Research Technical Report

IDWR Thrust Geothermal

DESCRIPTION OF GEOTHERMAL FLOW SYSTEMS IN THE VICINITY OF THE CARIBOU RANGE, SOUTHEASTERN IDAHO

by

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ABSTRACT

This report presents the results of a study of ground water flow systems near the Caribou Range in southeastern Idaho with a special emphasis on geothermal flow systems. The study analyzed thermal and nonthermal flow systems based upon hydrogeologic and chemical data collected at selected spring and well sites.

The geology of the area is extremely complex. The area has been intricately folded and faulted during periods of thrusting. The outcrops of the thrust faults are located on both the northeast and southwest borders of the study area. Only minor thrust faults are exposed in the study area. Relaxation of the compressive forces after thrusting produced major normal faults along the Swan, Grand, and Star valleys. These faults probably act as zones of high hydraulic conductivity.

Twelve of the twenty-three springs and two wells examined in this study have temperatures less than 15.5°C; nine have temperatures between 15.5 and 39°C; and four have temperatures above 39°C. The small total discharge of springs with temperatures above 39°C indicates there is very little deep movement of ground water. The springs and wells may be divided into two major groups based upon chemical characteristics. The first group has five springs that issue from graben forming faults associated with the Swan, Grand, and Star valleys. These springs have sodium and chloride as their dominant ions. The two other springs in this group are not located near major faults; rather, a line drawn between the two springs parallels the trace of the Swan and Grand valleys which

are located 30 km to the northwest. The dominant ions of these springs are sodium and sulfate. Temperature data from deep oil exploration wells in this area indicate an average geothermal gradient of 5.6°C/100 m, a value more than twice the world wide average. The average geothermal gradient was used to calculate maximum depths of circulation of 600 to 2400 m for springs in this group.

The second group of springs have lower temperatures and specific conductivities. The dominant ions for these springs and wells are calcium and bicarbonate. This group can be further divided into two sub-groups based upon temperature. The first sub-group includes four springs and two wells with temperatures of 16 to 23°C and low specific conductivities. All but one of these flow from Tertiary rhyolite. The maximum depths of circulation calculated for these springs is in the order of 200 to 300 m. The second sub-group includes twelve springs with temperatures of 6 to 14°C and low specific conductivities. These springs are the result of local flow systems formed by the discontinuous nature of the geologic units in this area.

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INTRODUCTION

Statement of the Problem

A research project directed by Dr. Dale R. Ralston of the University of Idaho was initiated in 1980 to study the thermal and nonthermal flow systems in the overthrust region in southeastern Idaho and portions of Utah and Wyoming. The project was divided into six graduate research studies at the University of Idaho. Three of the projects were areal reconnaissance studies of the Caribou Range, Meade Peak, and southern subareas. The remaining three projects were concerned with 1) the regional evaluation of hydrochemistry, 2) a regional evaluation of hydrostratigraphy, and 3) a geologic evaluation of the breccia zones associated with thrust faulting. This report provides the results of the investigation of the Caribou Range study area (figure 1). This region has the potential for geothermal development. Evidence for the geothermal resource includes warm springs, wells which yield warm water, and reports of high temperatures at depth from oil and gas test wells. The geology of the area is very complex with thrust faults, normal faults, and folding of the mostly sedimentary units influencing the movement of water.

The intent of this study is to provide a reconnaissance level examination of the hydrogeologic controls on thermal and nonthermal springs and wells in the area, using geologic, hydrologic, and chemical data at each site. Particular emphasis is placed on the geologic controls that thrust faulting has placed on the ground water flow systems in this area.

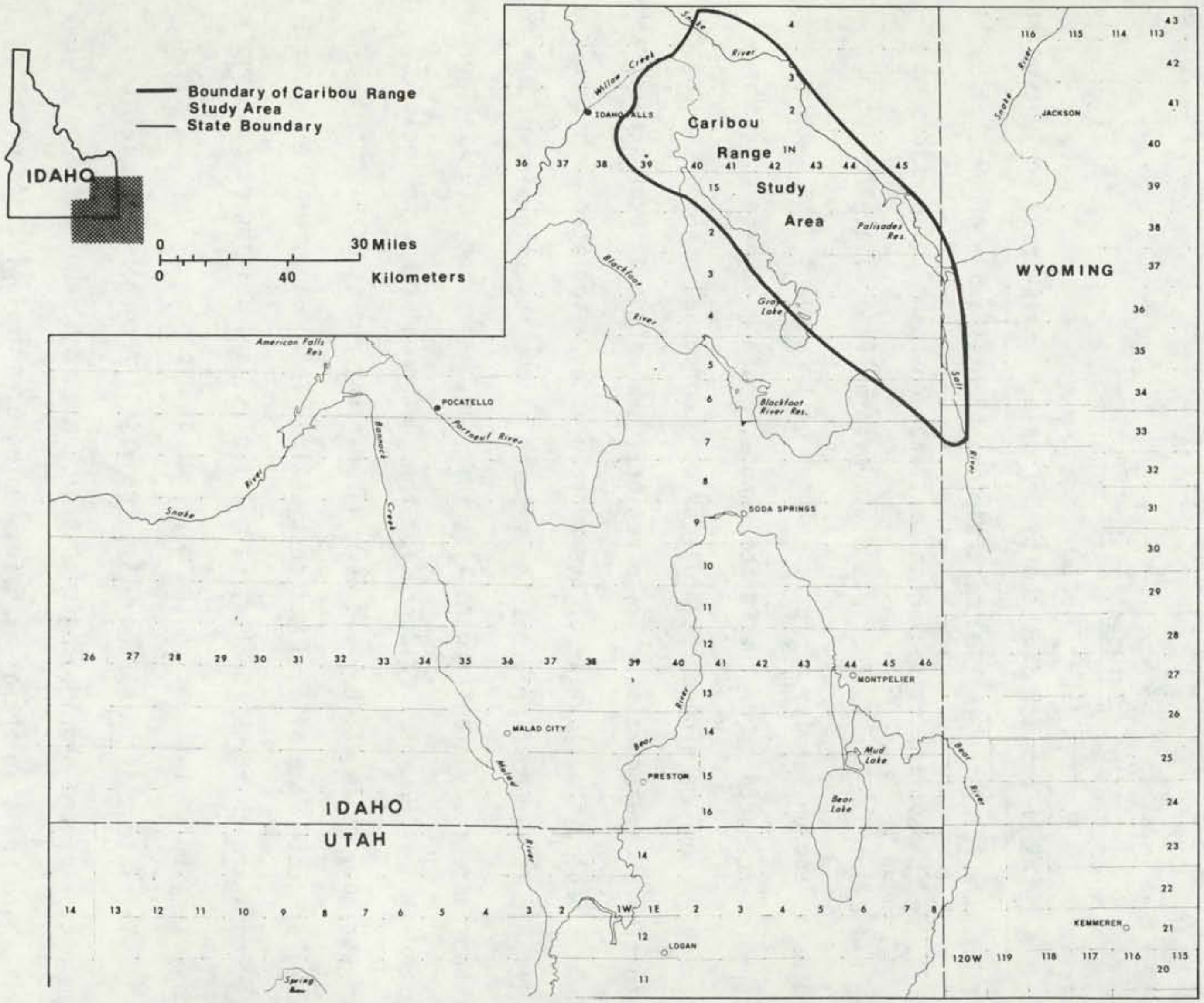

Figure 1. Location of Caribou Range study area in southeastern Idaho and western Wyoming.

Purpose and Objectives

The purpose of the research project is to better understand the extent and controls of ground water flow systems in southeastern Idaho with a special emphasis on geothermal flow systems. The general objective of this study is to describe geothermal and selected nonthermal ground water flow systems in the vicinity of the Caribou Range in southeastern Idaho. The specific objectives of this study are to:

1) Review the geology and hydrology of the area to formulate a conceptual model of the hydrogeologic framework and regional flow systems.
2) Inventory and collect physical and chemical data on all thermal and selected nonthermal springs and wells in the study area.
3) Analyze the springs and wells based upon location, hydrogeology, and water chemistry in order to categorize those springs or wells with similar characteristics.
4) Formulate and describe hypotheses for regional thermal and nonthermal ground water flow systems.

Method of Study

A literature search was conducted to obtain information regarding springs and the geology in this area. The field data collection program included locating selected springs, measuring the temperature and selected chemical characteristics of the water, collecting water samples, measuring or estimating the rate of flow, and examining the geologic setting. Water samples were then chemically analyzed in the laboratory to determine the concentrations of major ionic components. Data obtained from the literature survey, the field examination, and chemical analyses were then combined to complete this study.

Springs were initially identified by examining USGS topographic maps, Forest Service maps, or by word of mouth. The springs were then visited in the field and sampled. All springs or wells warmer than 15.5°C were sampled. In addition, perennial springs associated with major structural features, such as faults, were also sampled.

The geology was studied and the temperature, discharge, pH, and specific conductance was measured at each site. A summary of the field methods used in the data collection is presented in table 1. Samples were collected for lab analysis following the procedure outlined in USGS Open-file Report 75-68 (Thompson, 1975); the procedure was modified slightly in that the sample taken for silica was not diluted.

Laboratory water quality analyses were obtained 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., 1979). The Mohr volumetric method was used for chloride, a gravimetric method was used for sulfate, specific ion probe for fluoride, and concentrations of sodium, potassium, magnesium, calcium, and silica were determined by atomic absorption spectroscopy.

Spring and Well Numbering System

The numbering system used in this report is the same as used by the Idaho Department of Water Resources and the United States Geological Survey. It uses the official rectangular subdivision of public lands

Table 1. Summary of field methods used in the study of ground water flow systems in the vicinity of the Caribou Range in southeastern Idaho and western Wyoming

Measurement	Method
Temperature	Measured by Taylor pocket thermometer with 2°F divisions at point of emergence. Temperature is converted to C, and rounded to the nearest degree.
Discharge	Visually estimated or measured with a pygmy meter.
pH	Measured with either a VWR Model 45 Digital Mini pH Meter or a Corning Model 3D Portable pH Meter. Meters were calibrated with buffers before each use. Samples were collected from the point of discharge in a prerinsed beaker and the pH measured immediately.
Specific Conductance	Measured with a Hach Model 16300 Conductivity Meter.
Bicarbonate	Measured with a Hach Digital Titrator Kit utilizing the pH meter.

with reference to the Boise baseline and meridian. Figure 2 gives an example of well 1S 17E 23aab. The first two parts of the numbering system 1S and 17E refer to the township and the range, respectively. The next number is the section number and is followed by three letters and a number or the letter S. The first letter indicates the quarter section and is labeled a, b, c, or d in a counter-clockwise pattern starting from the northeast corner. The following two letters indicate the 40-acre tract and the 10-acre tract, respectively. If a S follows the last letter, then this site is a spring; otherwise, this indicates a well (Mitchell and others, 1980).

Geographic Setting

The boundaries of the Caribou Range study area are shown in figure 3. The Grand Valley fault forms the northern and eastern boundary of the study area. This fault is located along the north side of the Swan and Grand valleys and the eastern side of Star Valley. The location of the Meade thrust fault forms the southern boundary and the western boundary is the Snake Plain. The study area includes 3800 km^2 and is located predominately in Bonneville County with smaller portions in Caribou, Jefferson, and Madison counties, Idaho, and Lincoln County, Wyoming.

The study area lies within the Northern Rocky Mountain and Columbia Plateau physiographic provinces. The Northern Rock Mountain province is characterized by complexly folded and faulted mountain ranges. The majority of the study area is located in this province. The small northwestern portion of the study area is located in the Columbia Plateau

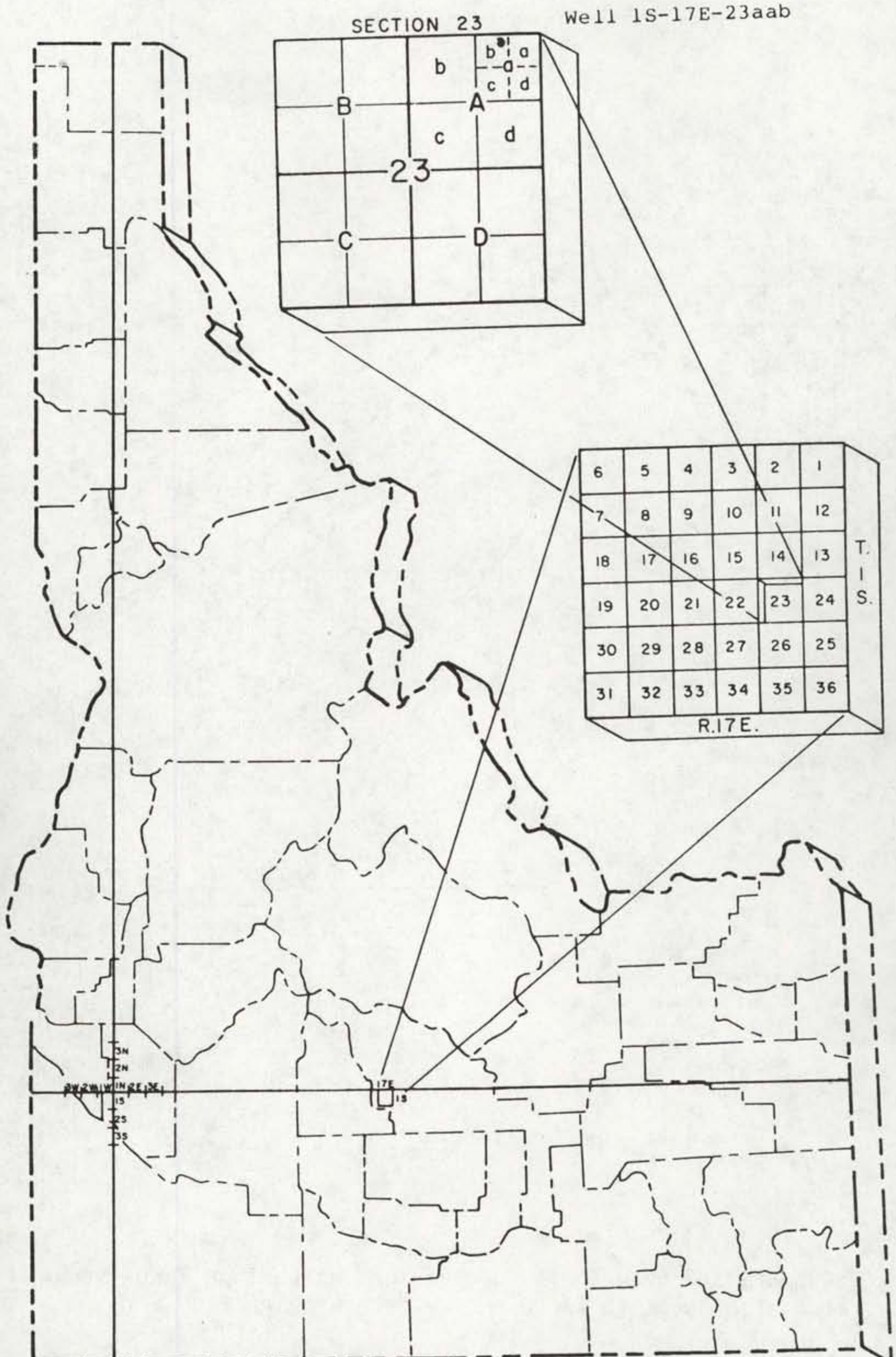

Figure 2. Diagram showing well and spring numbering system for Idaho.

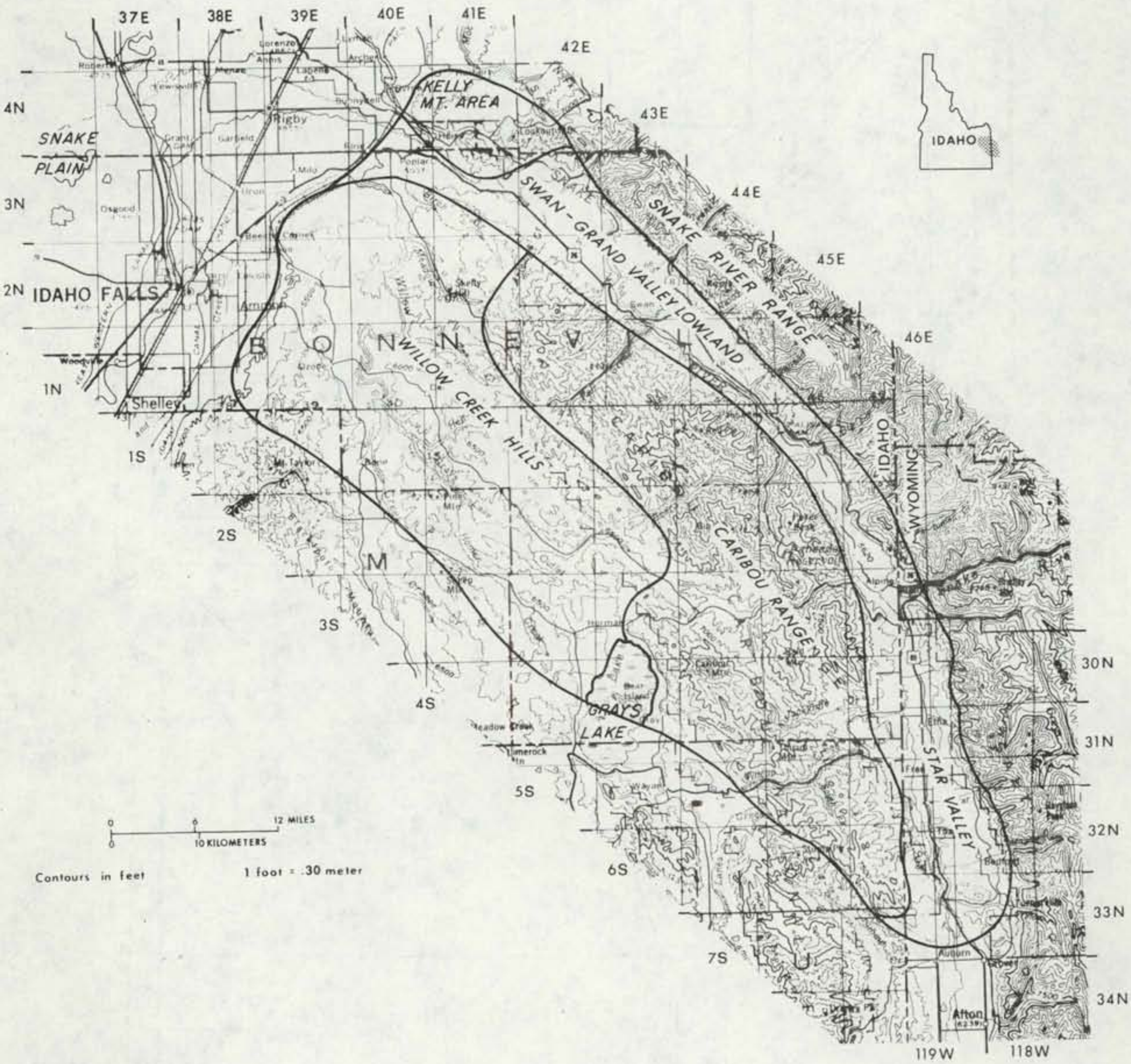

Figure 3. Boundary and geographic subdivisions of Caribou Range study area, southeastern Idaho and western Wyoming

physiographic province. This area is covered with Tertiary and Quaternary basalts and extrusive volcanic rocks.

The study area can be divided into several general areas (figure 3). The Swan-Grand Valley lowland is a northwest trending basin and range structure that extends from the Kelly Mountain area at the north to Alpine, Wyoming in the southeast. There it curves to the south and blends into Star Valley. These valleys slope toward the northwest with an average gradient of 3.6 m per km. The width varies from 7 km in Swan Valley to 0.3 km at Calamity Point, the site of Palisades dam. The waters backed up by this dam fill the entire length of Grand Valley. The elevation varies from 1850 m at Auburn, Wyoming, to 1550 m south of Lookout Mountain. The Kelly Mountain area is located northwest of the Swan-Grand Valley lowland. The highest elevation of this area is approximately 2000 m.

The Caribou Range is a rugged, mountainous area south of the Swan-Grand Valley lowland. It parallels the lowland for more than 80 km. The maximum elevation of this area is 2988 m at Caribou Mountain. Seven other peaks in this area have elevations over 2500 m. The streams in this area have cut deep canyons into this mountain range.

The Willow Creek hills form a western and southwestern portion of the study area. This is a hilly region with local relief of 100 to 150 m. The highest elevation is 1980 m near Herman with a general slope toward the northwest to the city of Ammon where the elevation is 1520 m.

Grays Lake is in the southern portion of this area. This marshy area was once flooded with water but at present has only a few open patches of water. The elevation at Grays Lake is 1950 m.

All streams in the study area are tributary to the Snake River. The Snake River enters the study area near Alpine, Wyoming, follows the Swan-Grand Valley lowland northwest to the Snake Plain where it changes its course to flow toward the southeast. The important streams that drain the study area are Tincup and Salt rivers, McCoy, Bear, Fall, and Willow creeks, and Grays Lake Outlet.

Generally, cloudy and unsettled weather prevails in the winter with snow accumulating in the hills and mountains. The weather warms gradually in the spring with these months generally the wettest of the year. In the summer the area usually has warm days with cool nights with precipitation limited to localized showers. The autumn has fine weather that is gradually replaced by unsettled weather in late fall. Snowfall usually begins in November or December (U.S. Department of Interior and U.S. Department of Agriculture, 1976).

Mean annual precipitation varies from less than 25 cm in the northwestern portion of the study area near Ammon to more than 89 cm on several of the higher mountains such as Big Elk Mountain or Caribou Mountain (U.S. Department of Interior and U.S. Department of Agriculture, 1976). The precipitation generally increases toward the southeast. More than half of the precipitation falls from October to March, with most of this as snow. The average annual temperatures as recorded at Idaho Falls, Irwin, and Afton are 5.3, 5.5, and 2.9 degrees Celsius (U.S. Department of Commerce, 1964).

The main population center near the study area is Idaho Falls with 39,590 people (U.S. Department of Commerce, Bureau of Census, 1981). The study area itself is sparsely populated with most people living in Swan and Star valleys in the small towns of Swan Valley, Irwin, Alpine, or Auburn. U.S. Route 26 and 89 follows these valleys from south of Auburn to Alpine, Wyoming, through Swan Valley to Idaho Falls. Local access in the area varies, with excellent main roads and fairly good to poor tributary roads.

Previous Investigations

The previous investigations in this area can be divided into three topics: geology, geothermal resources, and hydrology. The geology of this area was initially examined in 1877 by geologists of the Hayden Survey (St. John, 1879). Kirkham (1924) mapped six quadrangles in the eastern half of this study area on a reconnaissance level. This report dealt with the geology and the oil possibilities of this region. Mansfield (1927, 1952) mapped the western quarter and the southern portion of the study area. Neighbor (1953) presented a map of Big Elk anticline along with a drill log of a wildcat oil well drilled on Big Elk Mountain. Specific 7.5 and 15 minute quadrangle areas were mapped in detail from 1958 to 1963 (Rubey, Bedford Quadrangle, 1958; Vine, Fall Creek area, 1959; Gardner, Irwin Quadrangle, 1961; Jobin and Schroeder, Connant Valley Quadrangle, 1964a, Irwin Quadrangle, 1964b; Albee and Cullins, Poker Peak and Palisades Quadrangle, 1965; Staatz and Albee, Garns Mountain Quadrangle, 1966). The geology and mineral resources of Bonneville County were presented by Savage (1961). The origins and divisions of the thrusts in southeastern Idaho and adjacent Wyoming were discussed by Eardley (1967). In 1975, Witkind presented data on known and suspected active faults in the study area. Gravity and aeromagnetic surveys were conducted in the area of Heise Hot Springs by Mabey (1978). Prostka and Embree (1978) mapped suspected caldera structures in the Rexburg area and gave a summary of the geothermal occurrences in this area. In all, the surface geology has been mapped in detail for most of the study area except in portions of the Willow Creek Hills. The subsurface geology is poorly understood throughout this area.

Many publications have mentioned one or more of the thermal springs in this area. Stearns and others (1937) summarized the published and unpublished data from the files of the USGS on the thermal springs in this area. Ross (1971) published data on the geology and chemical analyses of selected warm springs in Idaho. Young and Mitchell (1973) inventoried and analyzed more selected thermal springs in the state. Breckenridge and Hinkley (1978) inventoried thermal springs in Wyoming and presented geologic and chemical data on the sites. Mitchell and others (1980) compiled all of the available geochemistry on the warm springs in the state along with a very brief description of the geology and possible uses of the water.

Little has been written about the hydrology of this area. Stearns and others (1938) discussed gains and losses of the Snake River from the Wyoming border to the Snake Plain. Walker's (1965) study of upper Star Valley included the eastern portion of the study area. He included an analysis from Auburn Hot Springs and postulated the possible origin of the sodium-chloride water. Winter (1979) provided relative hydraulic conductivities for the Dinwoody, Phosphoria, and Wells formation in connection with phosphate mining studies performed in southeastern Idaho.

Concurrent investigations include detailed analyses of the chemistry and hydrogeology of selected thermal and nonthermal springs and wells in the area around Bear River Range and the Meade thrust block (Baglio, 1982; Mayo, 1982). Souder (1982) is studying the chemistry of geothermal flow systems on a regional basis in an area bounded by Raft River on the west, the Island Park KGRA on the north, and the Idaho state line to the east and south. His analysis will utilize data from this study as well as age dating from several of the springs in this area. Coleman (1982) is investigating the physical characteristics of the Meade thrust, with an emphasis on the actual thrust plane. Arrigo (1982) is evaluating data from deep exploration oil wells, including down hole temperatures and geophysical information to determine the depth and character of the thrust and how this relates to the regional ground water flow systems. In addition, he is examining the hydrostratigraphy of selected formations in southeastern Idaho.

HYDROGEOLOGY OF STUDY AREA

The rocks within the study area range in age from Cambrian to Recent (table 2). The Paleozoic rocks are mostly marine limestones, with some sandstone and minor shales. Mesozoic rocks consist of alternating limestones, sandstone, and shales. Cenozoic strata consist of conglomerates, volcanic ash, sandstone, alluvium, and colluvium. Igneous rocks of Tertiary and Quaternary age consist of rhyolite tuffs and basalts.

A hydrogeologic classification of the formations is shown in table 2. The formations are classified as either an aquifer (rock unit that will yield significant quantities of water) or an aquitard (rock unit that will store water but yield only small quantities). This classification does not mean that the entire formation is an aquifer or an aquitard, but rather, the formation as a whole acts in the stated manner. The hydrogeologic classification is obtained from two sources. Studies conducted by investigators at the University of Idaho (Ralston and others, 1977 and Winter, 1979) supply data on the Mission Canyon Limestone, Wells, Phosphoria, Dinwoody, and Thaynes formations. The remaining formations are classified by comparing their physical characteristics to the ranges of values of hydraulic conductivity for given rock types as presented by Freeze and Cherry (1979). Formations are classified as an aquifer if they are predominantly made up of sandstone, limestone, dolomite, or basalt or as an aquitard if the main constituent is shale. This classification indicates that Ankerah Shale, Woodside Shale, Phosphoria,

Table 2. Composite geologic section of major rock units in the vicinity of the Caribou Range, southeastern Idaho and western Wyoming

Era	System	Formation, Group	Thickness (M)	Description and Symbol	Hydrogeologic Classification
	Quaternary			Plateau and canyon filling basalts (Qpmb), igneous felsic rocks (Qplf), alluvium (Qa), Pliestocene outwash, fanglomerate, and terrace gravels (Qpg), windblown deposits (Qw), colluvium (Qg)	Aquifer
Cenozoic				Airfall volcanics (Tpv), silicic welded tuff (Tpf), intrusive (Ti)	Aquitard
	Tertiary	Salt Lake Formation	0-200+	Conglomerate, volcanic ash, marl, calcareous clays, sandstone, and grit (Tpd)	Aquifer
		Wayan Formation	300-600	Sandstone, shale, conglomerate, limestone, and red beds (Ku)	Aquifer
		Bear River Formation	100-500	Shale and sandstone (Kl)	Aquitard
	Cretaceous	Gannett Group	100-600	Sandstone, shaley sandstone, and shale, (Tygee Formation); light gray, fine-grained limestone (Draney Limestone); red shale and siltstone (Bechler Formation); very light gray, fine-grained limestone (Peterson Limestone); red siltstone and sandstone, and dark-colored pebble conglomerate (Ephriam Conglomerate) (Kl)	Bechler-aquitard others-aquifers
Mesozoic		Stump Sandstone	50-100	Sandstone, glauconitic calcareous sandstone, and arenaceous limestone (Ju)	Aquifer
		Preuss Sandstone	0-200	Red shaley sandstone, and siltstone (Ju)	Aquifer
	Jurassic	Twin Creek Limestone	200-500	Shaley limestone, oolitic limestone, lithographic limestone, and siltstone (Jl)	Aquifer
		Nugget Formation	100-500	Well-sorted, fine-grained sandstone (Jl)	Aquifer

Table 2. Continued

Era	System	Formation, Group	Thickness (M)	Description and Symbol	Hydrogeologic Classification
Mesozoic	Triassic	Ankerah Shale	90-200	Red calcareous siltstone and shale (TR)	Aquitard
		Thaynes Formation	250-300	Fine-grained limestone and siliceous limestone with interbedded sandstone, siltstone, and shale (TR)	Aquifer
		Woodside Shale	100-400	Reddish brown siltstone and shale (TR)	Aquitard
		Dinwoody Formation	100-600	Greenish brown shale and siltstone, with interbedded silty limestone (TR)	Aquifer
Paleozoic	Permian	Phosphoria Formation	70-100	Fine-grained sandstone, black mudstone, phosphorite, dolomite, dolomitic limestone, and chert (PPs)	Aquitard
	Pennsylvanian	Wells Formation	300-900	Fine-grained well-sorted quartzite, cherty limestone and cherty dolomite (PPs)	Aquifer
	Mississippian	Mission Canyon Limestone	300-800	Thick-bedded limestone, thin-bedded dolomite and limestone breccia (Ms)	Aquifer
		Lodgepole Formation	200-400	Dark gray, thin-bedded, fine-grained limestone (Ms)	Aquifer
	Devonian	Darby Formation	200-300	Calcareous siltstone, and sandstone, silty limestone, and fine-grained limestone and dolomite (D)	Aquifer
	Ordivician	Bighorn Dolomite	20-200	Light-gray, fine- to medium-grained dolomite (OЄ)	Aquifer
	Cambrian	Gallatin Limestone	50-200	Dark gray thin-bedded limestone, with irregular patches of silty dolomite and partings of siltstone and shale (OЄ)	Aquifer

(After Mitchell and Bennett, 1979; Staatz and Albee, 1966; Mansfield, 1952; Jobin and Schroeder, 1964a, 1964b; Ralston and others, 1977; Winter, 1979)

Bear River, and Becher formations are aquitards and the remaining formations are aquifers.

The geology of the area is extremely complex (figure 4 and figure 5). The area has been intricately folded and faulted during periods of thrusting. The movement was toward the northeast with displacement in the order of 16 to 24 km (Armstrong and Oriel, 1965). The easing of the compressive forces associated with thrusting resulted in the formation of normal faults along the Swan-Grand Valley lowland. Igneous rocks complicate the geology in the northwestern portion of the study area. Proskta and Embree (1978) suggest that several calderas may be present in this region.

The distribution of hydraulic conductivity throughout the study area is highly variable. Overall, this area probably has a relatively high hydraulic conductivity at the surface which decreases with depth resulting from closing of fractures and increasing cementation and compaction.

The Swan-Grand Valley lowland is a graben with at least 300 m of displacement. It has been filled to its present level with an undetermined thickness of alluvium, colluvium, and in the northern portion, volcanics (figure 4). Rocks of Paleozoic, Mesozoic, and Cenozoic age lie beneath these valley filling sediments. Two major faults border this lowland. The northeastern fault associated with this graben is the Grand Valley fault. This high angle normal or reverse fault extends the full length of Swan, Grand, and Star valleys. The trace of this fault is hidden most of its length by rocks of the late Tertiary and Quaternary age. The southeastern boundary of this graben is the Snake River fault. It extends from the Snake Plain in the northwest to the Star Valley in

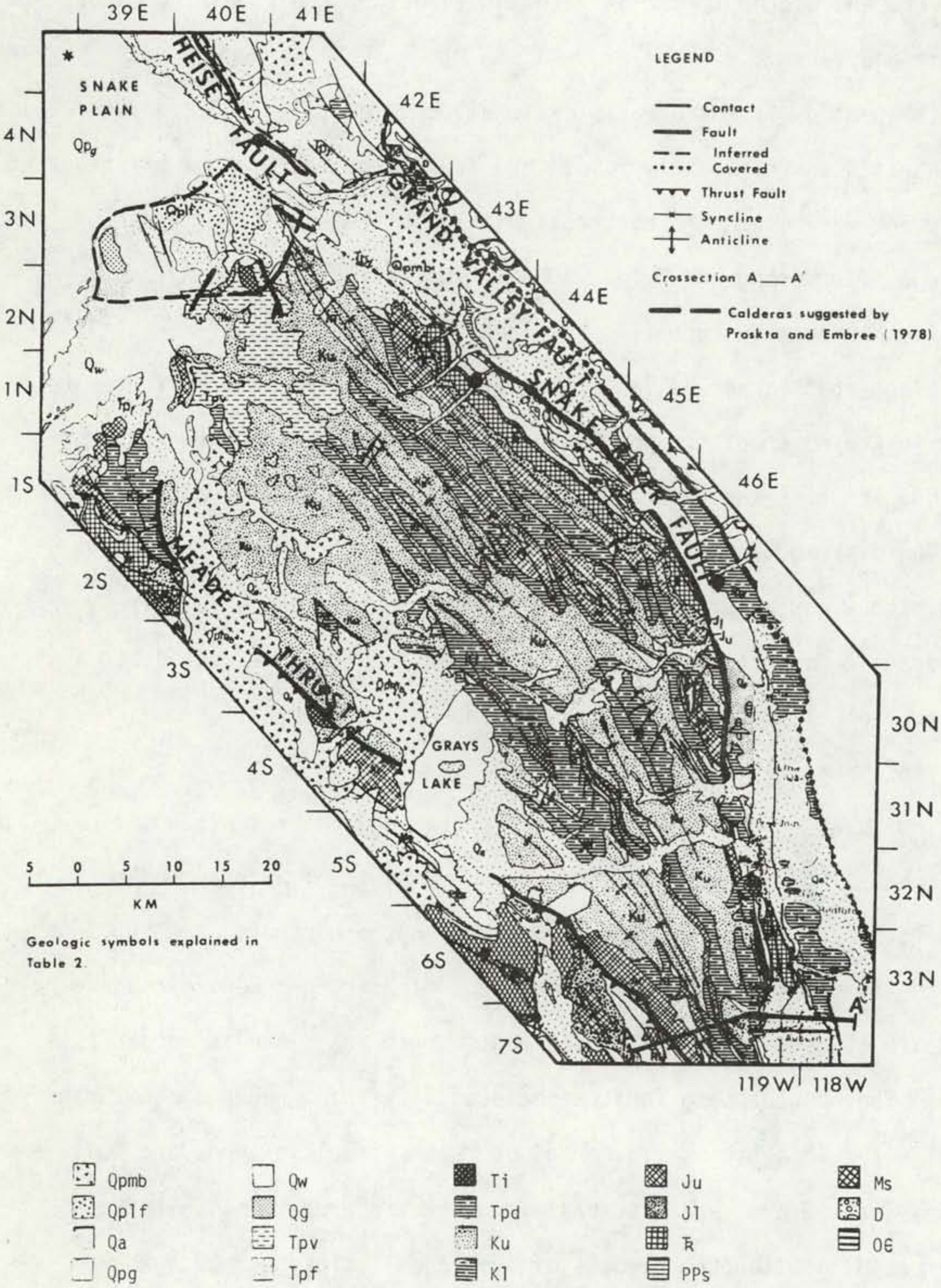

Figure 4. Geologic map of Caribou Range study area in southeastern Idaho and western Wyoming.

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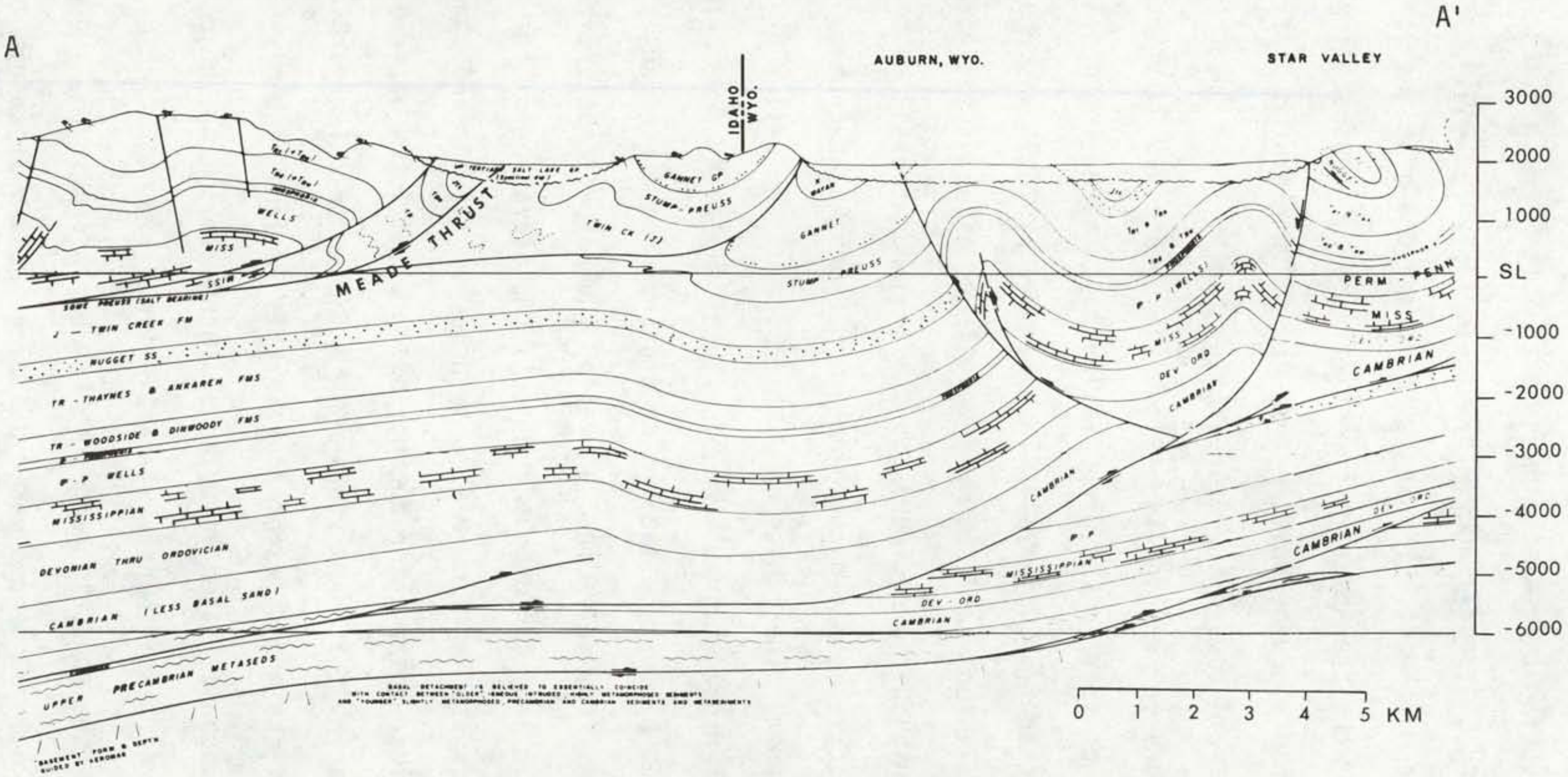

Figure 5. Cross section A-A' in the Caribou Range study area in southeastern Idaho and western Wyoming.

the southeast, where it joins the fault along the west side of Star Valley. The trace of this fault is also 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 northeast. The Snake River and Grand Valley faults may combine to join with the Absaroka thrust (figure 5, cross section A-A'). The downthrown block bounded by these faults is interpreted to be rotated to dip northeastward toward the Grand Valley fault. 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 unconsolidated sediments in the lowland probably have higher hydraulic conductivities than the older formations located below and to either side of them. The faults on either side of the valley probably act as a zone of higher hydraulic conductivity caused by fracturing. This is suggested by springs located on the trace of these faults.

Drill logs from wells in Swan Valley indicate the potential surface is very near land surface and reflects the elevation of the Snake River. Gain-loss studies from Alpine to Heise by Stearns and others (1938) show that the river gains water during low flow and loses water during high flow indicating that bank storage is a factor in this hydrologic system. Most of the ground water flow in this lowland probably occurs in the shallow unconsolidated alluvial sediments following the course of the valley toward the northwest. The relatively low elevation of this area relative to the mountain ranges to the north and south, suggest that this is a regional ground water discharge area. Discharge from regional flow systems should occur along Snake River and Grand Valley faults, not in the interior of the lowland.

On the northeastern boundary of the Swan-Grand Valley lowland is the Kelly Mountain area. This area is made up of Pliocene rhyolites and welded tuffs that overlie undifferentiated Paleozoic and Mesozoic rocks. It has been mapped as a caldera by Proskta and Embree (1978). The Grand Valley fault continues through the Kelly Mountain area; several major faults, including the Heise fault, parallel its trend. The Heise fault acts in the same manner as the Grand Valley fault, down dropping rocks on its southern border.

The caldera structure forms a closed basin bordered by faults. The primary hydraulic conductivity of the units filling the caldera is very low but zones with high hydraulic conductivity are formed by faulting, paleosoils, and interflow zones. There are many small springs in this area associated with the zones of high hydraulic conductivity, some of which are warm. There are no large springs in this area.

The Caribou Range is a mountainous area 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 predominantly of limestones, sandstones, and shales. The folding of these sedimentary rocks has affected the distribution of hydraulic conductivity in two ways. Folding changes the relative positions of aquifers and aquitards and the primary hydraulic conductivity is altered by the fracturing associated with folding.

Figure 5 shows tilted and deformed rocks on the surface with attenuation of folding as the depth increases. It is believed that the bedding planes are approximately horizontal at depth. The thrusts are also thought to be nearly horizontal under the study area. The entire study area, excepting possible caldera structures in the northern portions, has been overthrust with movement toward the northeast. The depth to the gliding plane of the thrust is unknown.

The Caribou Range is a regional high with a high rate of precipitation and probably is a recharge area for numerous local and intermediate flow systems. The large amount of relief and complex geologic structure probably limits the possibility of regional flow. The flow systems formed here are mainly controlled by the stratigraphic units and the geologic structures produced by folding and faulting. 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.

Grays Lake is a swampy lowland located southwest of the Caribou Range. This area has lacusterine sediments overlying sedimentary rocks of Jurassic and Cretaceous age. The lake is formed by the accumulation of runoff from the surrounding mountains; it may be a ground water discharge area.

The Willow Creek Hills are located west and are topographically lower than the Caribou Range. The southern portion of this area is made up of intensely folded and faulted sedimentary rocks of Cretaceous age which have been overlain in areas by canyon filling basalts. The northern portion of this area has Jurassic and Cretaceous sedimentary rocks overlain by silicic welded tuffs, air fall volcanics, and loess. Proskta and Embree (1978) suggest that there are calderas in the northern portion of this area (figure 4). Most of the area within the Willow Creek Hills is mapped on a reconnaissance level; portions are unmapped.

The Willow Creek Hills area has a lower potential for ground water recharge than the Caribou Range because it receives much less precipitation. Most of the springs in this area are small, many of which dry up during the fall. There are also a few perennial medium-sized springs but no large springs are present.

PHYSICAL AND CHEMICAL SETTINGS OF SPRINGS AND WELLS

Introduction

Twenty-three springs and two wells were inventoried in the study area. Short descriptions of the physical setting and characteristics of the springs and wells are presented in table 3. Chemical analyses of these springs and wells are presented in table 4. Multiple analyses for several sites have been presented where the data are available. The springs inventoried in the study area have been divided into three groups for discussion purposes: thermal springs that discharge highly mineralized water, thermal springs or wells that discharge water with relatively low concentrations of dissolved solids, and nonthermal springs.

Thermal Springs with High Specific Conductivities

Seven spring sites are included in this group: H-3 (I-3), H-9 (H-10 and I-10), H-16, I-21 (I-22), H-23 (I-23), H-26 (W-26), and H-27 (Figure 6). The temperatures and conductivity of the discharges range from 20 to 66°C and 6500 to 11,000 μmhos/cm, respectively.

Heise Hot Springs (H-3 and I-3)

This 48°C spring is located at the foot of a 300 m escarpment. It has deposited a 10-meter high travertine mound which is being eroded at its base by the Snake River. Heise Hot Springs resort, located 0.2 km northeast of the springs, has used water from this spring since the late 1800's for recreational purposes.

Table 3. Physical settings of springs and wells in the vicinity of the Caribou Range, southeastern Idaho and western Wyoming

Sample Number	Name, Location and Date Sampled	Water Temp. (°C)	Elevation (m above MSL)	Well Depth (m)	Depth to Water (m)	Discharge (1/s)	Site Description
H-1	Elkhorn Warm Spring 4N 30E 23cadS (7-31-80)	20	1580			10 E*	This spring is located 2.8 km northwest of Heise Hot Springs, 0.2 km north of the Heise fault and emerges from rhyolitic tuff. The spring is located within the southern edge of the Rexburg Caldera Complex.
H-2	Hawley Warm Springs 4N 40E 25bbdS (7-31-80)	16	1610			10 E	This spring is located 1.5 km northwest of Heise Hot Springs, 0.2 km north of the Heise fault and emerges from rhyolite tuff. The spring is located within the southern edge of the Rexburg Caldera Complex.
H-3	Heise Hot Springs 4N 40E 25ddaS (6-18-80)	48	1540			4 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 (6-30-80)	8	1770			2 E	This spring issues from the contact of Salt Lake formation and the Gallatin limestone formation. It is located 500 m southwest of the Grand Valley fault.
H-5	Buckland Warm Spring 3N 42E 12cca and ccdS (6-18-80)	11	1570			1000	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 (6-18-80)	23	1710			6 E	This spring issues from a rhyolitic tuff. A large northeast trending fault is located 0.2 km to the south.
H-7	Dyer Well 2N 39E 21bcc (7-21-80)	21	1540	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.
H-8	Anderson Well 2N 39E 29bac (7-21-80)	20	1520	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.

Table 3. Continued

Sample Number	Name, Location and Date Sampled	Water Temp. (°C)	Elevation (m above MSL)	Well Depth (m)	Depth to Water (m)	Discharge (1/s)	Site Description
H-9	Fall Creek Mineral Springs 1N 43E 9cbb1S (8-5-80)	24	1660			6 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 Snake River fault.
H-10	Fall Creek Mineral Springs 1N 43E 9cbb2S (8-5-80)	23	1660			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 (7-22-80)	9	1770			3 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 (7-22-80)	13	1680			4 E	This spring flows from the Salt Lake formation.
H-13	Unnamed Spring 1N 44E 30cbdS (7-7-80)	7	1840			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 1S 45E 4adaS (7-8-80)	6	1820			2 E	The spring flows from Salt Lake formation. 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 1S 45E 4acaS (7-8-80)	6	1880			4 E	This spring is located 300 m west of spring H-14. See description under H-14.
H-16	Unnamed Spring 1S 40E 4abcS (7-22-80)	21	1700			2 E	This spring flows from fractures in an outcrop of Ephriam Conglomerate. A minor fault is mapped at this site.
H-17	Unnamed Spring 1S 44E 1cbdS (7-7-80)	7	1800			10 E	This spring issues from the Twin Creek Limestone.

Table 3. Continued

Sample Number	Name, Location and Date Sampled	Water Temp. (°C)	Elevation (m above MSL)	Well Depth (m)	Depth to Water (m)	Discharge (l/s)	Site Description
H-18	Willow Spring 1S 41E 36cccS (6-29-80)	8	2010			6 E	This spring flows out of the Wayan formation, on the axis of a northwest trending syncline.
H-19	Unnamed Spring 2S 44E 1accS (6-20-80)	11	1780			100 E	This spring is flowing out of the Nugget formation.
H-20	Warm Spring 2S 44E 9aacS (7-23-80)	17	2180			10 E	This spring flows from near the contact of the Twin Creek Limestone and the Nugget formation. 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 (8-39)	56	1690			1.6 R	These springs are reported to discharge from alluvium and were depositing travertine; the springs are presently covered by waters of Palisades Reservoir. These springs are associated with the Snake River fault.
I-22	Alpine Hot Spring 2S 46E 19cadS (7-27-77)	37	1690			0.6 R	See description above.
H-23	Brockman Hot Spring 2S 42E 26dcdS (6-27-80)	35	1910			4 R	This spring flows out of either the Peterson or Bechler formation. The geology around this spring has been complexly folded and faulted by minor faults.
H-24	Unnamed Spring 3S 42E 15dccS (7-29-80)	10	2090			4 E	This spring issues from rocks of the Bechler formation on the west limb of a complexly faulted syncline.
H-25	Unnamed Spring 3S 42E 22abbS (7-6-80)	14	2080			3 E	This spring is located 100 m southwest of spring H-24. It flows from the contact of the Bechler and Peterson formation on the west limb of a complexly faulted syncline.

Table 3. Continued

Sample Number	Name, Location and Date Sampled	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 (7-25-80)	57	1850			3 E	These springs discharge from the Dinwoody formation on the axis of the northwest trending Hemmert anticline. Two faults, the Hemmert fault and the Freedom fault join at this site. Extensive deposits of travertine and free sulphur are present at these springs.
H-27	Johnson Springs 33N 119W 26adS (7-25-80)	54	1850			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, the Dinwoody formation. The trace of the Hemmert anticline and fault lie beneath this site.

*Accuracy of measurement
E = Estimated discharge
R = Reported Discharge
All others measured.

Table 4. Hydrochemistry of springs and wells in the vicinity of the Caribou Range, southeastern Idaho and western Wyoming

Sample Number	Name and Location	Water Temp. °C	Specific Conductance (μmho/cm)	TDS (mg/l)	pH	Ca	Mg	Na	K	Cl	F	HCO_3	SO_4	SiO_2	Error (%)**
						Concentration in mg/l (meq/l)[4]									
H-1	Elkhorn Warm Spring 4N 40E 23cadS	20	390	340	6.6	30 (1.5)	10 (0.8)	14 (0.6)	0 (0)	5 (0.1)	0.78 (0)	190 (3.0)	7 (0.1)	83	7.1
H-2	Hawley Warm Spring 4N 40E 25bbdS	16	350	340	7.5	36 (1.8)	10 (0.8)	10 (0.4)	0 (0)	4 (0.1)	0.7 (0)	190 (3.1)	5 (0.1)	88	4.4
H-3	Heise Hot Springs 4N 40E 25ddaS	48	6500	7600	6.1*	680 (34)	81 (6.7)	1500 (65)	200 (5.2)	2300 (65)	3.1 (0.2)	2100* (35)	720 (15)	58	1.8
I-3	Heise Hot Springs[2] 4N 40E 25ddaS	49	8800	6500	6.7	450 (23)	82 (6.7)	1500 (65)	190 (4.9)	2400 (68)	3.1 (0.2)	1100 (18)	740 (15)	30	.99
H-4	Lufklin Spring 3N 42E 2cbbS	8	450	530	6.9	130 (6.6)	0 (0)	0 (0)	0 (0)	2 (0.1)	0 (0)	380 (6.2)	5 (0.1)	9	1.7
H-5	Buckland Warm Spring 3N 42E 12cca + ccdS	11	830	680	7.0	110 (5.6)	26 (2.1)	31 (1.3)	0 (0)	38 (1.1)	0.14 (0)	350 (5.7)	110 (2.3)	13	.04
H-6	Unnamed Spring 3N 41E 32bbdS	23	650	550	7.2	71 (3.5)	19 (1.6)	44 (1.9)	0 (0)	42 (1.2)	0.14 (0)	270 (4.4)	51 (1.1)	49	2.4
H-7	Dyer Well 2N 39E 21bcc	21	530	440	7.7	50 (2.5)	13 (1.1)	50 (2.2)	3 (0.1)	61 (1.7)	0.29 (0)	190 (3.1)	1 (0)	68	9.2
H-8	Anderson Well 2N 39E 29bac	20	520	470	7.7	50 (2.5)	10 (0.8)	45 (2.0)	7 (0.2)	45 (1.3)	0.44 (0)	200 (3.3)	0 (0)	110	9.0
H-9	Fall Creek Mineral Springs 1N 43E 9cbb1S	24	7800	5500	6.2	470 (24)	100 (8.2)	1100 (46)	120 (3.0)	1900 (52)	1.4 (0.1)	1500 (24)	330 (6.8)	15	1.4
H-10	Fall Creek Mineral Springs 1N 43E 9cbb2S	23	6800	5100	6.2	430 (22)	88 (7.2)	1100 (46)	110 (2.8)	1700 (46)	1.3 (0.1)	1300 (21)	330 (6.8)	17	2.1
I-10	Fall Creek Mineral Springs[2] 1N 43E 9cbbS	25	7900	5300	6.3	440 (22)	96 (7.9)	1110 (48)	120 (3.1)	1900 (54)	1.7 (0.1)	1200 (20)	390 (8.1)	11	.16
H-11	Unnamed Spring 1N 39E 14acaS	9	470	400	7.0	48 (2.4)	17 (1.4)	15 (0.7)	0 (0)	38 (1.1)	0.18 (0)	210 (3.4)	3 (0.1)	71	1.4
H-12	Unnamed Spring 1N 40E 19cabS	13	300	320	7.2	39 (1.9)	6 (0.5)	5 (0.2)	0 (0)	4 (0.1)	0.21 (0)	160 (2.6)	0 (0)	110	.44
H-13	Unnamed Spring 1N 44E 30cbdS	7	450	470	7.1	85 (4.2)	10 (0.8)	3 (0.1)	0 (0)	7 (0.2)	0.26 (0)	310 (5.0)	8 (0.2)	49	1.9
H-14	Unnamed Spring 1S 45E 4adaS	6	390	340	7.4	60 (3.0)	16 (1.3)	0 (0)	0 (0)	0 (0)	0 (0)	250 (4.2)	3 (0.1)	15	1.0

Table 4. Continued

Sample Number	Name and Location	Water Temp. °C	Specific Conductance (µmho/cm)	TDS (mg/l)	pH	Ca	Mg	Na	K	Cl	F	HCO_3	SO_4	SiO_2	Error (%)**
						Concentration in mg/l (meq/l)[4]									
H-15	Unnamed Spring 1S 45E 4acaS	6	410	380	7.4	69 (3.4)	18 (1.5)	0 (0)	0 (0)	0 (0)	0 (0)	280 (4.5)	0 (0)	13	4.2
H-16	Unnamed Spring 1S 40E 4abcS	21	11000	9200	6.6	110 (5.5)	19 (1.6)	2800 (120)	40 (1.0)	880 (25)	4.6 (0.2)	2400 (40)	2900 (60)	62	3.0
H-17	Unnamed Spring 1S 44E 1cbdS	7	400	380	7.1	66 (3.3)	18 (1.5)	0 (0)	0 (0)	3 (0.1)	0.12 (0)	250 (4.1)	4 (0.1)	34	5.2
H-18	Willow Spring 1S 41E 36cccS	8	450	400	7.1	73 (3.6)	14 (1.2)	4 (0.2)	0 (0)	10 (0.3)	0.16 (0)	280 (4.6)	5 (0.1)	11	5.0
H-19	Unnamed Spring 2S 44E 1aacS	11	230	160	7.1	36 (1.8)	6 (0.5)	0 (0)	0 (0)	0 (0)	0 (0)	110 (1.8)	3 (0.1)	6	10.0
H-20	Warm Spring 2S 44E 9aacS	17	600	580	7.2	130 (6.4)	27 (2.2)	0 (0)	0 (0)	1 (0)	0.25 (0)	160 (2.7)	230 (4.9)	24	6.5
I-21	Alpine Hot Springs[3] 2S 46E 19bS	56		6800		530 (26)	93 (7.7)	1500 (67)	190 (4.8)	2400 (68)	2.8 (0.1)	920 (15.1)	1100 (22)	45	.10
I-22	Alpine Hot Springs[2] 2S 46E 19cadS	37	10000	7100	6.5	560 (28)	100 (8.2)	1500 (65)	180 (4.6)	2800 (79)	2.7 (0.1)	880 (14)	1000 (21)	40	3.8
H-23	Brockman Hot Spring 2S 42E 26dcdS	35	8800	7500	6.6	190 (9.3)	33 (2.7)	2000 (89)	38 (1.0)	550 (16)	2.3 (0.1)	2300 (37)	2400 (50)	38	.51
I-23	Brockman Creek W.S.[2] 2S 42E 26dcdS	35	8600	7300	6.4	150 (7.5)	41 (3.4)	2100 (91)	34 (0.9)	590 (17)	2.6 (0.1)	1900 (31)	2500 (52)	24	1.5
H-24	Unnamed Spring 3S 43E 15dccS	10	550	540	7.1	100 (5.2)	25 (2.1)	0 (0)	0 (0)	3 (0.1)	0.16 (0)	340 (5.6)	56 (1.2)	13	2.7
H-25	Unnamed Spring 3S 43E 22abbS	14	400	370	7.2	76 (3.8)	10 (0.8)	0 (0)	0 (0)	4 (0.1)	0.12 (0)	270 (4.5)	5 (0.1)	6	.71
H-26	Auburn Hot Springs 33N 119W 23dbdS	57	8000	5700	6.4	510 (25)	76 (6.3)	1300 (58)	160 (4.1)	1700 (49)	3.4 (0.2)	890 (14)	1000 (21)	68	5.1
W-26	Auburn Hot Springs[1] 33N 119W 23dbdS	62	6800	5700	7.5	400 (20)	70 (5.8)	1400 (61)	140 (3.6)	1700 (48)	0.6 (0)	860 (14)	1100 (23)	35	3.0
H-27	Johnson Springs 33N 119W 26adS	54	8100	6200	6.4	450 (23)	45 (3.7)	1500 (65)	180 (4.5)	1900 (55)	3.8 (0.2)	970 (16)	1100 (24)	88	.70

Table 4. Continued

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

** Charge-balance error, refer to page 58 in text

[1] Breckenridge and Hinkley, 1978

[2] Mitchell and others, 1980

[3] Ross, 1971

[4] Concentrations recorded as 0 mg/l imply a concentration less than 0.5 mg/l was present and that the procedure could not detect concentrations less than 0.5 mg/l.

Figure 6. Location and temperature of springs and wells in the vicinity of the Caribou Range, southeastern Idaho and western Wyoming

Heise Hot Springs is located in a structurally complex area. This spring is associated with two faults. The Heise fault, a major northwest trending normal fault, runs through the spring site, and a smaller arcuate shaped fault meets the Heise fault from the north less than 100 m to the east of the spring. The area south of the Heise fault is covered by alluvial sediments deposited by the Snake River. The smaller northeast-trending fault north of the Heise fault separates Tertiary rhyolitic tuff to the northwest, and undifferentiated Mesozoic and Paleozoic rocks to the southeast. The springs flow from the Tertiary rhyolite covered at this site by a mantle of travertine and colluvium (Proskta and Embree, 1978). The spring site is located near older sedimentary rocks as indicated by a 100-meter well drilled about 100 m north of the springs in 1936. This well encountered only a small amount of water and drilled through what was described as gray, pink, and blue limestone (Stearns and others, 1938).

Utilizing the gravity and magnetic data Mabey reports:

> The most prominent local gravity and magnetic anomalies are highs within the Rexburg caldera complex in the area of Heise Hot Springs. Although the crests of the anomalies are coincident, the extent of the anomalies are different and they cannot reflect entirely the same mass. Mesozoic sedimentary rocks overlian by Pliocene rhyolite flows and welded tuffs are exposed in the area of the anomalies. Rhyolite dikes are locally abundant. The northwest-trending Heise fault (Prostka and Hackman, 1974), which forms a southwest facing scarp locally 300 m high, is parallel to and near the crest of the anomalies. The correlation between the gravity high and outcropping Mesozoic sedimentary rock suggests that the gravity anomaly reflects in large part a structural high elevating the more dense pre-Tertiary rocks. The shape and extent of the magnetic anomaly, the abundant rhyolite dikes in the area, and the indication by the magnetic gradients that the source lies below the surface all

> suggest that a major part of the magnetic high is produced by a large buried intrusive body. Some features of the magnetic anomaly reflect the near-surface volcanic rocks.
>
> Heise Hot Springs and the warm springs to the northwest occur along the crest of the gravity and magnetic highs. The springs are in a structurally complex area where northwest-trending faults, probably related to the Basin and Range structure of Swan and Grand valleys, displace a structural high over the inferred intrusive body. Although the Heise fault forms a prominent southwest-facing scarp and the presence of the Snake River against this scarp attests to recent movement of the fault, the geophysical data indicate that the Heise fault is near the crest of the structural high. ... The gravity anomaly is attributed to a high on the surface of the pre-Cenozoic rocks at Heise Hot Springs and to an area of thicker Cenozoic rocks under the valley of the Snake River to the southwest. The depression containing the thicker Cenozoic rocks is parallel to and within a northwestward projection of the Swan-Grand Valley trend into the Rexburg caldera complex. The magnetic anomaly has two major components: a local high at Heise Hot Springs superimposed on broader, more deeply buried source. Both components probably reflect a large body of intrusive rock with the apex near Heise Hot Springs. The intrusive mass, which may be the same age as the rhyolite dikes, lies within the Rexburg caldera complex where the Swan-Grand Valley trend intersects the caldera (Mabey, 1978, p. 12-16).

This spring deposits travertine, gypsum, and free sulfur and has a hydrogen sulfide odor. The 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. A subsurface temperature of 79°C was estimated using a silicia geothermometer assuming quartz equilibrium and conductive cooling (Mitchell and others, 1980).

Fall Creek Mineral Springs (H-9, H-10, and I-10)

Several springs and seeps discharge water along a 1.2 km reach of Fall Creek (figure 6). The warmest spring (H-9) is 24°C and flows from a travertine deposit located next to the creek. Sample H-10 was collected from the bottom of a sinkhole where the water emerges to the surface for the distance of a meter and then disappears into a solution channel in the cavernous rock. Travertine 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 (Jobin and Schroeder, 1964a).

These springs deposit free sulfur and travertine and give off a strong hydrogen sulfide odor. Two other large deposits of travertine are located at a higher elevation on a ridge 0.5 and 1.6 km west of the springs. There are no springs associated with these deposits and their surface elevation ranges from 1680 to 1840 m.

The water from Fall Creek Mineral Springs have specific conductance values of 7800 and 6800 μmhos/cm and a pH of 6.2. The dominant ions are sodium and chloride. The subsurface temperature may be as high as 40°C as indicated by the quartz geothermometer (Mitchell and others, 1980).

Alpine Hot Springs (I-21 and I-22)

These springs are presently located under Palisades Reservoir (figure 6). The data presented here are based upon an investigation of the site prior to the creation of the reservoir and during a visit when the water level was low in the reservoir. The springs flow from Quaternary alluvium and are associated with the Snake River fault (Gardner, 1961). The springs were located on both sides of the former channel of the river. Six springs on the west side of the river had temperatures ranging from 31 to 62°C. An excellent description of this area was given by Bradley (Hayden, 1873). His measurements are converted to metric units in the paragraph below to maintain consistency in this report.

> Here also is located a cluster of warm springs, making calcareous, sulphurous, and saline deposits. The largest spring, the Washtub, has built up a flaring table, 0.3 m high, of an oval form, measuring about 1.4 m by 2.3 m, upon a mound consisting of calcareous mud, scarcely solidified, of from 1.5 to 2.1 m above the creek bottom in which it stands. The central table has contracted so as to crack across diagonally, and the flow now escapes at its western base, depositing a fine mud tinged in the full pools with a faint sulphur-yellow, but pure white in the dry ones. These pools cover the mound in descending steps of great beauty. The present flow is southward, though it has been on all sides in succession. One mound, no longer active is 1.5 m high, with a circular base of about 1.5 m diameter and an oval summit of about 0.3 m by 2.4 cm. Many small springs escape along the bank for 90 m or more. The deposits vary greatly in color. At some points the odors of sulphuorous acid and of sulphureted hydrogen were quite noticeable. The older deposits have built up a bank 3 m high along the base of the terrace, and the beavers have taken possession and have dammed up on it the waters of the cold springs which flow from the second terrace at short intervals along this plain. On the opposite shore two considerable springs have built up their deposits against the foot of the mountain, one of which appears to be nearly dead. The highest temperature observed here was 62.2°C. The Washtub gave 61.6°C and others 61.1°, 32.2° and 31.1°C, etc. (Hayden, 1873, p. 269).

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). The wide range of temperatures in these springs indicate that warm and cold ground water is mixing before reaching the surface.

There are two analyses for Alpine Hot Springs. Ross (1971) reports an analysis (I-21) performed in August of 1939. This sample has a total dissolved solids of 6800 mg/l, no reading for specific conductance, and a temperature of 56°C. The dominant ions are sodium and chloride. The other analysis was obtained in 1977 when the water level in the reservoir was particularly low. The water has a specific electrical conductance of 10,000 μmhos/cm, a total dissolved solids of 7,100 mg/l, a temperature of 37°C, and a pH of 6.5. The dominant ions are sodium and chloride. The subsurface temperature as indicated by a chalcedony geothermometer (silica temperature assuming equilibrium with chalcedony and conductive cooling i.e. no steam loss) may be as high as 61°C for I-22 (Mitchell and others, 1980).

Auburn Hot Springs and Johnson Springs (H-26, W-26, and H-27)

Auburn Hot Springs is located 1.6 km north of Johnson springs (figure 6). Auburn Hot Springs flow from over 100 vents over a 1.2 hectacre area. The maximum temperature measured is 62°C (Breckenridge and Hinkley, 1978). Johnson Springs consist of five travertine cones, 1.5 to 2.4 m high, with a small spring and several seeps, on and around them. The temperature of this spring is 54°C. Both groups of 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 which follows the crest of the anticline, and Freedom fault that roughly parallels this anticline one km to the west, join at Auburn Hot Springs. Both are westward dipping faults with 200 and 800 m of displacement respectively. The Auburn fault, located .5 km west of the Freedom fault, is interpreted as a eastward dipping normal fault with as much as 2 km of displacement (Hinkley and Breckenridge, 1977). 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) suggest a model whereby meteoric waters are heated at depth, perhaps by a cooling magma body, and migrate to the surface.

Auburn Hot Springs has a specific electrical conductivity of 8,000 μmhos/cm with a pH of 6.4. The dominant ions are sodium and chloride. Johnson Springs has a similar chemical composition with a specific electrical conductance of 8,100 μmhos/cm and a pH of 6.4. The dominant ions are sodium and chloride. Using SiO_2 and Na-K-Ca geothermometry, Renner and others (1975) estimated a reservoir temperature of 150°C at Auburn Hot Springs.

Unnamed Springs at 1N 40E 4abcS (H-16)

These springs are located in the bottom of a canyon formed by Willow Creek (figure 6). The springs discharge water at a temperature of 21°C from rocks of the Gannett group. They flow from fractures in an outcrop of chert pebble conglomerate at the base of the Ephriam Conglomerate. A northeast-trending fault intersects this site from the north displacing the Peterson Limestone, placing Bechler Conglomerate against the Ephriam conglomerate (Mansfield, 1952). The geology is complicated by rhyolite tuffs, basalts, and the Salt Lake formation which conceal most of the older sedimentary rocks where they have been exposed by the erosion by Willow Creek.

The springs give off an odorless gas, presumably carbon dioxide. Travertine deposits are located in rocks of the Bechler formation west of the present springs. Saline deposits surround the springs. These springs have a high specific electrical conductance of 11,000 μmhos/cm and a pH of 6.6. The dominant ions are sodium and sulfate.

Brockman Hot Springs (H-23 and I-23)

These springs flow from several small seeps and a 1.2 m diameter pool into Brockman Creek (figure 6). The springs have a temperature of 35°C and they give off an odorless gas, presumably carbon dioxide. Travertine 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 minor faults run through the area, the nearest of which is 200 m to the north (Gardner, 1961). A major northwest trending fault is located 1.7 km northeast of the spring.

This spring has a specific electrical conductance of 8,800 μmhos/cm and a pH of 6.6. The dominant ions in this water are sodium and sulfate. The subsurface temperature from sample I-23 may be as high as 38°C as indicated by the chalcedony geothermometer (Mitchell and others, 1980).

Thermal Springs with Low Specific Conductivities

Four springs (H-1, H-2, H-6, and H-20) and two wells (H-7 and H-8) are included in this group (figure 6). Temperatures ranged from 16 to 23°C with specific conductivities from 350 to 650 μmhos/cm.

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

Elkhorn and Hawley Warm springs are located 2.8 and 1.5 km northwest of Heise Hot Springs, respectively. Both springs are located on the escarpment formed by the Heise fault at an elevation of 40 to 70 m above Heise Hot Springs. The intrusive body suggested by Mabey (1978) to be under Heise Hot Springs is also believed to underlie these two springs. These springs emerge from relatively flat lying rhyolite tuffs on the southern edge of the Rexburg Caldera Complex (Proskta and Embree, 1978). These springs do not have associated travertine deposits and do not give off any gaseous odors.

Elkhorn Warm Spring has a specific conductance of 390 μmhos/cm, a temperature of 16°C, and a pH measurement of 6.6. The dominant ions are calcium and bicarbonate. Hawley Warm Spring has a specific electrical conductance of 350 μmhos/cm, a temperature of 20°C, and a pH of 7.5. The dominant ions are calcium and bicarbonate.

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

This 23°C spring discharges from a densely welded ash-flow tuff named the Tuff of Spring Creek within the postulated Willow Creek caldera (Protska and Embree, 1978). This tuff may only form a thin covering overlying older Mesozoic and Paleozoic rocks. This is suggested by an exploration oil well (Sorenson No. 1) drilled 2 km to the east which intersected the Nugget Formation at a depth of 6 meters (Savage, 1961). 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 electrical conductance of 650 μmhos/cm and a pH of 7.2. The dominant ions in this 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 located in a subdivision called Rim Rock Estates 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, respectively. Tertiary Salt Lake formation is mapped at the well sites with outcrops of rhyolite welded tuffs and associated ash nearby (Mansfield, 1952). The Salt Lake formation mapped in this area appears to be a thin covering overlying the welded tuffs. The drill log for the Dyer well indicates that the water is obtained from fractured rhyolite. There is a northwest trending fault mapped 0.2 km west of this well. In the Anderson well, the drillers log reports that the water is coming from sandstone (pumice?) or rhyolite.

The chemistries of these wells are similar. The specific electrical 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)

Warm Spring (H-20) is located at an elevation of 2180 m on the northwestern flank of Big Elk Mountain. Extensive deposits of travertine are present below the spring site. The spring surfaces near the contact of the Twin Creek Limestone and Nugget Sandstone. Beds of gypsum and anhydrite have been found at the base of the Twin Creek Limestone at some locations in Idaho and Wyoming. The presence of this bed would account for the high concentrations of calcium and sulfate in the water. This site is located 250 m west of the axis of the Big Elk Mountain anticline. Sun-Sinclair drilled an oil exploration well on the axis of the Big Elk Mountain anticline 4.8 km southeast of the spring site. The fluid from the Wells formation was tested at a depth of 1534 to 1545 meters at a recorded temperature of 103°C.

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

Nonthermal Springs

Twelve springs in this study area have low temperatures and low specific conductivities: H-4, H-5, H-11, H-12, H-13, H-14, H-15, H-17, H-18, H-19, H-24, and H-25 (figure 6). Their temperatures range from 6 to 14°C with specific electrical conductivities from 230 to 830 μmhos/cm.

Lufklin Spring (H-4)

This 8°C spring is located 0.5 km northwest of the Grand Valley fault on the escarpment formed by this fault. The spring flows from the Gallatin Limestone at the contact formed by this unit and the Salt Lake formation. Traces of travertine were found near the spring but travertine is not presently being deposited.

The water has a specific electrical conductance of 450 μmhos/cm and a pH of 6.9. The dominant ions are calcium and bicarbonate.

Buckland Warm Spring (H-5)

Buckland Warm Spring is located 0.3 km north of the concealed trace of the Grand Valley fault on the boundary of the Swan Valley lowland and the Snake River Range. This spring has the largest discharge of all the springs measured in the study area. Measurements taken by the USGS (U.S. Department of Interior, Geological Survey, 1970 and 1977) indicate a discharge of 1300 l/s in 1956 and 640 l/s in 1977, a difference of 48 percent.

This spring flows from Gallatin Limestone at the surface trace of the Baldy Mountain thrust fault. It appears that this spring is controlled by the thrust fault.

This 11°C spring has a specific electrical conductance of 830 μmhos/cm and a pH of 7.0. The dominant ions are calcium and bicarbonate.

Unnamed Spring at 1N 44E 30cbdS (H-13)

This spring is located above Indian Creek 3.2 km southwest of Irwin. This spring has been developed for stock watering purposes. It flows from alluvium and travertine overlying Mission Canyon Limestone and is associated with the northwest-trending Snake River fault (Jobin and Schroeder, 1964b). There are travertine deposits around the spring but travertine is not presently being deposited at this time.

This 7°C spring has a specific electrical conductance of 450 μmhos/cm and a pH of 7.1. The dominant ions are calcium and bicarbonate.

Unnamed Springs at 1S 45E 4adaS and 4acaS (H-14 and H-15)

These two springs are located on a north facing slope south of Sheep Creek. They both flow from the Salt Lake formation and are located near the Grand Valley fault, whose trace is concealed by overlying sediments. The water from both of these springs has deposited travertine on the valley floors but the springs do not appear to be currently forming travertine deposits.

These springs have a temperature of 6°C, a pH of 7.4, and a specific electrical conductance of 390 and 410 μmhos/cm for spring H-14 and H-15, respectively. The dominant ions are calcium and bicarbonate.

Unnamed Spring at 1S 44E 1cbdS (H-17)

This spring is located in the steep valley formed by Yeaman Creek. The spring flows from an outcrop of overturned Twin Creek Limestone, 0.3 km north of the Snake River fault.

This 7°C spring has a specific electrical conductance of 400 μmhos/cm and a pH of 7.1. The dominant ions are calcium and bicarbonate.

Unnamed Spring at 2S 44E 1accS (H-19)

This spring is located on the steep south facing slope of Red Ridge, west of Palisades Reservoir. It flows from a V-shaped notch on the side of the hill from the Nugget formation. The Nugget formation at this outcrop is well cemented but is fractured and jointed to give it a high secondary hydraulic conductivity. There are no structural features in the Nugget formation that would control the location of this spring.

This 11°C spring has a specific electrical conductance of 230 μmhos/cm and a pH of 7.1. This spring is the least mineralized spring in the study area. The dominant ions in this water are calcium and bicarbonate.

Unnamed Spring at 1N 39E 14acaS (H-11)

This spring is located 0.2 km west of the former townsite of Ozone. The spring has been developed and flows from a pipe into the creek. The spring box is located in the Salt Lake formation, but the water may originate from rhyolite tuff that outcrops 70 m north of this site (Mansfield, 1952).

This 9°C spring has a specific electrical conductance of 470 μmhos/cm and a pH of 7.0. The dominant ions are calcium and bicarbonate.

Unnamed Spring at 1N 40E 19cabS (H-12)

This spring is located in a small valley on the south side of Hatchery Creek. It flows from an undetermined thickness of the Salt Lake formation which mantles the surrounding area. Outcrops of sedimentary rocks exposed by the erosion of Willow Creek in the surrounding area indicate the sedimentary units below the Salt Lake formation are complexly folded and faulted.

This 13°C spring has a specific electrical conductance of 300 μmhos/cm and a pH of 7.2. The dominant ions are calcium and bicarbonate.

Willow Springs (H-18)

Willow Springs are located in an area of low lying hills east of Pine Mountain. The two small springs flow from the Wayan formation on the axis of a syncline (Mitchell and Bennett, 1979). This spring may be controlled by the outcrop of a unit within the Wayan formation that does not permit further downward movement of water.

This 8°C spring has a specific electrical conductance of 450 μmhos/cm and a pH of 7.1. The dominant ions are calcium and bicarbonate.

Unnamed Springs at 3N 42E 15dccS and 22abbS (H-24 and H-25)

These two springs are located 2.7 km northeast of Herman on either side of the McCoy Creek Road. These springs flow from the west limb of a complexly faulted syncline. The spring north of the road (H-24) flows from the Bechler formation and the other (H-25) flows from the contact of the Bechler and Peterson formations.

Springs H-24 and H-25, respectively, have temperatures of 10° and 14°C, specific electrical conductivities of 550 and 400 μmhos/cm, and pH values of 7.1 and 7.2. The dominant ions are calcium and bicarbonate for both of these springs.

ANALYSIS OF DATA

Analysis of Springs and Wells Utilizing Physical Data

Introduction

The physical data collection at each site includes information regarding the characteristics of the geologic setting such as the structural features near the springs and the formations from which they flow, the water temperature, the estimated or reported rate of discharge, the location, and the elevation. The geologic setting of the springs and wells provide information on the structural features influencing ground water flow and indicates which formations are aquifers. The relationship between temperature and discharge provides information regarding the amount of deep ground water flow. The water temperatures of the springs and wells are used to calculate estimated depths of circulation for ground water flow systems.

Structural Controls on Springs and Wells

The most important factor influencing ground water flow paths is the spatial distribution of hydraulic conductivity. This distribution is controlled by structural features such as folds and faults and the hydraulic properties of the formations. Structural controls are geologic features produced in rocks after deposition and often after consolidation. Faults may affect ground water flow in three ways. The fault may act as a conduit to flow, as a barrier to flow, or may have no affect. In addition, the offset in beds produced by the fault may place formations differing hydraulic characteristics against each other.

Thrust faults are prominant structural features in southeastern Idaho. The study area is bordered on three sides by the surface exposures of these faults and they pass beneath this area at various depths (figure 5, cross-section A-A'). Only one thrust fault has been mapped in the interior of the study area; there are no springs associated with this particular thrust fault. A study (Coleman, 1982) on surface exposures of the Meade thrust fault suggests that this thrust fault may not act as a barrier to ground water flow except as a secondary control in positioning lithologies with high hydraulic conductivities against those with low hydraulic conductivities. The hydrogeologic importance of thrust faulting is probably markedly different near the surface where it cuts across individual units from the character of the faulting at depth where it is probably parallel to bedding.

Only one spring in the study area appears to be controlled by a thrust fault. Buckland Warm Spring (H-5) flows from a block of Gallatin Limestone thrust over Mission Canyon Limestone by the Baldy Mountain thrust fault. This overthrust plate covers 3 km^2 and is believed to be less than 200 m thick (Staatz and Albee, 1966). Buckland Warm Spring emerges at the surface trace of the thrust fault and may act as a drain, discharging ground water from the overthrust plate. However, calculations using the recorded discharge of 460 l/s along with the size of the overthrust plate (3 km^2) indicate that the recharge must be approximately 7 m/year to maintain the discharge rate. The recharge area supplying water for this spring is obviously much larger than this overthrust plate.

The next most prominant structural features in the area are the graben forming faults along the Swan, Grand, and Star valleys. These faults probably create zones of high hydraulic conductivity along their paths. These faults extend very deep and probably influence all but the deepest flow systems (Figure 5, cross-section A-A').

Five thermal springs are associated with the faults along the edge of the Swan, Grand, and Star valleys. They are Heise Hot Springs (H-3 and I-3), Fall Creek Mineral Springs (H-9, H-10, and I-10), Alpine Hot Springs (I-21 and I-22), Auburn Hot Springs (H-26 and W-26), and Johnson Springs (H-27). Two other thermal springs, Elkhorn and Hawley warm springs (H-1 and H-2) are located near one of the major graben forming faults; however, these springs are not believed to be controlled by this fault but rather by zones of higher hydraulic conductivity in the Rexburg Caldera Complex. Five nonthermal springs (H-4, H-5, H-13, H-14, and H-15) are located near either the Snake River or the Grand Valley faults. It is not known if these springs are directly controlled by these faults.

Six more of the springs examined in this area are associated with minor faults. Four of these springs (H-6, H-7, H-16, and H-23) have warm temperatures; ground water is believed to move up the fault trace from depth. The remaining two springs (H-24 and H-25) are located in an intensely faulted area.

Geologic Formations Associated with Spring and Well Sites

The springs and wells sampled in the vicinity of the Caribou Range study area discharge from ten different formations ranging from Recent alluvial sediments to Cambrian Limestone (table 5). Most of the springs

Table 5. Geologic formations associated with springs and wells in the vicinity of the Caribou Range, southeastern Idaho and western Wyoming

Geologic Formation or Rock Unit	Spring Number
Alluvium	I-21*, I-22*
Salt Lake	H-11, H-12, H-14*, H-15*
Rhyolite	H-1*, H-2*, H-3*, H-6*, H-7*, H-8
Wayan	H-18
Bechler	H-24*, H-23*
	or
Peterson	H-25*, H-23*
Ephriam	H-16*
Twin Creek Limestone	H-17, H-20
	or
Nugget	H-19, H-20
Dinwoody	H-26*, H-27*
Mission Canyon Limestone	H-9*, H-10*, H-13*
Gallatin Limestone	H-4*, H-5*

*spring is located near fault

examined in the study area flow from zones of secondary hydraulic conductivity caused by faulting. The fault areas probably have considerably higher hydraulic conductivity than the undisturbed portions of the formations. The relationship between spring location and stratigraphic unit may thus not be a direct indicator of regional hydraulic properties of rocks.

Discharge of Springs

The total discharge of springs examined in this area is inversely proportional to the temperature. The springs in this study with temperatures less than 15.5°C have a total discharge of approximately 1200 l/s. The two largest springs have discharges of 100 and 1000 l/s. The springs with temperatures of 15.5 to 39°C have a total discharge of approximately 60 l/s. The largest of these springs has a discharge of 10 l/s. The total discharge of springs with temperatures above 39°C is approximately 9 l/s; the largest spring in this group has a discharge of 4 l/s. The small total discharge of the thermal water indicates that most ground water movement is relatively shallow.

The discharge-temperature relationship described for the study area in southeastern Idaho fits the general homogeneous models of flow systems as presented by Toth (1963) and Freeze and Witherspoon (1966, 1967). They found that approximately 90 percent of the total ground water in a homogeneous system circulates to very shallow depths and the remaining portion, in decreasing amounts, circulates to greater depths.

The rate of discharge varies over the course of the year for most springs. The amount of fluctuation in discharge is a function of the length of the flow path. The discharge from local flow systems fluctuates greatly, often ceasing during the year; intermediate flow systems show less fluctuation of discharge and regional flow systems have the least fluctuation of all. Only one of the springs in this area has been measured at different times of the year. Buckland Warm Spring's large discharge varies widely indicating that at least a portion of its total volume is supplied by ground water with a short flow path.

Temperature Versus Depth of Circulation

Heat flow is a term used to describe the transfer of thermal energy from the interior of the earth to the surface. It is equal to the product of the thermal conductivity of the media and the geothermal gradient (Brott and others, 1976). These two factors must be known to determine the heat flow of a region. The thermal conductivity of the geologic units in this region is not known. The measured geothermal gradient is utilized as an indicator of the heat flow based on the assumption that the thermal conductivity of the sedimentary rocks in the region is relatively uniform.

The average geothermal gradient of the earth's surface is approximately 2.5°C per 100 m depth (Freeze and Cherry, 1979). At depths to 30 m the subsurface temperatures are affected by climatic conditions and so have temperatures roughly equal to the mean annual air temperature. The geothermal gradient is not uniform throughout the earth's surface because of several factors: the spatial redistribution of heat by the movement of ground water, response to geologic units with differing thermal conductivities, or it may be due to the implacement of a heat source at depth (Freeze and Cherry, 1979). Springs with temperatures significantly above mean annual temperature normally are indicative of deep ground water flow patterns. The ground water flow is much deeper if the heat flow is low or fairly shallow if the local heat flow is great.

A regional geothermal gradient can be used to approximate the depth of circulation for springs and wells in this area. The following relationship is used to calculate the geothermal gradient of the area using bottom hole temperatures measured in oil exploration drill holes (Ralston and others, 1981).

$$G = \frac{T - A}{D}$$

where: G is the geothermal gradient (°C)

A is the mean annual temperature (5°C)

T is the maximum temperature of the bottom of the well

D is the depth of the well.

Figure 7 shows the location and calculated geothermal gradient in °C/100 m, for four wells drilled in this area. Three of the geothermal gradients are above 5.0°C/100 m while the one furthest to the east is only 2.3°C/100 m, a value less than the worldwide average. The reason for this abnormally low gradient is not known. It is omitted in the calculation of an average geothermal gradient (5.6°C/100 m).

An estimate of the depth of ground water circulation can be obtained by rewriting the equation above, using the average geothermal gradient and the water temperature. The estimated depths of circulation for thermal springs with high specific conductivities are presented in table 6. The depth of circulation is estimated from both the measured

Figure 7. Calculated geothermal gradients for selected oil and gas wells in southeastern Idaho.

Table 6. Estimated depths of circulation for thermal springs with high specific conductivities in the vicinity of the Caribou Range, southeastern Idaho and western Wyoming

Sample Number	Name and Location	Elevation (m)	Surface Temp. °C	Depth of Circulation[3] (m)	Geothermometer	Calculated Temp. °C	Depth of Circulation[3] (m)
I-3	Heise Hot Springs 4N 30E 25ddaS	1536	49	800	Quartz[1]	79	1300
I-10	Fall Creek Mineral Springs 1N 43E 9cbbS	1658	25	400	Quartz[1]	40	600
H-16	Unnamed Spring 1S 40E 4abcS	1699	21	300	--	--	--
I-21	Alpine Hot Springs 2S 46E 19bS	1689	56	900	--	--	--
I-22	Alpine Hot Springs 2S 46E 19cadS	1692	37	600	Chalcedony[1]	61	1000
I-23	Brockman Creek W.S. 2S 42E 26dcdS	1908	35	500	Chalcedony[1]	38	600
W-26	Auburn Hot Springs 33N 119W 23dbdS	1853	62	1000	Quartz[2]	138	2400
H-27	Johnson Springs 33N 119W 26adS	1853	54	900	--	--	--

[1]Mitchell and others, 1980

[2]Renner and others, 1975

[3]Calculated on the basis of a geothermal gradient of 5.6°C per 100 meters.

Quartz = Silica temperature assuming quartz equilibrium and conductive cooling.

Chalcedony = Silica temperature assuming equilibrium with chalcedony and conductive cooling.

surface temperature and the temperatures calculated using chemical geothermometers. Fornier (1977) provides information on the estimation of reservoir temperatures using geothermometers. The depths of circulation for thermal springs with high specific conductivities, relative to spring elevation, are estimated to be 300 to 1000 m using the surface temperature. The estimated depths of circulation using chemical geothermometers are 600 to 2400 m.

Analysis of deep drilling data from the Caribou Range study area indicates that several wells intersect fault zones at elevations of 380 to 455 m. These zones are identified by an altered stratigraphic sequence or by geophysical methods. The character of these faults is not known. Sufficient data are not available regarding the character of the subsurface geology to determine if the ground water circulates to depths where it may come in contact with thrust faults.

The estimated depths of circulation for thermal springs with low specific conductivities are presented in table 7. The maximum depths of circulation required for these springs are 200 to 300 m. These data conform with the concept that higher dissolved solids are indicative of longer flow paths.

Elevation of Discharge

The elevations of springs and wells in this area range from 1530 to 2180 meters. There appears to be no direct correlation between the elevation of spring discharge and water temperature. However, it is important to note that each spring is located in a local topographic low with one exception. Warm Spring (H-20) discharges at an elevation of 2180 meters near the crest of the Caribou Range.

Table 7. Estimated depths of circulation for thermal springs and wells with low specific conductivities in the vicinity of the Caribou Range, southeastern Idaho and western Wyoming

Sample Number	Name and Location	Surface Temp °C	Depth of Circulation* (m)
H-1	Elkhorn Warm Spring 4N 40E 23cadS	20	300
H-2	Hawley Warm Spring 4N 40E 25bbdS	16	200
H-6	Unnamed Spring 3N 41E 32bbdS	23	300
H-7	Dyer Well 2N 39E 21bcc	21	300
H-8	Anderson Well 2N 39E 39bac	20	300
H-20	Warm Spring 2S 44E 9aacS	17	200

*Calculated on the basis of a geothermal gradient of 5.6°C per 100 meters.

Analysis of Springs and Wells Utilizing Chemical Data

The chemical composition of the water discharging from a spring is the result of a complicated set of interactions determined by the chemical characteristics of the porous media through which it moves, the rate at which it flows, and the temperature and pressure of the ground water along its flow path. The chemical analysis of the water from a spring or well provides information on the rocks that chemically interacted with the water, the relative length of the ground water, the rate of flow, and the possible maximum temperature achieved. The combined interpretation of the chemical and physical data can be used to describe probable ground water flow systems.

Accuracy of Chemical Analysis

Duplicate samples were analyzed for each site in this study and the concentrations averaged. Paired samples with significant variations between them were reanalyzed to minimize error.

The accuracy of an analysis can be checked by computing the sum of the positive ionic charges and the sum of the negative ionic charges in the solution. The two should be equal if all dissolved ions are measured. The deviation in percent (E) is expressed as the charge-balance error by the relationship

$$E = \frac{\Sigma meq/l\ C - \Sigma meq/l\ A}{\Sigma meq/l\ C + \Sigma meq/l\ A} \times 100$$

where $\Sigma meq/l\ C$ is the sum of the cations in millequivalents per liter and $\Sigma meq/l\ A$ is the sum of the anions in the same units. Significant errors can be attributed to analytical errors or undetermined species that are not included in the analyses. It is possible to have offsetting analytical errors. The data in table 4 indicate that seven samples have charge-balance errors from 5 to 10.5 percent. These errors are within the range to be expected as a result of ion measurement omission.

Major Ion Species

The water samples collected at the spring and well sites were analyzed for eight ionic species: calcium, magnesium, sodium, potassium, chloride, flouride, bicarbonate, and sulfate. The samples were analyzed also for silica, a nonionic species.

Mineral availability and mineral solubility are the two main variables which control the chemical composition of ground water. The mineral availability determines the minerals which have the potential of dissolution into the ground water. The mineral solubility determines the amount of mineral which will dissolve into the solution. Many dissolution reactions need substantial time to complete the reaction at normal temperatures; however, these reactions speed up with increasing temperatures. A 10°C increase in temperature will generally double the rate of reaction (Hem, 1970). The solubility product of a mineral may be changed by several factors. An increase in temperature will increase the solubility of most minerals. Another factor that will increase the solubility is the ionic strength effect. As the ionic strength of the solution increases (increasing salinity) the activity coefficients decrease, thereby increasing the solubility. Freeze and Cherry (1979) provide further information on the ionic strength effect.

Calcium. The solubility of calcium in water is controlled largely by the hydrogen ion supply which, in turn, is predominantly a function of the carbon dioxide concentration. The dependence of calcium on the carbon dioxide concentration causes its solubility to decrease slightly with increasing temperature because CO_2 is less soluble in hot water than in cold water. Another process which decreases the concentration of calcium in ground water is cation-exchange where Ca^{2+} is exchanged for Na^+. The reverse of this process where Na^+ is exchanged for Ca^{2+} is not as common a process.

Most of the calcium found in ground water comes from the dissolution of the carbonate minerals found in limestone or dolomite. The study area has large deposits of limestone and dolomite in the sedimentary sequence of rocks. Calcium concentrations in the study area vary from 30 to 130 mg/l in nonthermal and thermal springs with low specific electrical conductivities to 110 to 680 mg/l in thermal springs with high specific electrical conductivities.

<u>Magnesium</u>. The magnesium concentration in most natural water is much lower than the calcium concentration. This is due, in part, to the fact that magnesium is less abundant in rocks than is calcium, and therefore is less available for solution in water (Hem, 1970).

The magnesium in ground water is obtained by the dissolution of sedimentary rocks, such as dolomite and limestone or from igenous rocks. Most of the magnesium found in the study area's ground water is probably originally obtained from dolomite or impure limestone. Magnesium concentrations in springs with low specific electrical conductivities in the study area vary from 0 (below detection limits) to 27 mg/l. Springs with high specific electrical conductivities have concentrations of 19 to 100 mg/l.

Sodium. Sodium has a very high solubility and tends to stay in solution. There are no important precipitation reactions which control the solubility of sodium; however, it is readily exchanged by adsorption on mineral surfaces with high cation exchange properties. This process can either increase or decrease the concentration of sodium depending on which way the exchange reaction occurs.

The major sources of sodium are evaporite sediments, clay minerals, and the weathering products of feldspar minerals. The concentration of sodium in springs with low specific electrical conductivities sampled in the study area range from 0 to 50 mg/l. The springs with high specific electrical conductivities have concentrations of sodium ranging from 1100 to 2800 mg/l.

Potassium. Potassium and sodium are both alkali metals but they have different behaviors in the natural system. Potassium is found in greater concentrations than sodium in most types of rock but it generally has a much lower concentration than sodium in water. This may be due to the resistance to which the potassium bearing rocks have to weathering and the strong tendency for potassium to be reincorporated into clays once weathering has occurred.

Potassium is most commonly obtained from feldspars, felspathoids, clays and some evaporites. Springs with low specific electrical conductivities in the study area have concentrations of potassium from 0 to 7 mg/l. The springs with high specific electrical conductivities have potassium concentrations of 34 to 200 mg/l.

Chloride. Chloride concentrations in water are not significantly reduced due to precipitation or other chemical processes. Once chloride enters the ground water flow system it tends to stay in solution.

Chloride in natural water is obtained from evaporites, sedimentary rocks, and as a minor source, igneous rocks. Chloride concentrations in the springs with low specific electrical conductivities varied from 0 to 61 mg/l. Those springs with high specific electrical conductivities had concentrations ranging from 550 mg/l to 2800 mg/l.

Flouride. Two processes keep flouride concentrations low in ground water: flouride tends to form strong solute complexes with many cations, and many of the common flourine minerals have low solubilities. Flouride solubility is increased by the ionic strength effect and pressure.

Flouride in ground water is obtained from amphiboles, apatite, flourite, mica, and sedimentary rocks (Todd, 1980). The flouride concentrations in the springs with low specific electrical conductivities range from 0 to 0.8 mg/l. The concentrations for springs with high specific electrical conductivities vary from 0.6 to 4.6 mg/l.

Bicarbonate. The carbon dioxide dissolved in ground water appears in chemical analyses as bicarbonate and carbonate. The dominant specie is bicarbonate in the normal pH range (6-9) of water. This ion is usually the dominant anion in ground water recharge areas. In highly calcareous environments some waters produce solutions that are supersaturated with carbonate and bicarbonate when exposed to air (Hem, 1970). These springs may then deposit travertine ($CaCO_3$) near the points of discharge. This process is common in the study area.

Bicarbonate in ground water is generally obtained from the dissolution of limestone and by carbon dioxide produced in the soil zone from biochemical activity. Bicarbonate concentrations in the study area range from 110 to 350 mg/l in springs with low specific electrical conductivity to 920 to 2400 mg/l in springs with high specific electrical conductivities.

Sulfate. The element sulfur is generally found in water in the form of the anion sulfate (SO_4^{-2}). In some instances it is found in the reduced state of sulfide as in hydrogen sulfide. The reduction of sulfate to sulfide is associated with a biochemical reaction.

The major sources of sulfate in ground water are from evaporite sediments in the form of gypsum or anhydrite or from the oxidation of pyrite or other sulfides from igneous and sedimentary rocks. The concentration of sulfate found in springs sampled in the study area are in the order of 0 to 230 mg/l for the springs with low specific electrical conductivities and 330 to 2800 for springs with high specific electrical conductivities.

Silica. The element silicon is the second most abundant element in the earth's crust. However, silica is generally found in low concentrations in water because of its resistance to chemical attack and because silica reaches saturation in water at low concentrations. The solubility of silica is strongly controlled by temperature and so is used as a chemical geothermometer.

Most of the silica in ground water is probably obtained from the dissolution of silicate minerals despite its resistance to weathering. The silica concentrations are found in concentrations of 6 to 110 mg/l. The high concentrations of silica are generally found in thermal springs and from springs discharging from silicic rocks.

Evolution of Major Ions in Ground Water Flow Systems

Chebolarev (1955) concluded that as ground water moves along its flow path, from recharge area to discharge area, it changes character chemically toward seawater. He noted the dominant anion species evolve in the following manner along a ground water flow path:

$$HCO_3^- \rightarrow HCO_3^- + SO_4^{2-} \rightarrow SO_4^{2-} + HCO_3^- \rightarrow SO_4^{2-} + Cl^- \rightarrow Cl^- + SO_4^{2-} \rightarrow Cl^-$$

Increasing age and distance of flow path →

(Freeze and Cherry, 1979, p. 242). Bicarbonate is the dominant ion in the beginning of the anion evolution. The sulfate concentration increases with increasing time and distance until it is the dominant ion and bicarbonate is secondary. This process proceeds until chloride is the dominant ion. The evolution of the anion species is controlled by two variables, the availability of minerals and the mineral solubility.

The cycle begins in the form of precipitation. Moisture moving through the soil zone is charged with carbon dioxide which reacts with the water to form a bicarbonate and a hydrogen ion. The hydrogen ion may react with calcite to form another bicarbonate plus a calcium ion. The upper limits of the concentrations attained by these reactions are controlled by the solubility of calcite and dolomite and the partial pressure of carbon dioxide. Sulfate concentrations increase in ground water along its flow path until it is the dominant ion. This process requires a long flow path because the major sources of sulfate in ground water, gypsum and anhydrite, are generally present only in trace amounts. Chloride may evolve to where if is the dominant anion species in some regions where the ground water is traveling through a deep ground water basin composed of sedimentary rocks.

The anion evolution can be correlated to Domenico's three ground water zones:

1. The upper zone - This zone is characterized by a high rate of ground water flushing through well leached sediments. The dominant anion in this water is bicarbonate. This water commonly has a low total dissolved solids.
2. The intermediate zone - This zone has less flushing actions than the upper zone and a higher concentration of total dissolved solids. The dominant anion in this water is sulfate.
3. The lower zone - The circulation of ground water at this zone is nearly stagnant with nearly unleached rocks. This water has highly mineralized water and the dominant anion is chloride. (Domenico, 1972, p. 292)

The anion evolution sequence provides information regarding the flow path of the ground water. It must be used with care because this process can be short circuited when the ground water comes in contact with soluble sediments such as evaporites. The use of the anion evolution sequence is also dependent upon the fact that the water flows through the same types of rocks throughout the system. Cation evolution is not used because the sequence is often reversed due to cation exchange.

The water analyses may be used to indicate the length of the ground water flow system by using the three dominant anion species, bicarbonate, sulfate, and chloride. The relative flow lengths are presented in table 8 with a bicarbonate water indicated as short system, a sulfate water as intermediate, and a chloride dominant water as a long flow system.

Total Dissolved Solids as an Indicator of Flow Path Length

The concentration of total dissolved solids can also be used as an indicator of the length of a ground water flow system. As ground water moves along its flow path from recharge area to discharge area it will attain higher concentrations of dissolved solids. Total dissolved solids cannot be specifically correlated to a time or distance in a flow path except to say that the concentrations of total dissolved solids increase with the distance of travel. This generalization assumes the water does not come in contact with formations containing highly soluble minerals, the temperature is constant throughout the flow path, and that the water flows through the same type of rocks throughout the system. The results from this generalization are presented in table 8. The concentrations of total dissolved solids break into two ranges, a high total dissolved solids of 4000 to 11,000 mg/l (long flow systems) and a low total dissolved solids of 100 to 700 mg/l (shorter flow systems).

Classification of Springs and Wells Using WATEQF

WATEQF is the Fortran IV version of the WATEQ computer program written by Truesdell and Jones in 1973. It models the equilibrium distribution of inorganic ions and complex species in solution using the chemical analysis and measurements of pH and temperature as input. The calculation is performed in the following manner:

> The water analysis is read in and ion concentrations are converted to molality. All values of equilibrium

Table 8. Results of analyses to determine relative length of flow paths by dominant anions and total dissolved solids and groups formed by cluster analysis in the vicinity of the Caribou Range, southeastern Idaho and western Wyoming

Sample Number	Sample Name and Location	Temp °C	Relative Length of Flow Path: Dominant Anion	Relative Length of Flow Path: Total Dissolved Solids	Cluster Analysis Group
H-1	Elkhorn Warm Spring 4N 40E 23cadS	20	short	short	1
H-2	Hawley Warm Spring 4N 40E 25bbdS	16	short	short	1
H-3, I-3	Heise Hot Springs 4N 40E 25ddaS	48	long	long	2
H-4	Lufklin Spring 3N 42E 2cbbS	8	short	short	1
H-5	Buckland Warm Spring 3N 42E 12cca and ccdS	11	short	short	1
H-6	Unnamed Spring 3N 41E 32bbdS	23	short	short	1
H-7	Dyer Well 2N 39E 21bcc	21	short	short	1
H-8	Anderson Well 2N 39E 29bac	20	short	short	1
H-9	Fall Creek Mineral Springs 1N 43E 9cbb1S	24	long	long	2
H-10, I-10	Fall Creek Mineral Springs 1N 43E 9cbbS	23	long	long	2
H-11	Unnamed Spring 1N 39E 14acaS	9	short	short	1
H-12	Unnamed Spring 1N 40E 19cabS	13	short	short	1
H-13	Unnamed Spring 1N 44E 30cbdS	7	short	short	1
H-14	Unnamed Spring 1N 45E 4adaS	6	short	short	1
H-15	Unnamed Spring 1N 45E 4acaS	6	short	short	1
H-16	Unnamed Spring 1S 40E 4abcS	21	intermediate	long	2
H-17	Unnamed Spring 1S 44E 1cbdS	7	short	short	1
H-18	Willow Springs 1S 41E 36cccS	8	short	short	1
H-19	Unnamed Spring 2S 44E 1accS	11	short	short	1
H-20	Warm Spring 2S 44E 9aacS	17	intermediate	short	1
I-21, I-22	Alpine Hot Springs 2S 46E 19cadS	56 37	long	long	2
H-23, I-23	Brockman Hot Springs 2S 42E 26dcdS	35	intermediate	long	2

Table 8. Continued

Sample Number	Sample Name and Location	Temp °C	Relative Length of Flow Path: Dominant Anion	Relative Length of Flow Path: Total Dissolved Solids	Cluster Analysis Group
H-24	Unnamed Spring 3S 43E 15dccS	10	short	short	1
H-25	Unnamed Spring 3S 43E 22abbS	14	short	short	1
H-26, W-26	Auburn Hot Springs 33N 119W 23dbdS	57	long	long	2
H-27	Johnson Springs 33N 119W 26adS	54	long	long	2

> constants are recalculated to the temperature of interest using the van't Hoff equation, unless experimental data are available. A cation-anion balance is calculated. If the charge balance error is greater than 30%, calculation is terminated at this point... As a final preparatory calculation, the Debye-Hückel solvent constants are corrected for temperature.
>
> During the next phase of computation, single-ion activity coefficients are calculated using the Davies equation or the Debye-Hückel approximation. With these, the activities of all possible aqueous species can then be computed. The distribution of these species is then calculated by means of a chemical model, which uses analytical concentrations, experimental solution equilibrium constants, mass balance equations, and the measured pH. This distribution is presented in the form of a table which contains the concentrations, in mg/l and molality, the activities, and the activity coefficients of all possible aqueous species.
>
> In the final phase of the calculation, saturation data are computed. Ion activity products for all possible reactions are calculated and compared with the temperature-corrected equilibrium constants. This information is, again, presented in a table containing ion activity products (IAP), equilibrium constants (KT), the ratio of these two values (IAP/KT)... (Hounslow and others, 1978, p. 138-139)

The results of these computations can be used to group springs with the same saturation states.

The saturation index for the minerals aragonite, calcite, and dolomite as calculated by WATEQF for the samples obtained in the study area are presented in table 9. These minerals are chosen because a large proportion of the study area is made up of carbonate rocks and because these three minerals are the most diagnostic minerals to divide these springs into separate groups. The saturation index (IAP/KT) indicates whether a solution is undersaturated or saturated with respect to these specific minerals. Values less than one indicate that the solution is

Table 9. Saturation index (IAP/KT) of selected minerals for springs and well in the vicinity of the Caribou Range, southeastern Idaho and western Wyoming

Sample Number	Sample Name and Location	Water Temp. (°C)	Aragonite	Calcite	Dolomite
H-1	Elkhorn Warm Spring 4N 40E 23cadS	20	.05	.07	.003
H-2	Hawley Warm Spring 4N 40E 25bbdS	16	.39	.61	.15
H-3	Heise Hot Springs 4N 40E 25ddaS	48	2.5	4.2	6.3
I-3	Heise Hot Springs 4N 40E 25ddaS	49	4.0	6.8	26
H-4	Lufklin Spring 3N 42E 2cbbS	8	.44	.74	--
H-5	Buckland Warm Spring 3N 42E 12cca + ccdS	11	.44	.72	.16
H-6	Unnamed Spring 3N 41E 32bbdS	23	.61	.92	.40
H-7	Dyer Well 2N 39E 21bcc	21	.96	1.5	.94
H-8	Anderson Well 2N 39E 29bac	20	.99	1.5	.76
H-9	Fall Creek Mineral Springs 1N 43E 9cbb1S	24	1.0	1.6	.98
H-10	Fall Creek Mineral Springs 1N 43E 9cbb2S	23	.82	1.2	.58
H-11	Unnamed Spring 1N 39E 14acaS	9	.13	.21	.02
H-12	Unnamed Spring 1N 40E 19cabS	13	.16	.26	.01
H-13	Unnamed Spring 1N 44E 30cbdS	7	.36	.62	.05
H-14	Unnamed Spring 1S 45E 4adaS	6	.42	.73	.17
H-15	Unnamed Spring 1S 45E 4acaS	6	.51	.90	.25
H-16	Unnamed Spring 1S 40E 4abcS	21	.56	.86	.22
H-17	Unnamed Spring 1S 44E 1cbdS	7	.24	.41	.05
H-18	Willow Spring 1S 41E 36cccS	8	.30	.51	.06
H-19	Unnamed Spring 2S 44E 1aacS	11	.08	.13	.004
H-20	Warm Spring 2S 44E 9aacS	17	.45	.70	.16
I-21	Alpine Hot Springs 2S 46E 19bS	56	2.7	5.0	15
I-22	Alpine Hot Springs 2S 46E 19cadS	37	1.8	2.8	3.5

Table 9. Continued

Sample Number	Sample Name and Location	Water Temp. (°C)	Aragonite	Calcite	Dolomite
H-23	Brockman Hot Spring 2S 42E 26dcdS	35	1.5	2.3	2.2
I-23	Brockman Creek W.S. 2S 42E 26dcdS	35	.66	1.0	.64
H-24	Unnamed Spring 3S 43E 15dccS	10	.51	.85	.23
H-25	Unnamed Spring 3S 43E 22abbS	14	.51	.80	.12
H-26	Auburn Hot Springs 33N 119W 23dbdS	57	2.1	4.0	8.3
W-26	Auburn Hot Springs 33N 119W 23dbdS	62	21	42	1200
H-27	Johnson Springs 33N 119W 26adS	54	2.0	3.6	4.1

undersaturated and values more than one indicate the solution is oversaturated with respect to that mineral. Solutions oversaturated with a mineral species favors precipitation of that mineral while undersaturation favors dissolution.

The data indicate that all of the springs grouped as thermal springs with high specific conductivities in the previous chapter are oversaturated with respect to one or more of these three minerals except sample H-16, unnamed spring at 1S 40E 4abcS. These data are verified by the observation of active travertine deposition at each of these sites. As the water from hot springs rises to the surface the pressure drops and the water cools causing the precipitation of some dissolved minerals. The data also show that the two wells tested in this area (H-7 and H-8) are oversaturated with respect to calcite. The equilibrium of these samples was altered when the water was pumped to the surface so the results of WATEQF may not be representative of the water in the aquifer. All of the other springs in this area are undersaturated with respect to aragonite, calicite, and dolomite.

Correlation of Springs and Wells Utilizing Stiff Diagrams

Stiff diagrams graphically show the concentrations of major cations and anions in milliequivalents per liter. The width of the patterns are an approximate indication of the total ionic content. These diagrams are useful for analyzing gross similarities in water quality and thus ground water flow systems. Stiff diagrams for the springs and wells in the Caribou Range study area are presented in figure 8.

Seven of these springs, Heise Hot Springs (H-3 and I-3), Falls Creek Mineral Springs (H-9, H-10, and I-10), Unnamed Spring at

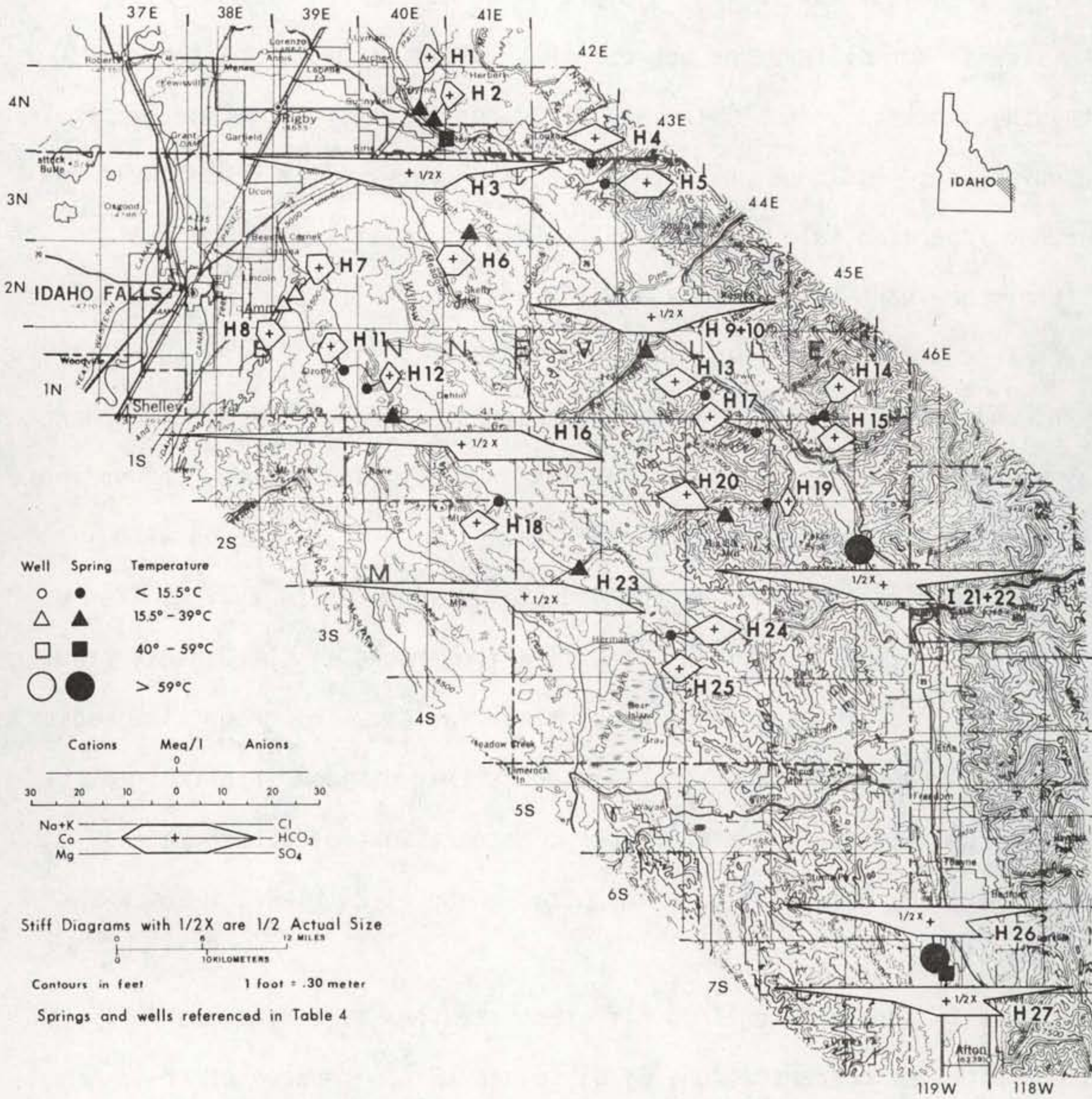

Figure 8. Stiff diagrams of water chemistries of selected springs and wells in the vicinity of the Caribou Range, southeastern Idaho and western Wyoming

1S 40E 4abcS (H-16), Alpine Hot Springs (I-21 and I-22), Brockman Hot Springs (H-23 and I-23), Auburn Hot Springs (H-26 and W-26), and Johnson Springs (H-27), shown in figure 8 are drawn at one-half actual width. The significant differences between these stiff diagrams and those of the other springs in both size and major constituents suggests that these seven springs should be put into a separate group. This group could be further separated into two smaller groups, one with sodium and sulfate as their dominant ions (H-16 and H-23) and those with sodium and chloride as their dominant ions (H-3, I-3, H-9, H-10, I-10, I-21, I-22, W-26, H-26, and H-27). The similarities between the chemistries of the springs may be due to similar geologic controls on their flow paths. The springs with sodium and chloride as their dominant ions are associated with faults bordering the Swan, Grand, and Star valleys. The springs with sodium and sulfate as dominant ions flow from rocks of the Gannett group but are apparently not controlled by major faults. The group with sodium and chloride as their major ions can be further divided into two groups of like chemistries, one with higher concentrations of bicarbonate (H-3, I-3, H-9, I-10, and H-10) than the other group (I-21, I-22, H-26, W-26, and H-27).

It is more difficult to differentiate the stiff diagrams for waters with low concentrations of dissolved solids because of their small overall size. These diagrams have more subtle differences than do those with high total ionic contents. One of these springs, Warm Spring (H-20), can be differentiated from the other springs due to the differences in the major ions. This spring has calcium and sulfate as the dominant ions whereas other springs in this group have calcium and bicarbonate as their dominant ions.

The stiff diagrams with low total ionic contents are best used to relate springs located closely together. Elkhorn and Hawley Warm Springs (H-1 and H-2) are similar to each other yet distinct from the others as are Dyer and Anderson wells (H-7 and H-8). Two other springs that may be grouped this way are Unnamed Springs at 1S 45E 4adaS and 1N 45E 4acaS (H-14 and H-15). It should be noted that Heise Hot Springs (H-3) and Elkhorn and Hawley Warm Springs (H-1 and H-2) do not have similar water chemistries despite the closeness in location, and the presence of thermal water in all three.

Statistical Analysis of Chemical Data

Introduction. The analysis of the chemical data requires the simultaneous examination of the twelve variables obtained at each site. The following steps are taken in the statistical analysis of the chemical data on springs and wells in the study area.

1) The data are summarized using the UNIVARIATE data summary program (SAS Institute Inc., 1979) to determine if they fulfill the assumption that the data are normally distributed which is required for subsequent analyses.
2) The second step of the analysis is a cluster analysis which groups like samples.
3) A stepwise MANOVA analysis is performed using the groupings from the cluster analysis to determine which variables are most useful in discriminating between the specified groups and to test if the groups can be statistically separated by using the most discriminating variables. This step is

accomplished by using SAS stepwise discriminate procedure (SAS Institute Inc., 1979).

UNIVARIATE Analysis. The UNIVARIATE data summary in the Statistical Analysis System was used to present the chemical data (results are presented in figure 9 and in Appendix A). This program includes calculation of the descriptive statistics and the graphical summarization of the data with a stem-and-leaf plot, a box plot, and a normal probability plot.

The first three moments calculated in the descriptive statistics are the mean, the standard deviation, and the skewness. The mean and variance indicate the "center" of the data and variability of the data about that center, respectively.

The skewness indicates the symmetry of the data around its mean. Data with a normal distribution have a skewness equal to zero; data that are skewed to the left have a positive value (i.e. mean is larger than the median). The data from this study are all positively skewed except the variable pH. The positive skewness shown by the variables in the UNIVARIATE data summary indicates that a logrithmic transformation is appropraite for all variables except pH to approximate the normality assumptions required for subsequent tests of significance. Six of these variables have some concentrations equal to zero: magnesium, sodium, potassium, chloride, flouride, and sulfate. A concentration of 1 mg/l has been added to each of the values of these variables before the transformation.

The stem-and-leaf plot is a histogram with the vertical axis, the stem, representing the leading digits of the data. The leaves are

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S T A T I S T I C A L   A N A L Y S I S   S Y S T E M
                        UNIVARIATE

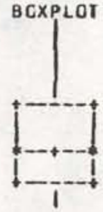
VARIABLE=TEMP

          MOMENTS                                       QUANTILES(DEF=4)                              EXTREMES

N            31      SUM WGTS         31     100% MAX    62     99%    62      LOWEST   ID         HIGHEST   ID
MEAN    24.2903      SUM             753      75% Q3     35     95%    59           6(H-15    )        49(I-3     )
STD DEV 17.2727      VARIANCE    298.346      50% MED    20     90%  55.6           6(H-14    )        54(H-27    )
SKEWNESS 0.923259    KURTOSIS  -0.380486      25% Q1     10     10%     7           7(H-17    )        56(I-21    )
USS       27241      CSS         8950.39       0% MIN     6      5%     6           7(H-13    )        57(H-26    )
CV      71.1094      STD MEAN    3.10227                         1%     6           8(H-18    )        62(W-26    )
T:MEAN=0 7.82986     PROB>|T|     0.0001     RANGE       56
W:NORMAL 0.859252    PROB<W        <0.01     Q3-Q1       25
                                             MODE         6

     STEM LEAF                      #
        6 2                         1
        5 67                        2
        5 4                         1
        4 89                        2
        4
        3 557                       3
        3
        2 5                         1
        2 0011334                   7
        1 67                        2
        1 01134                     5
        0 6677889                   7
          ----+----+----+----+
```

BOXPLOT



NORMAL PROBABILITY PLOT

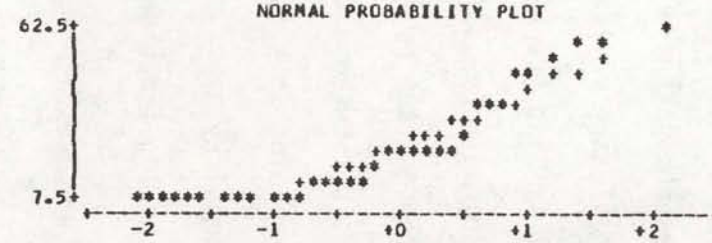


Figure 9. UNIVARIATE data summary of the variable temperature for springs and wells in the vicinity of the Caribou Range, southeastern Idaho and western Wyoming

shown on the horizontal axis and are the last digits of the data.

The box plot indicates six summary points: the minimum, the lower quartile, the median, the mean (+), the upper quartile, and the maximum. This plot indicates whether the data are skewed positively or negatively and the relative variation of each variable.

The normal probability plot graphs the raw data on the vertical scale versus the standard normal scores (Z scores) on the horizontal scale. The raw data are represented by asterisks versus the plus sign which represent normally distributed data. If the data are normal, one would expect the data to plot on a straight line. Any deviation form this line indicates non-normality.

The pH values and the log functions of the other variables are standardized by:

$$Z = \frac{X - \overline{X}}{s}$$

where: Z = standardized log normal variable

X = sample value

$\overline{X}$ = mean of the variable

s = standard deviation of the variable

(Huntsberger and Billingsley, 1977).

This procedure scales all values to a range of approximately -3 to +3, where each variable has a mean of zero and a standard deviation of one. In this way, each variable has equal weight in the subsequent cluster analysis.

Cluster Analysis. The chemical data in table 4 were run using SAS' hierarchical grouping, several variable cluster analysis (SAS Institute Inc., 1979). The clustering was performed on 31 samples in twelve dimensional space defined by pH, calcium, magnesium, sodium, potassium, chloride, flouride, bicarbonate, sufate, silica, total dissolved solids, and temperature. This technique reduced the data from 31 groups ultimately into one group. The cluster technique begins by the computation of a similarity or distance matrix between the samples. At each step two samples or clusters are joined, if they are the closest unjoined set. The final product is a dendrogram showing the stepwise joining of the samples (figure 10). If the diameter increases markedly when two clusters are joined the clustering process has gone too far. In figure 10 this occurs when two clusters are joined to make one (the diameter changes from 23 to 74).

The cluster analysis indicates that there are two distinguishable groups of chemistries (table 8). The first group is made up of samples with relatively low ionic concentrations, lower temperatures, and higher pH's. The second group has relatively high ionic concentrations, higher temperatures, and lower pH's.

Stepwise MANOVA Analysis. A stepwise MANOVA analysis (SAS Institute Inc., 1979) was run to determine if the two groups formed by the cluster analysis can be differentiated statistically and to indicate the water quality variables most useful in separating these two groups. The hypothesis to be tested is that the mean of the combined distribution of chemical constituents of one group (μ_1) is equal to the mean of the constituents of the other (μ_2). The null hypothesis (Ho) can be stated as $\mu_1 = \mu_2$ and the alternate hypothesis is the converse $\mu_1 \neq \mu_2$.

The results of the test are listed in table 10. The first column lists the variables which are most useful in discriminating the two

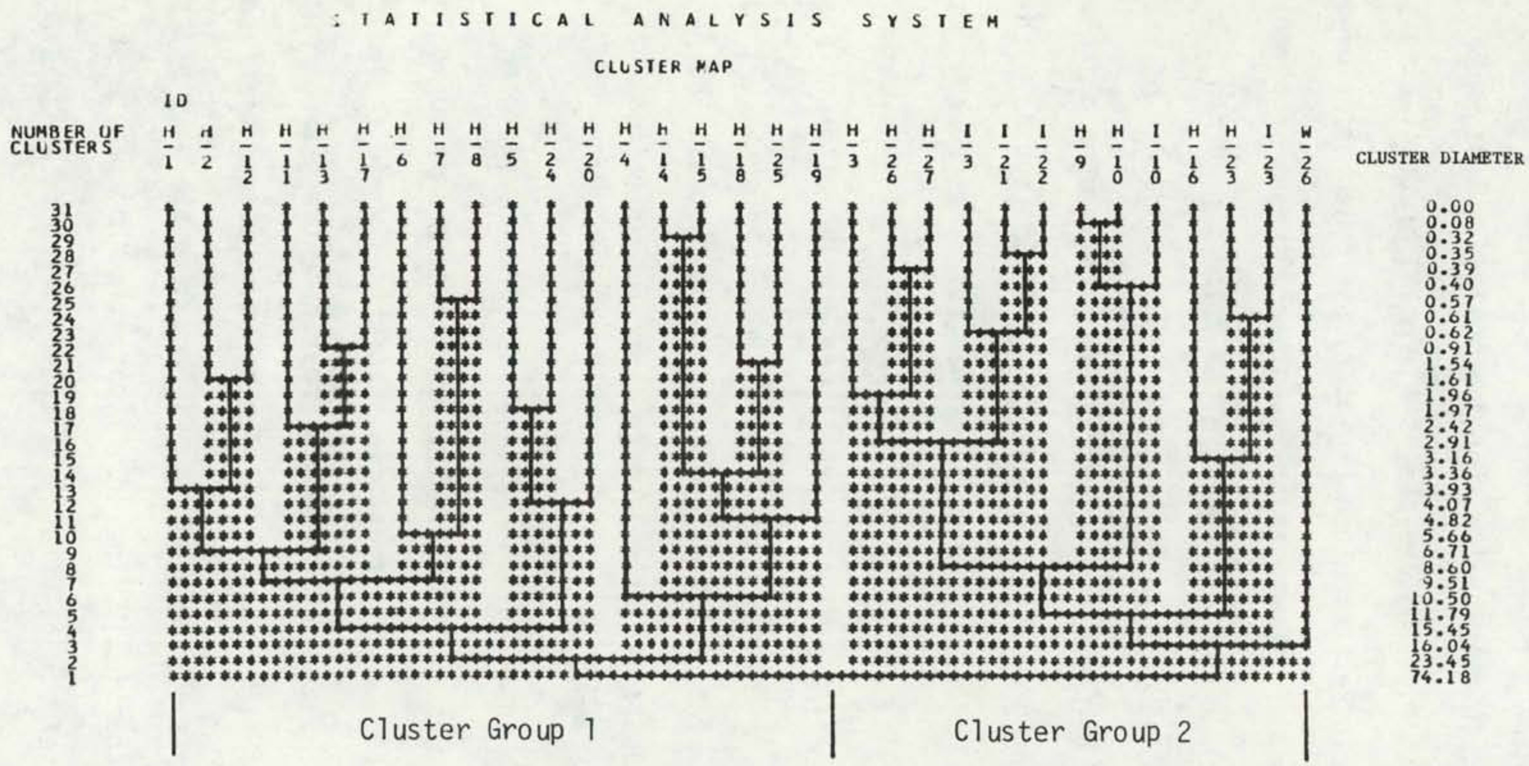


Figure 10. Twelve variable cluster diagram for springs and wells in Caribou Range study area, southeastern Idaho and western Wyoming

Table 10. Results of stepwise MANOVA analysis for springs and wells in Caribou Range study area, southeastern Idaho and western Wyoming

Variable	Wilk's Lambda	Prob.< Lambda
LTDS	.03476	0.0001
LK	.02214	0.0001
pH	.01914	0.0001
LCL	.01676	0.0001
LCA	.01383	0.0001
LF	.01098	0.0001

cluster groupings with the best discriminator at the top. The second column is the Wilk's lambda statistic. It is used to test for significance between the groups. A smaller value of the lambda statistic implies greater statistical significance between the groups. As more variables are added the statistical significance increases. The third column (Prob. <Lambda) is the probability of obtaining a Wilk's lambda statistic smaller than the observed statistic in column two when in fact the null hypothesis, that the means are equal, is true. Thus by using the most discriminating variable, LTDS, the chance of obtaining a value of lambda less than .03476 is <.0001 if Ho is true. This implies that there is a difference between the two groups. The addition of the remaining variables essentially does not improve the ability to discriminate between the two groups.

Discussion of the Results. The cluster analysis indicates that there are at least two major clusters. These two groups are shown in figure 7. The stepwise MANOVA analysis indicates that the most discriminating variable is log TDS and that by using this variable alone that these two clusters can be separated.

GROUND WATER FLOW PATTERNS

A ground water flow system is made up of three components: the recharge area, the flow path, and the discharge area. This investigation has concentrated on the physical characteristics and water quality at the discharge area. Postulated ground water flow paths for the springs examined in the study area are presented in this section using the physical and chemical setting of the springs and wells and basic hydrologic concepts.

The cluster analysis discriminated two groups of springs with similar chemistries. The first group of springs to be examined have high concentrations of all the major ions, low pH values, and elevated temperatures.

Five of the springs in this group are associated with the graben forming faults along the Swan, Grand, and Star valleys: Heise Hot Springs (H-3 and I-3), Fall Creek Mineral Springs (H-9, H-10, and I-10), Alpine Hot Springs (I-21 and I-22), Auburn Hot Springs (H-26 and W-26), and Johnson Springs (H-27). Two hypotheses for the ground water flow to these springs may be stated.

1) Recharge occurs in the mountain ranges, where there are high rates of precipitation. The intense structural deformation of the ranges increase the vertical hydraulic conductivity allowing downward movement of ground water. The water moves laterally along bedding planes to the fault systems bordering the Swan, Grand, and Star valleys

where the fault provides a conduit of high hydraulic conductivity allowing the thermal water to move to the surface. Some mixing and cooling of the deep thermal ground water creates variations in temperature and water quality found along these systems.

2) Recharge occurs along the surface exposure of the major faults bordering the Swan, Grand, and Star valleys. The water moves downward following the vertical conduit formed by the major faulting. This deep thermal water follows the trace of the fault to move to the surface at a site some distance from the recharge area. And again, some cooling and mixing of the deep thermal ground water would create variations in temperature and water quality as seen in the springs in this system.

The minimum depth of circulation estimated from surface temperatures varies from 400 to 1000 m for these springs. The maximum depth of circulation estimated from geothermometer temperatures is 600 to 2400 m.

The remaining two thermal springs in the first group with high specific conductivities are Unnamed Spring at 1S 40E 4abcS (H-16) and Brockman Hot Springs (H-23). The water from these springs must circulate to depths where they can be heated; however, there are no major faults closely associated with either of these sites. The ground water flow path of these springs probably circulate to a depth of 300 to 600 m. The closeness in their chemistries indicates that the processes which contribute to their chemistries are similar. Both springs issue from rocks of the Gannett group and have minor faults near them. Their locations to one another, relative to the trend of the Swan and Grand Valley faults, implies that there may be a linear feature which may relate these two springs.

The second group differentiated by the cluster analysis is made up of springs with lower concentrations of all the major ions, and as a group have higher pH values and lower temperatures. This group can be further separated into three subgroups by their geologic setting and temperatures.

The first subgroup has three springs and two wells that emerge from rhyolite in the northwestern portion of the study area: Elkhorn Warm Spring (H-1), Hawley Warm Spring (H-2), Unnamed Spring at 3N 41E 32bbdS (H-6), Dyer well (H-7), and Anderson well (H-8). All of these have temperatures between 16 to 23°C. These springs and wells appear to be associated with caldera structures in this area. The calderas form closed basins filled with permeable materials with faults around their rims (Proskta and Embree, 1978). Precipitation in the mountains recharges the ground water system where some of it follows faults to the depths where it is heated. The estimated depths of circulation for these springs are in the order of 200 to 300 m. The water rises to form warm springs or, if the piezometric head is not great enough to force it to the surface, it may lie at depth where it may be pumped to the surface by wells. The similarity in chemistries and closeness of location suggests that this group can be further divided to group Elkhorn Warm Spring and Hawley Warm Spring into one group, Dyer and Anderson wells into a second, and Unnamed Spring at 3N 41E 32bbdS into a third group.

The second subgroup has one spring, Warm Spring (H-20). Warm

Spring is unique in both its chemistry and its high elevation. The chemistry may be a function of the lithology and the elevated temperature may be due to relatively shallow circulation (200 m) of ground water in a region of high heat flow. The indication of high heat flow in this area is supplied by the well drilled 4.8 km southeast of this spring. This well has the highest calculated geothermal gradient (6.3°C/100 m) of the four wells drilled in the study area.

The third subgroup has twelve springs that probably represent shallow ground water flow systems controlled by the complex lithology and structure in this area. These springs are the result of local ground water flow systems formed by the discontinuous nature of the geologic units of this area. Their cool temperatures attest to shallow dpeths of circulation and the low ionic concentrations to short flow paths. Buckland Warm Spring (H-5) is associated with the Baldy Mountain thrust. This spring has a large discharge and a high ionic content relative to the other springs in this group which suggests that it has a longer flow path and a larger recharge area. The recharge area for this spring is located north of the study area in the Snake River Range.

CONCLUSIONS

The analyses of the physical and chemical characteristics of the springs and wells in the Caribou Range study area may be used to formulate hypotheses for ground water flow patterns. The major thermal discharges within the study area are located along structural features with the hottest water associated with deep normal faults along the Swan, Grand, and Star valleys. The combination of their locations relative to major faults, elevated temperatures, and high total dissolved solids lead to the following hypotheses for ground water flow:

1) Recharge occurs in the mountain ranges and moves vertically downward facilitated by the intense structural deformation in these areas. The ground water moves laterally along bedding planes to the faults bordering the Swan, Grand, and Star valleys. The faults allow upward migration of the thermal ground water to the surface.
2) Recharge occurs along some portions of the fault systems along the Swan, Grand, and Star valleys that allow deep migration of the ground water. The thermal ground water then moves upward along the fault zones to the surface some distance from the recharge site.

Thermal springs with high total dissolved solids are located in the Willow Creek Hills. Their high temperatures, high total dissolved solids, and location relative to minor faults suggest that the ground water supplying these springs circulates to depths where they are heated then move upward to the surface following minor faults.

Thermal flow systems associated with caldera structures in this area have temperatures less than 24°C and low specific electrical conductivities indicating shallow ground water flow systems. Recharge in surrounding areas moves to shallow depths where it is heated. The ground water then moves to the surface following minor faults. Nonthermal springs in the area probably represent relatively shallow ground water flow systems controlled by the complex lithology and structure in the area.

The following is a list of additional conclusions which may be drawn from the analyses of the data collected in the course of the study.

1) The springs and wells may be divided into two major groups based upon chemical analyses. The first group is characterized by high total dissolved solids, high temperatures, and low pHs. The second group characteristically has low total dissolved solids, lower temperatures, and higher pHs.

2) The chemistry and physical setting of Heise Hot Springs relative to Elkhorn and Hawley Warm Springs indicates that the ground water flow system represented by Heise Hot Springs is unrelated to these other springs. Heise Hot Springs appear to be closely related to the normal fault controlled springs in the sedimentary system and not to the rhyolite caldera system to the north and west.

3) The small total discharge of springs with temperatures above 39°C indicates there is very little deep movement of ground water.

4) Temperature data in three of the four oil exploration wells drilled in this area indicate a higher than normal geothermal gradient. The maximum depths of circulation for thermal springs with high specific electrical conductivities are estimated to be from 600 to 2400 m. The maximum depths of circulation for thermal springs with low specific electrical conductivities are estimated to be 200 to 300 m.

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APPENDIX A

Summary Statistics of Water Quality Data

Variable = TEMP is found in figure 9

STATISTICAL ANALYSIS SYSTEM

UNIVARIATE

VARIABLE=TDS

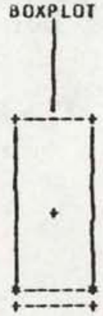
MOMENTS			
N	31	SUM WGTS	31
MEAN	3021.65	SUM	93671
STD DEV	3197.81	VARIANCE	10225982
SKEWNESS	0.527443	KURTOSIS	-1.55312
USS	589819989	CSS	306779465
CV	105.83	STD MEAN	574.343
T:MEAN=0	5.26104	PROB>|T|	0.0001
W:NORMAL	0.748442	PROB<W	<0.01

QUANTILES(DEF=4)			
100% MAX	9229	99%	9229
75% Q3	6310	95%	8291.79
50% MED	547	90%	7518.4
25% Q1	377	10%	336.2
0% MIN	160	5%	256.6
		1%	160
RANGE	9069		
Q3-Q1	5933		
MODE	160		

EXTREMES			
LOWEST	ID	HIGHEST	ID
160	(H-19)	7063	(I-22)
321	(H-12)	7344	(I-23)
335	(H-1)	7562	(H-23)
341	(H-2)	7667	(H-3)
348	(H-14)	9229	(H-16)

```
STEM LEAF                     #
   9 2                        1
   8
   8
   7 67                       2
   7 13                       2
   6 89                       2
   6 3                        1
   5 78                       2
   5 034                      3
   4
   4
   3
   3
   2
   2
   1
   1
   0 5555567                  7
   0 23333444444             11
     ----+----+----+----+
   MULTIPLY STEM.LEAF BY 10**+02
```

BOXPLOT



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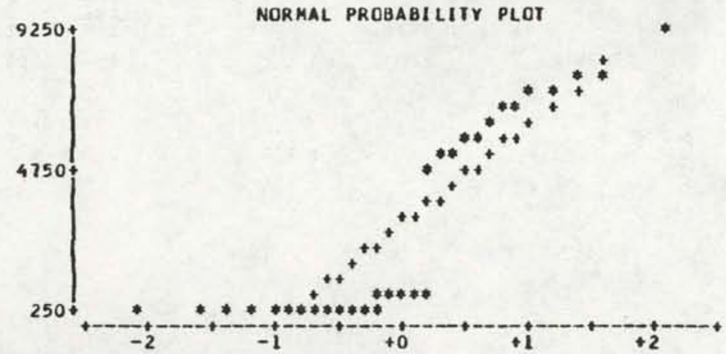


S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

UNIVARIATE

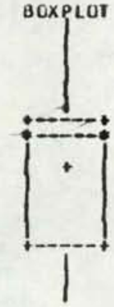
VARIABLE=PH

```
             MOMENTS                                      QUANTILES(DEF=4)                              EXTREMES

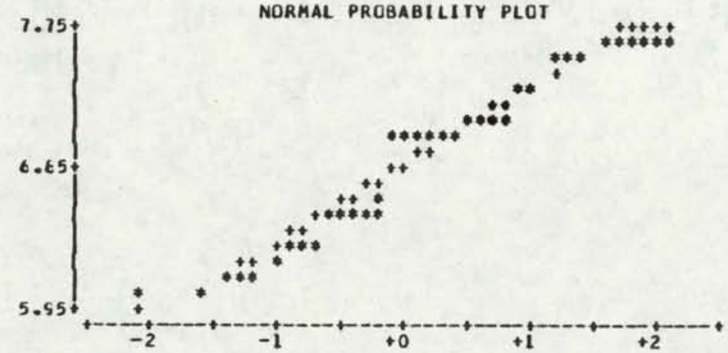
N                31   SUM WGTS          31     100% MAX     7.7     99%      7.7      LOWEST    ID            HIGHEST    ID
MEAN        6.87097   SUM              213      75% Q3      7.2     95%      7.7           6(H-4     )           7.4(H-15   )
STD DEV    0.490709   VARIANCE    0.240796      50% MED       7     90%      7.5         6.1(H-3     )           7.5(H-2    )
SKEWNESS -0.0751091   KURTOSIS    -1.13484      25% Q1      6.4     10%      6.2         6.2(H-9     )           7.5(W-26   )
USS         1470.74   CSS          7.22387       0% MIN       6      5%     6.06         6.2(H-10    )           7.7(H-7    )
CV          7.14178   STD MEAN    0.088134                           1%        6         6.3(I-10    )           7.7(H-8    )
T:MEAN=0    77.9605   PROB>|T|      0.0001     RANGE        1.7
W:NORMAL   0.941689   PROB<W         0.125     Q3-Q1        0.8
                                               MODE         7.1
```

```
  STEM LEAF                     #
    77 00                       2
    76
    75 00                       2
    74 00                       2
    73
    72 0000                     4
    71 00000                    5
    70 00                       2
    69
    68
    67 0                        1
    66 000                      3
    65 00                       2
    64 000                      3
    63 0                        1
    62 00                       2
    61 0                        1
    60 0                        1
    59
       ----+----+----+----+
  MULTIPLY STEM.LEAF BY 10**-01
```

BOXPLOT



NORMAL PROBABILITY PLOT



STATISTICAL ANALYSIS SYSTEM

UNIVARIATE

VARIABLE=CA

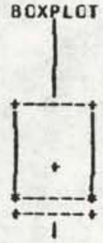
MOMENTS			
N	31	SUM WGTS	31
MEAN	213.871	SUM	6630
STD DEV	202.883	VARIANCE	41161.4
SKEWNESS	0.884922	KURTOSIS	-0.832323
USS	2652808	CSS	1234843
CV	94.8623	STD MEAN	36.4388
T:MEAN=0	5.86931	PROB>|T|	0.0001
W:NORMAL	0.783666	PROB<W	<0.01

QUANTILES(DEF=4)			
100% MAX	676	99%	676
75% Q3	440	95%	606.399
50% MED	110	90%	522.6
25% Q1	60	10%	36.6
0% MIN	30	5%	33.6
		1%	30
RANGE	646		
Q3-Q1	380		
MODE	36		

EXTREMES			
LOWEST	ID	HIGHEST	ID
30	(H-1)	473	(H-9)
36	(H-19)	509	(H-26)
36	(H-2)	526	(I-21)
39	(H-12)	560	(I-22)
48	(H-11)	676	(H-3)

```
STEM LEAF                  #
   6 8                     1
   6
   5 6                     1
   5 13                    2
   4 557                   3
   4 034                   3
   3
   3
   2
   2
   1 59                    2
   1 01133                 5
   0 5556777788           10
   0 3444                  4
     ----+----+----+----+
     MULTIPLY STEM.LEAF BY 10**+01
```

BOXPLOT



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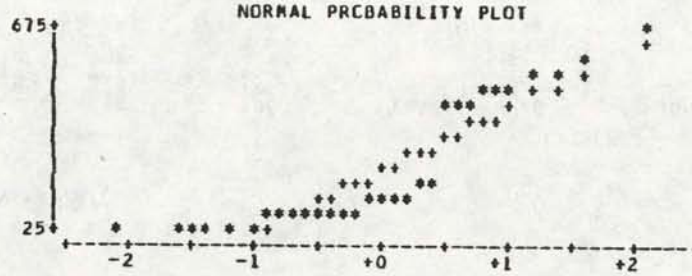


S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

UNIVARIATE

VARIABLE=MG

MOMENTS

N	31	SUM WGTS	31
MEAN	38.0323	SUM	1179
STD DEV	33.8659	VARIANCE	1146.9
SKEWNESS	0.623716	KURTOSIS	-0.987464
USS	79247	CSS	34407
CV	89.0452	STD MEAN	6.08249
T:MEAN=0	6.25274	PROB>|T|	0.0001
W:NORMAL	0.809612	PROB<W	<0.01

QUANTILES(DEF=4)

100% MAX	100	99%	100
75% Q3	76	95%	100
50% MED	19	90%	95.4
25% Q1	10	10%	6.8
0% MIN	0	5%	3.6
		1%	0
RANGE	100		
Q3-Q1	66		
MODE	10		

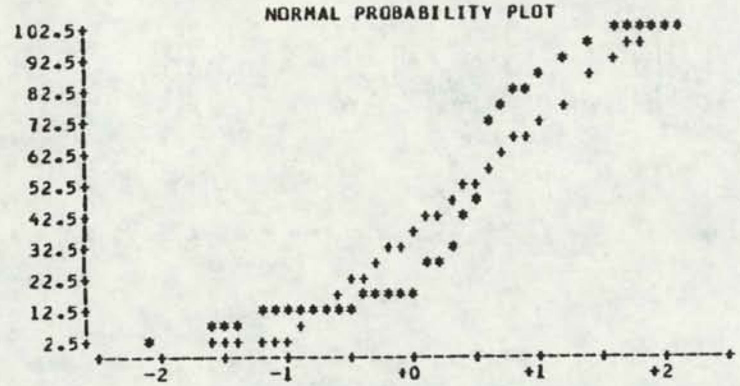
EXTREMES

LOWEST	ID	HIGHEST	ID
0	(H-4)	88	(H-10)
6	(H-19)	93	(I-21)
6	(H-12)	96	(I-10)
10	(H-25)	100	(H-9)
10	(H-13)	100	(I-22)

```
STEM LEAF                  #
  10 00                    2
   9 6                     1
   9 3                     1
   8 8                     1
   8 12                    2
   7 6                     1
   7 0                     1
   6
   6
   5
   5
   4 5                     1
   4 1                     1
   3
   3 3                     1
   2 567                   3
   2
   1 678899                6
   1 C000034               7
   C 66                    2
   0 0                     1
     ----+----+----+----+
```

BOXPLOT

NORMAL PROBABILITY PLOT



S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

UNIVARIATE

VARIABLE=NA

MOMENTS

N	31	SUM WGTS	31
MEAN	667.484	SUM	20692
STD DEV	844.525	VARIANCE	713223
SKEWNESS	0.863549	KURTOSIS	-0.398544
USS	35208260	CSS	21396684
CV	126.524	STD MEAN	151.681
T:MEAN=0	4.40057	PROB>|T|	.000123304
W:NORMAL	0.760221	PROB<W	<0.01

QUANTILES(DEF=4)

100% MAX	2843	99%	2843
75% Q3	1494	95%	2397.2
50% MED	44	90%	1941.59
25% Q1	0	10%	0
0% MIN	0	5%	0
		1%	0
RANGE	2843		
Q3-Q1	1494		
MODE	0		

EXTREMES

LOWEST	ID	HIGHEST	ID
0	(H-25)	1500	(I-22)
0	(H-24)	1532	(I-21)
0	(H-20)	2044	(H-23)
0	(H-19)	2100	(I-23)
0	(H-17)	2843	(H-16)

```
STEM LEAF                      #
  28 4                         1
  26
  24
  22
  20 40                        2
  18
  16
  14 090003                    6
  12 3                         1
  10 661                       3
   8
   6
   4
   2
   0 000000000011113445       18
     ----+----+----+----+
     MULTIPLY STEM.LEAF BY 10**+01
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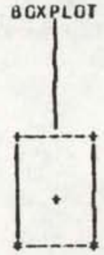

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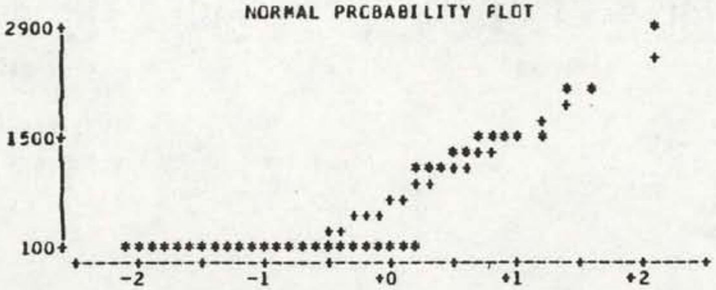


99

STATISTICAL ANALYSIS SYSTEM

UNIVARIATE

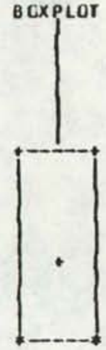
VARIABLE=K

```
                 MOMENTS                                          QUANTILES(DEF=4)                              EXTREMES

N                  31   SUM WGTS           31      100% MAX    204     99%      204      LOWEST    ID          HIGHEST    ID
MEAN           55.129   SUM              1709       75% Q3     120     95%    195.6           0(H-25     )        176(H-27     )
STD DEV         75.87   VARIANCE      5756.25       50% MED      0     90%    187.2           0(H-24     )        180(I-22     )
SKEWNESS     0.531279   KURTOSIS    -0.886551       25% Q1       0     10%        0           0(H-20     )        189(I-21     )
USS            266903   CSS            172687        0% MIN      0      5%        0           0(H-19     )        190(I-3      )
CV            137.622   STD MEAN      13.6266                           1%        0           0(H-18     )        204(H-3      )
T:MEAN=0      4.04568   PROB>|T|  .000338284      RANGE        204
W:NORMAL     0.712256   PROB<W          <0.01      Q3-Q1        120
                                                   MODE           0

     STEM LEAF                            #
       20 4                               1
       19 0                               1
       18 09                              2
       17 6                               1
       16 2                               1
       15
       14 0                               1
       13
       12 0                               1
       11 8                               1
       10 8                               1
        9
        8
        7
        6
        5
        4 0                               1
        3 48                              2
        2
        1
        0 0000000000000000037            18
          ----+----+----+----+
```

BOXPLOT



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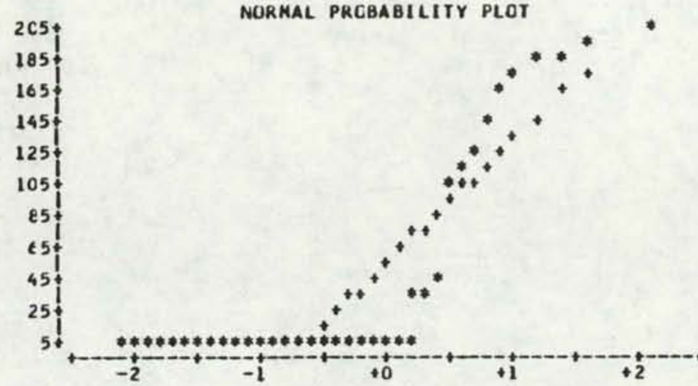
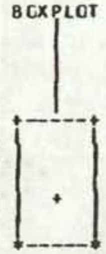
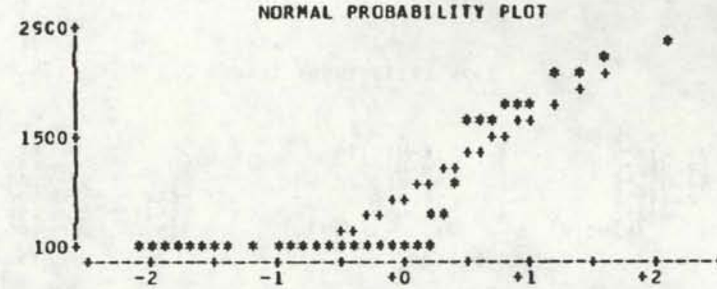


```
                              S T A T I S T I C A L   A N A L Y S I S   S Y S T E M
                                                 UNIVARIATE

VARIABLE=CL

              MOMENTS                                      QUANTILES(DEF=4)                                    EXTREMES

N                   31  SUM WGTS           31   100% MAX      2800     99%        2800       LOWEST   ID             HIGHEST   ID
MEAN           741.355  SUM             22982    75% Q3       1737     95%      2567.2            0(H-19     )          1947(H-27    )
STD DEV        975.601  VARIANCE       951798    50% MED        42     90%      2379.8            0(H-15     )          2299(H-3     )
SKEWNESS      0.847944  KURTOSIS    -0.979367    25% Q1          4     10%    0.199999            0(H-14     )          2400(I-3     )
USS           45591752  CSS          28553935     0% MIN         0      5%           0            1(H-20     )          2412(I-21    )
CV             131.597  STD MEAN      175.223                           1%           0            2(H-4      )          2800(I-22    )
T:MEAN=0       4.23092  PROB>|T|  .000200986    RANGE         2800
W:NORMAL      0.734852  PROB<W          <0.01   Q3-Q1         1733
                                                MODE             0

         STEM LEAF                      #
           28 0                         1
           26
           24 01                        2
           22 0                         1
           20
           18 505                       3
           16 504                       3
           14
           12
           10
            8 8                         1
            6
            4 59                        2
            2
            0 000000000001144446       18
              ----+----+----+----+
         MULTIPLY STEM.LEAF BY 10**+01
```

BOXPLOT



NORMAL PROBABILITY PLOT



STATISTICAL ANALYSIS SYSTEM

UNIVARIATE

VARIABLE=F

MOMENTS			
N	31	SUM WGTS	31
MEAN	1.20484	SUM	37.35
STD DEV	1.38035	VARIANCE	1.90537
SKEWNESS	0.985013	KURTOSIS	-0.350922
USS	102.162	CSS	57.1612
CV	114.567	STD MEAN	0.247919
T:MEAN=0	4.85982	PROB>|T|	0.0001
W:NORMAL	0.806378	PROB<W	<0.01

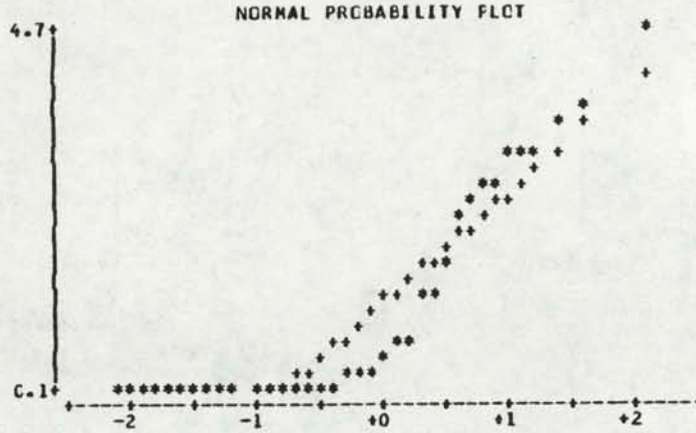
QUANTILES(DEF=4)			
100% MAX	4.6	99%	4.6
75% Q3	2.6	95%	4.11999
50% MED	0.44	90%	3.34
25% Q1	0.14	10%	0
0% MIN	0	5%	0
		1%	0
RANGE	4.6		
Q3-Q1	2.46		
MODE	0		

EXTREMES			
LOWEST	ID	HIGHEST	ID
0	(H-19)	3.1	(H-3)
0	(H-15)	3.1	(I-3)
0	(H-14)	3.4	(H-26)
0	(H-4)	3.8	(H-27)
0.12	(H-17)	4.6	(H-16)

```
STEM LEAF                  #
  46 0                     1
  44
  42
  40
  38 0                     1
  36
  34 0                     1
  32
  30 00                    2
  28 0                     1
  26 00                    2
  24
  22 0                     1
  20
  18
  16 0                     1
  14 0                     1
  12 0                     1
  10
   8
   6 008                   3
   4 4                     1
   2 1569                  4
   0 00002244668          11
     ----+----+----+----+
  MULTIPLY STEM.LEAF BY 10**-01
```

BOXPLOT

NORMAL PROBABILITY PLOT



S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

UNIVARIATE

VARIABLE=HCO3

MOMENTS			
N	31	SUM WGTS	31
MEAN	726.903	SUM	22534
STD DEV	691.254	VARIANCE	477832
SKEWNESS	1.20808	KURTOSIS	0.422781
USS	30714990	CSS	14334953
CV	95.0957	STD MEAN	124.153
T:MEAN=0	5.85491	PROB>|T|	0.0001
W:NORMAL	0.806886	PROB<W	<0.01

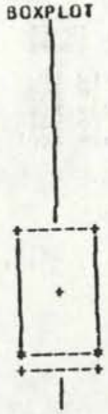
QUANTILES(DEF=4)			
100% MAX	2416	99%	2416
75% Q3	1100	95%	2319.4
50% MED	342	90%	2080
25% Q1	209	10%	167.6
0% MIN	10	5%	97.5999
		1%	10
RANGE	2406		
Q3-Q1	891		
MODE	168		

EXTREMES

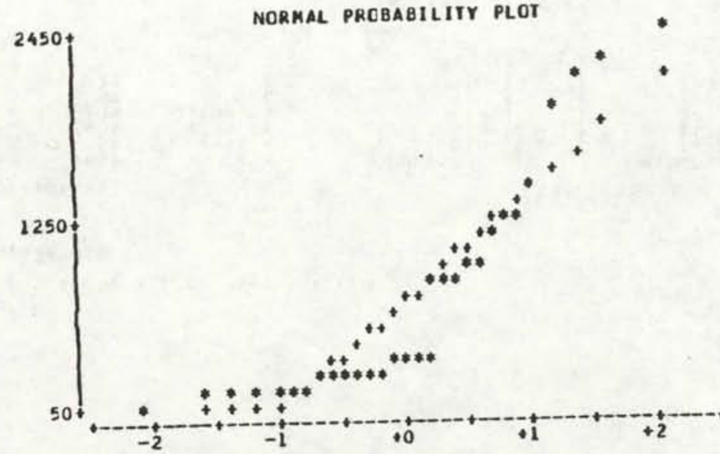
LOWEST	ID	HIGHEST	ID
10	(H-19)	1473	(H-9)
156	(H-12)	1900	(I-23)
163	(H-20)	2125	(H-3)
186	(H-1)	2255	(H-23)
188	(H-7)	2416	(H-16)

```
STEM LEAF                 #
  24 2                    1
  23
  22 5                    1
  21 2                    1
  20
  19 0                    1
  18
  17
  16
  15
  14 7                    1
  13
  12 07                   2
  11 0                    1
  10
   9 27                   2
   8 688                  3
   7
   6
   5
   4
   3 1458                 4
   2 01557788             8
   1 66999                5
   0 1                    1
     ----+----+----+----+
MULTIPLY STEM.LEAF BY 10**+01
```

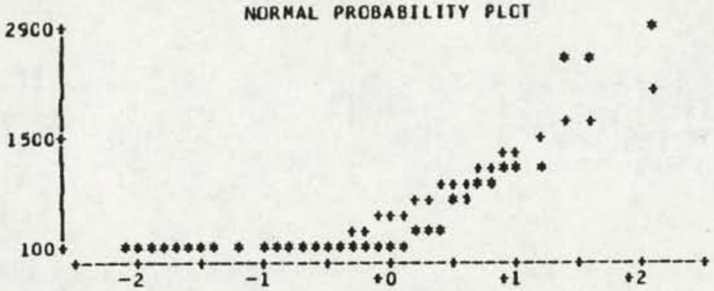
BOXPLOT



NORMAL PROBABILITY PLOT



```
                                        S T A T I S T I C A L   A N A L Y S I S   S Y S T E M
                                                            UNIVARIATE

VARIABLE=SO4

              MOMENTS                                                QUANTILES(DEF=4)                                       EXTREMES

N                 31    SUM WGTS              31      100% MAX       2858        99%        2858        LOWEST      ID           HIGHEST     ID
MEAN         517.968    SUM                16057       75% Q3         596        95%      2644.4             0(H-15     )         1100(H-26     )
STD DEV      796.385    VARIANCE          634228       50% MED         56        90%     2156.18             0(H-12     )         1129(H-27     )
SKEWNESS     1.83652    KURTOSIS         2.74233       25% Q1           4        10%    0.199999             0(H-8      )         2413(H-23     )
USS         27343861    CSS             19026853        0% MIN          0         5%           0             1(H-7      )         2502(I-23     )
CV           153.752    STD MEAN         143.035                                  1%           0             3(H-19     )         2858(H-16     )
T:MEAN=0     3.62127    PROB>|T|  0.00107441          RANGE          2858
W:NORMAL     0.69313    PROB<W            <0.01       Q3-Q1           992
                                                      MODE              5

        STEM LEAF                        #            BOXPLOT                                    NORMAL PROBABILITY PLOT
          28 6                           1
          26
          24 10                          2
          22
          20
          18
          16
          14
          12
          10 00503                       5
           8
           6 24                          2
           4
           2 3339                        4
           0 00000000000011561          17
             ----+----+----+----+
        MULTIPLY STEM.LEAF BY 10**+01
```



STATISTICAL ANALYSIS SYSTEM

UNIVARIATE

VARIABLE=SIC2

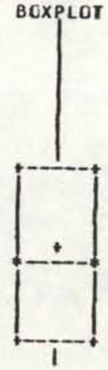
MOMENTS			
N	31	SUM WGTS	31
MEAN	42.0968	SUM	1305
STD DEV	31.3713	VARIANCE	984.157
SKEWNESS	0.753725	KURTOSIS	-0.427562
USS	84461	CSS	29524.7
CV	74.5218	STD MEAN	5.63445
T:MEAN=0	7.47132	PROB>|T|	0.0001
W:NORMAL	0.897037	PROB<W	<0.01

QUANTILES(DEF=4)			
100% MAX	111	99%	111
75% Q3	68	95%	111
50% MED	35	90%	88
25% Q1	13	10%	9.4
0% MIN	6	5%	6
		1%	6
RANGE	105		
Q3-Q1	55		
MODE	13		

EXTREMES			
LOWEST	ID	HIGHEST	ID
6	(H-25)	83	(H-1)
6	(H-19)	88	(H-2)
9	(H-4)	88	(H-27)
11	(H-18)	111	(H-8)
11	(I-10)	111	(H-12)

```
STEM LEAF                       #
  11 11                         2
  10
  10
   9
   9
   8 88                         2
   8 3                          1
   7
   7 1                          1
   6 88                         2
   6 2                          1
   5 8                          1
   5
   4 599                        3
   4 0                          1
   3 58                         2
   3 04                         2
   2
   2 44                         2
   1 557                        3
   1 11333                      5
   0 669                        3
     ----+----+----+----+
```

BOXPLOT



NORMAL PROBABILITY PLOT