group. The descriptions of these units given in this report are based chiefly on those by Malde, Powers, and Marshall (1963), and partly on those by Littleton and Crosthwaite (1957), and Ralston and Chapman (1969). The areal distribution and relationship of these units are shown in figures 4 and 5, respectively, and their geologic characteristics are given in table 1.



Conversion of degrees Celsius (°C) to degrees Fahrenheit (°F) is based on the equation, °F = 1.8°C + 32.

FIGURE 3. Temperature-conversion graph.

FIGURE 5. Idealized hydrogeologic section showing general relation of geologic units, recharge, and ground-water movement.

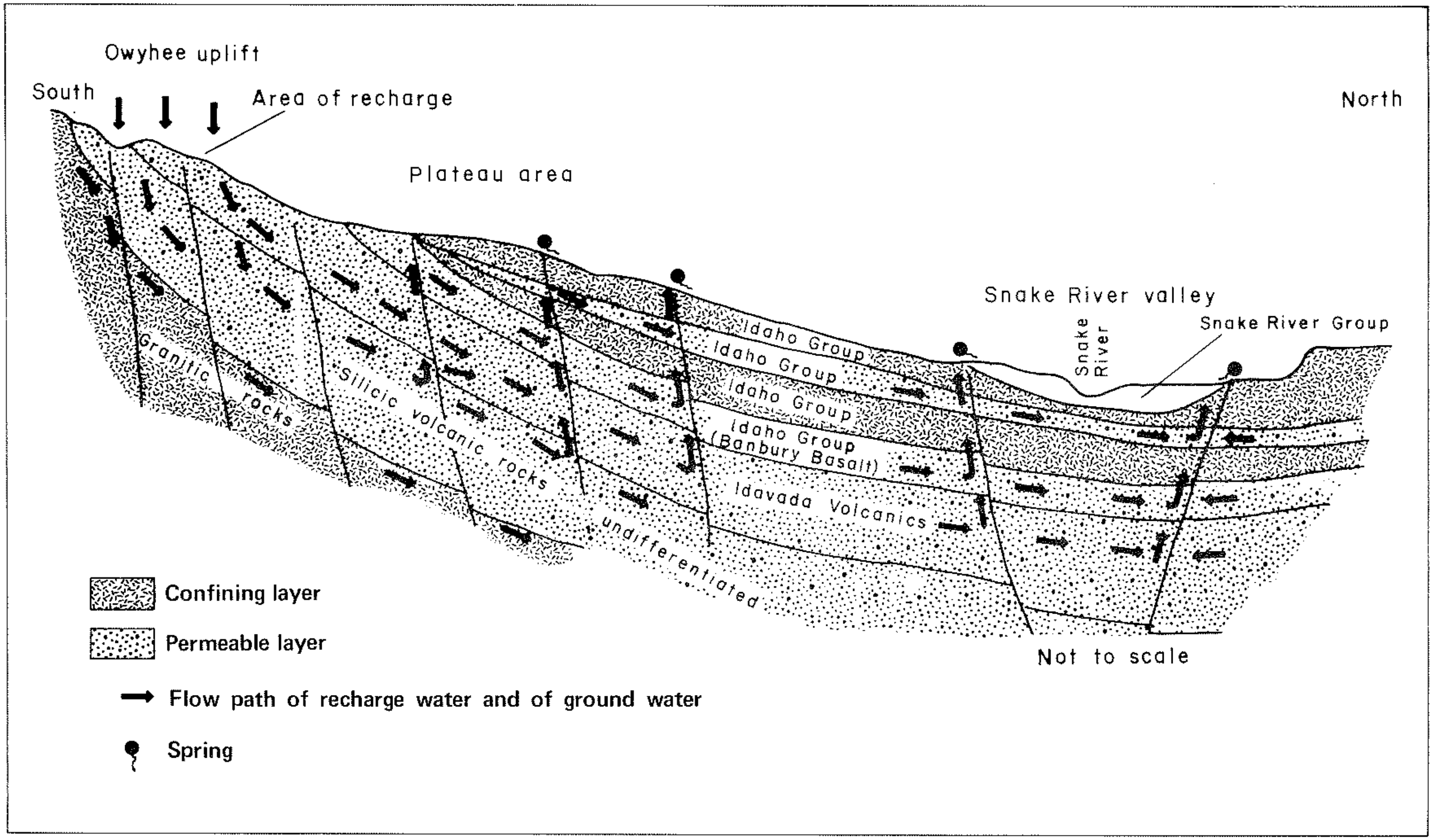


TABLE 1

DESCRIPTION AND WATER-BEARING CHARACTERISTICS OF GEOLOGIC UNITS

Era	Period	Epoch	Rock unit	Description[1]	Water-bearing characteristics[2]
Cenozoic	Quaternary	Holocene	Alluvium and dune sand (Qal, Qd)	Qal, alluvium; Qd, dune sand. Includes clay, silt, sand, and gravel. Chiefly fluvial and eolian deposits of Holocene age. The deposits form hills, mounds, and crescent-shaped dunes.	Surficial deposits that are not permanently saturated. Too limited in extent to be important as aquifers.
Cenozoic	Quaternary	Pleistocene	Melon Gravel of the Snake River Group (Qm)	Consists of boulders, cobbles, and pebbles in a matrix of basaltic sand. Boulders commonly 3 feet in diameter.	Surficial deposits that are not permanently saturated. Not important as aquifers.
Cenozoic	Quaternary	Pleistocene	Crowsnest Gravel of the Snake River Group (Qc)	Chiefly silicic volcanic pebbles but with abundant quartz and porphyry cobbles in places. Gravels occupy terraces about 50 feet above the Snake River.	Surficial deposits that are not permanently saturated. Not important as aquifers.
Cenozoic	Quaternary	Pleistocene	Unnamed gravel of the Snake River Group (Qg)	Consists of pebble and cobble gravels that occupy terraces along the Bruneau River.	Surficial deposits that are not permanently saturated. Not important as aquifers.
Cenozoic	Quaternary to Tertiary	Pleistocene to Pliocene	Idaho Group, undifferentiated (QTiu)	Poorly to well-stratified fluvial and lacustrine deposits of unconsolidated to consolidated gravel, sand, silt, and clay with layers of ash and intercalated basaltic lava flows. In places exceeds 3,000 feet in thickness.	Yields to wells vary from very poor to good depending upon unit penetrated. Important as an aquifer. See descriptions for individual units below.
Cenozoic	Quaternary	Pleistocene	Black Mesa Gravel of the Idaho Group (Qp)	Consists of gravel and sand as much as 25 feet thick. Remnants of a widely preserved pediment surface. Gravel is largely reworked from older gravels and is capped by a caliche layer several feet thick.	Not important as an aquifer. In most places the unit occurs above the water table.

TABLE 1. Description and water-bearing characteristics of geologic units. (continued)

Era	Period	Epoch	Rock unit	Description[1]	Water-bearing characteristics[2]
Cenozoic	Quaternary	Pleistocene	Bruneau Formation of the Idaho Group (Qbs, Qbb)	Canyon fill of undeformed, unconsolidated detrital material and interbedded basaltic lava flows associated with marginal deposits of gravel and basalt. Qbs, detrital material, dominated by massive lakebeds of white-weathering fine silt, clay, diatomite, and minor amounts of silt and sand. Includes beds of ironstained pebble and cobble gravel; Qbb, basaltic lava flows, locally stained brown and yellow. Exceeds 1,000 feet in thickness. Exposed in places along the Bruneau and Snake Rivers.	Yields water to wells slowly. Important as an aquifer only to stock and domestic wells owing to the fine-grained nature of the sedimentary deposits. The basalt unit generally lies above the water table in this area.
Cenozoic	Quaternary	Pleistocene	Tuana Gravel of the Idaho Group (Qt)	Consists of pebble and cobble gravel interbedded with layers of massive brown to gray sand and silt. Includes both silicic volcanic and bouldery quartzitic debris. Capped by a caliche layer several feet thick. Total thickness of the unit is about 200 feet.	Not important as an aquifer. In most places the unit occurs above the water table.
Cenozoic	Quaternary and Tertiary	Pleistocene and Pliocene	Glenns Ferry Formation of the Idaho Group (QTg)	Basin fill of poorly consolidated detrital material and minor lava flows of olivine basalt. Includes fluvial and lacustrine deposits characterized by abrupt lateral facies change. Facies include: Massive silt layers, evenly layered, thick, cemented sand beds; thin beds of dark clay, olive silt, and carbonaceous shale; ripple-marked sand and silt; granitic sand and fine pebble gravel; quartzitic cobble gravel; thin beds of silicic volcanic ash; and thicker beds of	Yields water to wells. Generally the yield is low but some wells produce as much as 3,600 gal./min. from sand zones. Important as an aquifer.

				fragmental basaltic material. Maximum exposed thickness is about 2,000 feet, with the lacustrine facies composing the greatest volume.	
Cenozoic	Tertiary	Pliocene	Chalk Hills Formation of the Idaho Group (Tc, Tcb)	Basin fill of consolidated, locally indurated, clastic deposits, and minor basaltic lava flows. Tc, lake and stream deposits and volcanic ash in variegated sequences of white, pink, brown, and gray beds; Tcb, lava flows of olivine basalt about 25 feet thick. Maximum exposed thickness is about 300 feet.	Yields water slowly to wells. Important as an aquifer only to domestic and stock wells.
Cenozoic	Tertiary	Pliocene	Banbury Basalt of the Idaho Group (Tb)	Lava flows of olivine basalt interbedded locally with minor amounts of stream and lake deposits. Flows mostly vesicular and less than 15 feet thick. Includes some basaltic pyroclastic material in vent areas. Maximum thickness is about 1,000 feet.	Yields to wells range from very poor to excellent depending upon degree of alteration present in area penetrated by the well. A highly altered zone of this basaltic unit tends to be a poor aquifer, whereas the unaltered unit is a good aquifer.
Cenozoic	Tertiary	Pliocene to Miocene	Silicic volcanic rocks (Tsv)	Silicic volcanic rocks, undifferentiated. Includes Idavada Volcanics and rhyolitic rocks.	Remarks for Idavada Volcanics and rhyolitic rocks apply to this unit.
Cenozoic	Tertiary	Pliocene	Idavada Volcanics (Tiv)	Silicic latite; chiefly thick layers of devitrified welded tuff, but includes some vitric tuff and lava flows. Rhyolitic rocks occur in minor amounts. Predominantly porphyritic with phenocrysts of andesine, clinopyroxene, hyperstene, and magnetite, but with no quartz, sanidine, hornblende, or biotite. Overlies older rhyolitic and related rocks, locally exceeds 3,000 feet in thickness.	The highly jointed and fractured character of these rocks make them a good aquifer in the study area and large well yields are obtained. It is believed that these rocks serve to transmit recharge-water to the area and thence upward to overlying units.
Cenozoic	Tertiary	Miocene(?)	Rhyolitic rocks (Tv)	Fine- to coarse-grained extrusive rocks rich in quartz and biotite. Locally cut by mineralized fault zones. Several thousand feet are exposed in the Owyhee uplift.	Unknown; may be an important aquifer.

TABLE 1. Description and water-bearing characteristics of geologic units. (continued)

Era	Period	Epoch	Rock unit	Description[1]	Water-bearing characteristics[2]
Mesozoic	Cretaceous	—	Intrusive rocks (Ki)	Intrusive granitic rocks of comparable age and composition to the Idaho batholith. Exposed in the southwestern part of the study area. Believed to form the basement complex.	Unknown; may be an aquifer.

[1]Modified chiefly from Malde, Powers, and Marshall (1963); and in part from Littleton and Crosthwaite (1957).

[2]Modified from Littleton and Crosthwaite (1957) and Ralston and Chapman (1969).

A study of the gravity and crustal structure in the western Snake River Plain by Hill (1963) suggests that this part of the plain is a graben in which basalt-filled fissures occur. See geologic section H-H' (fig. 6) and the regional gravity map (fig. 7a). On the north side of the graben, high-angle faults occur in a nearly continuous zone along the margin of the lowlands, as illustrated by the faults located northeast of Mountain Home (fig.7a). The southern flank of the graben, which contains the Bruneau-Grand View area, is laced with a system of northwest-trending faults (fig. 7a). This system of faults has been mapped only in the southeastern part of the study area (fig. 4). Faults in the remainder of the study area, if present, are masked by the overlying unconsolidated sedimentary rocks. However, the occurrence of a few warm- and hot-water springs suggests faulting in the underlying rocks at these springs.

Drillers' logs lend support to the existence of a northwest-trending system of semiparallel faults in the area. Although some graben- and horst-type structures are present, most faults have their downthrown side on the north towards the Snake River. The generalized geologic sections (fig. 6), which were compiled from drillers'logs and other geologic information, illustrate the fault system mentioned above. Sections B-B', D-E'D', C'E-E'D', G-G', and H-H', which are alined generally north-south, show that some geologic formations, particularly the Banbury Basalt and the Idavada Volcanics, may have been displaced downwards towards the Snake River, possibly by as much as 200-300 feet in a mile. In some instances, known faults (fig. 4) account for the differences in altitude of formations between wells. A system of northwest-trending faults, such as shown in figure 4 by Malde, Powers, and Marshall (1963), if present in the areas covered by the unconsolidated and poorly consolidated sedimentary rocks, could account for the differences in altitude of the formations shown in the north-trending geologic sections. Most known faults in the area trend to the northwest and have dips that generally range from 50 to 80 degrees to the northeast (Ralston and Chapman, 1969, p. 24). Littleton and Crosthwaite (1957, p. 168) found that vertical movement along most of the faults ranges from a few feet to several hundred feet.

Northeast-trending faults are also thought to be present in the study area (see geologic sections A-A', CF-C'E, and CF-F'). No surface indications of these suspected faults were noted in the field, and none are shown on the geologic map (fig. 4).

HYDROLOGY

Thermal ground water in the Bruneau-Grand View area occurs under artesian (confined) conditions in both the volcanic rocks and the consolidated and unconsolidated sedimentary rocks. The areal extent of these rock formations at the surface is shown in figure 4, and their water-bearing characteristics are given in table 1. (See also fig. 5.) For purposes of discussion in this report, the water-bearing units given in table 1 have been grouped into two general aquifer types: (1) the volcanic-rock aquifers, which include the Banbury Basalt, the Idavada Volcanics, and the rhyolitic and intrusive rocks; and (2) the overlying sedimentary-rock aquifers, which generally consist of units of the Idaho and Snake River Groups.

Because of its arid climate, recharge to the aquifers underlying the Bruneau-Grand View area probably has its source in precipitation (mostly winter snow) onto the plateau and the mountains to the south and southwest. Annual precipitation in the lowlands is less than about 10 inches, whereas at the higher altitudes, annual precipitation generally attains about 20 inches (Mundorff, Crosthwaite, and Kilburn, 1964).

Recharge to the volcanic-rock aquifers, excluding the Banbury Basalt, is believed to be from precipitation onto rocks cropping out at the higher altitudes. These rocks are quite permeable in many places, particularly where fractured by faults, and they readily accept water. Many small, intermittent stream channels, which seldom contain water, drain the scant runoff from the mountains. The only perennial stream crossing the Bruneau-Grand View area is the Bruneau River. The lack of perennial streams in the area is an indication of the ability of these units to accept water and to transmit it in the subsurface to lowland aquifers.

Recharge to the sedimentary-rock aquifers and the Banbury Basalt is believed to be chiefly by upward movement of water from the underlying volcanic-rock aquifers. In addition, percolation losses from the intermittent streams in the area may sporadically supply small amounts of recharge to the sedimentary-rock aquifers.

Possible Thermal Reservoir Rocks

Generally, water temperatures measured at wells producing from the Idavada Volcanics are significantly higher than temperatures measured at nearby wells producing from the overlying sedimentary-rock aquifers (see table 2). From this, it can be obviously deduced that the source of the hot water produced by wells in the Bruneau-Grand View area is the Idavada Volcanics or some underlying rock units. The underlying rock units, as exposed in outcrops, consist of rhyolitic rocks of Miocene(?) age that overlie the granites of Cretaceous age, apparently the basement rock. Data indicative of the ability of either the rhyolite or the granite to transmit and store significant quantities of water are lacking, and their potential as a reservoir rock cannot at this time be assessed. Therefore, the Idavada Volcanics are considered to be the only rocks in this area having the known capacity to act as a reservoir for thermal water.

Idavada Volcanics

The Idavada Volcanics is exposed in the southern part of the study area and probably underlies most of the Bruneau-Grand View area. It is considered to be the most important aquifer in the area and an aquifer that generally yields large quantities of water to wells (Littleton and Crosthwaite, 1957, p. 159). The Idavada Volcanics is also believed to act as the principal conduit that provides recharge to the overlying aquifers.

Although the thickness of the Idavada Volcanics in the study area is not known, an exposed section to the east is more than 3,000 feet thick (Malde and Powers, 1962, p. 1200). Penetration of these volcanic rocks by existing wells (based on drillers' logs, table 2) is usually limited to a few hundred feet. The yields of many wells open to the volcanic-rock aquifers of the Bruneau-Grand View area range from poor to excellent (0.01 to 7.8 ft^3/s). Aquifer characteristics, such as transmissivity and storage coefficient, are not known for the Idavada Volcanics in this area. Some drillers' logs contain water-level and yield data collected during short-term pumping tests made after completion of some wells, but the data are too scant to use for estimating aquifer characteristics.

TABLE 2
GEOHYDROLOGIC DATA FOR SELECTED WELLS AND SPRINGS

Well or spring identification number	Altitude of LSD (feet)	Well depth (feet)	Altitude of bottom of well (feet)	Casing depth (feet)	Major aquifer	Minor aquifer	Altitude of top of sedimentary rocks of Idaho Group (feet)	Thickness of sedimentary rocks of Idaho Group (feet)	Altitude of top of Banbury Basalt (feet)	Thickness of Banbury Basalt (feet)	Altitude of top of Idavada Volcanics (feet)	Water temperature at surface (°C)	Remarks
3S-1E-35dac1	2,340	300	2,040	60	Sedimentary rocks of Idaho Group							20.0	
4S-1E-25ccd1	2,520				Sedimentary rocks of Idaho Group							30.0	Flows
26abc1	2,510	1,700	810		Sedimentary rocks of Idaho Group							27.0	Flows
29ccd1	2,685	3,040	−355	517; 1,440 - 3,040	Idavada Volcanics		2,664	2,196	468	701	−233	70.0	Log;Flows
30bdb1	2,765	350	2,415		Sedimentary rocks of Idaho Group							16.5	
34bad1	2,570	2,960	−390	2,190	Idavada Volcanics	Banbury Basalt (?)	2,570	2,120	450	780	−330	75.5	Log;Flows
4S-2E-29dbc1	2,440	1,000+			Sedimentary rocks of Idaho Group							28.0	Flows
32bcc1	2,475	2,704	−229	700	Sedimentary rocks of Idaho Group	Banbury Basalt (?) Idavada Volcanics (?)			1,633 (?)		194 (?)	43.0	Log;Flows
5S-1E- 3aab1	2,585	1,900	685	60	Sedimentary rocks of Idaho Group							32.0	Flows

TABLE 2. Geohydrologic data for selected wells and springs. (continued)

Well or spring identification number	Altitude of LSD (feet)	Well depth (feet)	Altitude of bottom of well (feet)	Casing depth (feet)	Major aquifer	Minor aquifer	Altitude of top of sedimentary rocks of Idaho Group (feet)	Thickness of sedimentary rocks of Idaho Group (feet)	Altitude of top of Banbury Basalt (feet)	Thickness of Banbury Basalt (feet)	Altitude of top of Idavada Volcanics (feet)	Water temperature at surface (°C)	Remarks
5S-1E-10bdd1	2,650	2,960	−310	2,120	Idavada Volcanics	Banbury Basalt	2,610	2,065	545	735	−190	64.0	Log;Flows
21cbc1	2,750	660	2,090	96	Banbury Basalt (?)		2,686	557	2,129			65.0	Log;Flows
24acd1 [1/]	2,775	3,120	−345	160 1,080 2,100	Idavada Volcanics	Banbury Basalt	2,735	2,040	695	860	−165	66.0	Log;Flows
5S-2E- 1bbc1	2,395	1,800	595		Banbury Basalt (?)							49.5	Flows
2cda1 [2/]	2,450	2,460	−10	160	Sedimentary rocks of Idaho Group	Banbury Basalt(?)	2,390	1,720	670	601	69	36.5	Log;Flows
5bcd1	2,530	2,009	521		Sedimentary rocks of Idaho Group	Banbury Basalt (?) Idavada Volcanics(?)			892		534	42.5	Log;Flows
13ada1	2,465	1,748	717	126	Sedimentary rocks of Idaho Group		2,405	1,680	725			23.0	Log;Flows
5S-3E-14cbb1	2,370	2,300	70		Idavada Volcanics (?)	Banbury Basalt (?)						58.5	Flows
15cba1	2,365	1,620	745	32	Sedimentary rocks of Idaho Group		2,333					15.0	Log;Flows

1/ Some water possibly from uncased sedimentary rock section.

2/ Well has probably caved.

20ada1	2,430	2,420	10	1,620	Idavada Volcanics	Banbury Basalt	2,398	1,413	985	604	381	60.0	Log;Flows
20bbb1	2,465				Sedimentary rocks of Idaho Group							27.0	Flows
22aad1	2,375	1,300	1,075	60	Sedimentary rocks of Idaho Group							25.0	Flows
25bbb1	2,400	1,320	1,080		Sedimentary rocks of Idaho Group							18.0	Flows
26bcb1	2,485	2,970	−485	1,970	Idavada Volcanics	Banbury Basalt	2,466	1,493	973	1,238	−265	83.0	Log;Flows
26bcb2	2,485	2,970	−485		Idavada Volcanics(?)	Banbury Basalt(?)						67.0	Flows
27bdd1	2,540	2,900	−360		Idavada Volcanics(?)	Banbury Basalt(?)						60.0	Flows
28bcc1	2,535	2,540	−5	1,860	Idavada Volcanics	Banbury Basalt	2,535	1,845	690	605	85	65.0	Log;Flows
35ccc1	2,500	2,570	−70		Idavada Volcanics(?)	Banbury Basalt(?)						71.5	Flows
5S-4E-34ccb1	2,455	356	2,099		Sedimentary rocks of Idaho Group							27.0	
5S-5E-33bbd1	2,675	250	2,425	10	Basalt & Sedimentary rocks of Idaho Group							22.0	Log
34ddd1	2,725	885	1,840	609	Sedimentary rocks of Idaho Group							25.0	Log
6S-2W-14cba1S	5,900				Alluvium near Idavada Volcanics							11.0	

TABLE 2. Geohydrologic data for selected wells and springs. (continued)

Well or spring identification number	Altitude of LSD (feet)	Well depth (feet)	Altitude of bottom of well (feet)	Casing depth (feet)	Major aquifer	Minor aquifer	Altitude of top of sedimentary rocks of Idaho Group (feet)	Thickness of sedimentary rocks of Idaho Group (feet)	Altitude of top of Banbury Basalt (feet)	Thickness of Banbury Basalt (feet)	Altitude of top of Idavada Volcanics (feet)	Water temperature at surface (^{o}C)	Remarks
6S-1E-32bba1S	4,150				Granitic rocks							25.0	
6S-3E- 2cbc1	2,550	3,050	−495	106	Banbury Basalt	Sedimentary rocks of Idaho Group	2,515	1,993	522	430	92	62.0	Log;Flows
2ccc1	2,570	1,940	630	160	Banbury Basalt	Sedimentary rocks of Idaho Group	2,509	1,852	657			53.0	Log;Flows
4bcc1	2,610	1,680	930		Banbury Basalt(?)	Sedimentary rocks of Idaho Group						48.0	Flows
5cac1	2,670	3,600	−930	1,120	Idavada Volcanics	Banbury Basalt	2,640	2,202	438	668	−230	61.0	Log;Flows
9acc1	2,635	1,425	1,210	103	Banbury Basalt	Sedimentary rocks of Idaho Group	2,608	1,260	1,348			39.0	Log
11dad1	2,580	1,400	1,180	300	Banbury Basalt (?)	Sedimentary rocks of Idaho Group						34.0	
6S-4E-14abc1	2,665	1,905	760	1,600	Idavada Volcanics	Banbury Basalt	2,580	1,656	924	89	835	54.0	Log
18bcc1	2,460	455	2,005		Sedimentary rocks of Idaho Group							18.0	

25bcc1[1]	2,635	1,750	885	290	Sedimentary rocks of Idaho Group		2,635					20.0	Log
35cda1	2,690	955	1,735	730	Sedimentary rocks of Idaho Group		2,633					32.5	Log
6S-5E-10ddd1	2,520	1,667	853	78	Banbury Basalt	Sedimentary rocks of Idaho Group	2,510	1,657	853			38.5	Log;Flows
18ccb1	2,650	2,960	−310	651	Banbury Basalt	Sedimentary rocks of Idaho Group	2,638	1,994	644	744	−130	27.0	Log
20aab1	2,510				Banbury Basalt (?)	Sedimentary rocks of Idaho Group(?)						43.5	Flows
24bca1	2,525	1,095	1,430	76	Banbury Basalt	Sedimentary rocks of Idaho Group	2,507	662	1,845			33.5	Log;Flows
24ddb1	2,575	1,938	637	1,400	Banbury Basalt		2,575	1,100	1,475	825	650	32.5	Log
29dcc1	2,545	1,560	985	20	Sedimentary rocks of Idaho Group(?)		2,531					32.5	Log;Flows
35cca1	2,620	460	2,160	352	Sedimentary rocks of Idaho Group							22.0	
6S-6E-12ccd1	2,510	990	1,520	915	Sedimentary rocks of Idaho Group		2,505					37.0	Log
19ccd1	2,575	913	1,662	277	Banbury Basalt	Sedimentary rocks of Idaho Group	2,554	807	1,747			38.0	Log;Flows

[1] Well has caved.

TABLE 2. Geohydrologic data for selected wells and springs. (continued)

Well or spring identification number	Altitude of LSD (feet)	Well depth (feet)	Altitude of bottom of well (feet)	Casing depth (feet)	Major aquifer	Minor aquifer	Altitude of top of sedimentary rocks of Idaho Group (feet)	Thickness of sedimentary rocks of Idaho Group (feet)	Altitude of top of Banbury Basalt (feet)	Thickness of Banbury Basalt (feet)	Altitude of top of Idavada Volcanics (feet)	Water temperature at surface (°C)	Remarks
6S-6E-19dbd1	2,710	1,347	1,363	229	Banbury Basalt	Sedimentary rocks of Idaho Group	2,636	907	1,729			42.0	Log
32bdd1	2,570	1,402	1,168	850	Banbury Basalt	Sedimentary rocks of Idaho Group	2,483	973	1,510			34.5	Log;Flows
6S-7E- 1acb1	2,480	1,000+			Sedimentary rocks of Idaho Group	Banbury Basalt(?)						41.5	Flows
1dbd1	2,485	1,050+			Sedimentary rocks of Idaho Group	Banbury Basalt(?)						33.0	Flows
2cdd1	2,485	1,350	1,135		Sedimentary rocks of Idaho Group	Banbury Basalt(?)						34.5	Flows
8bba1	2,765	365	2,400	339	Sedimentary rocks of Idaho Group		2,762					23.0	Log
7S-3E- 4acd1	2,935	804	2,131	300	Sedimentary rocks of Idaho Group	Banbury Basalt	2,910	635	2,275			34.0	Log
7S-4E- 1acc1	2,655	1,800(?)	855	1,800(?)	Idavada Volcanics(?)	Banbury Basalt(?)						40.0	Flows
3abd1	2,730	1,142	1,588	399	Banbury Basalt		2,697	852	1,845			42.0	Log

5cca1	2,865	1,040	1,825	292	Banbury Basalt	Sedimentary rocks of Idaho Group	2,864	861	2,003			30.0	Log
10bdb1	2,755	1,145	1,610	537	Banbury Basalt		2,753	717	2,036			37.5	Log
11cbc1	2,760	1,500	1,260	250	Idavada Volcanics	Banbury Basalt	2,753	696	2,057	362	1,695	36.0	Log
12bdd1	2,660	1,105	1,555	675	Idavada Volcanics	Banbury Basalt	2,630	639	1,991	319	1,672	43.0	Log;Flows
13bcc1	2,690	1,060+		192	Idavada Volcanics	Banbury Basalt	2,667	467	2,200	270	1,930	39.0	Log
13dcd1	2,665	1,000	1,665	194	Idavada Volcanics	Banbury Basalt	2,639	396	2,243	303	1,940	40.0	Log;Flows
14abc1	2,725	1,146	1,579	223	Idavada Volcanics	Banbury Basalt	2,710	560	2,150	220	1,930	39.0	Log
15acd1	2,790	1,065	1,725	246	Idavada Volcanics	Banbury Basalt	2,755	475	2,280	210	2,070	38.5	Log
23cbb1	2,760	810	1,950	326	Idavada Volcanics	Banbury Basalt	2,749	311	2,438	278	2,160	38.5	Log
25adc1	2,745	735	2,010	60	Idavada Volcanics	Banbury Basalt	2,730	195	2,535	325	2,210	36.5	Log
26bcb1	2,750	867	1,883	181	Idavada Volcanics	Banbury Basalt	2,738	193	2,545	301	2,244	31.0	Log
27bcc1	2,770	1,390	1,380	19	Idavada Volcanics						2,751	27.0	Log
7S-5E- 5dbc1	2,600	2,405	195	1,300	Banbury Basalt		2,600	1,289	1,311			32.0	Log;Flows
7abb1	2,605	1,625	980	633	Idavada Volcanics	Banbury Basalt	2,590	500	2,090	485	1,605	39.0	Log;Flows

TABLE 2. Geohydrologic data for selected wells and springs. (continued)

Well or spring identification number	Altitude of LSD (feet)	Well depth (feet)	Altitude of bottom of well (feet)	Casing depth (feet)	Major aquifer	Minor aquifer	Altitude of top of sedimentary rocks of Idaho Group (feet)	Thickness of sedimentary rocks of Idaho Group (feet)	Altitude of top of Banbury Basalt (feet)	Thickness of Banbury Basalt (feet)	Altitude of top of Idavada Volcanics (feet)	Water temperature at surface (°C)	Remarks
7S-5E- 8ccc1	2,640	1,500	1,140	200	Idavada Volcanics		2,640	690	1,950	445	1,505	40.0	Log;Flows
9ddd1	2,665	2,065	600	550	Idavada Volcanics		2,615	995	1,620	935	685	40.0	Log;Flows
13aac1	2,690	150	2,540		Sedimentary rocks of Idaho Group(?)							25.0	
13cbb1	2,771	1,954	817	180	Banbury Basalt	Sedimentary rocks of Idaho Group	2,767	883	1,884			36.0	Log
16acd1	2,700	1,515	1,185	520	Idavada Volcanics	Banbury Basalt	2,679	687	1,992	516	1,476	39.5	Log
19ccc1	2,720	760	1,960	309	Idavada Volcanics	Banbury Basalt	2,664	253	2,411	331	2,080	36.5	Log
28acd1	2,810	1,003	1,807	234	Idavada Volcanics	Banbury Basalt	2,810	477	2,333	329	2,004	34.0	Log
7S-6E- 7aac1	2,585	1,086	1,499		Sedimentary rocks of Idaho Group	Banbury Basalt(?)						25.0	Flows
9bad1	2,580	910	1,670		Banbury Basalt(?)							50.0	Flows

16cdc1	2,595	513	2,082	389	Banbury Basalt		2,568	377	2,191			42.5	Log;Flows
21dbc1	2,635	760	1,875	167	Banbury Basalt		2,609	140	2,469			43.0	Log;Flows
22aad1	2,640	1,410	1,230	397	Idavada Volcanics(?)	Banbury Basalt	2,579	333	2,246	946	1,300	45.0	Log;Flows
23cad1	2,675	1,300	1,375		Idavada Volcanics(?)	Banbury Basalt(?)						44.0	Flows
26ada1	2,695	1,000	1,695	171	Idavada Volcanics (?)	Banbury Basalt(?)						38.0	Flows
27adb1	2,225	400	1,825		Banbury Basalt(?)							43.0	Flows
34dcb1S	2,645				Banbury Basalt(?)							41.0	
35bbb1S	2,620				Banbury Basalt							40.0	
8S-1E-20cca1S	5,900				Idavada Volcanics							9.5	
8S-6E- 3bdd1S	2,700				Banbury Basalt - Tuff Idaho Group							39.0	
9S-2E-13cbc1S	5,000				Idavada Volcanics							11.0	

Rhyolitic Rocks

Rhyolitic rocks of Miocene(?) age are exposed in the southern part of the study area. The areal extent and thickness of this unit are not known; however, more than several thousand feet of the unit are exposed in the Owyhee uplift (Malde and Powers, 1962). It is possible that these rocks underlie the Idavada Volcanics throughout the Bruneau-Grand View area and that they could, therefore, constitute a reservoir for thermal water. However, no known wells have penetrated this unit in the study area, and for this reason, its potential as a source of thermal water is not known.

Granitic Rocks

Granitic rocks similar to those of the Idaho batholith are exposed in the Bruneau-Grand View area. These rocks probably form the basement complex throughout this area, and, because granites are generally considered to be dense and relatively impermeable, they may not contain significant quantities of thermal water. However, the similarity in water quality of the thermal water in the Bruneau-Grand View area with that in the Idaho batholith (see section on geochemical surveys) indicates that the water in the Bruneau-Grand View area was in contact with the granitic rocks exposed in the mountainous recharge area to the southwest and that it retained its acquired distinctive chemical quality as it moved into and through overlying rock units. However, it is also possible that the upper part of the granite is either deeply fractured or decomposed, thereby constituting a significant aquifer and reservoir capable of both transmitting water long distances and of storing large quantities of thermal water. At the present time, the absence of data descriptive of the granite underlying the Bruneau-Grand View area precludes assessment of its potential as a reservoir for geothermal water.

GEOPHYSICAL SURVEYS

Geophysical surveys, including gravity, aeromagnetic, audio-magnetotelluric, and electrical-resistivity surveys, were made in the Bruneau-Grand View area prior to and in the period 1973-74 by the U.S. Geological Survey. Results from these surveys are used to help interpret the geology of the area and to assess the extent and some of the characteristics of the thermal anomaly in the area.

Included in this report are (1) a gravity map compiled by D. L. Peterson and D. R. Mabey, (2) an aeromagnetic map compiled by the Geological Survey, and (3) the results and interpretation of a reconnaissance audio-magnetotelluric survey by D. B. Hoover and C.L.Tippens. A report updating and summarizing all geophysical studies made in the Bruneau-Grand View area, including the resistivity survey, is currently being prepared by the Geological Survey.

Gravity and Aeromagnetic Surveys

The results of a gravity survey (fig. 7a) by Hill (1963) indicates that there are three major gravity anomalies in the western Snake River Plain, each of which is elongated to the northwest. These anomalies are believed to be caused by deeply buried basalt flows or dikes.

The largest gravity high is located about 10 miles northeast of Grand View and is approximately 90 miles long and 25 miles wide (fig. 7a). The effect of this gravity feature on the local gravity relief in the Bruneau-Grand View area (fig. 7b) is significant in that the sharp decrease in gravity values to the southwest, which reflects the southwest flank of this gravity high, would serve to overshadow such local gravity anomalies as may be present. The only local gravity features recognizable on fig. 7b are a low east of Hot Spring near the head of Bruneau Valley, and a high that trends southeast from the head of Little Valley.

The lines of equal magnetic intensity (fig. 8) resulting from aeromagnetic surveys compiled by the Geological Survey were released to the open file in 1971. Although these data are considered preliminary and have not been edited for conformance to Survey standards, they show a magnetic high in the Bruneau-Grand View area that trends to the northwest.

The gravity and magnetic data are included in this report to lend further support to the existence of northwest-trending subsurface structures (faults) as suggested by figure 6, particularly along the south side of the Snake River in the Bruneau-Grand View area.

Further interpretation of all gravity and magnetic data for the Bruneau-Grand View area will be made in the aforementioned forthcoming geophysical report.

Reconnaissance Audio-Magnetotelluric Survey

An AMT (audio-magnetotelluric) survey by D. B. Hoover and C. L. Tippens (app. A) has revealed a major northwest-trending conductive anomaly in the Bruneau-Grand View area. The center of this anomaly appears to be situated between Oreana and Grand View. The low resistivities (22 ohm-metres or less) are associated with the highest temperature ground waters (60 to 83°C) measured in the area (fig. 10). Within the conductive zone, apparent resistivities approaching 2 ohm-metres are indicated at depth. Resistivities in this range suggest a hot-water reservoir with some alteration of the reservoir rock by the hot water (app. A).

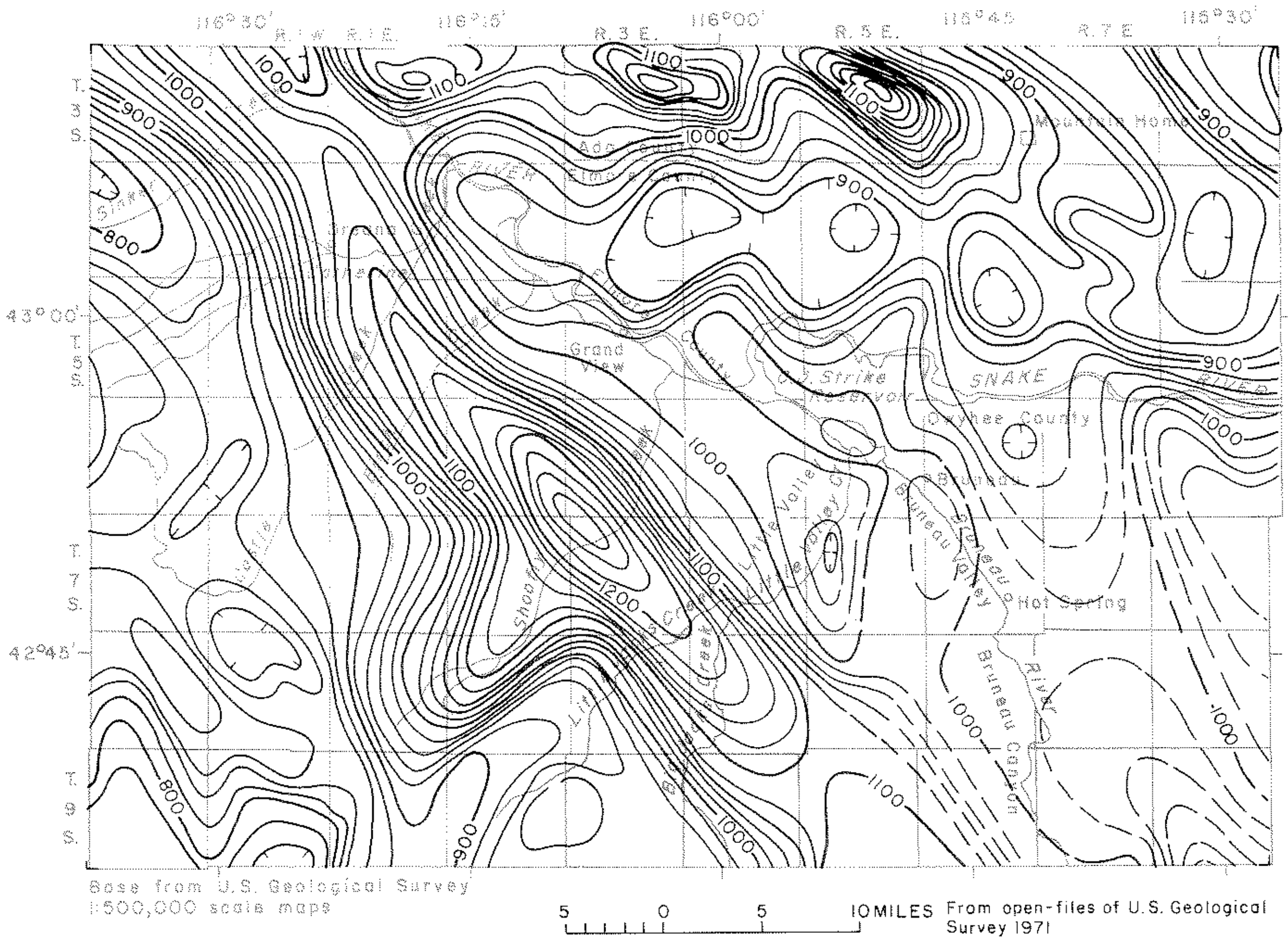
The conductive anomaly has distinct boundaries on the west and south, but those on the north and east are not well defined. The data indicate that the low-resistivity zone dips downward to the east and may extend eastward at a depth below the range of the current AMT survey.

The large area extent of the conductive anomaly in the Bruneau-Grand View area suggests a broad heat source for the thermal water.

GEOCHEMICAL SURVEYS

Eighty-seven wells and seven springs in the Bruneau-Grand View area were selected for water-quality sampling. The sites (fig. 4) selected provide for areal representation of the quality of the water in the aquifers supplying water to wells or springs, of measured ground-water temperatures, and of estimated temperatures at depth. Results of standard chemical analyses, plus boron, lithium, mercury, and arsenic, for the samples collected are given in table 3. Geohydrologic data for these wells, including altitudes, well depths, and aquifer units, are given in table 2.

FIGURE 8. Aeromagnetic map.



EXPLANATION

LINE OF EQUAL MAGNETIC INTENSITY —— 900 — —

Dashed where data are incomplete. Hachured to indicate closed area of lower magnetic intensity. Interval 20 gammas relative to arbitrary datum.

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: as $CaCO_3$	Hardness: Noncarbonate	Percent sodium	Sodium-absorption ratio	Specific conductance (field)	pH (field)	Water temperature (°C)	Chemical constituents in micrograms per litre: 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 as $CaCO_3$	Hardness Noncarbonate	Percent sodium	Sodium-absorption ratio	Specific conductance (field)	pH (field)	Water temperature (°C)	Chemical constituents in micrograms per litre: 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	46.0	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

Chemistry of Thermal Waters

The chemical composition of the sampled thermal waters in the Bruneau-Grand View area shows that they are generally of a sodium bicarbonate type and are characterized by low chloride and high bicarbonate concentrations and a nearly neutral pH (White, 1957, p. 1649). Although most of the thermal waters in the area are classified as a sodium bicarbonate type, certain marked differences in their chemical constituents serve to distinguish water in the sedimentary-rock aquifers of the Idaho Group (the Bruneau, Glenns Ferry, and Chalk Hills Formations) from water in the volcanic-rock aquifers (the Banbury Basalt of the Idaho Group and the Idavada Volcanics).

Thermal water from wells penetrating only the sedimentary-rock aquifers is high in dissolved-solids concentration (greater than 600 mg/1), is nearly neutral in pH, and usually contains fluoride concentrations of less than 2 mg/1. In striking contrast, water from wells penetrating the volcanic-rock aquifers is low in dissolved-solids concentration (less than 500 mg/1), high in fluoride concentration (usually greater than 8 mg/1), and is alkaline (pH greater than 8.5).

Chloride concentrations range from 2.7 to 79 mg/1 in the thermal waters sampled. Chloride concentrations for water from the volcanic-rock aquifers were less than 20 mg/1 and only slightly higher for most water issuing from the sedimentary-rock aquifers. Generally, sulfate concentrations were much higher in water from the volcanic-rock aquifers than in water from the sedimentary-rock aquifers. However, marked exceptions to this were noted in a few samples from shallow wells that were near the Snake River.

The reason for the low chloride, high fluoride, and high sulfate concentrations in the thermal water from the volcanic-rock aquifers is not understood. However, even though this water has distinct characteristics, it is not unlike other thermal water found in Idaho. As shown below, the chemical similarities of water from the volcanic-rock aquifers and thermal water from the Idaho batholith (which also contains low chloride and high fluoride and sulfate concentrations) is noteworthy (Young and Mitchell, 1973). This similarity indicates that rocks similar in mineralogy to the granite of the Idaho batholith may lie at depth below the Bruneau-Grand View area as proposed by Schoen (1972).

	Volcanic-rock aquifers		Idaho batholith	
	well 4S-1E-34bad1	well 5S-3E-26bcb1	Sunbeam Hot Springs 11N-15E-19c1S	Vulcan Hot Springs 14N-6E-11bda1S
Temperature (°C)	75.5	83.0	76.0	87.0
Silica (mg/1)	91	110	91	120
Calcium (mg/1)	1.0	2.1	1.5	1.8
Magnesium (mg/1)	0	0	0	.1
Sodium (mg/1)	99	110	85	94
Potassium (mg/1)	.8	1.7	2.4	3
Sulfate (mg/1)	40	62	54	43
Chloride (mg/1)	13	15	12	17
Fluoride (mg/1)	13	15	15	24

Chemical Ratios

The ratios of certain chemical constituents can be useful in describing and evaluating geothermal areas (White, 1970). One use of these ratios is to identify similar waters within a geothermal area. The $Cl/(HCO_3 + CO_3)$ (chloride/bicarbonate plus carbonate) ratio (Fournier and Truesdell, 1970), the Cl/B (chloride/boron) ratio (Ellis, 1970) and the Cl/F (chloride/fluoride) ratio (Mahon, 1970) have been used successfully to distinguish water discharging from different aquifers. The atomic and molar ratios of selected chemical constituents from sampled wells and springs in the Bruneau-Grand View area are given in table 4. The $Cl/(HCO_3 + CO_3)$, Cl/B, and Cl/F ratios are shown on figure 9.

Typically, the $Cl/(HCO_3 + CO_3)$ ratio is less than 0.1 for water from the sedimentary-rock aquifers and greater than 0.1 for water from the volcanic-rock aquifers in the Bruneau-Grand View area. Slight variations from these ratios are probably the result of mixing of water from the two aquifers.

The Cl/B ratios established for water from the sedimentary-rock and the volcanic-rock aquifers are not as indicative of water from the respective aquifers as are the $Cl/(HCO_3 + CO_3)$ ratios. The Cl/B ratio is generally less than 12 for water from the sedimentary-rock aquifers, whereas it ranges from less than 5 to greater than 20 for water from the volcanic-rock aquifers. The lower values for water from the sedimentary-rock aquifers are due to the higher boron concentrations generally found in this water. The Cl/B ratio for water from the volcanic-rock aquifers shows a marked decrease in value near the towns of Bruneau and Grand View due to an increase in boron concentrations.

The Cl/F ratios provide the most reliable chemical means of distinguishing between water from the volcanic-rock and water from the sedimentary-rock aquifers. The Cl/F ratio for water from the volcanic-rock aquifers is generally less than 0.6, owing to the high fluoride concentration of the water, whereas the ratio for water from the sedimentary-rock aquifers usually exceeds 1. The highest concentration of fluoride (29 mg/1) was found in water from a well, near the town of Bruneau, which is open to the volcanic-rock aquifer.

Ground-Water Temperatures

Owing to the natural increase of temperature downward in the earth's crust, water in deeper aquifers generally tends to be warmer than that from shallower aquifers. As would be expected, therefore, ground-water temperatures in the Bruneau-Grand View area increase as wells penetrate deeper aquifers. Temperatures of water discharged from wells and springs in the area ranged from 9.5° to 83.0°C (table 3 and fig. 10). Generally, the temperature of the water obtained from the sedimentary-rock aquifers seldom, with a few exceptions, exceeds 35°C, whereas temperatures of water from the volcanic-rock aquifers ranged from 40.0° to 83.0°C.

Because most wells in the area are not cased through much of their depth, it is difficult to calculate a thermal gradient for the area using existing wells. This is because the temperature of water entering an open well bore at some selected intermediate depth will differ significantly from the temperature of the water entering at or near the bottom of the well. For this reason, the temperature of the water discharged from the well may not be

TABLE 4

ESTIMATED AQUIFER TEMPERATURES AND CHEMICAL RATIOS FOR SELECTED SAMPLED WATERS

Well or spring identification number	Discharge (cubic feet per second)	Water temperature at surface (°C)	Aquifer temperature from geochemical thermometers (°C): a) Silica	b) Mixed water method: Temp. hot water	b) Mixed water method: Percent cold water	c) Sodium-potassium-calcium	Atomic Ratios: Sodium / Potassium Na/K	Magnesium / Calcium Mg/Ca	Sodium / Calcium Na/Ca	Chloride / Fluoride Cl/F	Chloride / Boron Cl/B	Chloride / Lithium Cl/Li	Sodium / Lithium Na/Li	Sodium / Boron Na/B	$\sqrt{\text{Calcium}}$ / Sodium $\sqrt{Ca}/Na$	Molar Ratios: Calcium / Bicarbonate Ca/HCO_3	Chloride / Bicarbonate plus carbonate $Cl/(HCO_3 + CO_3)$	Chloride / Bicarbonate Cl/HCO_3	Chloride / Sulfate Cl/SO_4
3S-1E-35dac1	–	20.0	106	–	–	56	9.92	0.379	1.74	1.96	39.2	50.2	352	275	0.680	0.266	.054	0.054	0.695
4S-1E-25ccd1	0.01	30.0	148	–	–	186	18.2	.191	21.6	22.3	7.63	6.04	116	146	.059	.040	.045	.045	10.3
26abc1	.01	27.0	135	–	–	200	14.7	.355	33.5	11.6	5.09	3.44	102	151	.052	.026	.029	.029	8.15
29ccd1	3.3	70.0	127	173	64	78	213	–	145	.536	24.4	235	3,020	314	.040	.026	.171	.299	.695
30bdb1	–	16.5	108	–	–	30	4.33	.160	.417	4.82	41.2	52.8	238	186	2.64	.389	.036	.036	.610
34bad1	–	75.5	132	176	61	81	210	–	173	.536	26.4	254	2,990	311	.037	.021	.188	.311	.734
4S-2E-29dbc1	.02	28.0	137	–	–	175	23.4	.541	27.4	55.4	15.3	9.63	158	250	.050	.032	.053	.053	1.56
32bcc1	.05	43.0	143	–	–	160	30.0	.199	45.1	1.05	5.19	12.8	174	70.6	.058	.023	.076	.076	7.38
5S-1E- 3aab1	–	32.0	148	–	–	192	15.2	.079	16.8	19.3	6.87	5.03	112	153	.073	.052	.039	.039	5.65
10bdd1	2.7	64.0	127	182	69	61	243	–	79.2	.464	24.8	254	3,020	294	.054	.053	.198	.355	.699
21cbc1	.81	65.0	123	169	66	72	243	–	134	.464	23.3	254	3,020	277	.041	.035	.207	.392	.699
24acd1	4.5	64.5	131	189	70	96	131	–	158	.500	28.5	137	1,510	314	.038	.020	.198	.294	.771
5S-2E- 1bbc1	.06	49.5	123	213	82	60	244	–	88.2	.572	4.44	313	2,600	36.8	.055	.056	.260	.599	5.09
2cda1	.02	36.5	131	–	–	187	19.3	.332	44.0	2.09	6.36	6.60	102	98.0	.046	.022	.064	.064	16.6
5bcd1	.17	42.5	143	–	–	149	38.1	.349	50.3	1.25	6.16	15.7	181	71.3	.055	.036	.115	.154	5.58
13ada1	.01	23.0	143	–	–	197	15.8	.330	34.9	10.7	7.63	7.07	94.6	102	.050	.026	.067	.067	21.2
5S-3E-14cbb1	.14	58.5	126	196	74	62	193	–	66.1	.419	4.99	352	2,750	38.9	.062	.055	.285	.469	4.06
15cba1	.01	15.0	153	–	–	171	23.8	.427	22.2	14.8	9.99	6.41	76.8	120	.061	.038	.070	.070	15.1
20ada1	–	60.0	143	242	79	73	206	.150	135	.423	5.87	–	–	51.3	.045	.062	.290	.956	5.29
20bbb1	.01	27.0	143	–	–	169	20.6	.153	9.55	32.3	11.6	8.04	95.1	137	.102	.091	.073	.073	10.1
22aad1	.01	25.0	157	–	–	170	23.6	.295	22.9	29.1	2.28	7.83	79.4	98.0	.063	.042	.096	.096	21.5
25bbb1	.01	18.0	122	–	–	168	21.3	.478	11.6	75.0	10.7	5.83	64.2	118	.099	.087	.091	.091	11.5
26bcb1	–	83.0	143	196	61	91	110	–	91.3	.536	8.03	73.4	830	90.8	.048	.145	.296	1.17	.546
26bcb2	–	67.0	137	208	72	95	125	.110	128	.536	8.32	97.9	1,110	94.1	.040	.065	.284	.738	.529
27bdd1	–	60.0	118	170	69	76	157	.110	96.5	.429	6.25	–	–	47.1	.054	.059	.285	.464	3.20
28bcc1	–	65.0	136	208	73	106	127	–	211	.383	7.38	147	1,460	73.6	.033	.045	.271	.956	3.46
35ccc1	–	71.5	137	202	68	75	170	–	79.2	.572	8.72	78.3	830	92.4	.033	.028	.265	.510	.502

5S-4E-34ccb1	–	27.0	134	–	–	71	11.8	.151	1.70	5.67	42.3	25.2	179	300	.403	.570	.136	.136	.169
5S-5E-33bbd1	–	22.0	92	–	–	62	41.9	1.26	3.45	44.7	50.9	42.6	223	267	.198	.308	.202	.202	.251
34ddd1	–	25.0	130	–	–	197	12.4	.682	11.4	21.4	10.5	10.7	130	128	.103	.071	.066	.066	4.52
6S-2W-14cba1S	.06	11.0	–	–	–	–	6.97	.412	2.55	33.6	64.1	–	–	129	1.05	.304	.387	.387	1.67
6S-1E-32bba1S	–	25.0	97	–	–	21	23.4	.379	1.04	22.5	214	–	–	345	1.00	.447	.287	.287	1.35
6S-3E- 2cbc1	–	62.0	137	217	75	128	72.9	–	174	.599	6.82	93.0	906	66.4	.033	.021	.235	.380	.953
2ccc1	1.6	53.0	137	244	82	146	46.8	.137	160	.567	7.23	88.1	830	68.1	.036	.015	.197	.258	1.51
4bcc1	–	48.0	143	–	–	167	29.2	–	120	.491	7.63	108	1,660	118	.042	.042	.142	.326	.591
5cac1	–	61.0	134	212	75	90	29.5	–	22.4	.473	19.7	190	1,780	185	.132	.090	.185	.214	1.10
9acc1	3.7	39.0	153	–	–	176	20.4	.046	47.0	.648	7.99	26.9	366	109	.071	.035	.104	.121	.591
11dad1	–	34.0	148	–	–	162	24.0	.088	26.8	.536	8.39	43.1	519	101	.100	.055	.122	.122	.753
6S-4E-14abc1	3.3	54.0	157	–	–	143	39.8	.033	38.4	.424	10.7	–	–	95.9	.074	.381	.343	1.63	.660
18bcc1	2.3	18.0	96	–	–	44	13.8	.131	1.14	7.04	35.1	60.0	382	224	.728	.401	.072	.072	.358
25bcc1	.20	20.0	120	–	–	92	12.4	.092	4.04	1.92	32.9	30.4	319	344	.245	.484	.187	.187	.166
35cda1	–	32.5	135	–	–	206	8.98	.036	17.8	.603	27.5	88.1	709	221	.166	.073	.161	.161	.847
6S-5E-10ddd1	.01	39.0	124	220	87	141	47.5	.190	80.5	.277	6.63	294	3,620	81.8	.049	.025	.145	.162	1.41
18ccb1	–	27.0	148	–	–	169	23.3	.042	44.7	.824	11.3	97.9	755	87.2	.072	.064	.291	.370	.869
20aab1	.01	43.5	110	150	76	151	33.4	.035	40.8	.380	5.46	66.5	664	54.5	.072	.036	.135	.148	10.4
24bca1	.01	33.5	131	–	–	141	44.4	–	58.1	.258	6.96	254	3,620	99.1	.057	.037	.131	.150	1.05
24ddb1	–	32.5	125	254	92	94	73.2	–	61.6	.236	8.83	215	2,990	123	.061	.034	.138	.149	.710
29dcc1	.01	32.5	148	–	–	161	23.5	.070	21.4	.423	11.4	41.9	375	102	.111	.092	.213	.221	.806
35cca1	–	22.0	120	–	–	73	10.7	.143	2.48	1.05	33.6	53.8	408	254	.415	.349	.114	.114	.376
6S-6E-12ccd1	–	37.0	148	–	–	178	20.4	.099	31.4	1.73	5.27	16.9	247	77.0	.064	.031	.066	.066	11.9
19ccd1	.01	38.0	130	253	90	133	51.0	–	54.0	.206	8.98	–	–	129	.068	.049	.152	.183	.594
19dbd1	–	42.0	128	223	86	91	84.1	–	71.2	.206	8.98	196	2,840	130	.059	.040	.154	.198	.806
32bdd1	.06	34.5	130	275	92	132	51.6	.053	52.9	.218	9.59	215	2,840	126	.068	.036	.135	.143	.887
6S-7E- 1acb1	.01	41.0	120	196	84	138	55.3	.141	64.8	7.55	12.6	52.8	341	81.6	.037	.017	.174	.174	41.2
1dbd1	.02	33.0	120	225	90	139	51.8	.244	53.8	13.2	12.7	70.3	343	61.9	.041	.021	.232	.232	49.6
2cdd1	.01	34.5	122	228	90	144	47.0	.142	63.1	3.95	10.1	548	3,170	58.1	.042	.017	.184	.184	45.2
8bba1	–	23.0	130	–	–	199	13.2	1.08	16.1	13.0	18.5	13.9	302	403	.077	.075	.055	.055	.154

a) Using curve A (equilibrium with quartz) Fournier and Truesdell, 1970
b) Model 1, Fournier and Truesdell, 1974
c) Fournier and Truesdell, 1973

TABLE 4. Estimated aquifer temperatures and chemical ratios for selected sampled waters. (continued)

Well or spring identification number	Discharge (cubic feet per second)	Water temperature at surface (°C)	Aquifer temperature from geochemical thermometers (°C): a) Silica	b) Mixed water method: Temp. hot water	b) Mixed water method: Percent cold water	c) Sodium-potassium-calcium	Atomic Ratios: Sodium/Potassium Na/K	Magnesium/Calcium Mg/Ca	Sodium/Calcium Na/Ca	Chloride/Fluoride Cl/F	Chloride/Boron Cl/B	Chloride/Lithium Cl/Li	Chloride/Lithium Na/Li	Sodium/Boron Na/B	$\sqrt{Calcium}$/Sodium $\sqrt{Ca}/Na$	Molar Ratios: Calcium/Bicarbonate Ca/HCO_3	Chloride/Bicarbonate plus carbonate $Cl/(HCO_3 + CO_3)$	Chloride/Bicarbonate Cl/HCO_3	Chloride/Sulfate Cl/SO_4
7S-3E- 4acd1	1.6	34.0	134	–	–	78	3.51	0.090	1.06	2.27	27.5	28.2	187	182	0.837	0.363	0.058	0.058	0.452
7S-4E- 1acc1	1.7	40.0	127	226	87	182	13.5	.048	13.4	.475	26.2	–	–	249	.180	.133	.166	.187	1.14
3abd1	3.7	42.0	134	250	88	194	10.6	.028	13.8	.524	22.1	170	1,390	180	.190	.100	.161	.170	.982
5cca1	4.1	30.0	135	–	–	85	6.12	.046	1.88	2.33	22.1	28.4	272	212	.476	.494	.097	.097	.151
10bdb1	1.1	37.5	137	–	–	198	9.63	.023	11.4	.490	23.9	168	1,420	201	.207	.106	.140	.140	.809
11cbc1	4.4	36.0	137	–	–	92	8.50	.031	4.90	.608	28.4	91.0	679	212	.323	.216	.142	.142	.700
12bdd1	–	43.0	135	250	87	185	12.4	.023	12.7	.517	25.6	–	–	240	.188	.110	.149	.149	1.12
13bcc1	3.3	39.0	134	267	90	193	10.7	.045	11.7	.476	24.4	157	1,480	231	.200	.125	.145	.155	.903
13dcd1	2.8	40.0	136	270	90	186	12.0	.019	10.6	.438	30.5	176	1,600	277	.202	.166	.170	.194	1.07
7S-4E-14abc1	3.7	39.0	135	275	90	196	9.81	.023	10.9	.723	22.5	159	1,360	193	.217	.105	.134	.134	1.02
15acd1	5.9	33.0	137	–	–	88	8.25	.057	3.64	.379	27.5	64.6	483	205	.363	.272	.139	.139	.414
23cbb1	7.3	38.5	135	275	90	188	11.3	.027	8.43	.589					.217	.169	.166	.175	.690
25adc1	6.1	36.5	137	–	–	93	6.64	.024	6.41	.393	28.0	215	755	98.0	.379	.101	.175	.175	.857
26bcb1	2.9	31.0	132	–	–	94	9.22	.051	6.03	.784	33.3	235	1,360	193	.291	.192	.200	.200	1.23
27bcc1	3.1	27.0	123	–	–	87	10.2	.134	5.01	1.14	38.8	274	1,390	197	.316	.223	.221	.221	1.13
7S-5E- 5dbc1	.05	32.0	122	248	92	175	17.6	.037	25.0	.621	17.1	186	1,900	174	.121	.077	.180	.188	.447
7abb1	7.8	39.0	132	256	89	187	11.7	.039	10.5	.541	33.2	192	1,540	267	.208	.135	.176	.176	1.30
8ccc1	1.8	40.0	132	244	88	183	13.6	.028	16.3	.453	25.8	–	–	235	.160	.111	.174	.198	1.11
9ddd1	2.0	40.0	131	246	88	90	12.5	.069	7.26	.438	45.8	176	1,510	392	.252	.215	.165	.182	1.13
13aac1	.78	25.0	133	–	–	91	9.43	.211	4.94	.536	25.4	97.9	770	200	.302	.274	.172	.172	.452
13cbb1	–	36.0	127	247	90	187	12.0	–	13.0	.438	21.1	176	1,510	181	.188	.119	.170	.180	1.07
16acd1	–	39.5	132	250	89	180	14.7	.025	13.8	.328	33.2	192	1,600	293	.177	.124	.179	.179	1.11
19ccc1	2.6	36.5	134	–	–	186	12.3	.021	12.5	.491	30.5	215	1,660	235	.183	.114	.184	.184	1.03
28acd1	2.5	34.0	134	–	–	199	9.61	.060	10.9	.463	26.4	–	–	222	.201	.130	.169	.169	.894

7S-6E- 7aac1	–	25.0	137	–	–	186	15.3	.059	38.0	.536	21.8	196	1,840	205	.100	.053	.179	.215	.982
9bad1	–	50.5	137	228	82	131	60.7	.309	109	.223	14.5	196	3,020	224	.046	.041	.168	.292	.836
16cdc1	–	42.5	126	213	85	91	16.3	.089	11.5	.542	45.8	176	1,480	384	.202	.114	.152	.156	1.13
21dbc1	–	43.0	127	213	85	94	20.0	.084	16.0	.402	39.2	–	–	363	.163	.099	.158	.170	1.13
22aad1	5.5	45.0	129	216	84	79	10.8	.196	4.36	1.22	28.5	82.2	604	209	.363	.196	.117	.117	1.26
23cad1	–	44.0	137	253	87	93	12.5	.151	7.70	.569	22.1	85.1	800	208	.237	.145	.119	.119	1.16
26ada1	2.3	38.0	127	232	88	80	8.87	.288	3.92	1.43	26.2	84.2	543	169	.404	.182	.110	.110	1.29
7S-6E-27adb1	1.2	43.0	128	219	85	86	13.2	.151	6.97	.853	32.8	168	1,450	282	.262	.142	.115	.115	1.14
34dcb1S	1.0	41.0	127	223	86	99	17.0	.080	15.5	.555	269	–	–	2,590	.164	.092	.139	.147	1.10
35bbb1S	–	40.0	131	245	88	86	11.0	.228	5.77	1.05	24.4	172	1,300	184	.305	.157	.120	.120	1.32
8S-1E-20cca1S	.01	9.5	–	–	–	–	14.6	.419	.951	5.36	30.5	–	–	141	2.01	.270	.056	.056	1.41
8S-6E- 3bdd1S	1.0	39.0	130	243	89	182	13.5	.152	14.2	.813	34.7	178	1,600	312	.175	.088	.133	.139	1.37
9S-2E-13cbc1S	.01	11.0	–	–	–	–	8.91	.341	1.37	11.3	48.1	–	–	129	1.24	.300	.153	.153	1.50

representative of temperature at the bottom of the well. However, if data are used for wells that are cased from land surface to a depth of at least 60 percent of the well's total depth, a plot of well depth versus the temperature of the water produced from the well can be used to calculate a thermal gradient of about 2°C per 100 feet of depth (fig. 11). This gradient is somewhat lower than has been measured elsewhere in Idaho [3.3°C per 100 feet in Camas Prairie (Walton, 1962, p. 90); 2.7°C per 100 feet in sedimentary rocks in Boise Valley (Nace and others, 1957, p. 72)]. In considering this gradient, it should also be realized that a higher temperature gradient may occur at wells intersecting faults that act as conduits for a rapid upward movement of hot water from depth, thereby effectively bypassing less warm water at intermediate depths. Well 7S-6E-16cdc1, figure 11, may be an illustration of this in that a thermal gradient calculated using this well is 6.3°C per 100 feet.

The depth to which a well must penetrate to yield water of a desired temperature can be approximated using the thermal gradient for an area as follows:

Desired water temperature = ... 150°C
Thermal gradient = ... 2° C per 100 feet
Average annual air temperature (which approximates the temperature
at a depth of 100 feet) = ... 10° C
Depth required = ... $100 \frac{(150° - 10°)}{2°} + 100 = 7{,}100$ feet

The calculated depth of 7,100 feet to obtain water of 150°C is based on the assumption that water occurs at this depth in the quantities desired. At the present time, information on the occurrence of water at depths of 7,000 feet or greater in the Bruneau-Grand View area is not available.

Ground-water temperatures at some unknown depth can be calculated using geochemical thermometers. In the Bruneau-Grand View area, ground-water temperatures at depth were estimated using the silica (Fournier and Truesdell, 1970), and the sodium-potassium-calcium geochemical thermometers (Fournier and Truesdell, 1973), and a new technique (Fournier and Truesdell, 1974) - to be described in following pages - which enables utilization of water samples containing a mixture of deep thermal water and shallow cold water to calculate the temperature of the hot-water component and the percentage of the cold water in the mixture.

The Silica Geochemical Thermometer

Estimated aquifer temperatures calculated using the silica thermometer for all sampled thermal water in the Bruneau-Grand View area ranged from 92° to 157°C (table 4 and fig. 10). The temperatures given are based on the assumption that: (1) all the silica in the sampled water was in equilibrium with quartz (rather than amorphous or other silica species) in the thermal aquifer, (2) no dilution or enrichment takes place as the water ascends to the surface, and (3) the water is cooled only by conduction as it moves to the land surface (curve A, Fournier and Truesdell, 1970). However, because of the high silica concentrations noted in the warm water issuing from the sedimentary-rock aquifers, the

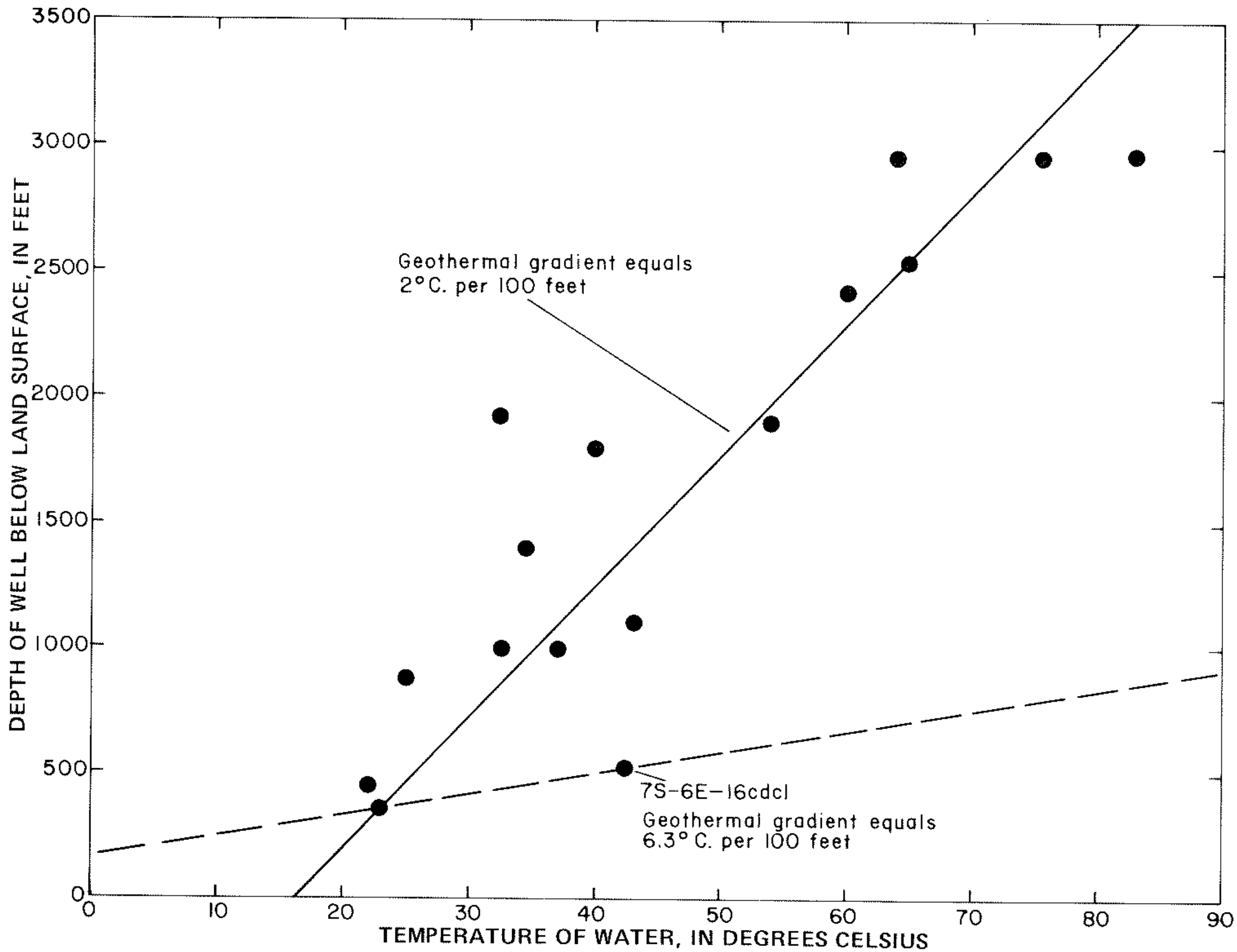


FIGURE 11. Ground-water temperatures with relation to depth in wells having at least 60 percent of the upper part of the well cased.

assumption of the silica content in the water being in equilibrium with quartz in the sedimentary-rock aquifers may be erroneous.

The sedimentary rocks were derived mainly from silica-rich volcanic rocks and, therefore, probably have an abundance of silicate minerals. Although the warm water moving through the sedimentary rocks is nearly neutral in pH (as measured at the surface), the possibility of its having dissolved silicate minerals and thereby containing amorphous silica was considered. To test this possibility, several water samples containing high silica concentrations at relatively low temperatures were examined to see if the high silica content was indeed in equilibrium with amorphous SiO_2. Water from well 4S-1E-25ccd1 has a silica concentration of 120 mg/1 and a temperature at the surface of 30.0°C. The solubility of amorphous SiO_2 at 30.0°C is 128 mg/1, which is very close to the 120 mg/1 silica found in the sample. Water from well 5S-3E-25bbb1 has a silica concentration of 98 mg/1 and a temperature at the surface of 18.0°C. The solubility of amorphous SiO_2 at 18.0°C is 102 mg/1. The difference between these two values is within the range of analytical error. Several other samples from wells completed in the sedimentary-rock aquifers were tested with ambiguous results. In several samples, the low-temperature water contained silica concentrations that were greater than what would be suspected under the assumption of equilibrium with amorphous SiO_2. However, the close agreement in most cases between the measured silica concentrations and the calculated silica concentrations, assuming equilibrium with amorphous SiO_2, indicate that silica concentrations in the water from the sedimentary-rock aquifers are not in equilibrium with quartz. Therefore, the assumption of the silica concentrations being in equilibrium with quartz is invalid, and the silica geochemical thermometer should not be used to estimate aquifer temperature at depth for water ascending through the sedimentary-rock aquifers.

Several samples of high-temperature water from the volcanic-rock aquifers were tested to see if their silica concentrations, at surface temperatures, were in equilibrium with amorphous SiO_2. In all cases, the silica concentrations in the samples were well below the solubility of amorphous SiO_2, indicating that the silica in this water probably is in equilibrium with quartz. However, it should be recognized that some of this silica in these alkaline waters may also have been derived from amorphous silica.

From the above discussion, it can be concluded that the temperatures estimated using the silica geochemical thermometer may well be in error and should be considered as tentative values only.

The Sodium-Potassium-Calcium Geochemical Thermometer

The molar concentrations of Na, K, and Ca are used in the Na-K-Ca (sodium-potassium-calcium) geochemical thermometer to calculate aquifer temperatures. Estimated aquifer temperatures for all sampled thermal waters in the Bruneau-Grand View area using this method ranged from 21° to 206°C (table 4 and fig. 10). This method assumes that these constituents are in chemical equilibrium in the thermal aquifer and that no dilution or enrichment takes place as the water ascends to the surface.

The higher values for dissolved solids in the thermal water from the sedimentary-rock aquifers compared to the lower values for dissolved solids in the thermal water of the volcanic-rock aquifers suggest that the water from the sedimentary-rock aquifers is enriched by aquifer materials. These sedimentary rocks contain appreciable amounts of volcanic ash and bentonitic clay (Littleton and Crosthwaite, 1957) that could provide large amounts of sodium and potassium minerals and much smaller amounts of calcium and magnesium minerals. The chemical quality of the warm water derived from the sedimentary-rock aquifers suggests enrichment of sodium and potassium with a smaller enrichment of calcium. This effectively reduces the sodium-to-potassium ratio and tends to increase estimated aquifer temperatures. Similar interbedded sedimentary rocks in the volcanic-rock aquifers could conceivably have the same effect on the composition of the thermal water.

The Mixed-Water Geochemical Thermometer

Many of the thermal waters appearing at or near land surface are the result of mixing of hot water from depth with cold water from upper zones. The original temperature of the hot water and the percentage of cold water in the mixture can be estimated (Fournier and Truesdell, 1974) from the temperature measured at the surface and the silica concentrations of the mixture and the upper nonthermal waters. Fournier and Truesdell (1974) suggest a simple test to determine if the thermal water sampled at the surface is of mixed origin. According to them, temperatures estimated by the Na-K-Ca geochemical thermometer that are within $\pm$ 25.0°C of the water temperature measured at the surface usually indicates chemical equilibrium and, thereby, that the sample represents an unmixed water. However, estimated temperature differences of more than $\pm$ 25.0°C indicate nonequilibrium conditions exist and, therefore, the sample represents a mixed water.

The mixed-water method was used in the Bruneau-Grand View area not only for estimating probable maximum temperatures of the hot-water component, but also as an aid in evaluating, as discussed below, the silica concentration in the waters sampled. Therefore, mixing models were constructed or attempted for all sampled thermal waters regardless of the relation of estimated Na-K-Ca temperatures to the water temperatures measured at the surface. The computed temperatures and percentage of cold water are given in table 4, and these temperatures are plotted in figure 9. The computations made were based on the following assumptions (model 1, Fournier and Truesdell, 1974): (1) water and newly formed steam rise together; (2) silica concentrations are in equilibrium with quartz; and (3) the temperature and silica concentrations of water from the sampled nonthermal springs (table 3) are representative of the nonthermal water in their respective areas.

Estimates of the temperature of the hot-water component and percentage of cold water were obtained for 48 of the 91 sampled thermal wells and springs. Estimated maximum temperatures of the hot-water components ranged from 150° to 275°C, and the percentage of cold water ranged from 61 to 92 percent. However, it is believed that estimated temperatures of above 220°C probably indicate that the water has been enriched by amorphous SiO_2, and that, therefore, some of the silica in the sampled water is not in equilibrium with quartz. No temperature estimates could be obtained for samples from wells penetrating the sedimentary-rock aquifers where it is believed the high silica content is due to amorphous SiO_2. The results for the higher temperature water flowing from the volcanic-rock aquifers are probably more sound, as the silica content of this water is probably in equilibrium with quartz.

Credibility of Estimated Temperatures

The silica geochemical thermometer is probably the best indicator of temperature at depth for selected water in the Bruneau-Grand View area. The silica concentrations observed in samples from the shallow sedimentary-rock aquifers generally do not seem to be in equilibrium with quartz; therefore, the silica geochemical thermometer should not be used to indicate the temperature of this water. The water samples for which estimated mixed-water temperatures exceed 220°C probably have been enriched by amorphous SiO_2. Therefore, the best estimates of temperatures at depth, using the silica geochemical thermometer, are probably those for the higher temperature water (greater than 45.0°C), which flows from the volcanic-rock aquifers where calculated temperatures by the mixed-water method are less than 220°C.

The Na-K-Ca geochemical thermometer should not be used to estimate temperatures at depth for water from the sedimentary-rock aquifers. The chemical composition of this water had evidently been altered owing to the solution of the aquifer materials and, therefore, erroneously high temperatures were calculated. The estimated temperatures by the Na-K-Ca method for the water from the volcanic-rock aquifers are probably much more reliable than those for water from the sedimentary-rock aquifer, especially where these temperatures have the support of the silica geochemical thermometer.

The estimated subsurface temperatures in the Bruneau-Grand View area probably do not exceed 150°C. This estimate is based on the silica concentrations of thermal water believed to have been sampled from only the volcanic-rock aquifers. However, if this sampled water is a mixture of a hot water from depth with cooler, shallower water, then silica concentrations would also reflect the mixing, and subsurface temperatures may exceed 180°C.

Minor Elements

The water samples collected were analyzed for the following selected minor elements: boron, lithium, mercury, and arsenic. The concentrations of these minor elements in the water samples collected are given in table 3. Although the measured concentrations for these constituents in all waters sampled were low, notable differences in the boron and lithium concentrations were measured in samples from both the sedimentary-rock aquifers and volcanic-rock aquifers and, in some instances, from only the volcanic-rock aquifers.

The highest concentrations of boron (1,900 ug/1) and lithium (1,100 ug/1) were measured in water from the sedimentary-rock aquifers. The higher values probably reflect contributions from evaporite beds within the sedimentary rocks.

The boron concentrations in the volcanic-rock aquifers show a wide range in measured values. Generally, the values ranged from less than 100 to 1,100 ug/1. The highest concentrations of boron occurred in the vicinity of Bruneau and Grand View. The higher concentrations of boron in the water near these towns may result from one or all of the aforementioned causes if some mixing of water from the sedimentary-rock and volcanic-rock aquifers has occurred, or if sedimentary deposits were interbedded in the volcanic rocks. However, it is also possible that the boron was contributed to the thermal water by solution of the Idavada Volcanics, which had been enriched by residual magmatic fluids, thus indicating a closer proximity to the source area of these volcanic rocks (Fairbridge, 1972, p. 88).

The lithium concentrations in the water of the volcanic-rock aquifers are very low and usually do not exceed 30 ug/1. Such low concentrations of lithium are usual in water from basaltic rocks (Ellis, 1970).

Mercury and arsenic concentrations in all the sampled thermal waters in the Bruneau-Grand View area are low, and ranged from 0 to 4.3 ug/1 and 0 to 78 ug/1, respectively. No pattern of occurrence and concentration for these minor elements was observed. However, the highest values found for both were in water from the volcanic-rock aquifers.

Gas Analyses

Gas samples were collected from 15 wells near Grand View and in the Castle Creek and Indian Cove areas. No gas was found in the water from other wells in the study area. The samples were analyzed for specific gases by the gas chromatograph technique, and the results are given in percentage by volume in table 5. The analysis technique yielded values for the individual gases accurate within $\pm$ 5 percent, although the sum of constituent percentages for any one sample may have a larger deviation. Part of the discrepancy for sums less than 100 percent probably results from the fact the samples usually were saturated with water, whereas the gases used for standards in the analysis technique were not.

The gases in the thermal water sampled consist primarily of nitrogen, oxygen, and methane. In no sample did carbon dioxide exceed 1 percent, nor did hydrogen exceed 0.1 percent. As shown by the analyses, water from the sedimentary-rock aquifers contains large volumes of methane, whereas water from five of the eight samples from the volcanic-rock aquifers contains no methane. The small amounts of methane reported in the other three analyses of water from the volcanic-rock aquifers indicate that some of the water in these wells is, in fact, derived from the sedimentary-rock aquifers. The methane in water from the sedimentary-rock aquifers probably results from decay of organic material in the sedimentary deposits. The low values of carbon dioxide and hydrogen reported in the gas samples from water of both aquifers suggest that, except for the methane, the gases in the water are those that were contained in the meteoric water recharging the system.

The ratio of nitrogen to oxygen can be used to support further the idea that the gases in the samples collected, excluding methane, were those in the original recharge water to the system. Assuming the temperature of the water recharged to the volcanic-rock aquifers to be 10.0°C, which is the measured temperature of selected cold springs in the area (see table 2), and assuming the nitrogen and oxygen in the air and water are in equilibrium, the ratio of nitrogen to oxygen in the recharge water would be 1.96 (Hodgman and others, 1953, p. 1610). The potential loss of oxygen from the water due to oxidation of minerals in the aquifer is much greater than the potential loss of nitrogen. This loss of oxygen would effectively increase the ratio of nitrogen to oxygen. The nitrogen-oxygen ratios in the gas from the volcanic-rock aquifers (table 5) are much higher than 1.96, thus indicating a loss of oxygen from the water. The nitrogen-oxygen ratios in the gas from the water of the sedimentary-rock

TABLE 5
GAS ANALYSES FROM SELECTED WELLS

Well or spring identification number	Water temperature[1] (°C)	Major aquifer	Percent by volume: Nitrogen (N_2)	Oxygen (O_2)	Methane (CH_4)	Carbon Dioxide (CO_2)	Hydrogen (H_2)	N_2/O_2 in sample	N_2/O_2 in water at 10°C	Sum
4S-1E-26abc1	27.0	Sedimentary rocks of Idaho Group	53	14.2	28.8	<1	< 0.1	3.73	1.96	96+
34bad1	75.5	Idavada Volcanics	72	16.6	0	<1	< .1	4.34	1.96	89±
4S-2E-29dbc1	28.0	Sedimentary rocks of Idaho Group	36	19.3	50	<1	< .1	1.87	1.96	105+
32bcc1	43.0	Sedimentary rocks of Idaho Group	38	13.5	40.4	<1	< .1	2.81	1.96	92±
5S-2E- 1bbc1	49.5	Banbury Basalt(?)	67	18.2	0	<1	< .1	3.68	1.96	85+
5S-3E-20ada1	60.0	Idavada Volcanics	72	19	0	<1	< .1	3.77	1.96	91+
20bbb1	27.0	Sedimentary rocks of Idaho Group	62	24.2	16.4	<1	< .1	2.56	1.96	103±
26bcb2	67.0	Idavada Volcanics(?)	76	12.1	0	<1	< .1	6.28	1.96	88+
27bdd1	60.0	Idavada Volcanics(?)	70	12.8	5.5	<1	< .1	5.47	1.96	88+
28bcc1	65.0	Idavada Volcanics	69	17.2	2	<1	< .1	4.01	1.96	88+
6S-3E- 2cbc1	62.0	Banbury Basalt	67	11 5	5	<1	< .1	5.83	1.96	84±
6S-5E-20aab1	43.5	Banbury Basalt(?)	84	16.5	0	<1	< .1	5.09	1.96	101±
6S-7E- 1acb1	41.0	Sedimentary rocks of Idaho Group	61	23.3	20.9	<1	< .1	2.62	1.96	105+
1dba1	33.0	Sedimentary rocks of Idaho Group	38	16.4	35.4	<1	< .1	2.32	1.96	90±
2cdd1	34.5	Sedimentary rocks of Idaho Group	38	17.6	46.3	<1	< .1	2.16	1.96	102±

[1]Temperature of the water at land surface at time of sampling.
ANALYSES BY: Katherine L. Pering, U. S. Geological Survey

aquifers are much lower than the nitrogen-oxygen ratios in the gas from water of the volcanic-rock aquifers; however, they are still higher than the same ratios in the gas from the suspected recharge water. The nitrogen-oxygen ratio in gas from the sedimentary-rock aquifers probably reflects mixing of water by vertical percolation from the volcanic-rock aquifers.

Well and Spring Deposits

Deposition of minerals by thermal ground waters is noticeably absent in the Bruneau-Grand View area. Some well casings and spring vents have a very thin coating of carbonate-type minerals. Evaporite-type deposits are found on some well casings that are exposed to the higher temperature water in the area. However, these types of deposits are the result of evaporation rather than precipitation due to excessive mineral concentrations in the water.

Stearns (1922, p. 7) reported that a spring in Shoofly Valley (T. 6 S, R. 3 E, sec. 14), was depositing large amounts of minerals. However, subsequent ground-water development of the sedimentary-rock aquifer in this area has caused this spring to cease flowing, and for this reason, fresh samples of the minerals deposited could not be collected. A sample of the old deposits was collected and analyzed for mineral content. The results show that the spring deposits contain chiefly calcium carbonate (travertine) with very small amounts of quartz (less than 3 percent).

The lack of mineral deposition by thermal waters in the Bruneau-Grand View area is probably due to the low dissolved-solids concentration of these waters.

SOURCE OF HEAT

The sources of heat for the above-normal ground-water temperatures in the Bruneau-Grand View area were first discussed by Piper (1924, p. 52). He gave three possible explanations: (1) Expiring volcanism at depth beneath the area, (2) mechanical heat generated by friction during recent earth movements, and (3) the upward migration of water from depth where observed temperatures are normal. He concluded that the upward migration of water from depth is the most probable source because: (1) observed volcanism in the area is restricted to thin, relatively fast-cooling, surface flows; and (2) similar faulted areas did not possess abnormally high ground-water temperatures. At the time of this investigation, no additional data have been collected that suggest expiring volcanism at depth or the generation of mechanical heat from major faulting in the Bruneau-Grand View area.

The large areal extent of the conductive anomaly, as defined by the AMT survey, and the widespread occurrence of thermal waters in the Bruneau-Grand View area, suggest a broad heat source. Therefore, the probable explanation of the above-normal ground-water temperatures in the Bruneau-Grand View area is deep circulation of water in an area of above-normal geothermal gradient. Heating of the ground water to a temperature of 83°C (maximum recorded water temperature at the surface) by a geothermal gradient of 2°C per 100 feet would require the circulation of water to a depth of about 3,750 feet.

Unpublished data by D. D. Blackwell (written commun., 1973) suggest that heat-flow values of 2.4 heat-flow units or 2.4 x 10^{-6} cal/cm^2/sec and a gradient of 50°C per kilometre (1.5°C per 100 feet) exist in the vicinity of Silver City, Idaho, which is approximately 30 miles west of Grand View. This gradient closely approximates that calculated (2°C per 100 feet) for the Bruneau-Grand View area.

The relatively high geothermal gradient occurring in the Bruneau-Grand View area probably is related to the thinning of the upper crust in the area of the Snake River Plain noted by Pakiser (1963). Pakiser stated that these areas of thin upper crust and low-density upper mantle usually have had a Cenozoic history of intense diastrophism and silicic volcanism.

SUMMARY

The rocks in the Bruneau-Grand View area range in age from Late Cretaceous to Holocene. Rocks of the Cenozoic Era have been subdivided into four groups: (1) an unnamed sequence of rhyolitic and related rocks, (2) the Idavada Volcanics, (3) the Idaho Group, and (4) the Snake River Group. For convenience, these rock units have been divided into two major groups according to their hydrologic properties: (1) the volcanic-rock aquifers that include the Idavada Volcanics, the Banbury Basalt of the Idaho Group, and undifferentiated silicic volcanic rocks; (2) the sedimentary-rock aquifers, which include chiefly sedimentary units of the Idaho and Snake River Groups.

Recharge to the volcanic-rock aquifer (except the Banbury Basalt) is thought to be chiefly from precipitation in the higher altitudes to the south and southwest of the study area where the rock units are exposed at the surface. Recharge to the sedimentary-rock aquifers and the Banbury Basalt is believed to be mainly by the upward movement of water from the underlying volcanic-rock aquifers.

The Idavada Volcanics or underlying rock units are believed to be the reservoir rocks for the thermal water in the Bruneau-Grand View area.

A system of northwest-trending faults has probably fractured and displaced rocks ranging in age from Pliocene to Pleistocene. Most of the faulting probably occurred in early Pliocene time, with progressively diminishing movements through Pleistocene time. Gravity and aeromagnetic surveys support the theory of a northwest-trending subsurface structure.

An AMT (audio-magnetotelluric) survey of the Bruneau-Grand View area has revealed a large conductive anomaly in the region between Oreana and Grand View. The areal extent of this anomaly implies that a broad heat source is present. The low resistivities observed, approaching 2 ohm-metres, imply a hot-water reservoir in which the reservoir rocks have been altered.

Sampled thermal water in the Bruneau-Grand View area is generally of a sodium bicarbonate type. In the study area, thermal water from the sedimentary-rock aquifers generally contains dissolved-solids concentrations greater than 600 mg/1, is nearly neutral in pH, and usually contains less than 2 mg/1 fluoride. Water from the volcanic-rock aquifers generally contains less than 500 mg/1 dissolved solids, has pH values higher than 8.0, and has fluoride concentrations in excess of 8 mg/1. Chloride concentrations range from 2.7 to 79 mg/1 for all sampled water with the values from the volcanic-rock aquifers usually less than 20 mg/1. Sulfate concentrations are much higher for water from the volcanic-rock aquifers than for the water from the overlying sedimentary-rock aquifers. The chemistry of the thermal water from the volcanic-rock aquifers is very similar to that of thermal water flowing from the granitic rocks of the Idaho batholith.

Ratios of concentrations of selected chemical constituents are used to distinguish water from the volcanic-rock and sedimentary-rock aquifers. The chloride-fluoride ratio is probably the best indicator with ratios generally less than 0.6 for water from the volcanic-rock aquifers and considerably greater than 0.6 for water from the sedimentary-rock aquifers. Chloride-boron ratios of the hotter water from volcanic-rock aquifers showed a marked decrease near Bruneau and Grand View because of increased boron concentrations.

Measured ground-water temperatures at the surface in the Bruneau-Grand View area range from 9.5° to 83.0°C with the higher temperatures (40° to 83°C) found in the water from the volcanic-rock aquifers. Temperatures of the water from the sedimentary-rock aquifers seldom exceed 35°C. The observed ground-water temperatures in the volcanic-rock aquifers seem to be related to the depth to the aquifers.

Estimated aquifer temperatures range from 92° to 157°C as calculated by the use of the silica geochemical thermometer and from 21° to 206°C using the Na-K-Ca geochemical thermometer. Estimated maximum temperatures, which were calculated by the use of the mixed-water geochemical thermometer, range from 150° to 275°C with the cold-water component ranging from 61 to 92 percent. Aquifer temperatures in the Bruneau-Grand View area were estimated at and probably do not exceed 150°C, except where the sampled water at the surface is of mixed origin; here, maximum temperatures at depth probably do not exceed 220°C.

A geothermal gradient of 2°C per 100 feet was calculated for the Bruneau-Grand View area using selected well data. Using this gradient, temperatures of 150°C could exist at a depth of 7,100 feet.

The gas in samples collected from water in the Bruneau-Grand View area consists primarily of nitrogen, oxygen, and methane. Methane was found primarily in samples from the sedimentary-rock aquifers. Analysis of the gas in water from the volcanic-rock aquifers indicates that the gas is essentially that contained in meteoric water recharging the system.

Mineral deposition at wells and springs in the Bruneau-Grand View area is noticeably absent, largely because of the low dissolved-solids concentration in the water.

The source of heat for the deeply circulating thermal waters in the Bruneau-Grand View area is believed to be an above-normal geothermal gradient. This above-normal gradient could be related to a thinning of the earth's upper crust in this area.

FUTURE WORK

The collection of data for this investigation was designed to give a preliminary evaluation of the areal extent and character of the Bruneau-Grand View thermal anomaly. This preliminary evaluation was based on geochemical sampling of thermal waters at the surface, existing geologic and hydrologic data, and selected surface geophysical surveys.

The findings presented in this report could be refined if additional data were available. Borehole geophysical logs for several existing deep wells could yield information about lithology, temperature, and water-quality conditions in the subsurface. This additional data, in conjunction with existing data, would make it possible to select a site for a deep test hole. A deep test hole (10,000 feet deep) in the area of the Bruneau-Grand View thermal anomaly could contribute significant data descriptive of:

The lithology of rocks at depth;
Temperatures of the thermal waters at depth;
Water levels and yield characteristics for the aquifers penetrated;
The quality of the thermal waters penetrated;
The heat-flow values.

Interpretation of data collected from a deep test hole should yield the information needed to enable a definitive assessment of the potential of the Bruneau-Grand View area as a prospective area for developing geothermal energy for power production.

SELECTED REFERENCES

Anderson, N. R., 1965, Upper Cenozoic stratigraphy of the Oreana quadrangle: Univ. of Utah, Ph. D. thesis, 212 p.

Buwalda, J. P., 1923, A preliminary reconnaissance of the gas and oil possibilities of southwestern and southcentral Idaho: Idaho Bur. Mines and Geology, Pamphlet 5, 10 p.

Ellis, A. J., 1970, Quantitative interpretation of chemical characteristics of hydrothermal systems, *in* Proceedings United Nations Symp. on the Development and Utilization of Geothermal Energy: Pisa, v. 2, Part 1, Geothermics, Spec. Issue 2, p. 516-528.

Fairbridge, R. W., ed., 1972, The encyclopedia of geochemistry and environmental sciences *in* Encyclopedia of earth sciences series: Van Nostrand Reinhold Company, v. IV A, p. 88.

Fournier, R. O., and Truesdell, A. H., 1970, Chemical indicators of subsurface temperature applied to hot spring waters of Yellowstone National Park, Wyoming, U.S.A., *in* Proceedings United Nations Symp. on the Development and Utilization of Geothermal Energy: Pisa, v. 2, Part 1, Geothermics, Spec. Issue 2, p. 529-535.

————1973, An empirical Na-K-Ca geothermometer for natural waters: Geochim. et Cosmochim. Acta., v. 36.

————1974, Estimation of temperature and fraction of hot water mixed with cold water, Part II, Geochemical indicators of subsurface temperature: U.S. Geol.Survey open-file report, 33 p.

Hill, D. P., 1963, Gravity and crustal structure in the western Snake River Plain, Idaho: Jour. Geophysical Research, v. 68, no. 20, p. 5807-5819.

Hodgman, C. D., Weast, R. C., and Wallace, C. W., eds., 1953, Handbook of chemistry and physics: Chemical Rubber Publishing Co., Cleveland, Ohio, 35th ed., 1953-54, 3163 p.

Kirkham, V. R. D., 1931a, Snake River downwarp: Jour. Geology, v. 39, no. 5, p. 456-482.

————193lb, Igneous geology of southwestern Idaho: Jour. Geology, v. 39, no. 6, p. 564-59l.

Littleton, R. T., and Crosthwaite, E. G., 1957, Ground-water geology of the Bruneau-Grand View area, Owyhee County, Idaho: U. S. Geol. Survey Water-Supply Paper 1460-D, p. 147-198.

Mahon, W. A. J., 1970, Chemistry in the exploration and exploitation of hydrothermal systems, *in* Proceedings United Nations Symp. on the Development and Utilization of Geothermal Energy: Pisa, v. 2, Part 2, Geothermics, Spec. Issue 2, p. 1310-1322.

Malde, H. E., 1959, Fault zone along northern boundary of western Snake River Plain, Idaho: Science, v. 130, no. 3370, p. 272.

Malde, H. E., and Powers, H. A., 1962, Upper Cenozoic stratigraphy of western Snake River Plain, Idaho: Geol. Soc. America Bull., v. 73, p. 1197-1220.

Malde, H. E., Powers, H. A., and Marshall, C. H., 1963, Reconnaissance geologic map of west-central Snake River Plain, Idaho: U.S. Geol. Survey Misc. Geol. Inv. Map I-373, 1 sheet.

Mundorff, M. J., Crosthwaite, E. G., and Kilburn, Chabot, 1964, Ground water for irrigation in the Snake River basin in Idaho: U.S. Geol. Survey Water-Supply Paper 1654, 224 p.

Nace, R. L., West, S. W., and Mower, R. W., 1957, Feasibility of ground-water features of the alternate plan for the Mountain Home Project, Idaho: U.S. Geol. Survey Water-Supply Paper 1376, 121 p.

Pakiser, L. C., 1963, Structure of the crust and upper mantle in the western United States: Jour. Geophys. Research, v. 68, no. 20, p. 5747-5756.

Piper, A. M., 1924, Geology and water resources of the Bruneau River basin, Owyhee County, Idaho: Idaho Bur. Mines and Geology, Pamph. 11, 56 p.

Ralston, D. R., and Chapman, S. L., 1969, Ground-water resources of northern Owyhee County, Idaho: Idaho Dept. Reclamation Water Inf. Bull. 14, 85 p.

Ross, C. P., and Forrester, J. D., 1947, Geologic map of the State of Idaho: U.S. Geol. Survey and Idaho Bur. Mines and Geology, 1 map.

Russell, I. C., 1903, Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon: U.S. Geol. Survey Water-Supply Paper 78, 53 p.

Schoen, Robert, 1972, Hydrochemical study of the National Reactor Testing Station, Idaho: Hydrogeology, 24th Intern. Geol. Cong., Montreal, Section 11, p. 306-314.

Stearns, H. T., 1922, Artesian water near Grand View, Owyhee County, Idaho: U.S. Geol. Survey open-file report, 10 p.

Walton, W. C., 1962, Ground-water resources of Camas Prairie, Camas and Elmore Counties, Idaho: U.S. Geol. Survey Water-Supply Paper 1609, 57 p.

White, D. E., 1957, Thermal waters of volcanic origin: Geol. Soc. America Bull., v. 68, no. 12, pt. 1, p. 1637-1657.

————1970, Geochemistry applied to the discovery, evaluation, and exploitation of geothermal energy resources, *in* Proceedings United Nations Symp. on the Development and Utilization of Geothermal Energy: Pisa, v. 1, Part 2, Geothermics, Spec. Issue 2.

————1973, Characteristics of geothermal resources, *in* Kruger, Paul, and Otte, Carol, eds., Geothermal energy, resources, production, simulation: Stanford Univ. Press, Stanford, Calif., p. 89-94.

Young, H. W., and Mitchell, J. C., 1973, Geochemistry and geologic setting of selected thermal waters, Part 1, Geothermal investigations in Idaho: Idaho Dept. Water Adm. Water Inf. Bull. 30, 43 p.

APPENDICES

APPENDIX A

A Reconnaissance Audio-Magnetotelluric Survey
Bruneau-Grand View Area, Idaho

by
D. B. Hoover and C. L. Tippens

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ILLUSTRATIONS

A Reconnaissance Audio-Magnetotelluric Survey Bruneau-Grand View Area, Idaho

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INTRODUCTION

The AMT (audio-magnetotelluric) survey has recently been used by the U. S. Geological Survey as a reconnaissance technique for the evaluation of potential geothermal areas. The rationale for this is that, being an inductive electromagnetic technique, it emphasizes conductive bodies that commonly are associated with the hot waters and alteration zones of geothermal reservoirs. The de-emphasis of highly resistive zones also makes it useful in looking through highly resistive surficial material where D.C. (direct current) resistivity techinques lose definition. However, the de-emphasis of highly resistive zones is also a disadvantage in that it contributes to large errors in estimating depths to conductive bodies.

In reconnaissance work, it is usually sufficient to verify the existence of conductive anomalies, measure their approximate values, and gain some idea of their lateral extent. This can be rather easily done with AMT techniques for relatively near-surface conductors. The depth of exploration is variable, depending on the resistivity section, but typically ranges from 660 to 6,000 feet at 8 Hz (hertz).

BASIS FOR AMT METHOD

The magnetotelluric method is one of three exploration techniques in which naturally occurring electromagnetic fields are used. The more familiar telluric and AFMAG (audio-frequency magnetics) methods are the others, and all suffer from being dependent upon vagaries in natural fields. In this investigation, the frequency range employed was from 8 to 18,600 Hz, and the technique is accordingly called AMT (audio-magnetotelluric) exploration.

Electromagnetic energy as it propagates into the earth is attenuated, with the energy loss dissipated as heat. The depth it penetrates into the earth is a function of earth properties and the frequency of the energy wave. "Skin depth" is a measure of this penetration and is defined as the depth at which the current density has fallen to 1/e of its surface value. This also is an approximate measure of the depth of exploration. The "skin depth" (δ) is given by equation (1) for a homogeneous earth.

$$\delta = \sqrt{2/\omega\mu\sigma} \qquad \text{equation (1)}$$

where –

δ = "skin depth" in metres

ω = angular frequency in radians per second

μ = magnetic permeability in Henries per metre

σ = conductivity in ohm-metres

For rocks that are not strongly magnetic, equation (1) reduces to:

$$\delta = 503 \sqrt{\rho/f} \text{ metres} \qquad \text{equation (2)}$$

where –

ρ = resistivity in ohm-metres

f = frequency in hertz

For example, if measurements were made over a uniform 100-ohm-metre earth, the resistivity would be measured from the surface down to about 120 feet at 18,600 Hz and to 5,900 feet at 8 Hz. It is the bulk properties of the rock, however, that are being measured in a volume approximately defined by radii 1 "skin depth" long from the measuring point. Material – and particularly low-resistivity material – nearest to the measuring point contributes most to the measurement. Where the "skin depth" is small, as at the highest frequencies, then a smaller volume of material is being averaged. Hence, at a given site, a decrease in the frequency being measured results in a resistivity measurement representative of a deeper penetration into the earth and a greater lateral extent. It is important to keep the latter concept in mind when examining AMT data.

A necessary assumption made in employing the AMT method is that the electromagnetic energy (derived from lightning) propagates as a plane wave essentially vertically into the earth. The plane-wave assumption is valid if the energy source is at least 4 "skin depths" from the measuring site. Only in the case of very local lightning storms or artificial disturbances is this assumption invalid. This audio-frequency energy in the ELF (extra low frequency) and VLF (very low frequency) band propagates for long distances around the earth in the waveguide formed by the earth and ionosphere. Propagating in this waveguide mode, the fields above the earth are approximately at grazing incidence. Because of the large change in impedance (index of refraction) at the earth-air boundary, the energy is refracted toward the normal, and for practical purposes, the energy propagates vertically. Associated with this downward propagating wave are mutually orthogonal, horizontal magnetic and electric fields. In the case of a homogeneous or horizontally homogeneous stratified earth, the electric field in the earth is radial to the source and the magnetic field is tangential to the source. Under these conditions, the apparent resistivity of the earth is a function of these horizontal fields, and the frequency as given by Cagniard (1953) is:

$$\rho a = \frac{(1)}{(5f)} \frac{(E^2)}{(H^2)} \qquad \text{equation (3)}$$

where—

ρa = apparent resistivity in ohm-metres
f = frequency in hertz
E = electric field in microvolts per metre
H = magnetic field in gammas.

Since the "skin depth" and apparent resistivity are both functions of frequency, the variation of resistivity with depth can be determined by measurements at the surface. Thus, if the apparent resistivity is measured as a function of frequency, a sounding is made much as with a direct-current sounding array (Keller and Frischknecht, 1966); but without expanding the electrode array.

In the AMT range of frequencies, the principal source of natural energy arises from worldwide lightning storms with tropical regions accounting for the preponderance of the energy. Bleil (1964), Ward (1967), and Strangway and others (1973) discuss in detail the temporal and spacial variations of these signals. Briefly, the main features of these variations affect the method by restricting operations to good-signal periods and by introducing scatter in the data. Considering temporal variations, the energy is weakest during winter months when storm activity is reduced. Measurements have been made as late as October, but energy is markedly lower toward the end of the month. This reduction in energy is particularly noticeable in the higher frequencies. There is also a tendency for the energy, particularly in the higher frequencies, to increase in the afternoon as thunderstorms approach the measuring site.

Propagation in the earth-ionosphere waveguide produces spectral characteristics that impose other restrictions on the method. In the low-frequency range, waveguide resonances produce energy peaks at discrete frequencies. These are the Schumann resonances, with the fundamental being about 8 Hz. Below this frequency, the energy decreases rapidly to a minimum around 1 Hz. In the midfrequencies, the waveguide has a strong absorption band near 2,000 Hz, which severely limits data acquisition in this range.

Since more than one major storm center can be supplying energy during a given period, some data scatter and nonrepeatability of data can be observed where lateral inhomogeneities exist. The response of two- and three-dimensional structures varies with the orientation of the source fields and sensor-array orientation. Data scatter is due to the varying source locations present during a given recording period; nonrepeatability is due to distinctly different source locations between different recording times. This precludes very precise analysis of the data for a layered structure and clearly emphasizes that the earth usually is not the simple horizontally stratified model that is often assumed.

Within the AMT frequency band, manmade signals are also present. Most troublesome is the energy radiating from power lines at the fundamental and at many of the harmonics. While in principle, these signals could be used if the source was at least 4 "skin depths" distance, this criterion is difficult to meet except in remote areas. The "skin depth" at 60 Hz for 100-ohm-metre material is 2,100 feet; therefore, a minimum distance would be 1.6 miles separation from the nearest power line for this situation and over 5 miles if the earth were 1,000-ohm-metre material. Thus, the large amount of energy from power lines generally constitutes only a difficult noise problem.

In the higher frequency range, VLF radio stations are present and may be used as an energy source. In this investigation, stations at 10,200 Hz and 18,600 Hz were used as a matter of convenience. During the rare periods when these stations are not transmitting, there is sufficient natural energy for operations.

INTERPRETATION

Where horizontal layering can be assumed, interpretation is similar to conventional resistivity techniques such as curve matching. The corresponding sounding curve can be computed for any postulated layered structure, so matches to theoretical sounding curves can be made. The problem of intermediate high-resistivity layers being masked, however, is a serious limitation to accurate depth interpretation. This is similar to a low-velocity layer being masked in seismic refraction surveying and is discussed in more detail by Strangway and others (1973) and Strangway and Vozoff (1970). They point out that an intermediate high-resistivity layer must be two to three times as thick as the upper layer to be seen.

In mining and some geothermal exploration, two- and three-dimensional structures are much more prevalent than the simple layered case. Methods of interpretation for this situation are severely limited, and most often, simple anomaly maps are used. This is the method used in this investigation. Some theoretical solutions for simple two-dimensional structures have been presented by Strangway and others (1973), Strangway and Vozoff (1970), Vozoff (1972), and Madden and Swift (1969). Limited three-dimensional data are available from model studies of Frischknecht (1973). These studies permit some generalizations that are useful when examining AMT anomaly maps or sounding curves.

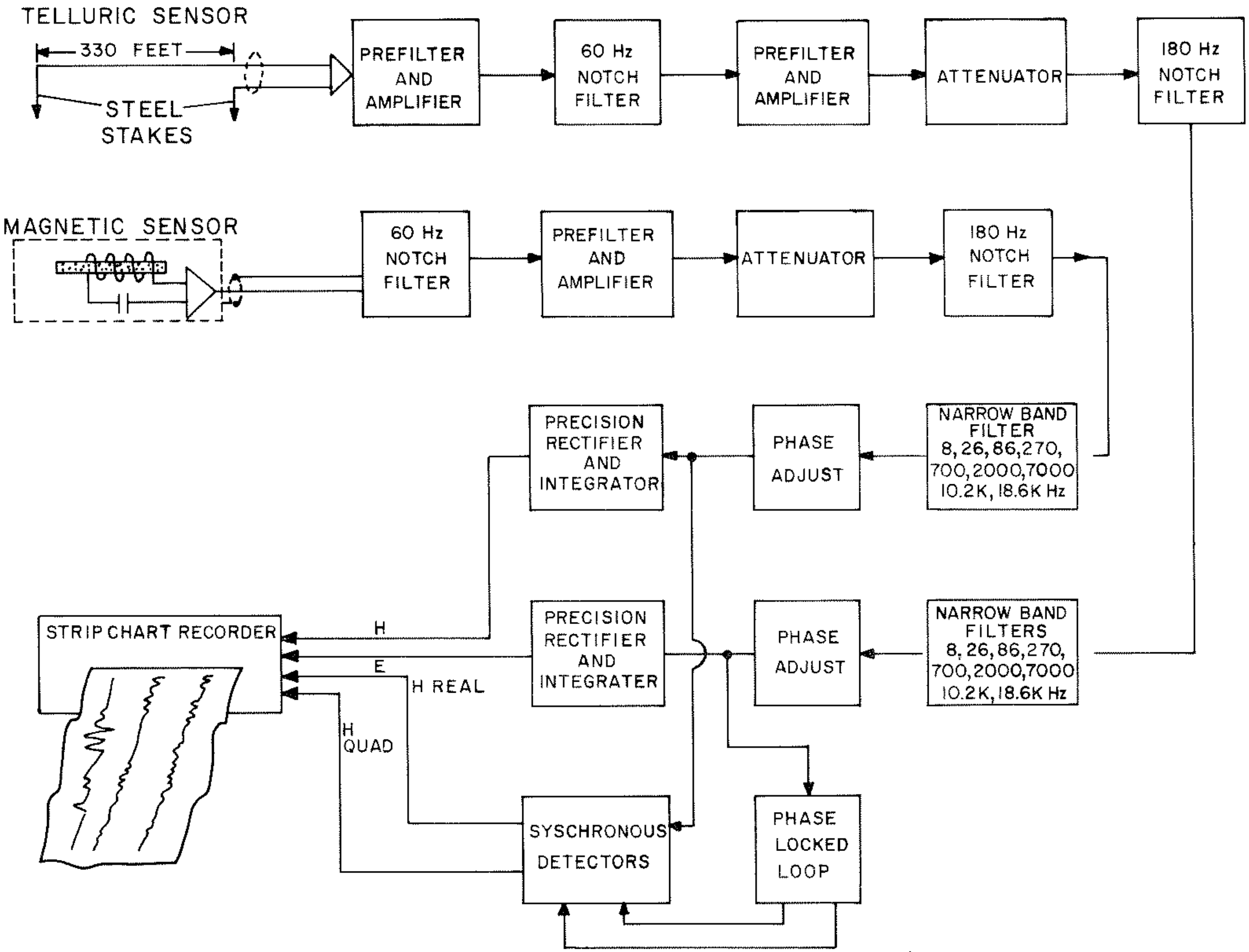
For two-dimensional structures, the most definitive measurements are made with the electric-field-measuring arrays oriented parallel and perpendicular to the strike of the structure. In general, "E-perpendicular" measurements will define the boundaries sharply, but will exhibit overshoot in the measured values near the boundary. This can result in measured apparent resistivities both higher and lower than the actual resistivities present in the section. Near-surface conductive layers, however, tend to suppress the overshoot. In the case of "E-parallel" measurements across a structure, generally they will define the boundaries poorly, but the values will vary smoothly without overshoot near the boundaries. A common situation would be an area in which approximately vertical, conductive fault zones are present. In this case, if one were not within the fault zone, the "E-parallel" measurements would be lower and "E-perpendicular" measurements higher than the background resistivities. If one were within the fault zone, just the opposite would result.

In a broad sense, these same generalizations apply to three-dimensional structures. "E-perpendicular" measurements are much more definitive of the boundary than the "E-parallel" measurements. This implies that spherical bodies will not give circular anomaly maps as is evident from Frischknecht's data (1973).

EQUIPMENT

AMT equipment is not yet available commercially, so the equipment used was designed and fabricated by the U.S. Geological Survey. The equipment is similar to that described by Strangway and others (1973), except that a means of preserving phase information was provided. A schematic diagram of the instrumentation is shown in figure 12. To measure the horizontal electric field, two steel stakes, generally 330 feet apart, are used as electrodes. The signal is amplified and prefiltered using R-C bandpass filters to prevent

FIGURE 12. U.S. Geological Survey AMT (audio-magnetotelluric) system.



limiting of strong transients in the early stages. Narrow-band, active-notch filters are used to remove 60 and 180 Hz power-line signals, which are very strong near power lines. The signals then enter a universal active filter connected in a high-Q bandpass configuration. Approximately constant Q is maintained at all filter settings, with the 6 db bandwidth at 8 Hz being 0.3 Hz. To define a sounding curve, nine selectable frequencies spaced logarithmically throughout the band are used, but selected so as to avoid the midband harmonics of 60 Hz. At present, the operating frequencies are 8, 26, 86, 270, 700, 2,000, 7,000, 10,200, and 18,600 Hz. The output of the narrow-band filter is rectified, integrated, and displayed on a strip-chart recorder to show the envelope of the received energy.

FIELD OPERATIONS

The strip-chart recorder and high-gain selective filters are operated from a carryall truck with power supplied by an inverter connected to the truck battery. The coil and common electrode of the electric line are located 100 feet from the truck to avoid electrical noise generated by the truck. Signals are transmitted to the truck through coaxial cable.

The electric line is laid out in either an east-west or a north-south direction, and the coil placed at a right angle to the line. System gains are adjusted to give 20 to 40 mm (millimetres) chart deflection of peak energy bursts on each channel. The corresponding electric and magnetic signals are measured for amplitude and their ratio computed for a sufficient number of signals to obtain a reliable average ratio. The apparent resistivity is then computed from a knowledge of system gain and equation (3).

Data are computed and plotted in the field for all frequencies while recording is underway to obtain a sounding curve. The electric dipole and coil are then rotated 90 degrees, and a second sounding is made and plotted. This permits the operators to correct any obvious errors and to check any data points that appear aberrant. The second sounding also provides information on lateral variations in conductivity or anisotropy of the earth.

An induction pickup consisting of a wire-wound ferrite core is used for the horizontal magnetic-field sensor. To span the broad range of frequencies, two separate coils were required. One covers the range of 8 to 700 Hz and the other 2,000 to 18,600 Hz. An integral part of each sensor is a low-noise preamplifier that feeds the magnetic field signal to a second channel essentially identical to that described for recording the electric field. The coil sensitivity is about 0.1 microvolt per milligamma at 8 Hz.

Phase information is preserved by means of a phase-locked loop and synchronous detectors as shown in the schematic diagram (fig. 12). Because the usefulness of the phase information is still being evaluated, no further discussion is presented here.

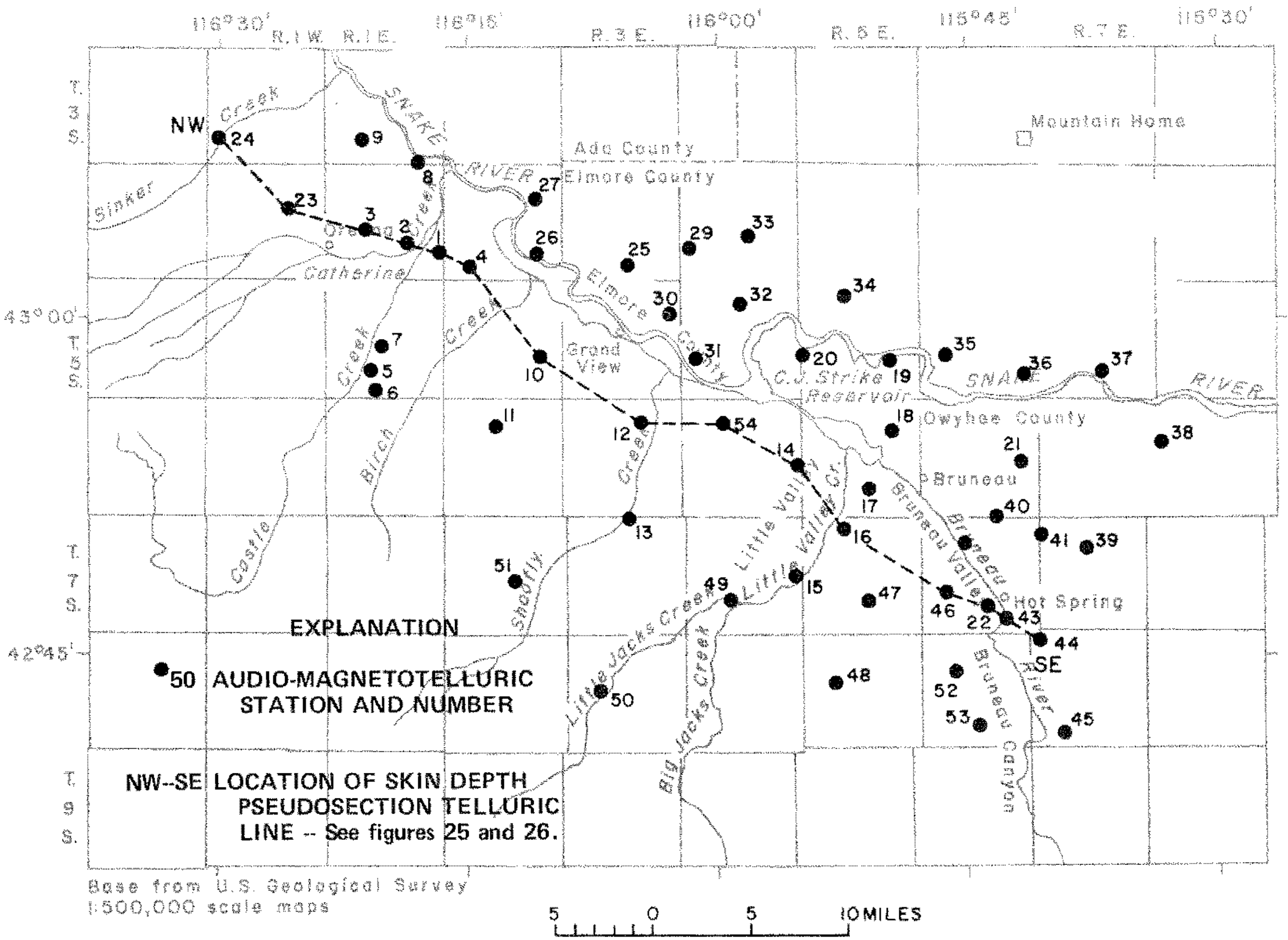
RESULTS

Figure 13 shows the location of the 54 soundings obtained in the Bruneau-Grand View area. These soundings cover an area of about 1,240 square miles giving a broad reconnaissance survey that defines the major conductive anomalies in this region. Because of the low station density, there may be local conductive anomalies that are not adequately defined. These are considered of minor importance in comparison to the broad anomaly discovered during this survey.

The deepest information was obtained at 8 Hz, and a map of the apparent resistivity at this frequency is shown in figure 14. Where different values of apparent resistivity were obtained for the north-south and east-west electrode orientations, an average value was used in contouring the data. This was done in part to reduce the number of maps and in the case of 8-Hz data because of the relatively few usable signals at this frequency.

Operations are made by two persons, one recording observations and the other computing resistivities. Typical production is eight soundings or four stations per day. Most of the time is spent waiting for a sufficient number of strong signals to provide good statistics on the ratio of E to H. Experience has shown that the amount of strong 8-Hz signals is often

FIGURE 13. Location of audio-magnetotelluric stations.



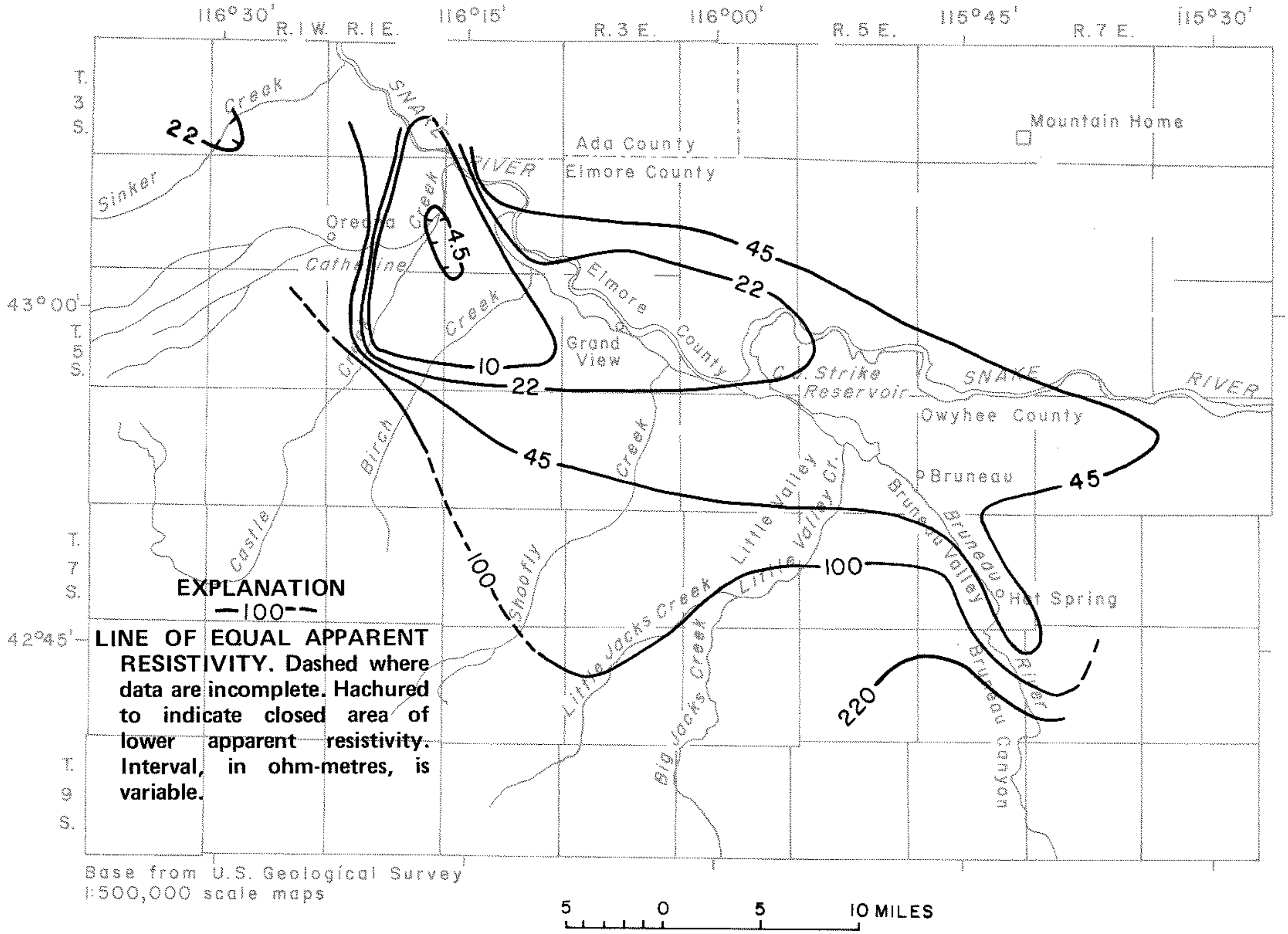


FIGURE 14. Apparent resistivity map at 8 hertz.

insufficient to provide good statistics; strong 26-, 86-, and 270-Hz signals are always available; 700-Hz signals tend to be variable; 2,000-Hz signals are virtually nonexistent; and 7,000-Hz and greater signals are very good.

These data define a broad conductive anomaly between Oreana and Grand View with rather sharp boundaries, except to the east, where the resistivity increases slowly east of Grand View. This broad resistivity trough is confined for the most part to the south side of the Snake River where the principal outcrops are fluvial and lacustrine deposits of late Tertiary and Quaternary age.

Near the mouth of Bruneau Canyon (near Hot Spring), a south-trending resistivity low was found. This is in an area of extensive hot-spring activity and undoubtedly reflects the hot waters and associated alteration in this region. The relatively high resistivities that were measured here suggest, however, that the zone of hot water is not broad but is confined to relatively narrow fracture zones along which the hot water is rising.

The data at 26 Hz are presented in figures 15 and 16. Because data at this frequency are much more reliable, two maps have been prepared, one for each of the two sounding orientations, as an aid in showing the effects of boundaries. These maps show the same broad trough of low resistivity along the south side of the Snake River evident in the deeper looking 8-Hz data (fig. 14). A number of features on these maps can be correlated with the known geology. The southern boundary of the trough is defined by a rather steep resistivity gradient that corresponds to a fault zone along which the northern block has been downdropped (fig. 6, sec. G-G'). The resistivity gradient is believed to define the zone along which the block has been faulted. The northern boundary is not as clearly defined; however, the 100-ohm-metre apparent-resistivity line on the north appears to define a major resistivity contrast that may be the northern boundary of a graben along the Snake River.

The minor conductive anomaly at the mouth of Bruneau Canyon is again present, but only in the data for the north-south orientation of the electric line (fig. 15). This probably indicates a more north-south trend of faulting in the area. The anomaly correlates well with the north-south alinement of hot springs.

Limited information from drillers' logs helps to explain two other features on the 26-Hz maps. South of Bruneau, the 100-ohm-metre apparent-resistivity line (fig. 15) swings abruptly to the north and then trends northeast, almost closing the low-resistivity trough. In the region between Bruneau Canyon and the northward swing of the resistivity line, the Idavada Volcanics is relatively shallow. Well information here indicates a depth of about 1,000 feet to the top of the Idavada Volcanics. Overlying the Idavada Volcanics is a relatively thin, 300-foot cover of Banbury Basalt, and above this cover lie sedimentary rocks of the Idaho Group. With apparent resistivities of a little over 100 ohm-metres, "skin depth" here is over 3,000 feet at 26 Hz. Because of its high resistivity, the Idavada Volcanics here and in its outcrop areas probably does not represent a good geothermal reservoir.

Farther east, the high resistivities are associated with a thicker sequence of the Banbury Basalt, which is presumably underlain by the Idavada Volcanics. This region, except for the limited area of hot-spring activity at the mouth of Bruneau Canyon, also has little geothermal potential. If an extensive heat source exists in Bruneau Canyon, it must be considerably deeper than 3,000 feet.

In contrast, a very curious correlation is seen in the vicinity of the major resistivity low. The limited deep-well data (fig. 6, A-A') shows a topographic high on the top of the Idavada Volcanics that corresponds closely with the low shown on the north-south 26-Hz AMT map (fig. 15). Well data unfortunately do not identify a northern boundary to the high delineated by a dashed line in figures 15 and 16. The dashed line is the approximate mean sea-level contour on the top of the Idavada Volcanics. Outside the contour of mean sea level, the altitude of the top of the Idavada Volcanics is about -200 feet; inside the contour, the top is as high as +500 feet above mean sea level. The hottest wells are around the periphery of the topographic high, which can in part be explained by their greater depth. The well data also show a thinning of the Banbury Basalt over the high.

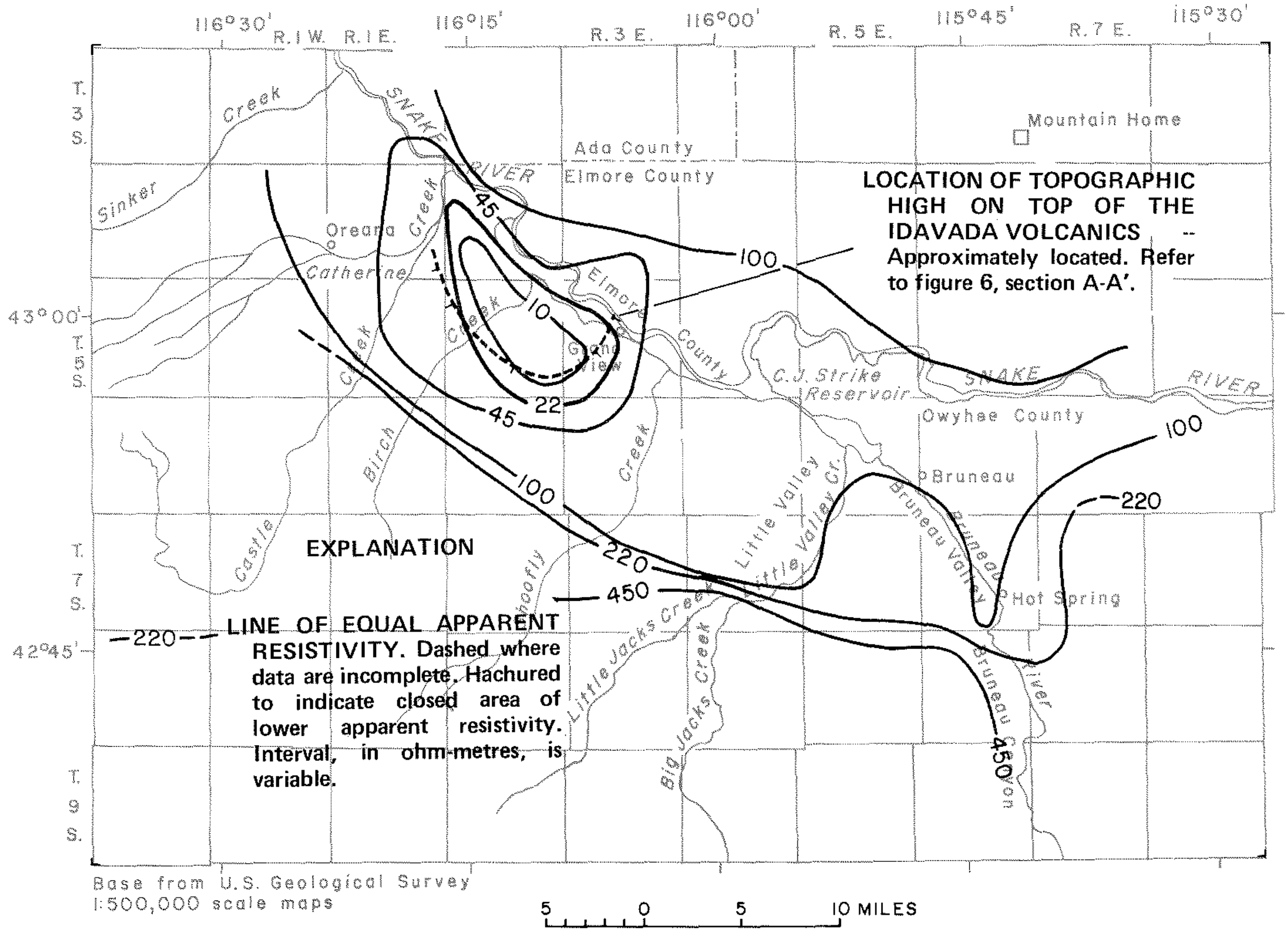
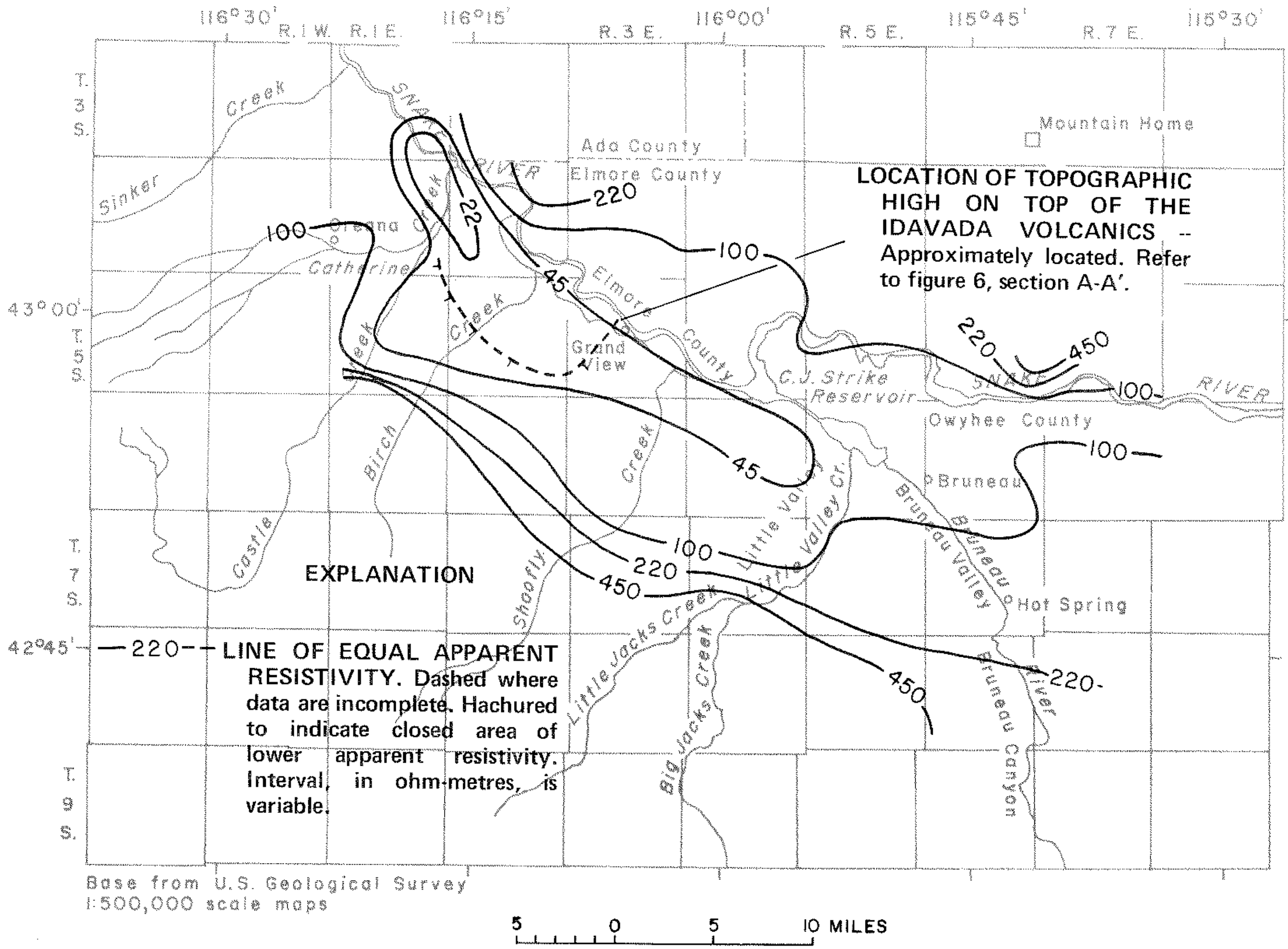


FIGURE 15. Apparent resistivity map at 26 hertz, electric line north-south.

FIGURE 16. Apparent resistivity map at 26 hertz, electric line east-west.



Drillers' logs show that the Banbury Basalt is a minor aquifer in this area and that the major deep and hot aquifer is the uppermost part of the Idavada Volcanics. The major resistivity anomaly could thus be explained by the near-surface, low-resistivity zone corresponding to the topographic high on the Idavada Volcanics. This, in part, is believed to contribute to the anomaly at the lower frequencies; however, the sounding data suggest that the top of the conductive anomaly is well above the Idavada Volcanics and is most likely above the Banbury Basalt. Yet the well data show no boundary higher than the Idavada Volcanics that can be correlated well with the AMT data. There is no satisfactory explanation for this discrepancy and, unfortunately, no geophysical well logs exist to aid in the interpretation.

The 26-Hz east-west data (fig. 16) show a more elongate low displaced to the northwest of the 26-Hz north-south low (fig. 15). These differences are due to lateral variations, which are strongly evident on many soundings along the central axis of the resistivity low. Owing to insufficient well data, it is not known if the closed low in figure 16 also corresponds to a topographic high on the Idavada Volcanics.

Figures 17 and 18 illustrate the effect of lateral resistivity contrasts at two of the stations, 6 and 10 respectively. A sounding was made at station 6 (fig. 17), which is at the head of Castle Creek and just south of the principal surface faulting. A thick, high-resistivity section is present here with no evidence of a deep conductive anomaly. The spread of resistivity values at the lower frequencies is due to the contrast in resistivity between the Idavada Volcanics and the more conductive Tertiary and Quaternary sedimentary rocks to the north.

The sounding at station 10 (fig. 18) is in the center of the major low and shows nearly an order of magnitude difference in the two sounding polarizations at the lower frequencies. This is indicative of large and nearby lateral resistivity contrasts. There is no direct evidence, either in the AMT maps, the surface geology, or in well data in the area, to suggest an explanation. In general, the soundings parallel to the long axis of the resistivity low across the whole area from Oreana to Bruneau Canyon illustrate this same sort of behavior. This trend coincides on the southeast with an inferred fault about 15 miles long cutting the mouth of Bruneau Canyon. Along the extreme eastern end of this inferred fault, several small, young, volcanic cones are present (sec. 36, T. 7 S, R. 6 E, Malde, Powers, and Marshall, 1963). Hence, the soundings along the midline of the graben provide further evidence of the fault and suggest its possible extension to the northwest.

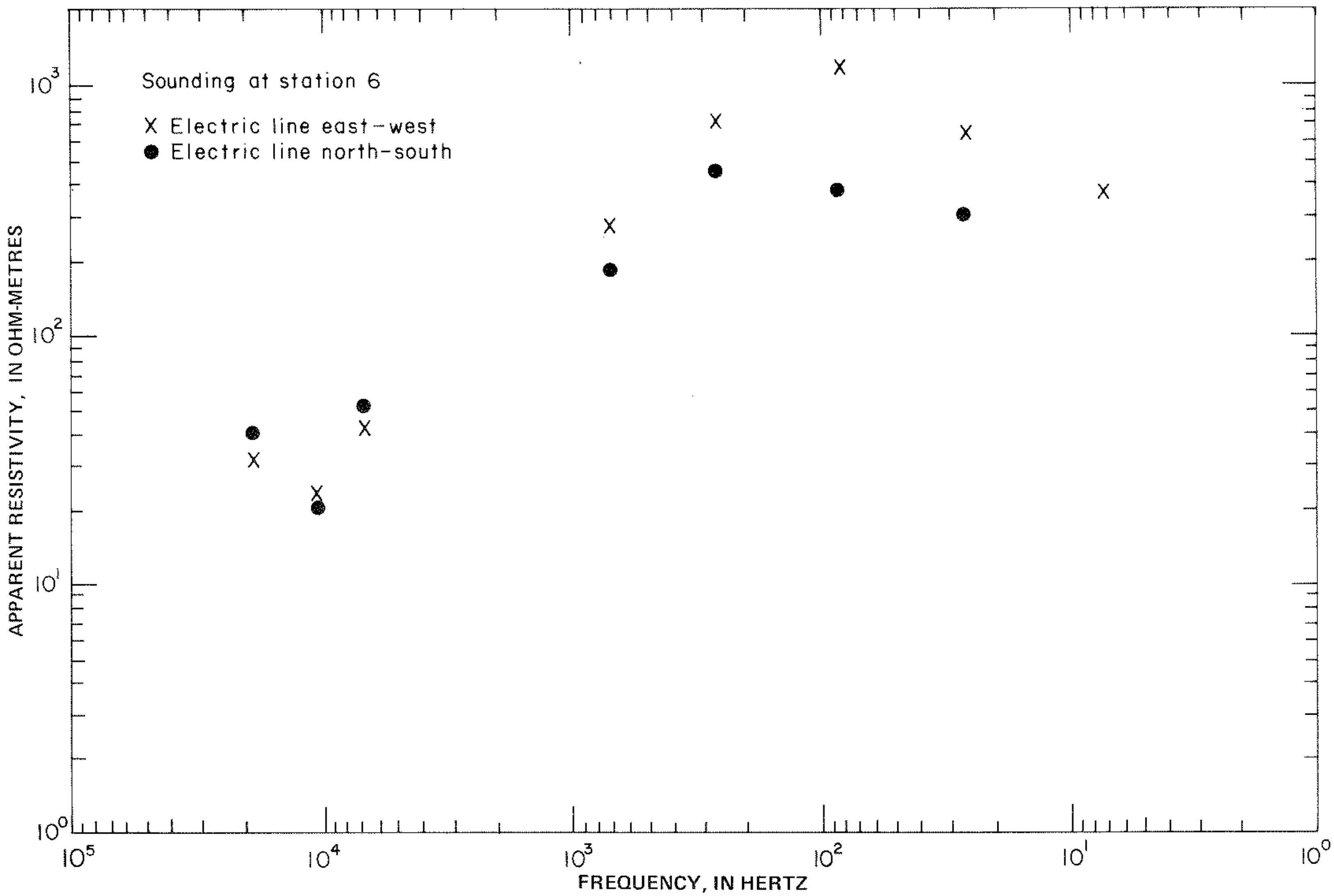
Figures 19 and 20 show the 86-Hz AMT data for north-south and east-west orientations, respectively, of the telluric lines. These maps are quite similar to the 26-Hz maps (fig. 15 and 16), but in addition, show a minor closed low south of C. J. Strike Reservoir. This low is not apparent on the lower frequency maps, so it must represent a relatively minor conductive zone.

Figures 21, 22, 23, and 24 are maps at 270, 700, 7,000, and 18,600 Hz in order of increasing frequency. A fairly abrupt change in the maps is evident between the 270-Hz data (fig. 21), which is similar to the lower frequency maps, and the 700-Hz data (fig. 22). Typical apparent resistivities here are around 100 ohm-metres, which corresponds to "skin depths" between 660 and 980 feet in this frequency range. Although the abrupt change indicates a principal electrical interface, there is insufficient geological data to correlate this to a lithologic boundary.

The 7,000-Hz map (fig. 23) reflects, in a broad sense, the surficial geology. The Holocene deposits have low resistivities, which are evident along Little Valley Creek. The older lacustrine deposits apparently have slightly higher resistivities, and the basalt and silicic volcanics have apparent resistivities above 100 ohm-metres. A similar pattern is shown in the 18,600-Hz data (fig. 24) but is somewhat less consistent because of local variations in soil depth at the widely spaced sounding stations. The correlation with surficial geology, in spite of the low station density, is considered to be good.

In magnetotelluric work, pseudosections are often used as interpretational aids. These most often show the resistivity variations along a

FIGURE 17. Apparent resistivities at station 6.



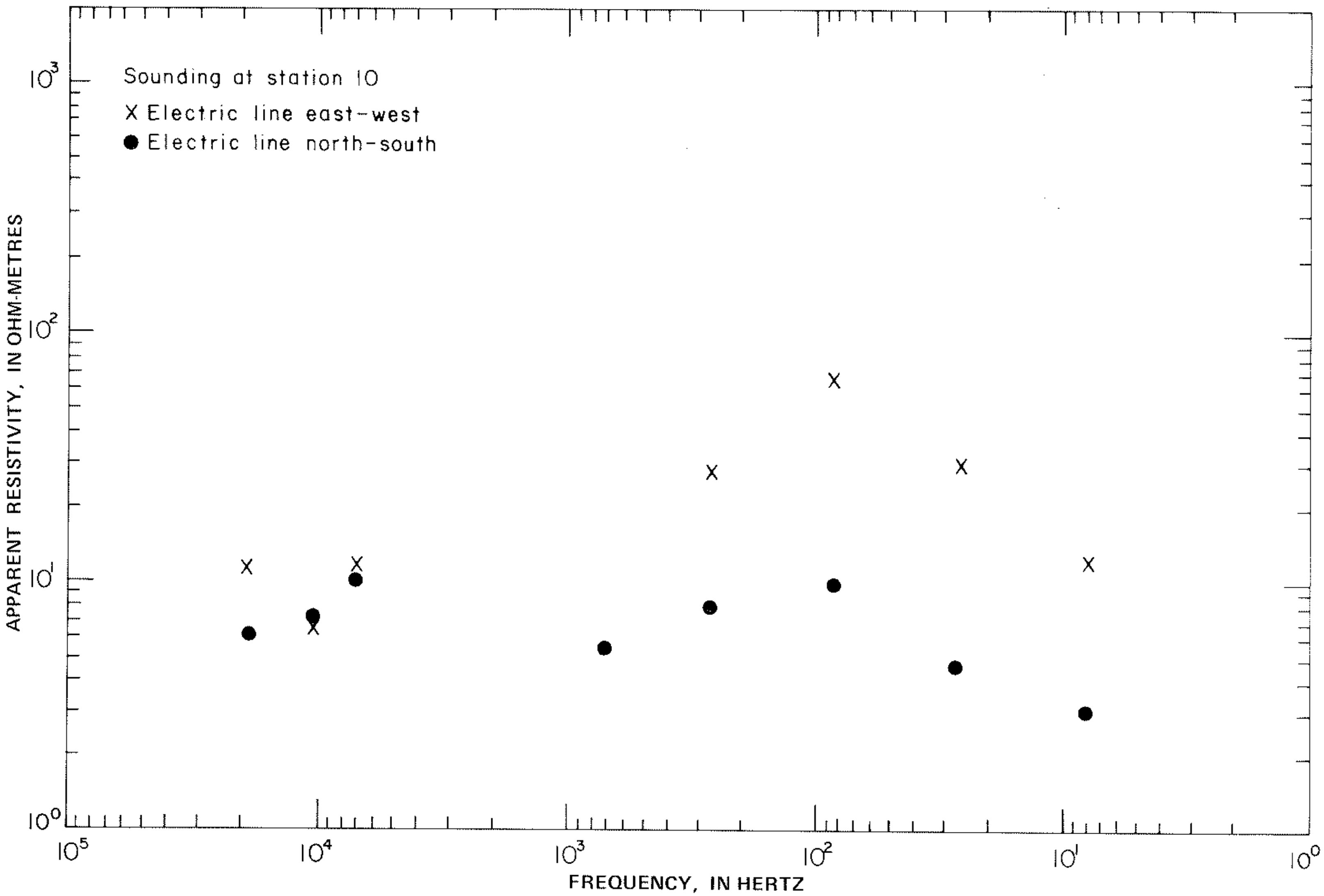
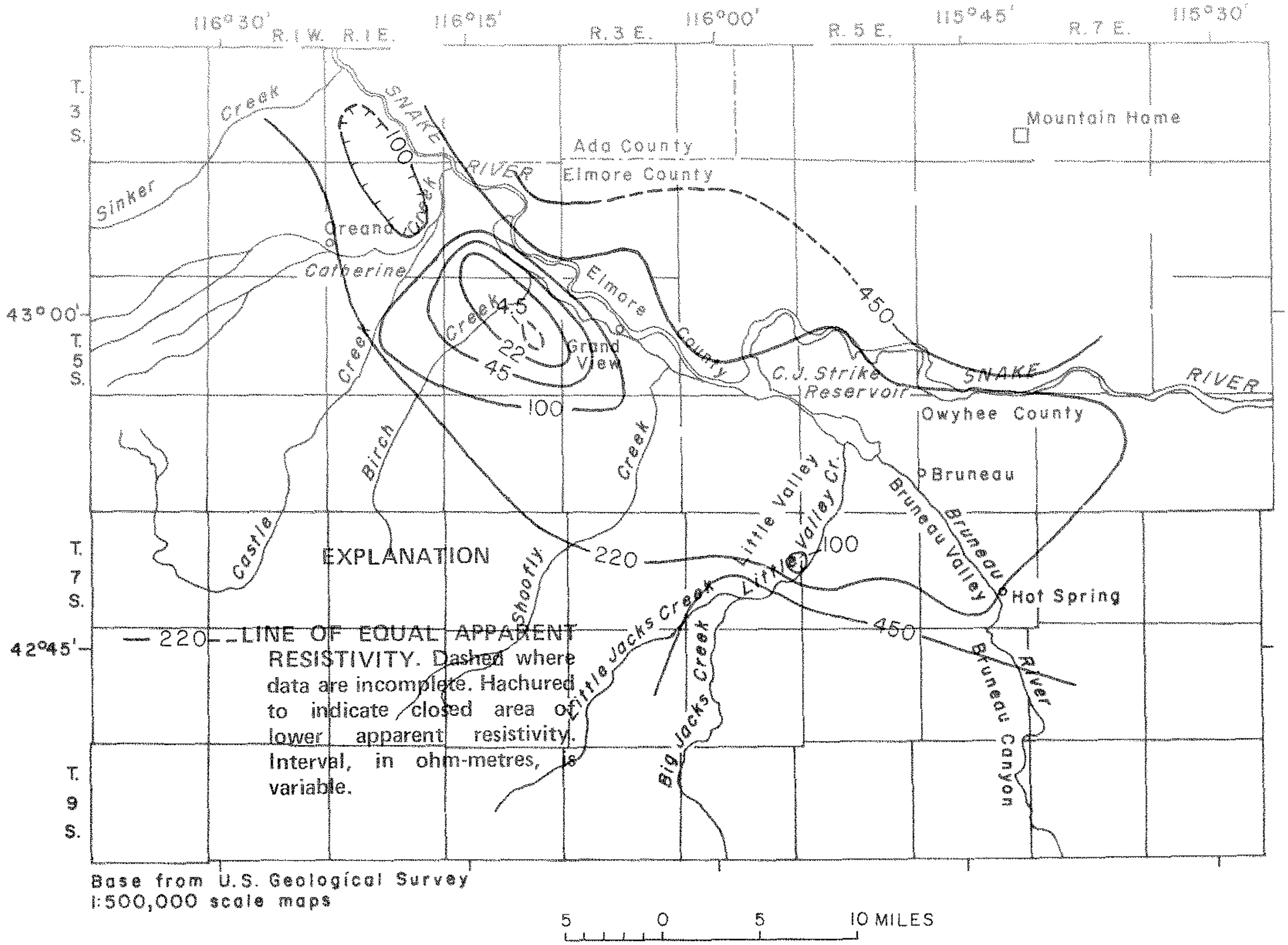


FIGURE 18. Apparent resistivities at station 10.

FIGURE 19. Apparent resistivity map at 86 hertz, electric line north-south.



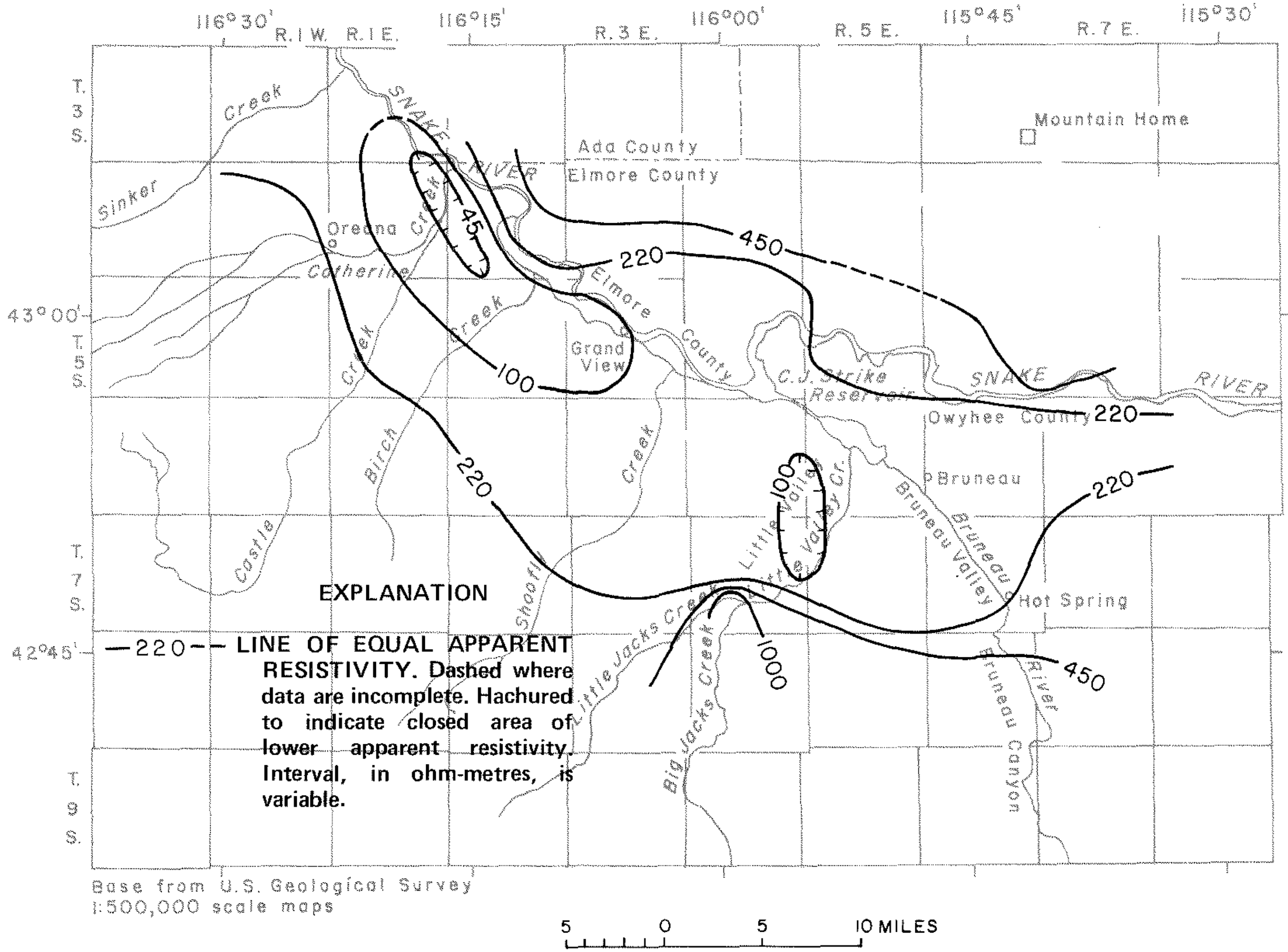
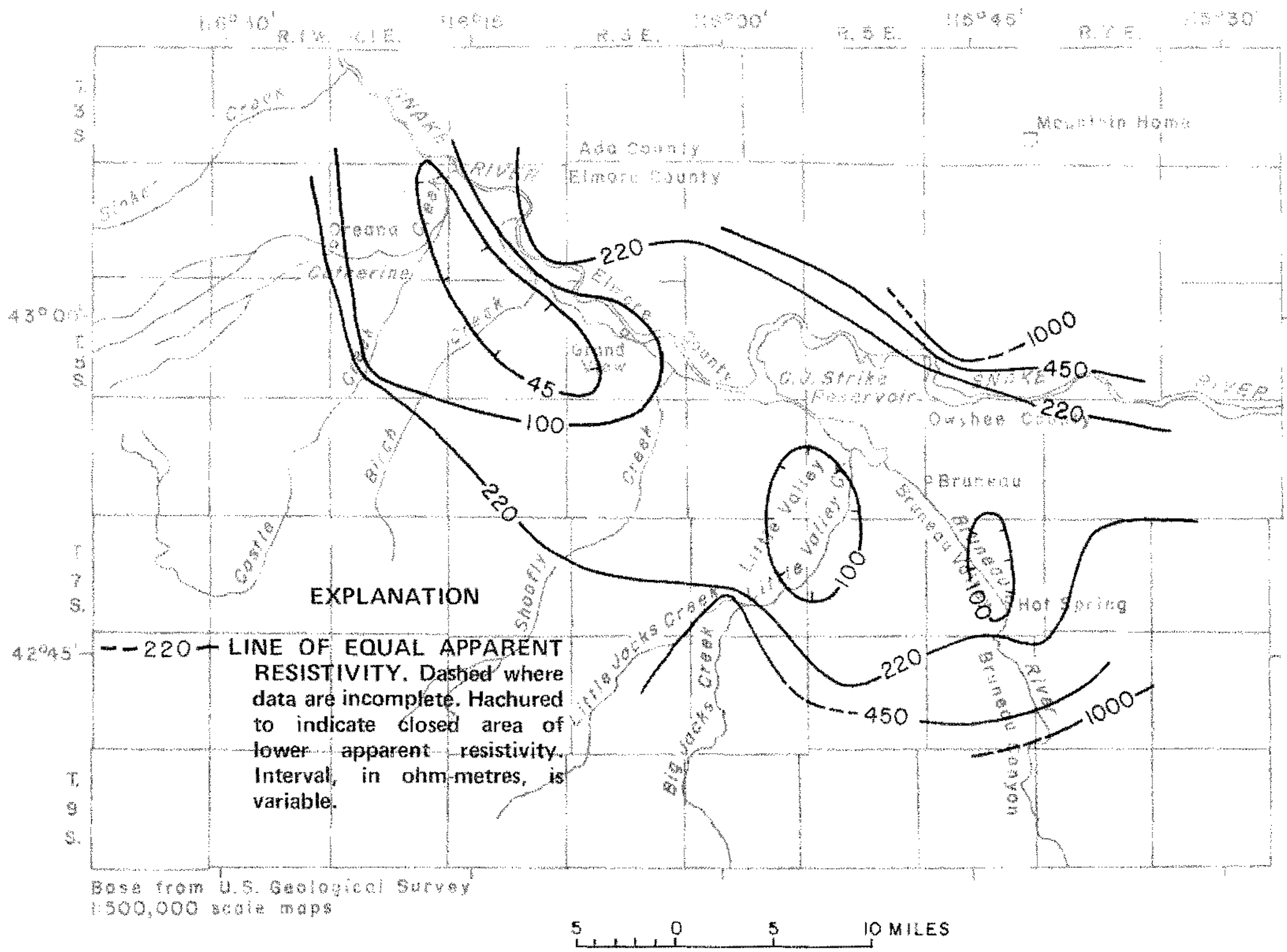


FIGURE 20. Apparent resistivity map at 86 hertz, electric line east-west.

FIGURE 21. Apparent resistivity map at 270 hertz.



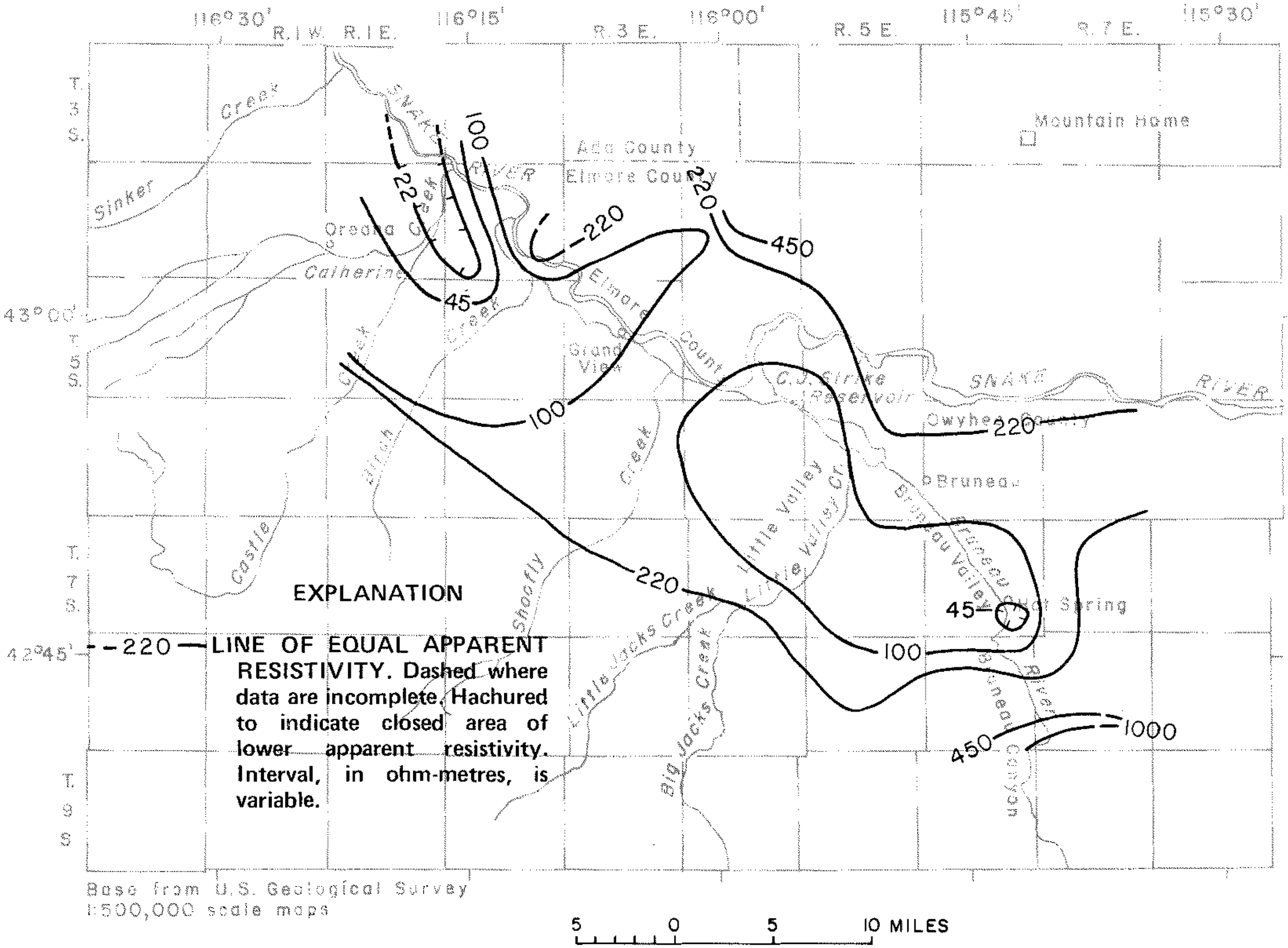
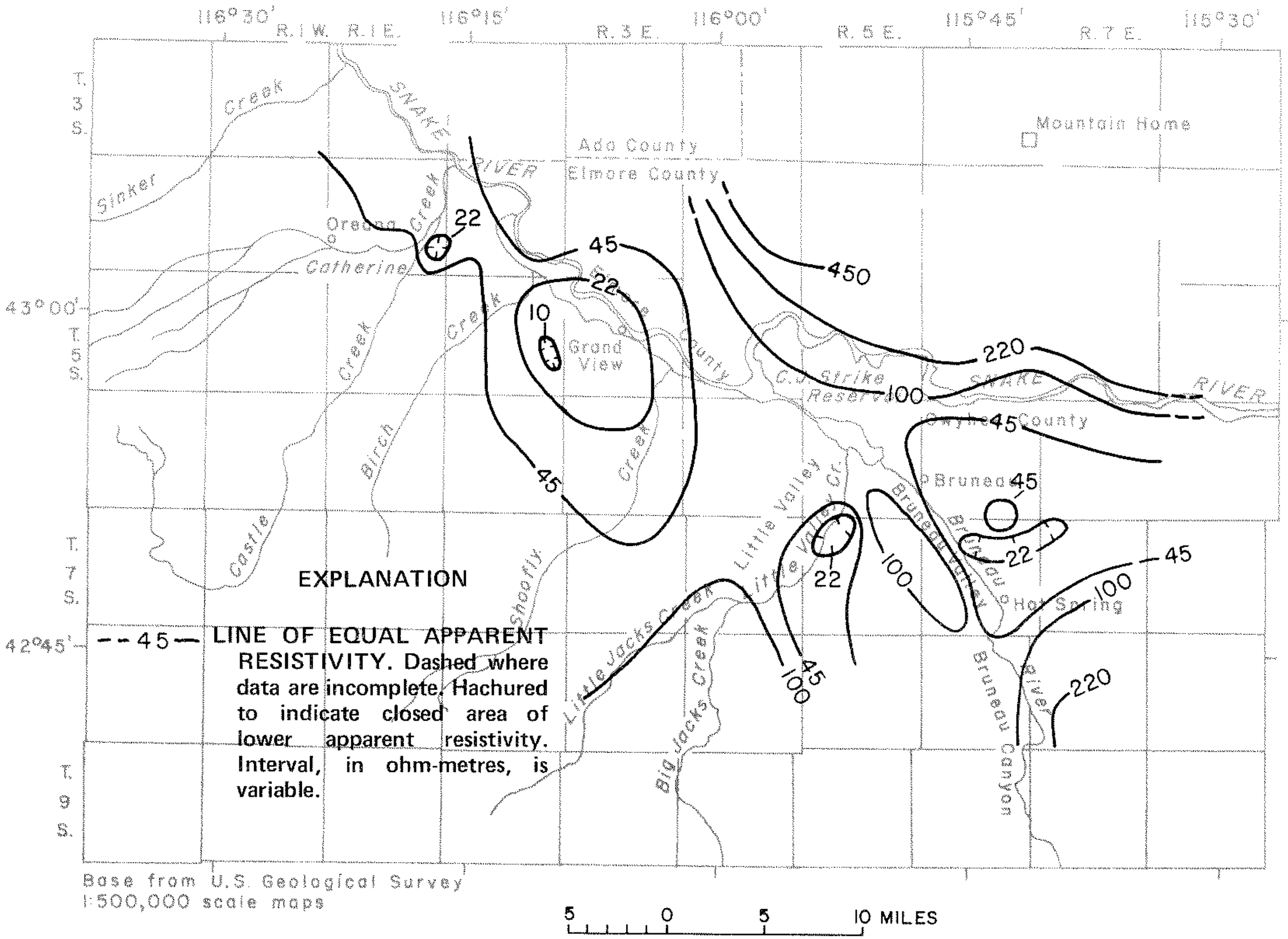


FIGURE 22. Apparent resistivity map at 700 hertz.

FIGURE 23. Apparent resisitivity map at 7,000 hertz.



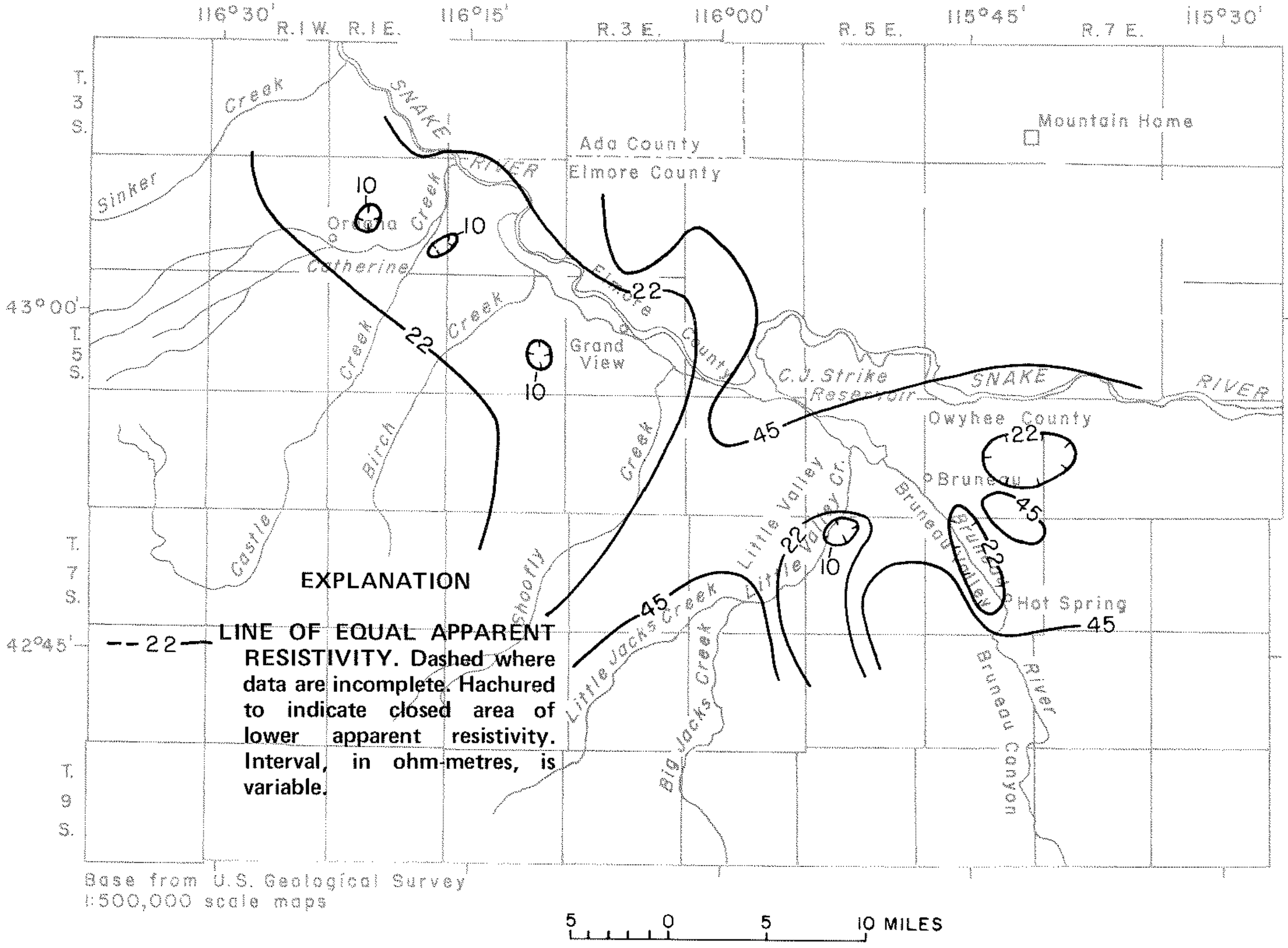


FIGURE 24. Apparent resistivity map at 18,600 hertz.

section as a function of frequency to give a qualitative indication of lateral and depth changes in resistivity, much as in induced polarization sections. In this investigation, AMT data are displayed in terms of "skin depth" pseudosections, in which an apparent resistivity is plotted vertically at the "skin depths" calculated for each measured frequency. This is, of course, another form of qualitative presentation that does not purport to indicate the actual depth to electrical interfaces. It gives an indication of the exploration depth and the variations of exploration depth, which can be very great in an area, something not shown by the normal pseudosections.

Figures 25 and 26 show two pseudosections along line NW-SE (fig. 13) from the mouth of Bruneau Canyon along the long axis of the resistivity low to west of Oreana. Figure 25 shows the north-south orientation of the electric line and figure 26 shows the east-west orientation. The sections clearly illustrate the large range in exploration depth obtained by this technique, as well as the limitation in depth in a low-resistivity section.

The pseudosections (fig. 25 and 26) show the principal resistivity anomaly extending close to the surface with a steep boundary on the west and a less steep boundary on the east. The AMT data give no indication of the thickness of the deep conductor. Other minor anomalies occurring at station 14 and at the mouth of the Bruneau Canyon are probably associated with fault zones and perhaps with broader sources at depths beyond the limit of the technique.

The principal resistivity low associated with the steep gradients in the gravity and magnetic field data (figs. 7 and 8) is perhaps indicative of faulting along a northwest trend through the region. However, there is no direct correlation between the principal AMT resistivity low and either the gravity or the magnetic field data. These latter data, and some additional information are now being reevaluated (D. R. Mabey, oral commun., 1973), so synthesis of this information would be premature at this time.

Extensive followup deep-resistivity investigations have recently been completed in this area, and the data are currently being interpreted. Preliminary results clearly support the AMT data (D.B. Jackson, oral commun., 1973).

CONCLUSIONS

This survey has revealed a major conductive anomaly in the region between Oreana and Grand View that is associated with thermal waters having a temperature range of 60° to 83°C as measured at land surface. The areal extent of the anomaly implies that a broad source of heat is present and that the thermal waters are not restricted to a few narrow fault zones, such as is implied in the Bruneau Canyon region.

The low resistivities observed at station 10 (fig. 26) are approaching a layer resistivity of about 2 ohm-metres, which implies a hot thermal-water reservoir whose rocks have been altered by the hot water. For example, 100°C saline water with 1,000 mg/l (milligrams per litre) salt concentration has a resistivity of about 2 ohm-metres (Keller and Frischknecht, 1966, p. 19), and the water analyses here are almost all less than 1,000 mg/l dissolved solids (table 3). Experience has shown that resistivities in the range of 2 ohm-metres are typical of rocks in the immediate vicinity of hot springs.

The limited data at present raises some serious problems in correlation between lithologic and electrical data in the region of the principal anomaly.

Additional geophysical work is now being interpreted, which, hopefully, will permit a synthesis of the deeper information. Certainly, recommendations for further work must be delayed until these additional data are available. There is, however, one piece of information that would contribute significantly to analysis of the electrical data. That is geophysical well-log information. Some of the deep wells reportedly have as much as 2,000 feet of open hole. A well-designed logging program in several of the deep wells would probably contribute significantly to the understanding of subsurface conditions.

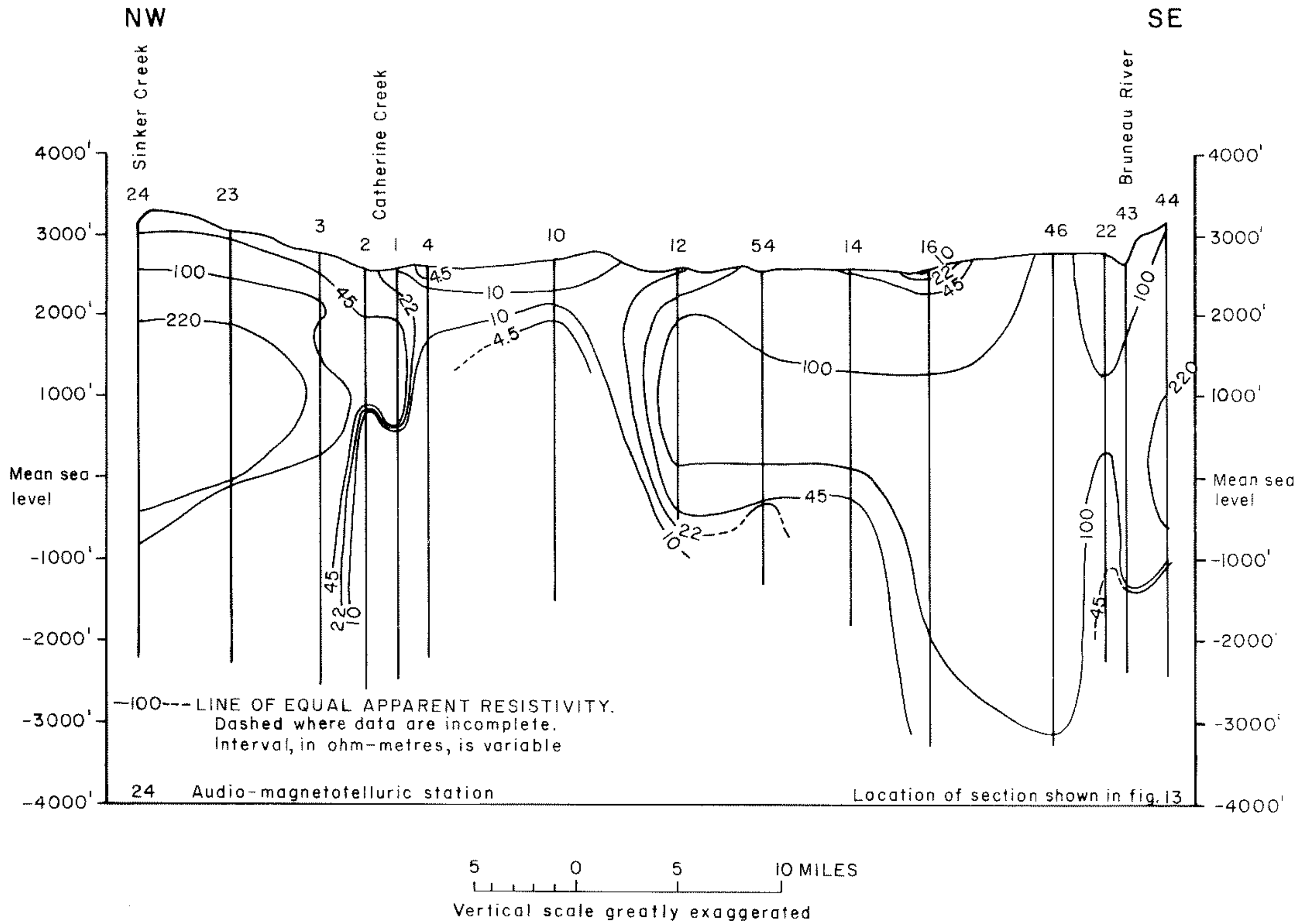
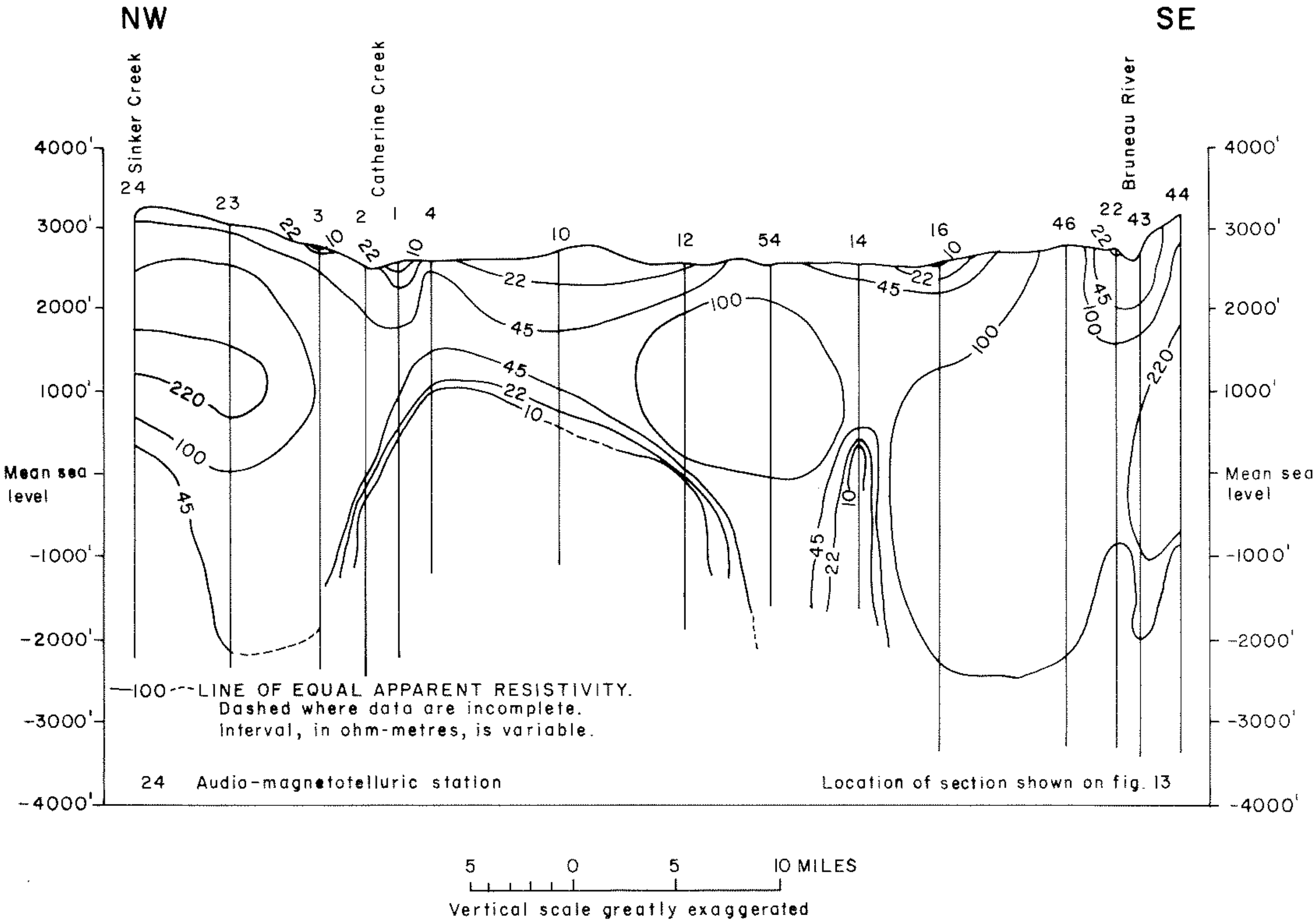


FIGURE 25. Skin depth pseudosection, telluric line north-south.

FIGURE 26. Skin depth pseudosection, telluric line east-west.



SELECTED REFERENCES

Bleil, D. F., 1964, Natural electromagnetic phenomena below 30 kc/s: Plenum Publishing Corp., New York, N. Y., 470 p.

Cagniard, Louis, 1953, Basic theory of the magnetic-telluric method of geophysical prospecting: Geophysics v. 18, no. 3, p. 605-635.

Frischknecht, F. C., 1973, Electromagnetic scale model study of geophysical methods using a plane wave source: Unpubl. thesis, Univ. of Colorado, 119 p.

Keller, G. V., and Frischknecht, F. C., 1966, Electrical methods in geophysical prospecting: Pergamon Press, Elmsford, N. Y., 519 p.

Madden, T. R., and Swift, C. M., Jr., 1969, Magneto-telluric studies of the electrical conductivity structures of the crust and upper mantle: p. 469-479.

Malde, H. E., Powers, H. A., and Marshall, C. H., 1963, Reconnaissance geologic map of west-central Snake River Plain, Idaho: U.S. Geol. Survey Misc. Geol. Inv. Map I-373, 1 sheet.

Strangway, D. W., Swift, C. M., Jr., and Holmer, R. C., 1973, The application of audio-frequency magneto-tellurics (AMT) to mineral exploration: Geophysics, v. 38, no. 6, p. 1159-1175.

Strangway, D. W., and Vozoff, Keeva, 1970, Mining exploration with natural electromagnetic fields, *in* Marly, L. W., ed., Mining and ground-water geophysics, 1967: Ottawa, Queens Printer, p. 105-122.

Vozoff, Keeva, 1972, The magneto-telluric method in the exploration of sedimentary basins: Geophysics, v. 37, no. 1, p. 98-141.

Ward, S. H., 1967, The electromagnetic method, *in* mining geophysics, v. 2, Theory: Tulsa, Okla., Soc. Explor. Geophysicists, p. 224-372.

APPENDIX B

LOGS OF WELLS

The drillers' logs of wells used to construct the geologic sections on figure 6 are given on the following pages. The logs were obtained from files of the U. S. Geological Survey and the Idaho Department of Water Resources. The terminology is that of the drillers and has only been slightly modified to give some degree of uniformity. The assignment of geologic units is based on the authors' interpretation of the logs.

LOGS OF WELLS

Material	Thickness (feet)	Depth (feet below land surface)
4S-1E-29ccd1 (Casing: 16-inch steel 0 to 100 feet; 14-inch steel 87 to 517 feet; 10-inch steel 1,410 to 3,040 feet)		
Topsoil	21	0
Idaho Group, undifferentiated		
Shale, blue	219	21
Shale, sandy, water	360	240
Shale, blue	1,617	600
Banbury Basalt		
Basalt	701	2,217
Idavada Volcanics		
Rhyolite, water	122	2,918
Total depth		3,040
4S-1E-34bad1 (Casing: 16-inch steel 0 to 1,030 feet; 10-inch steel 1,020 to 2,160 feet)		
Idaho Group, undifferentiated		
Clay, yellow	70	0
Shale, blue	130	70
Sand streak	5	200
Shale, blue	695	205
Shale, blue, sticky	590	900
Shale, sticky	140	1,490
Shale, gray, hard	350	1,630
Shale, blue, soft	110	1,980
Shale, white, chalky	30	2,090
Banbury Basalt		
Rock, gray	10	2,120
Shale, gray, rock layers	390	2,130
Rock, red (cinders)	10	2,520
Rock, black	140	2,530
Shale, gray	230	2,670
Idavada Volcanics		
Rock, gray, soft	80	2,900
Total depth		2,980

Material	Thickness (feet)	Depth (feet below land surface)
4S-2E-19acb1 (Casing: 14-inch steel 0 to 50 feet; 10¼-inch steel 0 to 402 feet; 6¼-inch steel 0 to 2,515 feet)		
Soil, sandy	4	0
Gravel, angular	38	4
Idaho Group, undifferentiated		
Clay, brown, with sand streaks	131	42
Clay, blue	237	173
Clay, blue, sandy	5	410
Clay, blue	242	415
Shale, blue	155	657
Shale, gray	155	812
Clay, blue	699	967
Cinder bed, consolidated	6	1,666
Cinders and shale, interbedded	13	1,672
Shale, gray	15	1,685
Cinder bed, consolidated	1	1,700
Shale, gray	35	1,701
Cinder bed, consolidated	4	1,736
Shale, gray	80	1,740
Cinder bed, consolidated	2	1,820
Clay, blue	118	1,822
Shale, gray	345	1,940
Banbury Basalt		
Basalt, black	6	2,285
Shale, gray	61	2,291
Basalt, black	8	2,352
Shale, gray	40	2,360
Basalt, black	95	2,400
Shale, gray	24	2,495
Basalt, rhyolite, and shale	43	2,519
Rhyolite	33	2,562
Shale, gray	241	2,595
Rhyolite	9	2,836
Shale, gray	1	2,845
Rhyolite	10	2,846
Shale, gray	4	2,856
Rhyolite	26	2,860
Shale, gray	2	2,886

Material	Thickness (feet)	Depth (feet below land surface)
4S-2E-19acb1--Continued		
Banbury Basalt (Cont'd.)		
Rhyolite	92	2,888
Sand, black, water	26	2,980
Shale, red	6	3,006
Idavada Volcanics		
Sand, black, water	18	3,012
Basalt, black	50	3,030
Total depth		3,080
5S-1E-10bdd1 (Casing: 12-inch steel 0 to 80 feet; 10¾-inch steel 0 to 1,150 feet; 10-inch steel 1,050 to 1,840 feet; 8⅝-inch steel 1,840 to 2,120 feet)		
Topsoil	40	0
Idaho Group, undifferentiated		
Shale, blue, soft	431	40
Sand streak	1	471
Shale	659	472
Rock (sedimentary)	4	1,131
Shale with hard streaks	146	1,135
Shale with rock floaters	62	1,281
Rock, purple	62	1,343
Shale, gray, hard	41	1,405
Shale, hard, soft layers	103	1,446
Shale, hard, soft white layers	20	1,549
Rock, gray, hard, (sedimentary)	19	1,569
Shale, gray, hard	63	1,588
Shale, blue and gray	40	1,651
Shale with hard streaks	409	1,691
Banbury Basalt		
Rock, white, hard	5	2,100
Rock, gray	70	2,105
Basalt, black, water	65	2,175
Shale, gray	320	2,240
Rock, gray, hard	60	2,560
Rock, gray	180	2,620
Shale, gray	40	2,800

Material	Thickness (feet)	Depth (feet below land surface)
5S-1E-10bdd1--Continued		
Idavada Volcanics		
Shale with hard streaks	26	2,840
Rock, gray, porous, water	94	2,866
Total depth		2,960
5S-1E-21cbc1 (Casing: 8-inch steel 0 to 96 feet)		
Sand and gravel	64	0
Idaho Group, undifferentiated		
Shale, blue	557	64
Banbury Basalt		
Basalt	39	621
Total depth		660
5S-2E- 2cda1 (Casing: 8-inch steel 0 to 160 feet)		
Not reported	60	0
Idaho Group, undifferentiated		
Shale, blue	550	60
Sand streak, water	2	610
Shale, blue, some rock floaters	591	612
Shale with sand streaks, water	307	1,203
Shale, gray	270	1,510
Banbury Basalt		
Rock, gray	30	1,780
Rock, gray, with black layers	480	1,810
Shale, gray	91	2,290
Idavada Volcanics		
Rock, gray	80	2,381
Total depth		2,461
5S-2E- 5bcd1		
Clay, yellow	124	0
Sand	3	124
Idaho Group, undifferentiated		
Shale	1,321	127
Shale, hard	88	1,448

Material	Thickness (feet)	Depth (feet below land surface)
5S-2E- 5bcd1--Continued		
Idaho Group, undifferentiated (Cont'd.)		
Lava	1	1,536
Sand, black	1	1,537
Banbury Basalt		
Lava	431	1,538
Cinders, shale, and lava	27	1,969
Idavada Volcanics		
Rock, very hard	13	1,996
Total depth		2,009
5S-2E-13ada1 (Casing: 6-inch steel 0 to 126 feet)		
Soil	20	0
Sand, red	40	20
Clay, yellow	30	60
Idaho Group, undifferentiated		
Gravel, dark	33	90
Shale, blue, sticky	12	123
Shale, blue	169	135
Rock, light-yellow, hard	1	304
Shale, blue, sand lense at bottom with water	155	305
Shale, blue, sand lense at bottom with water	18	460
Shale, blue, sand lense at bottom with water	111	478
Shale, blue, sand lense at bottom with water	165	589
Shale, blue, sand lense at bottom with water	8	754
Shale, blue, crevice at bottom	211	762
Shale, blue	43	973
Shale, blue	84	1,016
Shale, blue	50	1,100
Shale, blue	24	1,150
Shale, blue	244	1,174
Shale, blue, rock lense at bottom	17	1,418
Shale, blue, sand lense at bottom with water	42	1,435
Shale, blue, rock lense at bottom with water	12	1,477
Shale, blue, water	26	1,489
Rock, black, hard	6	1,515
Shale, blue	219	1,521
Banbury Basalt		
Lava, black, hard	8	1,740
Total depth		1,748

Material	Thickness (feet)	Depth (feet below land surface)
5S-3E-20ada1		
(Casing: 6-inch steel 0 to 1,620 feet)		
Topsoil and sand	25	0
Gravel	2	25
Clay	5	27
Gravel	2	32
Idaho Group, undifferentiated		
Clay with sand stringers	34	34
Gravel, water	11	68
Shale, blue, with gravel	33	79
Shale, blue, sand streak at bottom with water	428	112
Shale, blue, sand streak at bottom with water	385	540
Shale, blue	185	925
Shale, blue, with sand streaks	90	1,110
Shale with lava streaks	70	1,200
Lava	7	1,270
Pumice, purple	19	1,277
Lava	2	1,296
Shale with rock floaters	107	1,298
Rock, gray, sedimentary	2	1,405
Shale, gray	18	1,407
Rock, gray, sedimentary	20	1,425
Basalt with shale	115	1,445
Banbury Basalt		
Basalt	80	1,560
Shale, gray	164	1,640
Basalt	1	1,804
Shale	58	1,805
Basalt	4	1,863
Shale, purple	13	1,867
Shale, white-chalky	10	1,880
Rock, water	14	1,890
Rock, gray, water	46	1,904
Shale, reddish-brown	54	1,950
Shale, gray	36	2,004
Shale, soft	9	2,040
Idavada Volcanics		
Rock, gray	8	2,049
Shale, unusually hard, water	83	2,057
Basalt, black, with lime streaks	19	2,140
Sandstone, gray, with lime streaks	221	2,159

Material	Thickness (feet)	Depth (feet below land surface)
5S-3E-20ada1--Continued		
Idavada Volcanics (Cont'd.)		
Shale, gray, very hard	2	2,380
Shale	30	2,382
Rock, black, broken, water	8	2,412
Total depth		2,420
5S-3E-26bcb1		
(Casing: 14-inch steel 0 to 1,970 feet)		
Topsoil	2	0
Gravel	17	2
Idaho Group, undifferentiated		
Clay, yellow	18	19
Gravel	39	37
Clay, blue	18	76
Shale, blue	551	94
Shale, brittle	9	645
Sand	1	654
Shale, with sand	55	655
Shale, hard	110	710
Shale, soft, sand streaks	166	820
Sand	2	986
Shale, rock streaks	239	988
Rock, loose	7	1,227
Shale, rock streaks	26	1,234
Rock, hard	4	1,260
Shale	6	1,264
Rock	14	1,270
Shale, gray, hard	36	1,284
Shale, purple	34	1,320
Sandstone	38	1,354
Basalt, black	12	1,392
Shale	85	1,404
Basalt, interbedded shale	3	1,489
Shale	20	1,492
Banbury Basalt		
Basalt	320	1,512
Shale	10	1,832
Basalt	268	1,842
Shale	140	2,110

Material	Thickness (feet)	Depth (feet below land surface)
5S-3E-26bcb1--Continued		
Banbury Basalt (Cont'd.)		
Rock, soft	11	2,250
Rock, water	19	2,261
Shale, hard	10	2,280
Volcanic ash, gray	460	2,290
Idavada Volcanics		
Rock, gray, hard	30	2,750
Shale, red	10	2,780
Shale, gray	90	2,790
Rock, red, water	90	2,880
Total depth		2,970
5S-3E-34add1 (Casing: 8-inch steel 0 to 85 feet)		
Clay	25	0
Clay, yellow	45	25
Idaho Group, undifferentiated		
Shale	1,420	70
Total depth		1,490
6S-3E-2cbc1 (Casing: 12-inch steel 0 to 106 feet)		
Gravel and clay	40	0
Idaho Group, undifferentiated		
Shale, blue	882	40
Shale, gray, hard	88	922
Shale, soft, with hard streaks	630	1,010
Shale, gray (crumbling)	108	1,640
Rock, gray, hard	3	1,748
Shale, white, and limestone	19	1,751
Sandstone, hard	60	1,770
Sandstone, soft	7	1,830
Sandstone, water (5 inches)	30	1,837
Clay, blue, sticky	54	1,867
Clay with hard shale layers	49	1,921
Sandstone with clay layers	63	1,970
Banbury Basalt		
Basalt and cinders, black	13	2,033
Basalt	64	2,046

Material	Thickness (feet)	Depth (feet below land surface)
6S-3E-2cbc1 --Continued		
Banbury Basalt (Cont'd.)		
Basalt, hard	10	2,110
Shale, hard, water (at 2135)	25	2,120
Basalt, hard, rough	65	2,145
Basalt	15	2,210
Shale and cinders, black	7	2,225
Shale, with hard rock layers	228	2,232
Clay, red	3	2,460
Idavada Volcanics		
Rock, gray (rhyolite)	37	2,463
Pumice, gray	250	2,500
Shale, brown and gray	190	2,750
Pumice, gray	130	2,940
Total depth		3,070

6S-3E-2ccc1
(Casing: 10-inch steel 0 to 160 feet)

Topsoil	8	0
Gravel	14	8
Clay, yellow	39	22
Idaho Group, undifferentiated		
Clay, blue	341	61
Sand, fine	2	402
Clay, blue, water	496	404
Shale, blue and white	360	900
Sand streaks	20	1,260
Shale	266	1,280
Rock, black	34	1,546
Gravel, green, water	2	1,580
Shale with rock layers	38	1,582
Sand(?), water	5	1,620
Shale, green and gray, with rock layers	121	1,625
Rock, gray, hard	5	1,746
Sandstone, soft layers, water	162	1,751
Banbury Basalt		
Rock, broken, water	27	1,913
Total depth		1,940

Material	Thickness (feet)	Depth (feet below land surface)
6S-3E-11ccc1 (Casing: 6-inch steel 0 to 32 feet)		
Soil	9	0
Gravel, dark, hard	12	9
Clay, yellow, soft	6	21
Idaho Group, undifferentiated		
Shale, blue, hard, thin sand layers	399	27
Sand, gray, water	22	426
Sand, gray, interbedded shale, water	284	448
Shale, blue, hard, thin sand layers, water	346	732
Sand, black, soft, water	26	1,078
Shale, blue, hard	26	1,104
Sand, black and white, water	78	1,130
Shale, blue, hard	137	1,208
Sand, green, hard	30	1,345
Shale, green, hard	18	1,375
Sand, green, soft	30	1,393
Total depth		1,423
6S-3E-14bcc1 (Casing: 6-inch steel 0 to 426 feet)		
Soil	15	0
Gravel	9	15
Idaho Group, undifferentiated		
Clay, yellow, soft	2	24
Shale, blue, soft	228	26
Sand, gray, soft	154	254
Shale, blue, hard	582	408
Sand, black and blue, water	60	990
Sand, white to dark, soft, water	70	1,050
Shale, blue, hard	120	1,120
Sand, green, water	10	1,240
Total depth		1,250
6S-3E-23cdd1 (Casing: 14-inch steel 0 to 248 feet)		
Soil	20	0
Sand, gray	196	20

Material	Thickness (feet)	Depth (feet below land surface)
6S-3E-23cdd1--Continued		
Idaho Group, undifferentiated		
Clay, blue	5	216
Clay and sand	27	221
Clay, blue	122	248
Sand, water	3	370
Clay, blue	627	373
Sand, black	2	1,000
Clay, blue	148	1,002
Rock, blue and green, soft, water	20	1,150
Banbury Basalt		
Rock, black, hard, water	71	1,170
Total depth		1,241
6S-4E-14abc1 (Casing: 16-inch steel 0 to 320 feet; and 12-inch steel 0 to 1,600 feet)		
Clay	10	0
Clay, brown	50	10
Clay and gravel	25	60
Idaho Group, undifferentiated		
Clay, blue	35	85
Clay, brown	15	120
Clay, blue, water (at 180 feet)	80	135
Sand, blue and black	10	215
Sand, blue and black, very fine	6	225
Clay, blue	19	231
Sand	10	250
Clay, blue, with blue sandstone	60	260
Clay, blue, with white soapstone	155	320
Shale, blue	15	475
Clay, blue	85	490
Clay, blue, hard	20	575
Clay, blue, and sand	55	595
Clay, blue, trace of black rock	35	650
Shale, blue	30	685
Shale, blue, and sandstone, blue	180	715
Shale, blue, sticky	40	895
Shale, blue	80	935
Sandstone	5	1,015
Shale, blue, sticky	225	1,020

Material	Thickness (feet)	Depth (feet below land surface)
6S-4E-14abc1--Continued		
Idaho Group, undifferentiated (Cont'd.)		
Clay, blue, sticky	245	1,245
Rock, black	20	1,490
Shale, blue	13	1,510
Shale, white	2	1,523
Clay, blue, sticky	175	1,525
Clay, blue	20	1,700
Basalt, black	8	1,720
Clay, blue	13	1,728
Banbury Basalt		
Rock, hard, water	10	1,741
Rock, white and black	14	1,751
Shale, blue, water	10	1,765
Rock, black	20	1,775
Shale, blue, water	12	1,795
Sand, red	23	1,807
Idavada Volcanics		
Rhyolite, hard, water	23	1,830
Shale, blue, water	10	1,853
Rhyolite, water	35	1,863
Rhyolite, crevices, water	7	1,898
Total depth		1,905

6S-4E-35cda1
(Casing: 20-inch steel 0 to 26 feet;
18-inch steel 26 to 581 feet;
16-inch steel 491 to 892 feet;
perforated from 730 to 810 feet and
870 to 890 feet, 1,280 and 320 ¼-inch by 2-inch perforations respectively)

Topsoil	57	0
Idaho Group, undifferentiated		
Shale, gray	50	57
Shale, gray, water	68	107
Sand, gray, water	3	175
Shale, gray	46	178
Shale, brown	29	224
Shale, gray	22	253
Sand, gray, water	5	275

Material	Thickness (feet)	Depth (feet below land surface)
6S-4E-35cda1--Continued		
Idaho Group, undifferentiated (Cont'd.)		
Shale, gray	80	280
Sand and clay, gray	50	360
Shale, gray	15	410
Sand, gray, water	10	425
Shale, gray	88	435
Sand, gray, water	15	523
Shale, blue	112	538
Shale, gray	65	650
Sand, black	5	715
Shale, gray	27	720
Clay, tan	8	747
Clay, gray	27	755
Shale, gray	8	782
Sand, black, coarse, water	5	790
Shale, gray	42	795
Clay, brown	8	837
Shale, gray	110	845
Total depth		955

6S-4E-36ccc1
(Casing: 14-inch steel 0 to 140 feet;
12- inch steel 405 to 920 feet;
10-inch steel 895 to 958 feet;
8-inch steel 955 to 1,017 feet)

Material	Thickness (feet)	Depth (feet below land surface)
Soil	25	0
Clay	55	25
Idaho Group, undifferentiated		
Shale, gray	40	80
Shale, soft	15	120
Clay, shale and silt, gray	285	135
Sand, gray, fine	5	420
Shale, clay and silt	270	425
Clay, green	20	695
Cinders, black	15	715
Shale, gray, clay and silt	150	730
Sand, black, coarse, water	5	880
Clay, blue	28	885
Gravel, water	4	913

Material	Thickness (feet)	Depth (feet below land surface)
6S-4E-36ccc1--Continued		
Idaho Group, undifferentiated (Cont'd.)		
Clay, blue, sticky	98	917
Sand, water	5	1,015
Shale, gray, and clay, black	85	1,020
Banbury Basalt		
Basalt, black	12	1,105
Clay, black, and rock	8	1,117
Clay, red, and gravel, brown	16	1,125
Basalt	4	1,141
Clay, black	10	1,145
Rock, brown	5	1,155
Shale and clay	10	1,160
Basalt, black	30	1,170
Clay, brown	7	1,200
Basalt, black, hard	48	1,207
Clay, red and rock	15	1,255
Rocks and clay	30	1,270
Clay, gray and shale	56	1,300
Rocks, brown, and tuff, red, water	6	1,356
Rock, brown and black, and clay	98	1,362
Basalt, hard	10	1,460
Sand	5	1,470
Rock and clay	250	1,475
Sand, water	15	1,725
Rock and shale	150	1,740
Sand, brown, water	10	1,890
Basalt, black, broken, water	15	1,900
Idavada Volcanics		
Rhyolite, latite, water	85	1,915
Total depth		2,000
6S-5E-10ddd1 (Casing: 6-inch steel 0 to 78 feet)		
Soil	10	0
Idaho Group, undifferentiated		
Clay, yellow	49	10
Shale, blue	496	59
Sandstone, gray	20	555

Material	Thickness (feet)	Depth (feet below land surface)
6S-5E-10ddd1--Continued		
Idaho Group, undifferentiated (Cont'd.)		
Shale, blue	10	575
Sandstone, gray	40	585
Shale, blue	181	625
Rock, gray	2	806
Shale, blue, some sand	97	808
Rock, white to cream-colored	4	905
Sand, gray, water	211	909
Shale, brown	45	1,120
Sandstone, gray	15	1,165
Shale, brown	477	1,180
Sandstone, gray, water	10	1,657
Banbury Basalt		
Rock, hard		1,667
Total depth		1,667
6S-5E-18ccb1 (Casing: 12-inch steel 0 to 651 feet)		
Topsoil	12	0
Idaho Group, undifferentiated		
Clay, yellow	75	12
Clay, blue	374	87
Sand, water	1	461
Clay, blue	271	462
Shale, brown and green	172	733
Rock, black	16	905
Sandstone, water	11	921
Shale, gray	119	932
Basalt	2	1,051
Shale, gray	268	1,053
Sandstone	11	1,321
Basalt	57	1,332
Shale, gray, some rock	616	1,389
Banbury Basalt		
Shale, black	15	2,005
Basalt, mineralized	370	2,020
Shale and sandstone	310	2,390
Rock, black	40	2,700
Rock, caving	6	2,740

Material	Thickness (feet)	Depth (feet below land surface)
6S-5E-18cbb1--Continued		
Banbury Basalt (Cont'd.)		
Basalt, interbedded with shale	34	2,746
Idavada Volcanics		
Rock	129	2,780
Shale and rock	51	2,909
Total depth		2,960
6S-5E-24bca1 (Casing: 6-inch steel 0 to 76 feet)		
Soil	8	0
Gravel	10	8
Idaho Group, undifferentiated		
Clay, yellow	15	18
Shale, blue	395	33
Sand, blue	87	428
Shale, blue, sticky at base	106	515
Rock, gray, hard	18	621
Rock, black, hard	18	639
Sandstone, black, water	1	657
Shale, blue	8	658
Rock, black, soft	12	666
Shale, blue	2	678
Banbury Basalt		
Rock, black, hard, water	42	680
Rock, black, soft	12	722
Shale, blue	98	734
Rock, black, hard	8	832
Shale, blue	205	840
Not reported	50	1,045
Total depth		1,095
6S-5E-24caa1 (Casing: 6-inch steel 0 to 430 feet)		
Soil and gravel	30	0
Idaho Group, undifferentiated		
Clay, yellow	6	30
Shale, blue, soft, muddy crevice with water; water rose to 30 feet of surface	94	36

Material	Thickness (feet)	Depth (feet below land surface)
6S-5E-24caa1--Continued		
Idaho Group, undifferentiated (Cont'd.)		
Shale, blue, soft, muddy	170	130
Sand, bluish, fine	300	300
Shale, blue, with layers of sticky clay 2 to 10 feet thick	180	600
Lava, black	1	780
Not reported	136	781
Banbury Basalt		
Lava, black	3	917
Sand, gray, water, well flows 1 gpm	18	920
Lava, black	1	938
Shale, blue	21	939
Sand, gray, muddy with thin sandstone layers, water; well flows 15 gpm	365	960
Total depth		1,325
6S-5E-24ddb1 (Casing: 8-inch steel 0 to 240 feet; 6-inch steel 0 to 1,400 feet)		
Soil	10	0
Gravel, dark colored	18	10
Idaho Group, undifferentiated		
Shale, blue, crevice at bottom	212	28
Shale, blue	60	240
Sand, gray	300	300
Shale, blue, sand at bottom with water	340	600
Rock, black	4	940
Shale, blue	16	944
Sand	140	960
Banbury Basalt		
Rock, broken	300	1,100
Rock, soft, broken	525	1,400
Idavada Volcanics		
Rock, very hard	13	1,925
Total depth		1,938
6S-5E-29dcc1 (Casing: 4-inch steel 0 to 20 feet)		
Soil	10	0
Gravel, dark, hard	4	10

Material	Thickness (feet)	Depth (feet below land surface)
6S-5E-29dcc1--Continued		
Idaho Group, undifferentiated		
Clay, yellow	5	14
Shale, blue, some sand, water	935	19
Sand, gray, water	6	954
Shale, blue	150	960
Sand, gray	10	1,110
Shale, blue	40	1,120
Sand, gray	3	1,160
Shale, blue, thin layers of sand	235	1,163
Sand, white	10	1,398
Sand and shale, blue	11	1,408
Sand, white, water	32	1,419
Shale, blue	63	1,451
Sandstone, gray, water	46	1,514
Total depth		1,560
6S-6E-12ccd1 (Casing: 16-inch steel 0 to 5 feet; 12-inch steel 0 to 170 feet; 8-inch steel 0 to 915 feet; well screen set from 920 to 980 feet)		
Soil, sand, and silt	5	0
Idaho Group, undifferentiated		
Clay, light brown	55	5
Clay, blue	110	60
Shale, blue	180	170
Shale, blue, with seeps of water	100	350
Shale, blue, some sulphur	150	450
Shale, blue	340	600
Sandstone, water	50	940
Total depth		990
6S-6E-19ccd1 (Casing: 6-inch steel 0 to 277 feet)		
Soil	13	0
Gravel	8	13

Material	Thickness (feet)	Depth (feet below land surface)
6S-6E-19ccd1--Continued		
Idaho Group, undifferentiated		
Clay, yellow	64	21
Shale, blue	425	85
Sandstone, gray	90	510
Shale, blue, some sand and water at 820 feet	228	600
Banbury Basalt		
Rock, black	22	828
Shale, blue	17	850
Rock, black, water	13	867
Sandstone, gray	33	880
Total depth		913
6S-6E-19dbd1 (Casing: 6-inch steel 0 to 75 feet; 4-inch steel 0 to 229 feet)		
Soil	19	0
Clay, yellow	39	19
Gravel and sand	16	58
Idaho Group, undifferentiated		
Chalk, yellow	120	74
Shale, blue	486	194
Sand, blue	28	680
Shale, brown, sandy	42	708
Shale, blue, water	57	750
Talc, blue	1	807
Shale, blue	154	808
Rock, black, hard	3	962
Shale, blue	1	965
Rock, black, hard	11	966
Shale, blue	4	977
Banbury Basalt		
Rock, black, hard	32	981
Talc, blue	1	1,013
Rock, black, hard	6	1,014
Shale, blue	11	1,020
Rock, black, hard	2	1,031
Talc, blue	10	1,033
Shale, blue	5	1,043
Rock, black, hard	5	1,048

Material	Thickness (feet)	Depth (feet below land surface)
6S-6E-19dbd1--Continued		
Banbury Basalt (Cont'd.)		
Talc, blue	33	1,053
Rock, black, hard	7	1,086
Shale, blue	13	1,093
Rock, black, hard	1	1,106
Shale , blue	57	1,107
Rock, black, hard	3	1,164
Sand, black	4	1,167
Sand, light	10	1,171
Sandstone	119	1,181
Talc, light	1	1,300
Rock, light, hard	1	1,301
Sand, caving	10	1,302
Shale, sandy	35	1,312
Total depth		1,347
6S-6E-32bdd1 (Casing: 8-inch steel 0 to 850 feet)		
Soil	9	0
Sand and some gravel	78	9
Idaho Group, undifferentiated		
Clay, blue	653	87
Rock, black	1	740
Clay, blue	199	741
Shale, blue	8	940
Clay, brown	112	948
Banbury Basalt		
Lava, black	6	1,060
Clay, brown, sandy in lower part	336	1,066
Total depth		1,402
6S-7E-16bbb1 (Oil and gas exploratory hole; plugged and abandoned)		
Idaho Group, undifferentiated		
Shale and clay	71	0
Clay, sand, shale	266	71
Shale and clay	541	337
Shale and sand	1,092	878

Material	Thickness (feet)	Depth (feet below land surface)
6S-7E-16bbb1--Continued		
Idaho Group, undifferentiated (Cont'd.)		
Shale and rock	145	1,970
Shale	225	2,115
Shale and sand	213	2,340
Shale, sand, and lime	37	2,553
Shale	37	2,590
Banbury Basalt (2,550 feet)		
Shale, lime, and lava	26	2,627
Total depth		2,653
6S-8E-19bbb1 (Oil and gas exploratory hole, plugged and abandoned)		
Sand	85	0
Idaho Group, undifferentiated		
Shale	10	85
Gravel, sand, and shale	30	95
Sand and shale	90	125
Shale, blue	30	215
Shale	170	245
Shale, blue	195	415
Shale	275	610
Shale with sand streaks	370	885
Sand, hard	59	1,255
Shale	60	1,314
Shale and sand streaks	106	1,374
Sand and shale	30	1,480
Shale	270	1,510
Sand and shale	275	1,780
Shale	205	2,055
Shale, sand, and lime	205	2,260
Sand and shale	82	2,465
Banbury Basalt		
Sand and shale, lava streaks	78	2,547
Sand and lime, lava streaks	130	2,625
Sand and shale	44	2,755
Sand, shale, lime, and lava	86	2,799
Sand, lime, shale, and lava	82	2,885
Sand, lime and shale	78	2,967
Shale and sand	48	3,045
Sand, lava, and shale	20	3,093

Material	Thickness (feet)	Depth (feet below land surface)
6S-8E-19bbb1--Continued		
Banbury Basalt (Cont'd.)		
Lava and shale	69	3,113
Black shale, hard, and lime	28	3,182
Idavada Volcanics		
Basalt	598	3,210
Total depth		3,808
6S-8E-33ab1 (Casing: 14-inch steel 0 to 201.5 feet; 10-inch steel 192 to 400 feet; 8-inch steel 191 to 697 feet; 6-inch steel 674 to 2,118 feet)		
Idaho Group, undifferentiated		
Siltstone, shale, silty	410	0
Sandstone with basalt boulders	20	410
Siltstone, fine sandy, and sandstone	180	430
Siltstone and shale	330	610
Shale with ash fragments	270	940
Sandstone and siltstone	100	1,210
Silty shale and shale	250	1,310
Siltstone and silty shale	660	1,560
Banbury Basalt		
Shale and siltstone with basalt flows and cinder beds	537	2,220
Shale, silty and hard	187	2,757
Basalt	20	2,944
Shale and sandy shale	403	2,964
Cinder beds,siltstone, basalt layers shale, and sandstone with thin flows	138	3,367
Idavada Volcanics		
Basalt and cinder beds	398	3,505
Rhyolite tuff and shale	97	3,903
Total depth		4,000
7S-4E-3abd1 (Casing: 16-inch steel 0 to 399; 14-inch steel 373 to 953 feet; perforations ½-inch by 12-inch from 910 to 941 feet)		
Topsoil - sand and gravel	33	0
Idaho Group, undifferentiated		
Clay, brown	42	33

Material	Thickness (feet)	Depth (feet below land surface)
7S-4E-3abd1--Continued		
Idaho Group, undifferentiated (Cont'd.)		
Shale, gray	155	75
Sand, gray	55	230
Shale, gray, sandy	130	285
Shale, blue-gray	280	415
Sand, gray	30	695
Clay, brown	115	725
Sand and gravel	45	840
Banbury Basalt		
Basalt, black	30	885
Lava, reddish-brown, cindery, water	20	915
Basalt, gray	43	935
Lava, reddish-brown, cindery, water	17	978
Basalt, black	10	995
Lava, reddish-brown, cindery, water	10	1,005
Basalt, gray	30	1,015
Total depth		1,045
7S-4E-5cca1 (Casing: 20-inch steel 0 to 292 feet)		
Topsoil	1	0
Idaho Group, undifferentiated		
Clay, hardpan	2	1
Clay, brown, sandy	142	3
Clay, gray and sand	27	145
Clay, gray, sticky	98	172
Sand, gray	20	270
Shale, gray	220	290
Shale, gray, sandy	75	510
Sand, light brown	58	585
Clay, brown, sandy	20	643
Shale, gray	37	663
Shale, gray, and gravel	25	700
Shale, gray, sandy	35	725
Sand, brown, and gravel	8	760
Shale, gray, sandy	52	768
Shale, gray, sandy, and gravel	42	820
Banbury Basalt		
Lava, gray, hard	52	862

Material	Thickness (feet)	Depth (feet below land surface)
7S-4E-5cca1--Continued		
Banbury Basalt (Cont'd.)		
Lava, gray and brown, loose	9	914
Lava, gray, hard	69	923
Sand, brown	32	992
Shale, gray, and boulders	12	1,024
Lava, gray	4	1,036
Total depth		1,040

7S-4E-10bdb1
(Casing: 20-inch steel 0 to 24 feet;
16-inch steel 0 to 738 feet;
perforated from 537 to 568 feet and 616 to 737 feet
with 720 and 2,880 3/16-inch by 4-inch perforations, respectively)

Material	Thickness (feet)	Depth (feet below land surface)
Topsoil and pea gravel	2	0
Idaho Group, undifferentiated		
Shale, brown	66	2
Sand, black	10	68
Shale, blue	410	78
Shale, brown	12	488
Shale, brown, and pea gravel	28	500
Shale, brown	68	528
Shale, brown, and pea gravel	16	596
Sand, brown, coarse	12	612
Shale, brown	21	624
Sand, black, coarse	12	645
Shale, brown, and pea gravel	27	657
Basalt, clay, brown	35	684
Banbury Basalt		
Basalt, gray, and clay, red	5	719
Basalt, gray, and clay, brown	21	724
Basalt, gray, clay, blue	9	745
Basalt, gray, clay, brown	18	754
Basalt, brown, and clay, red	11	772
Basalt, gray	33	783
Basalt, gray, and clay, brown, water	22	816
Clay, blue	10	838
Basalt, gray, and clay seam	59	848
Clay, red	5	907
Basalt, gray, water	8	912

Material	Thickness (feet)	Depth (feet below land surface)
7S-4E-10bdb1--Continued		
Banbury Basalt (Cont'd.)		
Basalt, gray	8	920
Basalt, reddish-brown, water	4	928
Basalt, gray, water	18	932
Basalt, reddish-brown, water	12	950
Basalt, gray,and clay, brown	8	962
Basalt, gray, and clay, blue	13	970
Basalt, gray	15	983
Rhyolite,reddish-brown	28	998
Basalt, gray	14	1,026
Clay, brown	30	1,040
Sand, brown, and gravel	28	1,070
Cinders, dark-brown	47	1,098
Total depth		1,145
7S-4E-11cbc1 (Casing: 20-inch steel 0 to 250 feet; 16-inch steel 520 to 720 feet)		
Topsoil	7	0
Gravel	20	7
Idaho Group, undifferentiated		
Sand, yellow	78	27
Clay, blue, sandy	90	105
Clay, blue-gray	135	195
Shale, blue	115	330
Clay, black, sandy	5	445
Clay, brown	10	450
Shale, blue	35	460
Lava rock, black	15	495
Shale, blue	20	510
Clay, yellow, streaks of gravel, water	173	530
Banbury Basalt		
Basalt, black	52	703
Clay, red, and gravel	10	755
Basalt, black	50	765
Clay, red	6	815
Conglomerate, red and black	107	821
Clay, brown	13	928
Rock, black, water	124	941

Material	Thickness (feet)	Depth (feet below land surface)
7S-4E-11cbc1--Continued		
Idavada Volcanics		
Rhyolite, red and black	30	1,065
Rhyolite, red, water	105	1,095
Rhyolite, black	120	1,200
Rhyolite, brown	20	1,320
Rhyolite, rusty-red	35	1,340
Rhyolite, black	25	1,375
Rhyolite, red	10	1,400
Rhyolite, brown, water	45	1,410
Rhyolite, black	15	1,455
Rhyolite, reddish-brown	10	1,470
Rhyolite, gray, water	5	1,480
Rhyolite, reddish-brown	15	1,485
Total depth		1,500

7S-4E-12bdd1
(Casing: 14-inch steel 0 to 675 feet)

Material	Thickness (feet)	Depth (feet below land surface)
Soil	16	0
Soil and sand	14	16
Idaho Group, undifferentiated		
Shale, blue	15	30
Sand	15	45
Shale, hard	83	60
Sand	27	143
Shale, sandy	210	170
Rock, (Basalt), black	30	380
Sand, green and brown	41	410
Rock, (Basalt), black	33	451
Shale and sand, brown	71	484
Gravel and sand	5	555
Clay, bentonite	109	560
Banbury Basalt		
Basalt, black and dark gray	44	669
Tuff, red, tan, pink, clayey, ashy	17	713
Basalt, vesicular, black and dark gray	20	730
Not reported	10	750
Clay, dark tan, soft, sandy	25	760

Material	Thickness (feet)	Depth (feet below land surface)
7S-4E-12bdd1--Continued		
Banbury Basalt (Cont'd.)		
Basalt, gray, vesicular, hard	15	785
Basalt, black, hard, dense	10	800
Tuff, brown, tan	45	810
Basalt, black, hard, dense	23	855
Not reported	2	878
Sand, tan, water	40	880
Not reported	40	920
Basalt, dark gray	15	960
Clay, tuffaceous, tan and brown	13	975
Idavada Volcanics		
Bentonite, white	2	988
Obsidian, black	70	990
Latite, tan, porphyritic	45	1,060
Total depth		1,105
7S-4E-13bcc1 (Casing: 12-inch steel 0 to 192 feet)		
Soil and hardpan	4	0
Gravel and boulders	19	4
Idaho Group, undifferentiated		
Shale, blue, water	167	23
Lava, black, soft	4	190
Lava, black, hard	86	194
Conglomerate	210	280
Banbury Basalt		
Lava, black, very hard	46	490
Rock, red, water	86	536
Lava, black	62	622
Rock, reddish	76	684
Idavada Volcanics		
Rock, purple	34	760
Rock, brown	42	794
Rock, pink	104	836
Rock, purple	51	940
Rock, red, water	32	991
Rock, brown and red, water	18	1,023

Material	Thickness (feet)	Depth (feet below land surface)
7S-4E-13bcc1--Continued		
Idavada Volcanics (Cont'd.)		
Rock, red and cinders, water	19	1,041
Total depth		1,060
Well was later drilled to an unreported depth.		

7S-4E-13dcd1
(Casing: 12-inch steel 0 to 194 feet)

Soil	18	0
Boulders and gravel	8	18
Idaho Group, undifferentiated		
Clay, blue, sticky	165	26
Rock and layers of clay	9	191
Clay, light tan to yellow	10	200
Gravel, fine-grained, and sand	45	210
Basalt, dark gray to black	13	255
Sand, olive drab, coarse-grained	22	268
Not reported	25	290
Clay, light tan, sandy	20	315
Clay, light tan, very fine, sand	25	335
Clay, light tan to dark tan	20	360
Not reported	38	380
Sand, very fine-grained	4	418
Banbury Basalt		
Basalt, black	20	422
Olivine basalt, dark greenish-brown and black	8	442
Sand, light tan and black	23	450
Basalt, red and brown	7	473
Basalt and olivine basalt, black	55	480
Basalt and basaltic gravel	23	535
Olivine basalt, black to greenish shade	10	558
Basalt, black and brownish-black, dense	52	568
Basalt	20	620
Sand, black and tan, ashy	85	640
Idavada Volcanics		
Obsidian, black	71	725
Obsidian, black, partly crystalline glass	39	796
Latite, purple, porphyritic, vesicular	30	835

Material	Thickness (feet)	Depth (feet below land surface)
7S-4E-13dcd1--Continued		
Idavada Volcanics (Cont'd.)		
Latite, purple, porphyritic	35	865
Not reported	100	900
Total depth		1,000
7S-4E-14abc1 (Casing: 16-inch steel 0 to 223 feet)		
Soil and gravel	5	0
Gravel	5	5
Gravel and clay	5	10
Idaho Group, undifferentiated		
Clay, yellow	20	15
Sand, black	5	35
Sand, black, water	5	40
Sand, black, and clay	30	45
Sand, black	20	75
Clay, dark gray	70	95
Shale, blue	160	165
Rock, black	15	325
Rock, rusty yellow	60	340
Rock, slate-gray	25	400
Clay, rusty, and rock, black	60	425
Gravel, fine	20	485
Gravel and clay	35	505
Clay, rusty	15	540
Clay, rusty, and sand	5	555
Rock, black, and sand	15	560
Banbury Basalt		
Rock, black, water	25	575
Rock, black and gray	10	600
Clay, brown, and rock	5	610
Clay, red, and rock, brown	5	615
Rock, black	65	620
Rock, black, and shale, red, water	55	685
Rock, black	5	740
Rock, black, and shale, red	45	745
Clay, rusty brown	5	790

Material	Thickness (feet)	Depth (feet below land surface)
7S-4E-14abc1--Continued		
Idavada Volcanics		
Rock, gray, water	25	795
Rock, black, gray	35	820
Clay, red	20	855
Rock, gray	5	875
Rock, black and gray	10	880
Rock, black, gray, and red	10	890
Rock, black and gray	15	900
Rock, gray	65	915
Rock, rusty gray	10	980
Cinders, purple	15	990
Rock, gray, water	10	1,005
Rock, gray and brown	20	1,015
Rock, gray	50	1,035
Rock, brown, water (at 1,110)	60	1,085
Total depth		1,145
7S-4E-23cbb1 (Casing: 16-inch steel 0 to 326 feet)		
Gravel	11	0
Idaho Group, undifferentiated		
Clay, yellow	64	11
Gravel, fine	7	75
Shale, blue	43	82
Rock, soft	2	125
Shale, blue	173	127
Clay, blue, sticky and some rock	22	300
Banbury Basalt		
Rock, black, soft	4	322
Rock, black, water	6	326
Rock, reddish	9	332
Rock, brown, water	23	341
Rock, red	9	364
Rock, purple, hard	18	373
Rock, red	21	391
Rock, purple, water	23	412
Rock, red	54	435
Rock, pink, and clay	26	489
Clay, red, and broken rock	40	515
Rock, red, and clay	23	555

Material	Thickness (feet)	Depth (feet below land surface)
7S-4E-23cbb1--Continued		
Banbury Basalt (Cont'd.)		
Rock, red	22	578
Idavada Volcanics		
Rock, black, and clay, water	65	600
Rock, red	45	665
Rock, purple	13	710
Crevice, water	3	723
Rock, purple	19	726
Rock, red, very abrasive, water	65	745
Total depth		810
7S-4E-27bcc1 (Casing: 20-inch steel 0 to 19 feet)		
Sand and gravel	19	0
Idavada Volcanics		
Sandstone, black, water	179	19
Sandstone, black, with coarse white sand, water	52	198
Rhyolite, black, water	55	250
Rhyolite, dark brown	48	305
Rhyolite, reddish-brown	97	353
Rhyolite, dark brown	28	450
Rhyolite, dark gray	104	478
Rhyolite, gray	23	582
Rhyolite, gray, with reddish-brown stripes	215	605
Rhyolite, reddish-brown	20	820
Rhyolite, gray and reddish-brown	20	840
Sand, gray, some brown clay	55	860
Sand, gray, and clay, reddish-brown	115	915
Clay, reddish-brown, and rock, gray	15	1,030
Rhyolite, reddish-brown, some water	205	1,045
Total depth		1,250
7S-5E-5dbc1 (Casing: 16-inch steel 0 to 140 feet; 12-inch steel 140 to 504 feet; two 8-inch steel casings are placed side by side from 630 to 1,120 feet and 650 to 1,300 feet)		
Idaho Group, undifferentiated		
Topsoil, shale, and sand	737	0

Material	Thickness (feet)	Depth (feet below land surface)
7S-5E-5dbc1--Continued		
Idaho Group, undifferentiated (Cont'd.)		
Sand and shale streaks, water	38	737
Sand, water	125	775
Shale and sand streaks, water	389	900
Banbury Basalt		
Rock, black, water	38	1,289
Clay	7	1,327
Shale	42	1,334
Pumice	4	1,376
Rock, black	25	1,380
Clay	10	1,405
Rock	35	1,415
Shale	65	1,450
Basalt, black, water	179	1,515
Cinders, red, water	8	1,694
Basalt	22	1,702
Shale with rock layers	18	1,724
Rock, broken	26	1,742
Shale with rock floaters; water	62	1,768
Rock, red and black	74	1,830
Sandstone	206	1,904
Clay, red	20	2,110
Sandstone	40	2,130
Clay, red	8	2,170
Sandstone	21	2,178
Shale, blue, and clay	41	2,199
Sand	22	2,240
Shale and clay layers	81	2,262
Sand	13	2,343
Clay, red	19	2,356
Rock, brown	30	2,375
Total depth		2,405
7S-5E-7abb1 (Casing: 20-inch steel 0 to 228 feet; 16-inch steel 228 to 632 feet)		
Sand and gravel	15	0
Idaho Group, undifferentiated		
Sandstone and clay, blue	65	15

Material	Thickness (feet)	Depth (feet below land surface)
7S-5E-7abb1--Continued		
Idaho Group, undifferentiated (Cont'd.)		
Clay, blue	20	80
Sandstone, brown	35	100
Shale, blue	70	135
Clay, brown	15	205
Shale, blue	23	220
Clay, brown and blue	19	243
Shale, blue	113	262
Chert rock	41	375
Clay	21	416
Basalt and clay, mixed	18	437
Clay and streaks of cinder sand	60	455
Banbury Basalt		
Lava, black	8	515
Lava, black, hard	33	523
Lava, black and green, hard	6	556
Lava, black and green, very hard	6	562
Lava, black	10	568
Sandstone, brown	17	578
Lava, black, firm	9	595
Lava, black, hard	28	604
Rhyolite	993	632
Total depth		1,625
The Idavada Volcanics were believed to have started at about 1,000 feet below land surface.		

7S-5E-9ddd1
(Casing: 20-inch steel 0 to 550 feet;
18-inch steel 984 to 1,034 feet;
14-inch steel 1,337 to 1,432 feet;
12¾-inch steel 1,463 to 1,613 feet;
12-inch steel 1,587 to 1,624 feet;
8-inch steel 1,925 to 2,025 feet)

Material	Thickness (feet)	Depth (feet below land surface)
Topsoil and sand	50	0
Idaho Group, undifferentiated		
Clay, blue, sandy	240	50
Clay, blue	40	290
Sand, yellow	5	330

Material	Thickness (feet)	Depth (feet below land surface)
7S-5E-9ddd1--Continued		
Idaho Group, undifferentiated (Cont'd.)		
Clay, blue	10	335
Sand, yellow	75	345
Clay, yellow	2	420
Clay, yellow and black	78	422
Sand	20	500
Clay, yellow and blue	180	520
Clay, dark gray	77	700
Cinders, black	18	777
Rock, black	9	795
Clay, yellow and blue	59	804
Rock, black, hard	47	863
Clay, yellow, sticky	40	910
Clay	20	950
Clay, gravel, and sand in layers	55	970
Clay	20	1,025
Banbury Basalt		
Rock, black	380	1,045
Rock, black, softer	25	1,425
Rock, black, harder	50	1,450
Clay, sticky	20	1,500
Clay, multicolored	120	1,520
Clay, blue	100	1,640
Rock and clay in red and brown layers	105	1,740
Rock, black, soft	45	1,845
Clay, multicolored with rock layers	90	1,890
Idavada Volcanics		
Rock, purple, hard and fractured, water	85	1,980
Total depth		2,065
7S-5E-13cbb1 (Casing: 20-inch steel 0 to 710 feet; 10-inch steel 1,070 to 1,180 feet; 8-inch steel 1,510 to 1,680 feet; ⅛x3-inch perforations: 180-710 feet; 1,070 to 1,180 feet; 1,510 to 1,680 feet)		
Soil	4	0
Idaho Group, undifferentiated		
Sandstone, water	127	4

Material	Thickness (feet)	Depth (feet below land surface)
7S-5E-13cbb1--Continued		
Idaho Group, undifferentiated (Cont'd.)		
Sandstone, soft	49	131
Clay, yellow, chalky	470	180
Sand and some pea gravel, water	40	650
Chalk	20	690
Clay, blue	177	710
Banbury Basalt		
Lava, black	70	887
Lava, brown, soft	2	957
Rock, red	70	959
Lava, black	111	1,029
Sand	40	1,140
Lava, black	420	1,180
Rock, red	10	1,600
Tuff, red, with sand and gravel	30	1,610
Lava, black	11	1,640
Tuff, red, with sand and gravel	29	1,651
Rock, brown and red	160	1,680
Rock, black and red	114	1,840
Total depth		1,954
7S-5E-28acd1 (Casing: 16-inch steel 0 to 234 feet)		
Idaho Group, undifferentiated		
Chalk, rock	110	0
Sand, water	126	110
Lava, black	8	236
Clay, gray, sticky	80	244
Lava, black	9	324
Clay, sticky	17	333
Gravel, cemented	7	350
Clay, sticky	33	357
Sand (?)	12	390
Lava, black	28	402
Clay, sticky	47	430
Banbury Basalt		
Lava, black, hard	20	477
Lava, red, hard	26	497
Lava, black	227	523

Material	Thickness (feet)	Depth (feet below land surface)
7S-5E-28acd1--Continued		
Idaho Group, undifferentiated (Cont'd.)		
Lava, red	13	750
Red, sticky formation	15	763
Black sandy formation	28	778
Idavada Volcanics		
Lava, black (volcanic glass)	39	806
Rock, reddish-brown	49	845
Rock, red	2	894
Conglomerate, sand, clay, and water	94	896
Rock, black, hard	13	990
Total depth		1,003
7S-6E-15ba1 (Casing: 6-inch steel 0 to 65 feet)		
Soil	20	0
Gravel	44	20
Idaho Group, undifferentiated		
Shale, blue, soft	96	64
Sand, gray	15	160
Shale, blue, soft	552	175
Sand, gray, coarse, water	13	727
Shale, blue, soft	110	740
Sand, gray, soft, water	10	850
Shale, blue, hard	17	860
Sand, gray, soft, water	8	877
Shale, blue, hard	17	885
Banbury Basalt		
Rock (basalt), black, hard	8	902
Total depth		910
7S-6E-21dbc1 (Casing: 10-inch steel 0 to 167 feet)		
Topsoil	26	0
Idaho Group, undifferentiated		
Sandstone	59	26
Sand	77	85
Clay, blue	4	162
Banbury Basalt		
Rock black	5	166

Material	Thickness (feet)	Depth (feet below land surface)
7S-6E-21dbc1--Continued		
Banbury Basalt (Cont'd.)		
Clay, blue, and broken rock	19	171
Lava, black	50	190
Clay, blue, and broken rock	40	240
Rock, brown, water	11	280
Lava, black	19	291
Rock, red, water	15	310
Rock, red, and cinders, water	10	325
Lava, black	20	335
Clay, red	5	355
Sandstone, red	35	360
Rock, sand, and blue clay	20	395
Rock, black, and clay	20	415
Rock, red, water	5	435
Rock, black, hard	15	440
Rock, black, very hard	25	455
Rock, reddish, water	20	480
Rock and cinders, red and brown, water	25	500
Rock, black	22	525
Rock, red	9	547
Rock, black, and clay	9	556
Rock, black, hard	20	565
Rock, red	6	585
Rock, brown	6	591
Rock, brown and red, water	8	597
Rock, black	6	605
Rock, red, water	9	611
Rock, black	15	620
Rock, black, and clay	11	635
Rock, red, and clay	14	646
Rock, red, and cinders, water	13	660
Conglomerate, black	42	673
Rock, red, water	15	715
Rock, black, and clay	22	730
Rock, red, and clay	8	752
Total depth		760
7S-6E-22aad1 (Casing: 14-inch steel 0 to 400 feet)		
Soil	3	0
Gravel	58	3

Material	Thickness (feet)	Depth (feet below land surface)
7S-6E-22aad1--Continued		
Idaho Group, undifferentiated		
Sandstone	13	61
Gravel, fine	2	74
Sandstone, soft	17	76
Clay, sandy	39	93
Clay, yellow	178	132
Shale, brown	4	310
Clay, whitish color, sticky	80	314
Banbury Basalt		
Rock, brown and red	5	394
Rock, red	16	399
Rock, black	28	415
Rock, reddish-purple	18	443
Rock, red and brown, water	74	461
Rock, red, water	20	535
Rock, purple, water	10	555
Rock, red, water	10	565
Rock, brown, water	5	575
Rock, purple, water	5	580
Rock, red, hard	10	585
Rock, purple	13	595
Rock, red	52	608
Rock, black	14	660
Sand, orange-red, some clay	26	674
Clay, brown, and rock	11	700
Rock, black, and clay	40	711
Rock, black	15	751
Rock, red, water	4	766
Rock, black	50	770
Rock, red	20	820
Rock, brown	15	840
Rock, red	15	855
Rock, brown	30	870
Rock, red	40	900
Rock, black	25	940
Rock, black, and clay	15	965
Rock, red	20	980
Rock, purple	30	1,000
Rock, red	10	1,030
Rock, brown	10	1,040

Material	Thickness (feet)	Depth (feet below land surface)
7S-6E-22aad1--Continued		
Banbury Basalt (Cont'd.)		
Rock, black, hard	30	1,050
Sandstone, brown, or cinders	80	1,080
Sandstone, red, or cinders, water	180	1,160
Idavada Volcanics		
Rock, red, water	30	1,340
Rock, purple, water	40	1,370
Total depth		1,410

PUBLICATIONS LIST

IDAHO WATER RESOURCE BOARD

Publications

Planning Report No. One - *Idaho Water Resources Inventory*, 1968 (one 600 page volume plus 50-map* atlas)

Planning Report No. Two - *Economic Base Study for Water Requirements*, 1969
Volume I - Employment-Populations-M & I Water
Volume II - Agriculture-Forestry-Mining

*Planning Report No. Three - *Aquatic Life Water Needs*, 1969

Planning Report No. Four - *Recreational Water Needs* (study not published)

*Planning Report No. Five - *Agricultural Water Needs*, 1971

Planning Report No. Six - *Electric Power Water Needs*, 1970

Planning Report No. Seven -- *Navigation Water Needs*, 1970

Soils Surveys Reports - 15 Idaho Counties - Cassia, Twin Falls, Minidoka, Bingham, Butte, Bannock, Bonneville, Canyon, Payette, Power, Caribou, Oneida, Bear Lake, Franklin and Owyhee

Potentially Irrigable Lands in Idaho-Soils reports on remaining 29 Idaho counties

Potentially Irrigable Lands in Idaho Summary Report Number One, 1970

**First Biennial Report* - 7/1/67 to 6/30/69

Second Biennial Report - 7/1/69 to 6/30/71

Third Biennial Report - 7/1/71 to 6/30/73

Annual Report of the Idaho Water Resource Board - Fiscal Year 1974

First Annual Report Idaho Water Resource Board Revolving Development Fund. July 1, 1969 - October 31, 1970

Second Annual Report Idaho Water Resource Board Revolving Development Fund. July 1, 1970 through September 30, 1971

Third Annual Report Idaho Water Resource Board Revolving Development Fund. July 1, 1972 - June 30, 1973

**Fourth Annual Report* Idaho Water Resource Board Revolving Department Fund. July 1, 1973 - June 30, 1974

**Family Size Farms in Idaho*, 1969

Interim State Water Plan, Preliminary Report, July 1972

**A Survey of Public Attitudes and Opinions on Idaho's Water Resources*, October 1972

**A Survey of Public Attitudes and Opinions on Idaho's Water Resources*, December 1973

The Potential Impact and Assessment of Mitigation of Swan Falls and Guffey Dams on the Snake River Ecosystem, November 1972

Crane Falls Project, Feasibility Report, November 1972

Water: The Heritage of Man, January 1973

Summary of Public Information Meetings, Interim State Water Plan, March 1973

Testimony, Comments, Suggestions and Recommendations on Information and Concepts Contained in the Interim State Water Plan, Preliminary Report, June 1973

Comprehensive Rural Water and Sewage Studies - 25 Idaho Counties - Adams, *Bannock, Bear Lake, Bingham, *Blaine, Boise, Bonneville, Canyon, *Caribou, Cassia, Clark, Custer, Elmore, Gem, Jefferson, Jerome, Lemhi, Lincoln, Madison, Oneida, Owyhee, Payette, Shoshone, Twin Falls, Washington

Power Plant Siting and Water Needs for Future Power Generation in Idaho, May 1974

Indian Hills Project, November 1974

Water Availability for In-Stream Flows, Snake River, Swan Falls-Hells Canyon Dam, April 1974

*Out of print

IDAHO WATER RESOURCE BOARD (cont'd.)

Maps

Irrigated and Potentially Irrigable Lands in Idaho. Size 32" x 50", 1970

Pamphlets and Brochures

Your Idaho Water Resource Board (Brochure)

Loans for Water Resource Development - Information Pamphlet No. 1

**The Marysville Project* - Information Pamphlet No. 2

Idaho's Water Resources and the Future - Information Pamphlet No. 3

Idaho's Living Water - Information Pamphlet No. 4

IDAHO DEPARTMENT OF RECLAMATION

Water Information Bulletins

*No. 1 *Ground-Water Conditions in Idaho, 1966*
*No. 2 *Ground-Water Monitoring Network for Southwestern Idaho*
*No. 3 *Ground-Water Development in Idaho, 1967*
*No. 4 *Ground-Water Resource of the Mountain Home Area, Elmore County, Idaho*
No. 5 *Ground-Water Levels in Idaho, 1968*
*No. 6 *Record of North-Side Springs and Other Inflow to the Snake River between Milner and King Hill, Idaho, 1948-67*
No. 7 *Water Level Changes in the Mud Lake Area, Idaho, 1958-68*
No. 8 *Water Resources of the Goose Creek-Rock Creek Area, Idaho, Utah and Nevada*
No. 9 *Inflow to the Snake River between Milner and King Hill, Idaho*
No. 10 *Ground-Water Development in Idaho, 1968*
No. 11 *Ground-Water Levels in Idaho, 1969*
No. 12 *Artificial Recharge to the Snake Plain Aquifer, An Evaluation of Potential and Effect*
No. 13 *Hydrologic Reconnaissance of the Bear River Basin in Southeastern Idaho*
No. 14 *Ground-Water Resource of Northern Owyhee County, Idaho*
No. 15 *Ground-Water Resource of Southern Ada and Western Elmore Counties, Idaho*
No. 16 *A Reconnaissance of the Water Resources in the Portneuf River Basin, Idaho*
No. 17 *Ground-Water Development in Idaho, 1969*

The History of Development and Current Status of the Carey Act in Idaho, March 1970

IDAHO DEPARTMENT OF WATER ADMINISTRATION

Water Information Bulletins

No. 18 *Ground-Water Levels in Idaho, 1970*
No. 19 *The Raft River Basin, Idaho-Utah as of 1966: A Reappraisal of the Water Resources and Effects of Ground-Water Development*
No. 20 *Water Resources of the Blue Gulch Area - Eastern Owyhee and Western Twin Falls Counties, Idaho*
No. 21 *Reasonable Pumping Lifts for Idaho*
*No. 22 *Water Resources of the Twin Falls Tract, Twin Falls County, Idaho*
*No. 23 *Ground-Water Pumpage from the Snake Plain Aquifer, Southeastern Idaho*
*No. 24 *Ground-Water Levels in Idaho, 1971*
*No. 25 *Water Resources of Western Oneida and Southern Power Counties, Idaho*
*No. 26 *Some Effects of Land-Use Changes on the Shallow Ground-Water System in the Boise-Nampa Area, Idaho*
*No. 27 *Ground-Water Levels in Idaho, 1972*
*No. 28 *Water Resources of the Big Wood River-Silver Creek Area, Blaine County, Idaho*
*No. 29 *Ground-Water Development in Idaho, 1970-71*
No. 30 *Geothermal Investigations in Idaho, Part 1,* Geochemistry and Geologic Setting of Selected Thermal Waters*
Geothermal Investigations in Idaho, Part 2, An Evaluation of Thermal Water in the Bruneau-Grand View Area, Southwest Idaho
Geothermal Investigations in Idaho, Part 3, An Evaluation of Thermal Water in the Weiser Area, Idaho
*No. 31 *A Reconnaissance of the Water Resources in the Pahsimeroi River Basin, Idaho*
No. 32 *A Progress Report on Results of Test-Drilling and Ground-Water Investigations of the Snake Plain Aquifer, Southeastern Idaho, Part 1 and 2*

*Out of print

IDAHO DEPARTMENT OF WATER ADMINISTRATION (cont'd.)

*No. 33 *A Ground-Water Monitoring Network of Kootenai Flats, Northern Idaho*

No. 34 *An Estimate of Leakage from Blackfoot Reservoir to Bear River Basin, Southeastern Idaho*

No. 35 *Ground-Water Occurrence and Movement in the Athol Area and the Northern Rathdrum Prairie, Northern Idaho*

No. 36 *Water Resources of the Aberdeen-Springfield Area, Bingham and Power Counties, Idaho*

No. 37 *The Availability of Water in the Little Lost River Basin, Idaho*

No. 38 *A Progress Report on Results of Test-Drilling and Ground-Water Investigations of the Snake Plain Aquifer, Southeastern Idaho, Part 3*

Biennial Report of the Department of Water Administration - July 1, 1972 - June 30, 1974

*Out of print

DEPARTMENT OF WATER RESOURCES

Ground-Water Levels and Well Records for Current Observation Wells in Idaho, 1922-73, Parts A, B and C, September 1974

No. 39 *Chemical and Physical Data for Disposal Wells, Eastern Snake River Plain, Idaho*

Review of Boise River Food Control Management, November 1974

An Evaluation of Stream Channel Relocation, South Fork of the Coeur d'Alene River, December 1974

St. Anthony Pilot Recharge Project, 1970-1974, February 1975

Snake River Basin Study, Idaho-Wyoming, 1975 (pamphlet)

Silver Creek, A Water Resource Study in the Bellevue Triangle, March 1975 (pamphlet)

UNITED STATES DEPARTMENT OF THE INTERIOR
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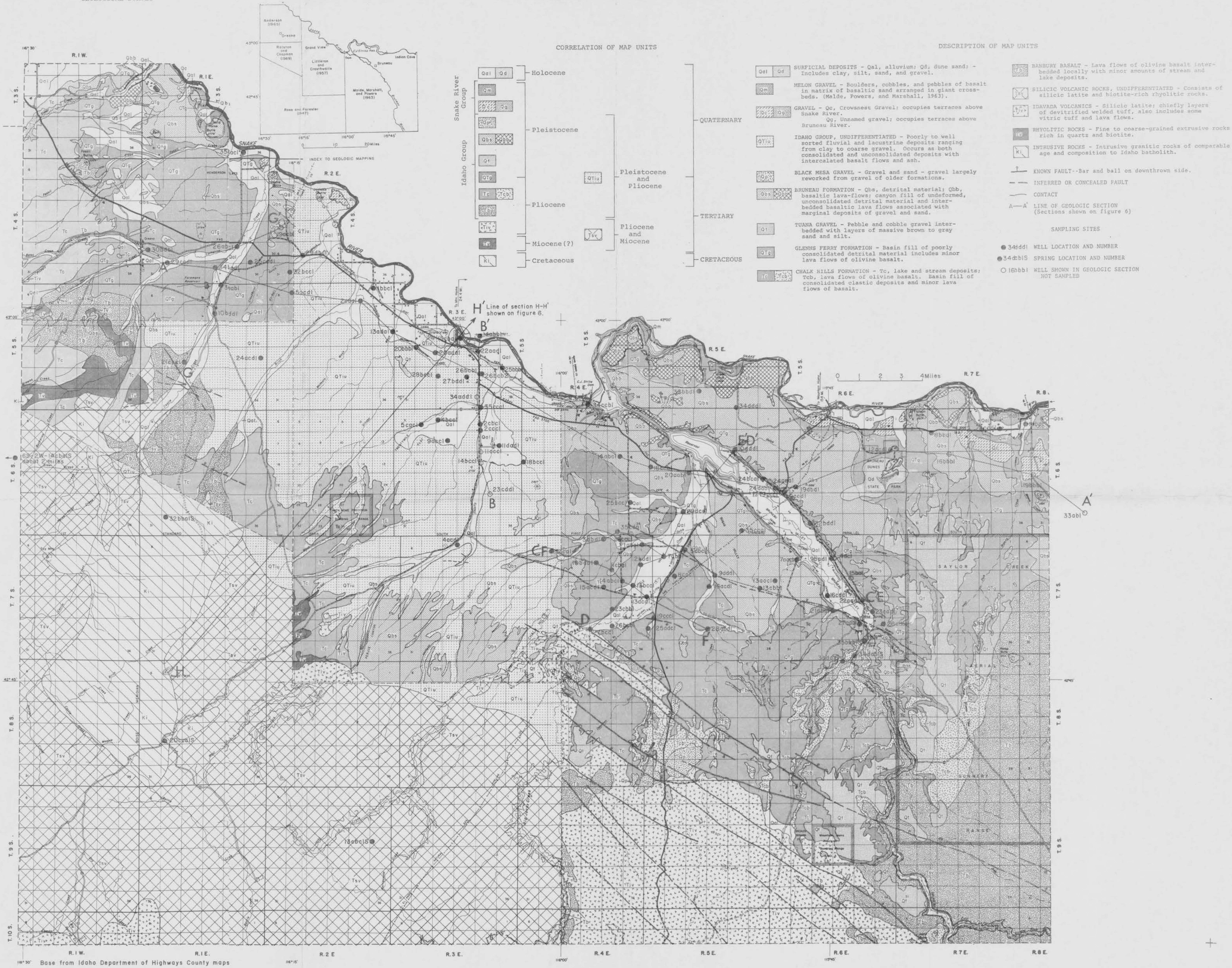

FIGURE 4.--Generalized geology, locations of sampled wells and springs, and lines of geologic sections in the Bruneau-Grand View area, southwest Idaho.

FIGURE 6.--Selected generalized geologic sections in the Bruneau-Grand View area and in part of the western Snake River Plain, Idaho.

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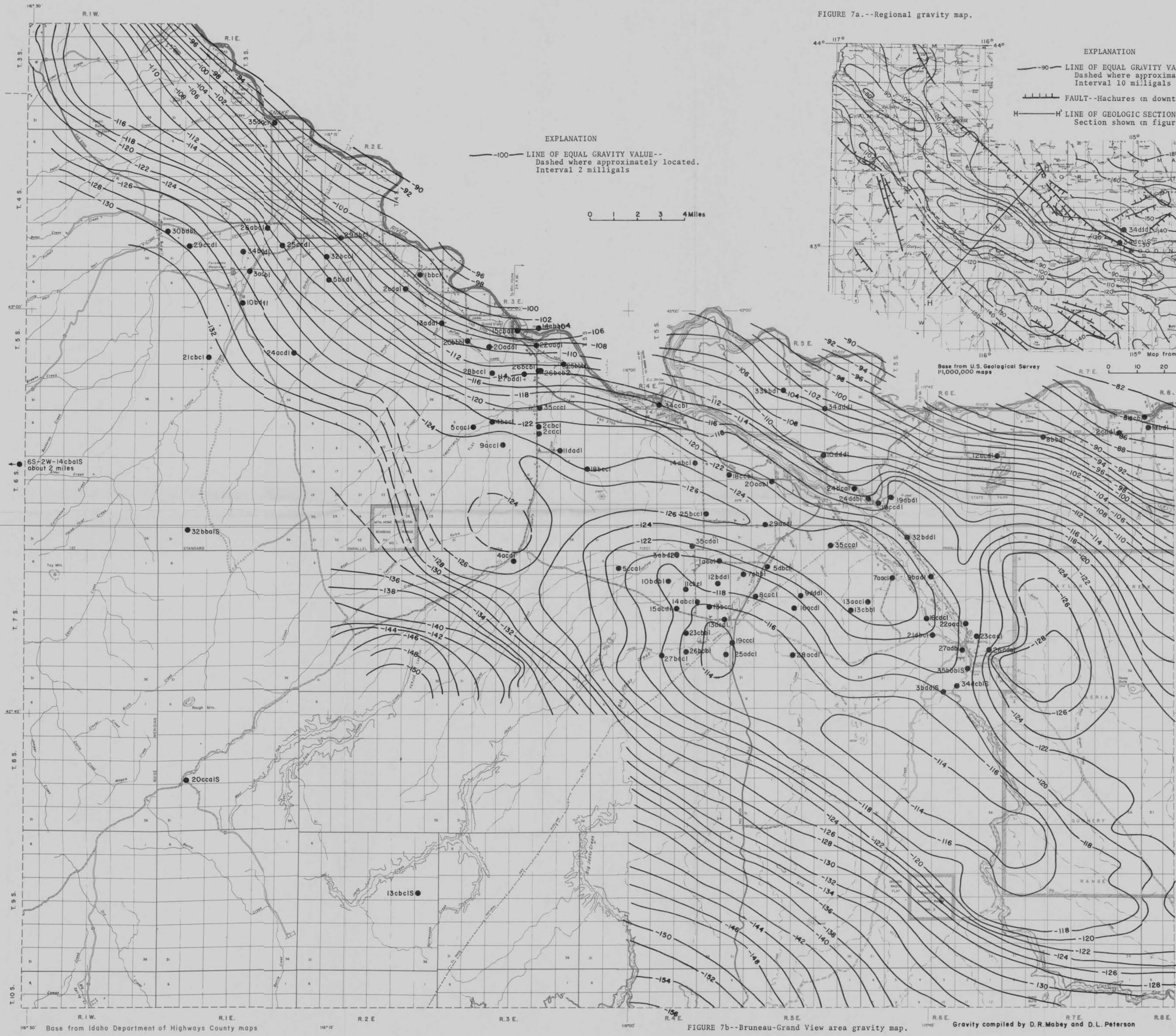

FIGURE 7.--Gravity anomalies in (a) a part of the western Snake River Plain and in (b) the Bruneau-Grand View area, southwest Idaho.

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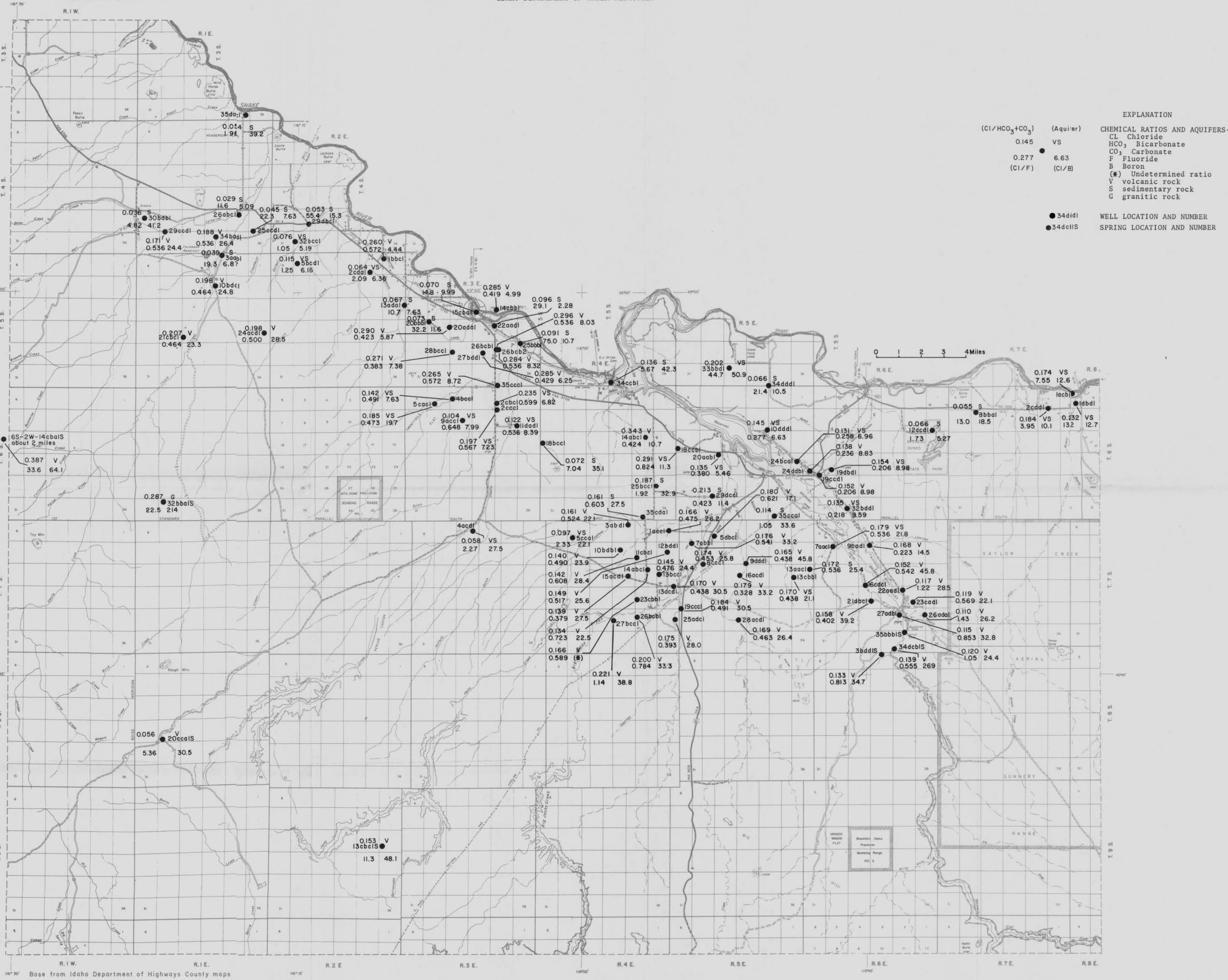

FIGURE 9.--Ratios of selected chemical constituents of water from sampled wells and springs in the Bruneau-Grand View area, southwest Idaho.

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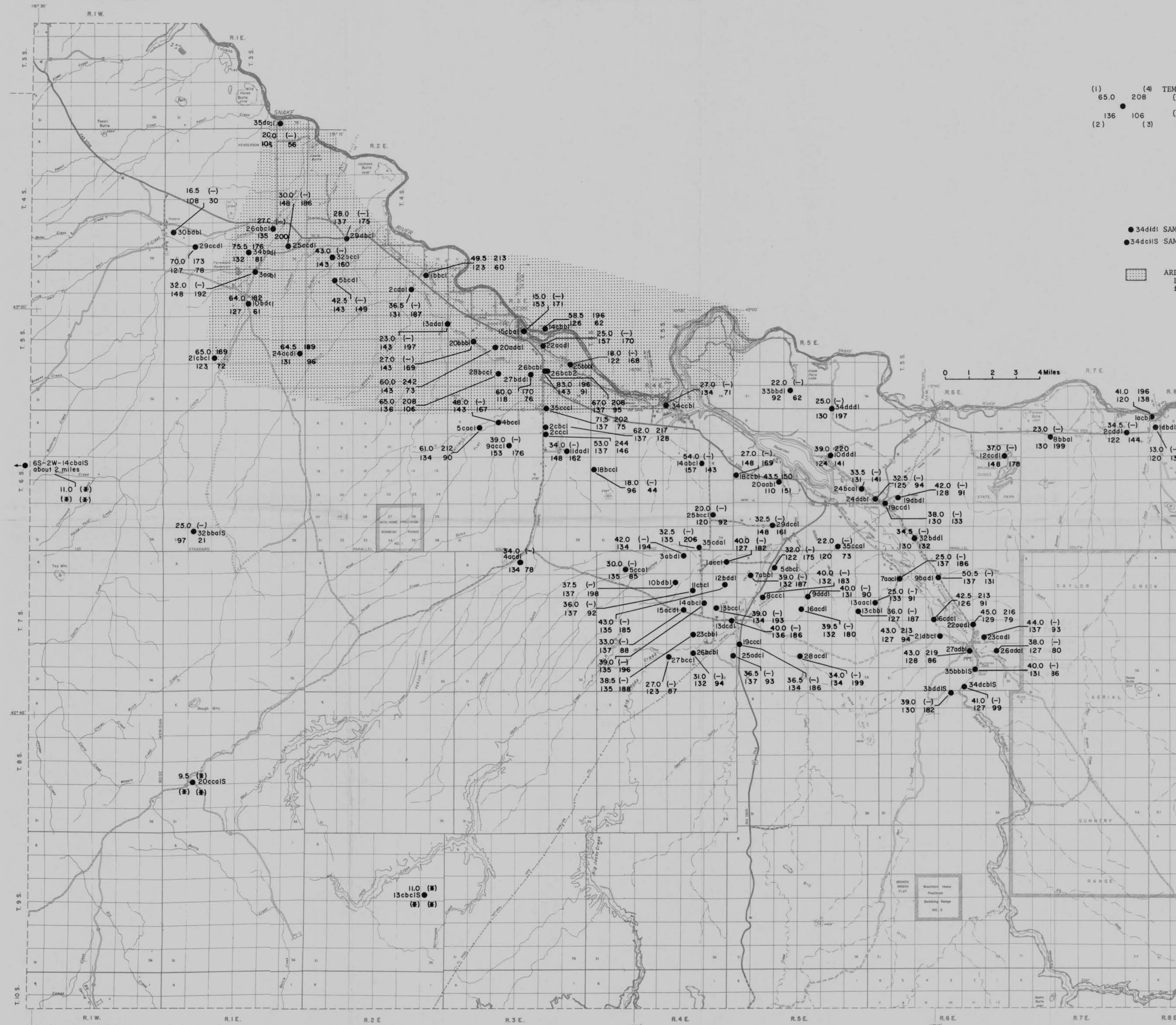

EXPLANATION

(1) 65.0, (4) 208, (2) 136, (3) 106 — TEMPERATURES, IN DEGREES CELCIUS-- (1) Measured water temperature at the surface. (2-4) Estimated aquifer temperatures: (2) silica geochemical thermometer, curve A, Fournier and Truesdell (1970); (3) sodium-potassium-calcium geochemical thermometer, Fournier and Truesdell (1973); (4) mixed-water method (temperature of the hot-water component) Fournier and Truesdell (model 1, 1974); dash indicates no intercept or temperature above 220°C. Asterisk indicates temperature not computed.

● 34ddd1 SAMPLED WELL AND NUMBER

● 34dcb1S SAMPLED SPRING AND NUMBER

AREA OF LOW RESISTIVITY
Less than 22 ohm-metres (adapted from fig. 14, app. A)

FIGURE 10.--Estimated aquifer temperatures and water temperatures at surface for sampled wells and springs in the Bruneau-Grand View area, southwest Idaho.