Water Information Bulletin No. 30
Part 13
Geothermal Investigations in Idaho

A Preliminary Geologic Reconnaissance of the Geothermal Occurrences of the Wood River Drainage Area

Idaho Department of Water Resources
April 1985

WATER INFORMATION BULLETIN NO. 30
GEOTHERMAL INVESTIGATIONS IN IDAHO

Part 13

A Preliminary Geologic Reconnaissance of the Geothermal Occurrences of the Wood River Drainage Area

by

John E. Anderson
and
Kim Bideganeta

With a Section on Stable Isotope Investigations of Selected Thermal and Nonthermal Waters

by

John C. Mitchell

Work performed under U.S. Department of Energy Contract
No. DE-AS07-77ET28407
Modification No. A009

Idaho Department of Water Resources
Statehouse
Boise, Idaho
02-30-831

April 1985

NOTICE

TABLE OF CONTENTS

	Page
ABSTRACT	vii
INTRODUCTION	1
WELL- AND SPRING-NUMBERING SYSTEM	1
USE OF METRIC UNITS	2
GEOMORPHOLOGY	2
CLIMATE	8
POPULATION AND INDUSTRY	8
GEOLOGY	9
STRATIGRAPHY	9
GENERAL STRUCTURE	14
DISCUSSION	14
HOT SPRINGS	16
MAGIC HOT SPRINGS	16
HAILEY HOT SPRINGS	19
CLARENDON HOT SPRINGS	22
GUYER HOT SPRINGS	26
WARFIELD HOT SPRINGS	28
EASLEY HOT SPRINGS	33
RUSSIAN JOHN HOT SPRINGS	35
STABLE ISOTOPE INVESTIGATIONS	38
THE STABLE ISOTOPE METHOD	38
SAMPLING	40
OBSERVATIONS	40
DISCUSSION	44
CONCLUSIONS	45
REFERENCES	47

LIST OF FIGURES

Figure		Page
1.	Location map	3
2.	General geologic map of the Wood River drainage area	4
3.	Well- and spring-numbering system	6
4.	Temperature conversion graph	7
5.	Generalized stratigraphy for the Wood River drainage area	10
6.	Geologic map of the Magic Hot Springs area	18
7.	Geologic map of the Hailey Hot Springs area	20
8.	Temperature-depth profile, Hailey Hot Springs area	23
9.	Geologic map of the Clarendon Hot Springs area	24
10.	Geologic map of the Guyer Hot Springs area	27
11.	Temperature-depth profile, Guyer Hot Springs area	30
12.	Geologic map of the Warfield Hot Springs area	32
13.	Geologic map of the Easley Hot Springs area	34
14.	Geologic map of the Russian John Hot Springs area	36
15.	Isotopic composition of selected thermal and nonthermal waters from the Wood River drainage area	39
16.	Isotope sample locations in the Wood River drainage area	43

LIST OF TABLES

Table		Page
1.	Water chemistry from Guyer-Greyhawk Hot Springs area	29
2.	Data on thermal waters in the Wood River drainage area	41
3.	Data on cold waters in the Wood River drainage area	42

ABSTRACT

The investigations of the Wood River area reported herein were done by the Idaho Department of Water Resources Geothermal Section for the purpose of evaluating the geothermal potential of the area.

Pre-Tertiary sediments of the Milligen and Wood River Formations consisting primarily of argillite, quartzite, shale and dolomite are, for the most part, exposed throughout the area and are cut locally by outliers of the Idaho Batholith. At some locations, Tertiary-age Challis Volcanics overlay these formations.

Structurally the area is complex with major folding and faulting visible in many exposures. Many of the stream drainages appear to be fault controlled. Hydrologic studies indicate hot spring occurrences are related to major structural trends, as rock permeabilities are generally low.

Geochemical studies using stable isotopes of hydrogen and oxygen indicate the thermal water in the Wood River region to be depleted by about 10 $^{o}/oo$ in D and by 1 to 2 $^{o}/oo$ in ^{18}O relative to cold water. This suggests the water could be meteoric water that fell during the late Pleistocene.

The geologic data, as well as the chemical data, indicate the geothermal waters are heated at depth, and subsequently migrate along permeable structural zones. In almost all cases the chemical data suggest slightly different thermal histories and recharge areas for the water issuing from the hot springs. Sustained use of the thermal water at any of the identified springs is probably limited to flow rates approximating the existing spring discharge.

INTRODUCTION

For several years residents of the Wood River area have known and used, on a limited basis, warm to hot spring water. Based on the number of occurrences, the increasing population and related development, and a limited supply of energy, the Department of Water Resources recognized the need for further evaluation of the Wood River region for its geothermal resources, particularly its potential for home and light industrial heating purposes.

The area under study includes 1,400 square miles with emphasis on seven different sites with thermal springs (Figure 1). A general geologic map of the region (Figure 2) was constructed by modifying the map of Rember and Bennett (1979). Site specific geology was plotted on United States Geological Survey 7.5 minute quadrangles. Limited well drilling in the area severely restricted subsurface geologic interpretations.

In addition to the surface and subsurface geologic surveys, a limited geochemical and isotope survey was conducted in order to obtain more information on thermal history. Shallow subsurface geologic and hydrologic data were obtained from existing well logs to determine aquifer potential and shallow geologic structure. Temperature gradient profiles were obtained from existing unused drill holes to assist in determining potential aquifer temperatures.

WELL- AND SPRING-NUMBERING SYSTEM

The numbering system used by the Idaho Department of Water Resources and the U.S. 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 Baseline 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 (Figure 3). Within the quarter sections, 40-acre and 10-acre tracts are lettered in the same manner. Well 11N-6W-10cca1 is in the NE1/4 of the SW1/4 of the SW1/4 of Section 10, T.11N., R.6W., and was the first well inventoried in that tract.

USE OF METRIC UNITS

The metric or International System (SI) of units is used in this report to present water chemistry data. Concentrations of chemical substances dissolved in the water are given in milligrams per liter (mg/l) rather than in parts per million (ppm) as in some previous Water Information Bulletins. Numerical values for chemical concentrations are essentially equal, whether reported in mg/l or ppm, for the range of values reported in this report. Water temperatures are given in degrees Celsius (°C). Conversion of °C to °F (degrees Fahrenheit) is based on the equation, °F = 1.8°C + 32. Figure 4 shows the relation between degrees Celsius and degrees Fahrenheit.

Linear measurements (inches, feet, yards, miles) are given in their corresponding metric units (millimeters, meters, kilometers). Weight and volume measurements are given in both metric and English units. Where metric units are not readily usable, such as for elevations on topographic maps, the English value is used.

GEOMORPHOLOGY

The Wood River drainage area , located in south-central Idaho, is near the southeastern margin of the Idaho Batholith. The areas of study, as contained in the region, are located from Magic Reservoir at the south to near Galena Summit to the north (Figure 1). The Wood River region generally is a mountainous region with marked relief, in which relatively level tracts are found only along the larger drainages as alluvial terraces and/or floodplains.

The principal drainage within the study area is the Big Wood River. It rises in the Boulder Mountains to the north, flows southerly through Ketchum, Hailey, and Bellevue prior to turning westward at the valley's mouth and flowing into Magic Reservoir. Many perennial and intermittent streams enter the river from both the east and west. At the headwaters of the Big Wood River, near Russian John Hot Springs, the relief is quite steep. The valley floor near the hot springs is at 6,800 feet above sea level with Easley Peak, a mere three miles away, at 11,115 feet above sea level. Generally, from Bellevue north, the relief is quite pronounced with relief between stream valleys and mountain peaks varying from 2,000 feet to 4,000 feet. The lowest relief found in the study area is from Bellevue south to Magic Reservoir. Local relief in this portion of the study area generally does not exceed 2,000 feet.

The alluvial flats of the Big Wood River Valley average about 2.4 kilometers in width from Ketchum south to Bellevue.

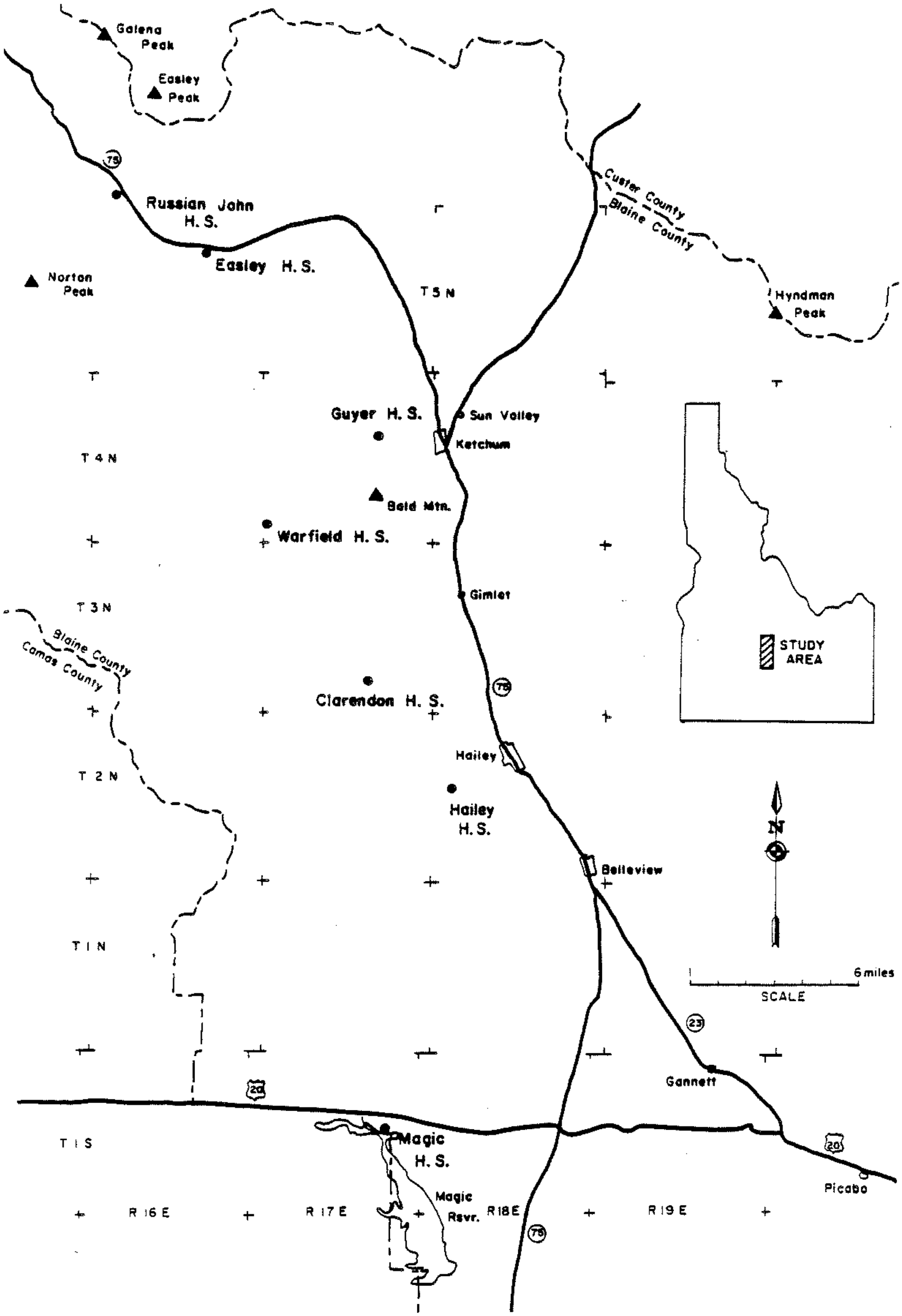


Figure 1. Location Map

MAP LEGEND

Qal: Alluvium

Qtg: Terrace Deposits

Qg: Glacial Deposits

Tiv: Idavada Volcanics

Tcv: Challis Volcanics

Ki: Idaho Batholith

PPw: Wood River Formation

Dm: Milligen Formation

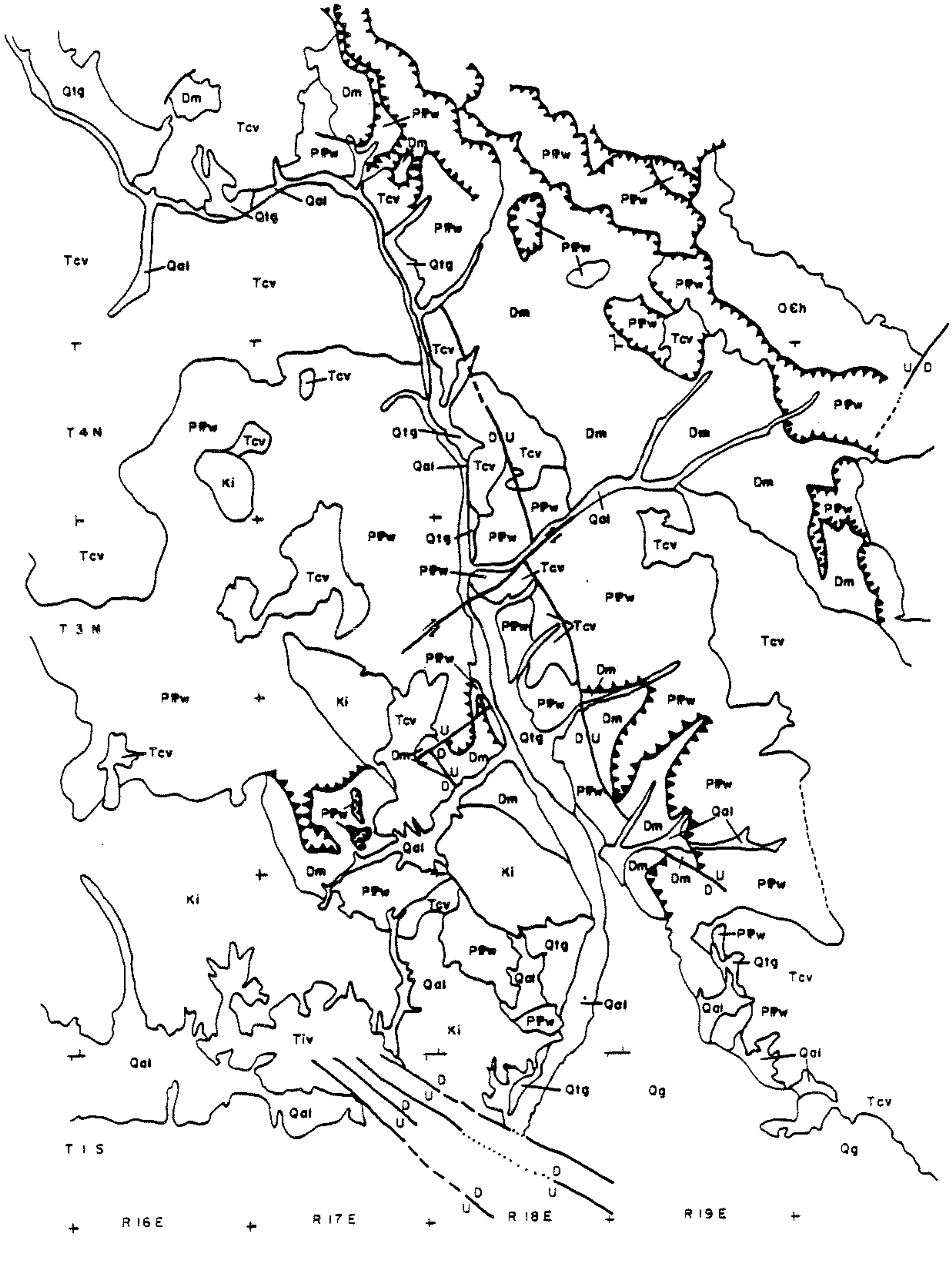
OЄh: East Fork and Hyndman Formations

Normal Fault - dashed where inferred, dotted where concealed

Strike-Slip Fault

Thrust Fault - teeth on upper plate

Figure 2. Geologic map of the Wood River drainage area (after Rember and Bennett, 1979).


T 4 N
T 3 N
T 1 S
R 16 E
R 17 E
R 18 E
R 19 E

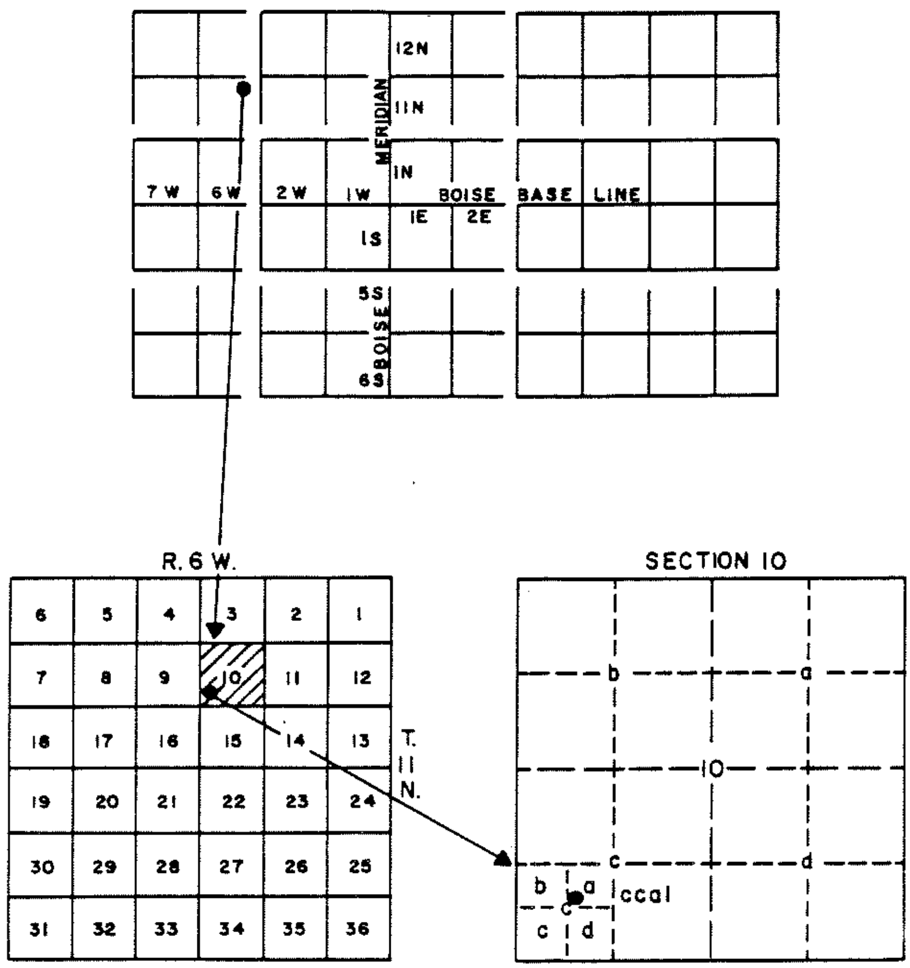
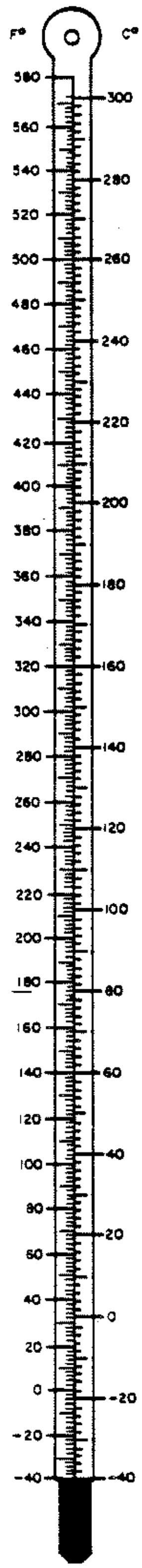


FIGURE 3. Diagram showing the well-and spring-numbering system. (Using well 11N-6W-10ccal.)



(APPROX.)

Figure 4. Temperature conversion graph

From Bellevue south, the valley broadens to nearly 21 kilometers wide at its mouth. This widening in a relatively short distance (16 kilometers) relates to several overlapping geologic events (Schmidt, 1961). Prior to the eruption of Snake River Basalt flows and related volcanics, the Wood River apparently flowed along the eastern flank of the valley in this area, turned east at the valley's mouth and flowed southeasterly eventually draining into the Snake River (Umpleby and others, 1930) . The widespread deposition of glaciofluviatile material at the valley's mouth is apparently due to intermittent damming of the river by basalt flows. The damming caused the Big Wood River to repeatedly change course prior to establishing its present channel. The valley floor from where the river now turns westward to Magic Reservoir, steepens gradually from an elevation of 4,840 feet above sea level to nearly 6,800 feet above mean sea level at Russian John Guard Station, a distance of about 72 kilometers.

CLIMATE

The Big Wood River Valley has moderately cold winters and relatively warm summers. The valley floor is sheltered somewhat from severe cold and strong winds by the surrounding mountains. At Hailey (elevation 5,329 ft), yearly precipitation is 15.33 inches; but less than 20 percent of the total precipitation falls during the growing season. The months of least precipitation are July, August, and September. It is not unusual for cumulative snow depths on the ridges and mountain tops in the area to be 60-70 inches.

Precipitation in the basin is sufficient to support sagebrush and native grasses on the lower mountain slopes and noncultivated areas of the valley floor. Forest growth in the mountains, which consists largely of Douglas fir and pines, is restricted to the higher elevations and the northern slopes of ridges. Cottonwood and willows border the Big Wood River and its tributaries at the lower elevations. Irrigated agriculture is practiced in the valley south of Hailey.

POPULATION AND INDUSTRY

Population centers within the Wood River study area, from south to north are: Bellevue, Hailey, Ketchum, Sun Valley, and North Fork. Hailey is the county seat of Blaine County. According to the 1980 census, Hailey has a population of 2,109. It is the principal supply center for the farming and ranching industries predominant in the southern portion of the Wood River Valley. Bellevue, nearly eight kilometers south of Hailey, had a population of 1,015. Ketchum had a population of 2,200; while neighboring Sun Valley had a population of 545. These two communities are about 25.7 kilometers north of Hailey, and are primarily tied to summer and winter recreation and associated support industries. North Fork, with a population of approximately 170 lies about 9.7 kilometers north of Ketchum on State Highway 75 and is primarily a recreation community.

Historically, metal mining has been the largest industry in the region. However, since the early 1920's there has been very limited mining related activity. Cash Industries, Inc., of Ketchum, a relatively new enterprise in the area, is involved in the mining and beneficiation of barite, and currently ranks as the largest mining operation in the area. The beneficiation plant, currently operating at 250 tons/week, is located about 6.4 kilometers southwest of Ketchum up Warm Springs Creek, about halfway between Guyer Hot Springs and Warfield Hot Springs.

Since the decline of the mining boom, the Sun Valley-Ketchum area has become a very popular year round recreation area. This has brought many new facilities to the area, including new resorts and condominiums. The ongoing construction of condominiums can be seen in and around the Ketchum-Sun Valley area as well as southward nearly to Hailey.

GEOLOGY

Formations exposed in the general study area range in age from Precambrian to Recent, and include a wide variety of rock types. These may be grouped broadly as pre-Tertiary sedimentary and granitic rocks, Tertiary intrusive and volcanic rocks, and Quaternary basalts and unconsolidated sediments.

STRATIGRAPHY

The following general descriptions, from oldest to youngest (Figure 5), are taken in part from Umpleby and others (1930).

Oldest Metasedimentary Units

Within the study area the oldest exposed rock units are a series of quartzites, marbles and schists found in a twenty square mile area near the heads of the East Fork of the Big Wood River and Hyndman Creek. Umpleby and others (1930) divided these rocks into the Hyndman and East Fork Formations. Originally assigned to the Precambrian, recent workers (Dover, 1969; Rember and Bennett, 1979) suggest late Precambrian to early Paleozoic ages (as young as Ordovician) for the units. The units are well exposed at the summit of Hyndman Peak.

QUATERNARY	alluvium terrace deposits glacial deposits	Snake River Grp.
TERTIARY		Idavada Volcanics Challis Volcanics
CRETACEOUS		Idaho Batholith
PERMIAN-PENNSYLVANIAN	Wood River Formation	
DEVONIAN	Milligen Formation	
SILURIAN	Trail Creek Formation	
ORDOVICIAN	Phi Kappa Formation East Fork Formation	
ORDOVICIAN-CAMBRIAN	Hyndman Formation	
PRECAMBRIAN	gneisses and schists	

Figure 5. Generalized stratigraphy for the Wood River drainage area

Phi Kappa Formation

The Ordovician-age Phi Kappa Formation consists of a thick sequence of interbedded black argillites, gray to black shale and slate, and light-colored quartzite. Sparse, poorly preserved graptolites suggest the Ordovician-age assignment.

The formation outcrops along the eastern crest of the Wood River drainage area. The base of the formation is not exposed as the unit is always found in fault contact with older rocks. The Phi Kappa is at least 915 meters thick, and, depending on internal relationships, may be much thicker.

Trail Creek Formation

A section of approximately 150 meters of rocks lithologically similar to the Phi Kappa Formation, but containing Silurian graptolites (Umpleby and others, 1930; Ross, 1934) have been designated as the Trail Creek Formation. The principal outcrops occur at the head of Trail Creek, and for the most part are obscured by talus and vegetation.

Milligen Formation

The Milligen Formation consists chiefly of black, phyllitic argillite with interbedded limestone, quartzite, and chert. In a few places, thin interbeds of graphitized coal are found within the argillite. While the Milligen Formation is distinct lithologically from the overlying Wood River Formation, black, non-phyllitic Milligen rocks resemble the black shale of the underlying Phi Kappa Formation.

Because of the complex deformation and poor exposures, no exact thickness has been determined for the unit. Its areal extent and the relief within the outcrop area indicate a thickness of 500 meters or more (Dover, 1969).

Originally considered to be Mississippian in age (Umpleby and others, 1930), the formation is now tentatively considered to be Devonian (Rember and Bennett, 1979).

Wood River Formation

The Wood River Formation consists primarily of gray to tan, sandy limestones or calcareous sandstones. Except for the conglomerate/breccia quartzite basal portion of the formation, it is thick (up to 3 meters) to medium bedded. Thin shale layers separate the beds. Umpleby and others (1930) reported a composite thickness of 2,350 meters for the unit. However, the structural complexities of the region and of the formation itself make this number suspect. At a minimum, 500 meters of Wood River Formation are thought to exist.

Originally assigned to the Pennsylvanian, fusilinids from outcrops near Bellevue indicate the rock unit accumulated during Pennsylvanian and Early Permian time (Bostwick, 1955).

Granitic Rocks Related to the Idaho Batholith

Granitic rocks have intruded the sedimentary rock units of the Wood River region in several places. Although varying in compositional detail, their general petrologic character and geologic relationships suggest they are part of the Idaho Batholith suite of intrusive rocks. The scattered outcrops in the region are probably genetically related and directly connected at depth.

In the northeastern portion of the drainage most exposures are of granodiorite with minor amounts of quartz monzonite and a border facies of diorite. Quartz monzonite is the principal intrusive exposed south and west of Bellevue. Some granodiorites outcrop, as does a border facies of diorite.

Most radiometric dates for rocks related to the Idaho Batholith indicate a Cretaceous age for the principal rock suite. Schmidt (1961) obtained a lead-alpha date of 114 million years before present from a quartz diorite near Hailey. Dover (1969) suggests that some of the quartz monzonites may be Tertiary in age.

In outcrop, these granitics are frequently deeply weathered, and display zones of intense jointing. The joint zones are significantly more permeable than the surrounding unbroken rock and are frequently the site of cold-water springs. Warfield and Clarendon Hot Springs are associated with granitic rocks where permeability and transmissivity are fault or joint controlled.

Challis Volcanics

Tertiary-age volcanics outcrop in most of the Wood River drainage area. Those in the northern and southeastern parts of the area are believed to be remnants of a much larger volcanic deposit which covered much of central Idaho. These Challis Volcanics were thought to be part of the Oligocene or Miocene Series (Umpleby and others, 1930; Smith, 1959), however the Geologic Map of Idaho (Bond, 1978) assigns them to the Eocene.

The unit can be divided into three general groups: a lower sequence of basalt and augite andesite, a thick middle sequence of latite and hornblende andesite, and an upper rhyolite sequence.

South of Magic Hot Springs the rhyolite sequence is overlain by Idavada Volcanics and the Quaternary Snake River Group. Some of the Challis Volcanics outcrop at elevations up to 10,500 feet above sea level in the northern, mountainous portions of the area. While the relief of the pre-eruption topography accounts for much of the elevation difference between outcrops, the rocks have been extensively faulted (Umpleby and others, 1930). Post-eruption dislocations have tilted the outcrops at some locations to the extent that dips approach 90 degrees.

In some outcrops, individual flow units are separated by thin sedimentary beds. Although the extrusive rocks have moderate permeability, their presence at or near land surface limits the amount of water that is stored in the unit. Some cold-water springs occur when relatively impermeable sedimentary interbeds restrict percolation.

Idavada Volcanics

North of Magic Reservoir in the southwest corner of the study area a sequence of Tertiary-age extrusives occur that are tentatively identified as Idavada Volcanics. The rock sequence consists of a rhyolite and an overlying basalt. Rember and Bennett (1979) in their map compilation of the area used the name Moonstone Rhyolite and grouped the unit with the Idavada Volcanics. They identifed the basalt as the Square Mountain Basalt and suggest a possible relationship to the Banbury Basalt of southwestern Idaho.

The rock units are treated as Idavada Volcanics in this report as a matter of convenience. Their outcrop area is relatively small, and as surface extrusives they are not important in understanding the regional hydrology.

Snake River Group

From the Picabo Hills and the Magic Reservoir area on the southern edge of the study area southward to the Snake River the surface rock units consist of Quaternary-age basalt flows. These flows and their intercalated sedimentary beds are considered to be Pleistocene to Recent in age (Malde and Powers, 1962). The rock assemblage varies in thickness depending on the volcanic history of any specific location. A deep well at the Idaho National Engineering Laboratory encountered 748 meters of basalts and interbedded sediments thought to belong to the Snake River Group.

Quaternary Sediments

Quaternary-age sediments in the Wood River drainage area are of glacial, glaciofluvial, alluvial, and eolian origin. Morainal deposits and remnants of high-level glaciofluvial terraces are visible in the upper valley of the Big Wood River and in some of the tributary valleys. Much of the surface material in the "triangle" south of Bellevue consists of glaciofluvial material. These deposits and their associated land forms are the result of alpine glaciation and the melt-water resulting from its recedence.

The nonindurated terrace and floodplain sediments in the valley are poorly to moderately sorted and generally coarsely clastic. They play an important role as suppliers of domestic and irrigation water, but are probably separate from the geothermal system.

GENERAL STRUCTURE

The sedimentary rocks of the Wood River region have been intensely folded and faulted, and locally are cut by igneous intrusions. Folding can be seen in most of the pre-Tertiary strata. The Milligen Formation is generally more intensely folded than the other formations. This folding is a combination of compound, highly fractured, and somewhat parallel anticlinal and synclinal structures, generally trending northwest to southeast. Many of these structures are overturned to some degree, with bedding being as much as 20 degrees past vertical (Umpleby and others, 1930). One small overturned syncline is visible just north of Guyer Hot Springs.

Faulting in the study area is widespread and ranges from major thrusting to many variations of normal faulting. Many of the synclines east of the Big Wood River show major thrusting on their northeast sides, with dips ranging from near horizontal to 45 degrees. In some cases these thrusts have visible strike lengths of several miles.

Umpleby and others (1930) described five different groups of normal faults in the area. However, they are not easily recognized, particularly in the Wood River and Milligen formations. Recent mapping projects (Rember and Bennett, 1979; Batchelder and Hall, 1978) within the area confirm the existence of widespread faulting in these formations.

Major structural trends were not observed crosscutting the Cretaceous-age granitics in any specific area; however, locally they are extensively jointed. This jointing may be related to large structural events.

The Tertiary-age volcanics and igneous rock are broken by major northwest trending faults. As described by Umpleby and others (1930) and Malde and Powers (1962), these faults may have vertical displacements of 300 meters or more. The structural history of the area is key to understanding the geothermal system. Only the deep, normal faults appear to provide migration paths for the thermal water.

DISCUSSION

The sequence of rock units in the Big Wood River area is of considerable interest to geologists. It is unique in that a rock sequence ranging in age from Precambrian through Tertiary is juxtaposed to rocks of the Idaho Batholith.

Although the rock types are unusual, the hot springs in the area are similar to other thermal water occurrences associated with the Idaho Batholith. The heat source for the area must be related to the batholith. The Tertiary-age extrusives are much too old to have significant retained heat. The sedimentary and metasedimentary rocks of Paleozoic age formed at atmospheric or oceanic temperatures, while the Precambrian rock units due to their elevated position and great age play no role in thermal-water history.

Circulation depths of two to three kilometers are probably required to attain the temperatures found in the thermal water of the area. Since the granitic rocks have no interstitial permeability, this deep circulation must depend on structural features that postdate the batholith.

For practical purposes, none of the indurated rock units in the area have sufficient interstitial permeability to form aquifers. The migration of thermal water in the area and its occurrence as hot springs is controlled by structural events which produced fracture permeability.

HOT SPRINGS

Seven hot spring areas were studied within the general study area. These specific hot spring areas were examined in detail by means of geologic mapping on 1:20,000 scale aerial photographs and field geologic mapping at 1:24,000 scale. U-2 stereo photographs along with enhanced infrared imagery photographs of 1:1,000,000, 1:500,000, and 1:250,000 scales were used to substantiate and/or augment geological interpretations. Driller's logs from water wells on file at the Department of Water Resources and mine exploration core logs were used to substantiate suspected subsurface lithologies and structures in some areas.

The following discussions of the geology and related geothermal systems for each hot spring area proceed by geographic location from south to north within the study area.

Magic Hot Springs

The Magic Hot Springs area is located in the southern portion of the study area on the north edge of Magic Reservoir in T.1S., R.17E., Section 23aab. The geothermal development at this location presently consists of a 79-meter well that has an artesian flow of 57 l/min (15 gpm) of 74°C water. This well was drilled near the former site of Magic Hot Springs, which had a surface discharge of 492 l/min (130 gpm) at a temperature of 36°C (Ross, 1971). As as result of the drilled well, the springs ceased flowing.

Another well located approximately 400 meters due east of the Magic well, located in T.1S., R.17E., Section 23aaa, was drilled to a depth of 117 meters. This well, penetrated granite from 96 meters to total depth, does not flow, and has a static water level temperature of 37°C.

Magic Hot Springs Landing and the hot springs area is easily accessible by turning south off U.S. Highway 20 for about one mile on an improved gravel road.

Geology

This site was examined in conjunction with staff of the University of Utah Research Institute. The data generated during the field studies are simplified for presentation in this report and differ from a detailed geologic map with cross sections prepared by Research Institute personnel that is available from the Idaho Department of Water Resources. Additional work by Research Institute staff has been described by Struhsacker and others (1982). Leeman (1982) has advanced the interesting hypothesis that a buried caldera exists in the Magic Reservoir area.

The main rocks exposed at or near the surface in the immediate area of the Magic Hot Springs are basalts, rhyolites, and rhyolitic ash-flow tuffs that are in places covered by Quaternary sediments (Figure 6). The oldest rock exposed in the immediate area is a coarsely porphyritic rhyolite flow containing phenocrysts measuring up to 15 millimeters in length. This unit is tentatively assigned to the Challis Volcanics.

Rhyolite ash-flow tuffs, as exposed in the Magic Reservoir area, are principally quartz-sanidine, rhyolite ash-flow tuffs. These ash-flow units overlie the older rhyolites. Overlying the tuff units is a distinctive pale orange, poorly-sorted pumice flow. The pumice has a silky, vitreous luster and a filamentous like texture. This unit is well exposed in prospect pits and outcrops just north of Magic Hot Springs Landing as well as in a quarry on the north side of Highway 20. The thickness of the pumice may be as much as 30 meters as indicated by Idaho Department of Transportation drill records. The ash-flow tuffs and pumice are probably related to the Idavada Volcanics.

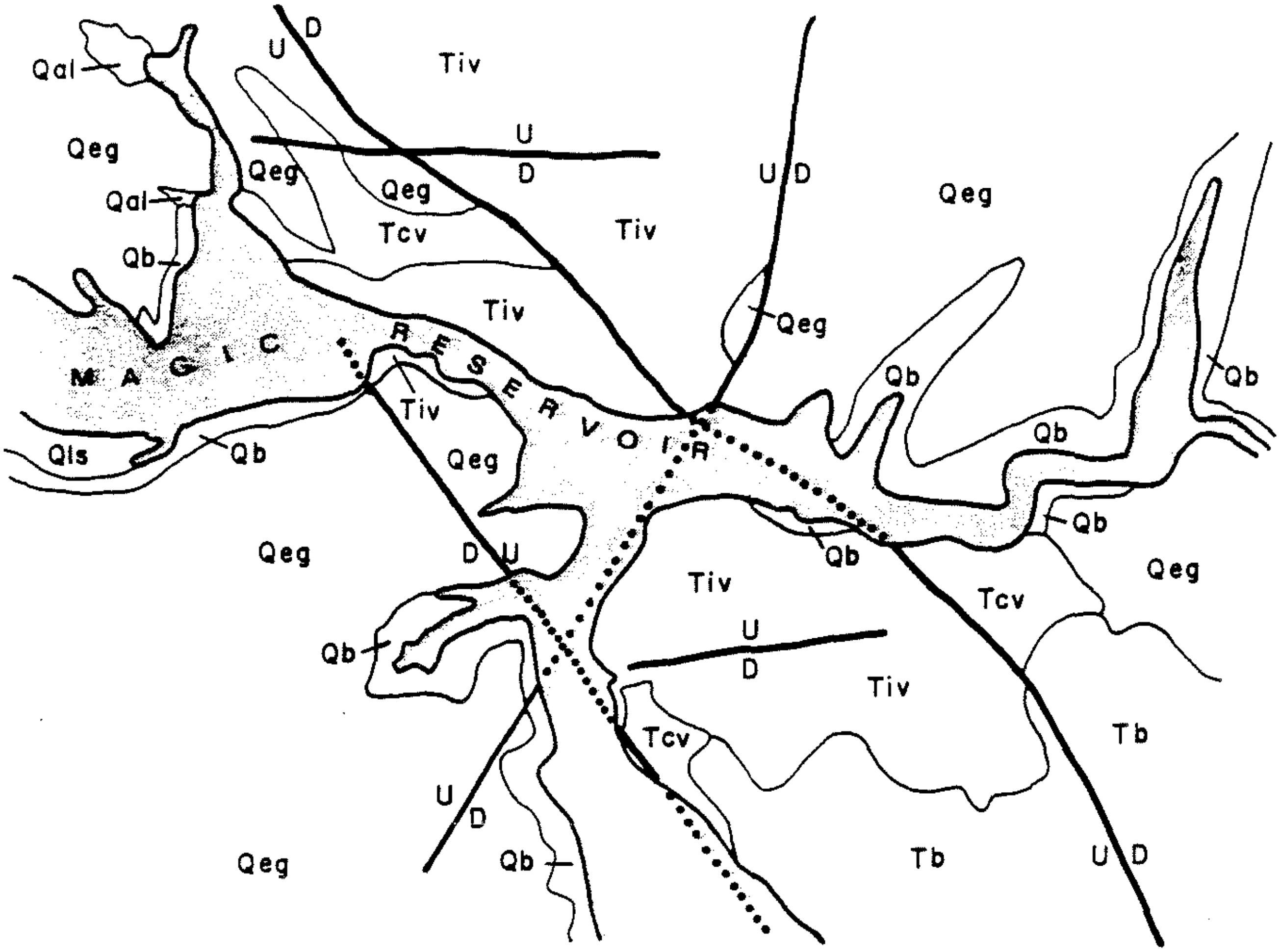
The youngest rocks in the area are Quaternary-age basalts. Typical of and generally considered to be related to the Snake River Group, at least some of the flows may be part of the slightly older Bruneau Formation (Malde and Powers, 1962; Malde and others, 1963; Rember and Bennett, 1979). Granitic rocks related to the Idaho Batholith outcrop within a few miles of the hot springs site and are believed to underlie the area. Leeman's (1982) caldera hypothesis suggests rhyolite is the "basement" rock for much of the Magic Reservoir area.

Quaternary sediments are locally exposed in the area, and may have a combined thickness of nearly 80 meters as indicated by water well data at the hot springs site. A coarse, nearly bouldery, sand and gravel overlies much of the area. This deposit appears to be alluvial material associated with the Camas Creek drainage. Its position above current drainage levels is fault controlled (Schmidt, 1961).

Structure

The area is cut by numerous, normal faults trending northeast, northwest, and west. The northwest and west trending faults appear to be the dominant structures, forming a horst block in the hot springs area.

Data from water well logs in the area and temperature gradient profiles suggest the resource is fault controlled. Those wells not intersecting major structural features or their related structural permeabilities have isothermal temperature gradients and yield little water. Those wells drilled on or near major structural features have higher temperature gradients and higher water yields.



Rock Units: Qal : Quaternary alluvium

Qls : Quaternary landslide debris

Qeg : Quaternary sand and gravel elevated above present drainage

Qb : Quaternary Bruneau Fm. basalt flows and sedimentary interbeds

Tivp: Tertiary Idavada Volcanics(?) - capping pumice layer

Tiv : Tertiary Idavada Volcanics(?) - rhyolitic ash flow tuffs

Tcv : Tertiary Challis Volcanics(?) - older rhyodacites and dacites

20,000 ft.

N

Map Symbols:

Fault - dotted where concealed

Contact

Figure 6. Geologic map of the Magic Hot Springs area

The geothermal resource at Magic Hot Springs is probably controlled by deep, convective circulation of waters along major faults, being heated by an unknown heat source at depth, eventually migrating upward and discharging at the surface at or near the intersection of these major structures.

Hailey Hot Springs

Hailey Hot Springs is located about three kilometers west of Hailey on the north side of Croy Creek in Democrat Gulch, T.2N., R.18E., Section 18dbb. The area is accessible by traveling west from Hailey and up Croy Creek by improved gravel road to Democrat Gulch. The spring is located about 550 meters north of this road, immediately next to the creek channel of Democrat Gulch.

The geothermal resource at this location consists of several tightly grouped spring discharges, with a cumulative flow of 265 l/m (68 gpm) at 59°C. Prior to their development, these springs discharged through the alluvial material of Democrat Gulch. Just a few feet west of the springs is a highly jointed exposure of Milligen Formation carbonates which presumably is an outcrop of the thermal water conduit.

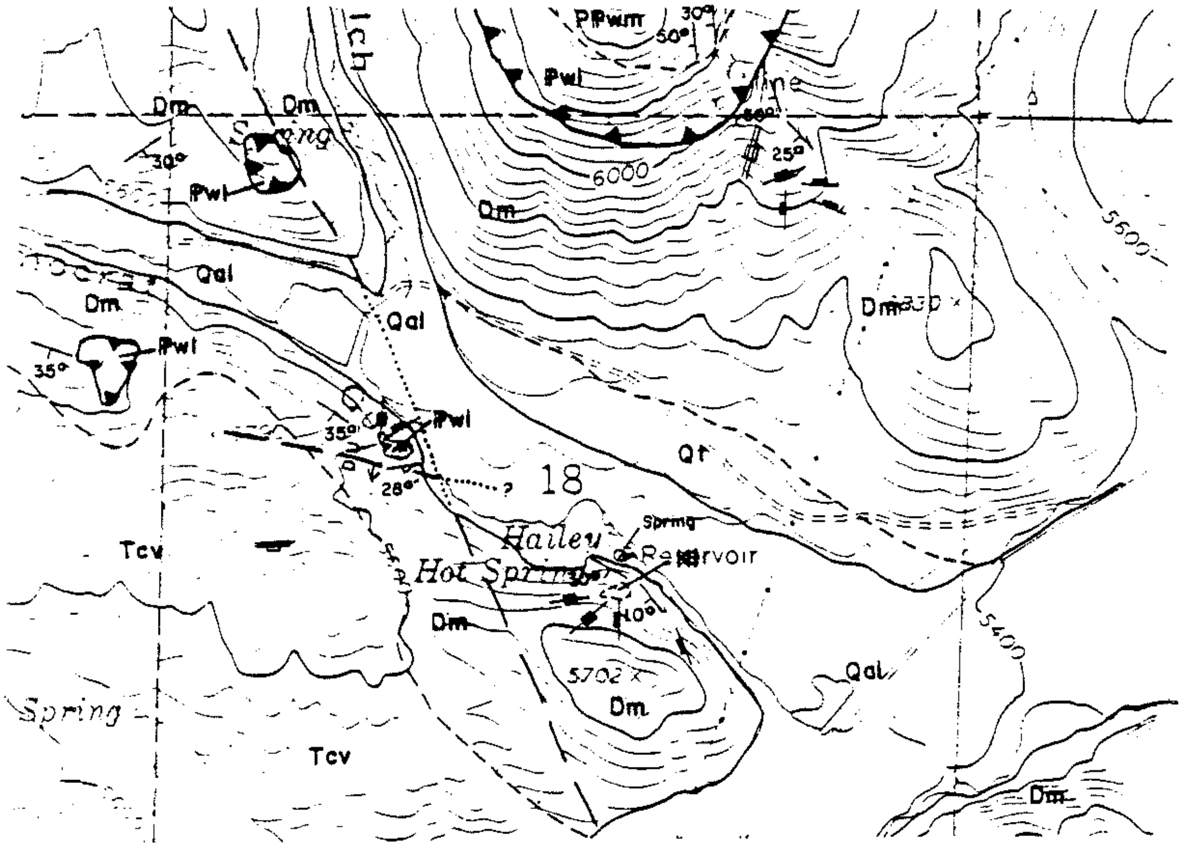
Much of the area of spring discharge has been enclosed by a concrete headbox with the hot water funneled into a buried pipe distribution system for swimming pool and space heating use in Hailey at the Hiawatha Hotel. Recently the hotel burned leaving the subsequent use of the resource questionable. A major rehabilitation of the collection system would be necessary if the system were to be reactivated.

Geology

The rocks exposed in the area of Hailey Hot Springs are the carbonates and argillites of the Milligen and Wood River Formations overlain on the west by Challis Volcanics (Figure 7).

The alluvial covered valley floor is nearly 210 meters wide at the springs, and is flanked on the east by a narrow deposit of elevated terrace gravels. The relief is moderate in the area with most of the slopes covered with sagebrush and bunch grasses.

North of the hot springs about 850 meters, at an elevation of approximately 6,000 feet, the Hailey conglomerate, the basal member of the Wood River Formation, is exposed. Other units of the Wood River Formation, as described by Batchelder and Hall (1978), are visible to the top of the hill, showing approximately 35 meters of vertical section. As the Wood River Formation is part of a thrust plate, the stratigraphic sequence that is normally seen in the Milligen Formation below the Wood River is absent.



Rock Units:
- Qal : Quaternary alluvium
- Qt : Quaternary talus
- Tcv : Tertiary Challis Volcanics
- Ki : Cretaceous Idaho Batholith
- PPwm: Permian-Pennsylvanian Wood River calcareous sandstone and quartzite
- Pwl : Pennsylvanian Wood River limestone and conglomerate
- Dm : Devonian Milligen Formation

1000 ft.
302 m.

N

Map Symbols:
- Strike and dip of bedding
- Strike and dip of joints
- Strike of vertical joint
- Strike and dip of veins
- Strike of vertical veins
- Hot spring
- Fault - dashed where uncertain, dotted where concealed
- Thrust fault - teeth on upper plate
- Contact - dashed where approximately located

Figure 7. Geologic map of the Hailey Hot Springs area

The hot springs, at an elevation of nearly 5,440 feet, are flanked directly on the southwest side by an exposure of highly jointed and mildly silicified dolomite of the Milligen Formation. This member of the formation is relatively resistant to weathering and, where exposed, shows prominent blocky outcrops. Bedding generally strikes northwest and dips 10-40 degrees southwesterly.

About 91 meters to the south of the hot springs, a highly altered, pale brown to white aplite dike containing many small calcite veinlets is exposed at the surface, however, this dike is not seen in the face of the exposure of dolomite next to the springs.

Further southwest of the hot springs is the contact between the Challis Volcanics and Milligen Formation. The volcanic, an andesite, generally consists of agglomerate, lapilli tuff, and fine ash that are commonly silicified. The thickness of this volcanic unit is unknown.

Two quartz veins cut the formations locally. One, exposed in the volcanics, strikes approximately N80E and dips to the south. It is only visible in places and shows little to no surface mineralization. The other, exposed east of the hot springs near the base of the thrust plate of Wood River Formation, consists of one main vein and several minor parallel veins. These veins cut the Milligen Formation and lower Wood River Formation, strike generally N30E, and stand nearly vertical. Visible surface mineralization consists primarily of sparse iron sulfides, however, minor local exploration has taken place along these veins where exposed at the surface.

Structure

As there are limited exposures in the area, structural trends are somewhat obscured. An exposed window of dolomite next to the springs indicates jointing may control the near surface migration of these waters. Secondary mineralization found along jointing planes (now sealed) in the exposure indicates thermal waters probably discharged above the present hot spring. The relationship between the local jointing and the major structural trends are unresolved at this time.

Because of the limited exposures, only two faults were mapped in the area. One fault, trending north 70 degrees west and dipping 55 degrees to the south appears to have minor (one meter) vertical displacement. Only minor secondary mineralization, consisting of calcite veinlets and iron oxide stain, was visible along the exposed portion of this system. The other fault, as depicted by Batchelder and Hall (1978), trends north 20 degrees west. The associated fracture permeability is enough to allow at least limited migration of waters along this system as other springs are noted to discharge from this zone several hundred meters north of the hot springs. These springs have a surface discharge temperature of slightly less than 20°C and do not flow year round. Based on one year's observation, discharge usually commences in late July indicating a seasonal recharge phenomenon. A two- to three-month lag from the principal snowmelt period suggests recharge is at some distance from these spring sites.

The subsurface geology in the area of the hot springs is relatively unknown as only limited well drilling has been done in the area. One well, located approximately 150 meters north of the hot springs in Democrat Gulch, was drilled to a depth of 34 meters. This well was drilled in close proximity to the north-south trending faulting; however, well logs indicate it penetrated primarily the alluvial valley fill. A temperature depth profile of this well (Figure 8) shows a temperature increase from 11°C (about normal groundwater temperature) at the static level (14 m) to 17.7°C at the bottom of the hole (34 m), with a resulting temperature gradient of .32°C/m. This may indicate that thermal waters migrating along this fault system, discharge and mix with the colder shallow subsurface waters in the overlying alluvial material.

From the field work and limited well drilling in the area, this resource appears to be structurally controlled as rock permeabilities are generally low.

Clarendon Hot Springs

Clarendon Hot Springs is located in the central portion of the general study area in T.3N., R.17E., 27dcb. The spring is located on the west side of Deer Creek, just above the Clarendon Hot Springs Resort. The area can be reached by turning off State Highway 75, just north of Hailey, and traveling west up Deer Creek about 6.4 kilometers.

The geothermal resource at this location consists of a spring discharging 378 l/m (100 gpm) at 47°C (Mitchell and others, 1980). This spring is currently utilized at the adjoining ranch which includes swimming facilities. It is proposed to use these waters for space heating at an adjoining recreation area under development.

Geology

The main rocks exposed in the Clarendon Hot Springs area are Cretaceous granitic intrusives, sandstone and quartzites of the Wood River Formation, and argillites of the Milligen Formation. Alluvium covers the narrow valley floor (Figure 9).

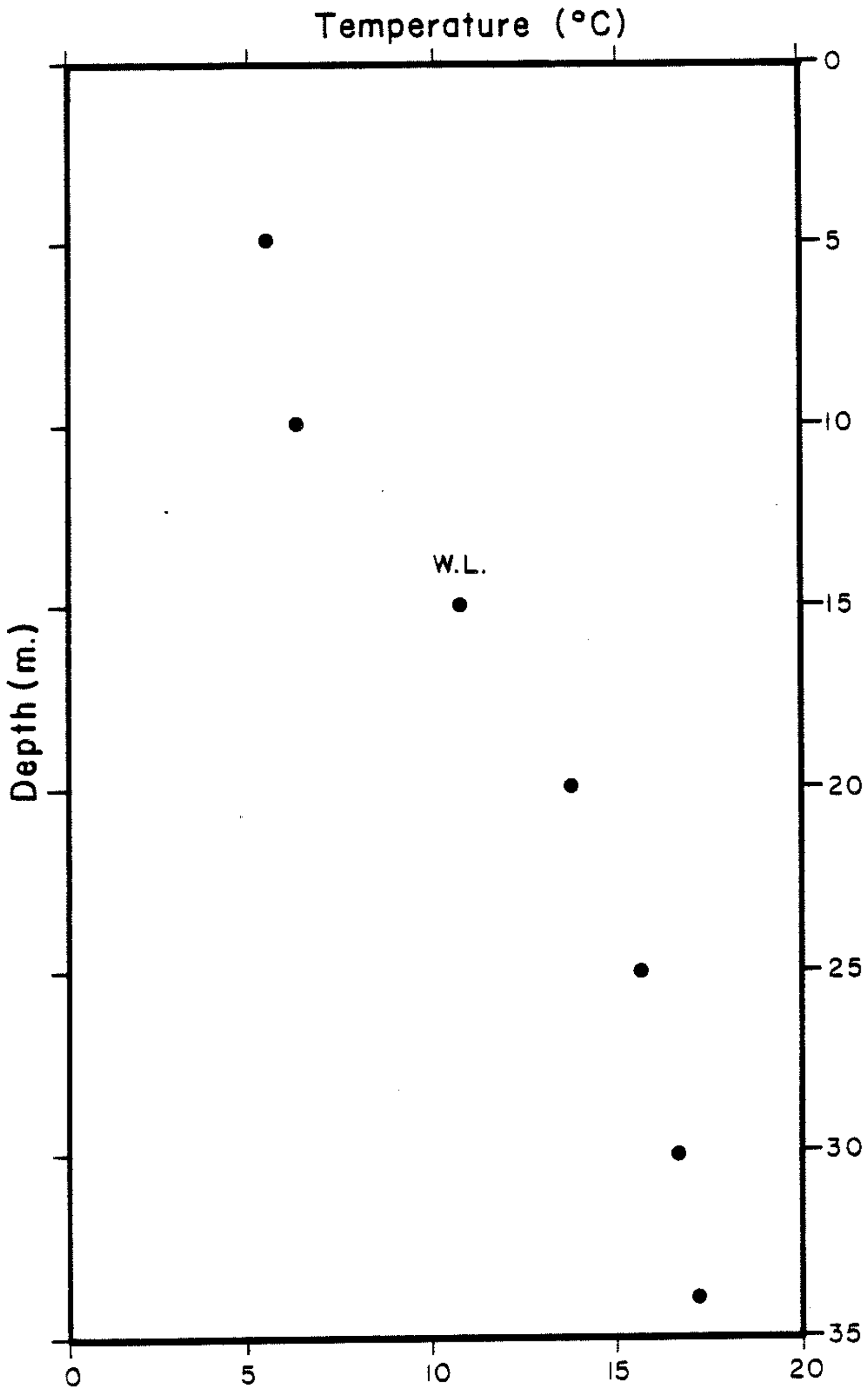
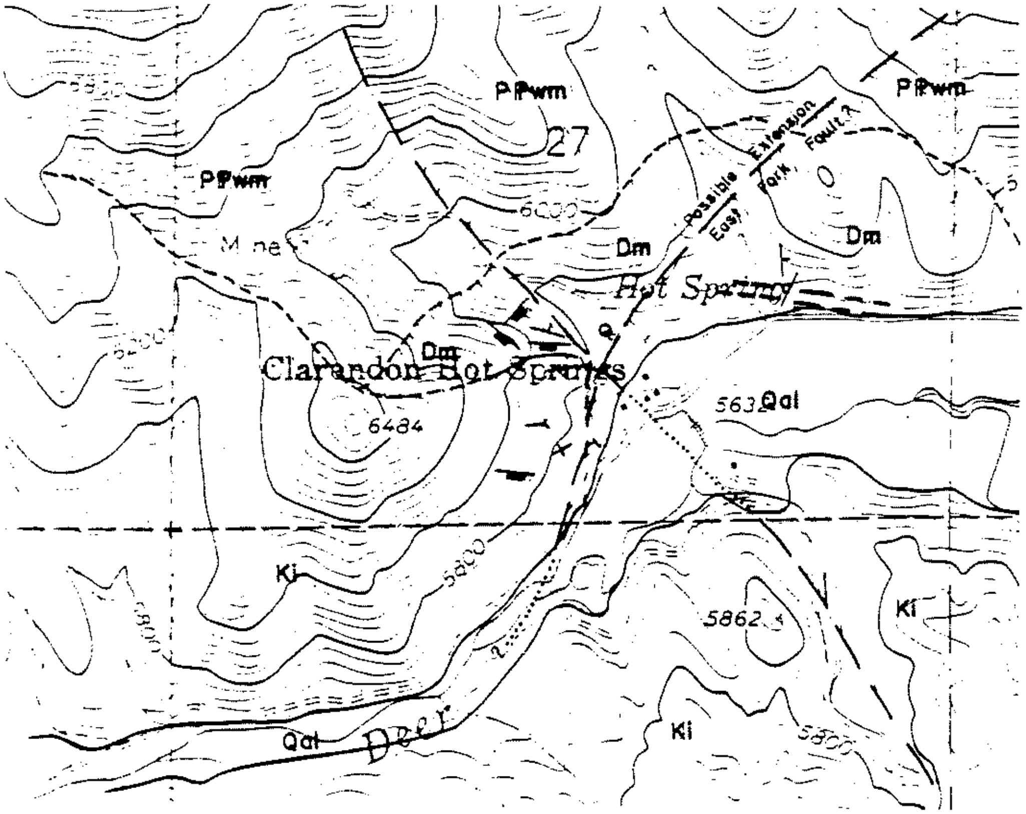


Figure 8. Temperature - depth profile, Hailey Hot Springs area; data from well 2N-18E-18acc



Rock Units:

- Qal : Quaternary alluvium
- Ki : Cretaceous Idaho Batholith
- PPwm: Permian-Pennsylvanian Wood River calcareous sandstone and quartzite
- Dm : Devonian Milligen Formation

1000 ft.
302 m.

N

Map Symbols:

- Strike and dip of bedding
- Strike of vertical beds
- Strike and dip of joints
- Strike and dip of foliations
- Fault - dashed where uncertain, dotted where concealed
- Contact - dashed where approximately located
- Open mine adit
- Hot spring

Figure 9. Geologic map of the Claredon Hot Springs area

The granitic rock, described as a quartz monzanite by Umpleby and others (1930) is medium grained with biotite and minor magnetite and generally is not porphyritic. A border facies of diorite, several feet in width, is visible along the contact. The diorite is coarse grained and contains abundant biotite. The granitic rock of the area weathers readily to sand.

Rocks of the Wood River and Milligen Formations exposed in the area are typical of the units, and are more resistant to weathering than the granitics and standout in prominent outcrops.

Structure

Tight folding and multiple jointing of the pre-Tertiary sediments is common at and near the contact with the intrusive. Bedding attitudes in some places along the contact are near vertical. Intrusive related quartz veins cut the sediments locally. Some have been explored during the early mining activity. Faulting along the contact is not clearly defined; however, intensive fracturing of the sediments along the contact suggests fair permeability along the contact.

Minor shearing, trending east-west, is evident in the granite just south of the contact. Some of these zones have also been exploited by early mining activities, however, the local mineralization found in these zones does not suggest they have been recent conduits for thermal waters.

A fault, trending northwest and dipping northeast, cuts the Paleozoic sediments between the contact and the point of spring discharge. The probable extension of this fault dips to the southwest in the granitics on the southeast side of Deer Creek illustrating the geologic complexity of the area. This fault may be acting as the permeable conduit, controlling the lateral or upward migration of the thermal waters. Other major faulting was not clearly defined in the area, however, evidence of shearing and minor displacement (20 to 25 cm) of the Paleozoic sediments in outcrops east of the springs near the road suggests normal faulting parallel to Deer Creek. This faulting may control stretches of the drainage and may be associated with the thermal water discharge at Clarendon. A northeast trending linear, interpreted from Landsat imagery, crosses the area intersecting the northwest-trending fault very near the point of spring discharge. This linear aligns and appears to extend southwestward from the East Fork Fault, however, the field investigation did not verify this.

Limited shallow well drilling in the area has met with varied success. Producing wells are used to support the resort facilities. The subsurface information and surface geology indicate rock and formation permeabilities are low with the thermal occurrence most likely structurally controlled.

Guyer Hot Springs

Guyer Hot Springs are located on the south side of Warm Springs Creek near the western city limits of Ketchum in T.4N., R.17E., Section 15aac.

The geothermal resource at this location is privately owned, and consists of several springs with a cumulative discharge of approximately 3,780 l/m (1,000 gpm). Temperatures vary from one discharge point to another but range from 55°C to 70°C. Much of the spring area has been capped by enclosed concrete headboxes. The thermal water is funneled into a single distribution system for local space heating and swimming pool use in Ketchum.

East of Guyer Hot Springs about 640 meters is Grayhawk Hot Springs. This spring, 4N-17E-14bbcs, discharges through the alluvial covered valley floor at nearly 8 l/m (2 gpm) at 55°C.

Geology

The rocks exposed at Guyer Hot Springs are the folded, faulted, and locally highly jointed Paleozoic sediments of the Wood River Formation (Figure 10). Local relief is steep with the north facing slopes heavily timbered. Just east of the hot springs, the narrow valley floor broadens significantly, forming wide alluvial flats flanked by terrace gravels.

Typically, the Wood River Formation shows prominent blocky outcrops where exposed in the area. One such outcrop, on the north side of the valley across from the springs, is indicative of the geological complexities associated with the area. Multiple calcite veining, up to 7.6 centimeters wide, both cuts and parallels bedding locally. Angular travertine float is abundant just below the outcrop. These features suggest that thermal waters once discharged at some point along the outcrop, but the discharge point is currently sealed off.

Structure

Structurally the area is complex. Major north-south trending folding is commonplace in the area. Bedding surfaces are nearly vertical in many places, and dense jointing is common. Vertical lineations are clearly visible on north-trending, vertical bedding planes north of Guyer Hot Springs. These may be associated with movements along bedding planes during folding or possibly to later occurring north-south faulting. Faulting appears to control the migrating thermal waters. Secondary mineralization found along a northwest trending fault system immediately east of the intersection with a north-south trending fault system suggests previous migration of thermal waters along that portion of the system.

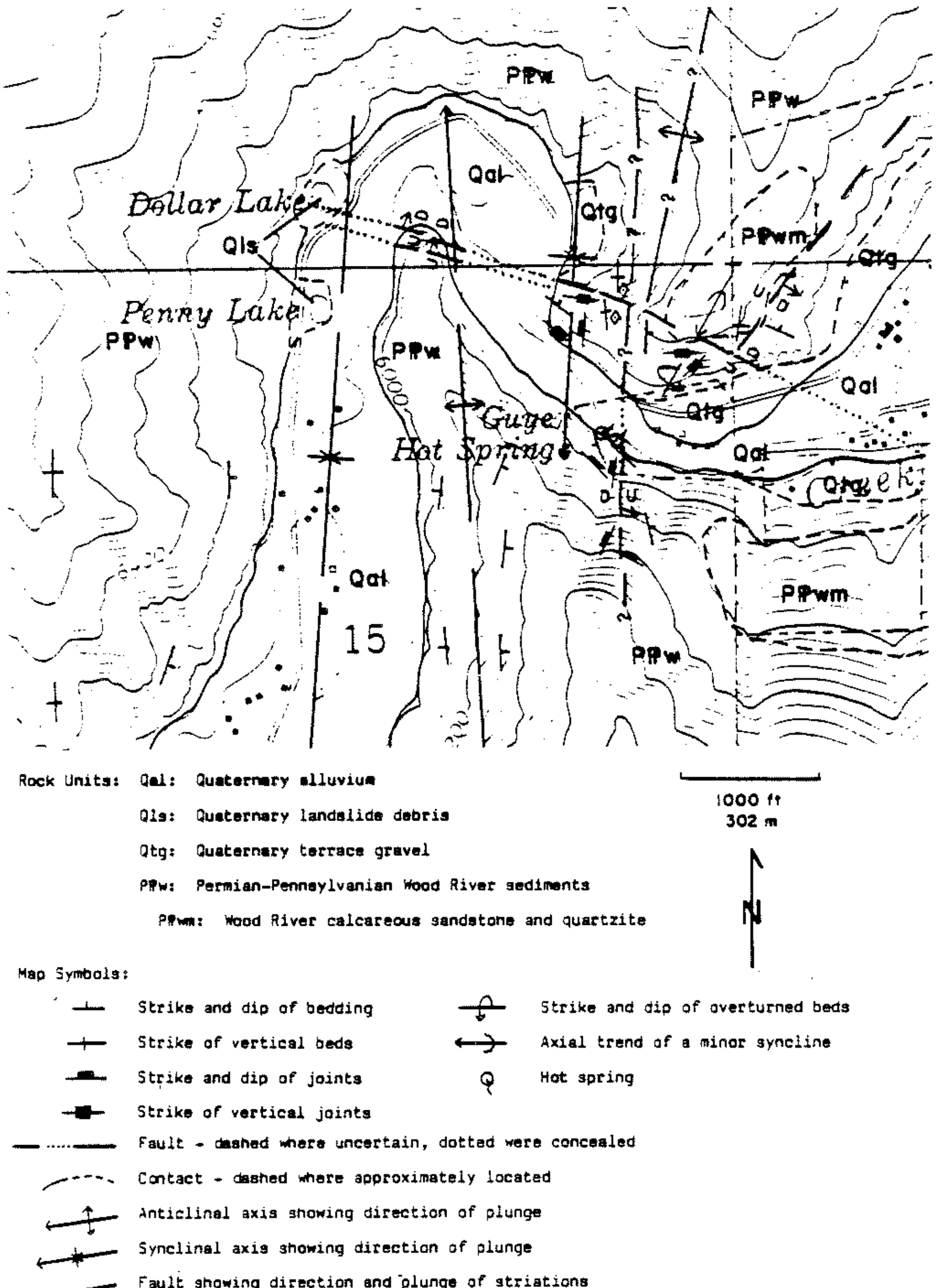


Figure 10. Geologic map of the Guyer Hot Springs area

Water chemistry data suggests Guyer and Greyhawk Hot Springs may be the same waters (Table 1). If this is the case, migration of these waters might be taking place, with the water migrating along one major fault system until encountering a major intersection, such as exists just north of Guyer, with the waters subsequently migrating along both permeable systems. This may be the case at Guyer and Greyhawk Hot Springs, as Guyer appears to be associated with the north-south faulting south of the intersection, and Greyhawk with the northwest-southeast faulting east of the intersection. Which of the fault systems is the major conduit for upward migration is unknown.

The surface discharge at Guyer Hot Springs is controlled by two primary joint sets. A third set has been sealed by secondary carbonate mineralization.

The subsurface geology in the area of the hot springs is relatively unknown as only limited drilling has been done in the area. One well located about 100 meters west and at the same elevation as Guyer, was drilled to a depth of 160 meters. The lithology of the well consisted entirely of Wood River carbonates. Prior to the well being shut in, it flowed at about 11 l/m (3 gpm). Currently shut-in pressure is 2 pounds per square inch. Subsequent pump testing indicates a yield of about 45 l/m (12 gpm). From the well data, it appears the permeable zone supplying Guyer was not intersected by this drilling. A temperature-depth profile for this well (Figure 11) indicates a temperature gradient of 0.14°C/m.

From the field work and limited well drilling, it appears this resource, as the others, is structurally controlled as formation permeabilities are generally low.

Warfield Hot Springs

Warfield Hot Springs is located west of Ketchum about 17.5 kilometers up Warm Springs Creek near the old Croney Cove Stage Depot. The area is sometimes called Frenchmans Bend Hot Springs by local residents. The geothermal resource at this location consists of two primary spring discharges and several minor discharges. One, a spring located in T.4N., R.16.E, Section 36aac, discharges from a locally highly jointed granitic rock at about 378 l/m (100 gpm) at 65°C. This spring, like the others, discharges below the high water mark of Warm Springs Creek and flows directly into it. The other, located in T.4N., R.17E., Section 31bbc, is a major seep. This seep discharges through highly fractured carbonate rocks at 62°C and is approximately 305 meters downstream from the spring. Other smaller seeps, discharging through a thin veneer of alluvium covering the carbonate rocks, are visible for a short distance (90 m) south of the main seep along Warm Springs Creek.

	Guyer Hot Springs (mg/l)	Greyhawk Hot Springs* (mg/l)
Sodium	73	78
Calcium	1	1
Silica	58	56
Fluoride	18	16
Chloride	11	5
Sulfate	59	63
Bicarbonate	92	99
Total Dissolved Solids	308	328

*as represented by water from well 4N-17E-14bbc

Table 1. Water chemistry from Guyer-Greyhawk Hot Springs area (total concentrations unless otherwise indicated; after Blackett, 1981).

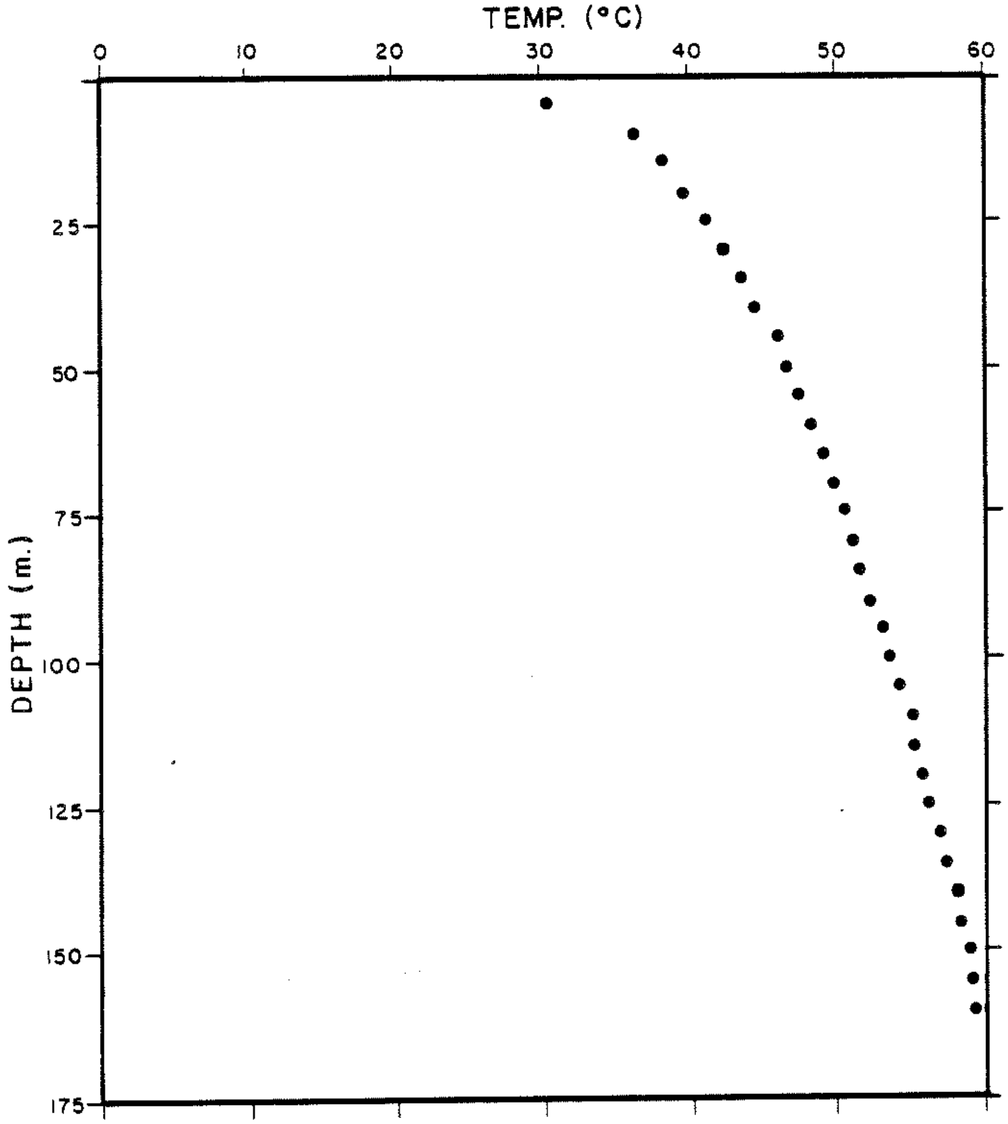


Figure 11. Temperature - depth profile,
Guyer Hot Springs area;
data from well 4N-17E-15aac

This area is easily accessible from Ketchum by an improved gravel road. Facilities at the site consist of a few hand-dug bathing pools and a small building providing "dressing-room" facilities. A few summer recreation cabins also exist just to the south of the springs.

Geology

The main rocks exposed in the Warfield Hot Springs area consist of a moderately weathered and jointed Cretaceous-age granite and the highly-jointed carbonate rocks of the Wood River Formation. A veneer of alluvium, consisting primarily of rounded granitic pebbles and quartzites, covers the narrow valley floor (Figure 12).

The main seep discharging from the carbonate rocks is about 40 meters east of the granite-carbonate contact. The contact strikes north-south through the area, dips about 35 degrees to the east, and in places is clearly defined. Faulting along the contact is not apparent in the area and the contact appears hydrologically tight.

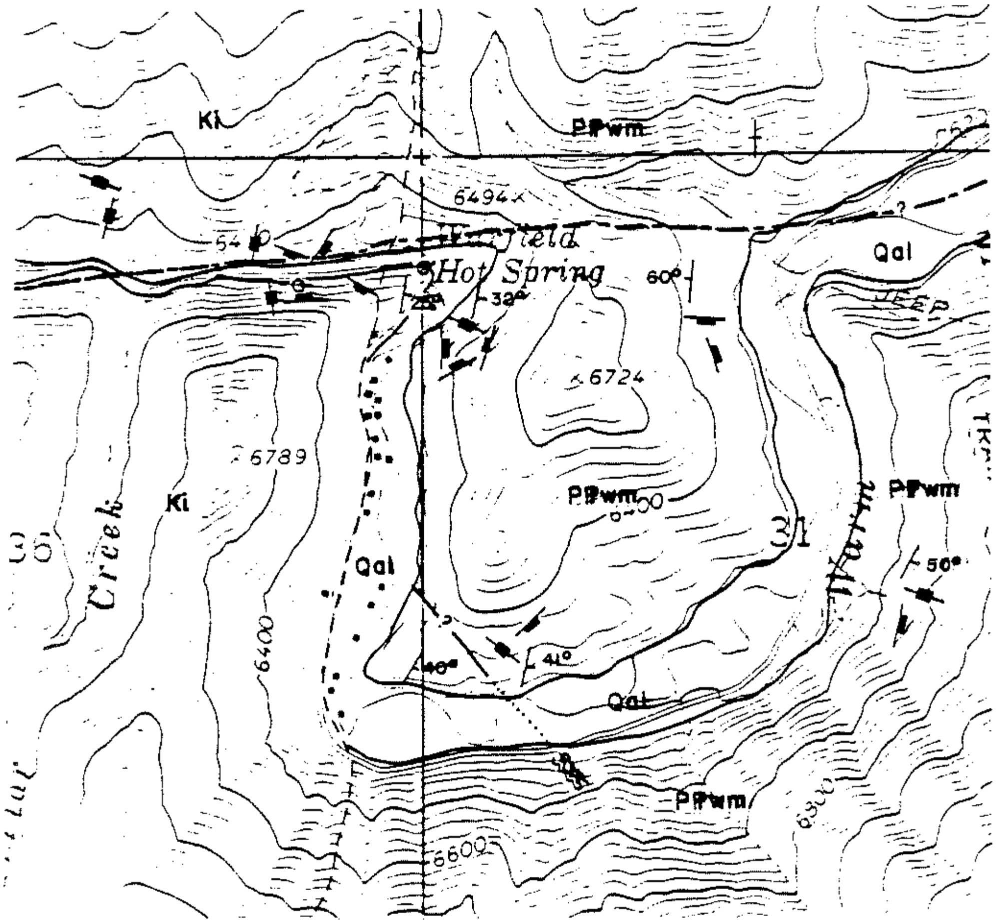
The carbonate rocks at this location are a dense, relatively fine-grained, highly silicified, jointed dolomite. Some fractures along bedding planes appear to have been filled with thin silica veinlets. The alteration of the dolomite is visible for approximately one hundred meters beyond the contact, with the most intense alteration occuring at the contact. The color of the dolomite at the contact is a light tannish-brown which changes to a pale gray-blue several meters beyond the contact. The dip of the bedding is generally consistent with the dip of the contact in the immediate area of the springs. Intrusive-related dikes of varied composition cut the dolomite near the contact but quickly decrease in abundance away from the contact.

The intrusive, as described by Umpleby and others (1930), is generally a soda granite. The granite, moderately weathered to a medium brown color, is locally highly jointed. Near the contact, is a border facies of hornblende-biotite diorite that is a relatively narrow zone, but is common along the contact.

Early mining activity immediately to the north of the hot springs did not intersect any thermal occurrences at higher elevations along this contact.

Structure

The thermal discharges of the area appear to be controlled near the surface by the major jointing found in the granite and dolomite. These discharges appear to be consistent with northwest and northeast trending joint sets which create enough permeability to allow migration of thermal waters.



Rock Units: Qal : Quaternary alluvium

Ki : Cretaceous Idaho Batholith

PPwm: Permian-Pennsylvanian Wood River calcareous sandstone and quartzite

1000 ft.
302 m.

N

Map Symbols:

Strike and dip of bedding

Strike of vertical beds

Strike and dip of joints

Strike of vertical joints

Shear zone

Hot spring

Fault mapped from aerial photos

Fault - dashed where uncertain, dotted where concealed

Contact - dashed where approximately located

Figure 12. Geologic map of the Warfield Hot Springs area

Major faulting in the area was not identified during the fieldwork. From the Landsat imagery, a major linear is interpreted to strike east-west following the drainage of Warm Springs Creek and crosscutting a portion of the dolomite in the area due west of the hot springs. The field examination of the dolomite in the suspected area of the linear did show a high degree of fracturing and jointing but no clear evidence of movement.

As no wells have been drilled in this area, the subsurface geology is unknown. From the field work, it would appear rock permeabilities are low. The thermal occurrences here, like the other study areas, appear to be structurally controlled and confined to avenues of fracture permeability.

Easley Hot Springs

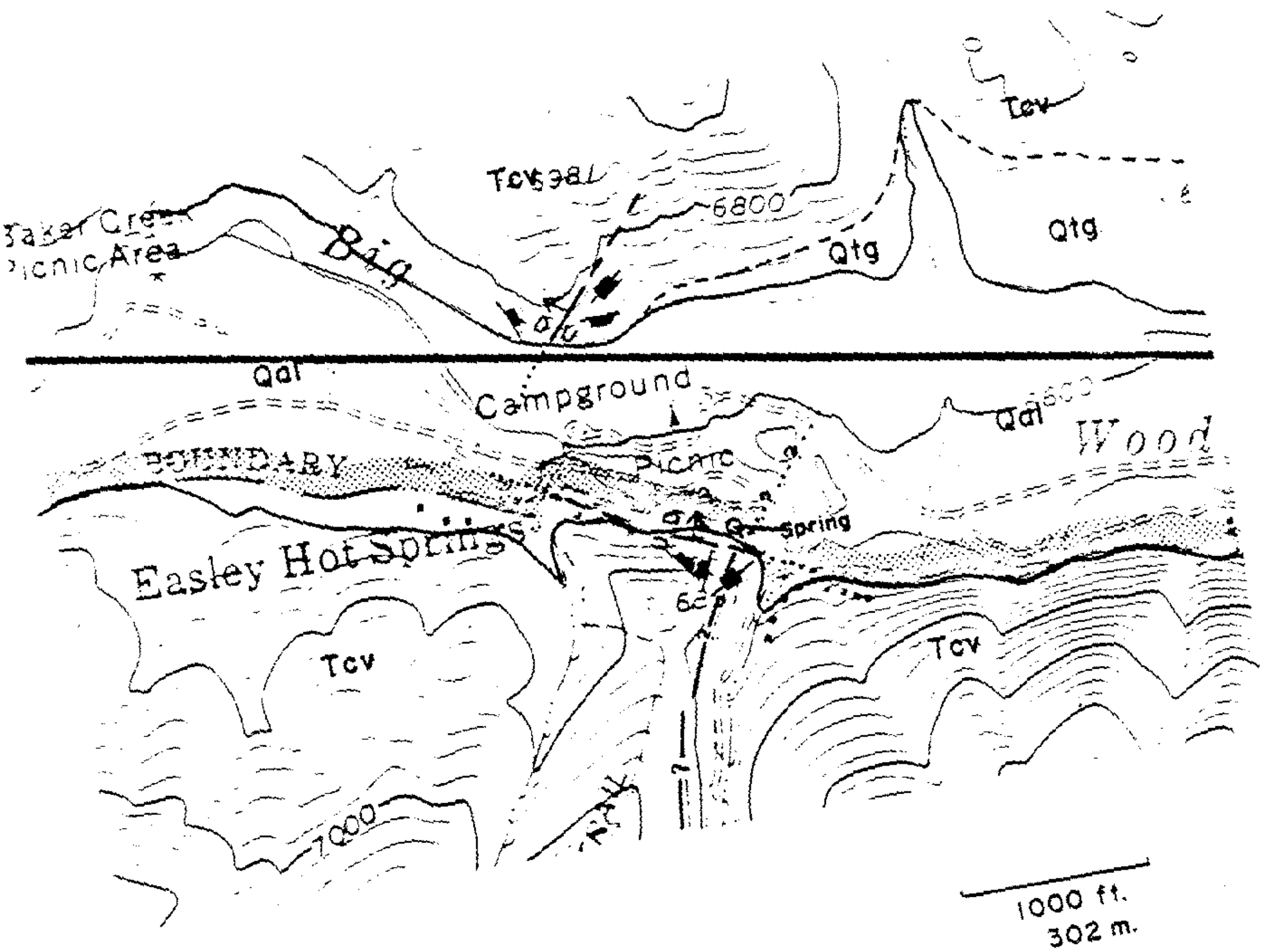
Easley Hot Springs is located in the northern portion of the study area in T.5N., R.16E., Section 10dbc (Mitchell and others, 1980). The spring occurs on the south side of the Big Wood River valley floor very near the southern boundary of the Sawtooth National Recreation Area.

The geothermal resource at this location consists of a spring with a discharge rate of approximately 68 l/m (18 gpm) at 37°C. This spring is located just a few feet above the valley floor, discharging from a highly jointed exposure of Tertiary-age Challis Volcanics. Just below the spring, within the alluvium covered valley floor, a shallow marshy pond is fed by thermal water migrating upward through what appears to be the same joint system. Presently, the spring is almost fully diverted for local use.

Facilities at this site consist of a large camping area including a modern outdoor swimming pool fed by the spring. This area, along with newly constructed support facilities, is managed by the First Baptist Church of Idaho.

Geology

The rocks exposed in the Easley Hot Springs area are primarily Challis Volcanics and Quaternary alluvium (Figure 13). The volcanics and alluvium found in the area are similar to those found near Russian John Hot Springs. Rock exposures in the area are limited due to the soil cover and overgrowth of brush and conifers. Angular volcanic float and remnant terrace gravels cover much of the steep slopes flanking the valley floor.



Rock Units: Qal: Quaternary alluvium

Qtg: Quaternary terrace gravel

Tcv: Tertiary Challis Volcanics

Map Symbols:

Strike and dip of joints

Strike of vertical joints

Hot spring

Fault - dashed where uncertain, dotted where concealed

Contact - dashed where approximately located

Figure 13. Geologic map of the Easley Hot Springs area

Structure

As rock exposures are limited in this area, the identification of major structures in the area was not possible. However, minor faulting in a small exposure of Challis Volcanics trends N30°E and dips about 70°SE. Jointing at the point of discharge is strong with orientations varying from northwest to northeast. Travertine deposits are visible along the major joint planes around the immediate spring area. A zone of very tight brecciation, trending parallel to the adjoining drainage, is visible about 30 meters west of the spring. This may indicate the drainage is fault controlled as evidence of shearing is visible about 1.6 kilometers up this drainage.

This area, like most of the other areas, has not been drilled, and the subsurface geology is relatively unknown. It appears that the thermal occurrence at Easley is structurally controlled as rock permeabilities are low.

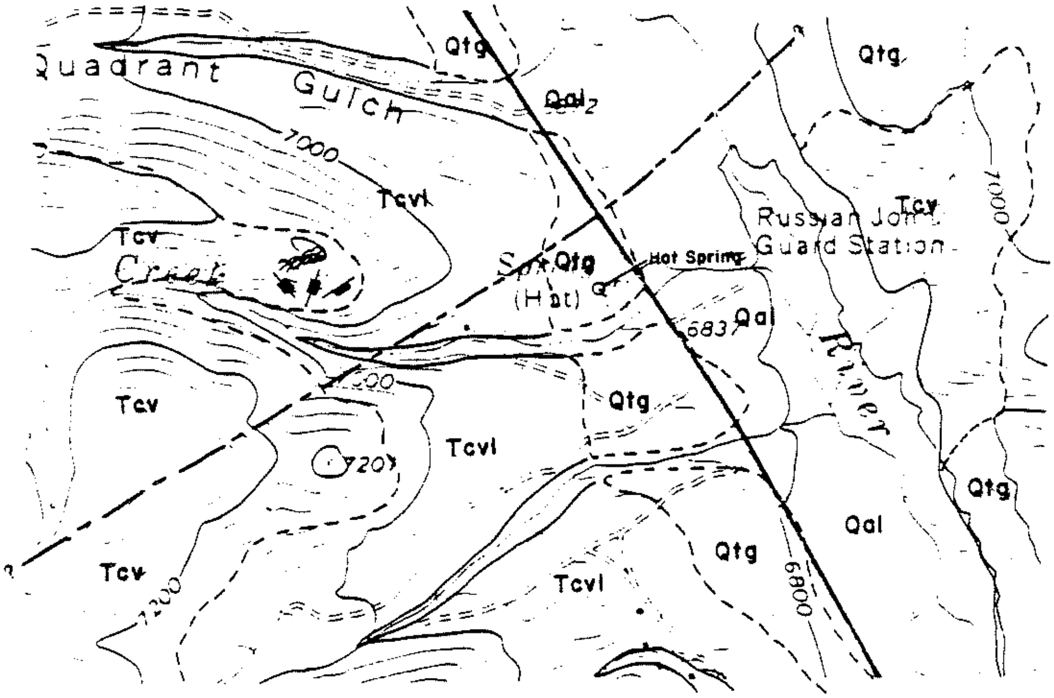
Russian John Hot Springs

Russian John Hot Springs is located in the very northern portion of the study area and lies within the Sawtooth National Recreational Area. The specific location is unsurveyed, but has been depicted as T.6N., R.16E., Section 33cca (Mitchell and others, 1980). The area can be found on the U.S. Geological Survey, 7.5 minute Easley Hot Springs Quadrangle, just west of State Highway 75 and Russian John Guard Station.

The geothermal resource at this location consists of a seep of about 4 l/m (1 gpm) with a surface temperature of 35°C. As this spring discharges from Quaternary alluvial material, there are hand-dug shallow bathing pools constructed at the site. About 245 meters to the east, in the valley plain, there are some shallow marsh-like ponds that have a surface temperature of 18°-20° C. These appear to be connected to the system as they rarely freeze during winter.

Geology

The main rocks exposed in the immediate area of Russian John Hot Springs are Quaternary alluvium and terrace gravels (Figure 14). Many of the stream valleys in the area have fragmental gravel terraces at different elevations along their flanks with extensive floodplain deposits in the bottom. This is particularly noticeable along the upper Big Wood River. These deposits primarily consist of quartzites, sandstones, and volcanics with minor fragments of porphyritic volcanics. The gravels are generally well rounded and the deposits contain some boulders up to three feet in diameter.



Rock Units: Qal : Quaternary alluvium

Qtg : Quaternary terrace gravel

Tcv : Tertiary Challis Volcanics - undifferentiated

Tcvl: Tertiary Challis Volcanics - latite member

1000 ft.
302 m.

N

Map Symbols:

Strike and dip of joints

Strike of vertical joints

Shear zone

Contact - dashed where approximately located

Fault located from aerial photos

Q Hot spring

Figure 14. Geologic map of the Russian John Hot Springs area

Part of the area to the west of the hot springs is covered by colluvium consisting of angular porphyritic volcanic fragments. This volcanic, a latite porphry with biotite, is exposed at an elevation of about 7,200 feet. Rember and Bennett (1979) show it as part of the Tertiary-age Challis Volcanics. Another small window of this volcanic rock is exposed just east of Russian John Guard Station at an elevation of 6,840 feet.

Structure

As the immediate area of the hot springs is covered by alluvium, no structure is visible. However, in an exposure of volcanics approximately 60 meters to the west of this spring, the volcanic rock is highly jointed and a zone of tight brecciation nearly 1.5 meters wide, trending northeast, is visible for about 30 meters.

As there have been no wells drilled in the area, little is known about the the subsurface geology. From the surface geology, it would appear that rock permeabilities are low. The thermal occurrence found here is most likely controlled by the convective circulation of water, heated at depth, migrating upward along structurally controlled avenues of higher permeability.

STABLE ISOTOPE INVESTIGATIONS
OF SELECTED THERMAL AND NONTHERMAL WATERS
IN THE BIG WOOD RIVER DRAINAGE AREA

by

John C. Mitchell

THE STABLE ISOTOPE METHOD

Isotopes are forms of the same element which differ only in the number of neutrons (uncharged atomic particles) in the nucleus of the atom. This means that different isotopes of the same element will differ only in their relative mass. It is this mass difference that governs their kinetic behavior and allows isotopes to fractionate during the course of certain chemical and physical processes occurring in nature.

The four stable isotopes that have proven most useful in water resource evaluation are hydrogen (^1H or H), deuterium (^2H or D), oxygen 16 (^{16}O) and oxygen 18 (^{18}O). These isotopes make up 99.9 percent of all water molecules.

Isotopic compositions are reported in "δ" notation in parts per thousand (per mil = $^o/oo$) relative to Standard Mean Ocean Water (SMOW) as defined by Craig (1961a), where i = $[(R_i/R_{std} -1] \times 1000$. R_i equals either $^{18}O/^{16}O$ or D/H while i and std represent the sample and standard, respectively.

The result of isotopic fractionation during evaporation of ocean water and subsequent condensation of vapor in clouds is that fresh (meteoric) water is generally depleted in ^{18}O and D (enriched in ^{16}O and H) compared to seawater. The isotopic variations of water in rain, snow, glacier ice, streams, lakes, rivers, and most nonthermal groundwaters are extremely systematic; the higher the latitude or elevation, the lower (more depleted in heavy isotopes) the δD and $\delta ^{18}O$ values of the waters. On the basis of a large number of analyses of meteoric waters collected at different latitudes, Craig (1961b) showed that the $\delta ^{18}O$ and δD values relative to SMOW are linearly related and can be represented by the equation:

$$\delta D = 8\delta ^{18}O + 10$$

which is plotted in Figure 15. Groundwater sampled in an area whose isotopic composition plots on the trend (meteoric water) line are generally considered to be meteoric waters. Gat (1971) reported that incongruous results in isotope hydrology studies have generally been interpreted to mean: (1) geographic displacement of groundwaters by flow, (2) recharge from partially evaporated surface waters, (3) recharge under different climatic

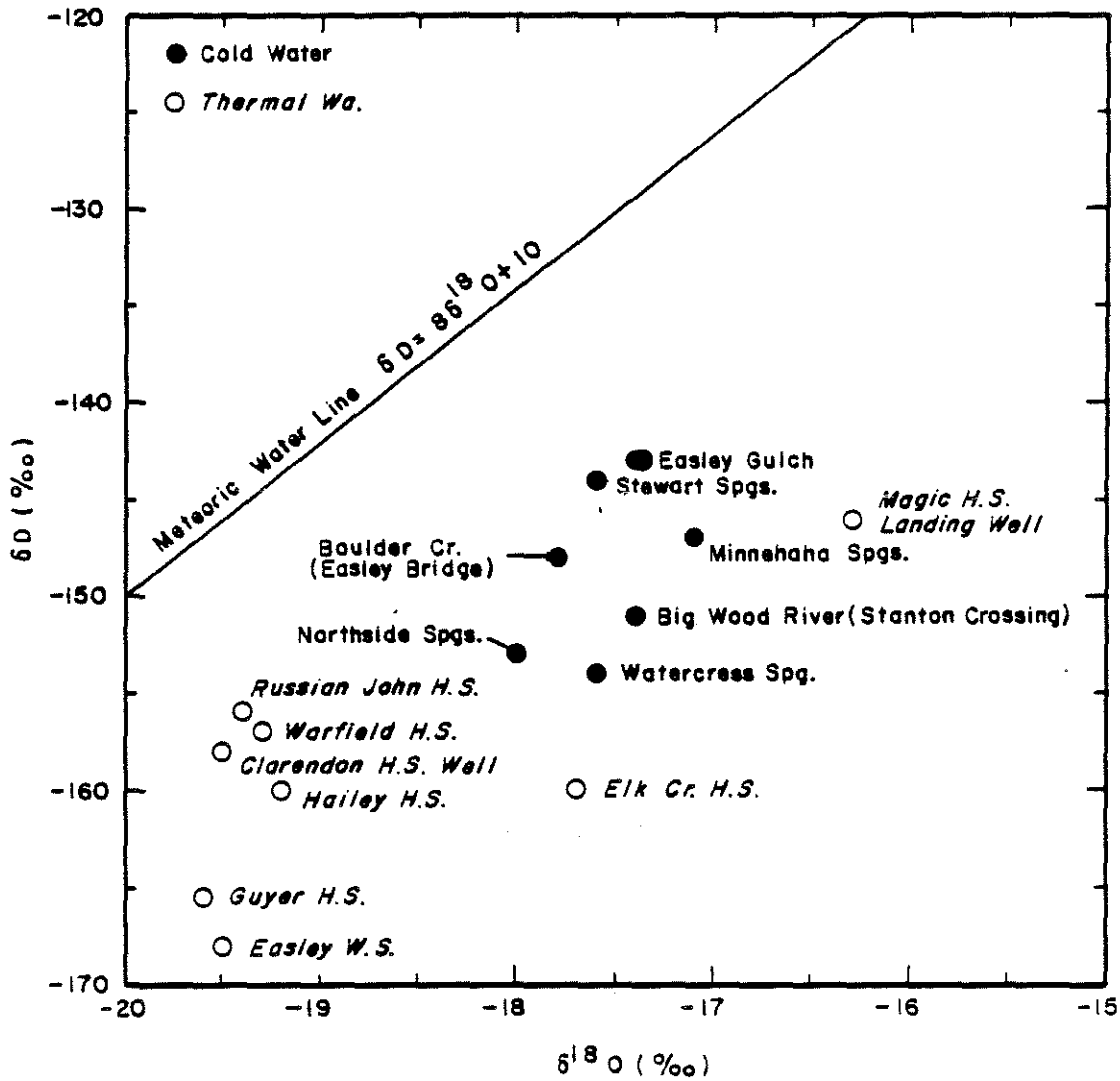


Figure 15. Isoptopic composition of selected thermal and nonthermal waters from the Wood River drainage area

conditions, (4) mixing with nonmeteoric water bodies--brines, sea-water, connate, metamorphic or juvenile waters, (5) differential water movements through soils or aquifers which result in fractionation processes (membrane effects), and (6) isotopic exchange or fractionation between water and aquifer materials. Several of these processes tend to be distinctive, either in enriching or depleting the waters in heavier isotopes, and can be recognized. Others tend to be similar in results; therefore, interpretations may be ambiguous.

SAMPLING

Mitchell and others (1980), noted the regular spacing of thermal springs in Idaho along narrow curved or arcuate zones. It was also noted that most thermal springs issue near horseshoe or U shaped bends in river courses or near stream confluences. This was cited as evidence for structural control thought due to the regular spacing of structural features (joints, faults, etc.) common to all springs along the arcuate trends. This could imply hydrologic interconnection for some of the thermal springs.

Eight thermal springs of the Big Wood drainage basin between Little Camas Prairie and Galena Peak and seven non-thermal springs and selected surface waters were sampled in the fall of 1980 for hydrogen and oxygen isotope analysis to determine, so far as possible, thermal and non-thermal water relationships. The limited scope of this investigation precluded further isotope sampling. Samples were analyzed by mass spectrometry by Krueger Enterprises, Inc., Geochron Laboratories Division, Cambridge, Mass. On the basis of duplicate samples and analyses, the data appear to be precise within 1 $^{o}/oo$ for δD and 0.2 $^{o}/oo$ for $\delta^{18}O$. These data are given in tables 2 and 3 and sample locations are shown in Figure 16.

OBSERVATIONS

From tables 2 and 3, the range of δD values for thermal waters (<20°C) sampled during this investigation is from -146 to -168 $^{o}/oo$. The range of $\delta^{18}O$ values is from -16.3 to -19.6 $^{o}/oo$. For cold waters sampled in this area, the range of δD values is from -143 to -154 $^{o}/oo$ and the range of $\delta^{18}O$ values is from -17.1 to -18.0 $^{o}/oo$. Most thermal waters are therefore depleted by about 10 $^{o}/oo$ in D and by about 1 to 2 $^{o}/oo$ in ^{18}O relative to cold waters sampled from the same areas.

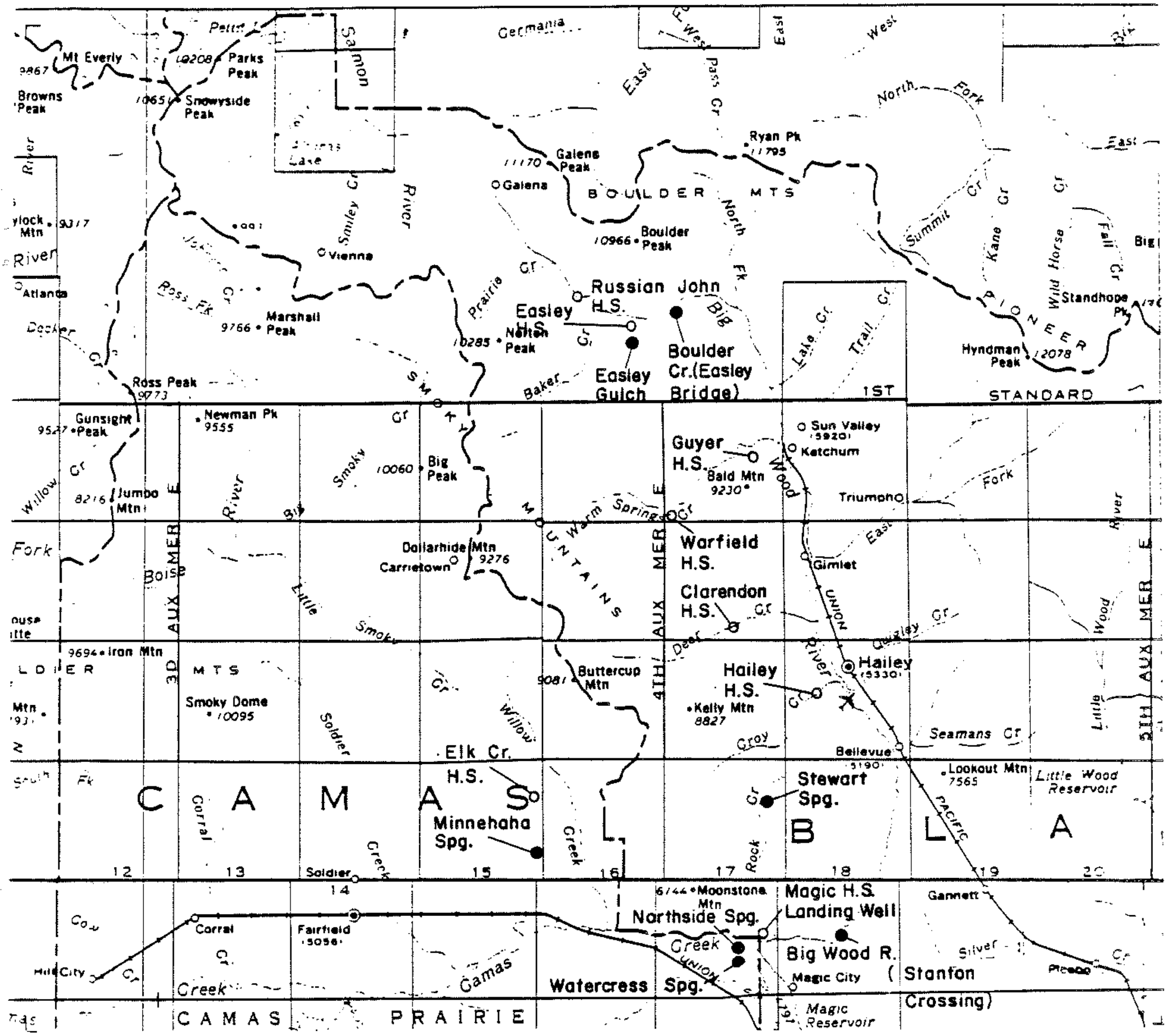
Figure 15 is a plot of δD versus $\delta^{18}O$ from thermal and non-thermal springs and surface waters sampled in the Big Wood drainage basin and adjacent areas. The plot shows the general depletion in D and ^{18}O of the thermal relative to the non-thermal waters in the sampled areas. This depletion appears typical of thermal waters in Idaho (Rightmire and others, 1976; Lewis and Young, 1980a and b; Young and Lewis, 1980; Mitchell, 1981;

Table 2. Data on thermal waters in the Wood River drainage area.

Spring/Well Name and Identification Number	Measured Surface Temperature °C	Latitude	Longitude	δD	δ18O
Russian John H.S. 06N-16E-33ccals	38	43.8052	114.5850	-156	-19.4
Easely W.S. 05N-16E-10dbcls	38	43.7795	114.5385	-168	-19.5
Guyer H.S. 04N-17E-15accls	70	43.6836	114.4101	-166	-19.6
Warfield H.S. 04N-17W-31bbcls	51	43.6413	114.4865	-157	-19.3
Clarendon H.S. Well 03N-17E-27dcbl	52	43.5605	114.4147	-158	-19.5
Hailey H.S. 02N-18E-18dbbls	55	43.5056	114.3542	-160	-19.2
Elk Creek H.S. 01N-15E-14adals	56	43.4232	114.6266	-160	-17.7
Magic H.S. Landing Well 01-13E-23aabl	71	43.3289	114.3980	-146	-16.3

Table 3. Data on cold waters in the Wood River drainage area.

Spring and Surface Discharge Name & Location	Latitude	Longitude	δD	$\delta^{18}O$
Northside Springs 1S-17E-21caals	43.3198	114.446	-153	-18.0
Watercress Spring 1S-17E-29dccls	43.3009	114.442	-154	-17.6
Big Wood River (Stanton Crossing) 1S-15E-21aab	43.3285	114.319	-151	-17.4
Minnehaha Springs 1N-15E-25cbcls	43.3861	114.623	-147	-17.1
Stewart Springs 1N-17E-14baals	43.4262	114.396	-144	-17.6
Easley Gulch 5N-16E-15addls	43.7714	114.538	-143	-17.4
Boulder Creek at Easley Bridge 5N-17E-12cba	43.7823	114.502	-148	-17.8



○ Thermal Spring or Well

● Cold Spring or Surface Water

Figure 16. Isotope sample locations in the Wood River drainage area

Mitchell and others, 1984; Mayo, 1982; Mayo and others, 1984). Figure 15 shows that none of the non-thermal waters sampled in likely recharge areas for thermal waters fall on the meteoric water line defined by the equation $\delta D = 8\delta^{18}O+10$. In general, thermal waters exhibit a very narrow range in $\delta^{18}O$ of less than 1 ^{o}/oo. Exceptions are the water from the Magic Hot Springs Landing well which plot in the general area of cold water (markedly enriched in ^{18}O compared to other thermal waters), and Elk Creek Hot Springs which shows more affinity to the other thermal waters sampled, although it too appears to be enriched in ^{18}O.

DISCUSSION

Thermal waters in Idaho, depleted in D and ^{18}O, have typically been explained as older meteoric waters that fell during a time of colder climatic conditions than those that prevail today. Actual radiocarbon ages of thermal discharges in the Nampa-Caldwell and Boise areas (Mayo and others, 1984) have yielded age dates of from 11,000 to 22,000 years before present, which would place them as late Pleistocene Epoch, or Ice Age waters. Mayo (1982) reported thermal waters in southeastern Idaho have radiocarbon age dates of 12,500 to 20,500 years, again late Pleistocene waters.

The chemistry and temperature of thermal water occurrences in the Big Wood River drainage generally are typical of other thermal waters found in or near rocks associated with the Idaho Batholith. It seems likely therefore that these waters also fell as precipitation thousands of years ago.

There are a number of possible explanations for the Magic and Elk Creek isotope values. In subsurface zones where temperatures are above 50-100°C, chemical interactions with the host rock alter the ^{18}O and D content of ground water. Magic Hot Springs Landing is geographically at the edge of the Snake River Plain, and the thermal water may have been affected by the rhyolites which typically underlie the plain. If the thermal water at this site had been at higher temperatures than the other thermal waters in the area, ^{18}O enrichment might have occurred because of intensified chemical interaction and a different host rock may not be required. Since the shallow ground-water systems are not heated, any mixing of cold and thermal water would tend to mask the effect of high-temperature chemical interaction. Mixing may be a contributing factor to the ^{18}O and D values at Magic, but the relatively high discharge temperature (74°C) seems to preclude the addition of large volumes of cold water to the thermal system.

The D content of the Elk Creek Hot Springs water is in the range of the majority of thermal waters in the area so the ^{18}O enrichment suggests higher temperatures at depth for this water. This site is northwest of Magic Hot Springs Landing and the host rock at depth may be different than that at any of the other thermal areas.

If the underground residence time for the water at Magic or Elk Creek Hot Springs was significantly different than that of the other thermal waters in the area the isoptopic variation may reflect a changed local meteoric water line. If the water discharging at either site fell as precipitation at a time when the local temperature regime was different than that for recharge of the other thermal sites, the variation seen today may reflect conditions of the original precipitation.

The narrow range for ^{18}O depletion shown by the other thermal waters suggests very similar thermal histories for these waters. They probably represent rainfall that occurred during a cooler period and have been elevated to similar temperatures at depth. The variation in δD, however, may indicate separate recharge areas and flow systems for the thermal springs in the area. This agrees with other published data indicating specific water chemistry and thermal histories for individual hot springs associated with the Idaho Batholith.

CONCLUSIONS

The standard geothermal model for the area and similar thermal-water occurrences along the northern edge of the Snake River Plain suggests recharge in the upland with downward migration of water along deep faults to depths of two or three kilometers. The heat source at these depths is generally considered to be related to the granitic rocks of the Idaho Batholith. The water is probably heated by simple conductance prior to its return to the land surface through fault generated permeable zones. The upward rate of flow is controlled by thermal gradients and hydrostatic pressure as well as the transmissivity of the permeable zone. The limited data in the Wood River drainage area suggest a geothermal gradient of approximately 30° C per kilometer.

The generally low dissolved-solids content of the thermal waters in the region (Mitchell and others, 1980) suggests that mineral precipitation is unlikely to restrict permeability at depth. Tufa or sinter deposition at some of the springs indicates at least some contact time between the thermal waters and the sedimentary or metasedimentary rock units at those locations. The location of spring discharge, in some cases, may be controlled by a lack of permeability along fault extensions within the rock units overlying the granitics. In all cases, however, spring discharge appears to be related to a nearby normal fault.

If each spring area has its own recharge area, it is likely that the resource consists of relatively small isolated thermal water reservoirs with limited development potential. None of the hot springs in the area have large discharges. If the Magic Hot Springs Landing well example can be applied regionally, the construction of one well may lower pressure heads sufficiently to terminate spring discharge. The effect of this well on the seeps that occur below the reservoir high water level has not been quantified, although they are known to still flow. Sustained yields from any hot springs area may be limited to a flow approximating present spring flow. The "drying up" of a spring may be a water rights problem that could seriously constrain resource development.

Any exploration strategy for the area must be keyed to the fault control of the thermal water system. None of the rock units in the area, except the modern alluvium and Quaternary glacial deposits, have the necessary permeability and transmissivity to serve as thermal water aquifers. Production wells in the Wood River drainage have to intersect the fault controlling upward movement of the thermal water. This is not the case in most other geothermal areas in the state (e.g., Raft River, Boise, Bruneau-Grandview) where, although fault controlled, leakage from the fault zone has created thermal aquifers in permeable rock units associated with the controlling fault or faults. Mapping fault traces at the surface is the logical first step. Infrared aerial photography may be useful in identifying fault traces associated with thermal water. Resistivity profiles at right angles to fault traces may be an appropriate geophysical tool in any thermal water search. Testing at faults known to be associated with hot water seems warranted. Linaments identified on Landsat imagery for this study could not be correlated with mappable faults in the area, however geophysical testing of selected linaments may be justified.

Published geochemical thermometer data for the region (Mitchell and others, 1980) indicate water of moderate temperature suitable for direct uses such as space heating, bathing, and fish culture. The elevated fluoride concentrations (>12 mg/l) in the thermal water will complicate commercialization of the resource. Since these waters do not meet state or federal standards for drinking water, regulatory agencies within the state are unlikely to approve surface discharge of spent thermal water in amounts greater than the existing spring flows.

REFERENCES

Batchelder, J.N., and Hall, W.E., 1978, Preliminary geologic map of the Hailey 7.5 minute quadrangle, Idaho: U.S. Geol. Survey Open-File Report 78-546, 1:24,000, 1 sheet.

Blackett, R.E., 1981, Preliminary investigation of the geology and geothermal resources at Guyer hot springs and vicinity, Blaine County, Idaho: Univ. Utah Research Institute, Earth Science Lab., 24 p.

Bond, J.G., 1978, Geologic map of Idaho: Idaho Bureau of Mines and Geology, Moscow, ID, 1:500,000, 1 sheet.

Bostwick, D.A., 1955, Stratigraphy of the Wood River Formation, south-central Idaho: Jour. Paleontology, v. 29, pp. 941-951.

Craig, H., 1961a, Standard for reporting concentration of deuterium and oxygen-18 in natural waters: Science, v. 133, p. 1833-1834.

_________, 1961b, Isotopic variation in meteoric waters: Science, v. 133, p. 1702-1703.

Dover, J.H., 1969, Bedrock geology of the Pioneer Mountains, Blaine and Custer Counties, central Idaho: Idaho Bureau of Mines and Geology, Moscow, ID, Pamphlet 142, 66 p.

Leeman, W.P., 1982, Geology of the Magic Reservoir area, Snake River Plain, Idaho: pp. 369-376 <u>in</u> Bonnichsen, B. and Breckenridge, R.M. (editors), 1982, Cenozoic geology of Idaho: Moscow, Idaho Bureau of Mines and Geology Bull. 26, 725 p.

Lewis, R.E., and Young, H.W., 1980a, Thermal springs in the Payette River Basin, west-central Idaho: U.S. Geol. Survey Water-Resources Investigations Open-File Report 80-1020, 23 p.

___________________________, 1980b, Geothermal resources in the Banbury Hot Springs area, Twin Falls County, Idaho: U.S. Geol. Survey Water-Resources Investigations Open-File Report 80-563, 41 p.

Malde, H.E, and Powers, H.A., 1962, Upper Cenozoic stratigraphy of the western Snake River Plain, Idaho: Geological Society of America Bull., v. 73, pp. 1197-1219.

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. Geologic Investigations Maps, I-373, 1:125,000, 1 sheet.

Mayo, A.L., 1982, Ground water flow patterns in the Meade Thrust allochthon, Idaho-Wyoming thrust belt, southeastern Idaho: unpublished Ph.D. dissertation, University of Idaho, 181 p.

Mayo, A.L., Muller, A.B., and Mitchell, J.C., 1984, Geothermal investigations in Idaho, Part 14, geochemical and isotopic investigations of thermal water occurrences of the Boise Front area, Ada County, Idaho: Idaho Dept. of Water Resources Water Information Bull. No. 30.

Mitchell, J.C., editor, 1981, Geothermal investigations in Idaho, Part 11, geological, hydrological, geochemical and geophysical investigations of the Nampa-Caldwell and adjacent areas, southwestern Idaho: Idaho Dept. of Water Resources Water Information Bull. No. 30, 143 p.

Mitchell, J.C., 1976, Geothermal investigations in Idaho, Part 7, geochemistry and geologic setting of the thermal waters of the Camas Prairie area, Blaine and Camas Counties, Idaho: Idaho Dept. of Water Resources Water Information Bull. No. 30, 44 p.

Mitchell, J.C., Bideganeta, K., and Palmer, M.A., 1984, Geothermal investigations in Idaho, Part 12, stable isotopic evaluation of thermal water occurrences in the Weiser and Little Salmon River drainage basins and adjacent areas, west-central Idaho, with attendant gravity and magnetic data on the Weiser area: Idaho Dept. of Water Resources Water Information Bull. No. 30, 45 p.

Mitchell, J.C., Johnson, L.L., and Anderson, J.E., 1980, Geothermal investigation in Idaho, Part 9, potential for direct heat application of geothermal resources: Idaho Dept. of Water Resources Water Information Bull. No. 30, 396 p.

Rember, W.C., and Bennett, E.H., 1979, Geologic map of the Hailey quadrangle: Idaho Bureau of Mines and Geology, Moscow, ID, 1:250,000, 1 sheet.

Rightmire, C.T., Young, H.W., Whitehead, R.L., 1976, Geothermal investigations in Idaho, Part 4, isotopic and geochemical analysis of water from the Bruneau-Grandview and Weiser areas, southwest Idaho: Idaho Dept. of Water Resources Water Information Bull. No. 30, 28 p.

Ross, C.P., 1934, Correlation and interpretation of Paleozoic stratigraphy in south-central Idaho: Geological Society of America Bull., v. 45, pp. 937-1000.

Ross, S.H., 1972, Geothermal potential of Idaho: Idaho Bureau of Mines and Geology, Moscow, ID, Pamphlet 150, 72 p.

Schmidt, D.L., 1961, Quaternary geology of the Bellevue area in Blaine and Camas Counties, Idaho: unpublished Ph.D. Dissert., University of Washington.

Smith, R.O., 1959, Ground-water resources of the middle Big Wood River - Silver Creek area, Blaine County, Idaho: U.S. Geol. Survey Water-Supply Paper 1478, 64 p.

Struhsacker, D.H., Jewell, P.W., Zeisloft, J., and Evans, S.H. Jr., 1982, The geology and geothermal setting of the Magic Reservoir area, Blaine and Camas Counties, Idaho: pp. 337-393 in Bonnichsen, B. and Brechenridge, R.M. (editors), 1982, Cenozoic geology of Idaho: Moscow, Idaho Bureau of Mines and Geology Bull. 26, 725 p.

Umpleby, J.B., Westgate, L.C., and Ross, C.P., 1930, Geology and ore deposits of the Wood River region, Idaho: U.S. Geol. Survey Bull. 814, 250 p.

Young, H.W., and Lewis, R.E., 1980, Hydrology and geochemistry of thermal ground water in southwestern Idaho and north-central Nevada: U.S. Geol. Survey Water-Resources Investigations Open-File Report 80-2043, 45 p.

Young, H.W., and Mitchell, J.C., 1973, Geothermal investigations in Idaho, Part 1, geochemistry and geologic setting of selected thermal waters: Idaho Dept. of Water Administration Water Information Bull. No. 30, 43 p.