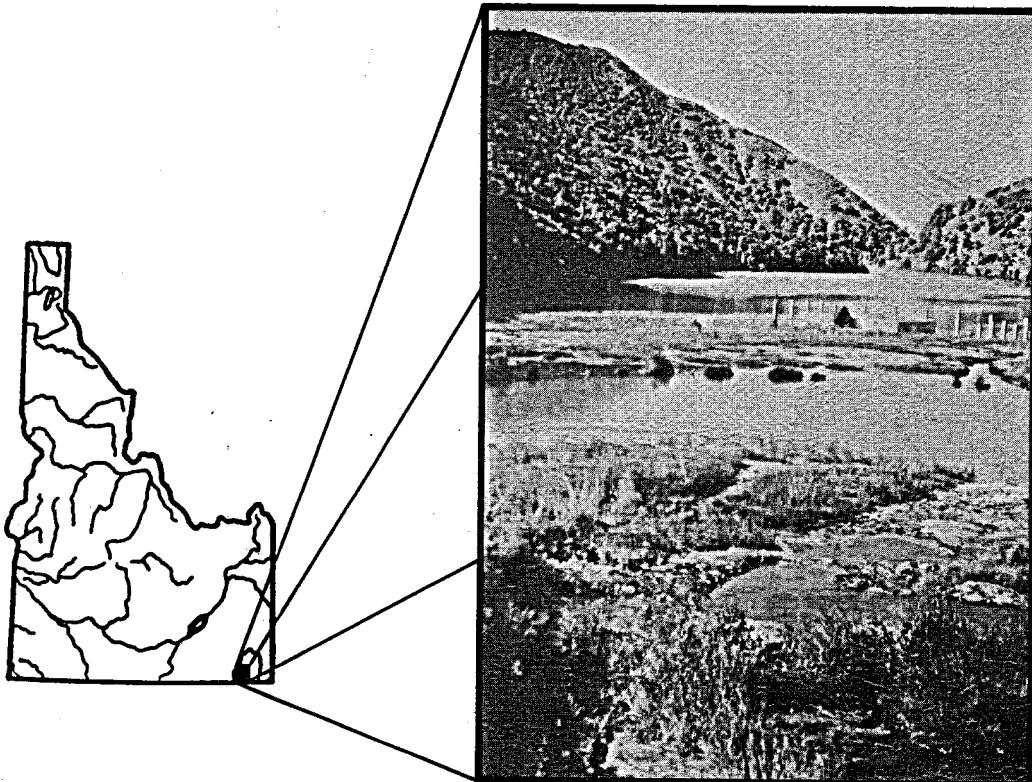


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GEOTHERMAL INVESTIGATIONS IN IDAHO

PART 5

GEOCHEMISTRY AND GEOLOGIC SETTING OF THE THERMAL WATERS OF THE NORTHERN CACHE VALLEY AREA, FRANKLIN COUNTY, IDAHO



MASTER

IDAHO DEPARTMENT OF WATER RESOURCES
WATER INFORMATION BULLETIN NO. 30
JULY 1976

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WATER INFORMATION BULLETIN NO. 30

GEOTHERMAL INVESTIGATIONS IN IDAHO

Part 5

**Geochemistry and Geologic Setting of the
Thermal Waters of the Northern Cache Valley Area,
Franklin County, Idaho**

by

John C. Mitchell

**Prepared and published by
Idaho Department of Water Resources 950
R. Keith Higginson
Director**

July 1976

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PREFACE

Geothermal energy (the natural heat energy of the earth) is receiving nationwide attention. The increasing involvement of many parties in exploration for and development of this energy source has been accelerated by four factors:

1. Ecologically, geothermal energy appears to be a better alternative than other methods of power generation such as nuclear, fossil fuel, or hydroelectric.
2. Economically, it competes favorably with hydroelectric and fossil fuel power generation, and may be cheaper than nuclear methods.
3. Enormous reserves of geothermal resources have been identified and can be developed if the effort is made to utilize them.
4. Efficient use of all energy sources is now recognized as necessary if present energy shortages are to be alleviated and future shortages avoided.

Published information on the geothermal potential in Idaho consists mostly of numerous reports that briefly describe or mention thermal water occurrences in particular areas or regions of the state. Seven reports (Stearns and others, 1937; Waring, 1956; Ross, 1971; Nichols and others, 1972; Warner, 1972; and Young and Mitchell, 1973; and Warner, 1975) have been written on Idaho's geothermal potential. Three of the reports are mainly compilations of pre-existing data collected by various investigators over an extended time interval of approximately 50 to 60 years. Waring (1965, p. 26-31) essentially updates the data of Stearns and others (1937, p. 136-151). Godwin and others (1971) classified approximately 15 million acres (60,705 square kilometers) of land in Idaho as being valuable prospectively for geothermal exploration. Ross (1971) published geologic and chemical information on 380 thermal water occurrences, and presented brief evaluations of the geothermal potential of different regions of the state. Nichols and others (1972) identified non-power uses and the economic impact of these uses on Idaho. Warner (1972 and 1975) dealt with Idaho's geothermal potential based on its regional geologic setting.

In Idaho, the prospects for early development of geothermal energy as a power source appear excellent. The regional geologic setting appears favorable for the existence of large geothermal fields although little is known of the full potential of this resource. A great deal more must be learned of geothermal occurrence, development, utilization, and regulation.

✓ The Idaho Department of Water Resources initiated a study of geothermal potential to generate interest in development of the resource and to properly perform the Department's regulatory function. Part 1 of the study, prepared jointly with the U.S. Geological Survey, located twenty-five areas in Idaho (fig. 1) where indications of potential for power development utilizing geothermal energy were found. Parts 2, 3, and 4, prepared by the U.S. Geological Survey, studied areas in west-central and southwest Idaho. Parts 5, 6 and 7, prepared by the Idaho Department of Water Resources, studied areas in south-central and southeastern Idaho. Part 8, prepared jointly by the Idaho Department of Water Resources and the Southern Methodist University, describes the heat flow regime in and around the Snake River Plain.

There are four objectives common to each of the studies: (1) to encourage the development of the resource through public knowledge of its occurrence, characteristics, origin, and properties; (2) to develop the expertise within the Department to properly perform its function of regulation of the resource; (3) to protect the ground and surface waters of the state from deleterious effects which might be brought about by large-scale geothermal development efforts by public or private parties; (4) to protect the geothermal resource from waste and mismanagement because of lack of knowledge of its occurrence, characteristics, and properties.

This study, part 5, summarizes a part of the effort to obtain additional data on the properties, origin, occurrence, and characteristics of this resource in Idaho.

ACKNOWLEDGMENTS

Many people have contributed to this study in the hope that the information will be of benefit to the people of the State of Idaho.

The Idaho Nuclear Energy Commission granted financial support for the chemical analyses necessary in collection of data. Aerojet Nuclear Company, a prime contractor of the Energy Resource and Development Administration, made available laboratory facilities, personnel, and equipment for neutron-activation analyses at the Idaho National Engineering Laboratory at a very minimal cost. The Bureau of Reclamation made available personnel and laboratory facilities for standard water-quality analyses.

The Department of Geology at Idaho State University provided X-ray laboratory facilities at no cost for the mineral identification study. The Department of Chemistry at Idaho State University made available, also at no charge, glass-blowing laboratory facilities as part of the neutron activation studies.

Thanks are extended to personnel of the Boise, Idaho and Menlo Park, California offices of the U. S. Geological Survey for their comments and criticisms in review of this manuscript.

All of these cooperative efforts are gratefully acknowledged and appreciated; without such generous support, this study could not have been accomplished.

COVER PHOTO

The Maple Grove Hot Springs and pool, located 25 kilometers northeast of Preston, are visible in the foreground and center of the photograph. The ruins of an old swimming pool and bath house are visible behind the hot springs, and in the background lie the waters of the Oneida Narrows Reservoir.

IDWR Photo Geo. 145, Oct. 1974

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ABSTRACT

The thermal waters of the north-south trending graben structure known as northern Cache Valley in southeastern Idaho were sampled during the summer and fall of 1973. Geologic and gravity data for the area indicate fault control for nearly all thermal water occurrences. Thermal-water discharges are generally restricted to the course of the Bear River with few known in areas away from the river. Spring deposits in the form of travertine may not be indications of low temperature thermal waters because abundant limestone and dolomite make up the geologic framework. Much gas, believed to consist mostly of carbon dioxide, is being evolved from many of the springs.

The hottest water is found near Battle Creek and Squaw hot springs approximately 4 kilometers northwest of the town of Preston. The springs are the surface expression of a classic U-shaped deep circulation system. Meteoric waters descend along fault planes, fractures, and fissures to depths at which they are heated by increasing rock temperatures (geothermal gradient of 5°C per 100 meters). Due to decreased density, the heated waters rise along the same or adjacent fault planes to the surface.

The quartz equilibrium geochemical thermometer applied to the thermal water discharges indicates temperatures approaching 150°C may be encountered by deep drilling. Mixing models, based on quartz solubility, indicate higher aquifer temperatures than the quartz equilibrium thermometer, but chloride concentration vs. temperature plots are not linear, a relationship which generally exists if mixing is taking place. The sodium-potassium-calcium geochemical thermometer indicates higher temperatures than quartz equilibrium and mixing models. Thermodynamic calculations show slight supersaturation in calcium with respect to calcite indicating near-equilibrium conditions, or minor continued rock-water reaction.

The thermal waters are higher in total dissolved solids (12,000 to 13,000 milligrams per liter) than are known elsewhere in Idaho and represent potential pollution hazards should large scale withdrawal be attempted. These saline waters may also present many engineering difficulties in their attempted utilization.

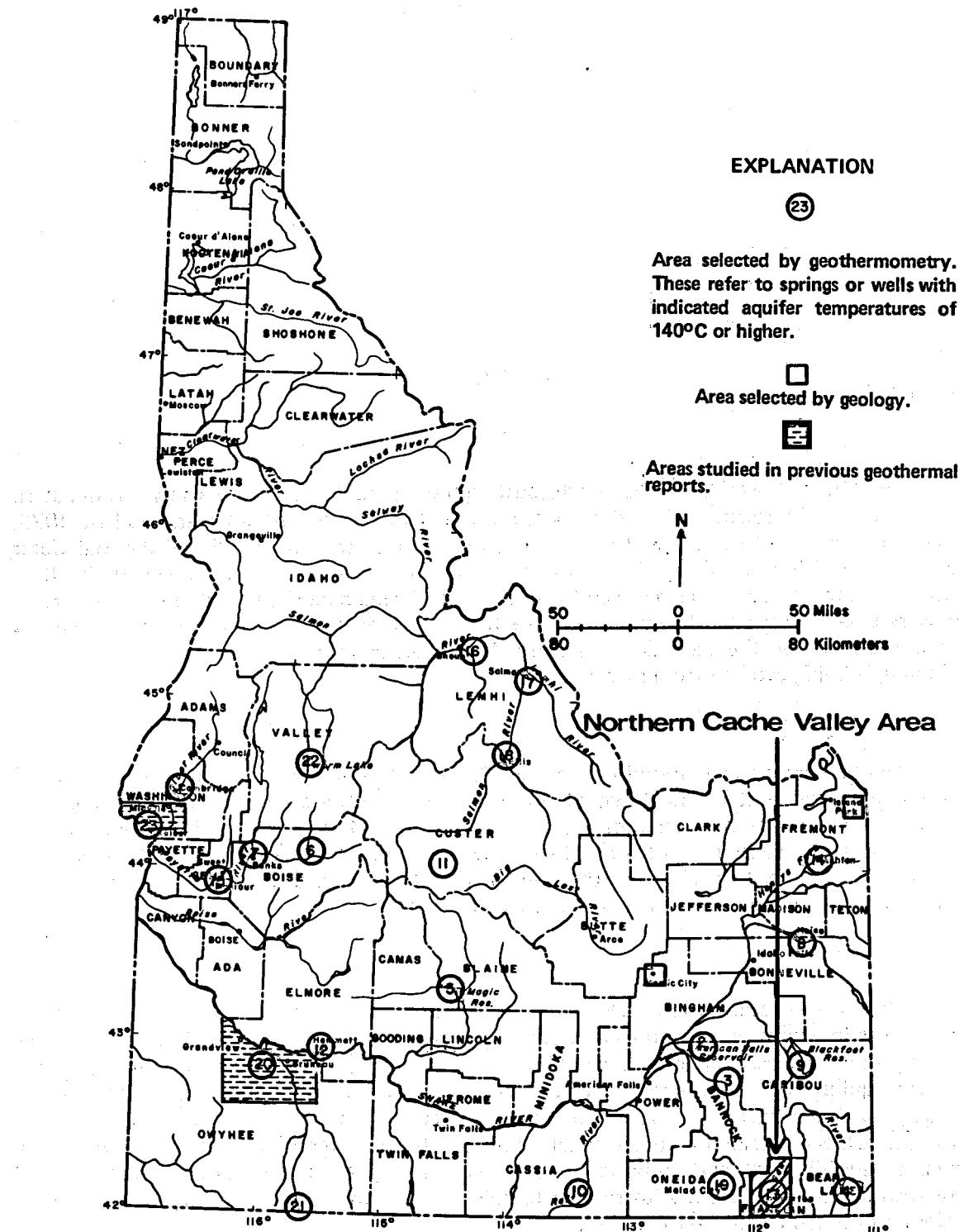


FIGURE 1. Index map of Idaho showing area of this report and areas selected for study by Young and Mitchell (1973).

GENERAL INTRODUCTION

Purpose and Scope

Reconnaissance geochemical sampling of geothermal waters within Idaho has given indications of at least 25 areas that may have potential for geothermal energy utilization (Young and Mitchell, 1973). The northern Cache Valley region was one of the 25 areas (fig. 1). This region was chosen for further evaluation of its geothermal potential for four reasons:

1. Preliminary geochemical sampling and application of the silica (Si) and sodium-potassium-calcium (Na-K-Ca) geochemical thermometers at several sites indicated the possibility that temperatures might be high enough for power generation at depth in this area.
2. Numerous thermal and mineralized springs with easy access meant additional data could be inexpensively and rapidly obtained.
3. Early application of mixing models (Young and Mitchell, 1973, unpublished data) indicated the possibility of higher temperatures at depth.
4. A built-in market for electrical energy without long distance power transmission exists; the world's largest known phosphate reserve is located 50 to 80 kilometers north and east. A prerequisite for large-scale development of this phosphate reserve is an inexpensive, abundant power source. Such development could have worldwide impact.

The purpose of this report is to further examine and evaluate the geothermal potential of the northern Cache Valley area by obtaining more thermal-water chemistry data from existing springs and wells; obtaining pertinent geological, geophysical, and hydrological data from the literature; presenting the field-work data; describing the occurrence and chemical characteristics of the thermal waters; interpreting the existing and newly acquired data and relating it to the geothermal potential; developing the information necessary to formulate regulatory strategies if and when deep drilling in the area commences; and recommending areas of additional work where needed.

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

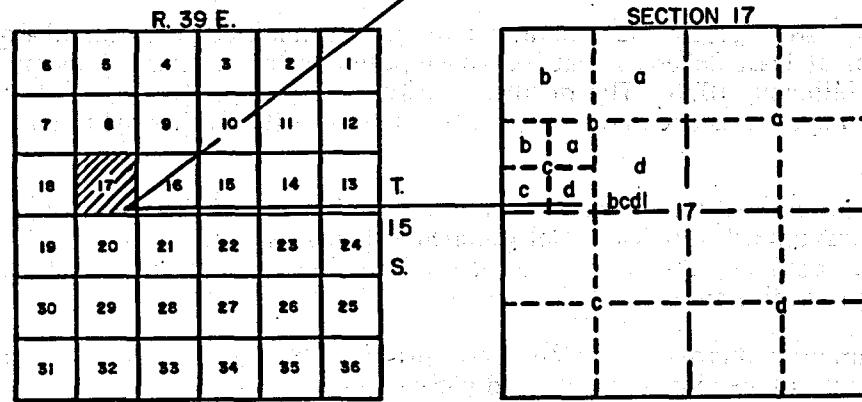
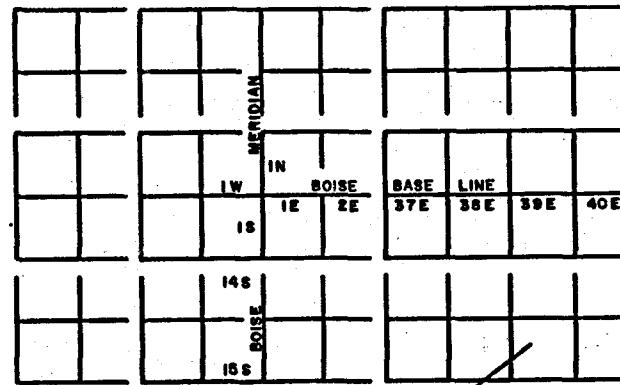


FIGURE 2. Diagram showing the well- and spring-numbering system.
(Using well 15S-39E-17bcd1.)

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 15S-39E-17bcd1 is in the SE $\frac{1}{4}$ SW $\frac{1}{4}$ NW $\frac{1}{4}$ Section 17, T. 15 S., R. 39E., and was the first well inventoried in that tract. Springs are designated by the letter "S" following the last numeral; for example, 15S-39E-17bcd1S.

Collection of Water Chemistry Data

All known accessible thermal-water occurrences in the northern Cache Valley area were visited. Several thermal-water samples were collected from each spring system to insure that representative samples were obtained for chemical analysis. Field data collected included measurement of pH, water temperature, and conductivity. The discharge rate from each spring vent or flowing well was measured or estimated. These measurements were made as close as possible to each spring vent or well discharge pipe.

A standard chemical analysis was run on each thermal-water sample taken. Trace metal analyses were conducted using neutron activation methods. Separate samples were taken for silica analysis and diluted in the field with distilled water (one part sample to nine parts distilled water) to prevent silica polymerization.

Carbonate and bicarbonate determinations were performed potentiometrically in the field because gas—believed to consist mostly of carbon dioxide (CO_2)—was being evolved from many spring vents and sample holding time was considered to be too short for reliable laboratory analysis of these constituents.

In addition, thermal-water deposit samples were collected from each spring or well (where active deposition was noted). The mineral constituents were identified using X-ray diffraction and field identification methods.

Use of Metric Units

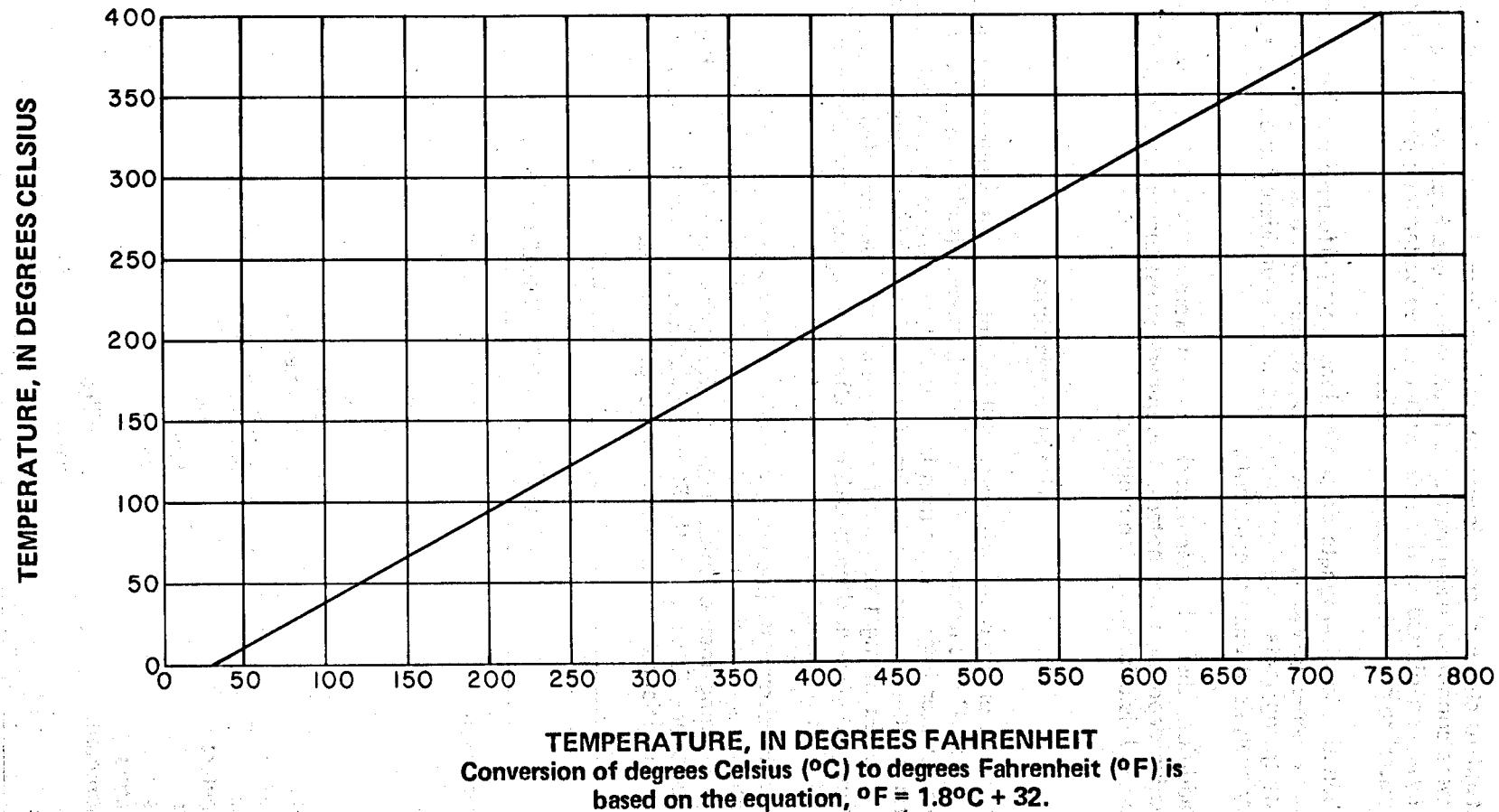
The metric or International System (SI) of units is used in this report to present water chemistry data. Concentrations of chemical substances dissolved in the water are given in milligrams per liter (mg/l) rather than in parts per million (ppm) as in some previous Water Information Bulletins. Numerical 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 ($^{\circ}\text{C}$). Figure 3 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 also given in their corresponding metric units. Table 1 gives conversion factors for these units. Area measurements are listed in both SI and English units except when referring to areas described by official rectangular subdivision of public lands.

TABLE 1
TABLE OF CONVERSION FACTORS

To Convert from	To	Multiply by
inches	centimeters	2.540
feet	meters	0.305
yards	meters	0.914
miles	kilometers	1.609
sq. miles	sq. kilometers	2.589
gallons	liters	3.785
ounces	grams	28.349
centimeters	inches	0.394
meters	feet	3.281
meters	yards	1.094
kilometers	miles	0.621
sq. kilometers	sq. miles	0.386
liters	gallons	0.264
grams	ounces	0.035

FIGURE 3. Graph showing Celsius-Fahrenheit temperature relationship.



GEOLOGY

Location and General Features

Cache Valley lies astride the Idaho-Utah border (fig. 4) in southeastern Idaho and northern Utah. The Idaho portion is an elongated, north-trending structural valley approximately 24 by 40 kilometers (km), covering nearly 900 square kilometers (sq km) (350 sq. mi.).

Cache Valley is bounded on all sides by mountain ranges: the South Hills on the south; the Wasatch, Malad, and Bannock ranges on the southwest, west, and northwest, respectively, the Portneuf Range on the north, and the Bear River Range on the east. These dominantly north-trending ranges rise to elevations of about 2,700 meters (m) with most crests between 2,100 and 2,700 m. The valley floor is a low, flat plain. Several hills—Clifton Hill, Mount Smart and Little Mountain—rise abruptly from the valley floor. Gently sloping alluvial fans, terraces, and deltas are well developed along the edges of the valley and flank the hills in the valley proper. The valley floor slopes gently southward, ranging in elevation from 1,684 m down to 1,338 m elevation above mean sea level.

Lake Bonneville, named in honor of the early western explorer, B.L.E. Bonneville (Gilbert, 1875), extended into many of the intermountain basins of northwestern Utah, southeastern Idaho, and a portion of eastern Nevada. It had a profound influence in shaping the topography and shallow groundwater systems of the area. Lake Bonneville was approximately 290 km wide and 480 km long north to south (King, 1878), and covered 32,200 sq. km (Bjorklund and McGreevy, 1971, p. 14). The Cache Valley embayment occupied nearly all of Cache Valley during much of Pleistocene time. Shoreline features are vividly etched along parts of the valley sides and on Mount Smart and other hills. Many deltas formed by streams entering Lake Bonneville are easily recognized near the mouths of canyons. The most prominent lies downstream from the mouth of Oneida Narrows. This large delta consists principally of red beds which may have been derived from the Triassic and Jurassic consolidated sedimentary rocks found east of Cache Valley (Bright, 1963, p. 77). The Bear River has eroded a broad, flat flood plain about 30 m deep into this delta. Groundwaters in the area are mostly derived from unconsolidated valley fill sediments deposited during the time of Lake Bonneville and deposits that accumulated subsequent to the draining of the lake.

Cache Valley lies within the Great Basin Physiographic Province. The mountains to the east, the Bear River Range, are in the middle Rocky Mountain Province (Fenneman, 1931).

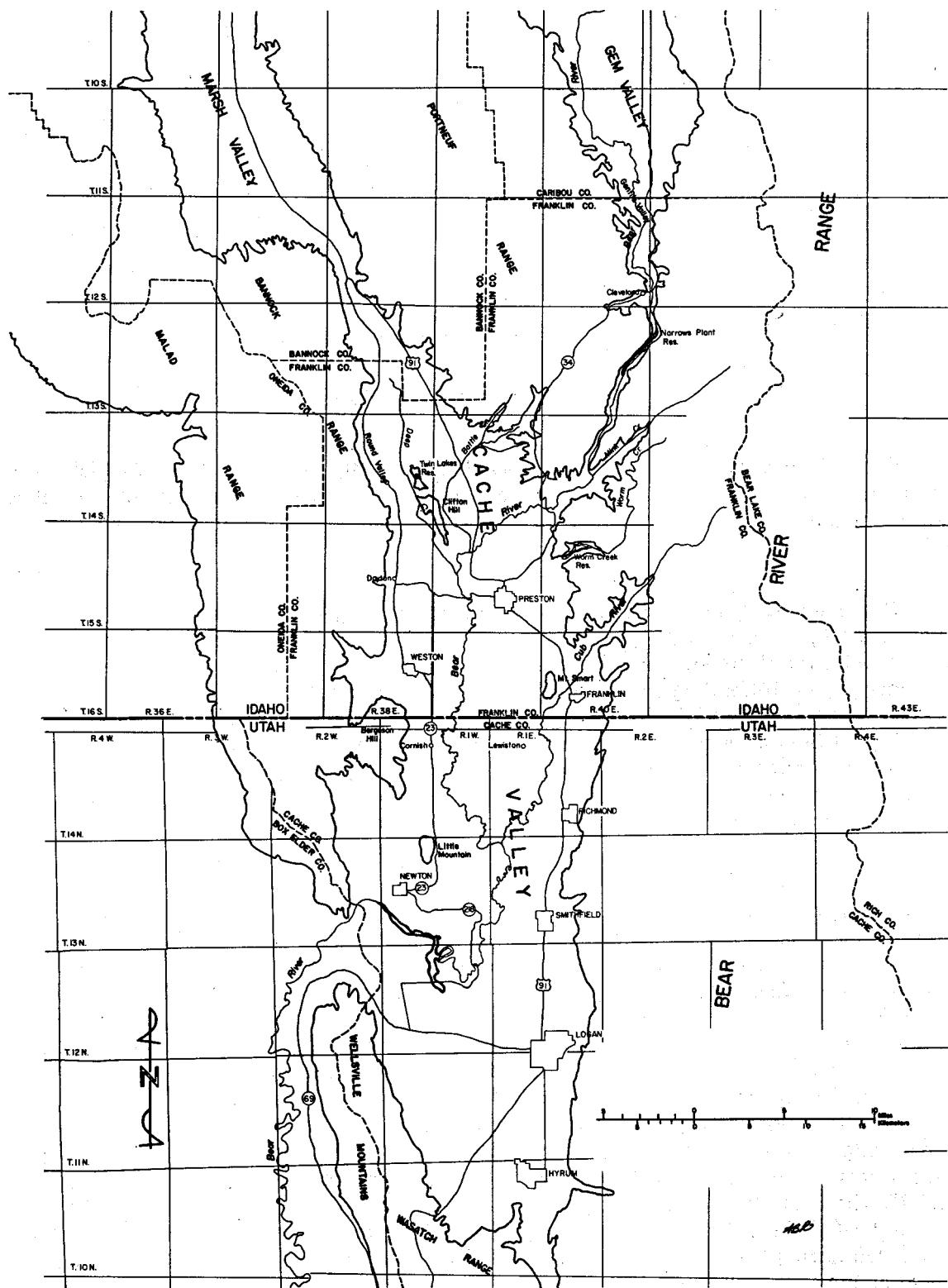


FIGURE 4. Map of the Cache Valley region showing principal physiographic features.

The principal drainage, Bear River, enters through a narrow gorge (Oneida Narrows) in the northeastern part of Cache Valley and meanders through a wide flood plain incised into the valley floor. The Bear River exits to the southwest through a low, broad canyon separating the Wasatch and Malad mountain ranges and empties into the Great Salt Lake. Several perennial streams, notably Mink and Worm creeks, and Cub River flow from the Bear River Range into the Bear River in northern Cache Valley. Deep and Battle creeks flow into the Bear River from the west and north and drain parts of the valley proper. Figure 4 illustrates the principal physiographic features of Cache Valley and adjacent areas.

The area has a semiarid climate with an annual rainfall of about 22.4 centimeters (cm) in the valley and up to 76 cm at elevations above 2,100 m (Coulter, 1956). The mean annual temperatures is about 8°C, with wide seasonal and daily temperature variations.

Cache Valley supports a vigorous agricultural industry devoted primarily to livestock, poultry and dairy products, sugar beets, corn, potatoes, grain and alfalfa. Of the approximately 50,000 inhabitants, most are rural, living in small towns, communities, or on farms.

Generalized Geology

Cache Valley lies near the eastern margin and within a long narrow curvilinear zone of earthquake activity stretching from Las Vegas, Nevada, on the south to Flathead Lake, Montana, on the north, known as the Intermountain Seismic Belt (Smith and Sbar, 1974). This zone is interpreted to be a boundary between subplates of the greater North American crustal plate, where differential movements between the Basin and Range and Colorado Plateau-Rocky Mountain provinces are taking place (Sbar and others, 1972). Plate and subplate boundaries are considered by most geothermal authorities to be excellent areas for prospecting for geothermal resources. Youthful magmatic activity, areas of high heat flow, and thermal spring activity are known to occur along the Intermountain Seismic Belt.

The geologic framework of the northern Cache Valley area is composed of complexly faulted and tilted rock masses of Precambrian through Cenozoic age. Structurally, Cache Valley is a complex graben composed of downthrown fault blocks which have been buried by Cenozoic rocks and unconsolidated valley fill. Gravity data of Peterson and Oriel (1970) suggest that this fill is about 2,400 m thick. Two drilled oil and gas wells encountered pre-Cenozoic rocks at 1,490 m and 1,580 m (Bjorklund and McGreevy, 1971, p. 14) in the Utah portion of the valley. Uplifted fault blocks form the various mountain ranges that surround the valley proper. Keller (1963, p. 2) thought the Bear River Range to be broad syncline broken into rectangular blocks and the Portneuf Range to be a block-faulted homoclinal with local complex areas as at Treasureton, believed to be related to bending at the Bear River-Portneuf Range junction. Bright (1963, p. 8) stated that these ranges contain minor folds, but were essentially homoclinal to the northwest. They are laced with a network of high angle faults. Bjorklund and McGreevy (1971, p. 12) maintain that the maximum vertical displacement along faults in parts of Cache Valley probably exceeds 3,000 m.

In general, two sets of faults are evident. One set trends northeast, the other northwest. Coulter (1956, p. 36) called the northeast-trending set longitudinal faults and the northwest set transverse faults. The longitudinal faults roughly parallel the trend of the Bear River Range. The transverse faults intersect the regional mountain trends at relatively high angles.

Branching, anastomosing and recurring are characteristics of the longitudinal fault traces, whereas the transverse fault traces are relatively straight. Coulter (1956, p. 12) further stated that in the area he mapped, fault surface of subsidiary faults within major fault zones have dips which reach or exceed 75 degrees. Features related to the faults indicated to Coulter downward movement of the hanging wall relative to the footwall. Bright (1963, p. 8) stated that many of the high angle faults are most likely early Pleistocene in age because they are younger than his Mink Creek conglomerate. Oriel and Platt's (1968) map shows no evidence of thrusting in the area of Cache Valley mapped by them (plate 1).

Several features of Cache Valley are probably related to the high angle faulting. Coulter (1956, fig. 3) mapped Mount Smart located northwest of the town of Franklin as a block of strongly brecciated Nounan and St. Charles limestones, separated by a high angle cross fault from a block of Garden City limestone located north of the other two formation outcrops. Coulter believed that the straight-line arrangement of the Mount Smart block with blocks of similar stratigraphy at Worm Creek and Oneida Narrows indicated a horst structure for this feature, rather than an outlier of an eastward thrust, or massive landslide block. Clifton Hill, located near Twin Lakes Reservoir east of Clifton may be bounded by northwest trending, high angle reverse faults on both its east and west sides (Petersen and Oriel, 1970, and Oriel and Platt, 1968). Witkind (1975) reported the east boundary fault to strike N25°W and to dip northeast. He listed a probable length for this fault of about 13 km. The latest movement along the fault was listed as probably late Cenozoic. Recent unpublished gravity data indicate that these faults may extend southward as far as Squaw and Battle Creek hot springs (Don Mabey, personal commun., 1974).

Landsat false color infrared imagery shows a linear feature extending from Bear Lake Valley near Sharon on the northeast, along Mink Creek and Bear River to Squaw and Battle Creek hot springs. This feature may also extend along the southern margin of the Bannock Range and through the Malad Range (plate 2). The intersection of this Mink Creek-Bear River lineament and the Clifton Hill boundary faults could be the controlling structure or focal point for the hot spring activity in this area.

Stratigraphy

Exposures of Precambrian, Paleozoic and Cenozoic age rocks are found in the area. An unconformity may exist at the base of Silurian System as evidenced by the absence of intervening fauna between the Swan Peak quartzite and the Fish Haven dolomite (Coulter, 1956, p. 28).

Precambrian strata consists of the Brigham quartzite, its argillite member, and various rock units found in the Bannock Range. Paleozoic rocks are mostly marine limestones and dolomites, some quartzites and minor amounts of shales. Cenozoic strata consists of coarse- and fine-grained detrital material (gravels, sands, silts, and clays) deposited subaerially, or under lacustrine (lake) conditions. A stratigraphic section for the Preston quadrangle is included with the geologic map on plate 1 (in pocket).

Igneous Rocks

Keller (1963, p. 54) reported the existence of a dike-like basic igneous rock rich in hornblende and plagioclase, which was intruded along the axis of a north-south trending anticline in the Cache Valley Formation just south of Oneida Narrows. A similar intrusion, but finer grained and somewhat metamorphosed (lamphrophyre dike?) was found at Clifton Hill (called Little Mountain by Keller, 1963, p. 55), south of Twin Lakes (Clifton) Reservoir, but the intrusion was not mapped.

The only other surface exposures of igneous rock known to occur near the northern Cache Valley area is the Gem Valley Basalt (plate 1), an olivine basalt mapped by Oriel and Platt (1968) north of the study area near Thatcher in Gem Valley.

Stanley (1972, p. 1820) on the basis of gravity and magnetic data, reported the presence of a mafic dike intrusion into Paleozoic and Precambrian bedrock just north of Lewiston, Utah in southern Cache Valley. He also reported the possible existence of a buried Tertiary lava flow located just south of the Idaho-Utah border midway between Cornish, Utah and Lewiston, Utah. The source of this flow was believed to be from the vicinity of the dike-like intrusive body north of Lewiston. Stanley also reported the existence of a magnetite body situated on or near a valley-boundary, normal fault 10 km southwest of Cornish, Utah. These bodies indicate that past igneous activity, albeit on a small scale, and mostly in the south, may have taken place in Cache Valley.

Geothermal Gradient and Heat Flow

Although not extremely reliable as predictors of drilling depths, geothermal-gradient measurements have been used in geothermal investigations to establish boundary conditions or possible limits to which one might reasonably expect water to be circulating. A temperature versus depth plot (fig. 5) for cold-water wells in the northern Cache Valley area was made from data of McGreevy and Bjorklund (1970, p. 17). A geothermal gradient of 1°C per 20 m was obtained from this plot. This gradient is not much higher than the normal geothermal gradient of 1°C per 30 meters. An average geothermal gradient of this magnitude extending uniformly to great depths suggests that a temperature of 200°C would exist at a depth of 4,000 m. For a temperature of 85°C (approximately that observed at the surface for the hottest thermal water known in Cache Valley), water would have to circulate to depths of at least 1,500 m.

The greater reliability of heat-flow measurements over simple temperature-gradient measurements or calculations in assessing an area's geothermal potential is well known. The geothermal gradient may be viewed as the potential difference between the earth's deeper layers and that found at the surface, and is dependent on the ability of the intervening rock layers to conduct heat (thermal conductivity). Heat flow measurements take this thermal conductivity into account and, therefore, are uniform with depth while abrupt and sometimes large variations in geothermal gradient occur with depth due to changes in thermal conductivity. A high heat flow, therefore, may indicate the presence of an intense heat source (regional or local) in the subsurface, while a high geothermal gradient may only reflect a lower thermal conductivity.

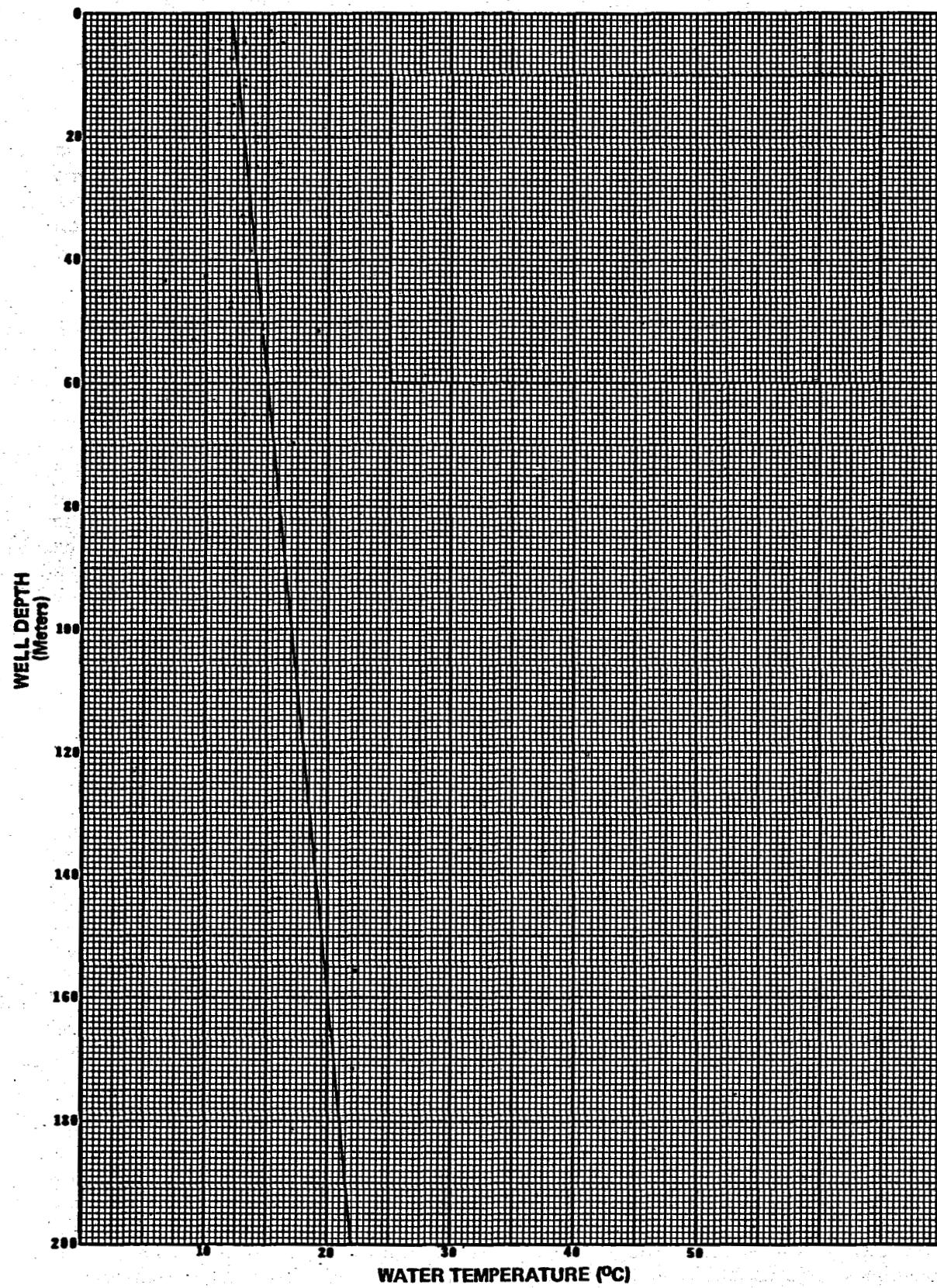


FIGURE 5. Groundwater temperature variation vs. depth of wells in northern Cache Valley area, Idaho. (Data from McGreevy and Bjorklund, 1970, p. 17.)

Although the thermal conductivity of the intervening rock layers in the northern Cache Valley area is not exactly known, reasonable heat flow assumptions can be made by simply knowing the limits of thermal conductivity of the types of rocks found in the area. For example, unconsolidated, poorly sorted sands and gravels usually exhibit a thermal conductivity between 3.5 and 9 giving a heat flow, in heat flow units, (HFU) of from $50^{\circ}\text{C}/\text{km} \times 3.5 \text{ cal/sec/cm}^2 = 1.75 \mu\text{cal/cm}^2/\text{sec}$ (1.75 HFU) as a lower limit and $50^{\circ}\text{C}/\text{km} \times 9 \mu\text{cal/sec/cm}^2 = 4.5 \text{ HFU}$ as an upper limit. A heat flow of 2 HFU would be similar to that found in the Basin and Range Physiographic province, while that approaching 3 HFU would be more typical of the Snake River Plain region (Brott and others, 1975, in preparation).

Since the area is part of the Basin and Range province, a heat flow of from 2 to $2\frac{1}{2}$ HFU would be a reasonable assumption. This above normal heat flow would be high enough to reasonably expect that the thermal waters in the area could be reaching maximum temperature through deep circulation, but not high enough to indicate the presence of a shallow, high-intensity heat source (magma) in the area unless the thermal conductivity of the rocks underlying the area are extremely low.

Gravity Data

Peterson and Oriel (1970, p. C114-C118) conducted a gravity survey of Cache Valley to determine the approximate thickness of the low density Cenozoic strata in the valley. Peterson and Oriel's (1970, figs. 3 and 4) data are shown in figure 6. Peterson and Oriel interpreted the data as follows:

... Near the Idaho-Utah State line a gravity saddle separates the southern gravity low from a low near Preston, Idaho. The gravity saddle is flanked on the east by a gravity high which extends southwestward into the valley near Lewiston, Utah. The high no doubt reflects the concealed southwestward extension of a block of bedrock that is exposed at Mount Smart...

Another gravity high on the west side of the valley extends from the Bannock Range southward through Bergeson Hill to Little Mountain. . . . Although strata exposed along this belt consist dominantly of the Tertiary Salt Lake Formation and overlapping Quaternary units (Stokes, 1963), gravity data indicate that these sediments are thin. Cambrian rocks are exposed beneath Cenozoic strata on Little Mountain, . . .

... a gravity low is located just south of Preston, Idaho. An interpretation across this low along profile C-C' (fig. 3) indicates a thickness of Cenozoic fill of about 5,500 feet (1,700 m). A bedrock high is located just west of the center of the model and is probably bounded on the east by a fault. This bedrock high probably is the subsurface extension of Clifton Hill, about 4 miles (6 km) to the north, where Precambrian rock is exposed (Oriel and Platt, 1968). The gravity data indicate faulting along the east and west margins of the valley.

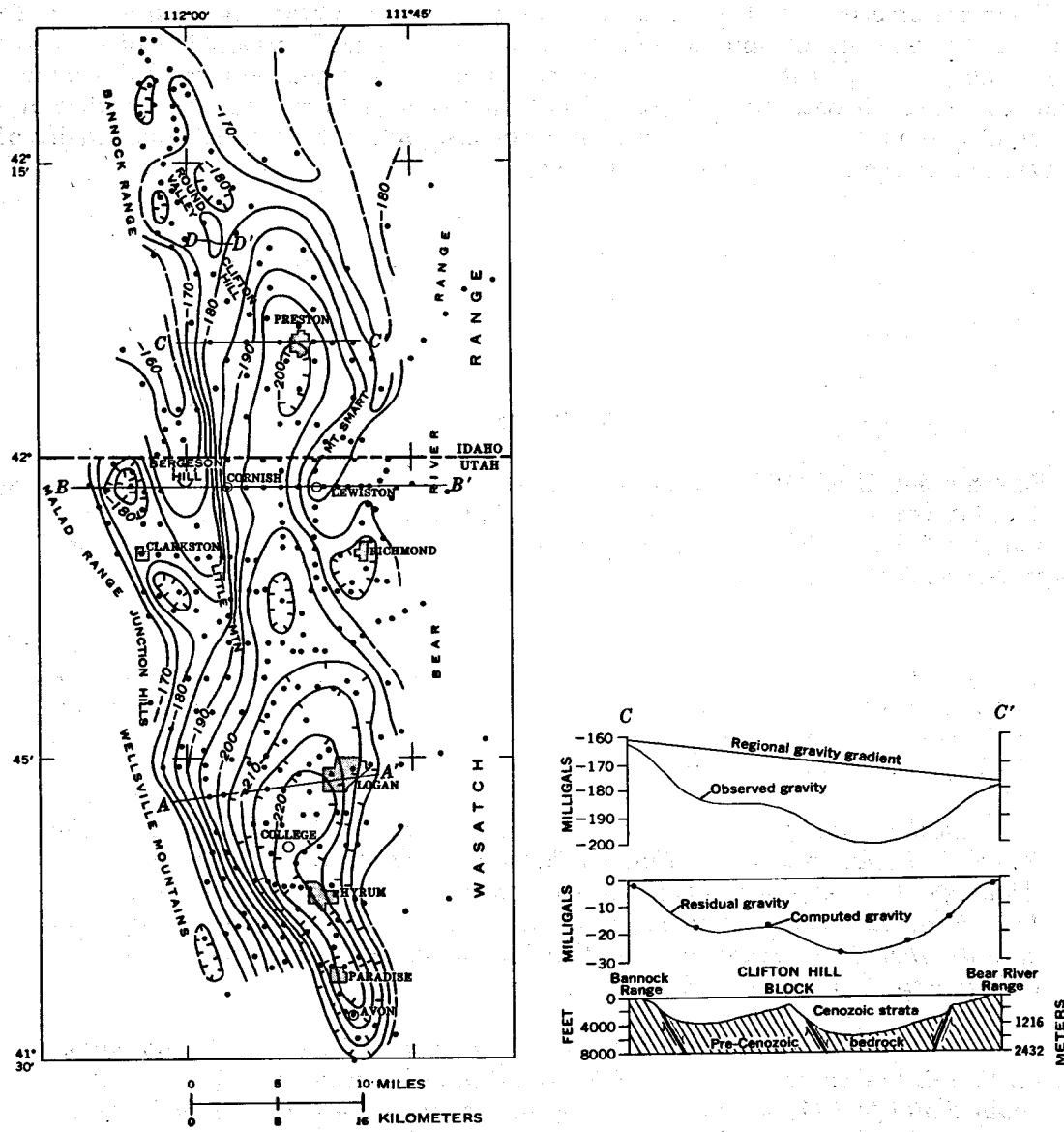


FIGURE 6. Bouger gravity map of Cache Valley, Utah and Idaho. Gravity contours are dashed where approximately located; contour interval 5 mgal; hachured contours enclose areas of low gravity. Dots indicate gravity stations. (From Peterson and Oriel, 1970.)

A detailed gravity survey was made of Clifton Hill in an attempt to determine whether the hill represents a rooted fault block (Oriel and Platt, 1968) or a block of Precambrian rock that slid eastward from the Bannock Range over Salt Lake strata . . . these data (profile D-D', fig. 4) indicates that Clifton Hill is bounded by a fault along its east side and that the bedrock is near the surface west of the hill. Whether the hill is bounded on the west by another fault cannot be determined from the available gravity data. Clifton Hill is interpreted to be the exposed part of a rooted and tilted northwesterly trending block of Precambrian rock that lies east of and lower than the Precambrian rock that forms the Bannock Range. Therefore, the slide interpretation is denied by the gravity data. Two small gravity lows occur north and northwest of Clifton Hill and indicate local thickening of the Cenozoic rock in the Round Valley area.

The gravity high along the west edge of the Bear River Range, north of the Idaho-Utah State line, is bordered on the east and northeast by an area of lower gravity values. The gravity high coincides with exposures of Brigham Quartzite and Cambrian limestone (Oriel and Platt, 1968) and connects with the Mount Smart block. The lower gravity values to the east and northeast coincide with a belt of exposed Salt Lake strata. A small closed gravity low (fig. 2) near Richmond, Utah, represents the wedge of Cenozoic sediments southeast of the Mount Smart block....

These gravity data along with the general geology, faulting, lack of abundant igneous rocks, etc., give no indication of large, shallow intrusive rock bodies (heat sources) within the subsurface in the northern Cache Valley area. The geologic and gravity data indicate fault control for several thermal springs located northwest of Preston, near the south-central portion of the study area. Geothermal-gradient and heat flow calculations indicate that the heat content of thermal springs and wells in northern Cache Valley could be due to a regionally high heat flow rather than a local, intense heat source caused by a geologically young, cooling, shallow intrusive rock body.



PLATE 2. Black and white reproduction of a NASA false color infrared satellite imagery slide. Area shown is the Cache Valley region, Idaho-Utah. The Mink Creek-Bear River lineament is shown within the long narrow rectangular block drawn on the photo. Its relationship to other features of the northern Cache Valley area is also shown.

THERMAL SPRINGS AND WELLS AND THEIR GEOCHEMISTRY

Location and General Description

Thermal springs and wells are scattered at irregular intervals along the Bear River (plate 1). They occur in conjunction with various types of consolidated and unconsolidated sedimentary rocks including travertine, limestone, quartzite, and alluvial deposits. Thermal wells penetrate only alluvial deposits.

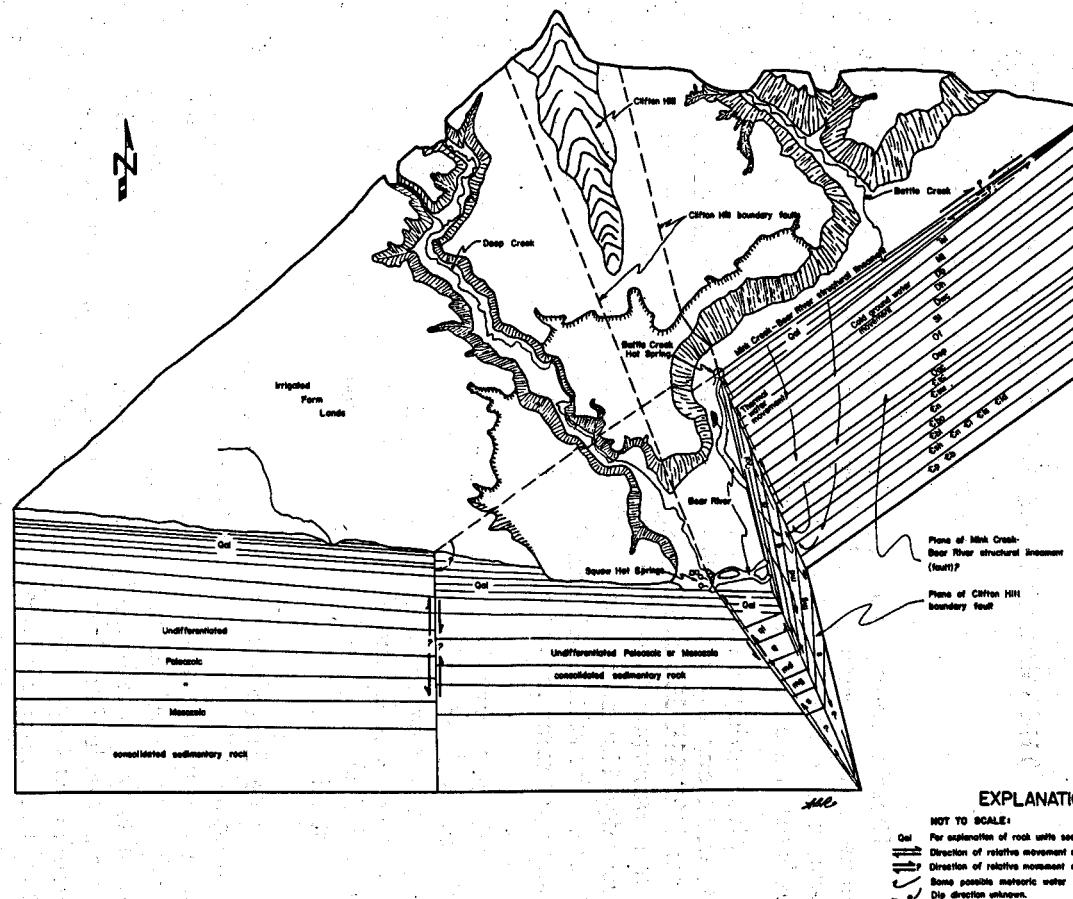
Most springs in the area appear to be fault related. The springs near Cleveland are situated along a northwest linear trend on both sides of Bear River. On the west side, spring vents (12S-41E-31cac1S-3S) issue from the bottom of circular pools 6 to 9 m in diameter within travertine formations. Numerous seeps and two much smaller pools occur near the river edge. Numerous seeps and spring vents issue from a travertine bluff overlooking Bear River on the east. Much gas, thought to consist mostly of CO_2 , escapes from the riverbed, audible for some tens of meters.

No fresh deposits of travertine were forming near Cleveland. The springs on the west side issuing from pools may even be dissolving the existing travertine deposits. The waters on the west side are much cooler (35°C) than the waters from the east bluff (66°C). Water from the vents on the west side have been used for recreational purposes. Samples were taken for chemical analyses from the large pools on the west side and from several vents on the east side.

Maple Grove Hot Springs (13S-41E-7aca1S-3S) are located in an area of intense local faulting near the shore of Oneida Narrows Reservoir. The numerous vents and seeps and the one large pool that make up the spring system are more or less aligned with each other. Unlike the Cleveland springs, Maple Grove waters are depositing much travertine. Gas, probably CO_2 , is also being evolved. Several small, cold (10°C) mud pots near the smaller vents at Maple Grove evolve small quantities of gas which bubbles up through the mud. The bubbling might be interpreted by a casual observer as evidence of boiling. These waters have been used for recreational purposes and also for power generation as evidence by an old Pelton wheel found below the spring on the shore of Oneida Narrows Reservoir. This may have been the first use of geothermal water for power generation in Idaho; even though the wheel was designed to make use of kinetic energy of the flowing water, rather than its enthalpy or heat content. Total installed capacity probably did not exceed 5 kilowatts (kw).

Well 14S-39E-36ada1, on the Bear River flood plain at Riverdale, has a surface water temperature of 40°C and was reportedly drilled to a depth of 12.1 m. For years, water from this well has been used for beneficial purposes in a dairy operation. Rulon F. Mitchell, a

FIGURE 7. Idealized block diagram of the Battle Creek-Squaw hot springs area northwest of Preston in northern Cache Valley depicting theoretical structural control for these two spring systems. In reality, the faults depicted may represent more broadly defined zones of faulting rather than single plane surfaces as represented on paper. It is also possible that the two springs occur on the same Clifton Hill boundary fault rather than on separate faults as shown. The trend of these features are fairly well known, but the direction of movement of the Mink Creek-Bear River structural lineament, depicted here as a fault, is unknown.



resident of the area for 40 years, reports that snow in a 40-acre tract around the well would melt much more quickly than in surrounding areas.

The Clifton Hill high angle boundary faults (plate 1) may exist at Battle Creek (Wayland) (15S-39E-8bcd1-4S) and Squaw hot springs (15S-39E-17bcd1-3S) Oriel and Platt, 1967; Peterson and Oriel, 1970; and Mabey, 1974, unpublished data). These faults may intersect the Mink Creek-Bear River lineament near these two hot springs (plate 2 and fig. 7). The structural implications of this transverse lineament are unknown but it could represent a strike-slip or normal fault. The controlling structure for these two hot springs could be the intersection of the Clifton Hill high angle boundary faults with the Mink Creek-Bear River (?) fault.

Battle Creek Hot Spring consists of one large pool about 6 m in diameter, a smaller pool (probably a collapsed travertine structure), numerous vents, and seeps. This spring system is located on the western edge of Bear River. Numerous vents are marked by gas bubbles in the riverbed. Travertine is actively being deposited around the pool and vents of this spring system. These waters have been used for hog carcass scalding and recreation. Samples were taken from the two pools and two smaller vents. Cold water seeps (temperature 6°C and total discharge 5-10 liters per minute [l/m]) were issuing from a clay bank just above the spring vents at Battle Creek Hot Springs. Other cold water seeps were issuing at approximately the same elevation as the thermal vents about 40 m down river from the thermal vents. The cold water may be seepage along impermeable clay layers from an irrigation canal which runs along the bottom edge of the uppermost terrace level of the river valley above the hot springs, or from irrigation water applied on farmlands above the canal. Significant quantities of cold water could be mixing with the thermal water.

Squaw Hot Springs (15S-39E-17bcd1-3S) are located about 1 km south of Battle Creek Hot Springs near the confluence of Deep Creek and Bear River. This system consists of one well, reportedly 6.7 m deep, four other vents and several seeps. Discharge from the well (15S-39E-17bcd1) is depositing travertine at the end of the discharge pipe some 30 meters from the well head, and a small mound of travertine 1.5 m high and 3 m across the base has been formed on the edge of Deep Creek. Only minor travertine deposition or evaporative incrustation was evident at the well head itself, where water samples were taken. The other vents are now only very minor depositors of travertine with small incrustations and a few travertine-coated pebbles along discharge channels. Older travertine deposits crop out in the immediate spring area, indicating prior deposition by the springs. Samples were taken from the well, from a vent situated near the road, and from another vent located near the Bear River-Deep Creek confluence. All spring vents were evolving minor quantities of gas, probably CO₂. The well being the most prolific gas evolver, gave a false appearance of vigorous boiling. These spring waters were formerly used for recreational purposes, and for heating hog houses.

Spring Deposits

Spring deposits, in the form of travertine, are sparsely scattered along the course of the Bear River (plate 1). Deposits of small areal extent occur in Gentile Valley 2.5 and 3.2 km north and south of Thatcher on the west and east sides of Bear River. Deposits are associated with active springs 1.2 km south of Cleveland (12S-41E-31cac1S) at the southern tip of Gentile Valley, at Maple Grove Hot Springs (13S-41E-7aca1S) near Oneida Narrows Reservoir, and at Battle Creek (15S-39E-8ddc1S) and Squaw hot springs (15S-39E-17bcd1S) northwest of Preston in Cache Valley.

TABLE 2
CHEMICAL ANALYSES OF THERMAL WATERS FROM THE NORTHERN CACHE VALLEY AREA
FRANKLIN COUNTY, IDAHO
(Chemical constituents in milligrams per liter)

Spring or well identification number & name	Temperature (°C)	Well depth below land surface (meters)	Discharge (l/min)	Silica (SiO ₂)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Total alkalinity as bicarbonate ion (HCO ₃)	Carbonate (CO ₃)	Sulfate (SO ₄)	Phosphate (PO ₄)	Chloride (Cl)	Fluoride (F)	Nitrate (NO ₃)	Boron (B)	Ammonia (NH ₃)	Specific conductance (Cond)	Field (pH)	Total dissolved solids	Sodium adsorption ratio (SAR)
12S-40E-36acd1S 36aca1S	35 33	10 10	54 52	265.0 259.0	68.0 64.0	563 517	127.0 137.0	704.0 704.0	0.0 0.0	788.0 755.0	0.01 0.01	632.0 633.0	2.2 1.9	0.93 0.37	3.40 3.40	1.3 1.2	4,149 4,199	6.6 6.6	3,020 2,932	8.0 7.5	
12S-41E-31cac1S 31cdb1S 31cca1S	66 61 56	20 50 10	60 64 63	208.0 178.0 172.0	50.0 50.0 50.0	458 460 460	98.0 102.0 100.0	718.0 576.0 583.0	0.0 0.0 0.0	533.0 530.0 538.0	0.01 0.01 0.01	532.0 530.0 532.0	1.9 1.9 1.9	0.11 0.21 0.76	2.80 2.90 2.80	1.6 1.5 0.8	3,229 3,379 3,189	6.4 6.5 6.5	2,499 2,324 2,335	7.4 7.9 7.9	
Maple Grove Hot Springs																					
13S-41E-7aca1S 7aca2S 7aca3S	78 72 60	20 100 935	84 85 86	85.0 93.0 93.0	30.0 29.0 25.0	492 501 492	82.0 82.0 80.0	494.0 495.0 494.0	0.0 0.0 0.0	256.0 261.0 251.0	0.01 0.02 0.01	596.0 601.0 584.0	1.1 1.1 1.0	0.07 0.12 0.06	2.30 2.30 2.30	1.4 1.3 0.9	2,909 2,979 2,899	6.6 6.8 6.8	1,953 1,980 1,939	11.7 11.6 11.7	
Ben Meek Well																					
14S-39E-36ade1	40	12	-	89	24.0	6.6	368	22.0	513.0	0.0	13.0	0.01	322.0	9.6	0.10	0.58	1.1	1,809	6.9	1,246	17.2
Battle Creek Hot Springs																					
15S-39E-8bcd1S 8bcd2S 8bcd3S 8bcd4S	82 43 81 84	50 2,160 107 5	109 166.0 162.0 97	174.0 15.0 19.0 215.0	19.0 3,071 3,053 24.0	3,161 535.0 533.0 4,184	552.0 697.0 757.0 686.0	696.0 0.0 0.0 610.0	0.0 0.0 0.0 0.0	35.0 29.0 37.0 33.0	0.01 0.01 0.01 0.01	5,241.0 5,048.0 5,034.0 6,967.0	6.0 6.0 6.0 6.4	0.11 0.42 0.28 0.06	3.50 3.40 3.60 5.30	7.6 7.3 7.2 10.0	16,619 15,439 15,949 18,479	6.7 6.5 6.5 6.8	9,326 9,026 9,062 12,033	60.8 61.2 60.5 72.2	
Squaw Hot Springs Well																					
15S-39E-17bcd1	84	7	115	124	279.0	24.0	4,368	782.0	791.0	0.0	35.0	0.02	7,398.0	4.3	0.12	4.30	8.1	20,459	6.5	12,895	67.4
Squaw Hot Springs																					
15S-39E-17acc1S 17bcd1S	73 69	450 140	126 126	241.0 135.0	26.0 23.0	3,844 4,184	533.0 708.0	866.0 816.0	0.0 0.0	23.0 27.0	0.02 0.03	6,396.0 6,877.0	4.8 4.3	0.06 0.16	4.60 4.20	9.7 7.3	16,859 20,519	6.6 6.5	11,396 12,062	62.8 87.6	
Myron Fonnesbeck Well																					
16S-38E-24acd1	23	157	4,165	74	78.0	27.0	68	18.0	418.0	0.0	4.3	0.03	91.0	0.5	0.08	0.42	0.1	889	6.8	686	1.7

Analyses by: U.S. Bureau of Reclamation

Older deposits, presumably associated with now extinct thermal or mineralized springs are generally light gray to buff in color and very porous with remnants of iron staining still visible in places. Circular, ledgy hills or mounds cover only small areas. Layering is evident but somewhat obscured by the coarse, open texture of the deposits.

Younger deposits, associated with still active springs are more massive, forming dense ledges and terrace structures. The deposits are light yellow, buff to reddish and yellowish brown in color from iron staining. X-ray diffraction analyses indicate the minerals calcite and slight amounts of quartz. Deposits from Maple Grove Hot Springs (13S-41E-7aca1S) contain calcite, quartz, and significant quantities of an unidentified mineral.

Geochemical Data

Major Constituents

Standard water quality chemical data from known thermal water occurrences in northern Cache Valley are given in table 2. These analyses provide a chemical comparison of the thermal waters in the northern Cache Valley area and were used to calculate selected chemical-constituent ratios and to estimate aquifer temperatures.

The chemical analyses suggest the thermal waters can be divided into two distinct classes or types. A sodium-bicarbonate-sulfate type issues from springs near Cleveland and from Maple Grove Hot Springs near Oneida Narrows Reservoir, both in the northern part of the study area. Sodium chloride type thermal waters found in the south contain much greater quantities of dissolved material (12,000-13,000 mg/l) than are known in any other part of Idaho.

They represent a potential pollution hazard should large-scale withdrawal be attempted. The high salinity will also present engineering difficulties from corrosion, deposition, etc. in their attempted utilization. The high dissolved solids in these thermal waters are indicative of fluid discharging from a hot water rather than a vapor dominated geothermal system of unknown volume.

Five general trends significant to the area's geothermal potential are observable from the data in table 2. These are:

1. Measured surface temperatures increase from a low of 35°C in the north to a high of 84°C in the south near Battle Creek and Squaw hot springs.
2. Dissolved silica concentration closely follows the trend in measured surface temperature; i.e., increasing from north to south.
3. Magnesium and sulfate show the opposite trend and decrease from north to south.
4. Sodium, chloride, fluoride, boron, and ammonia show an increase in concentration in thermal waters toward the south.
5. Total dissolved solids increase toward the south.

Each of these trends indicate a likelihood of higher aquifer temperatures in the southern part of the study area than in the north.

Trace Metals

Trace metal analyses performed by neutron activation techniques on long half life elements are listed in table 3. These give an insight into the likelihood of mineral extraction from thermal waters in the area. Valuable metals are known to be associated with geothermal brines in certain parts of the world. Knowledge of trace metal constituents is also valuable in engineering design for hot water extraction and utilization methods. Certain elements may represent potential pollution hazards if present in sufficient quantities.

Low concentrations of nearly all analysed trace elements are found in these thermal waters. The highly saline springs northwest of Preston (Battle Creek and Squaw hot springs) contain small quantities of barium (Ba) and rubidium (Rb), while the thermal springs in the northern part of the area contained minor chromium (Cr). Most of the thermal waters of the area contained minor amounts of strontium, but the sample from Squaw Hot Spring contained 13 mg/l. Other elemental concentrations with the exception of iron are in the micrograms per milliliter range.

TABLE 3
TRACE METAL ANALYSES OF THERMAL WATERS
FROM THE NORTHERN CACHE VALLEY AREA
FRANKLIN COUNTY, IDAHO
(Chemical constituents in milligrams per liter)

Spring or well identification number & name	Scandium (Sc) X10 ⁻⁴	Chromium (Cr) X10 ⁻²	Iron (Fe) X10 ⁻³	Cobalt (Co) X10 ⁻³	Zinc (Zn) X10 ⁻¹	Rubidium (Rb)	Strontium (Sr) X10 ⁻²	Silver (Ag) X10 ⁻²	Antimony (Sb) X10 ⁻²	Barium (Ba) X10 ⁻²	Cesium (Cs) X10 ⁻²
12S-40E-36acd1S	.42	34.	0.35	1.0	.18	.21	2.6	.34	0	0.18	.39
12S-41E-31cac1S	.55	44.	1.0	.14	.26	.15	1.5	.33	.12	.10	.26
Maple Grove Hot Springs											
13S-41E-7aca1S	.16	21.	5.2	.19	0	0	0	.10	0	0	0
Ben Meek Well											
14S-39E-36aca1	.13	1.3	.37	.26	.39	.03	.14	0	.07	.16	.12
Battle Creek Hot Springs											
15S-39E-8bdc1S	3.2	.11	2.5	.87	.25	2.6	8.0	0	0	1.1	.50
Squaw Hot Springs Well											
15S-39E-17bcd1	.57	.67	2.2	0	0	4.0	13.	.38	0	2.2	.35

Analyses by: Idaho National Engineering Laboratory.

Geochemical Thermometers and Atomic Ratios

Preliminary evaluations of geothermal systems are being successfully conducted using geochemical thermometers. In the Raft River Valley of southeastern Idaho, a geologic environment similar to that of the northern Cache Valley area, the reliability of these thermometers has been tested by deep drilling. The silica, and sodium-potassium-calcium (Na-K-Ca) predicted aquifer temperatures (Young and Mitchell, 1973) and mixing model calculations (Young and Mitchell, 1973, unpublished data) agreed very closely (within 10°C) with temperatures found at depth (Kunze, 1975). This proven reliability in the Raft River Valley gives some measure of confidence in applying the same methods to other similar areas of the state.

The degree of reliance to be placed on a geochemical thermometer depends on many factors. A detailed description of the basic assumptions, cautions, and limitations for these geochemical thermometers is included in the appendix. The basic assumption is that the chemical character of the water obtained by temperature dependent equilibrium reactions in the thermal aquifer is conserved from the time the water leaves the aquifer until it reaches the surface. The concentration of certain chemical constituents dissolved in the thermal waters can, therefore, be used to estimate aquifer temperatures.

Aquifer temperatures calculated from the silica, the Na-K-Ca geochemical thermometers, and mixing models, as well as the atomic ratios of selected elements found in the thermal waters of the northern Cache Valley area are given in table 4. These were calculated from values of concentration found in table 2. Observations from table 4 significant to the areas of geothermal potential are:

1. Silica calculated aquifer temperatures (T_1) assuming quartz equilibrium with no steam loss (evaporative concentration of silica) and silica calculated aquifer temperatures (T_2) assuming quartz equilibrium with maximum steam loss, both increase toward the south, following the general trend in measured surface temperatures. Aquifer temperature predicted by assuming no steam loss and those assuming steam loss generally agree within 10°C. This is expected at the dissolved silica concentrations found in these waters. Predicted aquifer temperatures using these geochemical thermometers range from 110°C in the north to the 150°C in the southern part of the area.
2. Silica calculated aquifer temperatures (T_3) assuming equilibrium with amorphous silica are always less than measured surface temperatures by 30° to 40°C; some predicted aquifer temperatures (those in the north) being below the freezing point of water. This indicates that this thermometer is unreliable. These temperatures range from -10° to 30°C.
3. The Na-K-Ca geochemical thermometer (T_5) predicts aquifer temperatures from 85° to 255°C with temperatures in the southern part of the area in general being about 45°C higher than those predicted for the northern part. They are much higher (from 150 to 200°C) than measured surface temperatures.
4. The sodium/potassium (Na/K) predicted aquifer temperatures (T_6) are somewhat higher for spring waters in the northern part of the study area than in the southern part, where they agree closely with Na-K-Ca predicted aquifer temperatures at Battle Creek and Squaw hot springs.

TABLE 4
ESTIMATED AQUIFER TEMPERATURES AND ATOMIC RATIOS
OF SELECTED CHEMICAL CONSTITUENTS

Spring or well identification number & name	Discharge (l/min)	Temperature (°C)	Aquifer temperatures from geochemical thermometers rounded to 50°C (see footnotes)									Atomic Ratios												
			T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇	T ₈	%	Na/K	Sodium Potassium	Sodium Chloride	Magnesium Calcium	Calcium Bicarbonate	Chloride Carbonate + Bicarbonate	Chloride Fluoride	Chloride Boron	Ammonia Chloride	Ammonia Fluoride	√Ca/Sodium	Chloride Sulfate	Calcium Fluoride
12S-40E-38acd1S 36aca1S	10	35	105	105	-10	75	225	305	170	135	85	7.54	3.70	0.42	0.57	1.55	153.97	58.63	0.00	0.68	3.32	2.17	57	
	10	33	105	105	-10	75	235	335	170	135	86	6.42	3.48	0.41	0.56	1.55	178.56	58.72	0.00	0.70	3.57	2.27	54	
12S-41E-31cac1S 31cdb1S 31ccs1S	20	66	110	110	-5	80	220	295	130	120	54	7.95	3.84	0.40	0.44	1.28	150.07	57.88	0.01	0.94	3.82	2.70	51	
	50	61	115	110	-5	85	225	300	145	125	63	7.67	4.51	0.46	0.47	1.58	149.51	55.69	0.01	0.88	3.33	2.71	44	
	10	56	110	110	-5	85	225	295	150	125	68	7.82	4.66	0.48	0.45	1.57	150.07	57.88	0.00	0.47	3.27	2.68	42	
Maple Grove Hot Springs																								
13S-41E-7aca1S 7aca2S 7aca3S	20	78	125	125	10	100	215	250	160	130	56	10.20	10.09	0.58	0.26	2.08	290.40	78.95	0.00	1.42	2.15	6.30	36	
	100	72	130	125	10	100	215	250	170	135	62	10.39	9.39	0.51	0.29	2.09	292.83	79.61	0.00	1.32	2.21	6.24	40	
	935	60	130	125	10	100	215	250	190	140	73	10.46	9.22	0.44	0.29	2.03	313.00	77.36	0.00	1.00	2.25	6.30	44	
Ben Meek Well																								
14S-39E-36ada1		40	130	125	10	103	165	130	260	165	89	28.45	26.73	0.45	0.07	1.08	17.98	169.14	0.01	0.13	1.53	67.08	1.1	
Battle Creek Hot Springs																								
15S-39E-8bdc1S 8bdc2S 8bdc3S 8bdc4S	50	82	140	135	20	115	255	260	190	140	61	9.74	31.67	0.18	0.38	12.96	468.17	458.20	0.00	1.41	0.48	405.51	13	
	2,160	43	140	135	20	115	255	260	999	175	0	9.76	32.25	0.15	0.36	12.47	450.93	452.32	0.00	1.36	0.48	471.39	13	
		81	140	135	20	115	255	260	190	145	62	9.74	32.85	0.19	0.33	11.45	449.68	426.01	0.00	1.34	0.48	368.44	12	
	5	84	135	130	15	110	255	250	170	135	55	10.37	33.93	0.18	0.54	19.66	583.45	400.48	0.00	1.74	0.40	571.72	15	
Squaw Hot Springs Well																								
15S-39E-17bcd1		115	84	150	145	30	125	260	265	205	150	63	9.50	27.29	0.14	0.54	16.10	922.11	524.15	0.00	2.10	0.44	572.40	30
Squaw Hot Springs																								
15S-39E-17acc1S 17bcd1S	450	73	150	145	30	125	240	225	225	155	71	12.27	27.81	0.18	0.42	12.71	714.18	423.60	0.00	2.25	0.46	753.07	29	
	140	69	150	145	30	125	260	255	235	160	75	10.05	54.03	0.28	0.25	14.51	857.17	498.84	0.00	1.89	0.32	689.75	28	
Myron Fonnesbeck Well																								
16S-38E-24acd1	4,165	23	120	120	5	92	85	335	999	195	0	6.43	1.52	0.57	0.28	0.37	97.55	68.01	0.00	0.22	14.81	57.31	73	

T₁ = Silica temperatures assuming quartz equilibrium and conductive cooling (no steam loss).
T₂ = Silica temperatures assuming quartz equilibrium and adiabatic expansion at constant enthalpy (maximum steam loss).
T₃ = Silica temperatures assuming equilibrium with amorphous silica.
T₄ = Silica temperatures assuming equilibrium with chalcedony.
T₅ = Na-K-Ca temperatures.
T₆ = Na-K temperatures.
T₇ = Fournier-Truesdell mixing model 1 temperatures (no steam loss).
T₈ = Fournier-Truesdell mixing model 2 temperatures (maximum steam loss).
% = Percent of cold water in T₇ calculation.
999 = Hot water temperature calculation not possible.
* Molar ratio.
- Discharge measurement or estimate not possible.

5. Mixing model predicted temperatures assuming no steam loss (T_7) and assuming steam loss (T_8) indicate higher aquifer temperatures near Battle Creek and Squaw hot springs in the south. Percent cold water mixed with hot (%) show no general trends.
6. Na/Ca , Cl/B , NH_3/F , Cl/CO_3 and Cl/SO_4 ratios all show an increase to higher values in the southern part of the area near Battle Creek and Squaw hot springs. The increase in these ratios should be observed if aquifer temperatures are higher in the south than in the north. These ratios are distinctive for each spring system with the exception of the two highest temperature springs (Battle Creek and Squaw hot springs) northwest of Preston, where they are similar. This indicates that the springs in the northern part of the area are from completely separate systems while the two spring systems west of Preston may be interconnected.
7. Mg/Ca ratios decrease from north to south, as would be expected if higher aquifer temperatures are to be found near the southern part of the area. This ratio is fairly low in the south, an indication of high temperature geothermal water.
8. The two warm wells (14S-39E-36ada1 and 16S-38E-24acd1) located in the central and extreme southern portion of the study area do not, in general, follow the above trends.

Discussion of Geochemical Data

The silica (quartz equilibrium aquifer temperatures) in column T_1 , table 4 most probably represent minimal temperatures at depth for Battle Creek and Squaw hot springs for the following reasons:

1. Quartz equilibrium rather than equilibrium with amorphous silica is suggested for the thermal waters. Measured surface temperatures are always much higher than amorphous silica aquifer temperatures (column T_3 table 4). The amorphous silica geochemical thermometer predicts temperatures below the freezing point of water in some instances. A measure of confidence can, therefore, be placed upon the quartz equilibrium predicted aquifer temperatures.
2. Dilution of silica by mixing of hot water with colder ground water, or precipitation of silica from solution would mean the quartz equilibrium predicted aquifer temperatures would be lower than the temperatures that had actually been attained by the hot waters at depth.
3. No evidence of steam loss (evaporative concentration of silica) i.e., dilute hot or warm springs (chloride concentration less than 50 mg/l) fumaroles, geyser activity, etc. are known to exist in the area, therefore, T_1 would be a closer approximation to actual aquifer temperatures than T_2 .
4. Other geochemical thermometers in Column T_5 through T_7 of table 4 (Na-K-Ca, Na/K, and mixing model calculations) predict higher aquifer temperatures than T_1 .

5. Equilibrium with other quartz polymorphs, (tridymite or cristobalite) is not considered likely. These polymorphs, rare in occurrence compared to quartz, generally are associated with siliceous volcanic rocks. No siliceous volcanic rocks are known to occur in the study area. Tridymite is known in a few instances to occur in metamorphosed, impure limestones, and cristobalite in metamorphosed sandstones. The geologic framework of the area would, however, suggest that the presence of these rock types is possible.
6. Chalcedonic varieties of silica (chert, jasper, agate, etc.) could also be the mineralized phase controlling the silica content in the thermal waters. If this is so, then aquifer temperatures 10 to 25°C lower than quartz equilibrium aquifer temperatures (T_1) would be found by deep drilling unless mixing is taking place. Arnórsson (1970, p. 537, 1975, p. 763) reports that chalcedony generally controls silica concentration in Icelandic thermal waters when aquifer temperatures are below 100-110°C. Chalcedonic equilibrium aquifer temperature calculations result in aquifer temperatures of 115-125°C for Battle Creek and Squaw hot spring waters, somewhat above Arnórsson's upper limit. Quartz equilibrium is, therefore, indicated for these spring waters if this criteria is applicable to northern Cache Valley. Chalcedony may be the mineraloid controlling silica in the other springs and wells in northern Cache Valley as chalcedony equilibrium aquifer temperatures in these waters are below 110°C.
7. The high salinity and particularly the low magnesium (Mg) content and magnesium/calcium (Mg/Ca) ratios from Battle Creek and Squaw hot springs indicate aquifer temperatures may be considerably above surface temperatures. The low Mg and Mg/Ca ratios in the northern Cache Valley area contrast sharply with those of other areas of southeastern Idaho such as the Blackfoot Reservoir area, where these values are very high and where the waters are from suspected low temperature geothermal systems (Mitchell, 1976). The quartz equilibrium geochemical thermometer (T_1), therefore, indicates that aquifer temperatures of at least 150°C may exist in the area of Battle Creek and Squaw hot springs.

The possibility of encountering even higher aquifer temperatures is perhaps indicated by the other geochemical thermometers (Na-K-Ca, Na/K, and mixing models). Because of the likelihood of hot and cold groundwater mixing particularly at Battle Creek and Squaw hot springs northwest of Preston, the silica temperatures of mixing (T_7 , model 1, table 4, and appendix) could be near the maximum aquifer temperatures at depth because:

1. The nearness of the springs to the Bear River suggests a high probability of mixing.
2. Cold spring vents issuing near the hot spring vents suggest the probability of mixing.
3. The high discharge of the springs indicate a possibility of mixing.
4. The Na-K-Ca predicted aquifer temperatures (T_4) are not in agreement with the measured surface temperatures which may indicate mixing, continued rock water reaction, or calcium deposition.

However, plots of chloride concentration vs. surface spring temperatures are not linear, a condition which usually exists if mixing is taking place unless considerable conductive cooling has occurred.

Thermodynamic calculations, using the method of Kharaka, and others (1973) indicates the thermal waters of the northern Cache Valley area are slightly supersaturated in calcium with respect to the mineral calcite. This probably means minor continued rock water reaction with respect to this mineral. This casts some doubt on the validity of the Na-K-Ca calculated aquifer temperatures and caution is advised in accepting them and Na/K as highest probable temperatures.

Table 5 summarizes the aquifer temperature indicators for the two highest temperature spring systems in the northern Cache Valley area.

Table 5 shows only two temperature indicators suggesting that the thermal waters in the northern Cache Valley area northwest of Preston may never have been very hot (greater than about 100°C). The other geochemical thermometers or indicators (12 in number) indicate hotter waters, perhaps as high as 150°C may exist in the northern Cache Valley area northwest of Preston.

TABLE 5
SUMMARY OF GEOCHEMICAL INDICATORS FOR BATTLE CREEK
(15S-39E-8bcd1S-4S) AND SQUAW (15S-39E-17bdd1S-3S) HOT SPRINGS
NORTHWEST OF PRESTON IN THE NORTHERN CACHE VALLEY AREA

Indicators of High Temperature	Indicators of Low Temperature
<ol style="list-style-type: none">1. Moderate to high silica2. Low Mg, Mg/Ca ratio3. High Ca/F ratio4. High Cl/F ratio5. High Na/Ca ratio6. High Cl/HCO₃ + CO₃ ratio7. High Na-K-Ca temperature prediction8. High discharge indicates equilibrium9. Or mixing10. High total dissolved solids11. High predicted mixing model temperatures12. Relatively high geothermal gradient	<ol style="list-style-type: none">1. Travertine deposits at some spring vents or well discharge orifice2. Absence of siliceous sinter

The fact that high and low temperature indicators both are found in the area is most easily explained by assuming the low temperature indicators (travertine deposition, lack of siliceous sinter) are erroneous. They could be the result of mixing of hot and cold groundwaters, contact of the thermal water with limestone in the subsurface, loss of CO₂ gas, or combinations of these factors. The abundant limestones making up much of the

geologic framework of the area suggests, along with thermodynamic calculations, that the waters could have dissolved minor amounts of limestone due to conductive cooling and pH changes. The major bulk of evidence supports the fact that high-temperature water is to be found at depth northwest of Preston in northern Cache Valley. The estimated aquifer temperatures in the northern Cache Valley area may not exceed those predicted by the quartz equilibrium geochemical thermometer. However, if the sampled water is a mixture of cold, shallow ground or river water with deeper geothermal water, then aquifer temperatures as high as those predicted by mixing model 1 may be encountered by deep drilling.

The available gravity data for the northern Cache Valley area does not reveal any density anomalies that appear to be related to a primary, high intensity heat source in the subsurface. The gravity and geologic data indicate that all of the hot springs in northern Cache Valley are associated with normal faulting. These data, together with few exposed igneous rocks, lead to the conclusion that a local, primary, shallow, high-intensity heat source may be lacking. The springs probably represent a classic U-shaped deep circulation system whereby meteoric waters descend along fault planes to depths where the waters are heated by the increasing temperature of the rock with depth (geothermal gradient). The heated waters, due to decreased density, then rise along other faults to the surface. During this rise, steam may form, cooling the thermal waters. Steam and hot water remix and/or mix with cold groundwater and finally emerge as a thermal spring. The volume of water and steam produced from such a density drive system could range from what is now being discharged by the springs to tens of thousands of liters per minute, depending on geologic and hydrologic conditions.

CONCLUSIONS

The available gravity data for the northern Cache Valley area does not reveal any density anomalies that appear to be related to a primary, high intensity heat source in the subsurface. The gravity and geologic data indicate that all of the hot springs in northern Cache Valley are associated with normal faulting. These data, together with few exposed igneous rocks, lead to the conclusion that a local, primary, shallow, high-intensity heat source may be lacking. The springs probably represent a classic U-shaped deep circulation system whereby meteoric waters descend along fault planes to depths where the waters are heated by the increasing temperature of the rock with depth (geothermal gradient). The heated waters, due to decreased density, then rise along other faults to the surface. During this rise, steam may form, cooling the thermal waters. Steam and hot water remix and/or mix with cold groundwater and finally emerge as a thermal spring. The volume of water and steam produced from such a density drive system could range from what is now being discharged by the springs to tens of thousands of liters per minute, depending on geologic and hydrologic conditions.

The high total dissolved solids are indicative of water ascending from a hot water rather than a dry steam aquifer or reservoir. The atomic ratios of elements found in the thermal waters indicate the thermal waters in the northern part of the area are from separate geothermal systems while those from Battle Creek and Squaw hot springs may be from the same aquifer or reservoir.

The geochemical data and surface temperatures indicate that the hottest waters are to be found near Battle Creek and Squaw hot springs, 3 to 4 km northwest of the town of Preston. Aquifer or subsurface temperatures near 150°C are likely to be found in the area; if mixing of hot and cold groundwaters is taking place then temperatures approaching 225°C may be found, provided, that quartz is the mineral controlling silica concentration in these waters. Temperatures of this magnitude would be sufficient to produce electrical power. If chalcedony is the mineraloid controlling silica concentration in these waters, then they are probably from an aquifer or reservoir of 125°C maximum temperature. Temperatures of this magnitude would be sufficient to have many industrial applications. These industrial applications could include: evaporation in sugar refining, fresh water distillation, drying and curing of light aggregate prefabricated cement slabs, hay and grain and other organic materials drying, space heating, greenhouse horticulture, refrigeration, animal husbandry, mushroom growing, and soil warming for increased crop production.

The highly saline waters may challenge engineers who work toward their utilization. Activities related to the large-scale withdrawal and use of these waters must be very carefully monitored. Cooperation between water users, state and local officials is necessary to avoid potential thermal and saline pollution, which could be a danger due to the higher temperatures and salinity of these waters should large-scale withdrawal be attempted.

RECOMMENDATIONS

The thermal waters in the northern Cache Valley area have a high dissolved solid content. Induced resistivity or audio-magnetotelluric (AMT) surveys might define the areal extent and depth of any thermal water reservoir or aquifer within equipment limits of depth penetration.

Several heat flux profile lines utilizing five to ten 150-meter deep drill holes to escape irrigation effects should be considered in a further evaluation of the thermal anomaly. The heat flow study and gradient measurements should help to further define the areal extent, as well as the theoretical depth to hot water of a given temperature.

More detailed gravity data would more firmly establish the presence or absence of a high-intensity heat source at depth and shed more light on possible fault control of the geothermal systems, particularly the Mink Creek-Bear River lineament.

Seismic listening should give some indication of depth to and location of movement along fault planes, as well as provide information on possible magmatic activity at depth.

Any further evaluation of the geothermal potential of the northern Cache Valley area should contain these elements of data collection.

SELECTED REFERENCES

Armstrong, F. C., 1953, Generalized composite stratigraphic section for the Soda Springs quadrangle and adjacent areas in southeastern Idaho: in Intermountain Assoc. Petroleum Geologists 4th Ann. Field Conf., 1953: chart in pocket.

_____, 1969, Geologic map of the Soda Springs quadrangle, southeastern Idaho: U.S. Geol. Survey Misc. Geol. Inv. Map 1-557, 2 sheets.

Armstrong, F. C., and Cressman, E. R., 1963, the Bannock thrust zone, southeastern Idaho: U.S. Geol. Survey Prof. Paper 374-J, 22 p.

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

Arnórsson, Stefán, 1970, Underground temperatures in hydrothermal areas in Iceland as deduced from the silica content of the thermal water: in Proceedings United Nations Symp. on the Development and Utilization of Geothermal Resources, Pisa, 1970, v. 2, Part 1, Geothermics, Spec. Issue 2, p. 537-541.

_____, 1975, Application of silica geothermometer in low temperature hydrothermal areas in Iceland, Amer. Jour. Sci., v. 275, no. 7, p. 763-784.

Barnes, H. L., ed., 1967, Geochemistry of hydrothermal ore deposits; New York; Holt, Rinehart, and Winston, Inc., 670 p.

Bjorklund, L. J., and McGreevy, L. J., 1971, Ground-water resources of Cache Valley, Utah and Idaho: State of Utah, Dept. of Natural Resources, tech. pub. no. 36, 72 p.

Bödvarsson, Gunnar, 1970, Evaluation of geothermal prospects and the objectives of geothermal exploration: Geoexploration, 8, 7.

Bright, R. W., 1963, Pleistocene Lakes Thatcher and Bonneville, southeastern Idaho: Minnesota Univ. (Minneapolis) Ph.D. thesis; available from University Microfilms, Inc., Ann Arbor, Mich.

Brott, C. A., Blackwell, D. D., and Mitchell, J. C., 1976, Geothermal Investigations in Idaho, part 8, heat flow studies of the Snake River Plain, Idaho: Idaho Dept. of Water Resources Water Inf. Bull. no. 30, in prep.

Burnham, W. L., Harder, A. H., and Dion, N. P., 1969, Availability of groundwater for large-scale use in the Malad Valley-Bear River Basin areas of southeastern Idaho - an initial assessment: U.S. Geol. Survey open-file rept., 40 p.

Coulter, H. W., 1956, Geology of the southeast Portion of the Preston Quadrangle, Idaho: Idaho Bur. Mines and Geol. Pamph. 107, 47 p.

Cox, Allan, Dalrymple, G. B., and Doell, R. R., 1967, Reversals of the earth's magnetic field: Sci. American, v. 216, no. 2, p. 44-54.

Dion, N. P., 1969, Hydrologic reconnaissance of the Bear River Basin in southeastern Idaho: Idaho Dept. of Water Resources Water Inf. Bull. 13, 66 p.

_____, 1974, An estimate of leakage from the Blackfoot Reservoir to Bear River Basin, southeastern Idaho: Idaho Dept. of Water Resources Water Inf. Bull. no. 34, 24 p.

Eldridge, G. H., 1895, A geological reconnaissance across Idaho: U.S. Geol. Survey Sixteenth Ann. Rept., pt. 2, 211-276.

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

Fenneman, N. M., 1917, Physiographic division of the United States: Assoc. Am. Geographers Annals 6, p. 19-98.

_____, 1931, Physiography of Western United States: New York, McGraw-Hill Book Co., 534 p.

Fournier, R. O., and Rowe J. J., 1966, Estimation of underground temperatures from the silica content of water from hot springs and wet steam wells: Am. Journ. Sci., v. 264, p. 685-695.

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

_____, 1973, An empirical Na-K-Ca geochemical thermometer for natural waters: Geochim. et. Cosmochim. Acta., v. 73, p. 1255-1275.

Fournier, R. O., White, D. E., and Truesdell, A. H., 1974, Geochemical indicators of subsurface temperature, Part 1, Basic Assumptions, Part 2, Estimation of temperature and fraction of hot water mixed with cold; U.S. Geol. Survey Jour. of Research, v. 2, no. 3, p. 259-270.

Gilbert, G. K., 1875, Lake Bonneville, in Report upon the geographic and geologic exploration and survey west of the 100th meridian: Washington, U.S. Govt. Printing Office, v. 3.

_____, 1890, Lake Bonneville: U.S. Geol. Survey Mon. 1, 438 p.

Godwin, L. H., Haigler, L. B., Rioux, R. L., White, D. E., Muffler, L. J. P., and Wayland, R. G., 1971, Classification of public lands valuable for geothermal resources: U.S. Geol. Survey Circ. 647, 17 p.

Greenberg, S. A., and Price, E. W., 1957, The solubility of silica in solutions and electrolytes: J. Phys. Chem. 61, p. 1539-1541.

Grose, L. T., 1971, Geothermal energy: geology, exploration, and developments; Part 1: Colorado School Mines Research Inst. Min. Industries Bull. v. 14, no. 6, 14 p.

Hardy, C. T., and Williams, J. Stewart, 1953, Geologic map of the northern Wasatch Mountains, Utah and Idaho, in Intermountain Assoc. Petroleum Geologists Guidebook 4th Ann. Field Conf., Geology of northern Utah and southeastern Idaho, 1953: pl. 1.

Healy, J., 1970, Pre-investigation geological appraisal of geothermal fields; in Proceedings United Nations Symp. on the Development and Utilization of Geothermal Resources, Pisa, 1970, v. 2, Part 1, Geothermics, Spec. Issue 2, p. 571-577.

Holland, H. D., 1965, Some application of thermochemical data to problems of ore deposits, II. Mineral assemblages and the composition of ore-forming fluids: Econ. Geol. v. 60, no. 6, p. 1101-1165.

_____, 1967, Gangue minerals in hydrothermal deposits: in Geochemistry of Hydrothermal Ore Deposits, H. L. Barnes, ed., Holt, Rinehart and Winston, Inc.

Kharaka, Y.K., and Barnes, Ivan, 1973, SOLMNEQ: Solution-mineral equilibrium computations: National Tech. Information Service publication PB-215 899, 82 p.

_____, 1963, Structure and stratigraphy behind the Bannock Thrust in parts of the Preston and Montpelier quadrangles, Idaho: Unpublished Columbia Univ., Ph.d. dissertation, 204 p.

King, Clarence, 1878, Systematic geology: U.S. Geol. Explor. 40th Parallel, v. 1, p. 127-227.

Kirkham, V. R. D., 1924, Geology and oil possibilities of Bingham, Bonneville, and Caribou Counties, Idaho: Idaho Bur. Mines and Geology Bull. 8, 108 p.

Kummel, Bernhard, 1954, Triassic stratigraphy of southeastern Idaho and adjacent areas: U.S. Geol. Survey Prof. Paper 254-H, p. 165-194.

Kunze, J. F., 1975, Idaho geothermal R&D project report for period January 1, 1975 to March 31, 1975, Idaho National Engineering Laboratory ANCR 1222, p. 17.

Lindal, Baldur, 1973, Industrial and other applications of geothermal energy, in Earth Sciences 12, Geothermal Energy, a Review of Research and Development, The Unesco Press, H. C. Armstead, Ed., p. 135-147.

Lindgren, Waldemar, 1900, The gold and silver veins of Silver City, DeLamar, and other mining districts in Idaho: U.S. Geol. Survey Twentieth Ann. Rept., pt. 3, p. 65-256.

Mabey, D. R., and Oriel, S. S., 1970, Gravity and magnetic anomalies in the Soda Springs region, Southeastern Idaho: U.S. Geol. Survey Prof. Paper 646 E., 15 p.

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 Resources, Pisa, 1970, v. 2, Part 2, Geothermics, Spec. Issue 2, p. 1310-1322.

Malde, H. E., 1959, Fault zone along the northern boundary of the western Snake River Plain, Idaho: Science, v. 130, p. 272.

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

Mansfield, G. R., 1927, Geography, geology and mineral resources of part of southeastern Idaho: U.S. Geol. Survey Prof. Paper 152, 453 p.

McGreevy, L. L., and Bjorklund, L. J., 1970, Selected hydrologic data, Cache Valley, Utah and Idaho: U.S. Geol. Survey open-file release (duplicated as Utah Basic-Data Release 21), 51 p.

Meinzer, O. E., 1924, Origin of the thermal springs of Nevada, Utah, and southern Idaho: Jour. Geol., v. 32, no. 4, p. 295-303.

Mitchell, C. M., Knowles, F. F., and Petrafeso, F. A., 1965, Aeromagnetic map of the Pocatello-Soda Springs area, Bannock and Caribou Counties, Idaho: U.S. Geol. Survey Geophys. Inv. Map GP-521.

Mitchell, J. C., 1976, Geothermal Investigations in Idaho, part 6, Geochemistry and geologic setting of the thermal and mineral waters of the Blackfoot Reservoir area, Caribou County, Idaho: Idaho Dept. of Water Resources Water Inf. Bull. 30, in preparation.

Nichols, C. R., Brockway, C. E., and Warnick, C. C., 1972, Geothermal water and power resource exploration and development for Idaho: Water Resource Research Inst. Tech. Completion Prep. Project NSF-Geothermal 47-517, 48 p.

Oriel, S. S., and Platt, L. B., 1968, Reconnaissance geologic map of the Preston quadrangle, southeastern Idaho: U.S. Geol. Survey open-file map, two sheets.

Peterson, D. L., and Oriel, S. S., Gravity anomalies in Cache Valley, Cache and Box Elder Counties, Utah, and Bannock and Franklin Counties, Idaho; in Geological Survey Research 1970: U.S. Geol. Survey Prof. Paper 700-C, p. C114-C118.

Piper, A. M., 1925, Ground Water for Irrigation on Camas Prairie, Camas and Elmore Counties, Idaho: Idaho Bur. Mines and Geology, Pamph. 15, 46 p.

Richards, R. W., 1911, Notes on lead and copper deposits in the Bear River Range, Idaho and Utah: U.S. Geol. Survey Bull. 470, p. 117-187.

Richards, R. W., and Mansfield, C. R., 1912, The Bannock overthrust, a major fault in southeastern Idaho and northeastern Utah: Jour. Geology, v. 20, p. 681-701.

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.

Ross, S. H., 1971, Geothermal potential of Idaho: Idaho Bur. Mines and Geology Pamph. 150, 72 p.

Sbar, M. L., Barazangi, Muawia; Dorman, James; Christopher, H. S.; Smith, R. B.; 1972, Tectonics of the Intermountain Seismic Belt, Western United States: Microearthquake seismicity and composite fault plane solution, Geol. Soc. Amer. Bull., v. 83, no. 1.

Schmidt, D. L., and Makin, J. H., 1962, Quaternary geology of the Bellevue area in Blaine and Camas Counties, Idaho, U.S. Geol. Survey Open File Report 625.

Siever, Raymond, 1962, Silica solubility, 0°-200° C. and diagenesis of siliceous sediments: Jour. Geol. v. 70, p. 127-150.

Smith, C. L., 1966, Geology of the Eastern Mount Bennett Hills, Camas, Gooding and Lincoln Counties, Idaho: Ph.D. Dissertation, Univ. of Idaho, Moscow, 129 p.

Smith, R. B., and Sbar, M. L., 1974, Contemporary tectonics and seismicity of the Western United States. Geol. Soc. Amer. Bull. v. 85, p. 1205-1218.

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.

Staley, W. W., and Prater, L. S., 1945, Sulphur in Idaho: Idaho Bur. Mines and Geology Min. Resources Rept. no. 2, 7 p.

Stanley, W. D., 1972, Geophysical study of unconsolidated sediments and basin structure in Cache Valley, Utah and Idaho. Geol. Soc. Amer. Bull. v. 83 n. 6 p. 1817-1830.

Stearns, N.D., Stearns, H. T., and Waring, G. A., 1937, Thermal springs in the United States: U.S. Geol. Survey Water-Supply Paper 679-B. p. 59-206.

Truesdell, A. H., and Jones, B. F., 1974, WATEQ, a computer program for calculating chemical equilibria of natural waters: Jour. Research U.S. Geological Survey, v. 2, no. 2, March - April, 1974, p. 233-248.

Umpleby, J. B., 1915, Ore deposits in the Sawtooth quadrangle, Blaine and Custer Counties, Idaho: in Contributions to Economic Geology: U.S. Geol. Survey Bull. 580, p. 221-249.

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.

Wallace, R. W., 1972, A finite-element, planar-flow model of Camas Prairie, Idaho: Univ. of Idaho Ph.D. dissertation.

Waring, G. H., (revised by R. R. Blankenship and Ray Bentall), 1965, Thermal springs of the United States and other countries of the world - a summary: U.S. Geol. Survey Prof. Paper 492, 383 p.

Warner, M. M., 1972, Geothermal resources of Idaho: in Geothermal Overviews of the Western United States, Geothermal Resources Council Special Report no. 1, p. 92-98.

_____, 1975, Special aspects of Cenozoic history of southern Idaho and their geothermal implications: in Proceedings 13th Ann. Eng. Geol. and Soils Eng. Symp., p. 247-270.

White, D. E., 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, 1970, v. 1, Part 2, Geothermics, Spec. Issue 2, p. 58-80.

White, D. E., Muffler, L. J. P., and Truesdell, A. H., 1971, Vapor-dominated hydrothermal systems compared with hot-water systems: Econ. Geol, v. 66, no. 1, p. 75-97.

Witkind, I. J., 1975, Preliminary map showing known and suspected active faults in Idaho: U.S. Geol. Survey open-file report no. 75-278.

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 Resources Water Inf. Bull. no. 30, 43 p.

Young, H. W., and Whitehead, R. L., 1975, Geothermal Investigations in Idaho, part 2, An evaluation of thermal water in the Bruneau-Grandview area, southwest Idaho: Idaho Dept. of Water Resources Water Inf. Bull. no. 30, 126 p.

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GEOCHEMICAL THERMOMETERS

Young and Mitchell (1973) gave a brief review of the then available geochemical thermometers. Their summary is as follows:

"Summary of Geochemical Thermometers Available"

In recent years the concentrations of certain chemical constituents dissolved in thermal waters have been used to estimate water temperatures in the thermal aquifer. However, these geochemical thermometers are useful only if the geothermal system is of the more common hot-water type rather than of the vapor-dominated or steam type, none of which is known to occur in Idaho.

Geochemical thermometers that are useful in describing and evaluating geothermal systems (excluding the sodium-potassium-calcium thermometer) have been summarized by White (1970). Part of his summary is as follows:

"Chemical indicators of subsurface temperatures in hot-water systems"

Indicator	Comments
1) SiO_2 content	Best of indicators; assumes quartz equilibrium at high temperature, with no dilution or precipitation after cooling.
2) Na/K	Generally significant for ratios between 20/1 to 8/1 and for some systems outside these limits, see text.
3) Ca and HCO_3 contents	Qualitatively useful for near-neutral waters. solubility of CaCO_3 inversely related to subsurface temperatures, see text and ELLIS (1970).
4) $\text{Mg}/\text{Mg}/\text{Ca}$	Low values indicate high subsurface temperature, and vice versa.
5) ***	***
6) Na/Ca	High ratios may indicate high temperatures (MAHON, 1970) but not for high-Ca brines; less direct than 3?
7) $\text{Cl}/\text{HCO}_3 + \text{CO}_3$	Highest ratios in related waters indicate highest subsurface temperatures (FOURNIER, TRUESELL, 1970) and vice versa.
8) Cl/F	High ratios may indicate high temperature (MAHON, 1970) but Ca content (as controlled by pH and CO_3^{2-} contents) prevents quantitative application.

9) ***

10) Sinter deposits

Reliable indicator of subsurface temperatures (now or formerly) $> 180^{\circ}\text{C}$.

11) Travertine deposits

Strong indicator of low subsurface temperatures unless bicarbonate waters have contacted limestone after cooling.

The general principles and assumptions on which the use of geochemical thermometers (White, 1970) is based are: (1) the chemical reactions controlling the amount of a chemical constituent taken into solution by hot water are temperature dependent; (2) an adequate supply of these chemical constituents is present in the aquifer; (3) chemical equilibrium has been established between the hot water and the specific aquifer minerals which supply the chemical constituents; (4) hot water from the aquifer flows rapidly to the surface; and (5) the chemical composition of the hot water does not change as it ascends from the aquifer to the surface.

The fact that these principles and assumptions more often than not can not readily be verified in a field situation requires that the concept of geochemical thermometers be applied with caution and in full recognition of the uncertainties involved. With that understanding, geochemical thermometers provide a useful point of departure for reconnaissance screening and provisional evaluation of thermal areas.

Silica Geochemical Thermometer

The silica method of estimating aquifer temperatures (Fournier and Rowe, 1966) appears to be the most accurate and useful proposed to date. Experimental evidence has established that the solubility of silica in water is most commonly a function of temperature and the silica species being dissolved, (fig 1)

Practical use of the silica geochemical thermometer assumes that there is

equilibration of dissolved silica with quartz minerals in high-temperature aquifers and that the equilibrium composition is largely preserved in the silica-bearing thermal waters during their ascent to the surface. White (1970) stated that while equilibrium is generally attained at high aquifer temperatures, silica may precipitate rapidly as waters cool to about 180°C and, therefore, the silica method commonly fails to predict actual aquifer temperatures much above 180°C . The rate of precipitation of silica decreases rapidly as the temperature cools below 180°C .

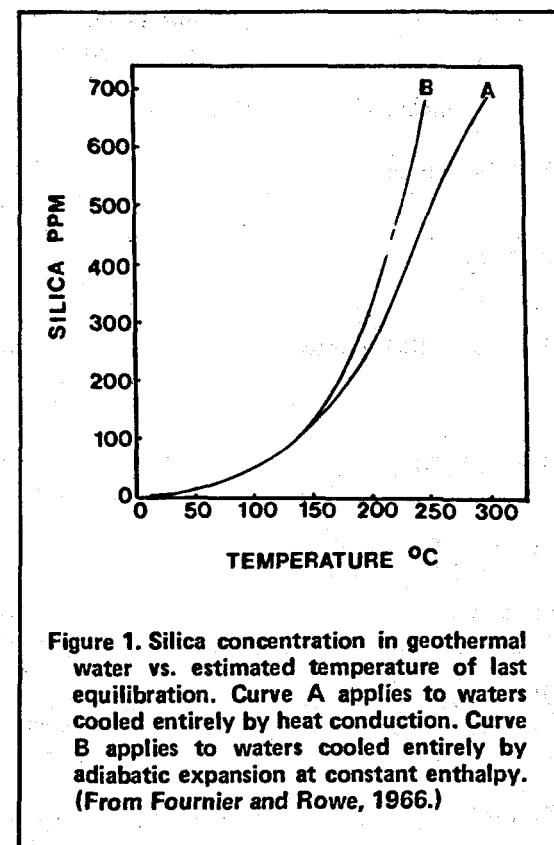


Figure 1. Silica concentration in geothermal water vs. estimated temperature of last equilibration. Curve A applies to waters cooled entirely by heat conduction. Curve B applies to waters cooled entirely by adiabatic expansion at constant enthalpy. (From Fournier and Rowe, 1966.)

White (1970) also cautioned against using the silica geochemical thermometer in acid waters which have a low chloride concentration, because at temperatures near or below 100°C these waters are actively decomposing silicate minerals and thereby releasing highly soluble amorphous SiO_2 . In this case, the basic assumption of equilibration with quartz would be rendered invalid.

The Sodium-Potassium and Sodium-Potassium-Calcium Geochemical Thermometers

The sodium-potassium (Na/K) geochemical thermometer plots the log of the atomic ratios of Na/K against the reciprocal of the absolute temperature. White (1970) stated that ratios are of general significance only in the ratio range between 8/1 and 20/1. He also reported that Na/K temperatures are not significant for most acid waters, although a few acid-sulfate-chloride waters yield reasonable temperatures. Fournier and Truesdell (1973) point out that Ca enters into silicate reactions in competition with Na and K and the amount of Ca in solution is greatly dependent upon carbonate equilibria. Calcium concentration from carbonates decreases as temperature increases, and may increase or decrease as the partial pressure of carbon dioxide increases, depending on pH considerations. Therefore, the Na/K ratio should not be used for purposes of geochemical thermometry when partial pressures of carbon dioxide are large, as higher carbon dioxide partial pressures may permit more Ca to remain in solution and consequently a smaller Na/K ratio. Fournier and

Truesdell (1973) suggest that this ratio should not be used when the $\sqrt{M_{\text{Ca}}/M_{\text{Na}}}$ (square root of molar concentration of calcium/molar concentration of sodium) is greater than 1.

The sodium-potassium-calcium (Na-K-Ca) geochemical thermometer devised by Fournier and Truesdell (1973) is a method of estimating aquifer temperatures based on the molar concentrations of Na, K, and Ca in natural thermal waters. Accumulated evidence suggests that thermal, calcium-rich waters do not give reasonable temperature estimates using Na/K atomic ratios alone, and that the Ca concentration must be given consideration.

Fournier and Truesdell (1973) showed that molar concentrations of Na-K-Ca for most geothermal waters cluster near a straight line when plotted as the function $\log K^* = \log (\text{Na}/\text{K}) + \beta \log (\sqrt{\text{Ca}/\text{Na}})$ versus the reciprocal of the absolute temperature, where β is either 1/3 or 4/3, depending upon whether the waters equilibrated above or below about 100°C and where K^* is an equilibrium constant. For most waters they tested, the Na-K-Ca method gave better results than the Na/K method. It is generally believed that the Na-K-Ca geochemical thermometer will give better results for calcium-rich environments provided calcium carbonate has not been deposited after the water has left the aquifer. Where calcium carbonate has been deposited, the Na-K-Ca geochemical thermometer may give anomalously high aquifer temperatures. Fournier and Truesdell (1973) caution against using the Na-K-Ca geochemical thermometer in acid waters that are low in chloride."

Dilution Effects, the Use of the Geochemical Thermometers and Mixing Models

Dilution effects caused by mixing of thermal with nonthermal waters can be a cause of erroneous temperature estimates. Cool groundwaters containing low silica concentrations that mix with thermal waters rich in silica would effectively lower the silica concentration of the thermal water, and a lower aquifer temperature would be indicated. Generally, the possible effect of both dilution and enrichment of thermal waters on the temperature calculated using any geochemical thermometer must be considered.

Fournier, White and Truesdell (1974) suggested several starting assumptions to apply to the interpretation of chemical data from hot springs and wells where little information on hydrologic conditions is available. They emphasized that these assumptions are not hard, fast rules applicable to every situation. Their recommended procedures are based on: (1) the discharge of the spring or well, and (2) the recorded surface temperature, as outlined below.

	Small Discharge	Large Discharge
Boiling Springs	Assume mostly conductive cooling. Apply chemical indicators assuming little or no steam loss (adiabatic cooling).	Assume steam loss (adiabatic cooling). Assume maximum steam loss, apply geochemical thermometers accordingly.
Springs below boiling	Probably no clearcut interpretation. May be (1) water that has never been very hot, (2) mixed water from different sources at different temperatures, (3) hot water cooled by conduction. Indicated temperatures most likely, minimum.	Assume no conductive cooling. Geochemical thermometers, particularly Na-K-Ca, if within $\pm 25^{\circ}\text{C}$ of measured surface temperature may be suggestive of equilibrium conditions. Higher indicated temperatures suggests a mixed water.

Small discharge was defined to be less than 200 l/min for single isolated spring, and 20 l/min for single spring vents of larger groups.

Fournier and Truesdell (1974) have developed a method of testing thermal waters to determine if mixing may be taking place. They maintain that mixing should be suspect where: (1) regular variations in surface temperatures with chloride, boron, or other nonreactive chemical constituents from several springs of an area are observed, (2) the Na-K-Ca geochemical thermometer indicates nonequilibrium conditions (Na-K-Ca indicated temperatures varies from the observed surface temperature by more than 20°C).

Under ideal conditions, Fournier and Truesdell's mixing models allow prediction of the temperature of the hot water before mixing. The models assume that the enthalpy (heat content - H_c) of the cold water multiplied by the fraction of cold water (X) plus the enthalpy of the hot water (H_h) multiplied by the fraction of the hot water ($1-X$) is equal to the enthalpy of the emerging spring water (H_{spg}). Stated mathematically:

$$(H_c)(X)+(H_h)(1-X)=H_{spg} \quad (1)$$

Similarly,

$$(Si_c)(X)+(Si_h)(1-X)=Si_{spg} \quad (2)$$

Where Si_c is the silica content of cold spring, Si_{spg} is the silica content of the hot spring water and Si_h is the enthalpy value for silica in hot water (table 1- equation 5). Equations 1 and 2 are each solved for the unknown X by simple algebraic rearrangement to give equations 3 and 4.

Fournier and Truesdell's suggested graphical method of solution for mixing model 1, in which the enthalpy of the hot water plus separated steam which heats cold water is the same as the initial enthalpy of hot water before steam separates (no steam loss by system; hence, no evaporative concentration), is as follows:

"1. Assume a series of values of temperature of hot water and using this corresponding enthalpy values listed in table 1 calculate X_t for each one, using equation 3.

$$X_t = \frac{(\text{Enthalpy of hot water}) - (\text{temp of warm spg})}{(\text{Enthalpy of hot water}) - (\text{temp of cold spg})} \quad (3)$$

2. Plot the calculated values of X_t vs. the assumed temperatures from which the hot water enthalpy values were derived. (See fig. 2, curve A for sample plot.)

3. Using a series of silica contents of hot water appropriate for the temperatures listed in table 1 evaluate X_{Si} for each silica content using equation 4.

$$X_{Si} = \frac{(\text{Silica in hot water}) - (\text{Silica in warm spg})}{(\text{Silica in hot water}) - (\text{Silica in cold spg})} \quad (4)$$

4. On the same graph previously used, plot the calculated values of X_{Si} vs. the temperatures for which the silica contents were obtained (see fig. 2, curve B)."

Table 1¹

Enthalpies of liquid water and quartz solubilities at selected temperatures and at pressures appropriate for steam and liquid water to coexist. Enthalpies from Keenan et al. (1969). Quartz solubilities at and below 225°C from Morey et al. (1962); above 225°C from unpublished data of R. O. Fournier.

Temperature °C	Enthalpy cal/gm	Silica ppm
50	50.0	13.5
75	75.0	26.6
100	100.1	48
125	125.4	80
150	151.0	125
175	177.0	185
200	203.6	265
225	230.9	365
250	259.2	486
275	289.0	614
300	321.0	692

¹Table from Fournier and Truesdell, 1974.

Table 2 gives the calculated X_t and X_{Si} values at selected temperatures and silica concentrations for this mixing model from sampled springs and wells in the northern Cache Valley area.

The intersection of the two curves represent the percent of cold water mixing with the hot (read directly below intersection point on the horizontal axis of the graph) and the temperature of the hot water component before mixing (read on the vertical axis of the graph directly to the left of the intersection point).

Their solution for mixing model 2, in which the enthalpy of hot water in the zone of mixing is less than the enthalpy of the hot water at depth, due to escape of steam during ascent is as follows:

1. Use the atmospheric boiling temperature for the value of H_h in equation 2 and calculate the corresponding value of X.
2. Use that value of X in equation 3 to estimate the residual silica content of the hot water at t_s .
3. Use the calculated residual silica content and curve A of Fournier and Rowe (1966, fig. 5) to estimate the original subsurface temperature before separation of steam. Curve A of Fournier and Rowe is roughly approximated by the equation

$$-\log C = \frac{1522}{t_{\circ}C - 273} - 5.75 \quad (5)$$

where C is the silica concentration, and t is temperature in degrees Celsius."

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FIGURE 2. Fraction of cold water relative to temperature for well 15S-39E-17bcd1.

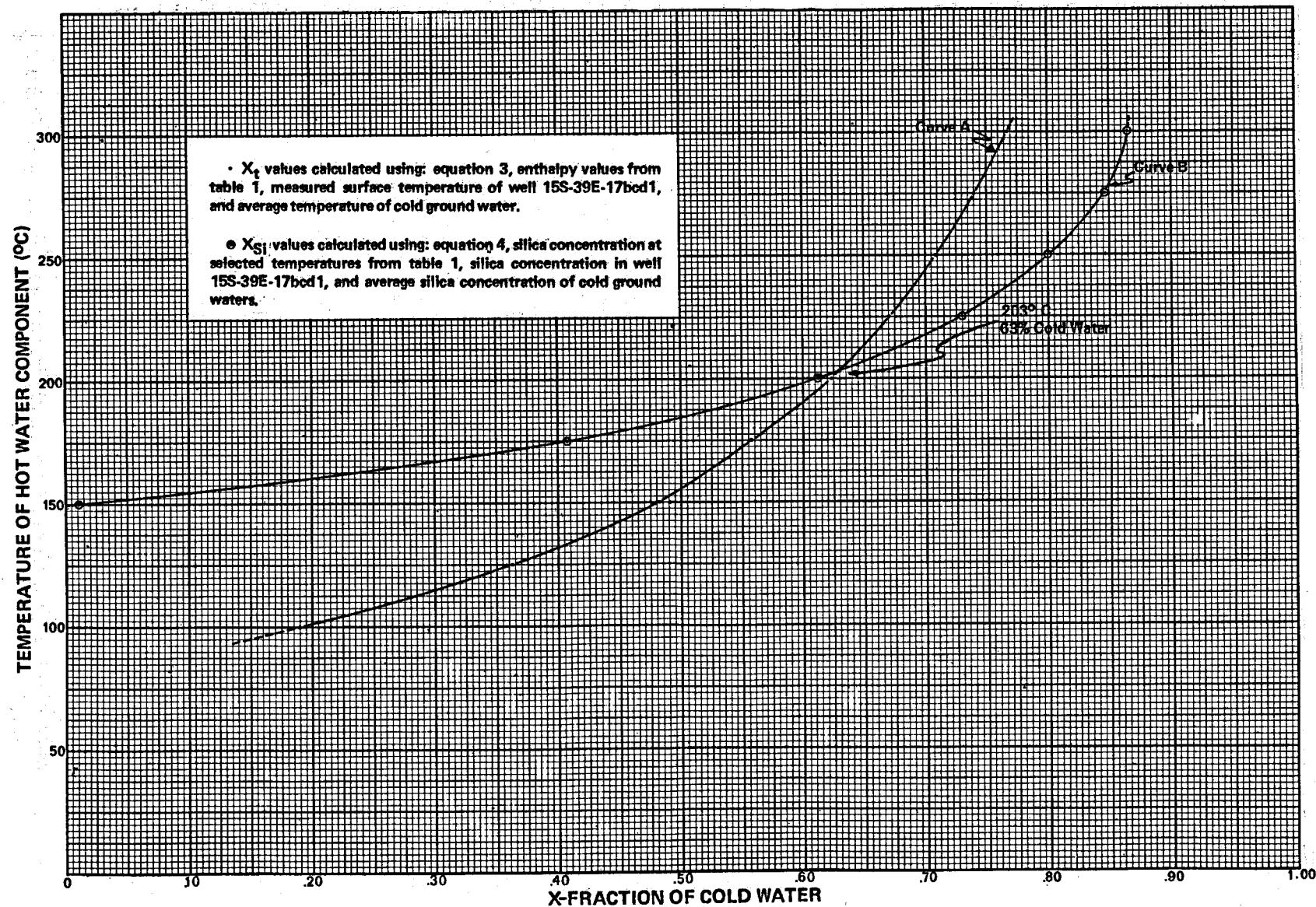


TABLE 2
 X_t AND X_{Si} VALUES AT SPECIFIED TEMPERATURES AND SILICA CONCENTRATIONS
FOR THERMAL WATERS OF THE NORTHERN CACHE VALLEY AREA
(Temperatures $^{\circ}$ C)

Spring No. 12S-41E-31cac1S

Surface temperature = 66°
 Silica = 60 mg/l
 Background silica = 35 mg/l
 Background temperature = 12°
 Boiling temperature = 95°

T	X_t	X_{Si}
75	0.143	-
100	.387	-
125	.524	0.479
150	.612	.722
175	.673	.833
200	.718	.891
225	.753	.924
250	.782	.944
275	.805	.957
300	.825	.962

Temperature of unmixed hot water = 132° .
 Percent of cold water = 54.

Spring No. 12S-41E-31cdb1S

Surface temperature = 61°
 Silica = 64 mg/l
 Background silica = 35 mg/l
 Background temperature = 12°
 Boiling temperature = 95°

T	X_t	X_{Si}
75	0.222	-
100	.444	-
125	.568	0.396
150	.647	.678
175	.703	.807
200	.744	.874
225	.776	.912
250	.802	.935
275	.823	.950
300	.841	.956

Temperature of unmixed hot water = 146° .
 Percent of cold water = 63.

Spring No. 12S-41E-31cca1S

Surface temperature = 56°
 Silica = 63 mg/l
 Background silica = 35 mg/l
 Background temperature = 12°
 Boiling temperature = 95°

T	X_t	X_{Si}
75	0.302	-
100	.501	-
125	.612	0.417
150	.683	.689
175	.733	.813
200	.770	.878
225	.799	.915
250	.822	.937
275	.841	.952
300	.858	.957

Temperature of unmixed hot water = 149° .
 Percent of cold water = 68.

Spring No. 12S-40E-36acd1S

Surface temperature = 35°
 Silica = 54 mg/l
 Background silica = 35 mg/l
 Background temperature = 12°
 Boiling temperature = 95°

T	X_t	X_{Si}
75	0.635	-
100	.739	-
125	.797	0.604
150	.835	.789
175	.861	.873
200	.880	.917
225	.895	.942
250	.907	.957
275	.917	.967
300	.926	.971

Temperature of unmixed hot water = 169° .
 Percent of cold water = 85.

Spring No. 12S-40E-36aca1S

Surface temperature = 33°
 Silica = 52 mg/l
 Background silica = 35 mg/l
 Background temperature = 12°
 Boiling temperature = 95°

T	X_t	X_{Si}
75	0.667	-
100	.762	-
125	.815	0.646
150	.849	.811
175	.873	.887
200	.890	.926
225	.904	.948
250	.915	.962
275	.924	.971
300	.932	.974

Temperature of unmixed hot water = 168° .
 Percent of cold water = 86.

Spring No. 13S-41E-7aca1S

Surface temperature = 78°
 Silica = 84 mg/l
 Background silica = 35 mg/l
 Background temperature = 12°
 Boiling temperature = 95°

T	X_t	X_{Si}
75	-	-
100	0.251	-
125	.418	-
150	.525	0.456
175	.600	.673
200	.656	.787
225	.698	.852
250	.733	.890
275	.762	.915
300	.786	.925

Temperature of unmixed hot water = 162° .
 Percent of cold water = 56.

Table 2. X_t and X_{Si} Values at Specified Temperatures and Silica Concentrations for Thermal Waters of the Northern Cache Valley Area (Continued)
(Temperatures $^{\circ}$ C)

Spring No. 13S-41E-7aca2S

Surface temperature = 72°
Silica = 85 mg/l
Background silica = 35 mg/l
Background temperature = 12°
Boiling temperature = 95°

T	X_t	X_{Si}
75	0.048	
100	.319	
125	.471	
150	.568	0.444
175	.636	.667
200	.687	.783
225	.726	.848
250	.757	.888
275	.783	.914
300	.806	.924

Temperature of unmixed hot water = 170° .
Percent of cold water = 62.

Spring No. 13S-41E-7aca3S

Surface temperature = 60°
Silica = 86 mg/l
Background silica = 35 mg/l
Background temperature = 12°
Boiling temperature = 95°

T	X_t	X_{Si}
75	0.238	
100	.455	
125	.577	
150	.655	0.433
175	.709	.660
200	.749	.778
225	.781	.845
250	.806	.886
275	.827	.912
300	.845	.922

Temperature of unmixed hot water = 190° .
Percent of cold water = 73.

Well No. 14S-39E-36ada1

Surface temperature = 40°
Silica = 89 mg/l
Background silica = 35 mg/l
Background temperature = 12°
Boiling temperature = 95°

T	X_t	X_{Si}
75	0.556	
100	.682	
125	.753	
150	.799	0.400
175	.830	.640
200	.854	.765
225	.872	.836
250	.887	.879
275	.899	.907
300	.909	.918

Temperature of unmixed hot water = 262° .
Percent of cold water = 89.

Spring No. 15S-39E-8bdc1S

Surface temperature = 82°
Silica = 109 mg/l
Background silica = 35 mg/l
Background temperature = 12°
Boiling temperature = 95°

T	X_t	X_{Si}
75		
100	0.205	
125	.383	
150	.496	0.178
175	.576	.507
200	.635	.678
225	.680	.776
250	.717	.834
275	.747	.872
300	.773	.887

Temperature of unmixed hot water = 190° .
Percent of cold water = 61.

Spring No. 15S-39E-8bdc2S

Surface temperature = 43°
Silica = 107 mg/l
Background silica = 35 mg/l
Background temperature = 12°
Boiling temperature = 95°

T	X_t	X_{Si}
75	0.508	
100	.648	
125	.727	
150	.777	0.200
175	.812	.520
200	.838	.687
225	.858	.782
250	.875	.839
275	.888	.876
300	.900	.890

Hot water temperature calculation not possible.

Spring No. 15S-39E-8bdc3S

Surface temperature = 81°
Silica = 109 mg/l
Background silica = 35 mg/l
Background temperature = 12°
Boiling temperature = 95°

T	X_t	X_{Si}
75		
100	0.217	
125	.392	
150	.504	0.178
175	.582	.507
200	.640	.678
225	.685	.776
250	.721	.834
275	.751	.872
300	.777	.887

Temperature of unmixed hot water = 191° .
Percent of cold water = 62.

Well No. 15S-39E-17bcd1

Surface temperature = 84°
 Silica = 124 mg/l
 Background silica = 35 mg/l
 Background temperature = 12°
 Boiling temperature = 95°

T	X _t	X _{Si}
75		
100	0.183	
125	.365	
150	.482	0.011
175	.564	.407
200	.624	.613
225	.671	.730
250	.709	.800
275	.740	.846
300	.767	.865

Temperature of unmixed hot water = 203°
 Percent of cold water = 63.

Spring No. 15S-39E-17bcd1S

Surface temperature = 69°
 Silica = 126 mg/l
 Background silica = 35 mg/l
 Background temperature = 12°
 Boiling temperature = 95°

T	X _t	X _{Si}
75	0.095	
100	.353	
125	.497	
150	.590	
175	.655	0.393
200	.703	.604
225	.740	.724
250	.769	.796
275	.794	.843
300	.816	.861

Temperature of unmixed hot water = 234°.
 Percent of cold water = 75.

Spring No. 15S-39E-8bcd4S

Surface temperature = 84°
 Silica = 97 mg/l
 Background silica = 35 mg/l
 Background temperature = 12°
 Boiling temperature = 95°

T	X _t	X _{Si}
75		
100	0.183	
125	.365	
150	.482	0.311
175	.564	.587
200	.624	.730
225	.671	.812
250	.709	.861
275	.740	.893
300	.767	.906

Temperature of unmixed hot water = 172°.
 Percent of cold water = 55.

Spring No. 15S-39E-17acc1S

Surface temperature = 73°
 Silica = 126 mg/l
 Background silica = 35 mg/l
 Background temperature = 12°
 Boiling temperature = 95°

T	X _t	X _{Si}
75	0.032	
100	.308	
125	.462	
150	.561	
175	.630	0.393
200	.682	.604
225	.721	.724
250	.753	.796
275	.780	.843
300	.803	.861

Temperature of unmixed hot water = 224°.
 Percent of cold water = 71.

Well No. 16S-38E-24acd1

Surface temperature = 23°
 Silica = 74 mg/l
 Background silica = 35 mg/l
 Background temperature = 12°
 Boiling temperature = 95°

T	X _t	X _{Si}
75	0.825	
100	.875	
125	.903	0.188
150	.921	.567
175	.933	.740
200	.943	.830
225	.950	.882
250	.956	.913
275	.960	.933
300	.964	.941

Hot water temperature calculation not possible.

