Research Technical Completion Report

GEOTHERMAL EVALUATION OF THE THRUST ZONE IN SOUTHEASTERN IDAHO

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ABSTRACT

This report presents the initial results of a regional study of geothermal flow systems in the thrust zone of Idaho and Wyoming. The study involved analysis of thermal and non-thermal ground water flow systems based upon hydrogeologic and hydrochemical data collection and interpretation. Particular emphasis was placed on analyzing the role that the thrust zones play in controlling the movement of thermal and non-thermal fluids.

The geology of the area is complex; thrust faulting, normal faulting and tear faulting are all important in controlling water movement through the thick sequence of mostly sedimentary strata. The thrust zones are not believed to create layers of either significantly higher or lower hydraulic conductivity because only thin zones of breccia were found; most movement probably occurred along bedding planes. Thrust zones are identified in deep drilling logs primarily by a repeat of section.

Thermal discharges within the study area are located along strictural features with the hottest water issuing from deep normal faults associated with the Cache Valley graben, the Wasatch Front and the Swan-Grand Valley graben. Thermal springs associated with faulting in the Meade thrust block have temperatures generally less than 25°C indicating shallow ground water flow systems. The hottest thermal discharges have Na and Cl as the dominant ions while cooler thermal discharges in the center of the study area are characterized by Ca/Mg and HCO as the dominat ions.

Temperature data from most of the deep test wells in the study area do not indicate a high geothermal gradient; however, four test wells located near the center of the study area away from major normal faults do have higher than normal bottom hole temperatures indicating a possible geothermal system.

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CHAPTER I

INTRODUCTION

Statement of the Problem

The thrust zone of southeastern Idaho and western Wyoming has potential for geothermal development to compliment oil and gas and phosphate resources. Evidence of the geothermal resource includes warm springs, warm water from shallow wells and reports of hot water at depth in oil and gas test holes. The geology of the area is complex; thrust faulting, normal faulting and tear faulting are important in controlling water movement through the thick sequence of mostly sedimentary strata.

This report presents the initial results of a regional study of geothermal flow systems in the thrust zone of Idaho and Wyoming (Figure I-1). The study involves analysis of thermal and non-thermal ground water flow systems based upon hydrogeologic and hydrochemical data collection and interpretation. Particular emphasis was placed on analyzing the role that the thrust zones play in controlling the movement of thermal and non-thermal fluids.

Purpose and Objectives

The purpose of this research is to utilize the sciences of hydrogeology, hydrochemistry and structural geology to evaluate the geothermal system believed present in the thrust belt of southeastern Idaho. The general objective of this project is to provide a reconnaissance

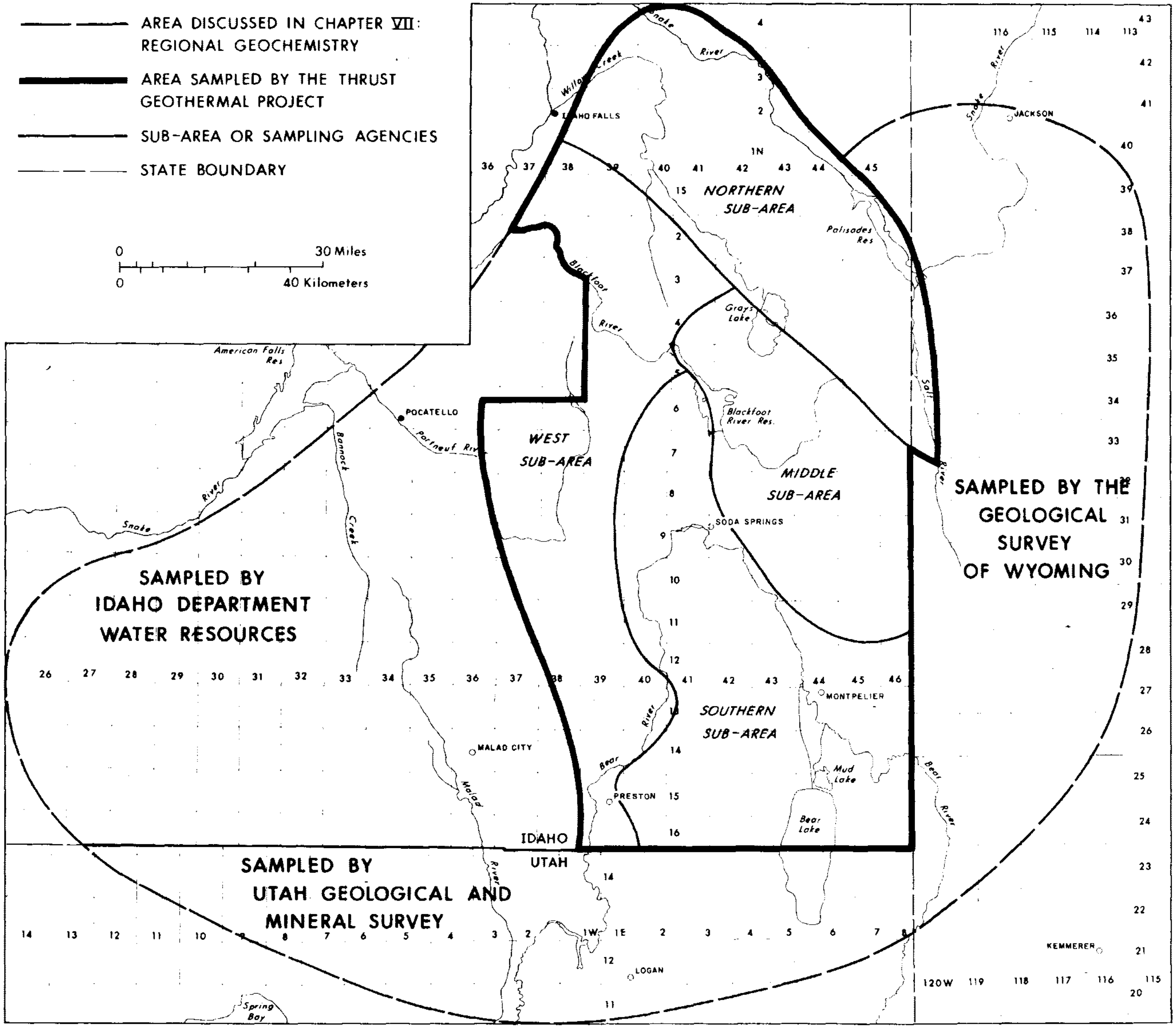


Figure I-1. Data sources and subareas.

evaluation of the hydrogeologic controls for the occurrence and movement of thermal ground water in the thrust belt of southeastern Idaho.

The specific objectives are given below:

1) Identify the structural framework of the thrust belt and the physical characteristics of the thrust zones.
2) Inventory and analyze the thermal and non-thermal ground water discharges controlled by thrust related structural features.
3) Analyze the available thermal and lithologic data from deep test holes drilled in the thrust belt in southeastern Idaho and western Wyoming.
4) Combine the above results into a reconnaissance evaluation of the hydrogeologic controls for the geothermal system underlying the general thrust zone.

Method of Study

This research project was undertaken by the College of Mines and Earth Resources at the University of Idaho in connection with the graduate programs in hydrology and geology. The project was divided into subprojects forming the master's research topics for four M. S. students in hydrology and one M. S. student in geology. In addition, one Ph. D. student in geology worked partially on this project and partially on a project funded through the Idaho Mining and Minerals Resources Research Institute. All but the master's student in geology were under the direct supervision of Dr. Dale R. Ralston, Associate Professor of Hydrogeology at the University of Idaho. The master's student in geology was jointly directed by Dr. Ralston and Dr. R. R. Reid, Professor of Geology at the University of Idaho. The preliminary results of the individual subprojects are presented as chapters within this report. The information presented is only an initial evaluation and interpretation of the research results. Three of the student theses should be completed by August 1981 with the remainder of the theses completed by December of 1981.

Three of the subprojects involved regional reconnaissance studies of thermal and non-thermal flow systems within three portions of the thrust area in Idaho and Wyoming (Figure I-1). Field work for these subprojects involved location, measurement, and sampling of ground water discharges that appeared to be controlled by structural features. Particular emphasis was placed on structural features associated with the thrust zones. Water samples were collected following EPA procedures and analyzed for selected chemical constituents. The results from these investigations are reported in Chapters III, IV, and V. The M. S. student in geology investigated the physical characteristics of the thrust zones associated with the Meade thrust block. Emphasis was placed on analysis of the degree and form of fracturing associated with the thrusting activity. The preliminary results of this investigation are included in Chapter II. One M. S. student examined the chemistry of geothermal flow systems on a regional basis bounded by Raft River on the east, northern Utah on the south, western Wyoming on the east and the Snake River on the north. His analysis included data collected by the other field investigators plus additional sites not covered as part of their studies. The preliminary results of this investigation are presented in Chapter VII. The last M. S. student evaluated data from deep drill holes including geological, geophysical, and temperature information. Analysis of these data provide important insights on flow system control by thrust faulting. This information is presented in Chapter VI of the report. The summary and preliminary conclusions of the study are presented in Chapter VIII.

Previous Investigations

Previous investigations of importance to this research effort are found in three different fields: geology, hydrology and geothermal. The geology of the thrust belt has been investigated by a number of individuals. Mansfield (1927) prepared an extensive report on the geology of the overthrust zone. Specific 7.5 and 15 minute quad areas were mapped in the 1950-1970 period by various USGS geologists (Cressman, 1964; Armstrong, 1969; Gulbandsen and others, 1956; and others). Papers by Armstrong and Cressman (1963), Eardly (1967), Rubey (1955) and Royse, Warner and Reese (1975) presented structural interpretations of the thrust zone. Maybe and Oriel (1970) conducted regional geophysical surveys of the southeast Idaho portion of the thrust area.

The ground water hydrology of the thrust zone has been the subject of major research effort at the University of Idaho. Ralston and others (1977) and Ralston and others (1980) reported on the investigation of ground water-surface water systems near existing or proposed phosphate mines. These two research reports summarize the findings from two Ph. D. dissertations and six master's theses. Dion (1969, 1974) investigated the ground water hydrology in the Bear River and Blackfoot Reservoir areas as part of a cooperative State of Idaho-U. S. Geological

Survey effort. An Environmental Impact Statement on Phosphate Mining (USDI, 1976) presented a general overview of the hydrology of the western phosphate field.

Three geothermal reports have been prepared that are concerned, at least in part, with the thrust area. All three reports were published by the Idaho Department of Water Resources as part of their series on the geothermal potential within the State. The study areas were the Cache Valley area, the Blackfoot Reservoir area, and as part of a statewide study (Mitchell, 1976a; Mitchell, 1976b; Mitchell, Johnson and Anderson, 1980).

Information from all of the above reports plus additional information on ground water flow systems, chemistry of geothermal and non-geothermal systems and structural geology were analyzed as part of the analysis of the geothermal potential of the thrust area.

CHAPTER II

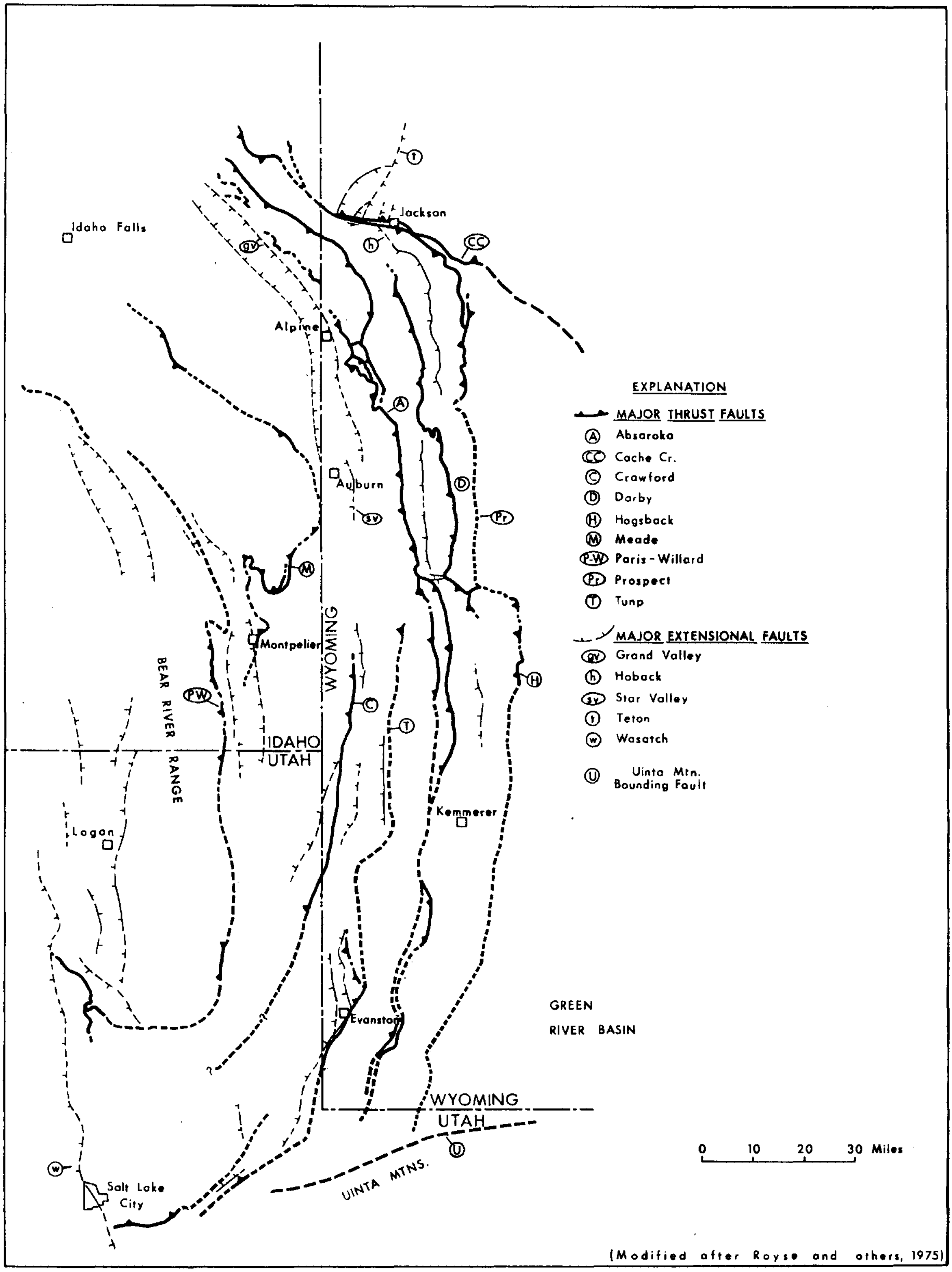
GEOLOGY OF THE THRUST ZONE

Introduction

The purpose of this chapter is to provide a brief summary of the geologic history of the thrust belt in Idaho, Wyoming and Utah and to present the preliminary results of the geologic investigation of the thrust zones.

Geologic History

The name "overthrust belt" has been applied by geologists, and more recently the general public, to that part of the Cordilleran Mountain system which lies in western Wyoming, southeastern Idaho and northern Utah (Figure II-1). This is part of a major system that may be traced from Mexico to Canada. The overthrust belt extends in an arcuate pattern from the Snake River Plain in the vicinity of Idaho Falls, Idaho, to the vicinity of Salt Lake City, Utah, a distance of some 320 kilometers. The east-west extent of the overthrust belt is less readily defined. The eastern margin is the Darby-Hogsback fault trace on the western edge of the Green River Basin in Wyoming. The western boundary lies well to the west of the trace of the Paris-Willard fault system and west of outcrops of Precambrian age rocks near Pocatello, Idaho. At present the western edge or root zone is poorly understood (Blackstone, 1977).



(Modified after Royse and others, 1975)

Figure II-1. Generalized structural map of the overthrust belt in southeastern Idaho, western Wyoming and northern Utah.

Geologic development of the overthrust belt has occurred in three major stages: 1) deposition in a miogeosyncline, 2) development of northward-trending folds and thrust faults, and 3) development of block faults that produced horst ranges and graben valleys. An excellent description of these stages is given by Armstrong and Oriel (1965). To maintain consistency in this report, their measurements are converted to metric units.

> During Paleozoic time about 20 km (kilometers) of marine sediments, mostly limestone and dolomite, were deposited in a miogeosyncline and about 2 km of mixed marine sediments were deposited on the shelf to the east... Starting in Mississippian time, the belt between shelf and miogeosyncline, where thicknesses increase markedly, shifted progressively eastward. During Mesozoic time about 11 km of marine and continental sediments were deposited in the western part of the region and about 4.5 km in the eastern part,... In late Triassic a belt on the west rose and the miogeosyncline started to break up. (Armstrong and Oriel, 1965, p. 1847).

The break up or distruction of the miogeosyncline began the second stage in the geologic development of the overthrust belt. The major faults in the overthrust belt are shown on Figure II-1.

> The second stage, which overlapped the first, produced folds overturned toward the east and thrust faults dipping gently west in a zone, convex to the east, 322 km long and 96 km wide. Stratigraphic throw on many larger faults is about 7 km; horizontal displacement is at least 16 to 24 km. Lack of metamorphism and mylonite along the faults is striking. From west to east, the thrust faults cut progressively younger beds,... Thrusting started in the west in latest Jurassic and ended in the east perhaps as late as early Eocene time;... (Armstrong and Oriel, 1965, p. 1847).

Block faulting is the third stage in the development of the overthrust belt. The easing of compressional forces resulted in the formation of major normal faults in the area. Faulting started in Eocene time and has continued to the Recent (Armstrong and Oriel, 1965). Block faulting produced major horst ranges and graben valleys forming the present topography. The major normal faults in the area are shown on Figure II-1.

The above is a simplified description of the complex geologic history of the overthrust belt. A typical diagrammatic cross-section of the overthrust belt is presented in Figure II-2. This diagram illustrates the complex structure of the overthrust belt.

Characteristics of the Meade Thrust

Introduction

The Meade thrust lies within the Aspen and Preuss ranges of southeastern Idaho (Figure II-1). The elevation of the area ranges between 1870 meters (m) and 3030 m.

The purpose of this portion of the research was to determine the characteristics and controls of the Idaho-Wyoming thrust belt as they are related to any geothermal systems which may lie beneath the thrust plates. The general objective of this research is to determine how the thrust zones control flow systems. The objective is being met by studying the petrologic characteristics of the thrust features, such as fault gouge, fault breccias and interbedded gouge.

Field work was carried out during a 60-day period in the summer and fall of 1980. Rock samples were collected from over 150 localities; from these, a total of 76 thin sections were made. Structural information is being evaluated with the use of the Kaliki-Von Frese computer program.

Porosity and permeability were measured in the laboratory using the method of Teodorovich. In this method empirical values are assigned

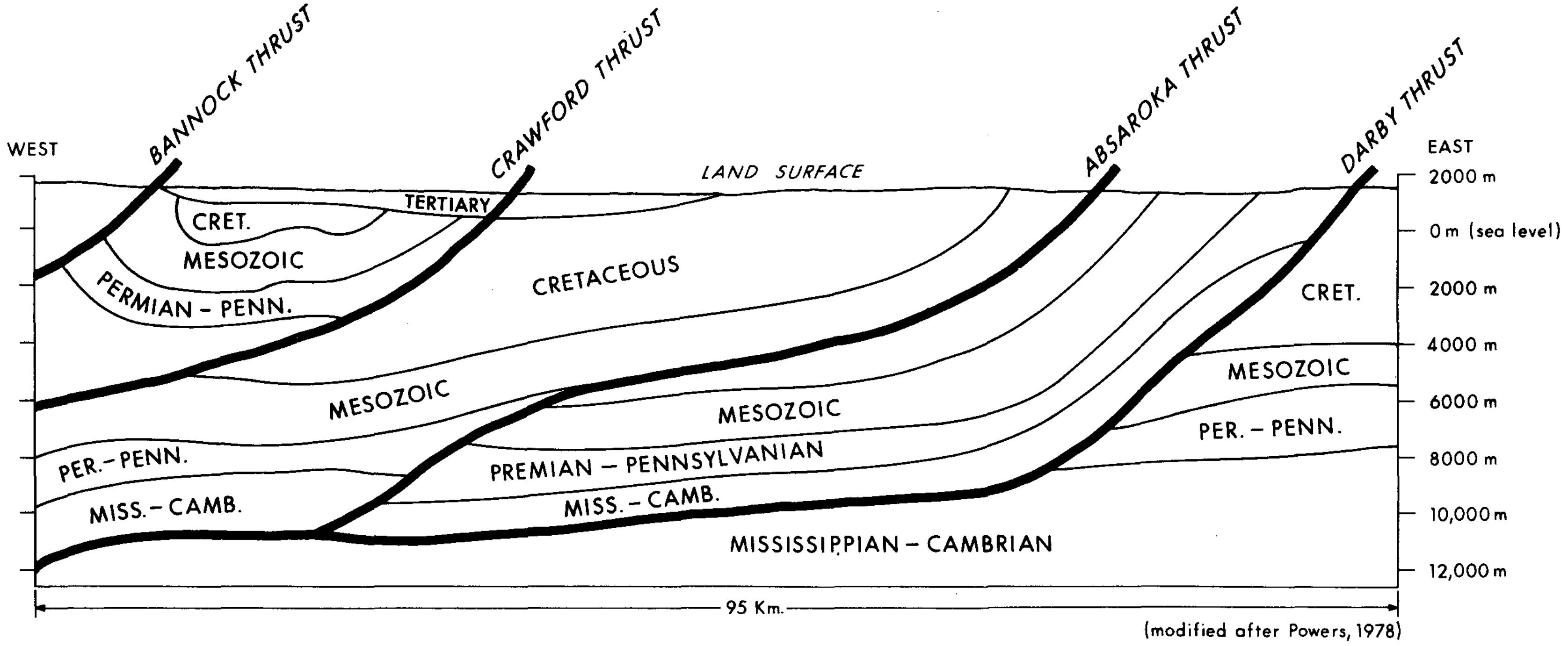


Figure II-2. Typical diagrammatic east-west cross section of the overthrust belt.

for the type, shape and amount of pore space in a thin section. In order to obtain a more valid statistical estimate of pore space, thin sections were viewed under cathodoluminesence, which scans only the top few microns of the thin section.

General Stratigraphy

The rocks within the Meade thrust plate range in age from Mississippian to Recent (Table II-1). Sediments of Mississippian to Jurassic age are predominately limestone, dolomite, shale and quartz sandstone. The sequence of lithologies from Mississippian to Cretaceous is conformable and is approximately 7300 m thick. Tertiary rocks are fluvial and lacustrine in nature and are found with varying thicknesses in the region. Small patches of Tertiary basalt can be found at several sites. No lithologies older than Mississippian can be found in the area. The Meade thrust has been dated by Cressman (1964) as Early-Cretaceous to Eocene.

The oldest rocks in the area have been previously mapped as the Madison limestone and the Brazer limestone. Current nomenclature calls for the Madison to be called the Lodgepole limestone. The Brazer was reclassified and labeled as part of the Mission Canyon limestone. Recent work by Sando and Sandberg now shows that the Mission Canyon label is not suitable and they are revising the formation name (Sando and Sandberg, personnel communication, 1980). The Lodgepole limestone is medium to dark in color, fine-grained, cherty and bioclastic (Crinoidal). The Mission Canyon limestone is medium to light gray in color, with interbedded siltstone and sandstone.

Table II-1. Generalized stratigraphy of southeast Idaho (after Cressman, 1964 and Armstrong, 1953).

System	Series	Group, Formation	Thickness (m)
Tertiary	Pliocene	Salt Lake Formation	920+
	Eocene	Wasatch Formation	not known
Cretaceous		Gannett Group	1500
Jurassic	Upper Jurassic	Stump Sandstone	100-150
		Preuss Sandstone	525±
	Middle Jurassic	Twin Creek Limestone	734-1410+
		Nugget Sandstone	275-520
Triassic		Ankareh Formation	60-120 +
	Lower Triassic	Thaynes Formation	325-1125
		Dinwoody Formation	425-550
Permian		Phosphoria Formation	170
Pennsylvanian		Wells Formation	425-580
Mississippian		Mission Canyon Limestone	450-600
		Lodgepole Limestone	200-300
Devonian	Upper Devonian	Three Forks Limestone	55±
	Middle Devonian	Jefferson Dolomite	285±
Silurian	Middle Silurian	Laketown Dolomite	390
Ordivician	Upper Ordivician	Fish Haven Dolomite	150
	Lower Ordivician	Swan Peak Quartzite	180±
		Garden City Limestone	420±
Cambrian	Upper Cambrian	St. Charles Limestone	290±
	Middle Cambrian	Nounan Dolomite	335±
		Bloomington Formation	215±
		Blacksmith Formation	320±
		Ute Limestone	215±
		Langston Formation	100±
	Lower Cambrian	Brigham Quartzite	1200±

The Pennsylvanian system is represented by the Wells formation. The Wells formation can be divided into a siliceous limestone unit, a sandy unit and a cherty limestone unit. The Wells formation is 730 m thick in the Georgetown Canyon area.

The Grandeur tongue of the Park City formation and the Phosphoria formation are of Permian age. The Grandeur tongue of the Park City formation is 23 m thick and is mostly dolomite with beds of chert. The Phosphoria formation has three members, the cherty shale, the Rex Chert and the Meade Peak phosphatic shale. Total thickness of the Phosphoria formation is approximately 140 m.

Triassic rocks in the area include the Dinwoody formation, the Woodside shale, the Thaynes formation and the Ankareh formation. The Dinwoody formation is composed of limestone, shale and siltstones. It is 490 m thick. The Woodside shale is a gray shale with interbedded limestone. The Thaynes formation is between 760 and 980 m thick. It is composed of sandstones, limestones, argillaceous and silty limestones. The Ankareh formation is predominately a red shale sandstone unit. It is approximately 270 m thick.

Jurassic rocks include the Nugget sandstone, the Twin Creek limestone and the Stump and Preuss sandstones The Nugget sandstone is a massive red sandstone with interbedded shale and limestone. The Nugget sandstone varies in thickness between 270 and 520 m. The Twin Creek limestone is a gray, shaly limestone to a brown sandy limestone. The thickness varies between 910 and 1520 m. The Preuss sandstone is a fine-grained, red, calcareous sandstone, 520 m in thickness. The Stump sandstone is a glauconitic, calcareous sandstone, interbedded with minor limestone and is between 90 and 150 m thick.

The Cretaceous system is represented by a number of lithologies included in the Gannett group. These are the Draney limestone, the Ephraim conglomerate, the Peterson limestone and the Belcher conglomerate. These units total about 1520 m in thickness.

Tertiary units include the Wasatch and Salt Lake formations. The Wasatch is a red conglomeritic unit of unknown thickness. The Salt Lake formation is a tuffaceous sandstone, siltstone, conglomeritic unit.

Petrology of Thrust Features

Fault Breccia. As noted by Cressman (1964) the trace of the thrust fault is marked by a breccia zone wherever Mississippian rocks are found in the upper plate. This breccia zone is seen in Georgetown Canyon near Church Hollow (Figure II-3). It is also found to the east of the Left Fork of Twin Creek and in Big Canyon, north of Georgetown and along the Star Valley thrust near Freedom, Wyoming. The breccia is yellow-red to gray in color, and variable in thickness, possibly up to 10 m thick. The breccia is vuggy and contains boxworks in places.

Cressman (1964) considered the breccia to be one unit, totally comprised of fault breccia. Petrographic examination of the breccia from the Meade block shows that it can be divided into three types: 1) a carbonate (limestone) unit, 2) a carbonate-clastic unit, and 3) a clastic unit. The carbonate unit (Type 1) can be described as a gray, non-permeable breccia. The clasts in this unit are angular to sub-rounded. Cathodoluminesence shows that the cement in this type is of one generation. The carbonate-clastic unity (Type 2) is comprised of two types of clasts. One is a grayish limestone and the other is a green to yellow clastic/carbonate. Cathodoluminesence shows that the cement in the carbonate portion is one

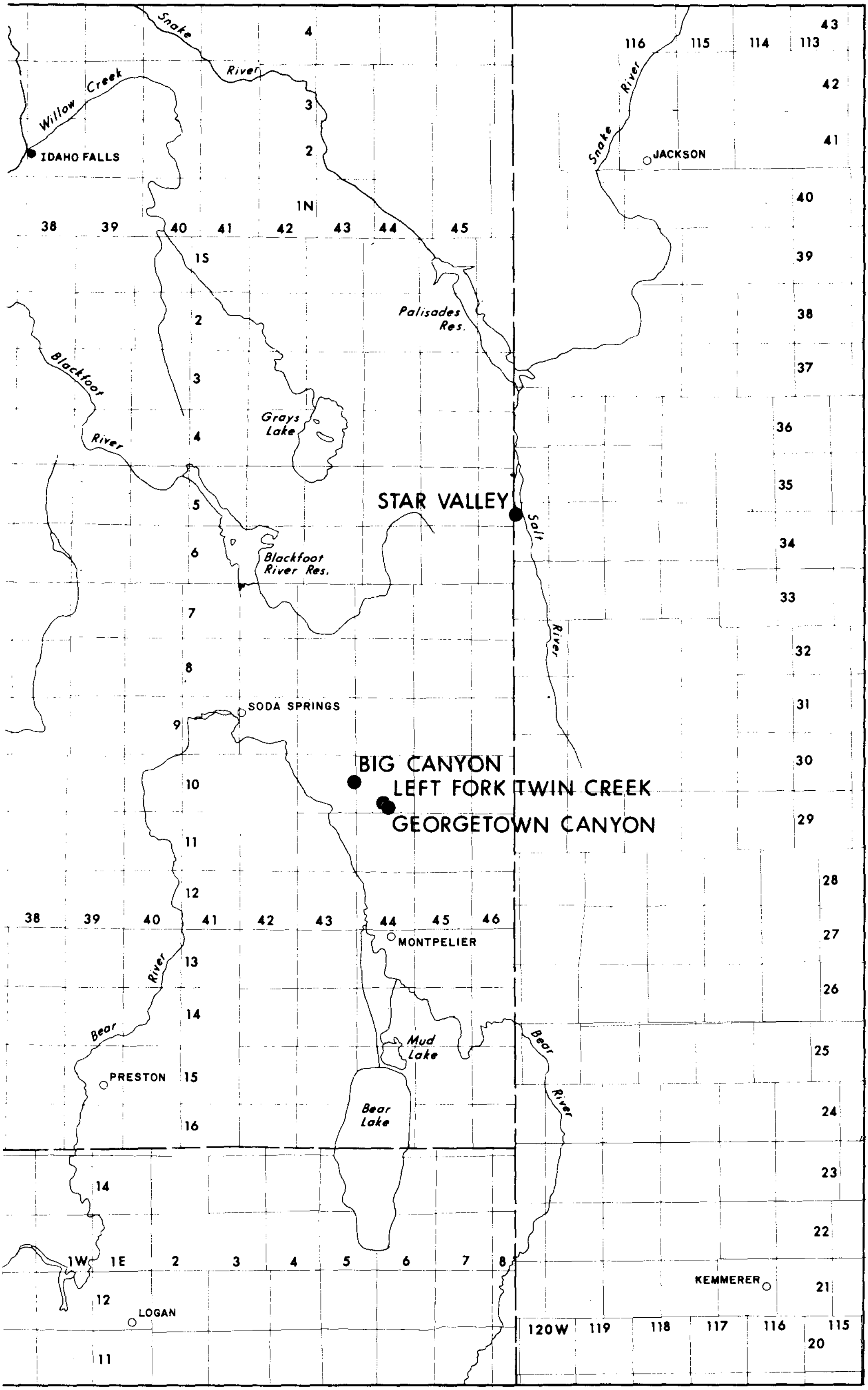


Figure II-3. Fault breccia sites in southeastern Idaho generation. The cement in the clastic/carbonate section is multi-generation. The clasts of both types are rounded. Type 3 is composed almost entirely of clastic grains that are rounded and have multi-generational cement.

Note that in the above discussion of breccias, the carbonate unit involved is predominately the Lodgepole limestone and this is almost exclusively limestone. While using the term clastic to describe one type of clasts, it should be pointed out that the "Clastic" units involved are the Twin Creek limestone and the Wells formation, which may have calcareous beds. These units are described as clastic because of the high amount of detrital quartz visible under cathodoluminesence.

Fault Gouge. Fault gouge is found only in one section in Georgetown Canyon (Figure II-3). The gouge is found within the Wells formation, above the chert layer. The gouge ranges in thickness between a few centimeters to a maximum of one meter. The gouge is black in color and is very friable. In thin section, the gouge is 99 percent chert. The gouge exhibits no definable character and may be termed an ultra-mylonite.

Interbedded Gouge. Interbedded gouge occurs in limited area, predominately in the Twin Creek limestone along Crow Creek (Figure II-3). It is difficult to recognize in the field. The gouge is characterized by micro-fractures along bedding planes in an otherwise massively bedded unit.

Porosity and Permeability. The laboratory measurements of porosity and permeability are preliminary results and do not take into account the amount of fracturing present in the lithology. Type 1 (carbonate) breccias generally have low porosity (1-5%) and low permeabilities (1-50 millidarcies) (md). Type 2 breccias have intermediate porosities (2-10%) and intermediate permeabilities (10-500 md). Type 3 breccias (clastic) have the highest porosities (5-17%) and the highest permeabilities (500-17,000 md).

All of the various lithologies have extremely low primary porosities (0-3%) and permeabilities (0-10 md). However, formations such as the Wells or Dinwoody may be highly jointed and fractured and thus may transmit a considerable amount of water.

It was not possible to measure the porosity of the gouge due to the nature of the material. In the field it appeared to be highly porous.

Interpretation of Results

Cressman (1964) states that the Meade thust started as a bedding plane thrust within or at the base of the Madison (Lodgepole) limestone. The thrust followed this horizon for 27 km before cutting up diagonally through Mississippian to Jurassic sediments before settling in as a bedding plane thrust again, now in the Jurassic Twin Creek formation. Gretener (1979) notes that thrust faults tend to linger in incompetent strata and step through competent strata at relatively steep angles. The Meade thrust fault seems to be no different in this respect.

The thrust deformation features were formed in the brittle field under lower pore pressure. All the thrust features occurred when the thrust was stepping up. Because brittle deformation tends to create a rock with high permeability and porosity, the fault breccias have the highest porosity and permeability of the samples measured. Ductile deformation tends to leave a dense rock. It is likely that this is the condition that existed for much of the time thrusting occurred.

In conclusion, because of the limited extent of thrust related features and because of their relatively high porosities and permeabilities, it is not likely that the thrusting within the Meade plate has created a barrier to any flow systems. The thrust may, however, be regarded as a secondary control in preferentially positioning lithologies with high permeability against less permeable lithologies.

CHAPTER III

HYDROGEOLOGIC RECONNAISSANCE OF THE NORTHERN SUBAREA

Introduction

This portion of the study is a hydrogeologic reconnaissance of thermal and non-thermal ground water flow systems in the northern portion of the project area (Figures I-1 and III-1). The northern subarea includes approximately 3800 square kilometers and is located predominantly in Bonneville County, with smaller portions in Caribou, Jefferson and Madison counties, Idaho, and Lincoln County, Wyoming.

Forty-six spring and well sites were examined of which 26 were sampled and studied in detail. These include 24 springs and two wells. The location and temperatures of these sites are presented on Figure III-1.

Method of Study

The method of study described in this section was followed for all three subarea studies. Springs were initially identified by examining USGS topographic maps, Forest Service maps, or by word of mouth by people in the area. The springs were then visited in the field. All springs or wells warmer than 15.5°C were sampled. In addition, perennial springs associated with major faults were also sampled.

The surrounding geology was studied at each site. The water temperature, pH, and specific conductivity of each spring was measured in the field. The spring discharges were either estimated or measured.

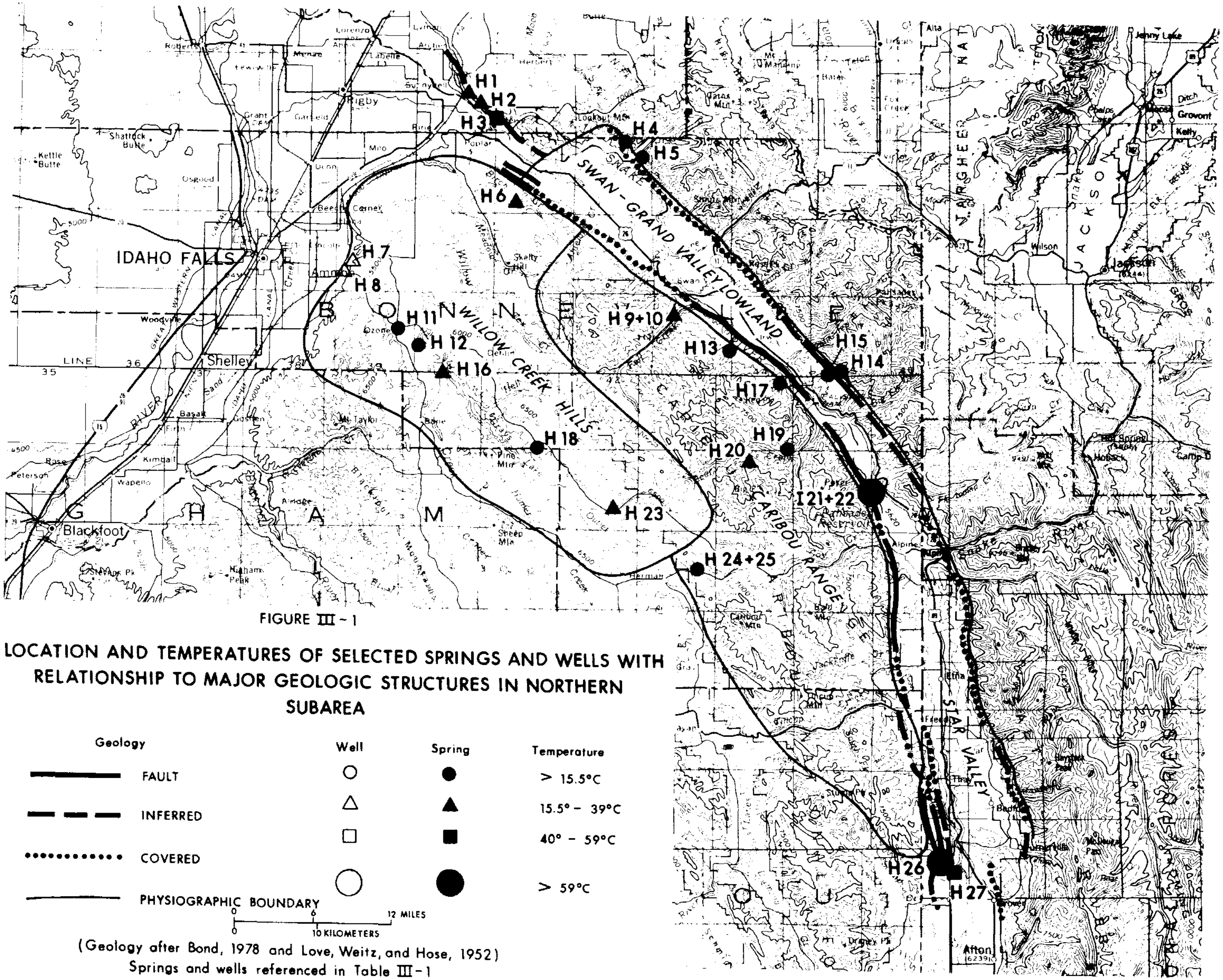


FIGURE III - 1

LOCATION AND TEMPERATURES OF SELECTED SPRINGS AND WELLS WITH RELATIONSHIP TO MAJOR GEOLOGIC STRUCTURES IN NORTHERN SUBAREA

(Geology after Bond, 1978 and Love, Weitz, and Hose, 1952)
Springs and wells referenced in Table III - 1

Portable field titration kits were used to obtain the concentrations of bicarbonate and total calcium and magnesium ions. Samples were collected for lab analysis following the procedure outline by Thompson (1975).

Laboratory water quality analyses were conducted by the field investigators utilizing equipment at the University of Idaho. Recommended Environmental Protection Agency practices were used for laboratory tests (U.S.E.P.A., 1974). The Mohr volumetric method was used for chloride, a gravimetric method was used for sulphate, specific ion probe for fluoride; concentrations of sodium, potassium, magnesium, calcium and silicia were determined by atomic absorption spectroscopy.

Geologic Setting

Exposures of Paleozoic, Mesozoic and Cenozoic rocks are found in this area. The Paleozoic rocks are mostly marine limestones, with some sandstones and minor shales. Mesozoic rocks consist of alternating limestones, sandstones and shales. Cenozoic strata consists of conglomerates, volcanic ash, sandstone, alluvium, and colluvium. Igneous rocks of Tertiary and Quaternary age, rhyolite tuffs and basalts overlie large areas in the north and western portions of this study area.

This subarea may be divided into several general areas for discussion purposes. The Swan-Grand Valley lowland is a northwest trending Basin and Range structure that starts at Kelley Mountain at the north and goes southeast to Alpine, Wyoming (Savage, 1961) (Figure III-1). There it curves to the south and blends into Star Valley. This graben has been filled to its present level with an undetermined thickness of alluvium, colluvium, and in the northern portion, volcanics. Palisades dam is located in the southeastern portion of this valley at Calamity Point. The waters backed up by the dam fill the entire length of Grand Valley. The northeastern fault associated with the graben is the Grand Valley fault. This high angle normal or reverse fault extends the full length of Swan-Grand Valley. The trace of this fault is hidden most of its length by rocks of late Tertiary and Quaternary age. The southeastern boundary of this graben is the Snake River fault. It extends from the Snake Plain in the north to Star Valley in the south, where it joins the fault along the west side of Star Valley. The trace of this fault is hidden most of its length by rocks of late Tertiary and Quaternary age. This fault is a high angle normal fault that dips to the east. Warm and cold springs mark the line of these two major faults on either side of the Swan-Grand Valley lowland. Both the Grand Valley and the Snake River faults are considered active. Witkind (1975) dates the last activity of the Grand Valley fault as having displaced beds of Holocene age (5000 years). The Swan Valley fault has been active in the last 20 million years and presently shows a lot of seismic activity.

The Caribou Range is a rugged, mountainous area south of the Swan-Grand Valley lowland that extends more than 80 km in a northwesterly direction. It is composed of Paleozoic and Mesozoic rocks intricately twisted in tight parallel folds and broken by faults. These sediments, which tend to get younger to the north, are made up mainly of limestones, sandstones, and shales.

The Willow Creek Hills are located northwest of the Caribou Range. These are low lying hills that have been disected by several streams. The southern portion of this area is made up of sedimentary Mesozoic rocks overlain in areas by silicic volcanics. In the northern part of this area, there are rhyolite tuffs and basalts capped by loess. The northern most portion of this area, near Birch and Meadow creeks, is interpreted to be a caldera (Proskta and Embree, 1978). Across from this area is Kelley Mountain which is bounded by one of the major faults in this area, the Heise fault. This fault is similar to the Grand Valley fault to the southwest, down dropping beds to the south.

Only one small thrust is mapped in the study area (Vine, 1959). It is located in T1S, R42E, below Skyline Ridge in the Falls Creek area. The trend of this thrust is in a northwesterly direction. This thrust has pushed rocks of the Bear River formation over top of Wayan formation sediments for a distance of 0.8 km. This is a minor thrust when compared to other thrusts located north or south of this subarea. The entire study area, excepting the possible caldera structures in the north, has been overthrust; the gliding plane is estimated to be located near mean sea level (Royce, Warner and Reese, 1975). Their cross-section shows tilted and deformed rocks on the surface with attenuations of folding as the depth increases. The bedding planes are believed to be approximately horizontal at depth. The thrusts are also believed to be horizontal under the northern subarea. The faults associated with the graben structures cut through at least a portion of this horizontal bedding and the thrusts.

Hydrology

This area is located in the Snake River drainage basin. The south fork of the Snake River enters this area near Alpine, flows into

Palisades Reservoir, where it is joined by the Salt River from the south, flows through the Swan-Grand Valley lowland and then flows northwest to the Snake Plain. Smaller streams enter the Snake River from the Caribou Range along the entire length of the river. Grays Lake, located south of the Snake River, drains to the north into Willow Creek and then into the Snake River near Idaho Falls.

Very little is known about the ground water resources in this area. Most of the wells are located in the valleys near the Snake River or on the Bench areas west of Ammon. Most of these wells are used for domestic purposes. Water is obtained from shallow unconfined alluvial aquifers in the Swan Valley area and silicic volcanic rocks, sands, and gravel in the area southeast of Ririe. Numerous small springs and seeps occur in the mountains but most of these dry up in the late fall. There are only a few large springs in this area.

Physical and Chemical Settings of Springs and Wells

The springs inventoried in the area have been divided into three groups: thermal springs that discharge highly mineralized water, thermal springs or wells with relatively low concentrations of dissolved solids and non-thermal springs. Short descriptions of the physical setting and characteristics of the springs are presented in Table III-1. Chemical analyses of these springs and wells are presented in Table III-2.

Thermal Springs with High Specific Conductivities

Six spring sites are included in this group. Temperatures range from 20 to 66°C with specific conductivities from 6500 to 10,500 µmhos/cm. See Figure III-1 for locations of the springs.

Table III-1. Physical settings of springs and wells in the northern subarea.

Sample Number	Name and Location	Water Temp. (°C)	Elevation (m above MSL)	Well Depth (m)	Depth to Water (m)	Discharge (l/s)	Site Description
H-1	Elkhorn Warm Spring 4N 40E 23cadS	20	1579			13 E	This spring is located 2.8 km northwest of Heise Hot Spring and emerges from rhyolite tuff. This spring is 0.2 km north of the Heise fault. This spring is within the southern edge of the Rexburg Caldera Complex.
H-2	Hawley Warm Spring 4N 40E 25bbdS	16	1609			13 E	This spring is located 1.5 km northwest of Heise Hot Spring and is associated with the Heise fault. The spring flows from the tuff of Spring Creek. This spring is within the southern edge of the Rexburg Caldera Complex.
H-3	Heise Hot Spring 4N 40E 25ddaS	48	1536			3.8 R	This spring issues from Tertiary silicic volcanic rocks within the southern edge of the Rexburg Caldera Complex. Two faults, the Heise fault and an unnamed northeast trending fault intersect at this site.
H-4	Lufklin Spring 3N 42E 2cbbS	8	1768			2 E	This spring is located 3.0 km northwest of Buckland Warm Spring. This spring issues from the contact of Salt Lake formation and the Gallatin limestone formation. This spring is associated with the Grand Valley fault which is implied to be 500 m to the southwest.
H-5	Buckland Warm Spring 3N 42E 12cca and ccdS	11	1567			1200	This spring flows out of the Gallatin formation and may be the primary discharge point for a flow system controlled by the thrust plate to the north.
H-6	Unnamed Spring 3N 41E 32bbdS	23	1707			6.3 E	This spring issues from the tuff of Spring Creek, a rhyolitic tuff. A large northeast trending fault is located 0.2 km to the south.
H-7	Dyer Well 2N 39E 21bcc	21	1537	171	137		This well probably obtains water from a broken rhyolite zone as recorded in the drillers log from 140 to 171 m. There is a northeast trending fault mapped 150 m to the west of this well.

Table III-1. Continued

Sample Number	Name and Location	Water Temp. (°C)	Elevation (m above MSL)	Well Depth (m)	Depth to Water (m)	Discharge (l/s)	Site Description
H-8	Anderson Well 2N 39E 29bac	20	1524	109	76		This well is located 1.6 km southwest of the Dyer's well. The drillers log indicates rhyolite from 69 to 75 m, sandstone (presumably pumice) 95 to 107 m and rhyolite 107 to 109 m.
H-9	Fall Creek Mineral Springs 1N 43E 9cbb1S	24	1658			6.3 E	This spring is one of a series of warm springs along the south side of Fall Creek. These springs flow from Quaternary alluvium with travertine deposits above Mission Canyon limestone. They are associated with the major northwest trending Swan Valley fault.
H-10	Fall Creek Mineral Springs 1N 43E 9cbb2S	23	1658			4.4 R	This spring flows in the bottom of the northern most sink hole. See description under H-9.
H-11	Unnamed Spring 1N 39E 14acaS	9	1765			2.5 E	This spring flows from the Salt Lake formation. It may originate from Tertiary rhyolite tuff outcropping 70 m north of this site.
H-12	Unnamed Spring 1N 40E 19cabS	13	1676			3.8 E	This spring flows from the Salt Lake formation.
H-13	Unnamed Spring 1N 44E 30cbdS	7	1841			0.7 E	This spring discharges from alluvium and travertine overlying Mission Canyon limestone. The spring is associated with the northwest trending Snake River fault.
H-14	Unnamed Spring 1N 45E 4adaS	6	1817			1.8 E	The spring flows from Salt Lake formation. This spring is currently depositing travertine below this site. The major northwest trending Grand Valley fault is located in this area, but it is concealed by the overlying Salt Lake formation.
H-15	Unnamed Spring 1N 45E 4acaS	6	1878			4.3 E	This spring is located 300 m west of Spring H-14. See description under H-14.
H-16	Unnamed Spring 1S 40E 4abcS	21	1699			1.8 E	This spring flows from fractures in an outcrop of Ephriam conglomerate. A minor fault is mapped at this site.

Table III-1. Continued

Sample Number	Name and Location	Water Temp. (°C)	Elevation (m above MSL)	Well Depth (m)	Depth to Water (m)	Discharge (l/s)	Site Description
H-17	Unnamed Spring 1N 44E 1cbdS	7	1804			13 E	This spring issues from the Salt Lake formation.
H-18	Willow Spring 1S 41E 36cccS	8	2007			6.3 E	This spring flows out of the Wayan formation, on the axis of a northwest trending syncline. The ground water may flow along bedding planes, draining the synclinal structure.
H-19	Unnamed Spring 2S 44E 1accS	11	1780			120 E	This spring is flowing out of the Nugget sandstone.
H-20	Warm Spring 4S 44E 9aacS	17	2182			13 E	This spring flows from near the contact of the Twin Creek limestone and the Nugget sandstone. This site is 250 m east of the northwest trending axis of the Big Elk Mountain anticline.
I-21	Alpine Hot Spring 2S 46E 19bS	56	1689			1.6 R	These springs are reported to discharge from alluvium and were depositing travertine; the springs are presently covered by the waters of Palisades Reservoir. These springs are associated with the Swan Valley fault.
I-22	Alpine Hot Spring 2S 46E 19cadS	37	1692			0.6 R	See description above.
H-23	Brockman Hot Spring 2S 42E 26dcdS	35	1908			3.8 R	This spring flows out of either the Peterson or Bechler formation. An inactive travertine mound is located 50 m to the south. The geology around this spring has been complexly folded and faulted by minor faults.
H-24	Unnamed Spring 3N 42E 15dccS	10	2085			4.3 E	This spring issues from rocks of the Bechler formation on the west limb of a complexly faulted syncline.
H-25	Unnamed Spring 3N 42E 22abbS	14	2079			2.5 E	This spring is located 100 m southwest of the unnamed spring at 3N 42E 15dccS. It flows from the contact of the Bechler and Peterson formation on the west limb of a complexly faulted syncline.

Table III-1. Continued

Sample Number	Name and Location	Water Temp. (°C)	Elevation (m above MSL)	Well Depth (m)	Depth to Water (m)	Discharge (l/s)	Site Description
H-26	Auburn Hot Springs 33N 119W 23dbdS	57	1853			2.5 E	These springs discharge from the Dinwoody formation on the axis of the northwest trending Hemmert anticline. Two faults, the Hemmert fault and the Freedon fault join at this site. Extensive deposits of travertine and free sulfur are present at these springs.
H-27	Johnson Springs 33N 119W 26adS	54	1853			0.01	This spring is located 1.6 km south of Auburn Hot Springs. The spring flows from a large travertine mound that overlies alluvium and at some depth, Paleozoic sedimentary rocks. The trace of the Hemmert anticline and fault lie beneath this site.

E = Estimated discharge

R = Reported discharge

All others measured

Table III-2. Hydrochemistry of springs and wells in the northern subarea.

Sample Number	Name and Location	Water Temp. °C	Specific Conductance (µmho/cm)	TDS (mg/l)	pH	Concentration in mg/l (meq/l)								
						Ca	Mg	Na	K	Cl	F	HCO_3	SO_4	SiO_2
H-1	Elkhorn Warm Spring 4N 40E 23cadS	20	385	335	6.6	30 (1.5)	10 (0.8)	14 (0.6)	0 (0)	5 (0.1)	0.78 (0)	186 (3.0)	7 (0.1)	83
H-2	Hawley Warm Spring 4N 40E 25bbdS	16	350	341	7.5	36 (1.8)	10 (0.8)	10 (0.4)	0 (0)	4 (0.1)	0.7 (0)	188 (3.1)	5 (0.1)	88
H-3	Heise Hot Springs 4N 40E 25ddaS	48	6500	7667	6.1*	676 (33.7)	81 (6.7)	1498 (65.2)	204 (5.2)	2299 (64.9)	3.1 (0.2)	2125* (34.8)	723 (15.1)	58
I-3	Heise Hot Springs[2] 4N 40E 25ddaS	49	8839	6495	6.7	450 (22.5)	82 (6.7)	1500 (65.3)	190 (4.9)	2400 (67.7)	3.1 (0.2)	1100 (18.0)	740 (15.4)	30
H-4	Lufklin Spring 3N 42E 2cbbS	8	450	527	6.9	132 (6.6)	0 (0)	0 (0)	0 (0)	2 (0.1)	0 (0)	379 (6.2)	5 (0.1)	9
H-5	Buckland Warm Spring 3N 42E 12cca + ccdS	11	830	678	7.0	112 (5.6)	26 (2.1)	31 (1.3)	0 (0)	38 (1.1)	0.14 (0)	349 (5.7)	109 (2.3)	13
H-6	Unnamed Spring 3N 41E 32bbdS	23	650	547	7.2	71 (3.5)	19 (1.6)	44 (1.9)	0 (0)	42 (1.2)	0.14 (0)	271 (4.4)	51 (1.1)	49
H-7	Dyer Well 2N 39E 21bccS	21	530	434	7.7	50 (2.5)	13 (1.1)	50 (2.2)	3 (0.1)	61 (1.7)	0.29 (0)	188 (3.1)	1 (0)	68
H-8	Anderson Well 2N 39E 29bacS	20	520	467	7.7	50 (2.5)	10 (0.8)	45 (2.0)	7 (0.2)	45 (1.3)	0.44 (0)	199 (3.3)	0 (0)	111
H-9	Fall Creek Mineral Spring 1N 43E 9cbb1S	24	7800	5416	6.2	473 (23.6)	100 (8.2)	1058 (46.0)	118 (3.0)	1851 (52.2)	1.4 (0.1)	1473 (24.1)	327 (6.8)	15
H-10	Fall Creek Mineral Spring 1N 43E 9cbb2S	23	6750	4961	6.2	431 (21.5)	88 (7.2)	1065 (46.3)	108 (2.8)	1650 (46.5)	1.3 (0.1)	1272 (20.8)	329 (6.8)	17
I-10	Fall Creek Mineral Spring[2] 1N 43E 9cbbS	25	7949	4658	6.3	440 (22.0)	96 (7.9)	1110 (48.3)	120 (3.1)	1900 (53.6)	1.70 (0.1)	1200 (19.7)	390 (8.1)	11
H-11	Unnamed Spring 1N 39E 14acaS	9	470	401	7.0	48 (2.4)	17 (1.4)	15 (0.7)	0 (0)	38 (1.1)	0.18 (0)	209 (3.4)	3 (0.1)	71
H-12	Unnamed Spring 1N 40E 19cabS	13	300	321	7.2	39 (1.9)	6 (0.5)	5 (0.2)	0 (0)	4 (0.1)	0.21 (0)	156 (2.6)	0 (0)	111
H-13	Unnamed Spring 1N 44E 30cbdS	7	450	468	7.1	85 (4.2)	10 (0.8)	3 (0.1)	0 (0)	7 (0.2)	0.26 (0)	306 (5.0)	8 (0.2)	49
H-14	Unnamed Spring 1N 45E 4adaS	6	390	348	7.4	60 (3.0)	16 (1.3)	0 (0)	0 (0)	0 (0)	0 (0)	254 (4.2)	3 (0.1)	15
H-15	Unnamed Spring 1N 45E 4acaS	6	410	376	7.4	69 (3.4)	18 (1.5)	0 (0)	0 (0)	0 (0)	0 (0)	276 (4.5)	0 (0)	13
H-16	Unnamed Spring 1S 40E 4abcS	21	10500	9229	6.6	110 (5.5)	19 (1.6)	2843 (123.7)	40 (1.0)	876 (24.7)	4.6 (0.2)	2416 (39.6)	2858 (59.5)	62

Table III-2. Continued

Sample Number	Name and Location	Water Temp. °C	Specific Conductance (µmho/cm)	TDS (mg/l)	pH	Concentration in mg/l (meq/l)								
						Ca	Mg	Na	K	Cl	F	HCO_3	SO_4	SiO_2
H-17	Unnamed Spring 1S 44E 1cbdS	7	400	377	7.1	66 (3.3)	18 (1.5)	0 (0)	0 (0)	3 (0.1)	0.12 (0)	252 (4.1)	4 (0.1)	34
H-18	Willow Spring 1S 41E 36cccS	8	450	395	7.1	73 (3.6)	14 (1.2)	4 (0.2)	0 (0)	10 (0.3)	0.16 (0)	278 (4.6)	5 (0.1)	11
H-19	Unnamed Spring 2S 44E 1aacS	11	225	160	7.1	36 (1.8)	6 (0.5)	0 (0)	0 (0)	0 (0)	0 (0)	109 (1.8)	3 (0.1)	6
H-20	Warm Spring 2S 44E 9aacS	17	600	576	7.2	128 (6.4)	27 (2.2)	0 (0)	0 (0)	1 (0)	0.25 (0)	163 (2.7)	233 (4.9)	24
I-21	Alpine Hot Springs[3] 2S 46E 19bS	56		6404		526 (26.2)	93 (7.7)	1532 (66.6)	189 (4.8)	2412 (68.0)	2.8 (0.1)	920 (15.1)	1052 (21.9)	45
I-22	Alpine Hot Springs[2] 2S 46E 19cadS	37	10499	6615	6.5	560 (27.9)	100 (8.2)	1500 (65.3)	180 (4.6)	2800 (79.0)	2.7 (0.1)	880 (14.4)	1000 (20.8)	40
H-23	Brockman Hot Spring 2S 42E 26dcdS	35	8750	7562	6.6	186 (9.3)	33 (2.7)	2044 (88.9)	38 (1.0)	553 (15.6)	2.3 (0.1)	2255 (37.0)	2413 (50.2)	38
I-23	Brockman Creek W.S.[2] 2S 42E 26dcdS	35	8649	6377	6.4	150 (7.5)	41.0 (3.4)	2100 (91.4)	34 (0.9)	590 (16.6)	2.6 (0.1)	1900 (31.1)	2502 (52.1)	24
H-24	Unnamed Spring 3N 42E 15dccS	10	550	543	7.1	104 (5.2)	25 (2.1)	0 (0)	0 (0)	3 (0.1)	0.16 (0)	342 (5.6)	56 (1.2)	13
H-25	Unnamed Spring 3S 43E 22abbS	14	400	373	7.2	76 (3.8)	10 (0.8)	0 (0)	0 (0)	4 (0.1)	0.12 (0)	272 (4.5)	5 (0.1)	6
H-26	Auburn Hot Springs 33N 119W 23dbdS	57	8000	5760	6.4	509 (25.4)	76 (6.3)	1327 (57.7)	162 (4.1)	1737 (49.0)	3.4 (0.2)	882 (14.5)	996 (20.7)	68
W-26	Auburn Hot Springs[1] 33N 119W 23dbdS	62	6800	5250	7.5	400 (20.0)	70 (5.8)	1400 (60.9)	140 (3.6)	1700 (48.0)	0.6 (0)	860 (14.1)	1100 (22.9)	35
H-27	Johnson Springs 33N 119W 26adS	54	8100	6310	6.4	454 (22.7)	45 (3.7)	1494 (65.0)	176 (4.5)	1947 (54.9)	3.8 (0.2)	973 (15.9)	1129 (23.5)	88

* pH meter may have malfunctioned causing inaccurate pH and HCO_3 readings.

[1] Breckenridge and Hinkley, 1978

[2] Mitchell, Johnson and Anderson, 1980

[3] Ross, 1971

Heise Hot Springs (H-3). This 48°C spring is located at the foot of a south facing 300 m escarpment. A large travertine mound has been deposited by the spring discharge. The spring flows from Tertiary silicic volcanics from within the southern border of the Rexburg caldera (Mitchell, Johnson, and Anderson, 1980). Two faults intersect at this site, the northwest trending Heise fault and a smaller northeast trending fault. Utilizing gravity and magnetic data, Mabey (1978) suggested that a large intrusive body, possibly young enough to supply heat, is located beneath Heise Hot Springs.

This spring deposits travertine and free sulfur and has a hydrogen sulfide odor. This mineralized water has a specific conductance of 6500 μmhos/cm and a pH of 6.7 (Young and Mitchell, 1973). Sodium and chloride are the dominant ions in this water.

Fall Creek Mineral Springs (H-9 and H-10). Numerous springs and seeps discharge water along a 1.2 km reach of Fall Creek. The warmest spring is 25°C and flows from a travertine deposit. These deposits fill the valley floor the entire length of the springs. The springs discharge from the Mission Canyon limestone and are associated with the northwest-trending Snake River fault. These springs also deposit free sulfur and give off a strong hydrogen sulfide odor.

The water is highly mineralized and has a specific conductance of 7800 μmhos/cm. The water is acidic with the pH at 6.2 and the dominant ions are sodium and chloride.

Unnamed Springs at 1N 40E 4abcS (H-16). This spring is located in the bottom of a canyon formed by Willow Creek. The geology is complicated by rhyolitic tuffs and basalts which surround the exposed older sedimentary rocks. The spring discharges water at 21°C from fractures in an outcrop of Ephriam conglomerate. A northeast-trending fault intersects this site from the north (Mansfield, 1952). The spring gives off an odorless gas, presumably carbon dioxide. Travertine deposits are located west of the present springs and saline deposits surround the springs.

This spring has a high specific conductance of 10,500 μmhos/cm and a pH of 6.6. The dominant ions in this water are sodium and sulfate.

Alpine Hot Springs (I-21). These springs are located under Palisades Reservoir. The springs flow from Quaternary alluvium and are associated with the northwest trending Snake River fault. The springs were located on both sides of the river. Six springs on the west side of the river had temperatures ranging from 31 to 62°C. On the east side of the river there were two main springs and several smaller ones with temperatures ranging from 49 to 66°C (Stearns and others, 1937). Bradley (1873, p. 269) noted that the springs gave off the odor of hydrogen sulfide and that the springs were "making calcareous, sulfurous and saline deposits".

The springs were sampled in 1977 when the reservoir level was particularly low. The water has a specific conductance of 10,499 μmhos/cm, a temperature of 37°C and a pH of 6.5. The dominant ions were sodium and chloride (Mitchell, Johnson, and Anderson, 1980).

Brockman Hot Spring (H-23). This spring flows from several small seeps and a 1.2 m diameter pool into Brockman Creek. The temperature of this pool was measured to be 35°C. Saline deposits surround the spring and an inactive travertine mound is located a short distance to the south.

The area around the spring site is complexly folded and faulted. This spring flows out of Quaternary alluvium overlying Bechler conglomerate or Peterson limestone. Several faults run through the area, the nearest of which is 200 m to the north.

This spring has a specific conductance of 8,750 µmhos/cm and a pH of 6.6. The dominant ions in this water are sodium and sulfate.

Auburn Hot Springs and Johnson Spring (H-26 and H-27). These two groups of springs are located on the same linear trend. Auburn Hot Springs flows from numerous vents over a 1.2 hectacre area. The maximum temperature measured here was 62°C (Breckenridge and Hinkley, 1978). Johnson Spring consists of five travertine cones with a small spring and several seeps, on and around them. The temperature of this spring was 54°C. Both springs give off the odor of hydrogen sulfide and deposit free sulfur along with the travertine.

These springs occur on the axis of the north-south trending Hemmert anticline. Two deep seated faults, the Hemmert fault that follows the crest of the anticline, and the Freedom fault that roughly parallels this anticline one km to the west, join at the spring site. The springs emerge from the Dinwoody formation of lower Triassic age (Mansfield, 1927). The roughly linear arrangement of these springs and other travertine deposits located 13 km north on the same trend suggest that these springs are structurally controlled (Breckenridge and Hinkley, 1978).

Auburn Hot Springs has a specific conductivity of 8,000 µmhos/cm with a pH of 6.4. The dominant ions in these waters are sodium and chloride. Johnson Spring has a similar chemical composition with a specific conductance of 8,100 μmhos/cm and a pH of 6.4. The dominant ions in this spring water are sodium and chloride.

Thermal Springs with Low Specific Conductivities

Elkhorn and Hawley Warm Springs (H-1 and H-2).

Elkhorn and Hawley warm springs are located 2.8 km and 1.5 km northwest of Heise Hot Springs, respectively. Both springs are located on the escarpment formed by the Heise fault. The intrusive body suggested by Mabey (1978) to be under Heise Hot Springs is also beneath these two springs. These springs emerge from rhyolitic tuffs on the southern edge of the Rexburg Caldera Complex (Prostka and Embree, 1978). They are located 0.2 km north of the Heise fault.

Elkhorn warm spring had a specific conductivity of 385 μmhos/cm and a temperature of 16°C. The pH measurement was 6.6 and the dominant ions were calcium and bicarbonate. Hawley warm spring has a specific conductivity of 350 μmhos/cm and a temperature of 23°C. The pH was 7.5 and the dominant ions were calcium and bicarbonate.

Unnamed Spring at 3N 41E 32bbdS (H-6).

This 23°C spring surfaces in a densely welded ash-flow tuff called the Tuff of Spring Creek. A 9.3 km long, northeast trending fault is located 0.2 km to the south of this spring site.

This spring has a specific conductance of 650 μmhos/cm and a pH of 7.2. The dominants ions in the water are calcium and bicarbonate.

Dyer and Anderson Wells (H-7 and H-8).

These two wells are representatives of a group of warm water wells drilled on the bench east of Idaho Falls. The wells are located 1.6 km apart with the Dyer well located northeast of the Anderson well. They have temperatures of 21 and 20°C. Tertiary Salt Lake formation is mapped at the well sites with outcrops of welded tuffs and associated ash nearby (Mansfield, 1952). Water is obtained from fractured rhyolite in the Dyer well. There is a northwest trending fault mapped 0.2 km west of this well. In the Anderson well, the water is obtained from sandstone (pumice) or rhyolite.

The chemistries of these wells are similar. The specific conductivity values are 520-530 µmhos/cm and the pH is 7.7. The dominant ions present are calcium and bicarbonate.

Warm Spring (H-20). This spring is located at a very high elevation for a warm spring (17°C). Extensive deposits of travertine are present. The spring surfaces near the contact of the Twin Creek limestone and the Nugget sandstone. This site is located 250 m west of the axis of the Big Elk Mountain anticline.

The water from this spring had a specific conductivity of 600 µmhos/cm. The pH is 7.2 and the dominant ions are calcium and sulfate.

Non-thermal Springs

Twelve springs were sampled in this study that have low temperatures and low specific conductivities. Their temperatures range from 6 to 14°C. These springs flow from several different geologic formations; five discharge from the Salt Lake formation, three in the Gannet group, two from the Nugget sandstone. Only one spring of this group, Unnamed Spring at 1N 43E 30cbdS, is located directly on a deep seated structural feature. Only two of these springs are currently depositing travertine and none of them give off any odor of hydrogen sulfide.

The specific conductivity of these springs range from 225 to 830 μmhos/cm with a mean of 443 μmhos/cm. The range of pH readings were from 6.9 to 7.4 with three below 7.0 and nine above. The dominant ions in all of these springs were bicarbonate and calcium.

Discussion of Results

The chemistry of the water discharging at each of the sites uniquely represents the rocks through which the water flowed, the length of the flow path and the maximum temperature the water has achieved. Figure III-2 shows "stiff diagram" representations of the chemistries of sampled sites in the northern subarea. "Stiff diagrams" graphically show the concentrations of major cations and anions in equivalents per million. These diagrams are useful for analyzing gross similarities in water quality and thus ground water flow systems.

The thermal springs with high concentrations of dissolved solids discharge from different formations; however, all but two springs, Brockman Hot Spring and Unnamed Spring at 1S 40E 4abcS (H-23 and H-16), are associated with deep seated faults that are located in the Swan, Grand and Star valleys. These faults probably act as conduits for upward movement of thermal water. The trend of three of these springs, Heise Hot Springs, Fall Creek Mineral Springs and Alpine Hot Spring (H-3, H-9, H-10 and H-21) parallel the trend of the two other springs, Brockman Hot Spring and Unnamed Spring at 1S 40E 4abcS, located 15 km to the southwest.

The chemical analyses of these springs show that five of the springs, Heise, Fall Creek, Alpine, Auburn and Johnson hot springs, have

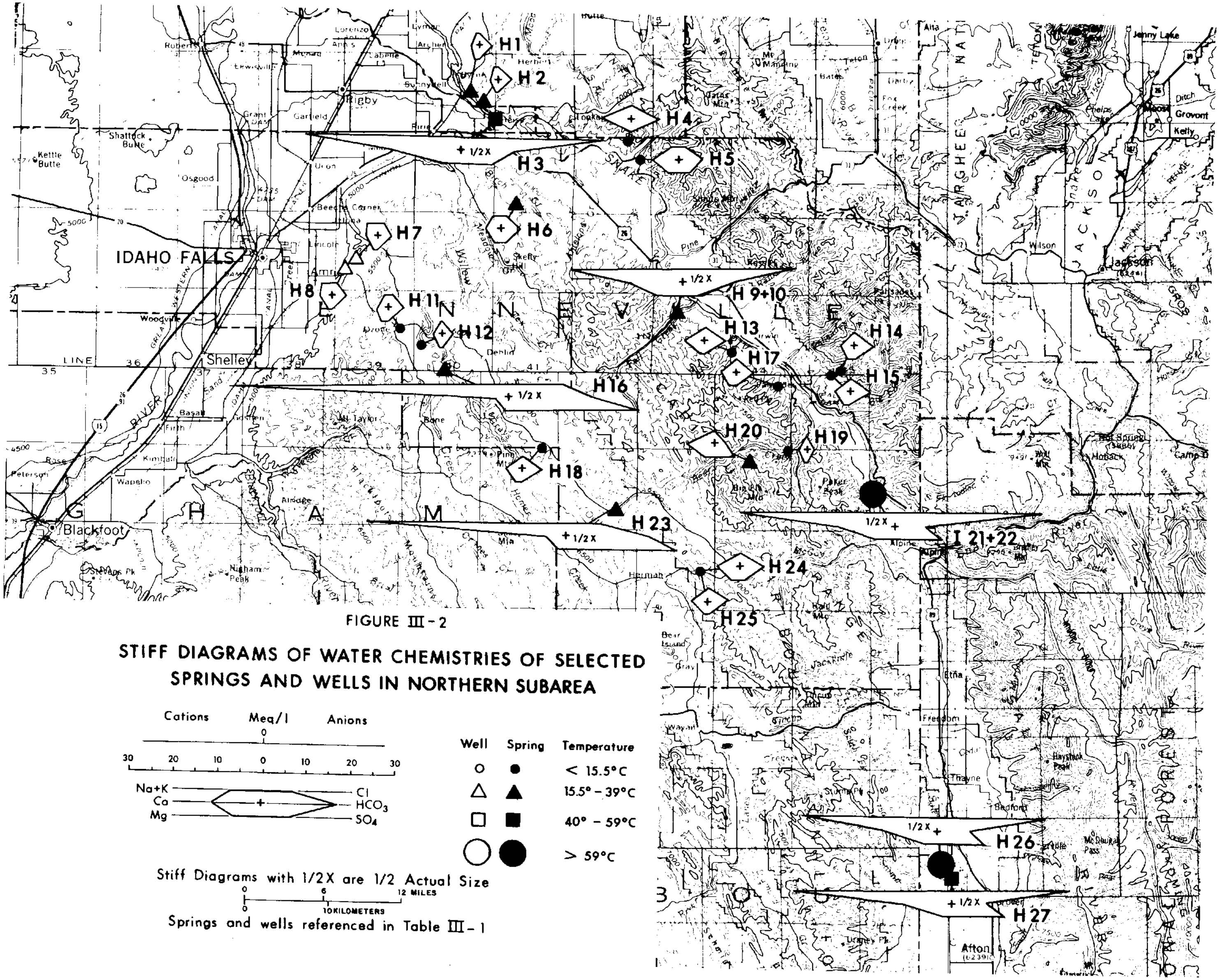


FIGURE III-2

STIFF DIAGRAMS OF WATER CHEMISTRIES OF SELECTED SPRINGS AND WELLS IN NORTHERN SUBAREA sodium and chloride as their dominant ions. The other two springs, Brockman Hot Spring and Unnamed Spring at 1S 40E 4abcS, have sodium and sulfate as their dominant ions.

Stiff diagrams for these springs shown in Figure III-2 are one-half the scale for the rest of the sites because of their high concentrations of dissolved ions. There are significant differences between these stiff diagrams and those of the other groups of springs, in both size and major constituents. Utilizing stiff diagrams, these springs can be further separated into smaller groups. Brockman Hot Spring and Unnamed Spring at 1S 40E 4abcS can be put in one group, Heise Hot spring and Fall Creek Mineral springs into another, and Alpine, Johnson and Auburn hot springs in a third group.

Thermal springs and wells with low total dissolved solids are Hawley and Elkhorn Warm Spring, Unnamed Spring at 3N 41E 32bbdS, Dyer and Anderson wells and Warm Spring (H-1, H-2, H-6, H-7, H-8 and H-20). All of these springs or wells obtain water from volcanic rocks except Warm Spring that discharges from sedimentary rocks. The dominant ions for these springs and wells are: calcium and bicarbonate for Elkhorn, Hawley, Unnamed Spring at 3N 41E 32bbdS, and Dyer and Anderson wells, and calcium and sulfate for Warm Spring. A comparison of stiff diagrams indicates that some of these springs can be further grouped by their chemistries. Elkhorn and Hawley warm springs are similar to each other yet distinct from the others, as are Dyer and Anderson wells. In general, all of these stiff diagrams resemble the non-thermal stiff diagrams except for Warm Spring. This site has a different chemistry than any other spring tested in this subarea. It should be noted the Heise Hot Springs and Elkhorn and Hawley warm springs do not have similar water chemistries despite the closeness in location, and the presence of thermal water in all three.

The non-thermal springs discharge from various geologic formations--Gallatin and Mission Canyon limestone, Salt Lake, Wayan, Bechler and Nugget sandstone. The dominant ions for all of these springs are calcium and bicarbonate.

CHAPTER IV

HYDROGEOLOGIC RECONNAISSANCE OF THE MEADE THRUST SUBAREA

Introduction

Ground water flow systems in the Meade thrust subarea have been evaluated both as a part of this study and as a research project related to phosphate mining under funding by the Idaho Mining and Minerals Resources Research Institute. This chapter includes only a brief description of the spring sites based upon work on this joint project. The Meade thrust subarea includes the Meade Peak allochthon and is situated between the northern and southern subareas (Figures I-1 and IV-1). (An allochthon is a body of rocks that has been moved a long distance from their original place of deposition by a tectonic process such as overthrusting.)

Geologic Setting

The Meade Peak allochthon consists mainly of Mesozoic and upper Paleozoic age carbonate, sands, shaly strata compressed into rather broad and open folds. The Meade thrust fault has steep inclinations near the surface, but flattens along its sole which has been broadly warped (Figure IV-2). The axes of the warp as well as the fold axes trend northward. Depth to the sole of the thrust ranges from 900 to 2500 m below land surface. Extension faults along the front of the Aspen Range and other ridges mark the western periphery of the allochthon.

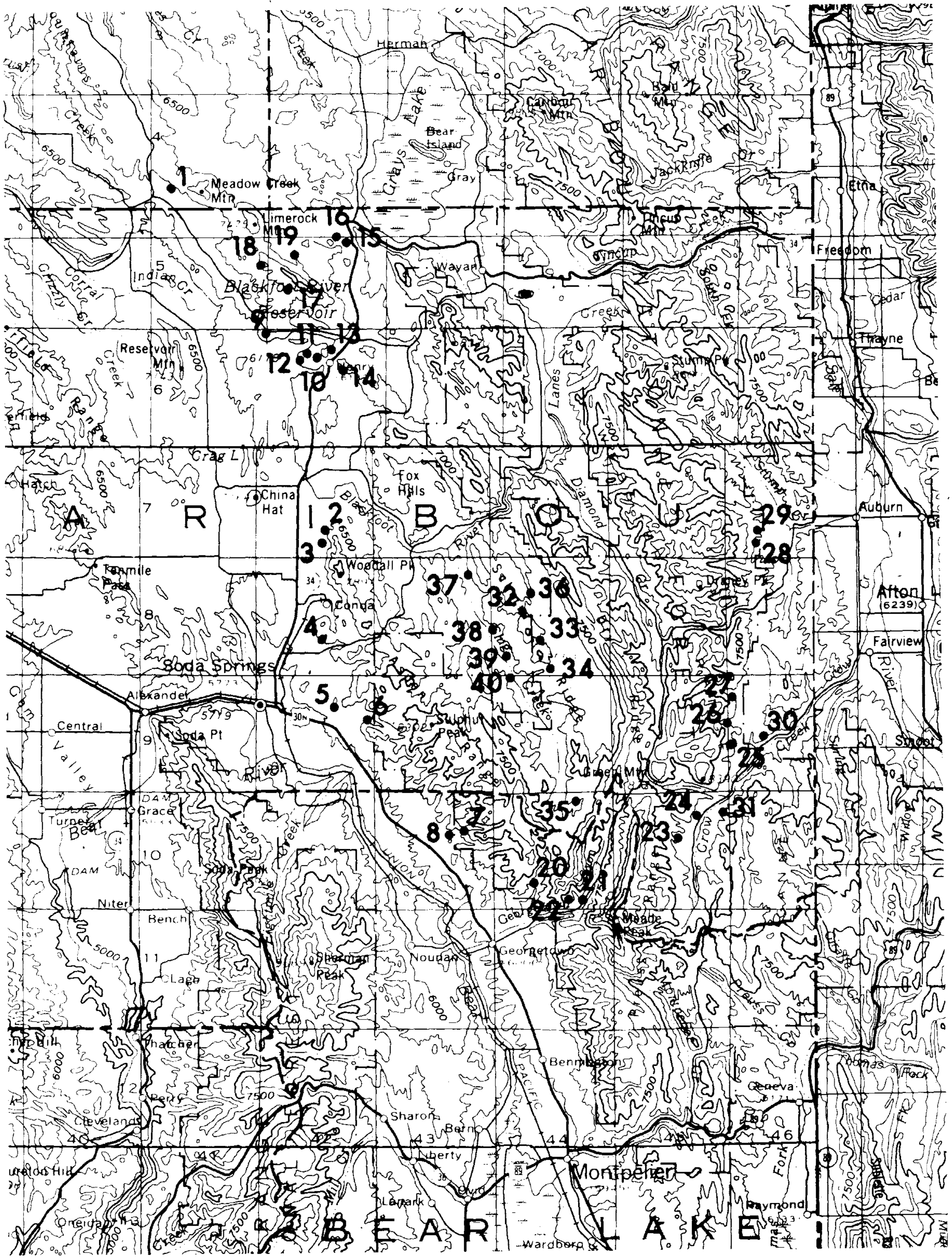


Figure IV-1. Sample sites in the Meade thrust subarea.

Vertical displacement along these faults is estimated to be more than 1500 m and has resulted in the formation of the northern Bear River and Blackfoot Reservoir grabens which form the western boundaries of the allochthon. The eastern periphery of the allochthon is marked by exposures of the Meade thrust at the base of the Webster Range and along the eastern edge of Grays Lake. Exposures of the Meade thrust mark the southern boundary and the northern boundary is largely obscured by Quaternary age basaltic lava flows. In all, the allochthon is a maximum of 40 km wide in an east-west direction and 100 km long in a north-south direction.

Hydrology

The interior of the Meade Peak allochthon is drained by the Blackfoot and Little Blackfoot rivers and by Meadow Creek. The Blackfoot River is the principal drainage of the ridge and valley system whose narrow, linear features dominate the topography of the allochthon's center. The Little Blackfoot River and Meadow Creek drains the northern ridges and valleys. Twin Creek, a tributary of the Bear River drains the southern flanks and Stump Creek, a tributary of Salt River, drains the eastern flank of the allochthon.

Four ground water flow systems have been identified in the area by previous investigators: 1) local flow systems in shallow unconsolidated material, 2) local flow systems in valley alluvium, 3) local and intermediate flow systems, and 4) regional flow systems (Ralston and others, 1977; Robinette, 1977). In general, the intermediate flow systems are restricted to near surface exposure of the Thaynes and

Dinwoody formations and the regional flow systems are in the underlying Wells, Brazer and Madison formations.

Physical and Chemical Settings of Springs and Wells

Water quality samples were collected from 37 springs and three wells. Site locations are shown on Figure IV-1; a summary of the physical setting and water chemistry of each site is given in Tables IV-1 and IV-2. Twenty-seven of the springs issue from the periphery of the allochthon and form the most part flow from the thrust fault or from extension faults which intersect the thrust fault. The remaining springs and wells issue from local, intermediate and regional flow systems in the allochthon's interior. The springs and wells have been grouped on the basis of physical and chemical characteristics.

Western Frontal Fault Springs

Nine springs along the western periphery of the Meade Peak allochthon have been placed into this group. The temperatures at these sites range from 9 to 19°C. Eight of the springs (M-2 to M-8) issue from steeply westward dipping extension faults associated with block faulting of the Aspen Range horst, the southern portion of the Blackfoot Reservoir graben and the northern portion of the Bear River Valley graben. The western front of the Aspen Range horst mainly consists of upper Paleozoic age carbonate strata which in a few locations are conformably overlain by Permian age phosphate bearing rocks and Triassic age carbonate and shaly strata at higher elevations. The surficial deposits that cover the southern portion of the Blackfoot Reservoir graben include Quaternary age basaltic lavas, travertine and alluvium; in the northern

Table IV-1. Physical settings of springs and wells in the Meade thrust subarea.

Sample Number	Name and Location	Water Temp. (°C)	Elevation (m above MSL)	Well Depth (m)	Depth to Water (m)	Discharge (l/s)	Site Description
M-1	Sink Hole 4S 41E 32bbS	19	1890			292	Flows from Wells formation along the Enoch Valley fault.
M-2	North Woodall 7S 42E 27acS	17	1900			28	Flows up an unnamed extension fault along the fault of the northern Aspen Range. Associated with Wells formation.
M-3	Woodall 7S 42E 34baS	13	1900			365	Flows up an unnamed extension fault along the fault of the northern Aspen Range. Associated with Wells formation.
M-4	Formation 8S 42E 27cbS	11	1875			488	Flows up an unnamed extension fault along the fault of the northern Aspen Range. Associated with Wells formation.
M-5	East Soda 9S 42E 10acS	9	1840			85	Associated with Salt Lake formation; several extension faults have been mapped in the area.
M-6	Sulphur Canyon 9S 42E 13bc	10	1870			8.5	Flows from Wells (?) formation in an area along the front of the Aspen Range which is bounded by extension faults.
M-7	Swan Lake #1 9S 43E 29ccS	16	1890			85	Flows from Wells formation along front of Aspen Range in an area of extension faulting.
M-8	Swan Lake #2 9S 43E 30ccS	9	1840			14	Flows from Wells formation along front of Aspen Range in an area of extension faulting.
M-9	Lone Tree 6S 42E 6abS	26	1870			3	Flow ascends up Slug Valley (?) fault.
M-10	Henry Warm #1 6S 42E 9acS	15	1867			88	Discharges on travertine terrace which overlies the intersection of the Henry and Slug Valley faults.
M-11	Henry Warm #2 6S 42E 9bcS	20	1870			55	Discharges on travertine terrace which overlies the intersection of the Henry and Slug Valley faults.
M-12	Warm Spring 6S 42E 8dbS	23	1880			14	Discharges on travertine terrace which overlies the intersection of the Henry and Slug Valley faults.

Table IV-1. Continued

Sample Number	Name and Location	Water Temp. (°C)	Elevation (m above MSL)	Well Depth (m)	Depth to Water (m)	Discharge (l/s)	Site Description
M-13	North Henry 6S 42E 10bcS	15	1883			56.5	Discharges on travertine terrace which overlies the intersection of the Henry and Slug Valley faults.
M-14	Little Blackfoot River 6S 42E 15baS	15	1880			7	Discharges from Wells formation along axis of Wooley Valley anticline.
M-15	Chubb 5S 42E 11ccS	12	1905			45	Flows from Monroe Canyon limestone along the Chubb springs fault.
M-16	West Chubb 5S 42E 10daS	12	1905			85	Flows from Monroe Canyon limestone along the Chubb springs fault.
M-17	Pelican Ridge #1 5S 42E 39dcS	7	1920			8.5	Flows from a fault bounded slice of the Dinwoody formation.
M-18	Pelican Ridge #2 5S 42E 24dcS	7	1985			3	Flows from a fault bounded slice of the Dinwoody formation.
M-19	North Pelican 5S 42E 17bcS	8	1915			14	Flows from Dinwoody formation in the Meadow Creek graben.
M-20	Big Spring 10S 44E 28ccS	8	1970			59.5	Waters emerge along a normal fault which cuts the Daisy sincline and Wells formation.
M-21	Georgetown Canyon 10S 44E 35dcS	7	1997			408	Flows from the Wells formation along a splay of the Meade thrust.
M-22	Georgetown Canyon Tailings 10S 44E 35cdS	8	1997			448	Flows from the Wells formation along a splay of the Meade thrust.
M-23	Crow Creek Ranch 10S 45E 15acS	7	2048			161	Flows from the Wells formation at the contact with Monroe Canyon limestone.
M-24	Brooks Spring 10S 45E 1daS	12	2009			99	Flows from a splay of the Meade thrust (?) and the Wells (?) formation
M-25	Fence Line 9S 46E 19adS	10	2120			25	Flows from the Meade thrust and Wells (?) formation.

Table IV-1. Continued

Sample Number	Name and Location	Water Temp. (°C)	Elevation (m above MSL)	Well Depth (m)	Depth to Water (m)	Discharge (l/s)	Site Description
M-26	South Fork 9S 46E 18daS	12	2270			100	Flows from the Meade thrust and Wells (?) formation.
M-27	Sage Valley 9S 46E 18adS	12	2270			246	Flows from the Meade thrust and Wells (?) formation.
M-28	Auburn Fish Hatchery 8S 46E 5baS	9	1980			142	Flows from Meade thrust and the Thaynes formation.
M-29	Star Valley Hatchery 7S 46E 32bdS	9	1975			100	Flows from contact of Portneuf (?) member and Timothy sandstone (?) member of Thaynes formation.
M-30	Nuggett 9S 46E 20caS	10	2090			15	Flows from slice of Nuggett sandstone near the Meade thrust.
M-31	New Salt 10S 45E 1daS	11	2060			15	Flows from Twin Creek limestone.
M-32	Slump Spring 8S 44E 17ddS	5	2080			5.5	Flows from Thaynes formation along Schmid syncline.
M-33	Lower Young Ranch 8S 44E 21acS	4	2080			17	Flows from Dinwoody formation along Schmid syncline.
M-34	Lower Lone Tree 8S 44E 28bbS	8	2065			5.5	Flows from Thaynes formation along Schmid syncline.
M-35	Cold Spring 10S 44E 3ddS	4	2095			3	Flows from Wells formation along Schmid syncline.
M-36	FMC 8S 44E 16bd	8	2000	435			Well penetrates only the Wells formation.
M-37	Square Pond 9S 44E 5ddS	8	1955			190	Flows from Dinwoody formation along Schmid syncline.
M-38	Knudsen Ranch 8S 44E 30dbS	12	1940			100	Flows from Dinwoody formation along Schmid syncline.

Table IV-1. Continued

Sample Number	Name and Location	Water Temp. (°C)	Elevation (m above MSL)	Well Depth (m)	Depth to Water (m)	Discharge (l/s)	Site Description
M-39	Purple Spring 8S 43E 11cdS	11	1935			35	Flows from Wells formation along Schmid syncline.
M-40	Peterson Ranch 9S 44E 5cd	8	1955				Well is shallow alluvium in Slug Creek Valley.

Table IV-2. Hydrochemisty of springs and wells in the Meade thrust subarea.

Sample Number	Name and Location	Water Temp. °C	Specific Conductance (μmho/cm)	TDS (mg/l)	pH	Concentration in mg/l (meq/l)								
						Ca	Mg	Na	K	Cl	F	HCO_3	SO_4	SiO_2
M-1	Sink Hole 4S 41E 32bbS	19		804	6.8	147 (7.3)	29 (2.4)	27 (1.2)	3 (0.1)	29 (0.8)	0.6 (0.03)	504 (8.3)	33 (0.7)	31
M-2	North Woodall 7S 42E 27acS	17	1640	1701	6.3	382 (19.1)	49 (4.0)	4 (0.2)	1 (0.04)	3 (0.07)	1 (0.05)	1182 (19.4)	48 (1)	31
M-3	Woodall 7S 42E 34baS	13	1040	1137	6.6	232 (11.6)	35 (2.9)	1 (0.1)	0.3 (0.01)	2 (0.05)	0.4 (0.02)	790 (12.9)	37 (0.8)	39
M-4	Formation 8S 42E 27cbS	11	920	931	6.6	190 (9.5)	29 (2.4)	0.4 (0.02)	1 (0.03)	6 (0.2)	0.3 (0.02)	622 (10.2)	57 (1.2)	25
M-5	East Soda 9S 42E 10acS	9	775	725	7	124 (6.2)	31 (2.5)	2 (0.1)	1 (0.03)	4 (0.1)	0.2 (0.01)	513 (8.4)	35 (0.7)	15
M-6	Sulphur Canyon 9S 42E 13bc	10	660	607	7.2	121 (6)	20 (1.6)	2 (0.1)	1 (0.03)	4 (0.1)	0.2 (0.01)	438 (7.2)	10 (0.2)	11
M-7	Swan Lake #1 (Lakey Res.) 9S 43E 29ccS	16	1020	1089	6.7	220 (11)	36 (3)	3 (0.1)	0.3 (0.01)	3 (0.1)	0.2 (0.01)	751 (12.3)	57 (1.2)	19
M-8	Swan Lake #2 9S 43E 30ccS	9	850	881	7.1	158 (7.9)	36 (3)	3 (0.2)	0 (0)	4 (0.1)	0.1 (0.01)	604 (9.9)	52 (1.1)	24
M-9	Lone Tree 6S 42E 6abS	26	1570	1506	6.4	314 (15.7)	39 (3.2)	26 (1.1)	18 (0.5)	26 (0.7)	1.7 (0.09)	989 (16.2)	75 (1.6)	17
M-10	Henry Warm #1 6S 42E 9acS	15	970	934	6.8	178 (8.9)	34 (2.8)	16 (0.7)	2 (0.06)	15 (0.4)	0.5 (0.03)	624 (10.2)	46 (1)	18
M-11	Henry Warm #2 6S 42E 9bcS	20	1410	1449	6.4	284 (14.2)	44 (3.6)	25 (1.1)	8 (0.2)	32 (0.9)	1 (0.05)	870 (14.3)	145 (3)	40
M-12	Warm Spring 6S 42E 8dbS	23	1510	1485	6.3	277 (13.8)	47 (3.9)	22 (1)	14 (0.4)	20 (0.6)	1.7 (0.09)	994 (16.3)	84 (1.7)	25
M-13	North Henry 6S 42E 10bcS	15	870	792	6.8	129 (6.4)	31 (2.5)	11 (0.5)	2 (0.05)	11 (0.3)	0.5 (0.02)	566 (9.3)	26 (0.5)	15
M-14	Little Blackfoot River 6S 42E 15baS	15	940	982	6.7	200 (10)	33 (2.7)	11 (0.5)	2 (0.04)	13 (0.4)	0.5 (0.03)	674 (11.1)	42 (0.9)	7
M-15	Chubb 5S 42E 11ccS	12	545	458	7.5	61 (3)	20 (1.6)	24 (1.1)	2 (0.05)	26 (0.7)	0.3 (0.02)	240 (3.9)	61 (1.3)	24
M-16	West Chubb 5S 42E 10daS	12	510	447	7.3	62 (3.1)	19 (1.6)	20 (0.9)	1 (0.03)	21 (0.6)	0.3 (0.01)	234 (3.8)	65 (1.4)	25
M-17	Pelican Ridge #1 5S 42E 39dcS	7	465	440	7.2	70 (3.5)	19 (1.6)	4 (0.2)	1 (0.01)	6 (0.2)	trace (0)	294 (4.8)	17 (0.4)	29
M-18	Pelican Ridge #2 5S 42E 24dcS	7	540	489	7.2	77 (3.8)	23 (1.9)	3 (0.2)	1 (0.02)	8 (0.2)	0.1 (0.01)	325 (5.3)	34 (0.7)	18

Table IV-2. Continued

Sample Number	Name and Location	Water Temp. °C	Specific Conductance (μmho/cm)	TDS (mg/l)	pH	Concentration in mg/l (meq/l)								
						Ca	Mg	Na	K	Cl	F	HCO_3	SO_4	SiO_2
M-19	North Pelican 5S 42E 17bcS	8	290	252	7.5	50 (2.5)	7 (0.6)	2 (0.08)	0.2 (0.01)	3 (0.07)	trace (0)	170 (2.8)	6 (0.1)	14
M-20	Big Spring 10S 44E 28ccS	8	505	465	7.3	90 (4.5)	16 (1.3)	trace (0)	0 (0)	2 (0.06)	0.1 (0.01)	244 (4)	96 (2)	17
M-21	Georgetown Canyon 10S 44E 35dcS	7		361	7.4	63 (3.1)	15 (1.2)	trace (0)	0.5 (0.01)	0 (0)	0.1 (0.01)	195 (3.2)	69 (1.4)	18
M-22	Georgetown Canyon Tailings 10S 44E 35cdS	8	350	335	7.5	64 (3.2)	16 (1.3)	trace (0)	0.5 (0.01)	0 (0)	0.2 (0.01)	250 (4.1)	2 (0.05)	2
M-23	Crow Creek Ranch 10S 45E 15acS	7	360	338	7.4	59 (3)	14 (1.2)	2 (0.07)	0.5 (0.01)	2 (0.05)	0.1 (0.01)	226 (3.7)	22 (0.5)	12
M-24	Brooks Spring 10S 45E 1daS	12	425	396	7.5	58 (2.9)	16 (1.3)	20 (0.9)	0 (0)	27 (0.8)	0.4 (0.02)	233 (3.8)	7 (0.2)	35
M-25	Fence Line 9S 46E 19adS	10	410	458	7.1	60 (3)	17 (1.4)	3 (0.1)	0.5 (0.01)	4 (0.1)	0.2 (0.01)	249 (4.1)	88 (0.2)	36
M-26	South Fork 9S 46E 18daS	12	400	353	7.4	54 (2.7)	21 (1.7)	4 (0.2)	0.5 (0.01)	10 (0.3)	0.3 (0.02)	236 (3.9)	0 (0)	27
M-27	Sage Valley 9S 46E 18adS	12	460	397	7.5	64 (3.2)	21 (1.7)	6 (0.2)	0 (0)	7 (0.2)	0.4 (0.02)	232 (3.8)	38 (0.8)	29
M-28	Auburn Fish Hatchery 8S 46E 5baS	9	440	368	7.5	58 (3.9)	21 (1.7)	6 (0.3)	1 (0.03)	2 (0.06)	0.1 (0.01)	232 (3.8)	16 (0.3)	32
M-29	Star Valley Hatchery 7S 46E 32bdS	9	590	347	7.7	54 (2.6)	17 (1.4)	2 (0.07)	0.5 (0.01)	4 (0.1)	0.2 (0.01)	231 (3.8)	15 (0.3)	23
M-30	Nuggett 9S 46E 20caS	10		427	7.4	68 (3.4)	24 (1.9)	7 (0.3)	0 (0)	5 (4.7)	0.2 (0.01)	256 (4.2)	37 (0.8)	30
M-31	New Salt 10S 45E 1daS	11	1150	906	7.4	144 (7.2)	29 (2.4)	82 (3.6)	2 (0.05)	87 (2.5)	0.3 (0.02)	277 (4.5)	241 (5)	44
M-32	Slump Spring 8S 44E 17ddS	5	460	413	7.1	82 (4.1)	13 (1)	6 (0.3)	0 (0)	12 (0.3)	0.1 (0.01)	262 (4.3)	19 (0.4)	19
M-33	Lower Young Ranch 8S 44E 21acS	4	500	490	7	108 (5.4)	10 (0.8)	1 (0.04)	0.5 (0.01)	10 (0.3)	0 (0)	312 (5.1)	19 (0.4)	29
M-34	Lower Lone Tree 8S 44E 28bbS	8	440	433	7.2	90 (4.5)	11 (0.9)	3 (0.1)	0.8 (0.02)	3 (0.07)	0.1 (0.01)	269 (4.4)	26 (0.5)	30
M-35	Cold Spring 10S 44E 3ddS	4		385	7.5	74 (3.7)	5 (0.4)	4 (0.2)	4 (0.09)	0 (0)	0.3 (0.02)	238 (3.9)	14 (0.3)	46
M-36	FMC 8S 44E 16bd	8	430	372	7.4	51 (2.6)	18 (1.5)	3 (0.1)	0.8 (0.02)	3 (0.08)	0.1 (0.01)	257 (4.2)	18 (0.4)	21

Table IV-2. Continued

Sample Number	Name and Location	Water Temp. °C	Specific Conductance (μmho/cm)	TDS (mg/l)	pH	Concentration in mg/l (meq/l)								
						Ca	Mg	Na	K	Cl	F	HCO_3	SO_4	SiO_2
M-37	Square Pond 9S 44E 5ddS	8	390	330	7.3	55 (2.7)	12 (1)	6 (0.3)	0.8 (0.02)	4 (0.1)	0.1 (0.01)	224 (3.7)	8 (0.2)	20
M-38	Knudsen Ranch 8S 44E 30dbS	12	360	367	7.5	63 (3.1)	15 (1.2)	8 (0.4)	2 (0.06)	5 (0.1)	trace (0)	238 (3.9)	17 (0.4)	19
M-39	Purple Spring 8S 43E 11cdS	11	440	376	7.3	50 (2.5)	21 (1.8)	7 (0.3)	2 (0.04)	4 (0.1)	0.2 (0.01)	254 (4.2)	21 (0.4)	17
M-40	Peterson Ranch 9S 44E 5cd	8	320	187	6.4	8 (0.4)	7 (0.6)	14 (0.6)	18 (0.5)	9 (0.2)	0.2 (0.01)	89 (1.5)	11 (0.2)	31

Bear River Valley graben, surficial deposits include Quaternary age basaltic lavas, travertine, alluvium and exposures of the Tertiary age Salt Lake formation.

The faults from which the springs issue are part of a major frontal fault zone extending more than 40 km in a north-northwesterly direction along the base of the Aspen Range. The fault zone has been investigated by serveral researchers. Mansfield (1927) originally identified much of the zone as the eastern edge of a window in his Bannock overthrust. More recent work by Armstrong and Cressman (1963), Cressman (1964), and Armstrong (1969) suggest the high angle fault interpretation with at least 900 to 1500 m of stratigraphic throw along the frontal fault zone. The ninth spring (M-1) in this group issues from the Enoch Valley fault at the base of Wilson Ridge.

All of the springs in this group are either actively depositing or have deposited large travertine terraces covering several square kilometers each. Several travertine deposits are present along the base of the Aspen Range not associated with active springs. These show the migration of discharge areas along the frontal fault zone. In all, the frontal fault travertine terraces extend for 48 km along the base of the Aspen Range covering about 43 km^2. The maximum thickness of the travertine deposits is not known; however, a collapse structure in the terrace at Swan Lake exposes more than 23 m of travertine during times of low lake level.

Henry Group

Six springs (M-9 to M-14) in the vicinity of Henry have been placed into this group. All of the springs are warm, with temperatures in the range of 14 to 26°C. Four of the springs issue from a 4.2 km^2 travertine terrace at Henry, one from a 0.9 km^2 terrace 5 km northwest of Henry and one from a samll travertine area along the Little Blackfoot River 1.6 km southeast of Henry. The springs occur along the northeast border of the central Blackfoot Reservoir graben. Several concealed fault traces which displace pre-Tertiary age strata were postulated by Mansfield (1927) to intersect in or to traverse the area. The springs are associated with travertine mounds, terraces, cones, ledges and pools. None of the springs appear to be actively depositing travertine.

Chubb Spring Group

The five springs which issue along a 3 km section of the Chubb Spring fault at the base of Little Grays ridge have been placed into this group. Water samples were collected from two sites (M-15 and M-16) which are located about 760 m apart. All of the springs have discharge temperatures of about 12°C and appear to have fairly constant flow.

Four of the springs flow from the carboniferous age Brazer formation along the base of Little Grays ridge while the fifth spring flows from basaltic lava which covers the fault trace. No travertine was associated with any of the springs.

Pelican Ridge Group

Six springs and numerous seeps were located in the Pelican Ridge area and water samples were collected at three sites. The first two sites (M-17 and M-18) issue from a narrow strip of Triassic age Dinwoody formation which crops out along the southern base of Pelican Ridge (Meadow Creek horst). The third spring sampled (M-19) is one of two springs and at least four seeps which issue from the base of a 5 km long, low ridge of Dinwoody formation along the south side of Meadow Creek graben. Rocks in the ridge dip 40° to 75° northward and are separated from Pelican Ridge by a slope wash covered trough. The trough contains the Limerock fault and delineates the boundary between the Meadow Creek graben and horst. Mansfield (1927) estimated the stratigraphic throw along the fault to be 900 to 1200 m.

The discharge from the springs and seeps is cold, about 8°C, and appears to decline substantially throughout the summer. North Pelican spring was flowing about 14 l/s (liters/second) in mid July, 1980.

Georgetown Canyon Group

Springs in the area issue from faults and appear to be related to the Georgetown and Dairy synclines. Georgetown Canyon spring (M-21) issues from a discontinuous splay of the Meade thrust separating slices of the Mississippian age Brazer limestone and the Pennsylvania age Wells formation in the closed end of the Georgetown Canyon syncline. A nearby spring (M-22) issues from the base of an abandoned phosphate mill tailing pile which fills a small tributary canyon. Big Spring (M-20) issues from the left fork of Twin Creek where a normal fault that cuts the closed end of Dairy syncline crosses the creek bed. The fault is part of the block fault system post dating the thrusting episode and has a stratigraphic throw of at least 900 m (Cressman, 1964).

Eastern Thrust Springs

Nine springs (M-23 to M-31) were sampled that issue from splays of the Meade thrust associated structures along the eastern edge of the allochthon. The thrust splays crop out along the eastern front of Webster Range; the springs are generally associated with the Wells and Brazer formations.

Dry Valley-Schmid Ridge-Slug Creek Group

The Dry Valley-Schmid Ridge-Slug Creek area was investigated to evaluate the chemical characteristics of ground water flow systems whose physical properties have been well documented (Ralston and others, 1977). Nine springs were sampled. Four (M-32 to M-35) are from intermediate flow systems in the Thaynes and Dinwoody formations; one well was sampled that is located in the recharge area of a Dry Valley-Slug Creek interbasin flow system (M-36). Three springs (M-37 to M-39) are in the discharge area of the interbasin flow system, and one well (M-40) sampled is in a local alluvial flow system in Slug Creek.

CHAPTER V

HYDROGEOLOGIC RECONNAISSANCE OF THE SOUTHERN SUBAREA

Introduction

This portion of the study is a hydrogeological reconnaissance of the region bordered roughly by the Blackfoot River on the north, Cache Valley on the west and the Idaho state line on the south and east (Figure I-1). The study area encompasses approximately 4,7000 km^2 in parts of Bear Lake, Caribou, and Franklin counties, Idaho.

A total of 34 springs and four wells were sampled during the 1980 field season. Twenty of these sites had water temperatures less than or equal to 15.5°C. Eleven sites had temperatures in the range of 15.5-40°C and seven sites had temperatures greater than 40°C. Eleven sites were known thermal discharges that had been previously analyzed. Thirteen selected wells sampled and analyzed by Dion (1969) are also included in this study. The spring and well locations are shown on Figure V-1.

The southern subarea is characterized by north and northwest trending mountain ranges and valleys. The principle mountain ranges in the study area are the Bear River Range trending north-south from Soda Springs southward into Utah, and the Chesterfield Range trending northwest from Soda Springs to the Blackfoot River. The Portneuf Range joins the Bear River Range in a hilly region on the western side of the study area.

Elevation generally increases from the southwest to the east and northeast. The lowest elevation is about 1,395 m near Franklin in the southwest corner, and the highest elevation is 2,998 m at the summit of Sherman Peak in the northern Bear River Range. Local reliefs of 300 to 600 m are common in the area.

Hydrogeologic Framework

Regional Geology

The Bear River and Chesterfield ranges combine to form a major north and northwest trending horst. The Paris thrust, on the eastern boundary of the horst, begins the series of great thrusts that comprise the overthrust belt. Here the rocks have intense folds, many of which are overturned to the east and cut by younger thrust faults of great length and displacement. In the horst and to the west, folding decreases in intensity and frequency, and normal faulting increases (Keller, 1963). Horsts and grabens, characteristic of the Basin and Range Province, continue to the west. The Portneuf Range joins the Bear River Range in an intensely faulted hilly divide north of the village of Mink Creek.

Bear River Range. The Bear River Range is bounded on the east by the Bear River valley and on the west by the Cache Valley to the south and the Gem Valley to the north. The Bear River Range is "a deeply eroded, synclinal, karst plateau, with wide basins and occasional ridges and peaks on top" (Keller, 1963, p. 60). The range consists mostly of Cambrian to Ordivician marine sediments of the Fish Haven syncline. The range is bounded on the east by the Paris overthrust and on the west by the East Cache fault. Witkind (1975), though, interprets the east side of the range as a normal fault. The flanks of the range are covered in large areas by Tertiary Salt Lake sediments.

Portneuf Range. Only the southern Portneuf Range where it joins the Bear River Range is within the study area and, consequently, of interest. The southern Portneuf Range is bordered by the Cache Valley to the south and Gentile and Mound valleys to the northeast. North of the junction with the Bear River Range, the Portneuf Range is composed of relatively simple, faulted homoclines of lower Paleozoic rocks dipping generally to the northeast. The structure becomes complex at the range junction with a very high intensity of normal and reverse faults. Keller (1963) notes areas at the junction of extreme brecciation. Highly altered Precambrian metasediments outcrop in several localities in this area.

Chesterfield Range. The southern extension of the Chesterfield Range, the Soda Springs Hills, are separated from the Bear River Range by Soda Gap. A major tear fault of the Paris thrust is interpreted by Armstrong (1969) as passing through the gap. The Soda Springs Hills are bordered on the west by Gem Valley and on the northeast by the Blackfoot Lava Field. The Soda Springs Hills are composed of middle Cambrian to Mississippian sediments in a block faulted homocline dipping generally to the northeast, although, relative movements of the blocks cause some variation in the dips. The range is separated from Gem Valley on the west by the East Gem Valley fault, and from the Blackfoot Lava Field on the east by the Bear River fault (Witkind, 1975). Northwest of Soda Springs Hills, the Paleozoic sediments of the Chesterfield Range are covered by extensive deposits of the Tertiary Salt Lake formation.

Bear River Valley Graben. The Bear River Valley graben is a long narrow graben extending from Bear Lake to near Blackfoot Reservoir. It is bordered on the east by a high angle normal fault extending in length at least 88 to 96 km and is reported to have broken basalts in the Blackfoot Lava Field (Witkind, 1975). The characteristics of the west border of the graben are uncertain. Keller (1963) calls it a half-graben bordered on the west by the Paris thrust fault, while Witkind (1975) shows an en echelon series of short high angle normal faults.

Gem Valley Graben. Gem Valley graben is bordered on the east by the East Gem Valley fault, a high angle normal fault extending about 48 km, and on the west by the West Gem Valley fault extending about 40 km (Witkind, 1975). Gem Valley is almost entirely covered with Quaternary basalts which are thin near the edges and thicken to about 620 m in the center (Mabey and Oriel, 1970).

Cache Valley Graben. The northern Cache Valley is a complex half-graben bounded on the east by the East Cache fault (Keller, 1963). The western boundary of the graben is covered by Pleistocene Lake Bonneville alluvium; the East Cache fault is covered in places by Tertiary sediments. The graben is filled with about 3,100 m of Tertiary sediments.

Hydrology

The Bear River is the predominant drainage in the area. A portion of the Portneuf River Basin in Gem Valley is included in the northwest corner of the study area. A small part of the Blackfoot River Basin is also included in the northeast corner of the area. The Bear River is a gaining stream along most of its course through Idaho, but appears to be losing water to the basalt aquifer along the reach between Alexander and Grace (Dion, 1969).

Four major non-thermal ground water flow systems have been identified in the subarea by previous investigators: 1) the Blackfoot Lava Field and Gem Valley basalt systems, 2) the Bear Lake Valley alluvial system, 3) the Cache Valley alluvial system, and 4) the Bear River Range system. Data on these systems are presented by Dion (1969, 1974), McGreevey and Bjorklund (1970), and Bjorklund and McGreevey (1971).

Thermal springs or wells occur at several locations within the area; most of them have been documented previously by the Idaho Department of Water Resources (Mitchell, 1976a, 1976b and Mitchell and others, 1980) and by the U. S. Geological Survey (Dion, 1969, and Mansfield, 1927). Groups of thermal springs occur at Soda Springs, the northeast shore of Bear Lake, the Cleveland area, and the east side of Gem Valley above Soda Gap; groups of thermal wells are located at Corral Creek and at Riverdale. Isolated thermal springs appear at Pescadero and Gentile Valley. These thermal occurrences all appear to be fracture or fault related.

Physical and Chemical Settings of Springs and Wells

The sites sampled were selected to represent as completely as possible the thermal and non-thermal ground water flow systems within the southern subarea. Descriptions of the physical settings of the sites are listed in Table V-1. The results of the chemical analyses are listed in Table V-2.

Table V-1. Physical settings of springs and wells in the southern subarea.

Sample Number	Name and Location	Water Temp. (°C)	Elevation (m above MSL)	Well Depth (m)	Depth to Water (m)	Discharge (l/s)	Site Description
B-1	Corral Creek Well 6S 41E 19bbd	40	1884	?	flowing		One of many phosphate exploration holes drilled by FMC into a broad north-northwest trending anticline of upper-Paleozoic rocks. The holes average 57 m in depth.
B-2	Gem Valley Spring #1 8S 40E 26bdcS	13	1707			5.7	Flows out of extensive flat travertine deposit over-Quaternary basalt, approximately on the East Gem Valley fault. Ordovician Garden City limestone outcrops in range near spring.
B-3	Thermal Gradient Well 8S 40E 26dbc	15	1707	61	flowing	1.4	Well drilled by Phillips Petroleum as thermal gradient hole. Located just south of spring B-2 along same graben-forming normal fault.
B-4	Gem Valley Spring #2 8S 40E 26dcbS	16	1722			14	Flows out of base of 3m high bluff in Quaternary basalt just south of sites B-2 and B-3. Spring is depositing thin layer of white calcareous tufa on the basalt.
B-5	Soda Creek Headwaters 8S 41E 26dabS	13	1814			140	One of many springs that well up through thin veneer of alluvium overlying basalt of Blackfoot Lava Field.
B-6	Hooper Spring 8S 41E 36dddS	10	1798			23	Flows out of Quaternary basalt of Blackfoot Lava Field near contact with Paleozoic sediments forming Soda Springs Hills.
B-7	Soda Springs Geyser 9S 41E 12adaS	29	1770				One of several small springs occurring along a north-south trending fracture trace through a large travertine mound in downtown Soda Springs.
B-8	Unnamed Spring 10S 42E 12ccbS	8	1800			0.8	Flows out of Tertiary Salt Lake formation, composed of large rounded quartzitic boulders, near contact with Bear River floodplain.
B-9	Cold Spring 10S 42E 31daaS	7	1950			160	Flows out of base of hill marking the contact between shallow alluvium of Cow's Fork and Cambrian Blacksmith limestone.

Table V-1. Continued

Sample Number	Name and Location	Water Temp. (°C)	Elevation (m above MSL)	Well Depth (m)	Depth to Water (m)	Discharge (l/s)	Site Description
B-10	Trout Creek Spring 11S 41E 15cdaS	5	1710			200 E	Flows out of Cambrian Nounan limestone. A short distance down the canyon is a large apparently old travertine deposit.
B-11	Unnamed Spring 12S 41E 18acdS	13	1510			440	Flows out of thin Quaternary alluvium in shallow broad valley overlying Paleozoic rocks, either the Cambrian Nounan or Cambrian St. Charles limestone.
B-12	Harris Spring 11S 41E 8dbcS	10	1600			<10 E	Spring emerges high on Quaternary basalt bluff where the lavas of the Gem Valley terminate above Gentile Valley.
B-13	Pescadero Warm Spring 11S 43E 36bdaS	23	1820			0.6 R	Spring flows from top of large travertine bluff overlooking Bear River. Extensive travertine mound overlies lower Triassic Thaynes limestone.
B-14	Unnamed Spring 12S 44E 7baaS	12	1940			3	Flows out of Tertiary Salt Lake formation and is piped about 90 m into watering trough.
B-15	Unnamed Spring 13S 43E 8daaS	11	1820			20	Spring occurs at the contact between the Quaternary alluvium and lower Triassic Thaynes limestone.
B-16	Williams Creek Spring 12S 41E 27bbaS	7	1710			420 E	Flows out of Cambrian Nounan limestone dipping approximately 10-15° to the northeast.
B-17	Unnamed Spring 12S 41E 31abcS	18	1540				Flows out of large travertine mound overlying Quaternary lacustrine sediments which also overlay Cambrian Blacksmith (?) limestone.
B-18	Mink Creek Spring 13S 41E 24bbcS	6	1800			280 E	Flows out of Cambrian Nounan limestone dipping 10-20° to the northeast. Highly faulted and fractured area.
B-19	Paris Creek Spring 14S 42E 13badS	9	2000			850 E	Issues from base of very high cliff at head of Paris Creek. Cliff is mostly Cambrian Bloomington limestone.
B-20	Jarvis Spring 14S 43E 19bcdS	7	1930			410	Flows out of Cambrian Blacksmith limestone in Bloomington Canyon.

Table V-1. Continued

Sample Number	Name and Location	Water Temp. (°C)	Elevation (m above MSL)	Well Depth (m)	Depth to Water (m)	Discharge (l/s)	Site Description
B-21	Unnamed Spring 14S 41E 15acdS	8	1910				Flows out of Cambrian Brigham Quartzite dipping approximately 30° to the east. Rock is very hard and appears highly fractured.
B-22	Burgquist Spring 15S 41E 10aadS	6	1780			420 E	Flows out of Cambrian Nounan limestone dipping about 10-20° to the northeast.
B-23	Sadducee Spring 16S 43E 8cbbS	6	2100			230	Issues from side of canyon and out of middle to lower section of Ordivician Garden City limestone.
B-24	Unnamed Spring 16S 40E 15ddbS	9	1440			3 E	Seeps out of Quaternary alluvium next to Maple Creek. Cement holding tank and pump house constructed over spring for domestic water supply.
B-25	Bear Lake Hot Spring #1 15S 44E 13ccaS	40	1810				Located along escarpment of East Bear River Valley fault. Mississippian Brazier limestone forms the slope.
B-26	Bear Lake Hot Spring #2 15S 44E 13cbaS	39	1810				Located about .3 km north of spring number B-25 along the escarpment.
B-27	Bear Lake Hot Spring #3 15S 44E 12ccdS	33	1810				Located 1.3 km north of spring B-25 along the escarpment. The spring seeps out of colluvium.
B-28	Gentile Valley Spring #1 11S 40E 5aaaS	22	1510			140	Flows at contact of Bear River alluvium and Ordovician Garden City limestone. Extensive travertine deposit on opposite side of hill, apparently unrelated to the spring.
B-29	Gentile Valley Spring #2 10S 40E 32abdS	14	1520			48	Spring flows out of fracture in Ordovician Swan Peak quartzite dipping 38° to the northeast at contact with Quaternary terrace gravels.
B-30	Gentile Valley Spring #3 11S 40E 8dddS	30	1520			45	Flows out of alluvium through clean gravel bottom, closest Paleozoic outcrop is Cambrian Blacksmith limestone, is about one mile to the northwest.

Table V-1. Continued

Sample Number	Name and Location	Water Temp. (°C)	Elevation (m above MSL)	Well Depth (m)	Depth to Water (m)	Discharge (l/s)	Site Description
B-31	Ben Meek Well 14S 39E 36ada	40	1380	12	1.8		Well drilled into Bear River alluvium about .3 km south of the river. Several wells in the vicinity also contain hot water. Well is located along Mink Creek lineament.
B-32	Orvil Rallison Well 16S 40E 16cac	15	1370	24	flowing		Well drilled into alluvium of Cub River about .5 km southeast of the river.
S-2	Blackfoot River W. S. 5S 40E 14bcdS	28	1850			0.3 E	Spring discharges out of large travertine mound on side of basalt bluff southeast of spring S-3 about 12-16 m above Blackfoot River.
S-3	Unnamed Spring 5S 40E 15bacS	18	1880				Water is standing in a 5 m high travertine mound at top of Quaternary basalt bluff just north of Blackfoot River, and is evolving CO_2 gas.
S-7	Mound Valley Warm Spring 12S 40E 13dcdS	34	1530			<0.1 E	Trickles out of large travertine mound about 30 m tall above Bear River floodplain about 150 m east of the river.
S-8	Cleveland Hot Springs 12S 41E 31cacS	55	1520				One of many discharges through a large travertine bluff overlooking Bear River. Discharges can be seen welling up in river also.
S-9	Unnamed Warm Spring 12S 41E 31badS	21	1510			30 E	Flows out of extensive travertine mound further down the hill from spring B-17.
S-10	Treasureton Warm Spring 12S 40E 36acdS	40	1510				One of several springs discharging through Quaternary alluvium on west side of Bear River from springs at S-8.
S-11	Maple Grove Hot Spring 13S 41E 7acaS	75	1500			2 E	One of many springs issuing from Cambrian Brigham quartzite. Spring is actively depositing tufa.
S-12	Unnamed Hot Spring 13S 41E 7dabS	62	1520			<1 E	About .5 km south of spring S-11 and also flows out of Cambrian Brigham quartzite. Associated small tufa deposits.

E = estimated discharge, R = reported discharge, all others are measured discharge.

Table V-2. Hydrochemistry of springs and wells in the southern subarea.

Sample Number	Name and Location	Water Temp. °C	Specific Conductance (μmho/cm)	TDS (mg/l)	pH	Concentration in mg/l (meq/l)								
						Ca	Mg	Na	K	Cl	F	HCO_3	SO_4	SiO_2
B-1	Corral Creek Well 6S 41E 19bbd	40	4900	5267	6.9	745 (37.2)	244 (20.1)	53 (2.3)	222 (5.7)	39 (1.1)	1.8 (0.09)	3016 (49.5)	915 (19)	31
B-2	Gem Valley Spring #1 8S 40E 26bdcS	13	1775	1806	6.6	261 (13)	126 (10.4)	23 (1)	8 (0.2)	13 (0.4)	0 (0)	1231 (20.2)	123 (2.6)	21
B-3	Thermal Gradient Well 8S 40E 26dbc	15	2400	2221	6.5	345 (17.2)	118 (9.7)	26 (1.1)	12 (0.3)	2 (0.07)	0 (0)	1529 (25.1)	147 (3.1)	42
B-4	Gem Valley Spring #2 8S 40E 26dcbS	16	2400	2320	6.5	361 (18)	120 (9.9)	28 (1.2)	12 (0.3)	13 (0.4)	0 (0)	1592 (26.1)	153 (3.2)	41
B-5	Soda Creek Headwaters 8S 41E 26dabS	13	1450	1595	6.2	124 (6.2)	141 (11.6)	49 (2.1)	16 (0.4)	10 (0.3)	0.4 (0.02)	1106 (18.1)	37 (0.8)	112
B-6	Hooper Spring 8S 41E 36dddS	10	1300	1406	6.3	106 (5.3)	111 (9.1)	36 (1.6)	11 (0.3)	9 (0.3)	0.5 (0.03)	1007 (16.5)	41 (0.9)	85
B-7	Soda Springs Geyser 9S 41E 12adaS	29	4025	4694	6.8	925 (46.2)	150 (12.4)	3 (0.1)	18 (0.5)	3 (0.08)	0.4 (0.02)	2778 (45.6)	771 (16)	46
B-8	Unnamed Spring 10S 42E 12ccbS	8	460	451	7.7	79 (3.9)	13 (1.1)	9 (0.4)	2 (0.05)	5 (0.1)	0.2 (0.01)	297 (4.9)	10 (0.2)	36
B-9	Cold Spring 10S 42E 31daaS	7	250	217	7.9	47 (2.4)	6 (0.5)	2 (0.09)	0 (0)	0 (0)	0 (0)	155 (2.5)	0 (0)	7
B-10	Trout Creek Spring 11S 41E 15cdaS	5	325	311	7.0	63 (3.1)	12 (1)	4 (0.2)	0 (0)	9 (0.3)	0 (0)	223 (3.7)	0 (0)	0
B-11	Unnamed Spring 12S 41E 18acdS	13	425	372	7.1	52 (2.6)	20 (1.6)	7 (0.3)	0 (0)	7 (0.2)	0 (0)	277 (4.5)	0 (0)	9
B-12	Harris Spring 11S 41E 8dbcS	10	650	543	7.1	111 (5.5)	0 (0)	9 (0.4)	0 (0)	17 (0.5)	0 (0)	361 (5.9)	18 (0.4)	27
B-13	Pescadero Warm Spring 11S 43E 36bdaS	23	1475	1380	7.0	194 (9.7)	46 (3.8)	70 (3)	13 (2.9)	74 (2.1)	2.3 (0.1)	749 (12.3)	215 (4.5)	17
B-14	Unnamed Spring 12S 44E 7baaS	12	550	464	7.0	72 (3.6)	21 (1.7)	11 (0.5)	0 (0)	10 (0.3)	0.2 (0.01)	317 (5.2)	0 (0)	33
B-15	Unnamed Spring 13S 43E 8daaS	11	440	346	7.0	42 (2.1)	19 (1.6)	22 (0.9)	0 (0)	8 (0.2)	0.2 (0.01)	236 (3.9)	4 (0.08)	15
B-16	Williams Creek Spring 12S 41E 27bbaS	7		325	7.2	55 (2.7)	17 (1.4)	0 (0)	0 (0)	3 (0.08)	0 (0)	250 (4.1)	0 (0)	0
B-17	Unnamed Spring 12S 41E 31abcS	18	775	666	7.1	94 (4.7)	28 (2.3)	37 (1.6)	3 (0.07)	30 (0.9)	0.3 (0.02)	439 (7.2)	26 (0.5)	9

Table V-2. Continued

Sample Number	Name and Location	Water Temp. °C	Specific Conductance (µmhc/cm)	TDS (mg/l)	pH	Concentration in mg/l (meq/l)								
						Ca	Mg	Na	K	Cl	F	HCO_3	SO_4	SiO_2
B-18	Mink Creek Spring 13S 41E 24bbcS	6	245	205	7.4	46 (2.3)	5 (0.4)	3 (0.1)	1 (0.03)	2 (0.05)	0 (0)	148 (2.4)	0 (0)	0
B-19	Paris Creek Spring 14S 42E 13badS	9	325	256	6.9	58 (2.9)	5 (0.4)	2 (0.1)	0 (0)	1 (0.03)	0 (0)	190 (3.1)	0 (0)	0
B-20	Jarvis Spring 14S 43E 19bcdS	7	350	284	7.0	48 (2.4)	17 (1.4)	0 (0)	0 (0)	6 (0.2)	0 (0)	213 (3.5)	0 (0)	0
B-21	Unnamed Spring 14S 41E 15acdS	8	440	361	7.2	77 (3.8)	9 (0.7)	2 (0.1)	0 (0)	4 (0.1)	0 (0)	259 (4.2)	3 (0.06)	7
B-22	Burgquist Spring 15S 41E 10aadS	6	300	271	7.7	56 (2.8)	11 (0.9)	1 (0.04)	0 (0)	4 (0.1)	0 (0)	195 (3.2)	4 (0.08)	0
B-23	Sadducee Spring 16S 43E 8cbbS	6	300	251	7.2	49 (2.5)	12 (1)	0 (0)	0 (0)	1 (0.03)	0 (0)	189 (3.1)	0 (0)	0
B-24	Unnamed Spring 16S 40E 15ddbS	9	310	221	7.3	40 (2)	8 (0.7)	0 (0)	0 (0)	3 (0.1)	0 (0)	159 (2.6)	2 (0.04)	9
B-25	Bear Lake Hot Spring #1 15S 44E 13ccaS	40	2250	1625	7.0	230 (11.5)	41 (3.4)	155 (6.7)	48 (1.2)	72 (2)	4.2 (0.2)	263 (4.3)	769 (16)	43
B-26	Bear Lake Hot Spring #2 15S 44E 13cbaS	39	1975	1634	7.2	227 (11.3)	41 (3.4)	151 (6.5)	44 (1.1)	75 (2.1)	4.2 (0.2)	255 (4.2)	791 (16.5)	46
B-27	Bear Lake Hot Spring #3 15S 44E 12ccdS	33	1900	1621	7.1	227 (11.3)	41 (3.4)	163 (7.1)	43 (1.1)	74 (2.1)	4 (0.2)	271 (4.4)	758 (15.8)	40
B-28	Gentile Valley Spring #1 11S 40E 5aaaS	22	1825	1698	6.1	239 (11.9)	47 (3.9)	92 (4)	34 (0.9)	78 (2.2)	0.2 (0.01)	1086 (17.8)	104 (2.2)	18
B-29	Gentile Valley Spring #2 10S 40E 32abdS	14	625	524	7.0	60 (3)	30 (2.5)	29 (1.3)	0 (0)	33 (0.9)	0.1 (0.01)	332 (5.4)	23 (0.5)	17
B-30	Gentile Valley Spring #3 11S 40E 8dddS	30		930	6.6	132 (6.6)	38 (3.1)	54 (2.3)	3 (0.07)	43 (1.2)	0.2 (0.01)	594 (9.7)	40 (0.8)	26
B-31	Ben Meek Well 14S 39E 36ada	40	1900	1349	7.4	23 (1.2)	5 (0.4)	348 (15.1)	20 (0.9)	321 (9.1)	11 (0.6)	526 (8.6)	5 (0.1)	90
B-32	Orvil Rallison Well 16S 40E 16cac	15	455	374	7.6	42 (2.1)	18 (1.5)	20 (0.9)	7 (0.2)	31 (0.9)	0.4 (0.02)	199 (3.3)	14 (0.3)	43
S-2	Blackfoot River W. S. 5S 40E 14bcdS	28	4600	4915	6.4	700 (34.9)	224 (18.4)	164 (7.1)	201 (5.1)	72 (2.0)	1.9 (0.1)	2371 (38.9)	1178 (23.9)	33
S-3	Unnamed Spring 5S 40E 15bacS	18		4851	6.3	688 (33.3)	312 (25.7)	149 (6.5)	182 (4.7)	64 (1.8)	1.3 (0.1)	2287 (37.5)	1171 (24.4)	17

Table V-2. Continued

Sample Number	Name and Location	Water Temp. °C	Specific Conductance (μmho/cm)	TDS (mg/l)	pH	Concentration in mg/l (meq/l)								
						Ca	Mg	Na	K	Cl	F	HCO_3	SO_4	SiO_2
S-7	Mound Valley Warm Spring 12S 40E 13dcdS	34	3100	2441	6.1	353 (17.6)	52 (4.3)	267 (11.6)	51 (1.3)	309 (8.7)	0.8 (0)	1106 (18.1)	278 (5.8)	24
S-8	Cleveland Hot Springs 12S 41E 31cacS	55	3600	2554	6.2	259 (12.9)	41 (3.4)	444 (19.3)	90 (2.3)	574 (16.2)	1.7 (0.1)	565 (9.3)	517 (10.8)	62
S-9	Unnamed Warm Spring 12S 41E 31badS	21	750	619	6.7	82 (4.1)	25 (2.1)	32 (1.4)	0 (0)	27 (0.8)	0.3 (0)	410 (6.7)	23 (0.5)	15
S-10	Treasureton Warm Spring 12S 40E 36acdS	40	4550	3179	6.4	336 (16.8)	48 (3.9)	542 (23.6)	110 (2.8)	629 (17.7)	2 (0.1)	726 (11.9)	735 (15.3)	54
S-11	Maple Grove Hot Spring 13S 41E 7acaS	75	3000	2177	6.3	132 (4.4)	24 (1.8)	550 (23.9)	71 (1.8)	586 (16.5)	0.3 (0)	466 (7.6)	282 (5.9)	66
S-12	Unnamed Hot Spring 13S 41E 7dabS	62	3150	2107	5.9	82 (4.1)	22 (1.8)	499 (21.7)	77 (2)	585 (16.5)	1 (0.1)	454 (7.4)	323 (6.7)	64
D-1**	A. M. Thompson Well 11S 44E 7ccb	*	511	350	7.7	74 (3.7)	30 (2.5)	5 (0.2)	1 (0.03)	3.3 (0.09)	0 (0)	310 (5.1)	48 (1)	12
D-2	Rebecca Buhler Well 12S 43E 25daa	*	539	351	7.8	61 (3)	27 (2.2)	16 (0.7)	4.6 (0.1)	17 (0.5)	0.1 (0.01)	292 (4.8)	30 (0.6)	40
D-3	Dave Gerber Well 12S 44E 33dcc	*	652	426	7.8	91 (4.5)	30 (2.5)	10 (0.4)	1 (0.03)	6.7 (0.2)	0.1 (0.01)	336 (5.5)	74 (1.5)	12
D-4	Dean Roberts Well 13S 43E 16dcc	*	576	351	7.7	66 (3.3)	20 (1.7)	30 (1.3)	1 (0.03)	27 (0.8)	0.2 (0.01)	340 (5.6)	0 (0)	23
D-5	Karel Thomas Well 14S 43E 35bba	*	556	336	7.9	67 (3.3)	26 (2.2)	17 (0.7)	1.9 (0.05)	12 (0.3)	0.1 (0.01)	356 (5.8)	12 (0.3)	19
D-6	Oscar Arnell Well 14S 44E 12ccc	*	765	475	7.7	83 (4.1)	34 (2.8)	39 (1.7)	2.1 (0.05)	40 (1.1)	0.1 (0.01)	352 (5.8)	74 (1.5)	15
D-7	Al Butterfield Well 8S 42E 7bda	*	718	422	7.3	75 (3.7)	50 (4.2)	8.2 (0.4)	3 (0.08)	8.1 (0.3)	0.3 (0.02)	464 (7.6)	23 (0.5)	29
D-8	Monsanto Chem Well 8S 42E 31adb	*	1000	684	7.6	88 (4.4)	60 (4.9)	48 (2.1)	6.9 (0.2)	59 (1.7)	1.5 (0.08)	392 (6.4)	147 (3.1)	44
D-9	Dewey Mansfield Well 10S 40E 14bba	*	760	454	7.8	59 (2.9)	48 (3.9)	34 (1.5)	4.9 (0.1)	38 (1.1)	0.5 (0.03)	360 (5.9)	51 (1.1)	23
D-10	Alvin Kingsford Well 10S 40E 36dcc	*	852	520	7.8	62 (3.1)	57 (4.7)	39 (1.7)	5.2 (0.1)	42 (1.2)	0.5 (0.03)	412 (6.8)	70 (1.5)	27
D-11	Clark Mickelson Well 11S 41E 30bdd	*	1430	998	7.8	128 (6.4)	78 (6.4)	89 (3.9)	3.6 (0.1)	98 (2.8)	0.3 (0.02)	520 (8.5)	228 (4.7)	28

Table V-2. Continued

Sample Number	Name and Location	Water Temp. °C	Specific Conductance (μmho/cm)	TDS (mg/l)	pH	Concentration in mg/l (meq/l)								
						Ca	Mg	Na	K	Cl	F	HCO_3	SO_4	SiO_2
D-12	Mack Hymas Well	*	625	368	7.6	69	30	21	1.9	30	0.4	326	22	21
	13S 40E 30acb					(3.4)	(2.7)	(0.9)	(0.05)	(0.9)	(0.02)	(5.4)	(0.5)	
D-13	Byron Tanner Well	*	866	550	7.9	89	35	58	5.6	30	0.5	496	40	45
	14S 39E 25add					(4.4)	(2.9)	(2.5)	(0.1)	(0.9)	(0.03)	(8.1)	(0.8)	

* not reported

** Numbers D-1 through D-13 are modified from Dion (1969).

Variations in chemistry with hydrogeologic regime are discussed in the following sections for the shallow, non-thermal ground water flow systems mentioned previously plus four groups of thermal systems. The thermal ground water systems include the area from Soda Springs to Blackfoot River, Bear Lake Valley, Gentile Valley to Mound Valley, and Cache Valley. The hydrochemistry of the springs and wells sampled are shown in Figure V-1 utilizing stiff diagrams.

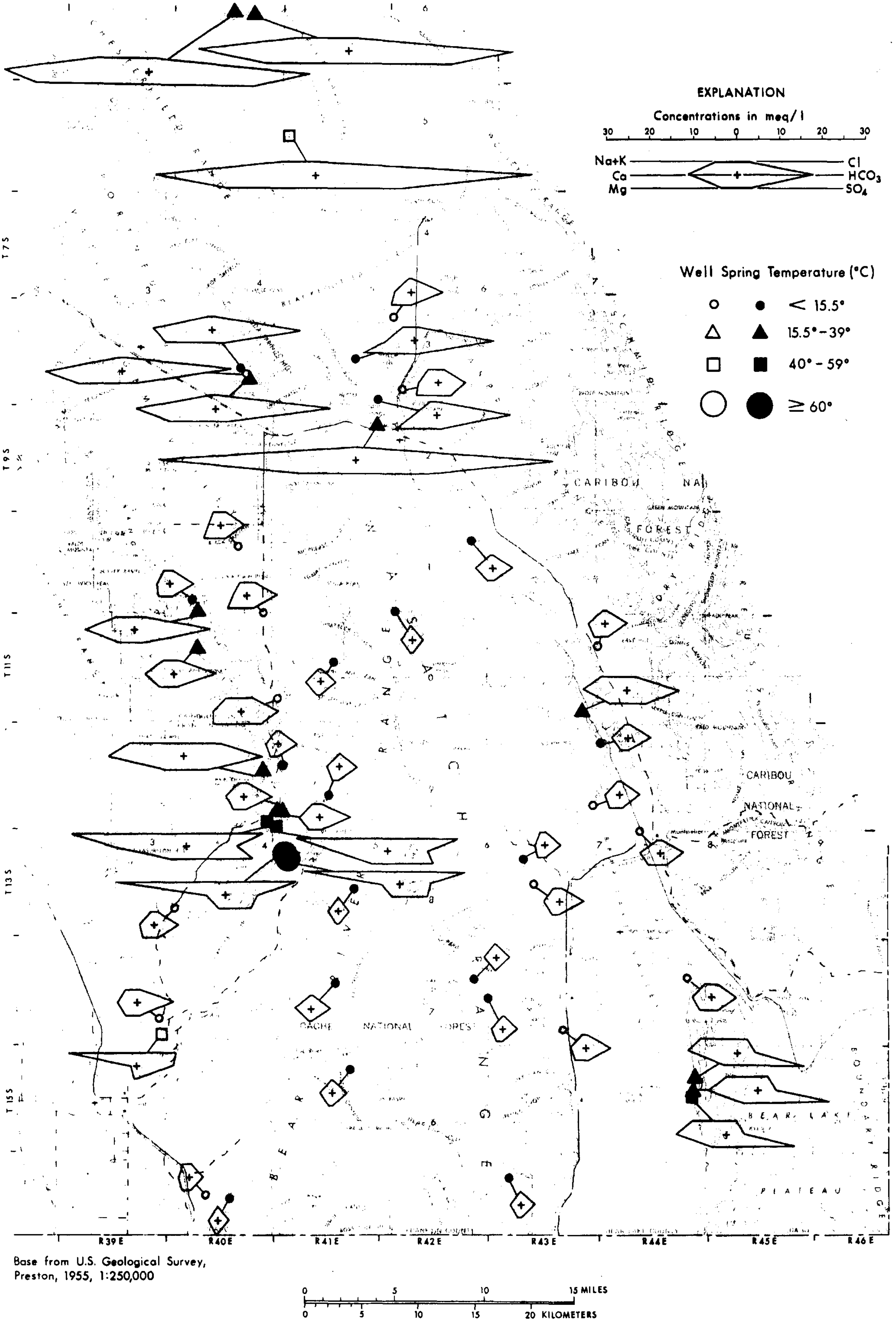
Range, Alluvial, and Basalt Non-thermal Systems

Ground water in the Range system is most likely fracture flow through the quartzites and shales and through karstic solution channels as evidenced by the many large springs on the flanks of the range. The ground water probably has a very short residence time. Waters from the Bear River Range are almost entirely characterized by low temperature, low TDS, and Ca and HCO_3 as the major ions (Type I on Table V-3).

The shallow ground water in the Bear Lake, Blackfoot Lava Field and Cache Valley areas flows through alluvium, lacustrine sediments, and basalt. Ground water from all these areas may be characterized as Ca and $MgHCO_3$ water with low temperature and low TDS (Type II on Table V-3).

Soda Springs to Blackfoot River System

A group of springs and wells in this area, both thermal and non-thermal, exhibit similar hydrochemical characteristics. This group may be further subdivided into: 1) the thermal springs at Soda Springs, the thermal springs near the Blackfoot River, and the wells at Corral Creek (samples S-2, S-3, B-1, B-7) and 2) Hooper Spring and Soda Creek headwaters on the east side of Soda Springs Hills (samples B-5 and B-6), and two



Base from U.S. Geological Survey,
Preston, 1955, 1:250,000

Figure V-1. Sample sites and regional hydrochemistry in the southern subarea.

Table V-3. Water "types" based on temperature, TDS, and geologic control.

Sample No.	Temp.	TDS	Geology
Type I - $CaHCO_3$			
B-8	8	415	Tertiary Salt Lake Formation
B-9	7	210	Cambrian Blacksmith Limestone
B-10	5	311	Cambrian Nounan Limestone
B-11	13	363	Cambrian St. Charles Limestone or Cambrian Nounan Limestone?
B-16	7	325	Cambrian Nounan Limestone
B-18	6	205	Cambrian Nounan Limestone
B-19	9	256	Cambrian Bloomington Limestone
B-20	7	284	Cambrian Blacksmith Limestone
B-21	8	354	Cambrian Brigham Quartzite
B-22	6	271	Cambrian Nounan Limestone
B-23	6	251	Ordivician Garden City Limestone
B-24	9	212	Tertiary Salt Lake Formation
mean	8	288	
Type II - Ca + $MgHCO_3$			
D-1	*	350	Quaternary Alluvium
D-2	*	351	Quaternary Alluvium
D-3	*	426	Quaternary Alluvium
D-4	*	351	Quaternary Alluvium
D-5	*	336	Quaternary Alluvium
D-6	*	475	Quaternary Alluvium
D-7	*	422	Quaternary Basalt
D-8	*	684	Quaternary Basalt
D-9	*	454	Quaternary Basalt
D-10	*	520	Quaternary Basalt
D-11	*	998	?
D-13	*	550	Quaternary Alluvium
B-15	11	331	Quaternary Alluvium Triassic Thaynes Formation?
B-29	14	507	Ordivician Garden City Limestone
B-32	15	331	Quaternary Alluvium
mean		472	
Type III - $CaHCO_3$			
B-1	40	5234	Quaternary Travertine
B-7	29	4648	Quaternary Basalt, Quaternary Travertine
S-3	28	4915	Quaternary Basalt, Quaternary Travertine
S-2	18	4850	Quaternary Basalt, Quaternary Travertine
mean	29	4912	

Table V-3. Continued

Sample No.	Temp.	TDS	Geology
Type IV - $CaHCO_3$, Ca + $MgHCO_3$, and $MgHCO_3$			
B-2	13	1785	Quaternary Basalt, Quaternary Travertine
B-3	15	2179	Quaternary Basalt, Quaternary Travertine
B-4	16	2216	Quaternary Basalt, Quaternary Travertine
B-5	13	1483	Quaternary Basalt
B-6	10	1321	Quaternary Basalt
mean	13	1916	
Type V - Ca + $MgHCO_3$			
B-17	18	657	Quaternary Alluvium, Quaternary Travertine
B-28	22	1680	Ordivician Garden City Formation
B-30	30	904	Quaternary Alluvium
S-9	21	614	Quaternary Alluvium, Quaternary Travertine
B-13	23	1363	Quaternary Travertine, Triassic Thaynes Formation
S-7	34	2512	Quaternary Travertine
mean	25	1288	
Type VI - $CaSO_4$			
B-25	40	1578	Mississippian Brazier Limestone
B-26	39	1584	Mississippian Brazier Limestone
B-27	33	1577	Mississippian Brazier Limestone
mean	37	1580	
Type VII - NaCl			
S-12	62	2160	Cambrian Brigham Quartzite
S-10	40	3029	Quaternary Alluvium
S-8	55	2552	Quaternary Alluvium, Quaternary Travertine
S-11	75	1856	Cambrian Brigham Quartzite
B-31	40	1258	Quaternary Alluvium
mean	54	2171	

* not reported

springs and a flowing well, and one slightly warm spring on the west side of Soda Springs Hills (samples B-2, B-3, B-4). The thermal discharges average 29°C and 4990 mg/l total dissolved solids and have Ca and HCO_3 as the dominant ions. The non-thermal discharges average 13°C, TDS of 1900 mg/l and have Ca or $MgHCO_3$ as dominant ions.

The surface material at most of the sites in this group is the Quaternary basalt of the Blackfoot Lava Field and Gem Valley. Travertine deposition is associated with all the sites except Hooper Spring and Soda Creek headwaters. Many of these springs and wells, particularly on the east side of Soda Springs Hills, are evolving carbon dioxide gas. The reasons for the high CO_2 content in this system is not known at the present time. The basalts are apparently thin in the area of these sites and most, if not all, of the sites are fault-controlled discharges from older underlying rocks.

Gentile Valley and Mound Valley Thermal Systems

Springs in Gentile and Mound valleys exhibit a peculiar variability in chemistry between springs very close in proximity. The water types range from a $CaHCO_3$ type warm (25°C) water with about 1300 mg/l TDS in Gentile Valley to a NaCl type warm (37°C) water with about 1600 mg/l TDS near Maple Grove to the south (Table V-3). Water temperatures increase from north to south.

The hottest springs near Cleveland and Maple Grove (S-8, S-10, S-11, S-12) occur at the junction of the Bear River and Portneuf ranges in an intensely faulted and fractured area. The springs at Maple Grove discharge from the Brigham quartzite, while the springs at Cleveland flow out of Quaternary alluvium and lacustrine sediments. The sediments, though, are probably thin in this area overlying fractured older rocks.

The warm springs in Gentile Valley are towards the west side of the valley and are in line with the West Gem Valley fault (Witkind, 1975). The geologic control of these discharges, however, is not very clear because Witkind (1975) does not extend the fault this far south.

Cache Valley Thermal System

The only thermal discharge in Cache Valley studied as part of this subarea was one of several thermal wells near the village of Riverdale (B-31). The water has Na and Cl as dominant ions with an unusually high HCO_3 concentration (see Type VII on Table V-3). This well is located along the Mink Creek fault depicted by Mitchell (1976a) as the control of Battle Creek and Squaw hot springs farther to the west.

Bear Lake Valley Thermal System

Two thermal discharges occur in Bear Lake Valley. One at Pescadero (B-13) and one, with many outlets, along the eastern shore of Mud Lake, north of Bear Lake (B-25, B-26, B-27). The spring at Pescadero discharges $CaHCO_3$ type water; the Bear Lake springs discharge $CaSO_4$ water (Table V-3). The spring at Pescadero is flowing from a large travertine mound overlying the Triassic Thaynes formation nearly in the center of the valley. The relationship between this site and the springs at Soda Springs and at Bear Lake is unclear. The springs at Bear Lake all occur along the escarpment of the East Bear Lake fault, and are very linear. The springs are undoubtedly discharging from the fault zone.

CHAPTER VI

GEOTHERMAL ANALYSIS FROM REGIONAL DEEP DRILLING

Objectives and Method of Study

The general objective of this portion of the study was to utilize data from deep drilling to help define the controls for geothermal systems in southeastern Idaho. This study is based upon the hypothesis that thrust associated structural features and regional stratigraphy form the major controls for geothermal systems in southeastern Idaho.

The specific objectives are listed below:

1) utilize drilling data from oil and gas exploration wells to delineate thrust associated structural features,
2) obtain and evaluate temperature data from deep drilling, and
3) utilize these data to describe controls for geothermal systems in southeastern Idaho.

This study was conducted by identifying and contacting sources of deep drilling data; U. S. Geological Survey, U. S. D. A. Forest Service, Idaho Department of Water Resources, Idaho Department of Lands, oil companies and consultants were contacted to obtain data on as many wells as possible. Geologic and temperature data from oil and gas exploration wells were then compiled and analyzed to determine controls on geothermal systems in southeastern Idaho.

Deep Drilling Data

Introduction

Wildcat exploration for oil and gas has been conducted in the Idaho segment of the overthrust belt since 1926. A total of 42 deep exploration wells have been drilled to date in this portion of the state. Locations of these wells are shown on Figure VI-1. Data available on these sites range greatly in quantity and quality. Little data are available on most of the wells drilled before 1950. Wells drilled in the last 30 years are generally deeper and better data are usually available.

A listing of oil and gas wells drilled in southeastern Idaho is presented on Table VI-1. General data such as location, operator, date, elevation and total depth are given. The availability of geologic or temperature data from these wells is also shown.

Oil and Gas Drilling

The occurrence of oil and gas depends upon three contributing factors. First, a source rock is needed to generate hydrocarbons. Second, a reservoir rock is needed to transmit and store the hydrocarbons. Third, the reservoir rock must be situated stratigraphically or structurally in a way that traps the hydrocarbons. Oil and gas exploration wells are drilled to tap these traps.

The overthrust belt in Idaho is thought to be one of the last major undeveloped onshore petroleum producing fields. Drilling for oil and gas in the area has increased dramatically the last few years. None of the deep exploration wells in southeastern Idaho have produced oil

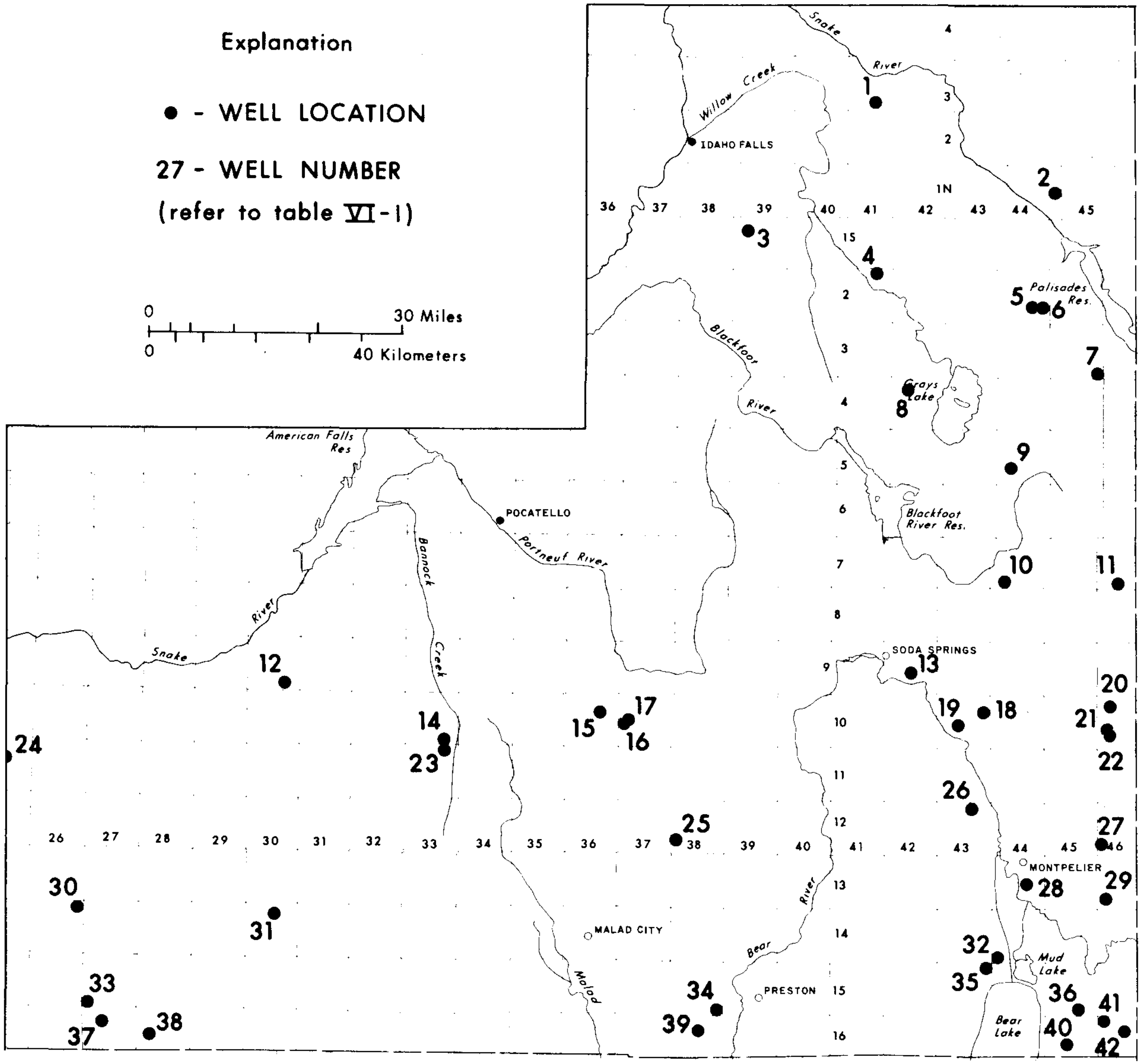


Figure VI-1. Location of oil and gas wells in southeastern Idaho.

Table VI-1. Inventory of oil and gas wells drilled in southeastern Idaho.

Number	Location	County	Well Name	Operator	Completion Date	Elevation (meters)	Total Depth (meters)	Available Data Geology	Available Data Temp.
1	3N 41E 33cc	Bonneville	Sorenson No. 1	California Company	1930	1783	1150	c	
2	1N 44E 24bc	Bonneville	Government No. 1	Edwin Allday	1966	1695	1756		
3	1S 39E 8cca	Bingham	Hoff 1-8 M	Union Oil of California	1979	1737	2625		
4	2S 41E 2aca	Bingham	King No. 2-1	American Quasar	1978	2012	4132	c	d
5	2S 44E 23db	Bonneville	Big Elk Mountain No. 1	Sun-Sinclair	1950	2473	1710	c	d
6	2S 44E 24bcc	Bonneville	T. J. Weber No. 1-A	Pan American	1964	2433	2962	c	
7	3S 45E 36cc	Bonneville	Black Mountain Federal No. 1	American Quasar	1977	2693	4368	c	d
8	4S 42E 9aac	Bonneville	Gentile Valley No. 1	Continental Oil	1978	2080	3021	c	d
9	5S 44E 2cac	Caribou	Stoor "A" No. 1	Phillips Petroleum	1980[a]	2059	246		
10	7S 44E 32aab	Caribou	Dry Valley	Standard Oil of California	1952	2060	2337	c	
11	7S 46E 34ccd	Caribou	Tygee No. 1	Great Western Oil	1926	1890	746		
12	9S 30E 35bb	Power	No. 1	Rockland Valley Oil	1926	1432[b]	472		
13	9S 42E 27dad	Caribou	Ira Ellis No. 1	James Fraizer	1956	1753[b]	1079		
14	10S 33E 35dc	Power	Porter No. 1	States Oil	1969	1575	1176		
15	10S 36E 14db	Bannock	Ashlette No. 1	Cache Oil and Gas	1958	1701[b]	915		
16	10S 37E 19cb	Bannock	Arimo Valley No. 2	Norton Oil and Gas	1928	1463	823		
17	10S 37E 19cc	Bannock	Arimo Valley No. 1	Norton Oil and Gas	1927	1448	412		
18	10S 43E 13dcd	Bear Lake	Big Canyon Federal No. 1-13	Union Texas Petroleum	1979	2070	3577	c	d
19	10S 43E 21ada	Bear Lake	State No. 1	Eastern Idaho Development Co.	1956	1865	1195		
20	10S 46E 8bda	Caribou	Federal No. 1-8	May Petroleum	1978	2337	5104	c	d
21	10S 46E 20dd	Caribou	Federal Elk Valley No. 1	May Petroleum	1976	2294	1194	c	d
22	10S 46E 28bdd	Caribou	Amerada T1-W1	Amerada Petroleum	1963	2285	1254	c	d
23	11S 33E 2ba	Power	Arbon Valley No. 1	Gem State Petroleum	1926	1596	1175		
24	12S 25E 17bb	Cassia		Marsh Basin Oil and Gas	1926	1402[b]	183		
25	12S 38E 8dca	Bannock	Bannock 1-A8	NuDay Exploration	1978	1743	561		
26	12S 43E 3cd	Bear Lake	Bennington No. 3-24	Ladd Petroleum	1979	1963	3590		
27	12S 46E 30bc	Bear Lake	Bear Lake Federal No. 1	Rocky Mountain Oil	1954	2195[b]	1528		
28	13S 44E 22ccd	Bear Lake	Jensen No. 21-1	American Quasar	1978	1806	3360		d
29	13S 46E 29dca	Bear Lake	Rigby Williams No. 1	Cities Service Co.	1979	1879	2513		

Table VI-1. Continued

Number	Location	County	Well Name	Operator	Completion Date	Elevation (meters)	Total Depth (meters)	Available Data Geology	Available Data Temp.
30	14S 26E 1bd	Cassia	Griffith-White No. 1	Al Griffith and Simplot	1973	1417[b]	2134-2438		
31	14S 30E 10cc	Oneida	Juniper No. 1	Phillips Petroleum and Utah Southern	1951	1610	2129		
32	14S 44E 31ccb	Bear Lake	99 x 101	J. Holme Dunford	1977	1808	247		
33	15S 27E 31cd	Cassia	No. 1	Al Griffith and Simplot	1974	1478[b]	1219		
34	15S 38E 36ba	Franklin	Idaho Willet No. 1	Willet Flying Service	1966	1402	1362		
35	15S 43E 1dd	Bear Lake	99 x 104	J. Holme Dunford	1977	1808	247		
36	15S 45E 34aa	Bear Lake	Government Sheep Creek No. 1	Standard of California	1954	2137	2063		
37	16S 27E 9cd	Cassia	No. 1	Al Griffith and Simplot	1974	1521	1250		
38	16S 28E 20bd	Cassia	Nielson No. 1	Al Griffith and Simplot	1973	1610	2129		
39	16S 38E 15ab	Franklin	August Jensen No. 1	Utah-Idaho Development	1956	1402[b]	1595		
40	16S 45E 21bbc	Bear Lake	North Eden Federal No. 22-11	American Quasar	1980	2103	2862	c	d
41	16S 46E 6bba	Bear Lake	North Rabbit Creek Federal No. 6-21	American Quasar	1980	2055	3539		d
42	16S 46E 10bc	Bear Lake	Grace Federal No. 10-1	American Quasar	1978	2323	3615	c	d

[a] Well not completed.

[b] Estimated from topographic map.

[c] Data on formations penetrated obtained.

[d] Data from bottom-hole temperature, high resolution temperature log or drill stem test obtained.

and gas. A few have had minor shows; all wells have been abandoned.

Geologic Data

Geologic data are availabe on 13 of the wells inventoried. Geologic data obtained from exploration wells consist of a list of depths at which various formations were penetrated. This information is generally referred to as the "formation tops". To obtain the most data, it was necessary to purchase top cards from Petroleum Information Corporation, a service dealing with drilling data. Geologic data from deep drilling, such as formation tops, can be used to interpret the subsurface structure in the area.

Analysis of deep drilling data indicates that several wells drilled in southeastern Idaho penetrated thrust zones. Many of the structural features are identified by the oil companies using sophisticated geophysical prospecting. Identification of thrusts or thrust zones in drill holes is partially based upon evidence of an altered stratigraphic sequence. Wells may penetrate a repeat of section or intersect a stratigraphically older formation above a younger formation. The zones between altered stratigraphic sequences are interpreted by oil companies to be thrusts or thrust zones.

Examples of this interpretation can be seen on four geologic logs presented on Table VI-2. The Union Texas Petroleum well, Big Canyon Federal No. 1-13 penetrated the Pennsylvanian Wells limestone formation and the Mississippian Madison limestone formation. Drilling then encountered the younger Jurassic Twin Creek limestone formation. Interpretation of this well by Union Texas Petroleum places the Meade thrust between the Madison formation and the Twin Creek formation.

Table VI-2. Examples of geologic logs from four wells drilled in southeastern Idaho showing faults penetrated.

Well Name and Location	Formation Age	Formation Name	Depth Penetrated (meters)
Big Canyon Federal No. 1-13 10S 43E 13dcd	Pennsylvanian	Wells	0-638
	Mississippian	Madison	638-841
		-fault-	
	Middle Jurassic	Twin Creek	841-1176
	Lower Jurassic	Nugget	1176-1442
	Upper Triassic	Ankareh	1142-1561
	Lower Triassic	Thaynes	1561-3186
	Lower Triassic	Woodside	3186-3307
	Lower Triassic	Dinwoody	3307-3557
			total depth 3557
Federal No. 1-8 10S 46E 8bda	Upper Jurassic	Pruess	0-495
	Middle Jurassic	Twin Creek	495-2332
	Lower Jurassic	Nugget	2332-2635
	Upper Triassic	Ankareh	2635-2996
	Lower Triassic	Thaynes	2996-3545
	Lower Triassic	Woodside	3545-3606
	Lower Triassic	Dinwoody	3606-3971
		-fault-	
	Lower Triassic	Woodside	3971-4606
	Lower Triassic	Dinwoody	4606-5105
			total depth 5105
Grace Federal No. 10-1 16S 46E 10bc	Upper Jurassic	Pruess	0-503
	Middle Jurassic	Twin Creek	503-1353
	Lower Jurassic	Nugget	1353-1650
	Upper Triassic	Ankareh	1650-1687
		-fault-	
	Lower Jurassic	Nugget	1687-2122
	Upper Triassic	Ankareh	2122-2518
	Lower Triassic	Thaynes	2518-3057
	Lower Triassic	Woodside	3057-3245
	Lower Triassic	Dinwoody	3245-3439
	Permian	Phosphoria	3439-3524
	Pennsylvanian	Wells	3524-3615
			total depth 3615
King No. 2-1 2S 41E 2aca	Cretaceous (?)	Unnamed	0-218
	Lower Cretaceous	Gannett	218-802
	Lower Cretaceous	Ephraim	802-976
	Upper Jurassic	Stump	976-1160
	Upper Jurassic	Pruess	1160-1556
		-fault-	
	Upper Jurassic	Stump	1556-1584
	Upper Jurassic	Pruess	1584-1829
	Middle Jurassic	Twin Creek	1829-2608
	Lower Jurassic	Nugget	2608-2960
	Upper Triassic	Ankareh	2960-3347
	Lower Triassic	Woodside	3347-3447
	Lower Triassic	Dinwoody	3447-4022
	Pennsylvanian	Wells	4022-4132
			total depth 4132

An example of a repeat of section is shown in the geologic log of well Federal No. 1-8 drilled by May Petroleum (Table VI-2). This well penetrated a normal sequence of strata from the Upper Jurassic Pruess formation through lower Triassic Dinwoody formation. The well then intersected the lower Triassic Woodside and Dinwoody formations for a second time. Interpretation indicates a thrust fault is between the repeat of section (Wagner, written communication, 1980). Other repeats of section are shown on the geologic logs of wells Grace Federal No. 10-1 drilled by American Quasar and well King No. 2-1 also drilled by American Quasar.

The Big Canyon Federal No. 1-13 drilled by Union Texas Petroleum penetrated the Meade thrust at 843 meters below the surface. Water reportedly, flooded the hole at a depth of 750 meters. It is not known whether this increased flow of water into the hole was caused in part by the thrust feature.

None of the data from deep drilling indicated that the thrust zones had either significantly higher or lower hydraulic conductivity than the adjacent units. It is possible that the most important hydrologic impact of the thrust zones at depth is the disruption of the normal stratigraphic sequence of formations.

Temperature Data from Deep Drilling

Temperature data were obtained on 12 of the deep wells drilled in southeastern Idaho (Table VI-3). Data for each well varies in quantity and quality. Three forms of temperature data are available from oil and gas exploration wells: 1) high resolution temperature log (HRT),

Table VI-3. Temperature data obtained on wells drilled in southeastern Idaho.

Well Name and Location	Type of Temperature Measurement	Measurement Depth or Interval (meters)	Maximum Recorded Temperature (°C)
King No. 2-1 2S 41E 2aca	HRT	0-3810	210*
Big Elk Mountain No. 1 2S 44E 23db	DST	1538-1545	103*
Black Mountain Federal No. 1 3S 45E 36cc	BHT	2040	50
	BHT	2709	73
	BHT	3673	92
	BHT	4158	100*
Gentile Valley No. 1 4S 42E 9acc	BHT	1175	160
	BHT	2913	158
	BHT	3010	150
	HRT	0-1149	68
	HRT	0-2915	166
	HRT	0-3008	160*
Big Canyon Federal No. 1-13 10S 43E 13dcd	DST	837- 845	110
	DST	1595-1615	104
	DST	3015-3053	143
	DST	3301-3360	159
	DST	3524-3551	161*
Federal No. 1-8 10S 46E 8bda	BHT	963	33
	BHT	2740	83
	BHT	3014	79
	BHT	4826	138
	BHT	4914	151
	BHT	5105	188*
Federal Elk Valley No. 1 10S 46E 20dd	BHT	1194	40*
Amerada T1-W1 10S 46E 28bdd	BHT	610	29
	BHT	1219	49*
Jensen 21-11 13S 44E 22ccd	BHT	3500	74*
North Eden Federal No. 22-11 16S 45E 21bbc	DST	2473-2551	81
	DST	2557-2618	92*
North Rabbit Creek Federal No. 6-21 16S 46E 6bba	BHT	3537	80*
Grace Federal No. 10-1 16S 46E 10bc	BHT	3615	83*

* indicates temperatures used to calculate gradient.

2) bottom hole temperature (BHT), and 3) drill stem test temperature (DST). The applicability of these data to a geothermal investigation is limited by the fact that the data were collected to aid oil and gas exploration and not for the assessment of geothermal systems. Temperature data are also limited by the accuracy of the instruments and the procedure used.

HRT logs are made with a resistance thermometer, an element whose electrical resistance changes with temperature (Lynch, 1962). HRT logs are generally run by the petroleum industry to check the placement of the cement grouts. Drying cement generates heat, thus, the location of the cement can be determined by running an HRT log. Given the limitations, the HRT log can also be used to profile the temperature in the borehole.

Temperatures at the bottom of a well are recorded when using most electric and radioactive logging techniques. A maximum recording resistance thermometer is used to record the maximum temperature at the bottom of a well. The BHT is used as a temperature correction to calibrate electrical and radioactive logs. The circulation of drilling fluids in the well greatly affects the temperature equalibrium. Generally, suites of electrical and radioactive logs are run after drilling has stopped and the fluid in the hole has reached approximate equalibrium. For the purpose of this study BHT readings are considered to represent the actual temperature at the given depth.

A drill stem test is the temporary completion of a well during drilling, or after setting casing, to measure formation pressures and to obtain samples of formation fluids or gases for evaluation (Jenner, 1973, p. 127). Drill stem tests are made by lowering a valve, a packer and a length of perforated pipe on the end of the drill pipe to the level of the formation to be tested. The packer is set to seal off the interval from the mud column above. Then the valve is opened allowing the formation fluid to flow into the hole and be produced through the drill pipe (Lynch, 1962). The temperature of the formation fluid is recorded during the drill stem test. This DST temperature is considered to be representative temperature of the fluid in the formation (Prestwitch, verbal communication, 1980).

Geothermal Gradient

The earliest estimate of a geothermal gradient for the area is 4.0°C/100 m (Mansfield, 1927, p. 320). Mitchell (1976b) estimated an identical gradient for the Blackfoot Reservoir area. Based upon heat flow, studies of the Sanke River Plain region, Brott and others (1976) estimated the gradient near Rexburg, Idaho, to be in the range of 1.6-11.8°C/100 m. The average geothermal gradient for the earth's crust as a whole is approximately 2.6°C/100 m (Decker, 1976).

Temperature data from deep drilling are used in this study to determine if any areas have a high geothermal gradient. The maximum recorded temperature (BHT, HRT, or DST) at the bottom of a well minus the mean annual air temperature 9°C (Mansfield, 1927) will give the actual temperature increase at depth. This value divided by the depth yields the temperature gradient at that site. The location of 12 wells in southeastern Idaho and the calculated gradient for each are shown on Figure VI-2. Figure VI-3 shows the geothermal gradients for deep holes in southeastern Idaho in comparison with Mansfield's (1927) estimate and the world-wide estimate.

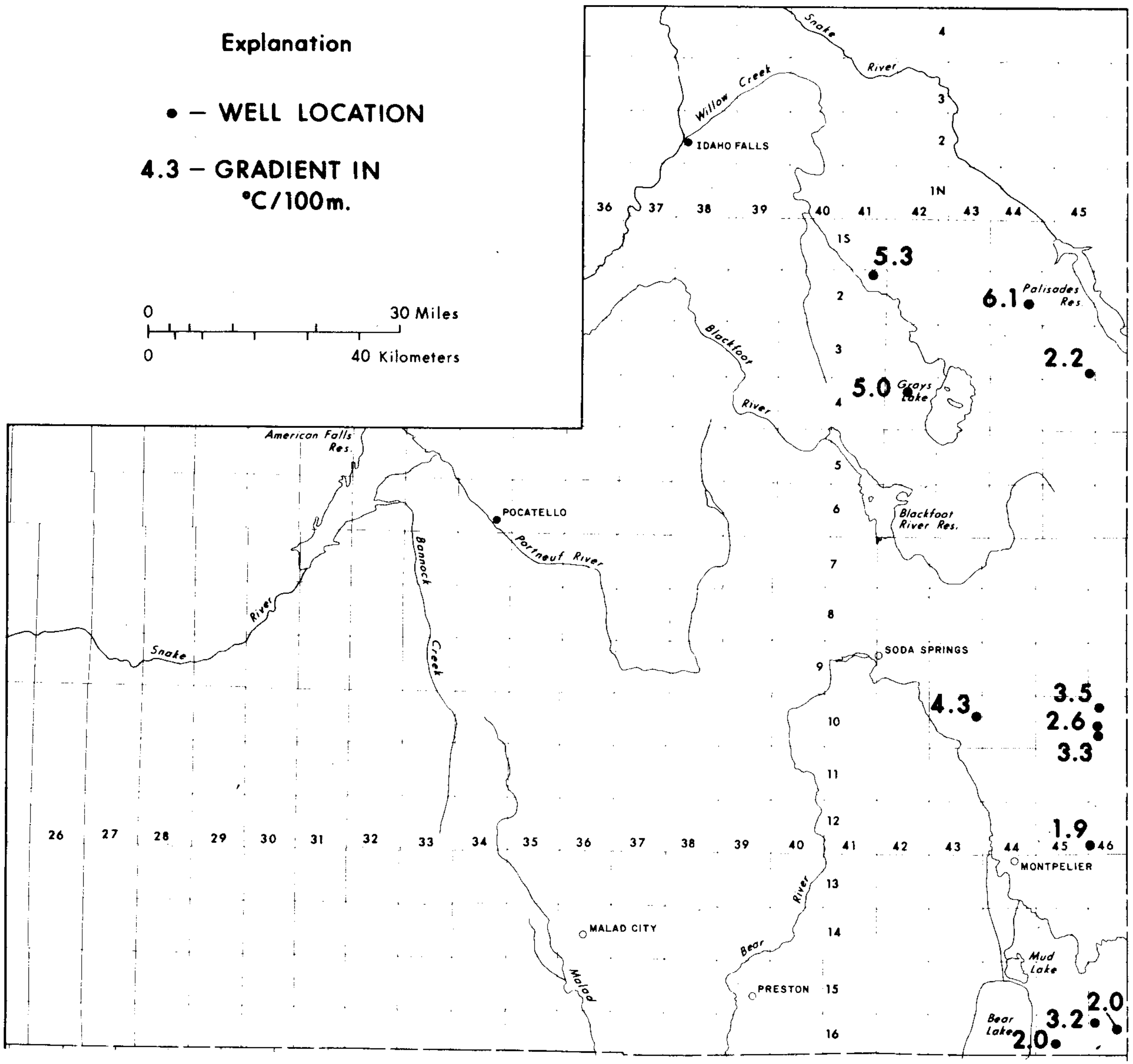


Figure VI-2. Calculated geothermal gradient of selected oil and gas wells in southeastern Idaho.

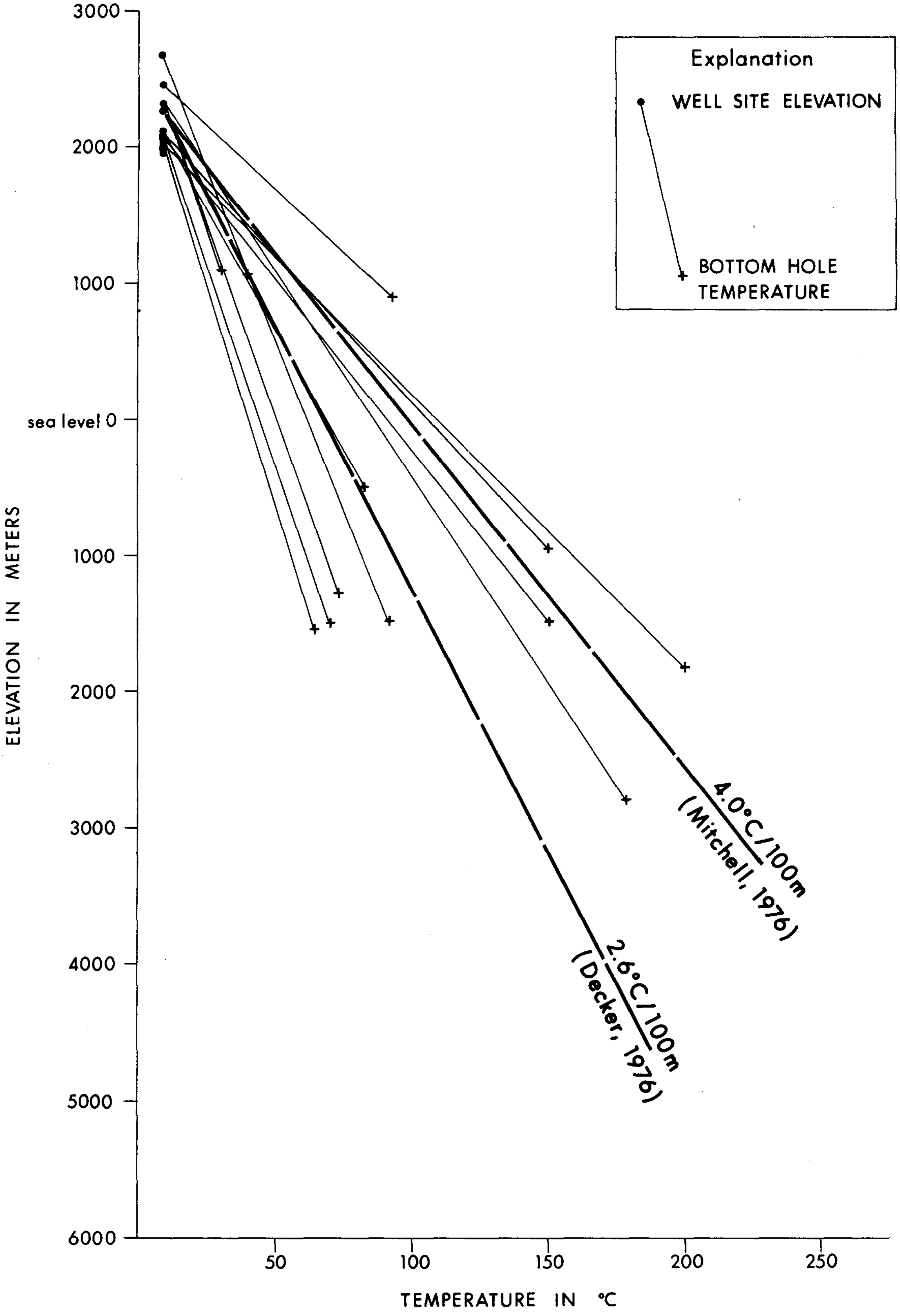


Figure VI-3. Bottom hole temperatures versus total depth and surface elevation in comparison to suggested geothermal gradients. (Assume mean annual air temperature of 9°C.)

The geothermal gradients presented in Figures VI-2 and VI-3 range from 1.9°C/100 m to 6.1°C/100 m. Four well sites have relatively high gradient values compared to the gradients discussed earlier. These well locations and their calculated gradients are:

King No. 2-1, T2S, R41E, 2aca, 5.3°C/100 m;
Big Elk Mountain No. 1, T2S, R44E, 23db, 6.1°C/100 m;
Gentile Valley No. 1, T4S, R42E, 9aac, 5.0°C/100 m; and
Big Canyon Federal No. 1-13, T10S, R43E, 13dcd, 4.3°C/100 m.

Further evaluation is required to determine if these wells penetrate a major geothermal system. The apparent high gradients may be caused by measurement error or by greater heat flow because of the close proximity of the test wells to the Snake River Plain and Blackfoot Lava Field, both possible heat sources in the area.

A geologic log and a DHT log for an individual well are presented to show the difficulty involved in determining if the thrust or thrust zone in the study area has any influence on the geothermal gradient. The geologic log and HRT log of well King No. 2-1, drilled by American Quasar, is presented in Figure VI-4. The geologic log indicates a thrust fault at 1556 meters. The HRT log does not deviate in any distinct manner near the fault. In this example, it appears that the thermal gradient does not significantly vary near the fault zone. This implies that the thrust zone does not control the geothermal system. Additional deep drilling data and continued study are needed to determine if this is a correct interpretation.

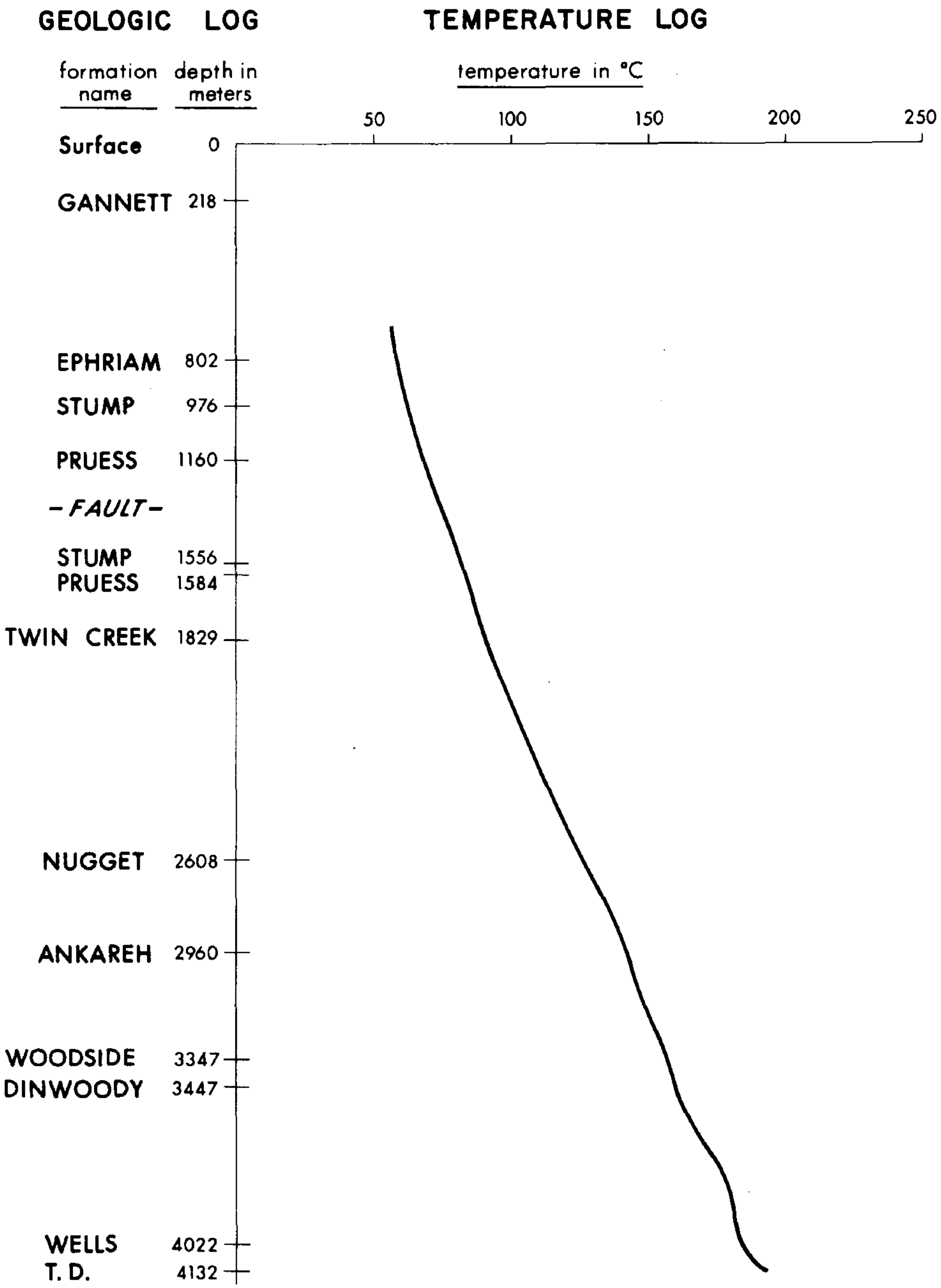


Figure VI-4. Geologic log and temperature log of well King 2-1.

CHAPTER VII

REGIONAL HYDROCHEMISTRY OF GEOTHERMAL SYSTEMS

Introduction

This chapter includes an analysis of the hydrogeochemistry of thermal waters in an area bounded by the Raft River Valley on the west, the Snake River on the northwest and northeast, the eastern and southern extent of the thrust zone about 60 km east into Wyoming and about 40 km south into Utah (see Figure I-1). Field data were obtained as part of this study in the north, Meade thrust and south subareas described previously plus the west subarea shown on Figure I-1. Previously published data were utilized for sections of Wyoming and Utah and for the portion of Idaho located west of Cache and Marsh valleys. Only those discharges with temperatures greater than 14.5°C were considered for this portion of the report.

The purpose of this subproject is to examine the water quality characteristics of thermal discharges. Geologic, geochemical and hydrologic controls for water quality are discussed. Thermal occurrences are grouped according to their similarity in terms of these parameters.

Source and Reliability of Data

Water quality data presented here were obtained from a variety of sources. As such, it is important to examine the reliability of the data to insure that they are comparable. Wyoming springs were sampled by the Geological Survey of Wyoming (Breckenridge and Hinkley, 1978). In Utah, springs and wells were inventoried and sampled by the Utah Geological and Mineral Survey (Goode, 1978). Selected thermal occurrences in Idaho have been sampled previously by the Idaho Department of Water Resources (IDWR).

Cation-anion balances were calculated for data from all sources. The maximum error allowed is 5% for samples with a total concentration greater than 5 milliequivalents per liter (meq/l) (Hem, 1970). Analyses considered unacceptable on this basis are so identified in Table VII-1.

Some of the thermal occurrences sampled as part of this research were previously sampled by IDWR (Mitchell, Johnson and Anderson, 1980). A stastical test was conducted to determine whether these two sets of data are comparable. Data from both sources were converted to log values to minimize the effect of comparing high and low concentrations. The null hypothesis was as follows; for a given constituent, the mean of analyses from this research is equal to the mean of analyses presented by IDWR. The alternate hypothesis was the converse of the above. Data from the two sources are comparable at the 0.05 level of significance.

Presentation of Data

Chemical analyses and temperatures for all of the thermal springs considered in this report are listed in Table VII-1. The sites are identified by a letter-number combination indicating the sampling agency (I-Idaho, U-Utah, and W-Wyoming) or subarea (H-northern, M-Meade thrust, B-southern and S-western) and the site number.

Table VII-1. Hydrochemistry of thermal springs and wells in the report area.

Sample Number	Name and Location	Water Temp. °C	Specific Conductance (μmho/cm)	TDS (mg/l)	pH	Concentration in mg/l (meq/l) Ca	Mg	Na	K	Cl	F	HCO_3	SO_4	SiO_2
H-1	Elkhorn Hot Spring 4N 40E 23cadS	20	385	335	6.6	30 (1.5)	10 (0.8)	14 (0.6)	0 (0)	5 (0.1)	0.8 (0)	186 (3)	7 (0.1)	83
H-2	Hawley Warm Spring 4N 40E 25bbdS	16	350	341	7.5	36 (1.8)	10 (0.8)	10 (0.4)	0 (0)	4 (0.1)	0.7 (0)	188 (3.1)	5 (0.1)	88
H-3	Heise Hot Springs 4N 40E 25ddaS	48	6500	7667	6.1	676 (33.7)	81 (6.7)	1498 (65.2)	204 (5.2)	2299 (64.9)	3.1 (0.2)	2125 (34.8)	723 (15.1)	58
H-6	Unnamed Spring 3N 41E 32bbdS	23	650	547	7.2	71 (3.5)	19 (1.6)	44 (1.9)	0 (0)	42 (1.2)	0.14 (0)	271 (4.4)	51 (1.1)	49
H-7	Dyer Well 2N 39E 21bccS	21	530	434	7.7	50 (2.5)	13 (1.1)	50 (2.2)	3 (0.1)	61 (1.7)	0.29 (0)	188 (3.1)	1 (0)	68
H-8	Anderson Well 2N 39E 29bacS	20	520	467	7.7	50 (2.5)	10 (0.8)	45 (2.0)	7 (0.2)	45 (1.3)	0.44 (0)	199 (3.3)	0 (0)	111
H-9	Fall Creek Mineral Spring 1N 43E 9cbb1S	24	7800	5416	6.2	473 (23.6)	100 (8.2)	1058 (46)	118 (3)	1851 (52.2)	1.4 (0.1)	1473 (24.1)	327 (6.8)	15
H-10	Fall Creek Mineral Spring 1N 43E 9cbb2S	23	6750	4961	6.2	431 (21.5)	88 (7.2)	1065 (46.3)	108 (2.8)	1650 (46.5)	1.3 (0.1)	1272 (20.8)	329 (6.8)	17
H-16	Unnamed Spring 1S 40E 4abcS	21	10500	9229	6.6	110 (5.5)	19 (1.6)	2843 (123.7)	40 (1)	876 (24.7)	4.6 (0.2)	2416 (39.6)	2858 (59.5)	62
H-20	Warm Spring 2S 44E 9aacS	17	600	576	7.2	128 (6.4)	27 (2.2)	0 (0)	0 (0)	1 (0)	0.25 (0)	163 (2.7)	233 (4.9)	24
H-23	Brockman Hot Spring 2S 42E 26dcdS	35	8750	7562	6.6	186 (9.3)	33 (2.7)	2044 (88.9)	38 (1)	553 (15.6)	2.3 (0.1)	2255 (37)	2413 (50.2)	38
H-26	Auburn Hot Springs 33N 119W 23dbdS	57	8000	5760	6.4	509 (25.4)	76 (6.3)	1327 (57.7)	162 (4.1)	1737 (49)	3.4 (0.2)	822 (14.5)	996 (20.7)	68
H-27	Johnson Springs 33N 119W 26adS	54	8100	6310	6.4	454 (22.7)	45 (3.7)	1494 (65)	176 (4.5)	1947 (54.9)	3.8 (0.2)	973 (15.9)	1129 (23.5)	88
M-1	Sink Hole 4S 41E 32bbS	19		804	6.8	147 (7.3)	29 (2.4)	27 (1.2)	3 (0.1)	29 (0.8)	0.6 (0.03)	504 (8.3)	33 (0.7)	31
M-2	North Woodall 7S 42E 27caS	17	1640	1701	6.3	382 (19.1)	49 (4.0)	4 (0.2)	1 (0.04)	3 (0.07)	1 (0.05)	1182 (19.4)	48 (1)	31
M-7	Swan Lake #1 (Lakey Res.) 9S 43E 29ccS	16	1020	1089	6.7	220 (11)	36 (3)	3 (0.1)	0.3 (0.01)	3 (0.1)	0.2 (0.01)	751 (12.3)	57 (1.2)	19
M-9	Lone Tree 6S 42E 6abS	26	1570	1506	6.4	314 (15.7)	39 (3.2)	26 (1.1)	18 (0.5)	26 (0.7)	1.7 (0.09)	939 (16.2)	75 (1.6)	17

Table VII-1. Continued

Sample Number	Name and Location	Water Temp. °C	Specific Conductance (μmho/cm)	TDS (mg/l)	pH	Concentration in mg/l (meq/l)								
						Ca	Mg	Na	K	Cl	F	HCO_3	SO_4	SiO_2
M-10	Henry Warm #1 6S 42E 9acS	15	970	934	6.8	178 (8.9)	34 (2.8)	16 (0.7)	2 (0.06)	15 (0.4)	0.5 (0.03)	624 (10.2)	46 (1)	18
M-11	Henry Warm #2 6S 42E 9bcS	20	1410	1449	6.4	284 (14.2)	44 (3.6)	25 (1.1)	8 (0.2)	32 (0.9)	1 (0.05)	870 (14.3)	145 (3)	40
M-12	Warm Spring 6S 42E 8dbS	23	1510	1485	6.3	277 (13.8)	47 (3.9)	22 (1)	14 (0.4)	20 (0.6)	1.7 (0.09)	994 (16.3)	84 (1.7)	25
M-14	Little Blackfoot River 6S 42E 15baS	15	940	982	6.7	200 (10)	33 (2.7)	11 (0.5)	2 (0.04)	13 (0.4)	0.5 (0.03)	674 (11.1)	42 (0.9)	7
B-1	Corral Creek Well 6S 41E 19bbd	40	4900	5267	6.9	745 (37.2)	244 (20.1)	53 (2.3)	222 (5.7)	39 (1.1)	1.8 (0.09)	3016 (49.5)	915 (19)	31
B-3	Thermal Gradient Well 8S 40E 26dbc	15	2400	2221	6.5	345 (17.2)	118 (9.7)	26 (1.1)	12 (0.3)	2 (0.07)	0 (0)	1529 (25.1)	147 (3.1)	42
B-4	Gem Valley Spring #2 8S 40E 26dcbS	16	2400	2320	6.5	361 (18)	120 (9.9)	28 (1.2)	12 (0.3)	13 (0.4)	0 (0)	1529 (26.1)	153 (3.2)	41
B-7	Soda Springs Geyser 9S 41E 12ada	29	4025	4694	6.8	925 (46.2)	150 (12.4)	3 (0.1)	18 (0.5)	3 (0.08)	0.4 (0.02)	2778 (45.6)	771 (16)	46
B-13	Pescadero Warm Spring 11S 43E 36bdaS	23	1475	1380	7.0	194 (9.7)	46 (3.8)	70 (3)	13 (2.9)	74 (2.1)	2.3 (0.1)	749 (12.3)	215 (4.5)	17
B-17	Unnamed Spring 12S 41E 31abcS	18	775	666	7.1	94 (4.7)	28 (2.3)	37 (1.6)	3 (0.07)	30 (0.9)	0.3 (0.02)	439 (7.2)	26 (0.5)	9
B-25	Bear Lake Hot Spring #1 15S 44E 13ccaS	40	2250	1625	7.0	230 (11.5)	41 (3.4)	155 (6.7)	48 (1.2)	72 (2)	4.2 (0.2)	263 (4.3)	769 (16)	43
B-28	Gentile Valley Spring #1 11S 40E 5aaaS	22	1825	1698	6.1	239 (11.9)	47 (3.9)	92 (4)	34 (0.9)	78 (2.2)	0.2 (0.01)	1086 (17.8)	104 (2.2)	18
B-30	Gentile Valley Spring #3 11S 40E 8dddS	30		930	6.6	132 (6.6)	38 (3.1)	54 (2.3)	3 (0.07)	43 (1.2)	0.2 (0.01)	594 (9.7)	40 (0.8)	26
B-31	Ben Meek Well 14S 39E 36ada	40	1900	1349	7.4	23 (1.2)	5 (0.4)	348 (15.1)	20 (0.9)	321 (9.1)	11 (0.6)	526 (8.6)	5 (0.1)	90
B-32	Orvil Rallison Well 16S 40E 16cac	15	455	374	7.6	42 (2.1)	18 (1.5)	20 (0.9)	7 (0.2)	31 (0.9)	0.4 (0.02)	199 (3.3)	14 (0.3)	43
S-1	Unnamed on Wolverine Creek 2S 38E 11bbcS	18	640	502	6.8	85 (4.2)	21 (1.7)	3 (0.1)	3 (0.1)	5 (0.1)	0.3 (0)	268 (4.4)	102 (2.1)	15
S-2	Blackfoot River Warm Spring 5S 40E 14bcdS	28	4600	4915	6.4	700 (34.9)	224 (18.4)	164 (7.1)	201 (5.1)	72 (2)	1.9 (0.1)	2371 (38.9)	1148 (23.9)	33
S-3	Unnamed on Blackfoot River 5S 40E 15bacS	18		4851	6.3	668 (33.3)	312 (25.7)	149 (6.5)	182 (4.7)	64 (1.8)	1.3 (0.1)	2287 (37.5)	1171 (24.4)	17

Table VII-1. Continued

Sample Number	Name and Location	Water Temp. °C	Specific Conductance (µmho/cm)	TDS (mg/l)	pH	Concentration in mg/l (meq/l)								
						Ca	Mg	Na	K	Cl	F	HCO_3	SO_4	SiO_2
M-10	Henry Warm #1 6S 42E 9acS	15	970	934	6.8	178 (8.9)	34 (2.8)	16 (0.7)	2 (0.06)	15 (0.4)	0.5 (0.03)	624 (10.2)	46 (1)	18
M-11	Henry Warm #2 6S 42E 9bcS	20	1410	1449	6.4	284 (14.2)	44 (3.6)	25 (1.1)	8 (0.2)	32 (0.9)	1 (0.05)	870 (14.3)	145 (3)	40
M-12	Warm Spring 6S 42E 8dbS	23	1510	1485	6.3	277 (13.8)	47 (3.9)	22 (1)	14 (0.4)	20 (0.6)	1.7 (0.09)	994 (16.3)	84 (1.7)	25
M-14	Little Blackfoot River 6S 42E 15baS	15	940	982	6.7	200 (10)	33 (2.7)	11 (0.5)	2 (0.04)	13 (0.4)	0.5 (0.03)	674 (11.1)	42 (0.9)	7
B-1	Corral Creek Well 6S 41E 19bbd	40	4900	5267	6.9	745 (37.2)	244 (20.1)	53 (2.3)	222 (5.7)	39 (1.1)	1.8 (0.09)	3016 (49.5)	915 (19)	31
B-3	Thermal Gradient Well 8S 40E 26dbc	15	2400	2221	6.5	345 (17.2)	118 (9.7)	26 (1.1)	12 (0.3)	2 (0.07)	0 (0)	1529 (25.1)	147 (3.1)	42
B-7	Soda Springs Geyser 9S 41E 12adaS	29	4025	4694	6.8	925 (46.2)	150 (12.4)	3 (0.1)	18 (0.5)	3 (0.08)	0.4 (0.02)	2778 (45.6)	771 (16)	46
B-13	Pascadero Warm Spring 11S 43E 36bdaS	23	1475	1380	7.0	194 (9.7)	46 (3.8)	70 (3)	13 (2.9)	74 (2.1)	2.3 (0.1)	749 (12.3)	215 (4.5)	17
B-17	Unnamed Spring 12S 41E 31abcS	18	775	666	7.1	94 (4.7)	28 (2.3)	37 (1.6)	3 (0.07)	30 (0.9)	0.3 (0.02)	439 (7.2)	26 (0.5)	9
B-25	Bear Lake Hot Spring #1 15S 44E 13ccaS	40	2250	1625	7.0	230 (11.5)	41 (3.4)	155 (6.7)	48 (1.2)	72 (2)	4.2 (0.2)	263 (4.3)	769 (16)	43
B-28	Gentile Valley Spring #1 11S 40E 5aaaS	22	1825	1698	6.1	239 (11.9)	47 (3.9)	92 (4)	34 (0.9)	78 (2.2)	0.2 (0.01)	1086 (17.8)	104 (2.2)	18
B-30	Gentile Valley Spring #3 11S 40E 8dddS	30		930	6.6	132 (6.6)	38 (3.1)	54 (2.3)	3 (0.07)	43 (1.2)	0.2 (0.01)	594 (9.7)	40 (0.8)	26
B-31	Ben Meek Well 14S 39E 36ada	40	1900	1349	7.4	23 (1.2)	5 (0.4)	348 (15.1)	20 (0.9)	321 (9.1)	11 (0.6)	526 (8.6)	5 (0.1)	90
B-32	Orvil Rallison Well 16S 40E 16cac	15	455	374	7.6	42 (2.1)	18 (1.5)	20 (0.9)	7 (0.2)	31 (0.9)	0.4 (0.02)	199 (3.3)	14 (0.3)	43
S-1	Unnamed on Wolverine Creek 2S 38E 11bbcS	18	640	502	6.8	85 (4.2)	21 (1.7)	3 (0.1)	3 (0.1)	5 (0.1)	0.3 (0)	268 (4.4)	102 (2.1)	15
S-2	Blackfoot River Warm Spring 5S 40E 14bcdS	28	4600	4915	6.4	700 (34.9)	224 (18.4)	104 (7.1)	201 (5.1)	72 (2)	1.9 (0.1)	2371 (38.9)	1148 (23.9)	33
S-3	Unnamed on Blackfoot River 5S 40E 15bacS	18		4851	6.3	668 (33.3)	312 (25.7)	149 (6.5)	182 (4.7)	64 (1.8)	1.3 (0.1)	2287 (37.5)	1171 (24.4)	17

Table VII-1. Continued

Sample Number	Name and Location	Water Temp. °C	Specific Conductance (μmho/cm)	TDS (mg/l)	pH	Concentration in mg/l (meq/l)								
						Ca	Mg	Na	K	Cl	F	HCO_3	SO_4	SiO_2
S-4	Portneuf River Warm Spring 7S 38E 26cbdS	41	2200	1849	6.3	275 (13.7)	48 (3.9)	85 (3.7)	60 (1.5)	53 (2.4)	0.7 (0)	1060 (17.4)	259 (5.4)	47
S-5	Lava Hot Spring 9S 38E 21ddaS	43	1590	1179	6.7	103 (5.1)	29 (2.4)	176 (7.7)	37 (0.9)	179 (5)	0.7 (0)	528 (8.9)	91 (1.9)	35
S-6	Downata Hot Spring 12S 37E 12ccdS	43	450	392	7.1	61 (2.7)	15 (1.2)	26 (1.1)	3 (0.1)	22 (0.6)	0.3 (0)	211 (3.5)	26 (0.5)	28
S-7	Mound Valley Warm Spring 12S 40E 13dcdS	34	3100	2441	6.1	353 (17.6)	52 (4.3)	267 (11.6)	51 (1.3)	309 (8.7)	0.8 (0)	1106 (18.1)	278 (5.8)	24
S-8	Cleveland Warm Springs 12S 41E 31cacS	55	3600	2554	6.2	259 (12.9)	41 (3.4)	444 (19.3)	90 (2.3)	574 (16.2)	1.7 (0)	565 (9.3)	517 (10.8)	62
S-9	Unamed near Cleveland 12S 41E 31badS	21	750	619	6.7	82 (4.1)	25 (2.1)	32 (1.4)	5 (0.1)	27 (0.8)	0.3 (0)	410 (6.7)	23 (0.5)	15
S-10	Treasureton Warm Spring 12S 40E 36acdS	40	4550	3179	6.4	336 (16.8)	48 (3.9)	542 (23.6)	110 (2.8)	626 (17.7)	2 (0.1)	726 (11.9)	735 (15.3)	54
S-11	Maple Grove Hot Spring 13S 41E 7acaS	75	3000	2177	6.3	132 (4.4)	24 (1.8)	550 (23.9)	71 (1.8)	586 (16.5)	0.3 (0)	466 (76)	282 (5.9)	66
S-12	Unamed near Maple Grove 13S 41E 7dabS	62	3150	2107	5.9	82 (4.1)	22 (1.8)	499 (21.7)	77 (2)	585 (16.5)	1 (0.1)	454 (74)	323 (6.7)	64
S-13	Battle Creek (Wayland) H. S. 15S 39E 8bdcS	77	16550	9581	6.5	179 (8.9)	16 (1.3)	2985 (129.8)	493 (12.6)	5092 (143.6)	6 (0.3)	681 (11.2)	39 (0.8)	90
S-14	Squaw Hot Spring Well 15S 39E 17bdc	82	24800	13167	6.9	261 (13)	21 (1.7)	3996 (173.8)	694 (17.7)	7291 (205.7)	4.9 (0.3)	725 (11.9)	35 (0.7)	139
I-1	Yandell Springs 3S 37E 31dbbS	32	950	714	7.1	150 (7.5)	35 (2.9)	22 (1)	7.2 (0.2)	29 (0.8)	0.9 (0)	240 (38)	330 (6.9)	32
I-2	Alkali Warm Springs 4S 38E 28dddS	34	1529	1040	6.6	210 (10.5)	68 (5.6)	34 (1.5)	37 (1)	17 (0.5)	0.9 (0)	640 (10.2)	340 (7.1)	34
I-4	Shoal Subdiv. Well 5S 34E 26dba	26		973		93 (4.6)	39 (3.2)	176 (7.7)	25 (0.7)	228 (6.4)	2.7 (0.1)	425 (6.8)	156 (3.2)	38
I-5	Dean Morris Well 9S 36E 3cdb	22	349	200	7.2	44 (2.2)	9.2 (0.8)	13 (0.6)	1.9 (0)	24 (0.7)	0.1 (0)	143 (2.3)	13 (0.3)	25
I-6	Indian Springs 8S 31E 18dabS	32	1099	599	7.5	76 (3.8)	19 (1.6)	110 (4.8)	10 (0.3)	220 (6.2)	0.7 (0)	254 (4.1)	19 (0.4)	20
I-7	Rockland Warm Spring 10S 30E 13cdcS	38	1109	575	7.6	92 (4.6)	33 (2.7)	62 (2.7)	14 (0.4)	250 (7)	0.8 (0)	160 (2.6)	23 (0.5)	22

Table VII-1. Continued

Sample Number	Name and Location	Water Temp. °C	Specific Conductance (μmho/cm)	TDS (mg/l)	pH	Concentration in mg/l (meq/l)								
						Ca	Mg	Na	K	Cl	F	HCO_3	SO_4	SiO_2
I-8	C & Y Ranch Well 11S 27E 5bab	29	655	432	7.6	26 (1.3)	7.2 (0.6)	100 (4.4)		90 (2.5)	3.4 (0.2)	230 (3.7)	14 (0.3)	78
I-9	6-S Ranch Well 11S 25E 11cca	60	574	372	7.7	8.2 (0.4)	0.5 (0)	110 (4.8)	3.9 (1)	55 (1.5)	14 (0.7)	125 (2.6)	59 (1.2)	60
I-11	Ward Warm Spring 13S 26E 17ccdS	21	217	176	8.7	34 (1.7)	0.6 (0)	14 (0.6)	3 (1)	25 (0.7)	0.5 (0)	92 (1.5)	9.5 (0.2)	45
I-12	Malad Warm Spring 14S 36E 27cdaS	24	7589	4345	6.5	240 (12)	79 (6.5)	1200 (52.2)	210 (5.5)	2100 (58.8)	0.4 (0)	958 (15.3)	25 (0.5)	19
I-13	Pleasantville Warm Spring 15S 35E 3aabS	25	2187	1217	6.8	110 (5.5)	33 (2.7)	280 (12.2)	29 (0.8)	470 (13.2)	0.7 (0)	331 (5.3)	110 (2.3)	21
I-14	M. Fonnesbeck Well 15S 39E 7dbcS	63	889	566	6.8	78 (3.9)	27 (2.2)	68 (3)	18 (0.5)	91 (2.5)	0.5 (0)	418 (6.7)	4.3 (0)	7.4
I-15	E. Bingham Well 16S 38E 24abcS	23	27999	14103	6.2	320 (16)	36 (3)	4600 (200.1)	770 (20)	7800 (218.4)	3.9 (0.2)	930 (14.9)	48 (1)	68
I-16	Woodruff Warm Spring 16S 36E 10bbcS	27	5369	3084	7.3	130 (6.4)	45 (3.7)	910 (39.6)	87 (2.3)	1600 (44.8)	0.6 (0)	454 (7.4)	58 (1.2)	29
I-17	Robert Brown Well 5S 34E 26dab	41	1170	706	7.7	70 (3.5)	25 (2)	150 (6.5)	21 (0.5)	87 (2.4)	3.2 (0.2)	478 (7.6)	95 (2)	20
I-18	Kent Warm Spring 12S 34E 36bcbS	24	479	292	6.7	56 (2.8)	19 (1.6)	15 (0.7)	43 (1)	35 (1)	0.3 (0)	226 (3.6)	18 (0.4)	33
I-22	Alpine Warm Spring 2S 46E 19cadS	37	10499	6615	6.5	560 (27.9)	100 (8.2)	1500 (65.3)	180 (4.6)	2800 (79)	2.7 (0.1)	880 (14.4)	1000 (20.8)	40
R-1	RRGE-1 15S 26E 23caa		2987	1478	7.8	53 (2.6)	0.6 (0)	469 (20.4)	33 (0.9)	709 (19.9)	5.7 (0.3)	34 (0.6)	40 (0.8)	134
R-2	RRGE-2 15S 26E 23aaa		2157	1330	7.6	32 (1.6)	0.7 (0)	331 (14.4)	31 (0.8)	701 (19.6)	7.9 (0.2)	42 (0.7)	29 (0.6)	155
R-3	RRGE-3 15S 26E 25bdc		7997	3824	7.2	127 (6.3)	1 (0)	1245 (54.2)	103 (2.7)	2116 (59.2)	3.7 (0.1)	26 (0.4)	44 (0.9)	158
R-4	RRGP-5B 15S 26E 22dda		2857	1076	7.5	50 (2.5)	0.5 (0)	179 (7.8)	34 (0.9)	590 (16.5)	6.2 (0.1)	40 (0.6)	40 (0.8)	136
R-5	RRGI-6 15S 26E 25ada		11594	6107	7.3	199 (9.9)	1.4 (0.1)	2020 (87.9)	32 (0.8)	3636 (101.8)	5.8 (0.1)	62 (1)	60 (1.2)	91
W-1	Big Fall Creek Warm Spring 28N 115W 20dcaS	16	712	524	7.8	110 (5.5)	29 (2.4)	4 (0.2)	1 (0)	4 (0.1)	1.1 (0.1)	160 (2.6)	260 (5.4)	13

Table VII-1. Continued

Sample Number	Name and Location	Water Temp. °C	Specific Conductance (μmho/cm)	TDS (mg/l)	pH	Concentration in mg/l (meq/l)								
						Ca	Mg	Na	K	Cl	F	HCO_3	SO_4	SiO_2
W-2	Granite Hot Spring 39N 113W 6dabS*	41	1050	670	8.3	32 (1.6)	46.4 (3.8)	180 (7.8)	8.6 (0.2)	140 (3.9)	6 (0.3)	200 (3.3)	150 (3.1)	49
W-3	Astoria Warm Spring 39N 116W 32daaS	37	1550	1160	7.8	170 (8.5)	43 (3.5)	120 (5.2)	13 (0.3)	97 (2.7)	0.4 (0)	300 (4.9)	520 (10.8)	
W-4	Boyles Hill Warm Spring 41N 117W 36caaS	30	2380	2480	7.6	430 (21.5)	120 (9.9)	28 (1.2)	13 (0.3)	3.9 (0.1)	0.5 (0)	160 (2.6)	1600 (33.3)	
U-1	Cyrstal Hot Springs 11N 2W 29dadS	56	58000	43500		830 (41.4)	230 (18.9)	15000 (652.5)	790 (20.2)	26000 (733.4)	0 (0)	479 (7.7)	480 (10)	32
U-2	Cutler Warm Spring 13N 2W 27dbd	23	3670	2120	7.6	84 (4.2)	43 (3.5)	620 (27)	22 (0.6)	1000 (28.2)	1 (0.1)	320 (5.1)	65 (1.4)	17
U-3	Morning Glory Pool 13N 3W 23acb	51	15000	15000	7.2	220 (11)	70 (5.8)	2900 (126.2)	120 (3.1)	4800 (135.4)	0.4 (0)	360 (5.8)	98 (2)	29
U-4	Bemont Ward Well 13N 3W 35dda	15.5	2390	1560	7.8	66 (3.3)	35 (2.9)	440 (19.1)	28 (0.7)	470 (13.2)	0.9 (0)	485 (7.8)	220 (4.6)	47
U-5	Blue Springs 13N 5W 29	28	3410	2010	7.9	56 (2.8)	24 (2)	636 (27.7)	22 (0.6)	895 (25.2)	0.4 (0)	329 (5.3)	84 (1.7)	19
U-6	R. W. Tolman Well 15N 6W 34ccc	20.5	1610	938	7.9	60 (3)	25 (2)	247 (10.7)	5.7 (0.1)	375 (10.6)	1 (0.1)	259 (4.1)	40 (0.8)	41
U-7	Chas Taylor Well 12N 1E 16ddd	22	534	336	7.4	56 (2.8)	26 (2.1)	32 (1.4)	0 (0)	12 (0.3)	0 (0)	327 (5.2)	16 (0.3)	17
U-8	Cache Valley Well 13N 1E 33aca	21	1480	789	6.8	42 (2.1)	36 (3)	204 (8.9)	49 (1.3)	342 (9.6)	0.3 (0)	286 (4.6)	1.2 (0)	13
U-9	D. J. Gancheff Well 14N 1W 33aca	31	7230	4380	7.6	132 (6.6)	46 (3.8)	1400 (60.9)	110 (2.8)	2280 (64.3)	3.2 (0.2)	548 (8.8)	71 (1.5)	23
U-10	Coyote Spring 14N 10W 33bccS	43.5	5590	5990	7.6	87 (4.3)	19 (1.6)	1070 (46.5)	56 (1.4)	1620 (45.7)	2.7 (0.1)	352 (5.6)	70 (1.5)	29
U-11	Ethyl Taylor Well 15N 9W 31abc	16	626	626	7.8	70 (3.5)	17 (1.4)	31 (1.3)	0 (0)	99 (2.8)	0 (0)	181 (2.9)	20 (0.4)	63
U-12	Peter Mayo Well 15N 10W 36bbb	16.5	502	324	7.4	59 (2.9)	17 (1.4)	18 (0.8)	0 (0)	51 (1.4)	0 (0)	198 (3.2)	23 (0.5)	56

Chemical characteristics of thermal occurrences vary widely over the report area. The chemical characteristics at specific sites are shown on Plate 1 using stiff diagrams. Total dissolved solids (TDS) ranges from low values (300-400 mg/l) up to a value of 43,500 mg/l at Crystal Hot Springs (U-1) in the lower Bear River Valley in Utah.

The temperatures of thermal springs and wells in the study area are shown on Figure VII-1. The highest temperatures occur in the Cache Valley (82°C at Squaw Hot Springs well, S-11) and nearby in the Oneida Narrows area. High temperature waters are also found in the Lower Bear River Valley in northern Utah and along the Swan Valley-Star Valley area in Idaho and Wyoming (62°C at Auburn Hot Springs, H-26). The highest temperature waters all appear to be associated with normal faults along which recent movement has occurred.

Geochemical and Hydrologic Controls

Many factors are involved in creating the chemical characteristics of a given thermal occurrence. These include: 1) rock types along the flow path, 2) soil and biological characteristics in the recharge zone, 3) length of the flow path, 4) residence time in a rock formation, 5) depth of circulation, 6) relative time of encounter of a given rock formation, and 7) the temperature of the water. Generally the most important factor controlling the water chemistry of a thermal spring or well is the rock type(s) through which it passes.

The most prevalent rock types in the study area are carbonates, sandstones, extrusive volcanics, and alluvial sediments. Evaporites may be present in parts of the sedimentary sequence or in the alluvial deposits

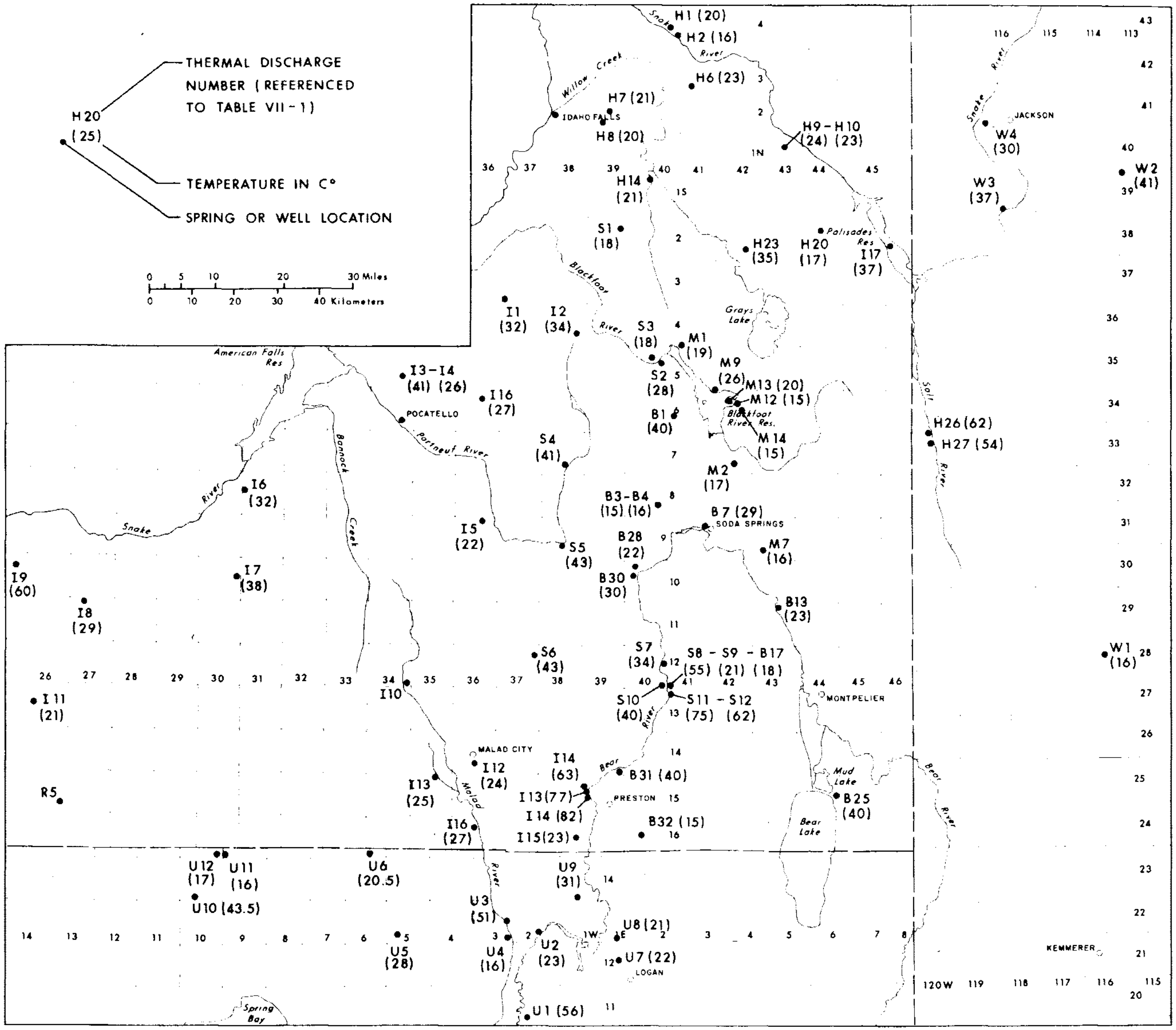


Figure VII-1. Locations and temperatures of thermal occurrences in southeastern Idaho, western Wyoming, and northern Utah.

in closed basins. A detailed discussion of the water-rock chemical reactions is outside the scope of this report; however, an overview is presented to facilitate the following discussion of hydrogeochemical environments.

Carbonates are by far the most common rock types within the report area. Probably all of the geothermal fluids pass through carbonates at some point in their flow paths. Limestone and dolomite dissolve in water charged with carbon dioxide to yield calcium, magnesium, and bicarbonate ions. This reaction is favored at lower temperatures (Freeze and Cherry, 1979). Conditions in the mountains in southeastern Idaho are favorable for the dissolution of carbonates.

The igneous extrusive rocks found in the study area are basalts and some rhyolites. Basalts cover many of the northern valleys although they are generally fairly thin. Rhyolities, cones and tuff are found near Blackfoot Reservoir and in the Heise Hot Spring area in Bonneville County. Calcium and magnesium are the principle ions expected from the dissolution of basalts (Hem, 1970). Rhyolites are likely to yield sodium on dissolution.

Alluvial deposits are quite thick in many of the Basin and Range valleys and may contain evaporites. Evaporite deposits are also present in the sedimentary sequence, in particular in the Preuss formation (upper Jurassic). Evaporites are highly soluble and will tend to control the chemistry of the waters which come in contact with them.

As a general rule, ground water gains in total dissolved solids as it progresses along its flow path. However, concentrations of given ions are not only dependent upon time of contact but also the rock types through which the water flows and the temperature to which the water is raised. A more complete interpretation of the chemical data will be presented in a later report after saturation calculations have been completed.

Hydrochemical Environments in the Report Area

Generalizations may be stated concerning hydrochemical environments in the study area. However, it is important to note that these generalizations are stated with the understanding that the knowledge of the complex patterns of ground water flow is largely lacking. Effort is continuing to sort out the complex stratigraphic and structural features that control the temperature and chemistry of each discharge site.

Swan Valley-Star Valley Thermal Waters

The Swan, Grand, and Star valleys in Idaho and Wyoming form a northwest to north-northwest trending graben through which the Snake and Salt rivers flow. The boundary faults are known to have been active since Pleistocene time (Witkind, 1975). The four thermal occurrences along this trend have temperatures ranging from 62°C at Auburn Hot Springs (H-26) in Wyoming to 23°C at Fall Creek Warm Springs (H-9 and H-10) in Bonneville County. Total dissolved solids range from 6000-9000 mg/l. The dominate ions are Na and Cl. The other major ions are also well represented. The relative concentration generally is Na>Ca>Mg and $Cl>HCO_3>SO_4$. However, at Alpine Hot Spring (I-17) and Auburn Hot Spring (H-26), in the south part of the trend, SO_4 is greater than HCO_3. Bicarbonate may be removed at these higher temperature springs (66°C and 62°C, respectively) due to calcite precipitation.

Meade Thrust Thermal Waters

The structure of the Meade Peak thrust block is characterized by shallow normal faults which are discontinuous at the surface (Royse, Warner and Reese, 1975). Thermal waters in this area are uniformly of the Ca/HCO_3 type with temperatures less than 26°C. TDS is generally between 800-1500 mg/l. Na, Cl and SO_4 concentrations are negligible in all springs in the Meade Peak block. Ca to Mg ratios are in the 3-5 range. The chemistry of these waters would seem to indicate comparatively short residence times.

Water from the Corral Creek Well (B-1) is somewhat different in chemistry from the other Meade Peak block occurrences. The water chemistry here is similar to that seen in the Paris thrust block which lies directly to the west of the Meade Peak block. Springs along the Blackfoot River (S-2 and S-3), the "geyser" at Soda Springs (B-7) and Corral Creek well (B-1) and are all higher in TDS than the Meade Peak waters. Their waters are still predominantly the Ca/HCO_3 type, but also contain significant concentrations of Mg and SO_4. With the exception of the Soda Spring geyser, these springs also have a significant Na concentration. None have an appreciable Cl content. If cation exchange (Ca exchanged for Na) is assumed to be the source of this sodium concentration, then all four waters would have had very similar original calcium concentrations (25-30 meq/l).

Basin and Range Thermal Waters

The Basin and Range province is considered to extend with in the report area from the south-flowing portion of the Bear River west beyond the Raft River Valley. These faults die out or are buried north towards the Snake River Plain. The Basin and Range province is characterized by deep normal faults and deep alluvium-filled valleys. Most of these faults have had recurrent movement since Miocene times (Witkind, 1975) and would therefore be expected to provide potential conduits for deep circulation of ground waters.

Temperatures in this area are as high as to 82°C at Squaw Hot Springs (S-11) in the Cache Valley, Idaho. Other high temperatures are found in the Cache Valley and the Lower Bear River Valley. TDS tends to be quite high; several thermal waters have a TDS in excess of 10,000 mg/l.

Thermal occurrences in the Basin and Range are repetitiously high in NaCl and depleted in all other ionic species. Ca, Mg, SO_4 and HCO_3 may be lost due to equilibria which favor the precipitation of $CaCO_3$ and $MgSO_4$ at higher temperatures. Ca and Mg are also likely to be depleted due to cation exchange with Na.

Many of the thermal waters found in Basin and Range valleys tributary to the Snake Plain in Cassia, Power and Bannock counties are more difficult to characterize. The waters from this part of the Basin and Range province are very distinct from the waters of the Basin and Range valleys tributary to the Great Salt Lake. The thermal waters in the Snake-tributary valleys are of low TDS and variable as to relative concentrations of major ion species. All of these discharges have a significant component of Na and Cl. However, these ions are not necessarily dominant, nor are they necessarily present in approximately equal amounts. Some of these springs are of the Ca/HCO_3 type. Other occurrences are of the Na/Cl or $Na/HCO_3/Cl$ type.

Transition Zone Thermal Occurrences

The Onieda Narrows to Mound Valley area along the Bear River is in a transition zone between the Basin and Range province and the Middle Rocky Mountain province. It also represents a transition between the Ca/HCO_3 type waters of the thrust blocks and the Na/Cl waters of the Basin and Range. Nine thermal occurrences are noted along this 24 km reach of the Bear River Valley. Springs in Mound Valley are of the Ca/HCO_3 type. However, they have significant concentrations of Na and Cl. Waters are high in SO_4, Ca, and HCO_3 at the Cleveland (S-8) and Treasureton (S-10) hot springs. The Maple Grove hot springs (S-11 and S-12) on the other hand resembles the Basin and Range type thermal springs.

CHAPTER VIII

CONCLUSIONS

Only limited conclusions can be stated as a result of this first phase of geothermal research in the thrust zone of southeastern Idaho, western Wyoming and northern Utah. None of the subproject theses have been completed; data analysis is not yet complete with much work remaining in chemical saturation analysis and correlation of chemical data with individual geologic units. However, the following tentative conclusions may be stated based upon work completed to date.

1) Thermal discharges within the study area are located along structural features with the hottest water issuing from deep normal faults associated with the Cache Valley graben, the Wasatch Front and the Swan-Grand Valley graben.

2) Thermal springs associated with faulting in the Meade thrust block have temperatures generally less than 25°C indicating shallow ground water flow systems.

3) The hottest thermal discharges have Na and Cl as the dominant ions while cooler thermal discharges in the center of the study area are characterized by Ca/Mg and HCO_3 as the dominant ions.

4) Temperature data from most of the deep test wells in the study area do not indicate a high geothermal gradient;

however, four test wells located near the center of the study area away from major normal faults do have higher than normal bottom hole temperatures indicating a possible geothermal system.

5) The thrust zones are not believed to create layers of either significantly higher or lower hydraulic conductivity because of only thin zones of breccia; most movement probably occurred along bedding planes. Thrust zones are identified in deep drilling primarily by a repeat of section.

6) Shallow geothermal development (less than 2 km) in the vicinity of the Meade thrust block will probably not yield water greater than 50°C.

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