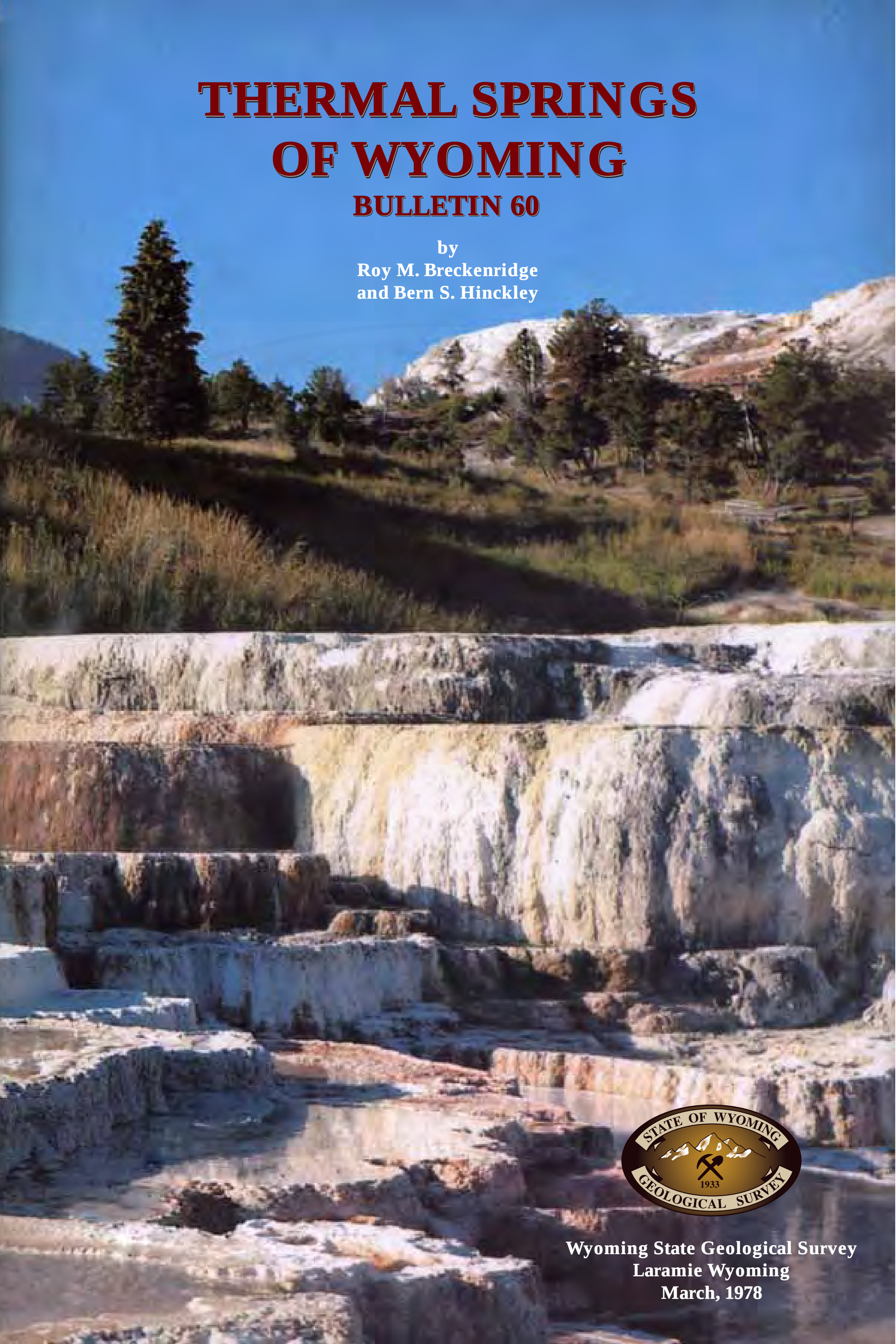
THERMAL SPRINGS OF WYOMING

BULLETIN 60

by
Roy M. Breckenridge
and Bern S. Hinckley



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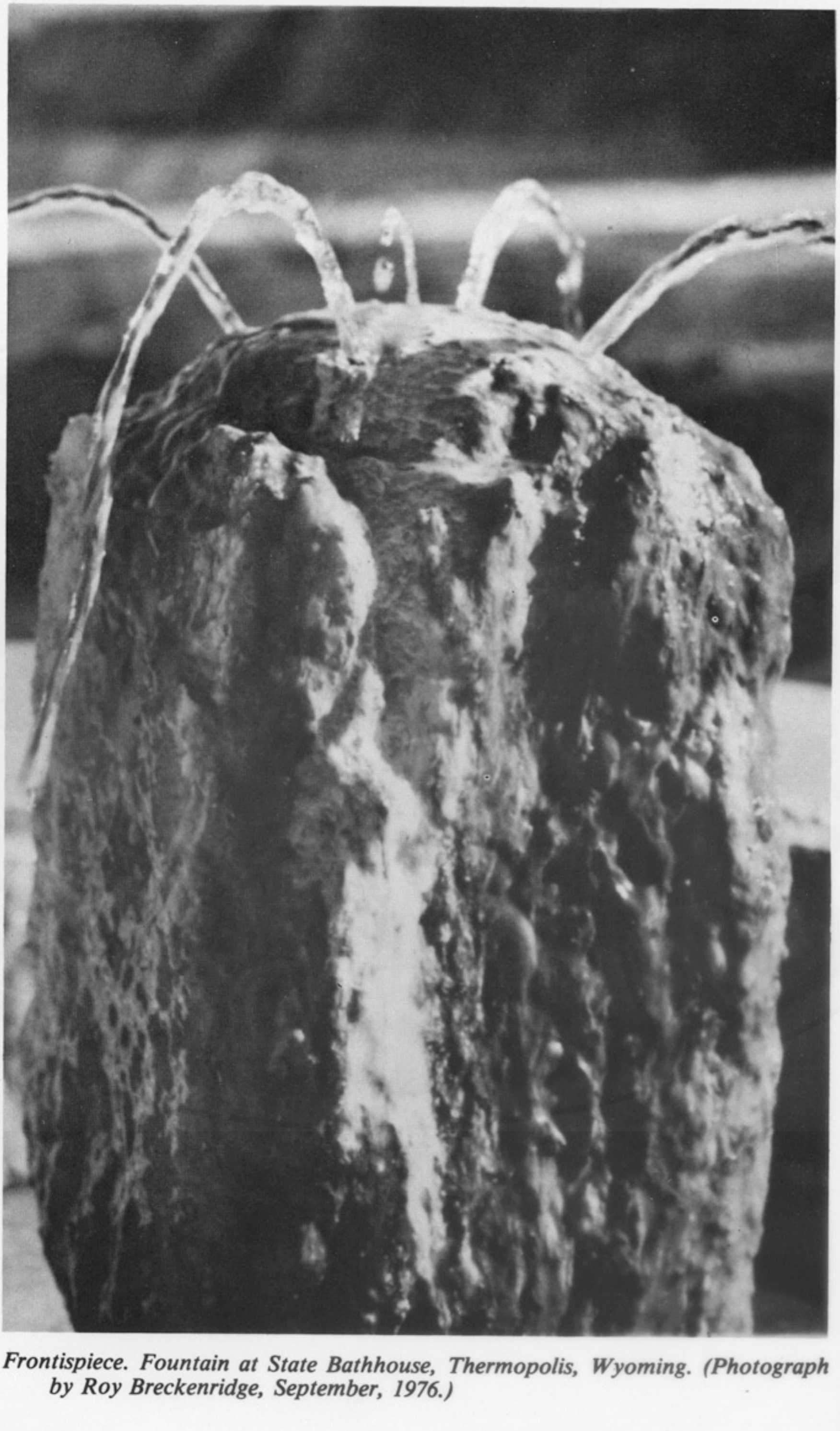
Wyoming State Geological Survey
Laramie Wyoming
March, 1978

THERMAL SPRINGS OF WYOMING



Frontispiece. Fountain at State Bathhouse, Thermopolis, Wyoming. (Photograph by Roy Breckenridge, September, 1976.)

THE GEOLOGICAL SURVEY OF WYOMING

Daniel N. Miller, Jr., State Geologist

BULLETIN 60

THERMAL SPRINGS OF WYOMING

By

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With a chapter on flora
by Terry T. Terrell

Box 3008, University Station
Laramie, Wyoming 82071
March, 1978

TABLE OF CONTENTS

ILLUSTRATIONS

TABLES

NOTES ON THE CHEMICAL ANALYSES

Many chemical species are dissolved in natural water. In our tables of chemical analyses, all major ions, minor ions or elements, and trace elements are reported in parts per million (ppm) by weight, nearly equivalent to milligrams per liter (mg/1) in dilute solution.

	Cations		*Anions*	
Major:	Ca	calcium	CO_3	carbonate
	Mg	magnesium	HCO_3	bicarbonate
	Na	sodium	SO_4	sulfate
	K	potassium	Cl	chloride
			NO_3	nitrate
Minor:	F	fluoride		
	S	sulfide		
	SiO_2	silica		
	B	boron		
Trace:	As	arsenic	Cr	chromium
	Cu	copper	Pb	lead
	Fe	iron	Se	selenium
	Mn	manganese	Ag	silver
	Zn	zinc	Hg	mercury
	Ba	barium	Ni	nickel
	Cd	cadmium		

Temp	Temperatures are given in degrees Celsius, unless otherwise noted.
TDS	Total Dissolved Solids is the weight of the solid, anhydrous salts residual of an evaporated water sample, converted to ppm.
Cond	The Specific Conductance of a solution, measured in micromhos, is a general measure of the amount of dissolved constituents. For most waters, conductance, times a factor dependent upon the general chemical character of the water, approximates TDS.
pH	pH is a measure of the hydrogen ion concentration or activity in a solution. A value of seven is neutral, lesser values are more acidic, and higher values to fourteen are progressively more basic. Most natural waters in the United States are slightly basic. The normal range is 6.0 to 8.0.
Hard	Total hardness of water is generally an expression of dissolved alkaline earths (Ca and Mg). It is the weight (ppm) of $CaCO_3$ calculated from the amount of CO_3 necessary to form $CaCO_3$ and $MgCO_3$ from all the reported Ca and Mg. "Temporary hardness," or "carbonate hardness," is engendered by salts of the alkaline earths that can be removed by treatment. "Permanent hardness," or "noncarbonate hardness" is engendered by salts that can be removed ony with great difficulty.
Tot CO_3	Total CO_3 is a measure of all the possibly available carbonate in a solution which could be precipitated as $CaCO_3$, and is the sum of the reported CO_3 and one-half the reported HCO_3.

INTRODUCTION

On the average, the temperature within the earth increases .8° C with each 100 feet of depth. Lower values occur in rapidly filling sedimentary basins and values up to 190° C per 100 feet occur over short intervals in areas of volcanic activity such as Yellowstone National Park.

The flow of heat toward the surface of the earth provides energy for the entire geologic cycle. For warming a spring or setting the very continents adrift, the power is supplied by heat from within the earth. This bulletin will explore but one manifestation of that earth-moving energy flow, the occurrence of warm and hot waters at the earth's surface.

Spring waters are generally called "thermal" if their temperature exceeds the average annual surface temperature by 9° C or more. In Wyoming, where the average annual surface temperature is 5.3° C, springs can be classified as thermal above 14° C.

In this work, 50 separate thermal springs or groups of springs are described in the inventory section for Wyoming outside of Yellowstone National Park. The Park is estimated to contain nearly 10,000 individual thermal features. Wyoming's thermal springs range from the 16° C in seeps on Conant Creek to boiling in springs at Yellowstone. They are found in settings as diverse as is the state itself, and their study presents a unique look at a heretofore neglected facet of Wyoming's geology.

Because of the great amount of research already devoted to the Yellowstone National Park area, the primary emphasis of this study is on Wyoming outside of the Park. While a general discussion and annotated bibliography are presented for Yellowstone, it is not treated to the same extent as are Wyoming's less famous thermal areas.

This bulletin attempts, first, to provide a comprehensive inventory of the thermal springs of Wyoming; second, to explore the geologic and hydrologic factors producing these springs; and, third, to analyze the springs collectively as an indicator of the geothermal resources of the state. The bulletin includes a general discussion of the state's geology and the mechanisms of thermal spring production, along with a brief comparison of Wyoming's springs with worldwide thermal features. A discussion of geothermal energy resources, a guide for visitors, and an analysis of the flora of Wyoming's springs follow the spring inventory.

We have attempted to present as complete a discussion of Wyoming's thermal features as possible while maintaining a format comprehensible to the interested reader. Thus, certain technical aspects of hot springs will not be explored in this bulletin; but, we hope, the treatment is sufficiently rigorous to be of value to the scientific community. Since the study is basically geological, a certain amount of geological jargon has unavoidably been used. A short glossary is provided at the back for those readers who find our terminology more a hinderance than a help. Appendix II has been included to explain Centigrade-Fahrenheit, flow rate, and geothermal gradient conversions. For purposes of chemical comparison, U.S. Public Health Service standards for drinking water (adopted by Wyoming Department of Health and Social Services in 1973) are also provided in Appendix II. A geologic column is presented in Appendix I to help the reader sort out time and rock unit order and equivalency.

THERMAL SPRINGS

Introduction

While most springs cannot be called "thermal," a surprisingly large number qualifies. Waring (1965) lists thousands of thermal springs from around the world. They are usually associated with Tertiary or later volcanism or with geologically recent faulting and folding, and commonly approach temperatures of 100° C. Flow is much less accurately known than is temperature; however, 50 thermal springs in the United States were estimated by Waring to flow over 3000 gallons per minute.

On the North American continent the most concentrated thermal activity is in the volcanic areas of Central America, of the Caribbean, of the western United States, and of Alaska. Of 1115 springs cited by Waring for the United States, 1027 occur in the 13 western states, 116 of them in Wyoming.

Interest in Wyoming's thermal springs has historically centered on their recreational and medical potential. Anderson (1890) presents a very thorough discussion of the medical properties of mineral waters, and Boyer (1932) makes the following claims for the Thermopolis waters:

> *"The hot medicinal water is prescribed and has been found efficacious in the treatment of the following, as well as other diseases: Rheumatism, Arthritis, Sciatica, Stomach Disorders, Skin Diseases, Nervous Disorders, Diseases of the Bladder and Kidneys, Partial Paralysis, Liver Disorders, Alcoholism . . . A few days suffice to relieve the pain . . . About three weeks are, as a rule, required to effect a cure."*

We leave the validity of such claims to the reader's judgement, but note that recent studies in Ohio have shown a definite relationship between high magnesium drinking water and reduced incidence of heart disease (Moog, 1976).

Recent scientific interest centers on the energy potential of thermal spring areas. The ways in which useful energy can be extracted from naturally warm waters vary from simple space heating to steam turbine electrical generation. As this important topic deserves more than passing consideration, an energy resources chapter is presented following the Thermal Spring Inventory.

Origins

> *"And you shall strike the rock, and water shall come out of it, that the people may drink" (Exodus, 17:6).*

There, issuing from solid rock, was a stream of water, a spring. From tiny seeps to emerging rivers, springs cover the earth, flowing readily from apparently solid ground. No wonder the ancients regarded springs as miraculous.

Often chosen as sites of religious significance, springs have been a subject of thought for millenia. Plato and Aristotle theorized that vast underground rivers flowing up from the sea supplied water to springs, and steadfastly argued that precipitation was a totally inadequate water source. Typical of the "science" of that day, the mechanisms of this return flow were not considered, all motivation proceeding simply from the "nature of things." A variety of theories appeared in succeeding centuries, but it wasn't until 1674 that Pierre Perrault's careful demonstrations of the sufficiency of precipitation laid the basis for our modern perceptions of groundwater hydrology.

The first requirement of a spring system is a reservoir of porous, permeable rock. Good reservoir rocks are sandstone, fractured limestone, and fractured granite. Shales and siltstones are impermeable, and so form barriers to water flow.

The reservoir rock stores surface water, and slowly releases that water to springs at lower elevations.

Controlling spring occurrence in the simplest system are topography (the lay of the land) and stratigraphy (the lay of the reservoir rocks underground). Where an impermeable rock layer (stratum) prevents further downward percolation of water in a reservoir rock, and a topographic low provides surface escape, a normal spring occurs (Figure 1).

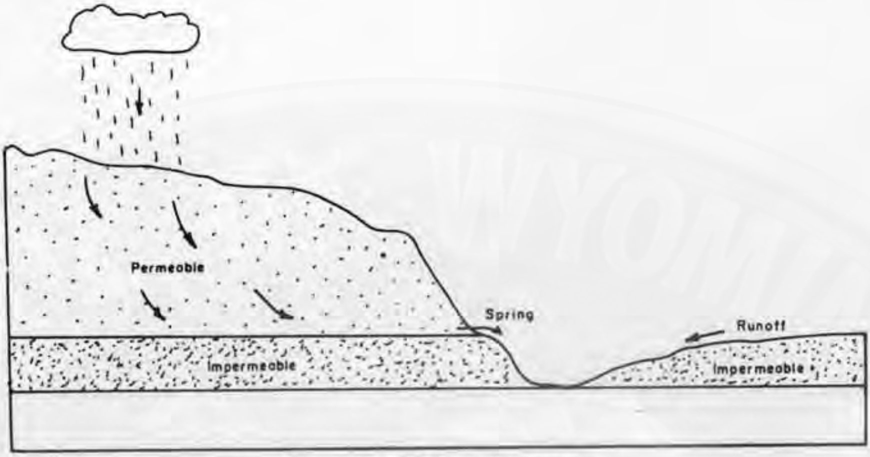


Figure 1. Simple spring system

Since a thermal spring calls for generally deeper circulation than a normal spring, an artesian system is necessary. This occurs where an impermeable rock stratum caps the reservoir rock. Water, sandwiched in this closed system, is conducted deep within the earth before returning to the surface and escaping as a spring. The structure of a thermal spring system is also more complicated because the rock layers must dip away from, then return to, the earth's surface (Figure 2) to create the heating conditions necessary for a thermal spring.

The system is pressurized in proportion to the elevation difference between the source area and the spring (or flowing well) which occurs where the impermeable cap is breached: this pressure is called "head" or "hydrostatic head," or, in this case, "artesian head." An idealized artesian system is shown in Figure 2. It typifies the most common system in Wyoming, outside of Yellowstone.

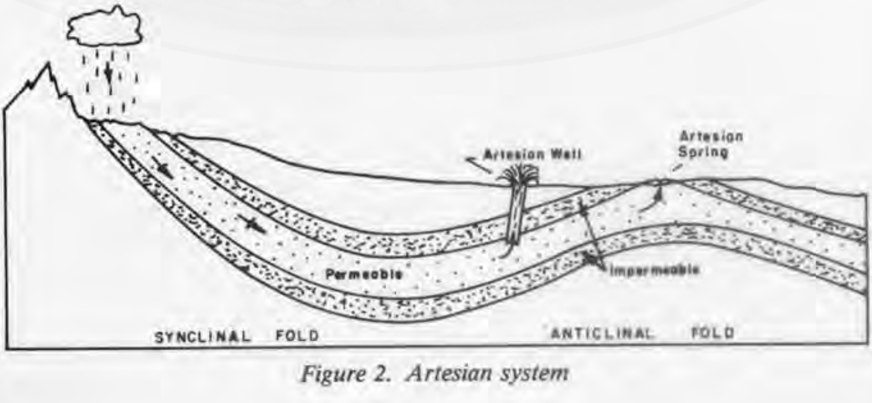


Figure 2. Artesian system

The other type of flow present in thermal springs is due to convection: as water is heated its density decreases slightly, which causes it to rise through cooler waters. In Wyoming, outside of Yellowstone National Park, convection is of secondary importance; but, in the very hot waters of the Park, convection causes nearly all the thermal spring flow. Figure 11, page 74, shows the features of a convection system.

Of course, many variations on these idealized systems occur. Complex folds of strata may seal or reroute an artesian system. Permeabilities may vary greatly between and within rock units: artesian pressure is reduced by resistance of a rock to the flow of water. Faults, cracks, or solution cavities may provide ready conduits for pressurized water. A fault may also seal off a permeable layer against an impermeable one. Thus, in the details of its geology, each spring system must be analyzed separately.

The landscape of Wyoming is uplifted mountain ranges with intervening basins. Strata dip steeply down off the mountains into the basins. Water supplied to the high, upturned ends of these strata is transmitted under artesian pressure to lower areas. Commonly, on the flanks of major mountain structures are smaller anticlines which bring water-bearing formations to the surface (see Figure 2). As shown on the Wyoming Structure Map (Figure 3), all of the state's thermal springs occur in areas of structural complexity bordering major uplifts. Springs with sources in the Hartville uplift and the Laramie, Wind River, Owl Creek and Bighorn mountains, surface in small anticlinal folds (see Figure 2). Those in the Teton area and in the Wyoming and Salt River ranges appear to result from faults which allow hot waters to rise from depth. Thermal springs do not, as a rule, occur far from mountains,

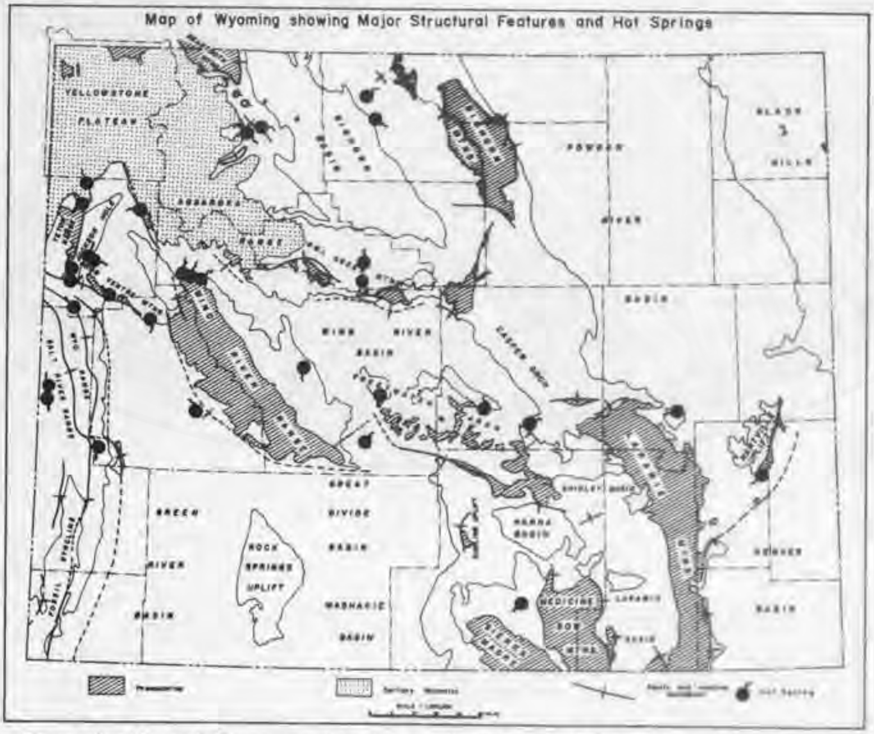


Figure 3. Map of Wyoming showing major structural features and hot springs

because of the extreme thickness of basin-filling sediments covering the reservoir rocks. In the Hanna Basin, for example, the major formations exposed on the mountain flanks are buried beneath 10,000 feet of Tertiary material at the basin center.

Spring waters are warmed primarily by the general temperature increase with depth in the earth. This rate, called the geothermal gradient, may vary greatly from place to place. It is affected by such things as subcrustal heat flow, radioactive heating within rocks, rock conductivity, and geologic structure. The gradient is known only approximately for most areas in Wyoming. Generalized gradients from the literature and temperature measurements from local wells are used in the Thermal Spring Inventory to evaluate the part heat addition plays in each spring. In non-volcanic areas, temperatures corresponding to depths on the order to two to three thousand feet are necessary to produce thermal springs. In areas of recent volcanism, like Yellowstone, such temperatures occur at or near the surface. In these cases molten rock has risen from great depth and is still giving off tremendous amounts of heat as it cools.

Various other mechanisms have been proposed which may contribute slightly to the natural heating of groundwaters. Several chemical processes known to occur in rocks are exothermic; i.e., they produce heat: but no quantitative work has been done on these proceses in natural rock formations. Another process, the generation of heat by simple friction as large masses of rock slide past one another along fault planes, has been used to explain some thermal effects. Another theory proposed by Adams (1924) suggests that ground water may be heated nearly 5.7° C per kilometer of depth as water is forced through tiny pore spaces in rocks. This process is called porous-plug expansion and, like the other mechanisms discussed, has yet to be used to explain an existing spring system.

THERMAL SPRING INVENTORY

Introduction

The most complete listing to date of Wyoming thermal features is in Waring's (1965) "Thermal Springs of the United States and Other Countries of the World—A Summary." His list was compiled from data published over 90 years, and understandably contains omissions and inaccuracies. Since nearly all published references to thermal springs are peripheral to the discussion of some other topic, they are often insufficient in detail.

Therefore, all thermal features in this inventory (with the exceptions of springs beneath Jackson Lake, Alcova and Buffalo Bill reservoirs and Buffalo Fork River) were examined on site by one or both authors. When possible, residents of each area were questioned about the history of the springs and the existence of any other such features.

How complete is this inventory? To appear in either the literature or the local folklore a spring must, of course, first be recognized as "thermal." Many on the cooler end of the scale have been noted merely as "tepid," or "doesn't freeze in the winter." Large springs, hot springs, or those with extensive deposits, on the other hand, will presumably have caught someone's attention and become at least locally well known. While it is likely that almost all the springs above 38° C (100° F), are included, it is likely that listings in the 14 to 24° C range are only representative of a larger population.

This inventory presents a listing and analysis of Wyoming's thermal springs. Springs are arranged alphabetically by county. A general discussion of Yellowstone National Park follows as a separate chapter. Many of the springs listed do not have generally recognized names: where local or mapped names were not found, a simple geographic name has been assigned. Each spring is located on a U.S. Geological

Figure 4. Spring location system

Survey topographic quadrangle by Section, Township, and Range. The Section is further divided into quarter-quarter-quarters, with each division designated by a letter, as illustrated in Figure 4.

After location are tabulated data on elevation, ownership, access, water temperature and flow rate. Temperatures are followed by the date of measurement (same date as flow rate estimation and chemical and flora sample collection) or by a reference. Temperatures were taken with both maximum and constant reading mercury thermometers. Several readings were made to determine each reported maximum spring temperature. All temperatures were taken near the surface, as close to the vents as possible. Rates of flow were visually estimated as channel cross-section area multiplied by a timed surface flow rate. Where more accurate measurements are presented, a reference is cited. (Comparison of our Thermopolis estimates with carefully determined U.S. Geological Survey values showed our estimates to be 7% high.) Rates of flow are presented in gallons per minute (gpm), although many rates were estimated in cubic feet per second (cfs), converted (448.8 gpm = 1 cfs), and then rounded off to avoid too many significant figures.

Chemical samples were taken using a porcelain dipper and one liter plastic bottles. Samples for sulphur and trace element analysis were chemically treated at the collection site in accordance with the Wyoming State Chemist's procedures. Samples were taken from fast flowing zones as close to the vent as possible. In general, analysis for thirteen elements and ions was made on all waters (Ca, Mg, Na, K, CO_3, HCO_3, SO_4, Cl, NO_3, F, S, SiO_2, B). Thirteen trace elements were also checked for samples from public use areas (As, Cu, Fe, Mn, Zn, Ba, Cd, Cr, Pb, Se, Ag, Hg, Ni). All analyses were made in the Wyoming State Chemist's laboratory, and the laboratory's reference number follows each analysis. Where additional chemical determinations were made, they are listed and referenced, for comparison. (See Notes on Chemical Analyses, page viii, for explanations of values reported in the chemical tables.)

Flora samples were taken by hand from the bottoms and sides of spring channels or pools and were preserved in glass vials of formaldehyde for microscopic identification. We attempted to select a sample of each major group present.

Following the tabulated data, we describe each spring system and discuss its history, general characteristics and uses, geology, hydrology, and chemistry. We propose a brief geothermal model where sufficient data exist.

Big Horn County

LITTLE SHEEP MOUNTAIN SPRING

Photograph 1. Little Sheep Mountain Spring

Location: Sec.17aaa, T.55N., R.94W.
Elevation: 3675 feet
Quadrangle: Spence
Ownership: Federal—BLM
Access: South off U.S. 14-A, then along railroad into Little Sheep Canyon
Temperature: 18° and 20° C (8/17/77)
Flow: 1800 gpm
Chemistry: One analysis, page 10

This spring is in a steep canyon with access limited to a narrow railroad bed. With a fairly low temperature and difficult access the spring remains in relative obscurity, although most people in the area know of its existence. Fisher (1906) mentioned the spring briefly in a survey of the Bighorn Basin but mistakenly identified its source as Cretaceous rocks. It was also noted in cave descriptions of the Bighorn Mountains by Hill and others (1976).

At the time of field examination in August of 1976, Little Sheep Mountain Spring was flowing just below water level on the west side of the Bighorn River. Flow of the spring rose above the river level displacing river waters. The clearer spring waters created a conspicuous though quickly absorbed plume in the silty, brown river.

Two source vents 30 feet apart issue from the base of a small cavernous cliff. The upstream vent is hotter at 20° C and smaller, with a flow of 0.3 gpm. Both vents are apparently caverns which extend into the cliff near the river level. Spelunkers have mapped one cavern to a length of 2087 feet and mention an adjacent cave and spring system to the north (see Hill and others, 1976). The cave waters, reported to have a temperature of 27° C, give off heat to the cave before reaching the river.

Little Sheep Mountain Spring issues from a fine-grained, light brown zone of the Madison Limestone. The Madison is exposed here, at the core of the Little Sheep Mountain Anticline, where the Bighorn River has cut across the structure. In this area the exposed limestone has large cracks and caverns, as well as contorted bedding. The hydrologic setting is similar to that of Sheep Mountain Springs.

SHEEP MOUNTAIN SPRINGS

Location: Sec.35dbd, T.54N., R.94W.
Sec.35dbd, T.54N., R.94W.
Sec.35cdc, T.54N., R.94W.

Elevation: 8350 feet

Quadrangle: Sheep Canyon (southernmost spring shown)

Ownership: Federal—BLM;
Federal—BLM;
Private—Burlington Northern Railroad

Access: East off U.S. 310, north along the railroad into Sheep Canyon, east across the river from the railroad.

Temperature: 21° C (8/16/76)

Flow: Total 450 gpm

Chemistry: One analysis, page 10

Photograph 2. Sheep Mountain Springs

Mentioned by Fisher in 1906, the springs have received little attention since. The southernmost spring of the group is shown on the U.S.G.S. topographic map of the Sheep Canyon quadrangle; but, because of difficult access, these springs are less known than those in Little Sheep Canyon. This upstream (southern) spring is by far the largest, and was sampled for temperature, chemistry and flora. It is accompanied by three small seeps extending 50 feet south along the river. All three seeps occur at river level and empty into the river across a small silt bar. Their principal source is a six foot deep cavity along a bedding plane crack, 20 feet above the river.

The water cascades down through a thick stand of moss and mint, flowing nearly 450 gpm. The outcrop is dark brown, medium crystalline, silty Madison Limestone. There are abundant fractures parallel to bedding (approximate dip = 20° SW), and a conspicuous vertical fracture zone runs nearly the full height of the cliff 150 feet north of the spring.

Stucturally, these springs, near the core of the Sheep Mountain Anticline, correspond with the springs on Little Sheep Mountain Anticline.

The two downstream springs were not examined closely since it is necessary to cross the river to look at any of these springs. From a distance, neither spring appears to flow more than one gpm. They are approximately 300 feet apart and, at the time of inspection, issued from bedding plane fractures in Madison Limestone, six inches and two feet above river level, respectively. They flow directly into the river since the canyon walls are sheer. The springs issue from the same general stratigraphic level as the larger spring system upstream. These springs were not checked for temperature, but it is assumed they are thermal because of their close association with the sampled spring system.

Hydrologically, the springs in both Sheep and Little Sheep canyons represent fairly straightforward artesian systems. Water enters extensive Madison Limestone outcrops along the west slope of the Bighorn Mountains. As the strata dip westward beneath less permeable formations the confined water gains hydrostatic head or pressure, and forms springs where the Madison is breached by the Bighorn River in the anticlines forming Sheep and Little Sheep mountains.

Madison Limestone crops out in Sheep and Little Sheep canyons at 3740 and 3660 feet, and in the Bighorn Mountains at 5400 feet (Horse Creek), 6000 feet (Five Springs Creek), 5200 feet (Cottonwood Creek) and a minimum of 4500 feet (Shell Creek). Thus a head of at least 1000 feet exists at the spring sites.

Spring temperatures are consistent with the model above. Between the anticlines and the mountains the youngest formation present is the Cretaceous Frontier Formation. Using typical thicknesses for the section gives a maximum depth for the Madison of 3515 feet. To heat water to the 27° C (22° C above the mean annual surface temperatures) reported from inside the Little Sheep Mountain cave requires an average geothermal gradient of only .63° C/100 feet. The gradient for the area reported by Kehle (1972) is .78° C/100 feet. The inferred and observed gradient data would imply that anomalous heat sources are not needed to explain the observed spring temperatures.

Chemical data for the Sheep and Little Sheep Mountain springs reflect geologic similarity. In nearly all components the waters are comparable. Although there is insufficient data to chemically identify the parent aquifer, there seems little reason to look beyond the Madison Limestone in which the springs occur.

Table 1. Chemical analyses for thermal springs in Big Horn County

Spring	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3	F	S
Sheep Mtn. Sp.	51	22	5.3	1.4	0	230	42	3.7	0	.8	<.001
Little Sheep Mtn. Sp.	54	25	4.7	1.4	0	210	81	4.5	.7	.5	.001

Spring	SiO_2	B	TDS	Cond	pH	Na%	Hard	Tot CO_2	Date	Reference
Sheep Mtn. Sp.	19	.03	270	490	8.1	5	220	110	8/16/76	State Lab No. 7-1364
Little Sheep Mtn. Sp.	82	.02	296	471	8.0	230	230	100	8/16/76	State Lab No. 7-1365

See Notes on the Chemical Analyses, page viii, for explanation of reported values.

Hot spring. Hot springs are the result of surface waters percolating downward, becoming heated in the earth, and rising along zones of weakness. *Wyoming Travel Commission Photo*

Geyser. Where hot rising waters are restricted in complex passages, steam (boiling) can violently force a column of water from the tube.

Mudpot. Mudpots are hot springs which result from dissolved rock material and sparse water supply.

Fumarole. Fumaroles emit gas phases of heated fluids and usually occur on high ground above the water table.

Plate 1. Types of thermal springs.

Travertine terraces at Thermopolis.

Sinter deposits forming from geyser runoff.
Wyoming Travel Commission Photo

Cone buildup with sulfur deposits at Auburn Hot Springs.

Plate 2. *Hot spring deposits.* Mineral deposits are common products of hot spring phenomena. Minerals dissolved from rocks undergdround by thermal waters are precipitated as pressure and temperature decrease at the surface. Commonly, deposits are one of two types, travertine (carbonate or sinter (silica). Formed by the buildup of countless thin layers over many years, terraces occur at more quiescent springs while cones form at geysers. Thin crusts near pools are treacherous ground underfoot.

Carbon County

SARATOGA HOT SPRINGS

Location: Sec.13bbc, T.17N., R.84W. (Hobo Pool)
Sec.13bbc. T.17N., R.84W.
Sec.12ccd, T.17N., R.84W.
Sec.13bba, T.17N., R.84W.
Sec.13bba, T.17N., R.84W.
Sec.13bbd, T.17N., R.84W.

Elevation: 6780 feet

Quadrangle: Saratoga

Ownership: City of Saratoga
Private—Union Pacific Railroad
Private—Saratoga Inn
Private—Saratoga Inn
Private—Bellamy
Private—Union Pacific Railroad

Access: In city of Saratoga

Temperature: 48° C (7/20/76)
48° C
43° C
48° C
54° C
30° C

Flow: 120 gpm
3-5 gpm
Very small
Undetermined
Pumped for pool
None

Chemistry: Four analyses from Hobo Pool, page 15

Photograph 3. Hobo Pool

According to Bartlett (1926), the wonderful medicinal properties of Saratoga's waters were "discovered" in June of 1911. Details of that revelation are unclear, but Bartlett reports that the waters of the Saratoga Hot Springs were bottled and sold nationwide as 'Radioactive' Mineral Water.

The area was reportedly used by Indians before it was discovered by white pioneers who called it "Warm Springs." In 1886, Fenimore Chatterton settled and surveyed a townsite renaming it Saratoga after the famous health resort in upper New York State. As early as 1886 (Peale), a resort development was reported at Saratoga. The single largest spring (see Figure 5), known as the Hobo Pool, was the site of the earliest development and is still the main attraction at Saratoga Hot Springs City Park.

The Hobo Pool, which is the principal public spring, flows 120 gpm into a dirt-bottomed bathing pool levied up with masonry. It was walled in by the Conservation Corps in the 1930's to keep the North Platte River from flooding the spring. The Hobo Pool spring also supplies pumped water to a large public swimming pool built from donations in the 1950's. The smaller pool is free and always open, whereas use of the large pool is regulated and requires a small fee.

A second spring, across the river from the Hobo Pool, consists of a cluster of seeps in the river bank muds. The third spring is confined to a ten-foot-square masonry pool. The pool supports a lush crop of algae and discharges through subsurface seeps. The fourth spring is on a sandbar in the North Platte River. It, too, is confined within a four-foot-square covered concrete tank. The fifth spring is enclosed in a ten-foot-square concrete pool which feeds a private swimming pool. The last spring, also enclosed, appears to tap the same source as the others but at present shows little or no flow (note the low temperature) and is not used. Though not strictly a spring, yet another outlet for thermal waters is an artesian well at the Frank Nixon residence (sec.14ada) which supplies three to five gpm to a small swimming pool. Finally, the Saratoga Inn owns a well from which hot mineral waters are pumped to their commercial swimming pool.

For all these springs Montagne (1955) reports that the flow is stable all year.

At the surface the springs flow from the Miocene North Park Formation and overlying alluvium. However, chemical analyses (see below) indicate an origin in lower formations. The springs are aligned along a N.51E. trend, strongly suggesting structural control. Montagne (1955) has mapped a covered fault through the springs apparently based on this lineation. The extent and displacement of the assumed fault are both unknown because of the thicknesses of younger sediments and sparse subsurface information. Visher (1952), cites several examples of fault-controlled springs in the area (none hot) and notes flows up to 1300 gpm from such springs in the North Park Formation.

As diagrammed by Montagne, Paleozoic and Mesozoic sections thicken rapidly toward the north and east beneath the Miocene cover. Well records indicate that only 840 feet of sediments cover the granites beneath sec.24, T.16N., R.84W., eight miles south of the springs. But in sec.1, T.17N., R.84W., adjacent to the springs, it is 2740 feet just to the top of the Paleozoic section. Records further northwest demonstrate a continually thickening section.

Decker (1976) infers that the "normal" geothermal gradient is about .76° C/100 feet. If such a gradient were extended downward, a depth of some 7000 feet would be required to produce the maximum observed temperature of the Saratoga system. If we assume as a possible model the confinement of waters to the Paleozoic

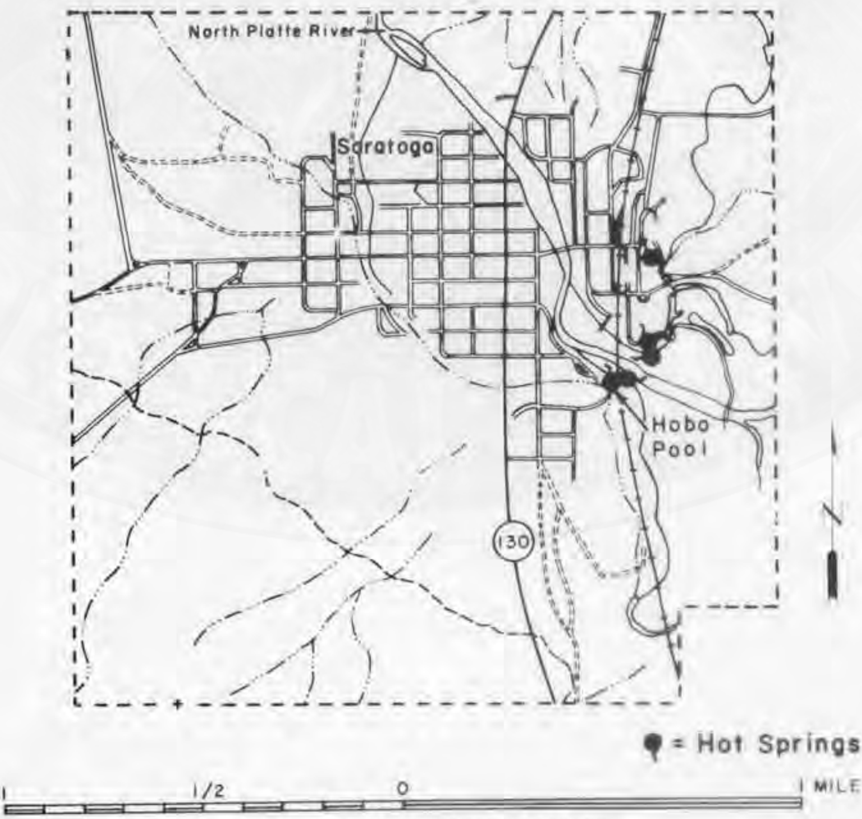


Figure 5. Hot springs at Saratoga

section, the required depth is readily attainable. In the Pass Creek Flats area north of Saratoga, the Paleozoic section is buried nearly 10,300 feet (using formational thicknesses from Visher, 1952). Given recharge of the section through outcrops along the northern Medicine Bow Mountains, water would escape from beneath the Mesozoic section where it thins and is faulted as at Saratoga. Such a model is admittedly based on several assumptions which cannot be proven now, but does present both hydrologic and geothermal conditions adequate to produce the Saratoga Hot Springs.

Table 2. Chemical analyses for Saratoga Hot Springs

(four analyses from Hobo Pool)

Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3	F	S	SiO_2	B
117	8.0	513	21.5	74.4		443	536				125	
123	6.3	321	60.2	20.1		470	535				63.7	
140	11	450	23	24	130	570	540	0	6.1	.075	63	1.7
125	9.0	453	29	0	77	568	511	6.5	6.5		62	1.1

TDS	Cond	pH	Na%	Hard	Tot CO_2	Date	Reference
1842							Knight, 1900
1702							Bartlett, 1926
1920	12900	8.9	70	380	87	7/20/76	State Lab No. 7-0285
1830		7.3		349		9/16/67	State Lab No. 1-68-49

Trace Element Analyses

As	Cu	Fe	Mn	Zn	Ba	Cd	Cr	Pb	Se	Ag	Hg	Ni
.05	.01	.05	<.05	<.02	<.5	<.01	<.1	<.1	<.001	<.5	<.001	<.01

Date	Reference
8/6/76	State Lab No. 7-1573

See Notes on the Chemical Analyses, page viii, for explanation of reported values.

Other springs issuing from the North Park Formation (Visher, 1952) show significant chemical differences from the Saratoga waters. Visher characterizes North Park waters as either calcium bicarbonate type, or, less commonly, calcium sulfate type. The Saratoga waters, however, are predominantly sodium sulphate and chloride types. North of Saratoga, water analyses of springs show a correlation with the Tensleep-Madison section. Montagne (1955) interprets rocks underlying Saratoga as consisting of Miocene sediments directly overlying Mesozoic and Paleozoic rocks. Chemical data from southeast Wyoming as a whole (U.S. Geological Survey, 1971) seem to preclude the Miocene section as a water source; but the Saratoga waters do not show exclusive affinity for any one of the lower formations. Geologic evidence of fault control seems to indicate that mixing of formational waters has occurred.

Converse County

DOUGLAS WARM SPRING

Location: Sec. 8cd, T.31N., R.71W.
Elevation: 4760 feet
Quadrangle: Chalk Buttes
Ownership: Private—Bill Weiss, Douglas, owner

Access: Seven miles south of Douglas on Esterbrook Road
Temperature: 30° C (7/29/76)
Flow: 800 gpm (Weiss, 1976)
Chemistry: One analysis, page 17

Photograph 4. Douglas Warm Spring

The Douglas Warm Spring has been well known locally for some time. Bartlett (1926) refers to the spring and notes its use for bathing and irrigation. In terms of early history, one can only speculate that this spring provided an occasional warm bath to travelers along the Platte River. Spelman (1959) reports that previous to 1959 the water was piped several hundred feet north to a concrete swimming pool, the remains of which were still visible. Bill Weiss, owner of the spring since 1965, states that the present bathing and swimming facilities known as "Jackalope Plunge" were constructed in 1961.

The spring is now confined in a ten-foot-diameter, six-foot-deep steel tank. Water is pumped out at a rate of 390 gpm to a commercial pool two-tenths miles north. Overflow from the spring runs into the North Platte River and supports a dense fish population.

The spring issues from the alluvium of the Platte River covering the Permian Goose Egg Formation. Immediately above the spring the Goose Egg crops out as a dirty, thin-bedded, medium-grained limestone interbedded with fissile mudstone. Below the outcrop, the slope is covered with a friable, purple-grey, limey siltstone. To evaluate the rock directly beneath the spring, investigations were made four miles west on the Sheep Mountain anticline where equivalent units of the Goose Egg are exposed. The same muddy limestone and limey siltstone (together 30 feet thick) were located, here underlain by 50 feet of red, silty sandstone. Both units are incompetent, producing a marked contact with the well-indurated Casper Sandstone beneath them. Spelman (1959) and Barlow (1950) describe the same lithologies in the area and cite the lower siltstone as the Opeche Shale and the limestone as the Minnekahta Limestone, both members of the Goose Egg Formation. Thus, the springs seem to occur in the upper Opeche Shale, which is mostly covered at the spring site.

Structurally, the spring occurs at the crest of the northwest trending LaBonte anticline. A conspicuous fault in the limestone at the spring is represented by a zone of fault breccia, two feet wide, due to fracturing at the anticline crest. Spelman cites many examples of folding and fracturing within the Minnekahta and interprets such features as shallow. Shallow fracturing would preclude a deep-seated water source for the springs. Between the spring and the Laramie Range, Tertiary deposits mask the structure. Mesozoic strata dip steeply beneath these deposits from east and west.

Downward extrapolation of an assumed moderate geothermal gradient of .7° C/100 feet would produce the spring's temperature at a depth of 3200 feet. The spring waters are similar chemically to Opeche Shale water. According to sections from Spelman (1959) and Mort (1939) a maximum depth of 3000 feet can be estimated for the Opeche between the spring and the Laramie Range. Allowing for cooling in transit to the earth's surface, this gradient seems insufficient to produce the observed temperature. In addition, oil wells drilled east and north of the spring site have commonly encountered temperatures higher than 30° C in the Mesozoic section, within 3000 feet of the surface. Since we lack obvious evidence of igneous activity or other heating mechanisms, further investigation appears necessary to define the gradient and the heat sources acting at this site.

As noted, the chemical makeup of these waters appears to derive primarily from the Opeche Shale from which they flow. Comparison with data on formational waters compiled by Hodson (1975) and the U.S. Geological Survey (1971) shows that the best correlation is with the shale. Some similarities with Casper Formation water exist; but these spring waters differ substantially from natural springs in the Casper as analyzed from T.32N., R.73W. (Rapp, 1953).

Table 3. Chemical analysis for Douglas Warm Spring

Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3	F	S	SiO_2	B
86	25	72	7.0	0	200	240	59	.5	1.2	<.001	27	.06

TDS	Cond	pH	Na%	Hard	Tot CO_3	Date	Reference
642	948	7.7	32	320	97	7/28/76	State Lab No. 7-1334

See Notes on the Chemical Analyses, page viii, for explanation of reported values.

Fremont County

CONANT CREEK SPRINGS

Location: Sec.26ddb, T.33N., R.94W.
Elevation: 6280 feet
Quadrangle: Blue Gulch
Ownership: Private
Access: Nine miles along the telephone line northwest from Sand Draw, then up Conant Creek 2.5 miles
Temperature: 16° C (10/8/76)
Flow: 300 gpm
Chemistry: One analysis, page 18

Photograph 5. Conant Creek Springs

The springs on Conant Creek are towards the cooler end of the "thermal" spring spectrum. Still, they are geothermal waters and are representative of a potentially useful class of artesian geothermal systems (see Geothermal Resources chapter). In the only previous reference to the springs, Hares (1917) makes no mention of their temperature.

There are other springs in the area. The Conant Creek Springs are three to four degrees centigrade warmer than the others, and are by far the most sulfurous. At present the springs flow from a cluster, 15 feet across, of vents at the base of a stream cutbank. This is the source of Conant Creek, although there is evidence that runoff occasionally flows from higher in the valley. The springs smell moderately of sulfur.

The springs flow from the valley alluvium above the Phosphoria Formation. To the east the valley wall is formed by a steep slope of eastward dipping Chugwater Formation strata. Structurally, the springs are at the nose of the northward plunging Conant Creek anticline, and lie just below Beaver Rim. Occurring at an elevation of 6280 feet, they are at the lowest outcrop of the Paleozoics in the core of the anticline. Geological mapping (Keefer, 1970) shows three faults through the spring site. These faults could provide ready surface access for waters rising above the strata.

Extensive outcrops of Paleozoic rocks lie along the northeast flank of the Wind River Mountains, some 25 miles to the southwest. These rocks crop out above 7000 feet, providing artesian pressure for the south end of the Wind River Basin which includes the Conant Creek area. Keefer's work shows two faults interrupting the strata between the Wind River Mountains and the spring site; but in neither case are Eocene or older rocks offset. Thus, the first opportunity for Paleozoic water to escape from under the less permeable Chugwater Formation is where that formation is breached by folding and faulting on Conant Creek. Such a circuitous route would logically not accommodate a large flow, and this is consistent with the springs' small flow.

Depths encountered through the proposed route are greater than 12,000 feet as interpreted from surface and well data (Keefer, 1970). Therefore, temperatures higher than those observed in the spring could be produced using a modest thermal gradient. The low flow rate of the springs may allow time for cooling as waters rise to the surface. For example, a well one-third mile southeast of the spring flows about 250 gpm at 20° C.

In summary, the Conant Creek Springs are not exceptional but do demonstrate that practically any artesian system can be expected to produce geothermal waters of a quality proportional to depth and flow.

Table 4. Chemical analysis for Conant Creek Springs

Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3	F	S	SiO_2	B
160	59	89	16	0	210	570	63	0	2.8	2.2	15	.14

TDS	Cond	pH	Na%	Hard	Tot CO_2	Date	Reference
1100	1430	7.6	23	630	100	10/8/76	State Lab No. 7-2586

See Notes on the Chemical Analyses, page viii, for explanation of reported values.

FORT WASHAKIE HOT SPRINGS

Photograph 6. Fort Washakie Hot Springs

Location: Sec.2aad, T.1S., R.1W
Elevation: 5470 feet
Quadrangle: Ethete
Ownership: Wind River Indian Reservation
Access: Three and one-half miles west-southwest of Ethete
Temperature: 44° C (9/20/76)
Flow: Approximately 150 gpm
Chemistry: Three analyses, page 19

The Fort Washakie Hot Springs are located just south of the Little Wind River in the heart of the Wind River Indian Reservation. Bartlett (1926) reports the following description from Captain Bonneville's early 1800's explorations:

> *". . . several warm, or rather, hot springs of considerable magnitude, pouring forth streams in every direction over a bottom of white clay. One of the springs was about twenty-five yards in diameter, and so deep that the water was of a bright green color."*

Since the time of Bonneville's account, the springs have been used by Indians and white men, current development including a concrete pool and bathhouse adjacent to the natural pool, with an associated Reservation recreational complex. The natural pool is approximately 100 feet across, averaging three feet in depth. The waters take on a deep green color because of abundant algal growth on the gravelly bottom. Several vents enter the pool near its center from deep holes in the alluvium. Flow from these vents is accompanied by gentle bubbling.

There may be slight variation in temperature, for reported temperatures differ. Bartlett (1926) cites 44.5° C, Whitcomb and Lowry (1968) cite 46.5° in 1945, and this survey cites 44.0° C in September, 1976. Since the first two are not reported with flow data it is impossible to distinguish seasonal from long term variation.

The springs issue from the valley alluvium of the Little Wind River. Subcrop is the Chugwater Formation, which is exposed in valley walls north and south of the springs. Using formation thicknesses compiled for this area (Kirkwood, 1957), the spring site is approximately 300 feet above the base of the Chugwater Formation.

The springs occur at the crest of the Sage Creek anticline, one of a series of anticlines on and parallel to the northeast flank of the Wind River Mountains. The Sage Creek anticline is folded gently on the northeast side and is broken by mountainward thrusting along steep faults on the southwest side. One fault in this group has been drilled and the results indicate 1,100 feet of vertical displacement in the Cambrian section (Kirkwood, 1957).

Interpretation by Kirkwood (1957) puts the top of the Tensleep Formation 780 feet below the springs. The fault system runs through the springs and provides a zone for water movement from as deep as Precambrian rocks. West of the springs the strata dip deeply into a syncline before emerging again at around 7000 feet on the flank of the Wind River Mountains. Keefer's (1970) cross-sections show that the Paleozoic section is folded down 8000 feet between mountains and springs. Artesian pressure is produced from mountain outcrops and released where surface access is provided by the Sage Creek anticline and associated faults. This relief of 8000 feet and a geothermal gradient of 0.5° C/100 feet would be sufficient to produce temperatures like those of the springs. Thus, a modest gradient would explain the temperature of the springs and allow for some cooling and dilution as the water rises through the alluvium to the surface.

Little chemical variation can be seen between these samples. This, and the relatively consistent temperature records, indicate stable chemistry and temperature and probably equally stable flow. According to Whitcomb and Lowry (1968), Tensleep sandstone is "probably the source of the water issuing from Chief Washakie Hot Spring." They do not explain this conclusion but do report well waters of similar chemistry from the Tensleep and note the water-producing capabilities of the formation. Temperatures for Tensleep waters are commonly quite warm, and range to as high as 56° C (Whitcomb and Lowry, 1968). Kirkwood (1957), reports "hot sulfur water" flowing from a Tensleep well in the same anticline as the hot springs. Chemical data preclude a Chugwater origin for the springs, and the Phosphoria Formation in this area is characteristically higher in sulfate. Despite this, data is insufficient to rule out at least a partial origin in sub-Tensleep aquifers.

Table 5. Chemical analyses for Fort Washakie Hot Springs

Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3	F	S	SiO_2	B
166	36	43	17		281	363	43	10		*	46	
162	41	49			290	362	41	.1	2.6	*	34	
140	34	41	13	0	260	320	42	0	3.8	.5	32	.09

TDS	Cond	pH	Na%	Hard	Tot CO_2	Date	Reference
1006						1926	Barlett, 1926
801	1180	7.3	16	573		5/18/45	Whitcomb & Lowry, 1968
832	1090	7.5	15	490	130	9/20/76	State Lab No. 7-2616

Trace Element Analyses

As	Cu	Fe	Mn	Zn	Ba	Cd	Cr	Pb	Se	Ag	Hg	Ni
<.05	<.01	0	<.05	<.02	<.5	<.01	<.1	<.1	<.001	<.5	<.001	<.1

Date	Reference
9/20/76	State Lab No. 7-2616

See Notes on the Chemical Analyses, page viii, for explanation of reported values.

JAKEYS FORK SPRING

Photograph 7. Jakeys Fork Spring

Location: Sec.29bda, T.41N., R.106W.
Elevation: 7060 feet
Quadrangle: Torrey Lake
Ownership: Private—CM Ranch
Access: Three miles up Jakeys Fork off U.S. 287
Temperature: 20° C (5/26/77)
Flow: Less than four gpm
Chemistry: One analysis, this page

The spring, reported to flow 20° C by Peale in 1886, has apparently changed very little since then. No development has taken place, although nearby cool springs supply the State Fish Hatchery downstream.

The spring issues from a cavern at the top of a broad travertine cone, one of three such cones in the area. Waters flow across the surface only 40 feet before sinking into the porous travertine.

Both of the other cones show some spring activity of lesser magnitude. One has a ten-foot diameter stagnant pool at the crest, and the other seeps only enough to moisten the ground. The most active cone is tree covered while the others are barren. These cones mark an isolated travertine occurrence extending along the south side of Jakeys Fork for approximately one-half mile. Several springs flowing cooler than 10° C issue from the base of this travertine complex, supplying well over ten cubic feet per second to the fish hatchery.

Geologically, the Jakeys Fork Spring is similar to Warm and Little Warm springs, which are described in detail next. The spring and associated travertine occur near the base of the gently dipping Chugwater formation. The contrast in both flow and temperature with nearby cool springs reflects the deeper circulation of the warmer waters. The chemistry is similar to that of Little Warm Spring.

Table 6. Chemical analysis for Jakeys Fork Spring

Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3	F	S	SiO_2	B
140	40	19	6.1	0	540	92	24	0	1.6		15	.11

TDS	Cond	pH	Na%	Hard	Tot CO_2	Date	Reference
648	1040	7.2	7.2	510	270	5/26/77	State Lab No. 7-7945

See Notes on the Chemical Analyses, page viii, for explanation of reported values.

LITTLE WARM SPRING

Location: Sec.14bbd, T.41N., R.107W.
Elevation: 7200-7240 feet
Quadrangle: Dubois
Ownership: Private—Josephine Albright, owner
Access: Two miles southwest of Dubois on Little Warm Spring Creek Road
Temperature: 25° C (9/20/76)
Flow: 560 gpm
Chemistry: One analysis, page 22

Little is known of the early history of Little Warm Spring. Since neither the spring nor the associated creek are mentioned in St. John's 1879 report, its recognition by white men probably came somewhat later. Now the spring is part of a vacation complex owned by Josephine Albright of Woodstock, Vermont.

Photograph 8. Little Warm Spring

Clarence Allison, owner of the ranch immediately downstream, is resident caretaker.

The spring consists of many vents and seeps in a 100-foot by 50-foot basin along Little Warm Spring Creek. The basin is impounded by a concrete dam. A headgate allows the stream free passage in winter but, when closed, creates a six-foot deep swimming pool. The spring's flow is accompanied by gentle bubbling through stream gravels.

As on Warm Spring Creek, this site is heavily mantled by travertine and travertine cemented gravel. The lowest rocks of the Chugwater Formation lie directly beneath the travertine. The subcrop relationships are confused by a fault just upstream from the spring. Near the spring, the Chugwater dips quite gently away from the mountains. Upstream the rocks are deformed to near vertical. The fact that this fault is not mapped by Keefer (1970) may indicate its small extent. Keefer, however, mapped several discontinuous reverse faults along this stretch of the mountain flank.

Travertine deposition along Little Warm Spring Creek is extensive. Terraces on both sides of the creek are capped by massive travertine deposits. Interbedded with travertine sheets and cones are thick sections of cemented alluvial gravel. It is difficult to imagine the current level of spring activity producing such a quantity of material.

Except for the faults noted above, the strata dipping off the northeast flank of the Wind River Mountains present what appears to be a fairly simple structure. Strata are readily recharged where streams flow across outcrop areas. Since the spring's temperature requires considerably greater depth than the few hundred feet to the Tensleep, either underlying formations or deeper parts of the Tensleep must be involved hydrologically. Chemically (see below), the spring water cannot be assigned to a specific formation.

It is difficult to explain heating by downward extrapolation of a gradient. For example, if 1° C/100 feet is extended, a depth of 3000 feet is needed to produce these temperatures. Granitic basement rock is around 3500 feet beneath the travertine occurrence.

Several alternatives may be considered for a hydrologic model. An artesian system in the lower Paleozoic section or even deeper could produce sufficient heat but would require some structural control like a syncline-anticline or fault system. Based on the consistent association of springs and travertine at the upper Paleozoic contact, it appears that the principle control is stratigraphic.

One possible hydrologic model is waters moving down dip in the Paleozoic rocks, percolating upward as permeability allows, and then migrating up along the confining Chugwater Formation to escape at the observed springs.

It should be noted that the springs are within 20 miles of the Absaroka volcanics. Heat associated with that vast igneous complex may have an effect on the area of the springs.

Further study of geochemistry, particularly of the travertine deposits, may define the past character of, and conditions responsible for, the thermal springs on Warm and Little Warm Spring creeks.

For nearly all chemical constituents the Little Warm Spring values are within the range of values for Warm Spring Creek Springs (see page 24). As with the Ft. Washakie Spring, Whitcomb and Lowry (1968) assign these waters to the Tensleep

Formation. Comparison to their data shows this is generally consistent except that bicarbonate values from Warm Spring Creek and Little Warm springs are nearly twice that of any Paleozoic waters analyzed. According to Crawford (1940), Tensleep waters are characteristically low in bicarbonate, and comparison to Wind River Basin data shows a better correlation with the Phosphoria Formation waters. However, neither author includes many analyses of waters below the Tensleep Formation, so a Madison or lower origin cannot be ruled out chemically.

Table 7. Chemical analyses for thermal springs on Warm Spring Creek and Little Warm Spring Creek

Spring	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3	F	S
Warm Spring Creek Springs	123	38	17	7.0	0	479	84	23	0	1.2	*
	172	32	17	6.5	0	500	89	21	0	1.1	.009
Little Warm Spring	140	34	22	6.1	0	530	83	27	0.4	1.0	<.001

Spring	SiO_2	B	TDS	Cond	pH	Na%	Hard	Tot CO_3	Date	Reference
Warm Spring Creek Springs	18	.11	547	937	6.8	7	464		9/21/65	Whitcomb & Lowry, 1968
	18	.06	578	922	7.7	6.3	560	250	9/21/76	State Lab No. 7-2444
Little Warm Spring	21	.06	634	989	7.4	9	490	260	9/20/76	State Lab No. 7-2465

*H_2S noted in sample

Trace Element Analysis

	As	Cu	Fe	Mn	Zn	Ba	Cd	Cr	Pb	Se	Ag	Hg	Ni
Little Warm Spring	.01	<.01	0	<.05	.07	<.5	<.001	<.01	<.01	<.001	<.05	.001	<.1

Date	Reference
5/26/77	State Lab No. 7-8096

See Notes on the Chemical Analyses, page viii, for explanation of reported values.

SWEETWATER STATION SPRINGS

Location: Sec.15abd, T.29N., R.95W.
Sec.15acd, T.29N., R.95W.
Elevation: 6640-6660 feet
Quadrangle: Happy Spring
Ownership: Private
Access: Four miles south of U.S. 287 on Bison Basin Road
Temperature: 30° C (10/7/76)
31.5° C
Flow: 500 gpm
Chemistry: Two analyses, page 23

Photograph 9. Sweetwater Station Springs

Apparently there has never been any development of these warm springs, located south of Sweetwater Station. Perhaps because of their proximity to the Oregon Trail route, they are listed in Peale's (1886) *Mineral Springs of the United States.* Bartlett, however, makes no mention of them in his 1926 list of Wyoming hot springs.

Table 8. Chemical analyses for Sweetwater Station Springs

Spring	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3	F	S
Spring #1	73	22	130	15	0	230	230	100	0	1.6	.16
Spring #2	73	22	120	15	0	230	230	120	0	1.6	.66
	62	26	126	18		200	220	119	0	1.6	

Spring	SiO_2	B	TDS	Cond	pH	Na%	Hard	Tot CO_3	Date	Reference
Spring #1	28	.54	746	1180	7.8	48	270	110	10/7/76	State Lab No. 7-3211
Spring #2	33	.26	674	1100	7.9	48	270	110	10/7/76	State Lab No. 7-2587
	27	.40	698	1140	7.7	39	270		8/18/65	U.S.G.S., 1971

See Notes on the Chemical Analyses, page viii, for explanation of reported values.

There are two warm springs. The northern spring, accounting for only about 50 gpm of the combined flow, flows from a shallow 15-foot-diameter pool below a small alluvial embankment. The second spring creates a ten-foot-diameter pool, in places up to two feet deep. This second pool is 900 feet southeast of the first spring. The outflows of the two pools combine to form a tributary of Warm Spring Creek.

Both springs occur on a relatively flat plain, and issue from the stream alluvium. Beneath the alluvium is the Miocene Split Rock Formation (Keefer, 1970), which overlies complex Paleozoic rock structures. The springs are at the intersection of the northwest-southeast trending Mormon Trail anticline and the east-west trending Ellis fault. As shown in the cross-section (Figure 6), the rocks beneath the springs are warped and fractured. The Paleozoic section is recharged in high strata flanking the Wind River Mountains and descends 10,000 feet as rocks dip northwestward off the mountains. As at Conant Creek, the ground water flow is complex and involves several structural elements.

A hot spring cited in Bartlett (1926) as running 40-50° C water was investigated 12 miles northwest of the Sweetwater Station Springs. Although the spring is shown on the 1958 U.S. Geological Survey topographic map of the quadrangle (Sec.11dac, T.30N., R.97W.) as a "hot spring," it appeared to the authors in October, 1976, to have ceased flowing many years ago. As mapped, the spring issued from the Phosphoria Formation, exposed where Beaver Creek cuts through the Chugwater Formation in a small anticline. The geothermal artesian system which produced this spring was probably similar to that which produced the Conant Creek and Sweetwater Station springs.

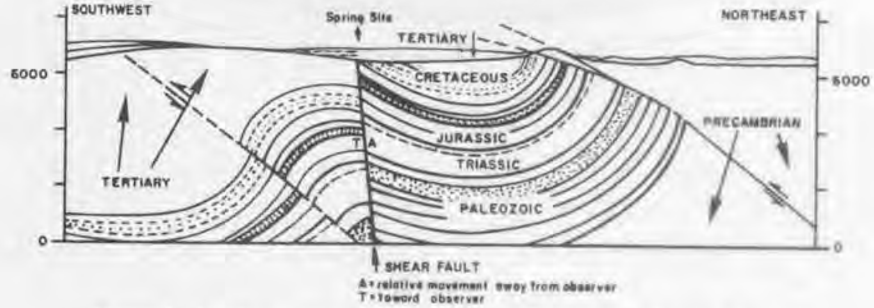


Figure 6. Geologic cross section through Sweetwater Station Springs

WARM SPRING CREEK SPRINGS

Photograph 10. Warm Spring Creek Springs

Location: Sec.32bcc, T.42N., R.107W.
Elevation: 7400 feet
Quadrangle: Dubois
Ownership: Federal—BLM; Leasee: Bob Harrison, Wagon Bar Ranch
Access: One mile south off U.S. 287
Temperature: 29° C (9/21/76)
Flow: Approximately 133 gpm
Chemistry: Two analyses, page 22

While these springs themselves are not conspicuous, the extensive travertine deposits in the area could hardly pass notice. The creek upon which the springs occur is referred to as Warm Spring Creek in a 1879 geological report by Orestes St. John, who both measured and diagrammed a pool on the terrace above the main spring. He further reports a 29° C spring downstream, perhaps referring to the mud spring located in sec. 4ba. In discussing the extent of travertine deposits, St. John mentions a third, cooler spring flowing 20° C water near the mouth of Jakey's Fork. There has apparently never been any development of the Warm Spring Creek springs, and only the terrace pool appears on the U.S. Geological Survey topographic quadrangle. There is no evidence of geyser activity although this grotto pool is locally known as "The Geyser."

Photograph 11. "The Geyser"

The "Geyser" pool occupies the bottom of a hole 18 feet deep, is about 35 feet across at its surface, and extends down into a very deep vent. It is fairly easy to climb down the travertine sides and reach the pool which, in the restricted light, looks deep blue-green. There is no obvious outflow from the pool and, were it not for a few small bubbles and the maintenance of the temperature, one might assume it to be entirely stagnant. The chemical and floral samples come from this pool.

At the level of the creek, 80 feet below the pool, a number of springs gush turbulently upward from under the travertine cliff. A number of springs enter the stream with enough force to raise the water several inches. The temperature at the vents is also 29° C, further supporting the obvious connection with the pool.

The Phosphoria Formation lies beneath the travertine mantle at the spring site. It strikes N.24W. and dips 20 degrees north, and is part of a complete Triassic-to-Precambrian section which dips northeasterly off the Wind River Mountains. Neither the authors' investigations nor Keefer's mapping discovered significant faults in the strata: this leads to the assumption that the structure is fairly simple.

Travertine deposition has evidently continued for a long time. At least three distinct terrace levels can be seen, the highest at 7800 feet, 600 feet above the present springs. The deposits are thick travertine sections of varying density and extensive travertine cemented gravels. Discontinuous travertine occurrences are reported along the Wind River from four miles above Warm Spring Creek to 30 miles below it (Keefer, 1957 and 1970, and Gilliland, 1959). The deposits are always associated with the Phosphoria-Chugwater section along the southeast side of the Wind River. Hydrologic and geothermal features of the Warm Spring Creek Springs are discussed with those on Little Warm Spring Creek because of their similarities (see page 20).

Hot Springs County

Introduction

Certainly the most famous hot spring system in Wyoming, after Yellowstone, is Hot Springs State Park. Thermopolis and Hot Springs County are named after these thermal features, popularly known as "The World's Largest Mineral Hot Springs."

The springs have long been noted for their supposed curative properties. Used extensively by Indians since prehistoric times, they were originally included in lands ceded to the Shoshone and Bannock tribes by the 1868 Fort Bridger Treaty. A 55,040 acre tract, including the springs, was purchased by the federal government in 1896. The following year a full section around the center of thermal activity was given to the State of Wyoming. The purchase, in 1937, of an additional 291 acres resulted in the present Hot Springs State Park (Erwin, 1946).

The Park contains several springs, two commercial swimming pools, the State Bathhouse, two "teepees" (cones formed by mineral deposition around standpipes) and a variety of terrace deposits.

Photograph 12. Rainbow Terraces

We describe the major springs and four wells tapping the same thermal system just north of the State Park (Figure 7) and a less clearly related spring near the mouth of Wind River Canyon.

Inventory

VAN NORMAN WELL

Location: Sec.24cd, T.43N., R.95W.
Quadrangle: Thermopolis
Ownership: Private—Van Norman, Thermopolis, owner
Access: Ten yards west of U.S. 20, just south of Red Lane Gulch

Temperature: 51° C (9/2/76)
Flow: Controlled artesian well
Chemistry: Not sampled

This is a four-inch well drilled around 1919. Collier (1920) describes a well drilled on the "left" bank of the Bighorn River, one and one-half miles below Thermopolis, as producing water at 25 psi from a depth of 498 feet. He claimed the drill dropped 28 feet into a cavity whereupon the well began to flow. Which of the

Payne's Fountain of Youth

Teepee Pools

State Bathhouse

Star Plunge

Plate 3. *Hot Springs State Park I.* Bathing and swimming facilities include State Bathhouse, three commercial swimming pools, and two commercial mineral tub baths (in hotels).

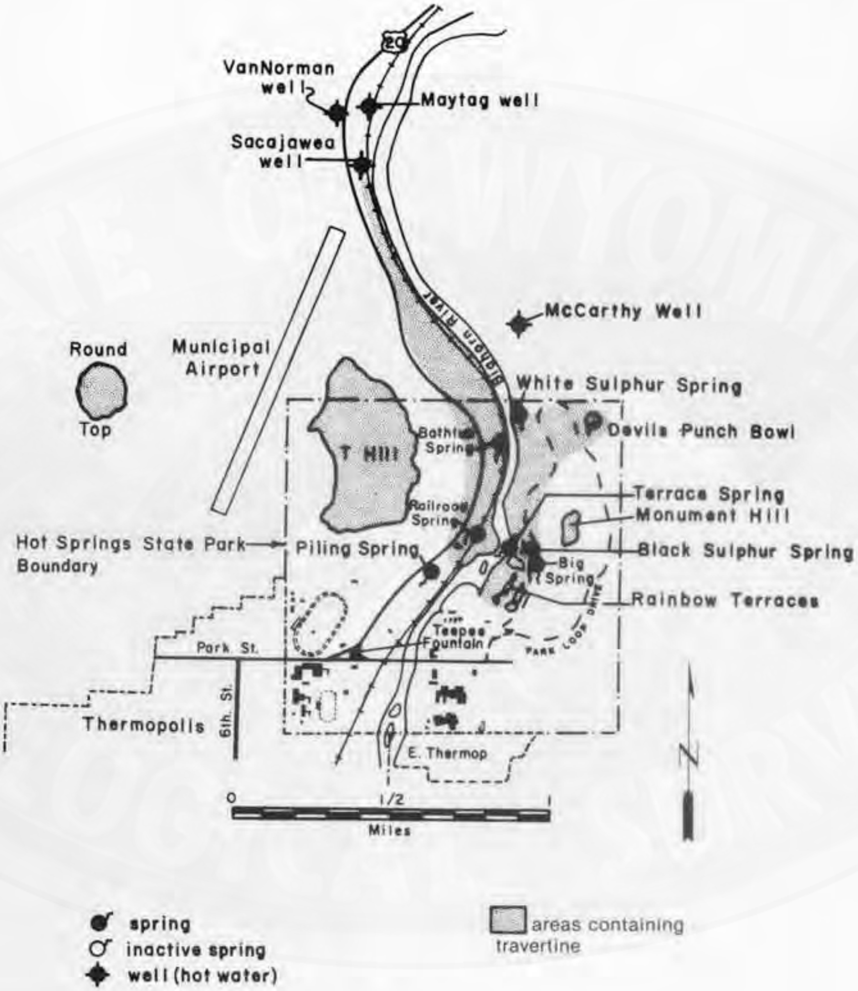


Figure 7. Hot Springs State park and vicinity

Hot Springs State Park

Rainbow Terraces

Teepee Fountain. *Wyoming Travel Commission Photo*

Big Spring. *Wyoming Travel Commission Photo*

Plate 4. *Hot Springs State Park II.* Although not the world's largest mineral hot springs, these springs are certainly large and spectacular. The area is a popular tourist and resort attraction, the center of which is Hot Springs State Park. Bathing, picnicking, and sightseeing can be enjoyed here.

Abandoned terrace deposits above White Sulphur Spring. *Wyoming Travel Commission Photo*

Old travertine terrace blocks in landslide jumble near Silvergate, Yellowstone. *Wyoming Travel Commission Photo*

Solution cavity in travertine deposit on Little Warm Spring Creek.

Plate 5. Ancient spring deposits. Thermal systems are constantly changing: old vents and underground passages become clogged and new ones are established. History has shown many changes in position and activity of hot springs. Deposits in extinct areas can be used to interpret geothermal activity, subsurface hydrology, and geology.

Photograph 13. Van Norman Well

three wells in this group (Van Norman, Maytag, and Sacajawea) Collier referred to is unclear, but the other two he reported to be 900 feet deep.

The Van Norman well was originally adapted to heating an adjacent home in 1930. The well waters are still used to heat the Van Norman home and are delivered to subfloor units through a plastic pipe. (Denver Post, March 1, 1977). The well water is also used for local irrigation. A travertine cone formed around an abandoned standpipe is located in the front yard of the Van Norman home, just north of the well.

MAYTAG WELL

Photograph 14. Maytag Well

Location: Sec.24dc., T.43N., R.95W.
Quadrangle: Thermopolis
Ownership: A local irrigation district
Access: Between U.S. 20 and Burlington Northern Railroad tracks on Red Lane Gulch
Temperature: 54° C (1/2/76)
Flow: 539 gpm (King, 1976)
Chemistry: Not sampled

This ten-inch well was drilled to 900 feet in 1919 (Payne, 1976). Water now rushes turbulently into a ten-foot diameter masonry pool from which it is ditched for irrigation. A small flow is diverted to the home of Fred Baines where it is used for domestic purposes after treatment in a settling pond.

SACAJAWEA WELL

Location: Sec.25ab, T.43N., R.95W.
Quadrangle: Thermopolis
Ownership: Private—Oscar and Etta Payne, Thermopolis
Access: Between U.S. 20 and Burlington Northern Railroad tracks 1.5 miles north of Thermopolis
Temperature: 52° C (12 feet from source) (9/2/76)
Flow: 1220 gpm (King, 1976)
Chemistry: Two analyses, page 37

The Sacajawea Well was drilled to 900 feet in 1918 in an attempt to find oil. When the operator, C. J. Cross, first hit water, artesian pressure produced an eight foot fountain which precluded further drilling. The well has been managed as a mineral swimming pool for some years. It was purchased by the Paynes in 1968, at which time the present five foot high mineral cone had already started forming. The well presently feeds a large swimming pool operated under the name, "Payne's Fountain of Youth."

Photograph 15. C. J. Cross at Sacajawea Well, 1918. Photo courtesy of Mrs. Etta Payne.

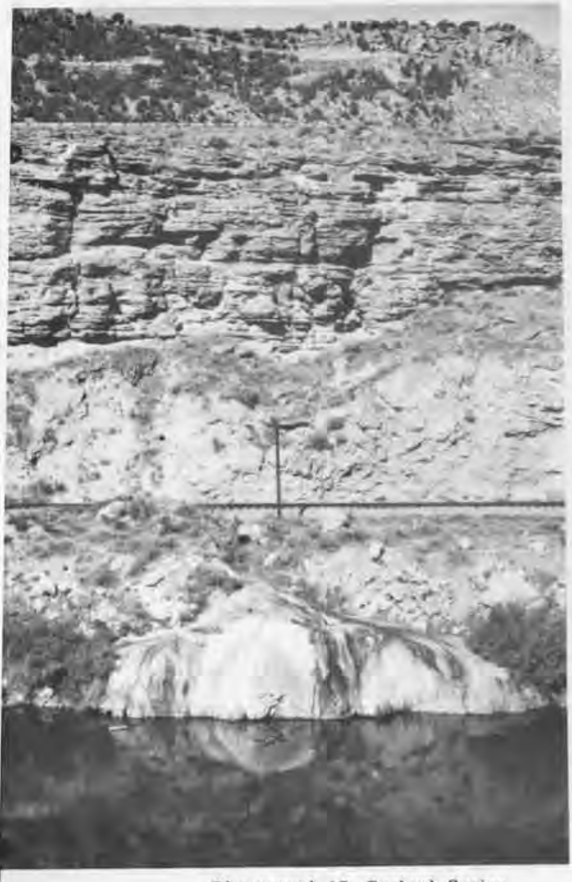
Photograph 16. Sacajawea Well

McCARTHY WELL

Location: Sec.30cb, T.43N., R.94W.
Quadrangle: Thermopolis
Ownership: Private—Scott Taylor, Thermopolis
Access: One-third mile north from the end of Park Loop
Temperature: 54° C (9/2/76)
Flow: 583 gpm (King, 1976)
Chemistry: One analysis, page 37

McCarthy Well was drilled to a depth of 510 feet in 1920. Water is produced from the Phosphoria Formation (Bartlett, 1925). Flowing under artesian pressure from 6-5/8 inch casing, it has built up a small cone. The current owners plan to use the thermal waters for space heating in a future house addition (Taylor, 1976).

BATHTUB SPRING



Photograph 17. Bathtub Spring

Location: Sec.25dd, T.43N., R.95W.
Quadrangle: Thermopolis
*Ownership:*Hot Springs State Park, State of Wyoming
Access: Between Burlington Northern Railroad and Bighorn River, downhill from U.S. 20
Temperature: 53° C (9/2/76)
Flow: Two gpm
Chemistry: One analysis, page 37

This spring issues from the base of a relict travertine terrace, 15 feet above the level of the Bighorn River. The relatively small discharge is accompanied by slight bubbling of escaping gases. Spring waters flow under the railroad. A fan shaped travertine terrace (25 feet maximum width) forms where they enter the river.

WHITE SULPHUR SPRING

Location: Sec.30ccb, T.43N., R.94W.
Quadrangle: Thermopolis
Ownership: Hot Springs State Park, State of Wyoming
Access: Park Loop
Temperature: 53° C
Flow: 206 gpm (King, 1976)
Chemistry: Two analyses, page 37

Photograph 18. White Sulphur Spring

White Sulphur Spring is one of the major springs in the State Park. Travertine distribution suggests that this spring previously flowed from an area 40 feet uphill from its present location. A local old-timer claims that, as recently as 80 years ago, the spring flowed from the higher travertine complex and cascaded off the cliff and into the river. Now, the spring issues from a deep cavity at the base of a travertine complex, approximately six feet above the level of the Bighorn River. A ten-foot wide travertine fan has formed between the vent and the river. The White Sulphur Spring access road has obliterated several pits from which sulfur was mined for a short time.

RAILROAD SPRINGS

Location: Sec.36aad, T.43N., R.95W.
Quadrangle: Thermopolis
Ownership: Hot Springs State Park, State of Wyoming
Access: Between Burlington Northern Railroad and Bighorn River, in the cut above the footbridge
Temperature: Not measured
Flow: Less than three gpm
Chemistry: Not sampled

These springs are recent, and result from the excavation of the railroad cut in which they occur. Workers attempted, unsuccessfully, to seal one spring with concrete. Another's waters are confined within a two-foot square concrete box which overflows into the river through a small ditch.

Photograph 19. Railroad Springs

PILING SPRING

Location: Sec.36ac, T.43N., R.95W.
Quadrangle: Thermopolis
Ownership: Hot Springs State Park, State of Wyoming
Access: Ten yards east of U.S. 20
Temperature: 35° C (In the pool the inflow may be hotter) (9/2/76)
Flow: Less than three gpm
Chemistry: Not sampled

This minor spring flows from a recess under part of the road bed of U.S. 20. The cavern was apparently shored with pilings. Outflow occurs on an area of seeps immediately downhill.

BLACK SULPHUR SPRING

Photograph 20. Black Sulphur Spring

Location: Sec.31bc, T.43N., R.94W.
Quadrangle: Thermopolis
Ownership: Hot Springs State Park, State of Wyoming
Access: On the Park Loop
Temperature: 55° C (9/2/76)
Flow: Little or none
Chemistry: One analysis, page 37

Apparently inactive, Black Sulphur Spring is reported to have been the site of the bathhouse of Washakie, Chief of the Shoshone Indians.

Residents of the area claim that the spring flowed at the surface until the Hebgen Lake, Montana, earthquake in 1959. Bartlett (1925) reported a flow of 15.7 gpm at 53° C. Since the spring was reported as "slow moving" by Burke in 1952, it may be that 1959 marked only the end of declining flow. Recent attempts to reactivate this spring by excavating a new vent were unsuccessful.

The spring forms a five- by twelve-foot pool in a 20-foot deep cavern, with no surface outlet. Gas continually bubbles up through the pool, and fresh watermarks indicate recent three- to four-foot fluctuations in level. The pool presumably experiences some flow-through to maintain its high temperature. We recently conducted trace dye tests which show that Terrace Spring is a direct outlet for Black Sulphur pool.

TERRACE SPRING

Location: Sec.36aad, T.43N., R.95W.
Quadrangle: Thermopolis
Ownership: Hot Springs State Park, State of Wyoming
Access: Just above river level at the base of the main terraces, north of footbridge; difficult to reach except by boat
Temperature: Not measured
Flow: Ten gpm
Chemistry: Not sampled

Flowing a one-and-one-half-inch diameter spout of water, this spring issues a few feet above river level from the side of a large travertine terrace complex. It is located on the apparent contact of modern and older travertine masses. The spring's proximity to Black Sulphur Spring and the occurrence of warm earth between the two springs suggest, and dye tests have substantiated, that Terrace Spring is the diverted flow of Black Sulphur Spring.

Photograph 21. Terrace Spring

BIG SPRING

Location: Sec.31bc, T.43N., R.94W.
Quadrangle: Thermopolis
Ownership: Hot Springs State Park, State of Wyoming
Access: On the Park Loop
Temperature: 56° C (9/2/76)
Flow: 2908 gpm (King, 1976)
Chemistry: Six analyses, page 37

Big Spring is by far the largest and most impressive feature in the area. It produces a large stream at scalding temperatures, feeds an extensive terrace complex, and supplies several pools and bathhouses.

While Indians have known and used the spring for centuries, the white man's knowledge of it probably dates from the early 1800's. The spring was known well enough by 1886 to appear in Peale's listing of mineral springs of the United States, and since then has been the subject of periodic geological investigations. The temperature of the spring waters seems to have remained constant throughout this century. All reported temperatures fall in the 56-57° C range.

Photograph 22. Big Spring

Estimates of the flow of Big Spring have differed greatly, extreme estimates by a factor of 30. Darton (1906) says the flow has been "stated to be over 1000 gallons per second" (60,000 gpm and 1/10 the flow of the Bighorn River). Woodruff estimated 3000 to 4000 gallons per minute in 1909 while the Wyoming State Geologist measured the flow at 2778 gpm in 1926 (Bartlett), fairly close to the present 2908 gpm flow. In 1941, a Wyoming Writer's Program publication cited a figure of 18.6 million gallons per day (12,500 gpm). This number, also mentioned by Bartlett (1925), has been enshrined in a bronze plaque at the spring and so has become the authoritative estimate in many reports. The Wyoming State Engineer's estimates indicate an irregular variation between 2280 and 3173 gpm over the past eight years, with an average of 2648 gpm (King, 1976).

Although accurate flow estimations are difficult, and the tendency to hyperbolize is great, the agreement of 1909, 1926 and recent data seems to indicate a fairly stable flow. This is substantiated by the consistent temperature measurements (easily determined), which would be expected to fluctuate with extreme flow variations.

Big Spring enters a 25-foot diameter pool through vents in the pool bottom. Inflow is accompanied by constant gas bubbling which produces a churning, boiling effect. Two manmade ditches and a buried pipeline accommodate outflow. One ditch flows into a swimming pool 170 yards south while the other, larger channel feeds water across 200 yards of extensive and spectacular terrace formations (Rainbow Terraces), then into the State Bathhouse and a second swimming pool. In addition, the underground pipe system serves the pools and bathhouse. Outflow from all these springs finally enters the nearby Bighorn River.

Spring waters piped to commercial establishments at the south end of the park have a vapor vent in the form of a standpipe. Around this pipe mineral deposition has created a 20 feet high cone known as Teepee Fountain.

As noted in the introduction, many writers have expounded on the medicinal qualities of hot mineral waters. Hot Springs State Park is the most developed spring system in the state and has always been noted as a center for "taking the waters." In addition to the State Bathhouse, five commercial establishments feature hot mineral bathing or swimming. Chemical analyses for most of the springs and wells are compiled on page 37. As a permanent water supply these waters do not meet U.S. Public Health Service requirements for sulfate, chloride, flouride, and Total Dissolved Solids, which is not to say they may not be beneficial in small quantities.

As noted for the Maytag well, one household uses the thermal waters for a domestic supply. Ill effects? No, indeed! In fact, the owner says the water has produced new growth on his previously bald head! Another resident reports that the high magnesium water of Bathtub Spring cured her ulcers. While Bathtub Spring is somewhat lower in magnesium than others in the system, her ulcers remain cured. Of the many chance contacts made during our field work, all had stories to tell of the health-building powers of the waters and, every day, many devotees dip their daily dose from Big Spring.

The chemical chart clearly shows the close relationship of the various thermal waters in the immediate Thermopolis area and the lower concentrations in water of Wind River Canyon Spring, nearer the source area.

While the concentrations of certain constituents seem to vary somewhat from spring to spring and year to year, such fluctuations are small, and composition is constant overall. The chemistry of Big Spring has been monitored closely and results seem to show a slight decrease in Total Dissolved Solids, (accounted for by decreases in sulfate, bicarbonate and calcium), and a slight increase in flouride, over the past 40 years.

Table 9. Chemical analyses for Hot Springs County

Spring	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3	F
Sacajawea Well	396	76	227	46	0	741	819	300	.1	
	340	79	270	40	0	760	840	300	0	5.4
McCarthy Well	350	76	270	40	0	760	830	300	0	4.4
"Bathtub Spring"	340	73	270	44	0	730	780	330	0	4.2
White Sulphur Spring	383	80	253	45		784	773	308	.10	3.8
	340	77	270	42	0	750	820	300	0	8.1
Black Sulphur Spg.	385	75	266	49		740	777	334	.10	3.8
Big Spring	315	113	83	91			556	84		
	315	113	258	91			556	355		
	385	76	262	49		766	769	328	.10	3.7
	380	67	280	53	0	740	777	314	0	3.0
	360	86	250	51	0	708	774	294	0	5.5
	310	71	250	37	0	710	730	300	0	6.8
Wind River Canyon Spring	146	50	41	7.4	0	377	276	39	.3	1.2
	140	49	40	6.7	0	390	290	38	0	1.3

Spring	S	SiO_2	B	Fe	TDS	Cond	pH	Na%	Hard
Sacajawea Well			.37			3170	6.6	27	
	<.001	35	.45	0	2390	3140	7.0	32	1200
McCarthy Well	<.001	36	.41		2380	3120	7.1	32	1200
"Bathtub Spring"	.001	39	.49		2330	3090	7.1	33	1100
White Sulphur Spring		37		.05	2321	3090			1286
	<.001	37	.45		2350	2990	7.0	32	1200
Black Sulphur Spg.		71		.05	2378	2990			1262
Big Spring		40		(2.45)*					
		40		(2.45)*					
		38		.08	2373				1274
		40		.06	2280	3150	6.4		1220
		35	.61	.04	2200	2860	7.0		1250
	.006	37	.54	0	2190	2960	6.9	33	1100
Wind River Canyon Spring		13	.12	.09	759	1150	8.0		570
	<.001	12	.10		800	1160	7.5	13	560

Spring	Tot CO_2	H_2S	Date	Reference
Sacajawea Well			4/21/69	State Lab No. 908058
	370		9/2/76	State Lab No. 7-1797
McCarthy Well	370		9/3/76	State Lab No. 7-1800
"Bathtub Spring"	360		9/3/76	State Lab No. 7-1801
White Sulphur Spring		2.3	6/12/33	Lohr, 1940
	370		9/2/76	State Lab No. 7-1799
Black Sulphur Spg.		1.4	6/12/33	Lohr, 1940
Big Spring	443			Darton, 1906
	443			Bartlett, 1926
		4.5	6/12/33	Lohr, 1940
			4/11/58	Lowry and Lines, 1972
			2/24/71	Lowry and Lines, 1972
	350		9/2/76	State Lab No. 7-1796
Wind River Canyon Spring			7/7/70	Lowry and Lines, 1972
	190		9/1/76	State Lab No. 7-1798

Trace Element Analyses (mg/l)

	As	Cu	Mn	Zn	Ba	Cd	Cr	Pb	Se	Ag
Sacajawea Well	<.05	<.01	<.05	<.02	<.5	<.01	<.1	<.1	<.001	<.5
Big Spring	<.05	<.01	<.05	<.02	<.5	<.01	<.1	<.1	<.001	<.5

	Hg	Ni	Date	Reference
Sacajawea Well	<.001	<.1	9/2/76	State Lab No. 7-1797
Big Spring	.001	<.1	9/2/76	No. 7-1796

See Notes on the Chemical Analyses, page viii, for explanation of reported values.

Photograph 23. Panorama of Hot Springs State Park and vicinity: (1) Sacajawea, Van Norman, and Maytag Wells; (2) McCarthy Well; (3) White Sulphur Spring; (4) Bathtub Spring; (5) "Railroad Cut" Spring; (6) Piling Spring; (7) Black Sulphur Spring; (8) "River" Spring; (9) Big Spring; (10) Rainbow Terraces; (11) Teepee Fountain; (12) State Bathhouse; (13) Owl Creek Mountains

WIND RIVER CANYON SPRING

Photograph 24. Wind River Canyon Spring

Location: Sec.25bc, T.42N., R.95W.
Elevation: 4370 feet
Quadrangle: Wedding of the Waters
Ownership: Private
Access: Ten yards east of U.S. 20 at the mouth of Wind River Canyon
Temperature: 22° C (9/1/76)
Flow: 989 gpm
Chemical: Two analyses, page 37

This relatively cool spring fills a rock-lined 10 x 15-foot, 12-foot deep pool from which it flows under Highway 789 and into the Bighorn River. Hill (1976) cites another small spring on the opposite (west) side of the river but, even at −18° C air temperature, there is no surface evidence of the other spring.

Geology

The geohydrology of the Thermopolis spring system is that of a nearly ideal natural artesian system (see Figure 8). Water enters the exposed portions of Paleozoic formations in the Owl Creek uplift. From 4430 feet above sea level at the base of the Madison Limestone to 4380 feet at the top of the Permian Phosphoria Formation, the Wind River cuts a course across these northward dipping strata. The rocks differ in their water capacity and transmission characteristics, leaving the exact water pathway open to speculation, although all units within the section are fair aquifers. At the Jurassic Chugwater Formation, however, permeability is greatly decreased and a cap rock is formed.

The acquifers are again brought up by the fold of the Thermopolis Anticline with the springs appearing at 4360 feet on the Bighorn River.

The distribution of travertine deposits (Figure 7) indicates that the springs have not always issued from their present locations. Very recent changes have been described for Black Sulphur and White Sulphur Springs, providing additional evidence of the transience of these features. Woodruff (1909) claims the springs were once situated approximately three miles northwest of Thermopolis (still at the crest of the anticline) and have slowly migrated towards their present site.

Travertine deposits can be found at 5000 feet on Round Top Mountain, one mile west-northwest of the present springs. When these deposits were formed, they were near the base-level of the valley, and subsequent erosion has left them capping small mesas. Either the same artesian system created them, or both the source and vents were at relatively higher elevations.

There are extensive travertine formations on T Hill, on Monument Hill, and all along the river north of Big Spring. Particularly spectacular are those above White Sulphur Spring, where erosion has dissected intricate travertine sheets.

All the springs now flow from the crest of the anticline from outcrops of the red Chugwater Formation. That the Chugwater is not the source rock for so much water is indicated by both its poor permeability and the water chemistry: the Chugwater characteristically has Total Dissolved Solids

Photograph 25. Travertine deposits above White Sulphur Spring

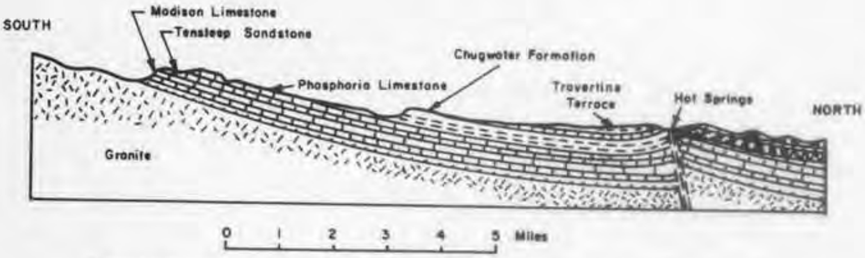


Figure 8. Geologic cross section through Hot Springs State Park

>30,000 ppm (Crawford, 1940). Because strata are bent so sharply at the anticlinal crest, many have fractured and shifted, providing a ready water pathway from much lower formations.

Darton (1906a) maintained that the spring flow came from neither the redbeds nor the underlying Phosphoria limestone. He suggested the Tensleep, a sandstone which frequently produces springs elsewhere, as the major conduit, but noted that it doesn't descend deep enough between the mountains and the springs to increase the water temperature to that observed.

Berry and Littleton (1961) hold that the Madison Limestone is the source because that formation has the cavities and channels necessary to accommodate such large water flows.

Using Crawford's (1940) chemical data on formational waters in the Bighorn Basin and the authors' spring analyses, the best correlation is with Tensleep waters. Berry and Littleton (1961), on the other hand, describes the spring water as "similar in quality" to Madison water. Burk (1952) refers to a non-artesian well on the Thermopolis anticline (six miles northwest of Thermopolis) which struck 62° F water rushing into a large cavity in the Madison. Thus, the most reasonable hypothesis at present appears to the authors to be that the water comes in large part from the Madison, probably modified in chemistry as it cools and rises through rock units above it.

The Wind River Canyon Spring issues from a chert zone in Phosphoria limestone at a temperature of 22° C. The presence of the spring seems to indicate that groundwaters move to some degree between most of the upper Paleozoic rocks.

Heat

The main problem in explaining the Thermopolis spring system is the source of heat (general heating mechanisms have been discussed, and are further discussed in the Geothermal Resources chapter). Darton (1906a) points out that the Tensleep reaches a maximum depth of only 2000 feet in the syncline south of Thermopolis. Application of Darton's fairly high geothermal gradient of 1.1° C/100 feet would account for an increase of only 22° C. To produce the observed spring temperatures at this gradient requires a depth of 4500 feet. Judging by formation thicknesses determined in wells in the area (Berry and Littleton, 1961 and Petroleum Information File) the base of the Madison Limestone occurs at a depth of around 3580 feet and the base of the underlying Bighorn dolomite at 3730 feet. Water from a depth of 4500 feet would come from lower Cambrian strata. By using a gradient of .89°C/100 feet, developed by the American Association of Petroleum Geologists (Kehle, 1972), such temperatures would occur well into basement granite at a depth of 5500 feet.

Woodruff (1909) reports intrusive igneous rock outcrops just north of Thermopolis, suggesting a possible hot igneous mass at depth. Later workers have not verified his claim, but, even without surface evidence, have suggested the possibility of an igneous heat source. Alternatively, Bartlett (1926) proposed a series of exothermic chemical reactions to heat the water.

Thus, a variety of possibilities have been proposed. Chemical or frictional heating may contribute some energy, but to what extent this might supplement gradient heating is unknown. If the waters are assumed to circulate into the Madison and deeper, a locally high geothermal gradient may account for the observed temperatures. Such an explanation is, however, based on a poorly understood geothermal gradient and the supposition that waters have fairly rapid access to the surface to prevent cooling enroute. Until all these factors are more clearly defined, no explanation can be completely accepted.

Lincoln County

AUBURN HOT SPRINGS

Location: Sec.23db, T.33N., R.119W.
Elevation: 6080 feet
Quadrangle: Bedford
Ownership: Private—Keith Hyde
Access: Two and one-half miles north of Auburn

Temperature: 62° C (9/22/76)
Flow: 37gpm (Renner, 1975)
Chemistry: Four analyses, this page

Despite their spectacular appearance, the Auburn Hot Springs have experienced only slight development. An early reference (Peale, 1886) contains no mention of any use or development. According to Keith Hyde, long-time owner of the springs, there was once an old pool and building, both of which burned down in 1945. Following the fire, a new facility was constructed but has deteriorated somewhat.

Hyde reports that sulfur was mined from the springs deposits in 1947-49, and that several thousand tons of up to 94 percent pure sulfur were recovered. The operation folded when the sulfur tested somewhat less pure than reported. Also in the 1940's, a San Francisco firm contacted Hyde about possible geothermal development, but nothing was ever done.

According to geochemical work by Renner and others (1975), subsurface temperatures of the Auburn system are up to 150° C, making it one of the two areas in the state, outside of Yellowstone, which even approach electrical generation potential (the other is Huckleberry Hot Springs). In 1975, Geothermal Resource Permits were issued by the State Board of Land Commissioners for three tracts in the Auburn-Thayne area. Three more tracts, just inside Idaho, are under consideration for federal geothermal leases.

The Auburn Hot Springs cover approximately three acres around Hyde's house. Included in the area are over 100 separate vents which form mud pots, tiny terraces, large terraces, weak geysers, cones, sulfur veins, and two large pools. Flow is accompanied by profuse bubbling, a strong hydrogen sulfide smell, and a lush growth of multicolored algae.

Table 10. Chemical analyses for Auburn Hot Springs

Temp	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3	F	S
62	400	70	1400	140	0	860	1100	1700	0	0.6	.8
	431	97	1314	114		154	1904	1725			
62	134	74	1410	156		94	1100	1890		3.5	
16	252	70	1500	180		70	1430	2000	6.6	3.5	

SiO_2	B	TDS	Cond	pH	Na%	Hard	Tot CO_2	Date	Reference
35	2.15	5250	6800	7.5	68	1300	420	9/22/26	State Lab No. 7-2565
20									Mansfield, 1927
	1.8								White, 1972
	3.0								White, 1972

Trace Element Analyses

As	Cu	Fe	Mn	Zn	Ba	Cd	Cr	Pb	Se	Ag	Hg	Ni
<.05	<.01	0	<.05	.34	<.5	<.01	<.1	.5	<.001	<.5	<.001	<.1

Date	Reference
9/22/76	State Lab No. 7-2565

See Notes on the Chemical Analyses, page viii, for explanation of reported values.

Photograph 26. Panorama of Auburn Hot Springs: Cones, terraces, and pool in foreground mark the area of greatest thermal activity. The light patch left of the pool is the tailings pile of an abandoned sulphur mining operation. The building on the left houses a concrete pool fed by the springs. An older travertine deposit forms the gentle hill in the left middle background, and behind it is the first ridge of the Salt River Range.

The most intense thermal activity is confined to a small area furthest north, uphill, with minor seeps and pools stringing out downhill. A 300-foot well drilled near the travertine cones produces a moderate flow of 62° C water, the hottest in this system.

The hot springs are a rather spectacular miniature geyser basin similar to some in Yellowstone. A large boggy area has formed as spring waters have dispersed downhill. The springs are used now only to supply an old private swimming pool.

The roughly linear arrangement of the Auburn thermal features and the occurrence of inactive travertine deposits over eight miles on the northward extension of the same line (see Figure 9, page 44) suggests that the springs are structurally controlled. On a southward extension of the line, approximately one mile distant, are the Johnson Springs.

JOHNSON SPRINGS

Location: Sec.26ad, T.33N., R.119W.
Elevation: 6020 feet
Quadrangle: Bedford
Ownership: Private—Orson Johnson
Access: One and one-half miles north of Auburn

Temperature: 46° C (9/22/76)
Flow: Two gpm
Chemistry: None collected

Particularly in comparison to the more spectacular Auburn Springs a mile north, these springs are minor. Were it not for the unexpected occurrence of five travertine cones up to eight feet high near the springs, they would easily escape notice. Apparently the springs have never been developed: they merely run off into a pasture. Because the Auburn and Johnson Springs systems are so similar (Johnson

Springs seems to follow the same linear pattern noted for Auburn system) they are discussed as one system.

Geologically, the springs occur along the crest of the tightly folded, north-south trending Hemmert anticline (Mansfield, 1927). The springs surface in the lower Triassic Dinwoody Formation, but the Phosphoria Formation is exposed at the center of the anticline, just north of the springs. Mansfield (1927) mapped three deep-seated faults trending north-south through the area: the Hemmert fault fracturing the crest of the anticline, the Freedom fault joining the Hemmert from the northwest at the spring site, and the Auburn fault one-third mile west. Armstrong and Cressman (1963) reexamined the area and concluded that there was some "doubt as to the existence of the Auburn fault." They suggested that the Star Valley Overthrust may be a high-angle reverse or normal fault. Regardless of the exact character of the faults, surface travertine deposits along the faults leave little doubt that they have conducted mineral rich waters to the surface. Since the geologic structure is not mapped in precise detail, this survey, beyond very local circumstances, cannot venture a hydrogeologic model. Both the hydrology and geothermal significance of the springs warrant further investigation. It should be noted that Tertiary and Quaternary igneous rocks outcrop extensively in Idaho as close as four miles due west of the springs.

Photograph 27. Johnson Springs

Renner and others (1975) have used Auburn water chemistry to speculate on

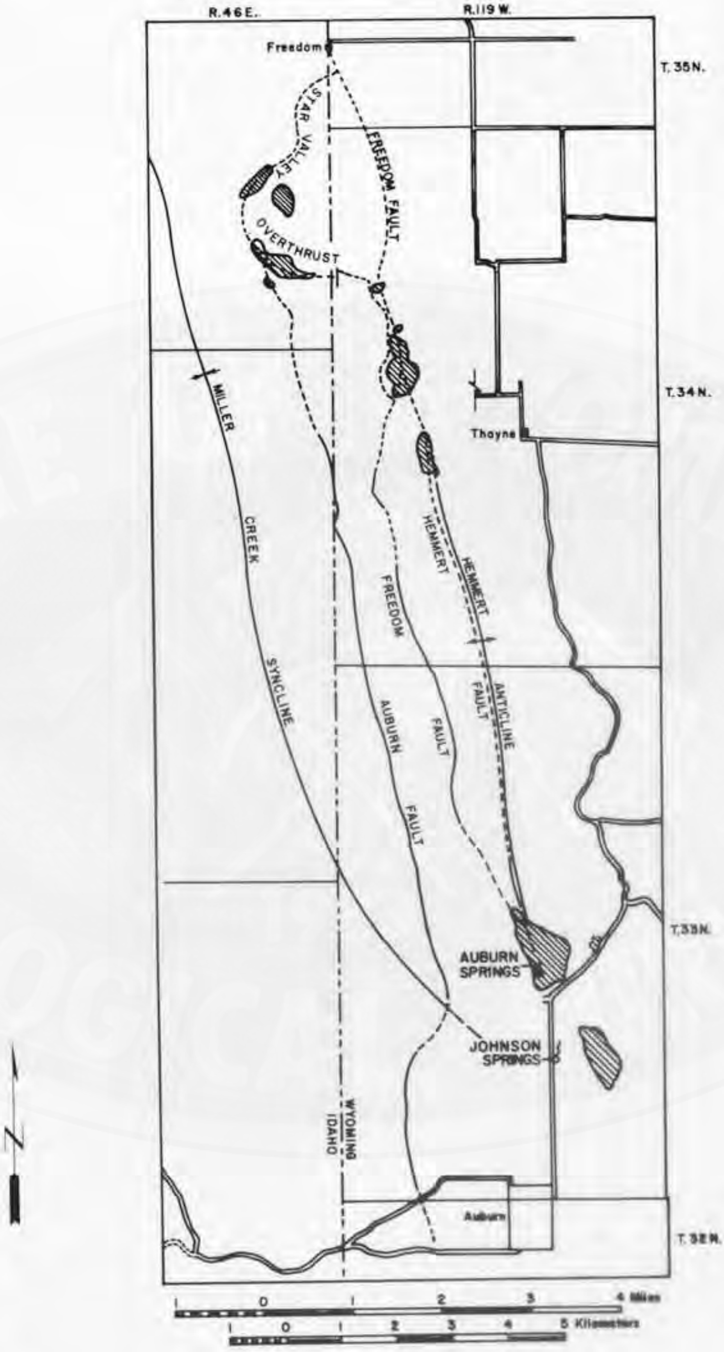


Figure 9. Geolgoic structure map of Auburn Hot Springs area

▨ Travertine Deposits

subsurface temperatures. Rubey and Marata (1941) analyzed water samples from two springs of different temperatures in the Auburn group and found the hotter one less mineralized, though the overall chemical proportions were very similar. Gas samples, on the other hand, showed that the hotter spring carries more hydrogen sulfide and carbon dioxide. Based on the common occurrence of these two gasses as magma exsolution products and the thermal and chemical relationships of the hotter and cooler springs, they suggested a contribution of "about 5%" of the springs' flow from magma generated steam. By this model, steam is produced as the underlying magma cools. Steam rises and dilutes groundwaters, while at the same time adding thermal energy.

Natrona County

ALCOVA HOT SPRINGS

Location: Sec.24ddc, T.30N., R.83W.
Sec.25aba, T.30N., R.83W.
Sec.25abc, T.30N., R.83W.
Sec.25abd, T.30N., R.83W.
Elevation: 5500 feet (reservoir surface)
Quadrangle: Alcova
Ownership: Federal—U.S. Bureau of Reclamation
Access: Beneath Alcova Reservoir
Temperature: 54° C (Bradley, 1935)
Flow: 100 gpm (variable)
Chemistry: Two analyses, page 46

Photograph 28. Alcova Hot Springs, now under water. Photo from Bartlett, 1926.

The locations, temperature, flow and chemistry of these springs come from work by Bradley (1935). Since the springs now lie beneath Alcova Reservoir, all information comes from published sources. The springs are cited in Peale's 1886 inventory of U.S. mineral springs. Hares (1917) mentions the Alcova Springs in his structural study of central Wyoming, and Bartlett (1926) provides chemical and thermal data, predicting "the place will become famous as a health resort." Bartlett might have proved right had not the U.S. Bureau of Reclamation, in 1938, dammed the North Platte immediately downstream from the springs and covered the site with 160 feet of water. The present condition of the springs is, of course, unknown, particularly since the reservoir may have equalized the hydrostatic head creating the springs and thus shut them off entirely.

The springs flowed from four main vents within five feet of the level of the North Platte River. Most of the flow came from two springs, each flowing about 40 gpm. Bradley (1935) noted a variation of spring flow in direct relation to river flow with a delay of approximately two days.

The springs all issued from the Mississippian-Pennsylvanian Amsden Formation, which, at the spring site, formed a 188-foot cliff of limestone with interbedded limey sandstone. Bradley reported that, before the dam was built, exploration drill holes showed that the Amsden was locally quite porous due to enlargement of fissures and channels by hot waters. Large flows of hot water were encountered in

Table 11. Chemical analyses for Alcova Hot Springs

Temp	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3
54	157	27	199	14	0	91	458	287	.1
59	163	59.3	210	13.2		138	460	296	

Temp	Fe	SiO_2	TDS	Hard	Na%	Date	Reference
54	.10	41	1260	503	45	5/25/29	Bradley (1935)
59		39.6	1381				Knight (1900)

See Notes on the Chemical Analyses, page viii, for explanation of reported values.

many Amsden holes and even in thick sections of river gravels. No flow estimates are reported from these holes, but they must have been substantial to displace cool river water through 40 feet of gravel.

Since the dam is apparently founded on the Tensleep Formation, and since spring and borehole flows were confined to the Amsden, which outcrops only over a short stretch of the canyon, the reservoir reasonably can be expected to have slowed artesian flow (see figure 10).

Structurally the spring is on the crest of the Alcova Anticline. As the Tensleep Formation was upwarped, the river cut down through it exposing the top of the Amsden Formation at the bottom of the canyon. Geologic maps by Sheffer (1951) and Mitchell (1957) show that the anticline was broken on the south limb by a major fault. The Amsden was displaced some 1500 feet across the fault that serves as the spring water conduit. The Paleozoic section is recharged five to six miles southwest of the spring along the flank of the Granite Mountains. River waters cross the upturned strata, and the springs emerge at a lower elevation downstream.

Chemical data indicate little interaction with formations deeper than the Amsden. From structural conditions, a maximum depth of 3000 feet is postulated for the Amsden artesian system. Bradley's theory that the higher river levels at the head of the system show up two days later at the springs requires fairly rapid water passage, so cooling would presumably be slight. A vertically uniform gradient of 1.6° C/100 feet is required to produce the observed spring temperature. This is likely an unusually high gradient if the thermal conductivities of the sandstones and carbonates in the overlying section are high. Another possibility is that water migrates up the fault from deep within the underlying granite. There is evidence for water circulation and considerable fracturing and brecciation in a drill hole in Precambrian rocks southwest of these springs (Decker, 1976).

Water chemistry data (U.S. Geological Survey, 1971) for southeast Wyoming strongly indicates an Amsden origin for the spring waters. They are substantially lower in Na and HCO_3 and higher in SiO_2 than waters from the Madison, the only other good aquifer present in this sedimentary section. Chemical data are sparse on

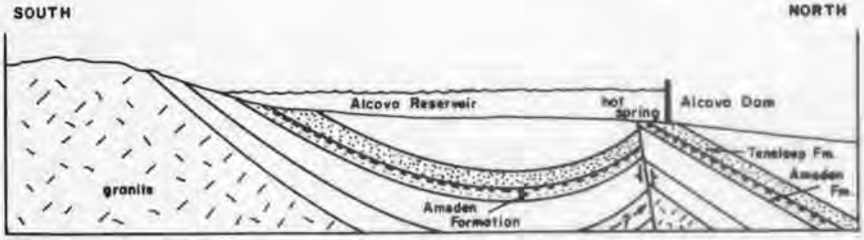


Figure 10. Simplified cross section through Alcova Hot Springs

the underlying granite, so it cannot be ruled out as at least a supplemental source. The waters supplied to the Amsden by the North Platte River should reflect surface water chemistry. However, substantial chemical modification apparently has taken place. Total Dissolved Solids load is increased around four times with large increases in every constituent except HCO_3.

HORSE CREEK SPRINGS

Location: Sec.35bd, T.32N., R.86W.
Elevation: 6780 feet
Quadrangle: Horse Creek Springs
Ownership: Private
Access: North 16 miles off Wyo. 220, through Keester Basin and up Horse Creek
Temperature: 23-24° C (9/1/76)
Flow: 2200 gpm
Chemistry: One analysis, this page

Photograph 29. Horse Creek Springs

Horse Creek Springs are about as far off the beaten track as any in this book. Nonetheless, published references appear as early as 1886 (Peale). They are the source of Horse Creek, which provides a year-round water supply to the dry country between the springs and the Sweetwater River.

There are two main spring areas, about 30 feet apart. Both areas are made up of many small vents issuing from a 20° slope of bouldery colluvium. Water runs around and through the rocks and collects in a large, shallow pool 12 feet down slope. The pool has a white sandy bottom and supports a lush growth of aquatic plants. The clear, warm spring water runs over soft mats of watercress, algae, and moss to create a unique spot indeed in comparison with the dry, sagebrush covered hills surrounding it.

Tensleep sandstone outcrops immediately uphill from the springs, but structural complications leave some doubt as to the actual subcrop. The North Granite Mountains fault system, a complex group of east-west faults extending from the Platte River to the Beaver Rim, transects the springs, and brings Paleozoic rocks on the north against late Tertiary rocks on the south. The fault system has been active several times during the Cenozoic and has up to 5,000 feet of vertical displacement (Love, 1970).

Eocene igneous intrusive rocks of the Rattlesnake Mountains are present northwest of the spring area. The nearest source area where Paleozoic rocks are exposed is about three miles west-northwest of the springs. These rocks crop out above an elevation of 7100 feet, and are associated with two igneous masses. The springs

Table 12. Chemical analysis for Horse Creek Springs

Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3	F	S	SiO_2	B
120	26	8.8	8.8	0	170	290	1.8	.4	1.6	<.001	21	.03

TDS	Cond	pH	Na%	Hard	Tot CO_2	Date	Reference
582	798	7.7	4	400	82	9/1/76	State Lab. No. 7-1774

See Notes on the Chemical Analyses, page viii, for explanation of reported values.

occur at 6800 feet above sea level. Clearly, sufficient hydrostatic head exists to supply a spring. Heat is available either from depth along deep faults or from cooling igneous rock. The faults accompanying emplacement of the igneous rocks in the northern Granite Mountains so complicate the structure, however, that we cannot present a precise hydrologic model.

Chemically, Horse Creek waters are dominated by calcium and magnesium. This is a characteristic of the Paleozoic section. The analysis shows somewhat closer connection to the Tensleep Sandstone than to other units. The low bicarbonate, chloride and Total Dissolved Solids are generally indicative of Tensleep waters, as is the high secondary salinity* (Crawford, 1940).

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*If the strong acid ions (Cl, SO_4, NO_3) are greater in charge than the alkali ions (Na, K), excess of strong acid ions and the alkaline earth ions (Ca, Mg) which balance them induce secondary salinity (Crawford, 1940, p. 1215, 1220).

Park County

BUFFALO BILL RESERVOIR SPRINGS

Location: Sec.14ac, T.52N., R.103W.
Sec.10ad, T.52N., R.103W.
Sec.12bd, T.52N., R.103W.
Sec.12bb, T.52N., R.103W.
Elevation: 5369 feet
Quadrangle: Devils Tooth
Ownership: Federal—U.S. Bureau of Reclamation
Access: Under water
Temperature and Flow: Warm and voluminous enough to keep an area in Section 12 ice free throughout the winter (Bailey, 1976)
Chemistry: Not sampled

The white man's first description of these springs came from mountain man John Colter. Colter, credited to be the first white man in the Bighorn Basin, passed through the area in the winter of 1807-08 and brought back stories of a "boiling tar spring" and a variety of other thermal phenomena. Several later descriptions exist, but evidently no geological work was done on these sites before they were covered by the waters of the Buffalo Bill Reservoir in 1907. The locations given are on a map with spring sites reconstructed by Love and Good (1970). Pierce (1970) mapped travertine deposits just above water level in sections 11 and 12.

As mapped, the springs issue from the Phosphoria Formation on the southwest flank of the Rattlesnake anticline. The anticline is bounded on the southwest by a number of steeply dipping faults which have left strata vertical or overturned. If the fault zone extends into Precambrian granites, it could provide a conduit for warm waters (see map, Pierce, 1966).

According to Pierce's 1970 map, travertine occurs on steeply dipping rocks approximately one-half mile southwest of the main fault. The springs cannot be studied closely, but probably have an origin similar to that of the De Maris Springs on the north side of the anticline.

DE MARIS HOT SPRINGS

Location: Sec.3bc, T.52N., R.102W.
Elevation: 4960
Quadrangle: Cody
Ownership: Private—Kit Cody, Wyoming, owner
Access: Across river on private road off U.S. 14-20, two miles west of Cody
Temperature: 27-36° (varies between vents) (8//1/76)
Flow: Approximately 1700 gpm
Chemistry: Eight analyses, page 51


Photograph 30. De Maris Hot Springs

De Maris, like the springs at the west end of the Shoshone River canyon, were first described when John Colter related his 1806-07 travels through what became known as "Colter's Hell." The Stinkingwater River, which has since been renamed Shoshone, clearly was identified by the sulfurous gases issuing from the hot springs. The springs themselves are named for Bill De Maris who developed them for swimming and bathing.

According to Bartlett (1926) there had been a resort at the springs since 1894. At De Maris' death, the springs and facilities were purchased for the Bronze Boot (a supper club) and, in turn, were sold to Kit Cody around 1970 when the facility was moved away from the spring site (Ratliff, 1976). The springs are now abandoned, and Mr. Cody uses the access road to stage commercial float trips. The Bronze Boot Spa, located on the terrace across from the springs, pumps 208 gpm from a 168 foot deep well to supply a commercial pool (Ratliff, 1976), obviously tapping the same supply.

Hill and others (1976) describe Spirit Mountain Caverns, 1200 feet above the springs, as perhaps reflecting a thermal water origin. There are extensive travertine deposits on the terraces on both sides of the river. Pierce (1966) mapped travertine up to 75 feet thick in the vicinity of the springs. Isolated patches of travertine also lie one mile upstream from De Maris and at the southeast tip of the Rattlesnake anticline. Eldridge (1894) cited these outcrops as evidence for previously greater activity. However, this is not the necessary conclusion: the springs may simply have been active for a very long time.

Woodruff (1909) reports that 850 tons of sulfur associated with the hot springs were produced in 1906. This involved constructing a mill and processing 2833 tons of ore. Sulphur was mined here intermittently until 1917 (Pierce and Andrews, 1941).

Presently the De Maris Hot Springs occur in an area approximately 75 yards long, near the river level, on the north bank of the Shoshone River. Individual vents flow less than one gallon per minute to over 500 gpm. Seven distinct vents were counted, although many more probably issue through the river bottom. Most of the springs are in the 27-28° C range. One notable exception is the vent furthest upstream which runs over 400 gpm at 36° C.

The spring furthest downstream occupies a ten-foot-diameter pool surrounded by the remains of a concrete building. All the other springs run directly into the river. Some bubble up through the sand and others pour from deep cracks, up to two feet wide, in the canyon wall. The samples for chemical analysis came from the largest vent of each temperature group.

Another small hot spring called "Needle Hot Spring" is reported to issue from the lower Madison, approximately two miles upstream from De Maris at sec. 5db, T.52N., R.102W. (Willis, 1976). The site was covered by earth fill during construction of the present highway, preventing its verification.

All the De Maris springs issue from the Permian Phosphoria Formation, an interbedded sequence of massive limestone beds and thin shaley layers at this site. Here, on the northeast limb of the Rattlesnake anticline, the strata dip 16° off of the mountain. The rock has been altered throughout this stretch of Shoshone Canyon by hot spring activity. Fractures are often large: the hottest spring flows from a crack two feet wide and 15 feet deep. Small pods and nodules of native sulphur can be found associated with travertine deposits at the spring site.

Since both the De Maris Springs and those under Buffalo Bill Reservoir flow from the same stratigraphic position, although on opposite sides of the Rattlesnake anticline, their origins may be similar. Chemically the waters do not correlate well with those of any of the area's formations, as analyzed by Crawford (1940) or Lowry and Lines (1972). Generally they seem consistently less mineralized than well waters recovered from the same rock section. While Fisher (1906) suggested the Tensleep as a source, he cited no evidence and claimed that for heat to be depth generated a Cambrian origin is required. His model proposed heating in the basal Cambrian section, 2,200 feet below ground level, with surface access by fractures along the flanks of the anticline. Kehle's (1972) gradient of .67° C/100 feet requires a depth of 4,650 feet for the warmest spring waters. Pierce (as reported in Love and Good, 1970) proposed the theory that water warmed deep in the Dry Creek syncline to the south migrates up both sides of the Rattlesnake anticline to produce the springs. Pierce's (1966 and 1970) maps show that the Phosphoria is nearly 8000 feet deep beneath much of the area south and west of the springs. Thus, Kehle's gradient can easily explain the observed temperatures.

Well logs from the area show measured temperatures greater than those of the springs. In sec.13, T.52N., R.102W., Tensleep waters were measured at 47° C and in sec.24 at 40° C. Further west in R.103-105W., temperatures of 41° to 46° C were encountered in the Tensleep and the Madison, 4000-6000 feet deep. While well temperatures are often depressed by drilling fluids and drilling disruptions, it is reasonable in most cases to assume that they represent minimum formation temperatures. Thus, the temperature of De Maris does not require a geothermal anomaly, but requires merely a hydrogeological system which routes the water through deeper, warmer strata.

Hydrostatic head calculated from well tests (Petroleum Information File) in the Phosphoria and Tensleep show an equal pressure surface sloping from at least 5200 feet near Wapiti to around 5000 feet south of Rattlesnake Mountain. Since the springs occur at 4900 feet, their flow is readily explained.

An artesian well produces 69° C water from 1476 feet in the Tensleep in sec.31 (Decker, 1976). Just how the strata are recharged is unclear, though, because the Paleozoic section is covered by thousands of feet of Tertiary volcanics in the apparent recharge areas west of the springs.

Presumably, water moves east from the Absaroka Mountains through permeable volcanics at depths of 4000 to 6000 feet. The water is then forced up around the Rattlesnake anticline under artesian pressure. Where erosion has cut most deeply into the structure, the hot waters escape. Contained by the less permeable Mesozoic section, the waters issue onto the surface from the Phosphoria Formation at De Maris and under the Buffalo Bill Reservoir. Surface venting is provided by faults and fractures associated with the anticline.

Some cooling enroute is evidenced by the spring temperature differences, the warmer waters presumably arriving by a more direct route. Where wells provide a conduit, still warmer water flows. Contributions of heat from deep seated volcanic sources are unknown.

Recent chemical data for the De Maris Springs differ from Bartlett's 1926 data. Whether or not these differences (e.g. for S and Na) indicate a true change is unclear because of different analytical procedures. Between the 1968 and 1976 analyses there is a general decrease in concentration of many constituents, possibly due to sampling at different seasons. Variation with time appears greater than variation with location, which seems consistent with the assumption of a common source. Greater mineral solubilities in the warmer water could account for the increased mineralization of the 36° C spring.

Crawford's (1940) data on formational water chemistry in the Bighorn Basin shows that these springs best correlate with the Madison Limestone water. The Total Dissolved Solids values for De Maris are generally higher than for Amsden, Tensleep and Phosphoria waters, but fall within the range of Madison figures. The preponderance of the bivalent cations also suggests the Madison.

Reaction capacity proportions, however, show some deviation from Madison chemistry, particularly in secondary salinity. Thus, if the water does originate in the Madison, there is some chemical modification or addition of other formational waters, or both, as it moves upward toward the springs.

Table 13. Chemical analyses for De Maris Hot Springs

Temp	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3	F	S	SiO_2	B	Fe**	TDS	Cond	pH	Na%	Hard	Tot CO_2	Date	Reference
24	217	173	258			681	39	17.1			205	18.8		(53.9)							1926	Bartlett, 1926
28	354	72	33	16		952	422	21	.1	2.0	18		.06		1970	6.9			1180		2/15/68	Lowry, 1972
27	322	66	30	18		917	402	16	0	1.9		19	.55	.05	1320	1880	7.0		1080		8/14/70	Lowry, 1972
27	369	63	33	16		993	418	20	.1	2.0		18		.20		1960	7.1		1180		2/15/68	Lowry, 1972
27.5	324	70	30	17		900	418	17	0	1.9		18	.10	.08	1340	1790	7.0		1100		8/14/70	Lowry, 1972
27	300	74	28	13	0	880	400	17	0	2.7	<.001	17	.33	0	1340	1570	6.5	4.2	1100	430	8/17/76	St. Lb. No. 7-1571
37	188	367	256			872	641	29.1			104	37.7		(23.7)							1926	Bartlett, 1926
36	380	86	47	20	0	1200	500	25	0	2.9	<.001	21	.49	0	1730	1800	7.0	7.1	1300	570	8/18/76	St. Lb. No. 7-1572

*Note: Two distinct temperatures are found at De Maris. Therefore, analyses from the cooler (27-28 degrees C) springs are presented first, then those from the warmer (36 degree C) spring. Also, analyses 2 & 3 are for the same springs (different dates), as are analyses 4 & 5.

**Values in parentheses are Fe + Al

Trace Element Analysis

Temp	As	Cu	Mn	Zn	Ba	Cd	Cr	Pb	Se	Ag	Hg	Ni
27	<.05	<.01	<.05	<.02	<.5	<.01	<.1	<.1	<.001	<.5	.003	<.1
36	<.05	<.01	<.05	<.02	<.5	<.01	<.1	<.1	<.001	<.5	.001	<.1

Date	Reference
8/17/76	State Lab No. 7-1571
8/17/76	State Lab No. 7-1572

See Notes on the Chemical Analyses, page viii, for explanation of reported values.

Platte County

IMMIGRANTS WASHTUB

Photograph 31. Immigrants Washtub

Location: Sec.4cd, T.26N., R.66W.
Elevation: 4420 feet
Quadrangle: Wheatland NE
Ownership: State of Wyoming
Access: South along the west side of the Platte River off U.S. 26, then two miles up Warm Springs Canyon
Temperature: 21° C (7/29/76)
Flow: 23 gpm
Chemistry: Two analysis, page 53

During the 1840's, the warm springs, near the present town of Guernsey, were perhaps the most famous thermal feature in the state. Although folks may have heard vague tales of "Colter's Hell" and the Yellowstone country, thousands of them had actually seen the Guernsey springs. The immigrants of the Oregon Trail knew this spring as a welcome landmark, a place to soak sore feet and wash dusty clothes. Along the Oregon Trail, the springs are 662 miles out of Independence, Missouri and four miles from Register Cliff (Haines, 1973). In 1858, soldiers of nearby Ft. Laramie set up a lime kiln to use the limestone from which the springs rise. The springs were then known as "Lime Kiln Springs."

Early descriptions of the site come from many sources including John C. Fremont (1842) and Orson Pratt (1847) (see Haines, 1973). The springs' desert location must be remembered for the stories to be at all credible. Such descriptions as, "gushes with considerable noise, furnishing a beautiful streamlet," and, "shaded by precipitous rocks . . . a very large spring gushes with considerable force," are hardly to be expected from observers today. The Guernsey Gazette of Feb. 14, 1930 reports remains of the army's lime kiln and a wagon train fight near the springs. Little evidence of either exists today, and the springs are two tepid tributaries to a usually dry creekbed in the hills southwest of Guernsey.

Today the springs serve as watering holes for cattle. There are two springs, approximately 200 feet apart, which both produce 21° C water. This temperature is apparently quite constant, for it is reported as the year-round temperature in 1930 (Guernsey Gazette, Feb. 14). The upstream spring is smaller, flowing no more than three gallons per minute. The spring bubbles up through the sandy bottom of a small, shallow pool, flows a short distance, and then disappears into the stream gravel. The second spring flows around 20 gpm from two vents in an irregularly fractured limestone outcrop. The water trickles down a crack and into a two-foot-deep pool before flowing down the valley.

The springs issue from an isolated outcrop of the Hartville Formation. Here the Hartville is a massive, fine-grained, dark brown limestone with interbedded thin, platey siltstone layers and lenses. The springs occur at the base of the exposed formation, a ten foot thick, fractured limestone striking N.56E. and dipping 5° north. The Hartville crops out along the north bank of the stream but disappears beneath Miocene sediments within a short distance. The isolated outcrop probably reflects pre-Miocene topography rather than structure. The only other Hartville outcrops in the region are several miles north.

The structural and stratigraphic relationships of the Guernsey site are unclear. The area is at the north end of the Julesberg Basin which extends along the east side of the Laramie Range south to Colorado. Northeast of the springs the Hartville is exposed in the Hartville uplift. To the west, the Tertiary sediments thin out against the granites of the Laramie Range: the Hartville does not appear there, having thinned out under younger strata.

The Hartville Formation has been little explored as an aquifer, because much better supplies are available from shallower Tertiary deposits. In the Glendo area, 20 miles northwest of Guernsey, four artesian wells flow from the Hartville Formation (Morris and Babcock, 1960), and Dana (1962) reports a non-flowing artesian well in the underlying Guernsey Formation (Mississippian) even miles northeast. The very small exposure of the Hartville at the springs is inadequate to locate it stratigraphically in the 1000-foot-thick Hartville section. If the 5° dip observed at the spring is extrapolated, the strata could reach a depth of 2000 feet within four and one-half miles. The only apparent source of artesian pressure to drive the system is the Hartville Uplift. We cannot propose a specific model at this time.

Comparison of Guernsey spring chemistry to data compiled for all units in southeast Wyoming (U.S. Geological Survey, 1971) shows best correlation with Hartville waters. There are also similarities with waters of the Casper Formation, which intertongues with the Hartville to the south and west.

Table 14. Chemical analyses for Immigrants Washtub

Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3	F	S	SiO_2	B
52	22	19	4.2	0	200	92	3.7	1.2	2.5	<.001	18	.06
						86		1.2				

TDS	Cond	pH	Na%	Hard	Tot CO_2	Date	Reference
322	517	7.9	15	220	99	7/29/76	State Lab No. 7-1333
340						10/24/73	State Chemist for John King

See Notes on the Chemical Analyses, page viii, for explanation of reported values.

Sublette County

KENDALL WARM SPRINGS

Location: Sec.2cda, T.38N., R.110W.
Elevation: 7840 feet
Quadrangle: Klondike Hill
Ownership: U.S. Forest Service
Access: 26 miles north of Cora on the Green River Lakes Road
Temperature: 29.5° C (9/24/76)
Flow: 3600 gpm
Chemistry: Two analyses, page 54

Few historical references to the Kendall Warm Springs exist, although travelers and trappers on the Green River surely noticed the warm waters. The springs have never been developed and are now protected because they are the only waters where the Kendall Warm Springs Dace is found. This species of fish developed after travertine deposits formed a waterfall isolating its ancestors from the river. It is noteworthy that the

Photograph 32. Kendall Warm Springs

Table 15. Chemical analyses for Kendall Warm Springs

Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3	F	S	SiO_2	B
215	52	4.0	2.7		120	650	3.2	0	2.1		15	
220	46	2.3	2.8	0	130	650	2.3	.2	.4	<.001	17	.05

TDS	Cond	pH	Na%	Hard	Tot CO_2	Date	Reference
1000	1250	7.8		749		8/9/66	Welder, 1968
1060	1230	8.0	.7	730	61	9/24/76	State Lab No. 7-2443

See Notes on the Chemical Analyses, page viii, for explanation of reported values.

springs flow across a glacial terrace no more than 10-15 thousand years old: this gives us the maximum time of isolation for the Dace's evolution.

The springs presently flow from a gently westward-dipping slope of the Phosphoria Formation. The six main springs collect into several pools and finally into a single stream within 250 feet of the source. The stream runs west beneath the road and then off a 150 foot wide, 15 foot high travertine cliff into the Green River. Much of the terrace across which the stream flows appears to be underlain by travertine.

The complex structure of the area is poorly exposed because of extensive glacial cover. The springs occur just west of the Wind River Mountains, the western flank of which is cut by many major thrust faults. Thrusting has been largely southwestward, pushing Precambrian crytstalline rocks over the Paleozoic section along most of the front. Where the Paleozoics do crop out they are broken by many faults and deformed into tight folds, most of which follow the trend of the mountains. The Kendall Springs occur where the Phosphoria Formation is exposed near the crest of one such anticline. Immediately east of the Kendall anticline, the strata descend into a syncline. Further east, the Phosphoria re-emerges, overturned against the Wind River thrust (Richmond, 1945).

Recharge for the spring system appears to take place at nearly 9000 feet elevation on the flank of the mountains, either through outcrop or through subcrop beneath porous glacial material. With a maximum depth of around 4200 feet (Richmond, 1945) for the intervening syncline, the waters would be expected to flow from the spring at temperatures equal to or greater than those observed. Artesian pressure can easily drive the system since the springs issue from the Phosphoria at 7800 feet.

While data for Paleozoic chemistry of the Green River Basin are too sparse to allow assignment of these waters to a formation, it does appear that only Paleozoic rocks crop out in the recharge area. Beyond that, the water pathway is a function of rock permeabilities and small scale structures.

STEELE HOT SPRINGS

Location: Sec.16bbb, T.32N., R.107W.
Elevation: 7025 feet
Quadrangle: Fremont Butte
Ownership: Private
Access: One-half mile south of Wyoming 353

Temperature: 35.5° C
39° C (9/24/76)
Flow: 20 gpm
5 gpm
Chemistry: Three analyses, page 55

Bartlett, in 1926, reported the presence of "small bath houses . . . at the Steele Springs." According to Mike Dermody, present caretaker of the springs, the Steele homestead was one of the earliest in the area, so the springs have been privately owned for some time. He further reports that earlier structures had so deteriorated

Photograph 33. Steele Hot Springs

by 1966 that a new shelter was constructed. During the fall of 1976 this structure also was being destroyed in preparation for building yet another facility.

Taking advantage of both the hot springs present, the pool has a large swimming area fed by the cooler spring and a smaller separate bathing area fed by the hotter spring. Dermody reports that the spring temperatures are constant to within ½° C all year. The owners are contemplating using the springs in the future for space heating.

There are two hot spring vents, approximately 150 feet apart, issuing from the base of a granite hill. Each is contained in a concrete box from which PVC pipe carries water 300 feet to the pools. Thermal, chemical, and flow data are given for the larger, cooler spring as No. 1 and the smaller, hotter spring as No. 2.

The springs issue from the corner of Fremont Butte, an 800 foot granite hill surrounded by Quaternary alluvium and Tertiary sediments, on the southwest flank of the Wind River Mountains. The only Paleozoic rocks cropping out within 40 miles are a few small, isolated outcrops just west of Fremont Butte. Strata older than middle Tertiary have been either overridden by thrust faults or deeply buried. According

Table 16. Chemical analyses for Steele Hot Springs

Spring	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3
1	2.4	.2	91.0	1.2		17	14	70	.1
1	2.8	0	90	1.2	29	0	8.2	76	0
2	2.1	0	92	.9	30	0	11	83	0

Hydroxide—1.0 ppm

Spring	F	S	SiO_2	B	Fe	TDS	Cond	pH	Na%
1	14		49	.1	.41	268	460	9.3	
1	14	.8	46	.02	0	302	456	9.6	96
2	14	.8	46	.03	0	300	461	9.7	97

Spring	Hard	Tot CO_2	Date	Reference
1	7.0		9/22/76	Welder, 1968
1	7.0	29	9/24/76	State Lab No. 7-2560
2	5.2	30	9/24/76	State Lab No. 7-2567

Trace Element Analyses

Spring	As	Cu	Mn	Zn	Ba	Cd	Cr	Pb	Se	Ag	Hg	Ni
1	<.05	<.01	<.05	<.02	<.5	<.01	<.1	<.1	<.001	<.5	<.001	<.1
2	<.05	<.01	<.05	<.02	<.5	<.01	<.1	<.1	<.001	<.5	<.001	<.1

Date	Reference
9/24/76	State Lab No. 7-2560
9/24/76	State Lab No. 7-2567

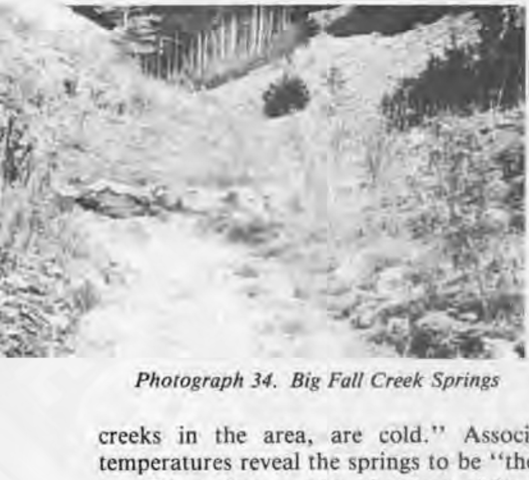
See Notes on the Chemical Analyses, page viii, for explanation of reported values.

to Love (1950) the Paleozoic section is about 26,000 feet deep ten miles southwest of Steele Springs. The chemistry of the Steele waters seems to preclude any but a granite origin. Associated faults in the basement rocks may provide a conduit for convectively rising thermal waters. The low flow of the springs does not require a large recharge area or a high pressure head, and faults of the magnitude observed along this side of the Wind River Mountains could easily provide access from depth.

The Steele waters basically contain sodium carbonate and sodium chloride. They are the only springs analyzed in this report showing measurable hydroxide, and have the highest pH: this is definitely unlike any usual Paleozoic formation waters and, except for the geologic relationships, might suggest Mesozoic or later sediments (Crawford, 1940). The very high flouride values are considered rare in any natural waters as is the high pH (Hem, 1959), particularly associated with low Total Dissolved Solids values.

In sum, this chemistry shows very little resemblance to any data on sedimentary formations. Since granitic ground waters have not been well studied, we assign the Steele waters to a granitic origin more by default than by close correlation.

BIG FALL CREEK SPRINGS



Photograph 34. Big Fall Creek Springs

Location: Sec.20dca, T.28N., R.115W.
Elevation: 8350 feet
Quadrangle: Mt. Thompson
Ownership: U.S. Forest Service
Access: Three miles up creek from the LaBarge Creek Road
Temperature: 16° C (10/7/76)
Flow: 2700 gpm
Chemistry: One analysis, page 57

These springs are not on a major travel route and seem for the most part to have escaped notice. The only reference to their thermal properties comes from Hauf (1963), who writes, "The waters, though slightly warmer to the touch than are waters of other creeks in the area, are cold." Associated travertine deposits and measured temperatures reveal the springs to be "thermal."

The springs consist of at least eight separate sources along approximately 200 feet of Big Fall Creek. Chemical samples are from the largest and highest of the springs, which forms a small pool at the beginning of the creek. Flow is accompanied by constant bubbling, and a sulfurous odor is present. In the area immediately downstream from the hot springs, many more springs occur, all in the 8-9° C range.

The most noteworthy aspect of these springs is the extensive travertine deposition along Big Fall Creek. There are no travertine deposits in the immediate vicinity of the present hot springs, but for two miles below the springs, the creek flows over many travertine terraces and clifflets. The ocurrence of so many nearly level terraces with intervening drops produces a winding, braided stream with frequent falls. The falls are up to three feet high and the terraces commonly fill the falley floor: nowhere has deposition extended much above the present stream level. There is no sign of current deposition. All deposits observed seem to be abandoned or deteriorating. The significance of such past activity is not known, but a chemical study of the travertine is in progress.

The springs issue from the talus just above the creek. The outcrop immediately uphill is a well indurated, medium-grained, dirty sandstone. The unit is moderately fractured and dips downstream at 30°. According to Hauf (1963), the springs are in

Photograph 35. Big Fall Creek terraces

the lower Triassic Dinwoody Formation, stratigraphically just above the contact with the Phosphoria Formation.

On a local scale, the springs occur in an undisturbed section of rocks dipping uniformly southwest an average of 35°. Regionally, the springs occur in the Wyoming Thrust Belt, the structure of which is anything but simple, Here, low angle thrust faulting has sliced the strata into imbricate sheets, which form long belts of north-south trending mountains: this structural style is unlike the pattern of simple anticlinal uplift and block faulting discussed for other Wyoming ranges. The springs on the Big Fall Creek occur in one of these thrust sheets, the Cabin Creek overthrust. There are no obvious faults at the surface near the springs, but subsurface control is sparse and conditions at depth are not known.

Table 17. Chemical analysis for Big Fall Creek Springs

Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3	F	S	SiO_2	B
110	29	4.1	1.4	0	160	260	4.0	.7	1.1	<.001	13	.02

TDS	Cond	pH	Na%	Hard	Tot CO_2	Date	Reference
524	712	7.8	2.3	380	81	9/7/76	State Lab No. 7-2585

See Notes on the Chemical Analyses, page viii, for explanation of reported values.

Teton County

ABERCROMBIE WARM SPRINGS

Location: Sec.2cb, T.41N., R.116W.
Elevation: 6360 feet
Quadrangle: Gros Ventre Junction
Ownership: National Park Service
Access: One-fourth mile west off U.S. 287
Temperature: 27° C (9/23/76)
Flow: 250 gpm
Chemistry: One analysis, page 65

Photograph 36. Abercrombie Warm Springs

These springs were privately owned until 1975 by Fred Abercrombie. They supplied a large concrete pool. Now the pool is substantially deteriorated, and apparently the Park Service has decided to return the springs to their natural state. There is

Photograph 37. Abercrombie Pool

some private interest in the geothermal potential of the area, and an exploratory well may be drilled soon.

There are two separate spring areas in the system. The southern, larger area forms a 70-foot-diameter natural pool three to four feet deep. Many small vents add hot water and gentle bubbling to the clear water of the pool. Outflow is through a ditch to the old concrete swimming pool, and thence into Spring Gulch. The second area, downhill, forms a 20-foot-diameter, apparently stagnant, shallow pool in a swampy area. There are no deposits associated with these springs, and they are the lowest in Total Dissolved Solids of all the springs sampled.

The springs flow from a surface of Holocene loess. East Gros Ventre Butte, just south of the springs, consists of Paleozoic rocks intruded and covered by Tertiary or Quaternary andesites (Love, 1975). What actually subcrops beneath the springs is, therefore, not known.

Structurally, the springs issue along the Warm Springs fault, an east-west normal fault mapped by Love (1975). The fault is concealed by the loess at the spring site, so the magnitude and depth of faulting is undetermined. Cenozoic igneous rocks which occur near the springs may cause a locally high geothermal gradient and account for the warm water surfacing along the fault.

ASTORIA SPRINGS

Photograph 38. Astoria Pool

Location: Sec.32daa, T.39N., R.116W.
Elevation: 5875 feet
Quadrangle: Munger Mountain
Ownership: Private—Porter Estates
Access: On U.S. 89, 17 miles south of Jackson
Temperature: 37° C (9/22/76)
Flow: 100 gpm or more (Bartlett, 1926)
Chemistry: One analysis, page 65

Schultz noted in 1918 that these springs had been first described by F. H. Bradley of the 1872 Hayden Survey. Bradley described "a small cluster [of springs which] escape among the gravel on the south side [of the Snake River] . . . though mixed with river waters they are 117° F (47° C)." He further described a travertine-dammed natural pool from which water flowed at 35°C. Schultz investigated the area in 1906 and reported similar observations, and the addition of a small bathhouse.

Peale (1886) cited temperatures of 38° to 40° C and reported residents' use of the waters for bathing, limited irrigation, and treatment of rheumatism. He further noted that access was by horseback, and expounded upon the suitability of the site for a dude ranch. The time at which the name Astoria was applied is not clear, but it seems to have been well established on the 1963 U.S. Geological Survey topographic map of the area.

Astoria Springs presently consists of a substantial resort development which includes two large bathhouses and a swimming pool. Bill Blakeman, manager of the springs, informed us that most of the complex is around 18 years old, and that previously there was only a natural mud pool.

The actual springs rise through a thick section of alluvium, producing a large marshy area inside a meander of the Snake River. Two concrete collecting boxes have been sunk into the swampy hot spring area. Water is delivered to the pool by gravity and to the bathhouses by pump.

No travertine deposit appears to be forming at the spring site. The report of an early travertine dam and the higher temperatures cited in early publications may suggest an overall decrease in both temperature and mineralization.

The geology of the area has been mapped by Albee (1968). The Astoria Springs rise through Quaternary river gravels from subcropping Mission Canyon Limestone (Madison Formation equivalent). Structurally, the spring site is at the crest of a steep, north-south-trending anticline. On the southern part of the anticline are exposed only post-Mission Canyon sandstones and shales: these units have been breached by the Snake River at Astoria. This is the topographically lowest exposure of the Mission Canyon, and thus the logical place for springs to occur. On both sides of the crest the Mission Canyon Formation rapidly descends some 3000 feet whereupon the structure changes substantially under the influence of several large faults. There are north-south faults on both sides of the springs and the major Darby thrust fault cutting from east to west beneath the area.

Whether the spring is artesian or convective or a combination is obscured by the complicated structure. Precise geothermal models are equally tenuous; but, if water were confined to the Mission Canyon Formation, the observed temperature could be readily obtained at modest gradients.

BOYLES HILL SPRINGS

Location: Sec.36caa, T.41N., R.117W.
Quadrangle: Jackson
Ownership: State of Wyoming
Access: Two miles west off U.S. 189 on a gravel road: a path leads to the west side of the hill
Temperature: 30° C (9/23/76)
Flow: 50 gpm
Chemistry: One analysis, page 65

The warm springs issuing from the west slope of Boyles Hill have attracted little attention through the years. The earliest geologic reference to them comes from a geologic map of the Jackson Quadrangle (Love and Albee, 1972). Their flow and temperature measurements for the springs are slightly higher than this study's. Current use of these thermal waters is limited to flood irrigation of adjacent meadows.

The Boyles Hill Springs consist of several small springs and seeps, flowing from the bases of talus slopes along 200 yards on the west side of the Hill. The largest vent of the group was selected for sampling and represents

Photograph 39. Boyles Hill Springs

about two-thirds of the total flow. Spring waters feed directly into a small tributary of Crane Creek. No significant mineral deposits have been formed by these rather heavily mineralized waters.

Spring flow is from the Cambrian age Gallatin Limestone. These rocks at the spring site dip steeply north and are faulted against much younger strata by a conspicuous east-west trending fault, immediately north of the main (and northernmost) vent. Mapping by Love and Albee (1972) shows this fault to be part of the Jackson thrust, a major thrust fault with northward movement. Displacement on the fault is difficult to determine, but the formations brought into contact bracket over 10,000 feet of the geologic section.

The complex structure of the area precludes determination of precise hydrology; but it can readily be seen that extensive fault zones are available to conduct deep-heated waters to the surface. The Jackson thrust fault, for example, is extrapolated to a depth of at least 3000 feet (Love and Albee, 1972), enough to account for the observed temperatures if the geothermal gradient is in the range .7 to .9° C/100 feet.

GRANITE FALLS HOT SPRINGS

Location: Sec.6ddd, T.39N., R.113W.
Elevation: 6840 feet
Quadrangle: Granite Falls
Ownership: U.S. Forest Service
Access: 12 miles up Granite Creek off U.S. 189

Temperature: 45° C (9/22/76)
Flow: 120 gpm
Chemistry: Not sampled

The Granite Falls Hot Springs are a minoir group which seem closely related to Granite Hot Spring. The Falls Springs consist of three separate vents, all flowing from the east bank of Granite Creek just below the falls. Two enter the creek from just above river level and the third issues from a high fracture, forming a 20-foot waterfall. There is no sign of accompanying mineral deposits. All three springs flow from massive outcrops of the Cambrian Flathead Formation.

GRANITE HOT SPRING

Photograph 40. Granite Hot Spring

Location: Sec.6dab, T.39N., R.113W.
Elevation: 7040 feet
Quadrangle: Granite Falls
Ownership: U.S. Forest Service—private lease
Access: At the end of the road, 12 miles up Granite Creek off U.S. 189
Temperature: 41° C (9/22/76)
Flow: 300 gpm
Chemistry: Two analyses, page 65

The primary use of Granite Hot Spring has always been recreation. In 1933 the Civilian Conservation Corps built the present 50-foot-diameter pool for the free use of National Forest visitors. According to Bill Kunkle, present manager of the pool, user abuse led the Forest Service to lease the pool in 1960 to private firms which could charge a use fee and perform caretaker functions. The spring is currently managed under that system, with use of the pool and dressing rooms available for a small fee.

The single spring runs directly into the concrete pool. Outflow is through several pipes into Granite Creek. Temperature varies inversely with flow rate because thermal water dilution accompanies spring runoff. Temperatures rise from 34° to 45° C as flow decreases. An extreme low temperature measured by the caretaker in June, 1976 was a mere 29° C.

Granite Hot Spring issues from a deep fracture in the Cambrian Death Canyon Limestone not far above its contact with the underlying Flathead Formation. The sediments at the spring site are not steeply dipping, and units up through the Tensleep Formation are exposed on the mountains above Granite Creek. Just south of the spring a large fault juxtaposes Cambrian and Pliocene sediments. With such large displacement, subsurface structure cannot be determined.

The variable flow of the spring indicates communication with surface runoff. Total Dissolved Solids values for shallow wells and non-thermal springs in the area (Cox, 1976) are up to 350 ppm while the Hot Spring concentration appears to be around 635 ppm. Further study of chemical, flow, and thermal variations of the spring could allow us to distinguish shallow (seasonal) from deep water makeups but, at present, the thermal and chemical characteristics of the deep contributions cannot be defined.

The occurrence of springs in deeply fractured parts of both the Death Canyon and Flathead Formations (Granite Falls Springs) suggests ready communication with underlying granites. Cox (1976) notes that the Death Canyon section "probably would not yield more than a few tens of gallons per minute," and the granites of the Teton area "may yield from a few tens to 200 gpm." So rocks beneath the Death Canyon exhibit adequate permeabilities to produce the spring system.

HUCKLEBERRY HOT SPRINGS

Location: Sec.20ba, T.48N., R.115W.
Elevation: 6830 feet
Quadrangle: Huckleberry Mountain
Ownership: U.S. Forest Service—private lease
Access: 1.5 miles west off U.S. 287
Temperature: 61° C (9/21/76)
Flow: 300 gpm
Chemistry: Three analyses, page 65

Peale (1886) mentions these springs near the Snake River; but the first real geologic reference is to "Polecat Springs" (Allen and Day, 1935, p. 336), for the creek which the springs enter. According to Love and others (1975), the springs were long known as Flagg Ranch Hot Springs for the large dude ranch nearby, and acquired their present name in the 1960's when they were developed as a resort.

Renner and others (1975) have used chemical evidence to suggest a subsurface temperature of 150° C, which makes Huckleberry one of two systems in Wyoming, outside of Yellowstone, with possible geothermal generating potential (the other is Auburn Hot Springs).

Photograph 41. Huckleberry Hot Springs

Photograph 42. Huckleberry Pool

The springs now support a small resort complex consisting of a campground, a laundry, and a swimming pool. The springs occur along 750 feet of Polecat Creek as clusters and individual vents or seeps flowing up to ten gallons per minute. Spring temperatures are between 45° and 61° C. The chemistry and flora samples were collected from the swimming pool source, a 45° C natural pool. This 20-foot-diameter by three-foot-deep pool is the only one naturally formed: all other vents run directly into the creek. One of the small vents supplies 61° C water for the laundry. A small dam with headgates has been erected below the group of springs furthest downstream. This gate may be closed to provide a second large, natural-banked swimming pond. According to the present holders of the Huckleberry lease, a water-heated lodge is planned.

Love (1956) has mapped an area of nearly a square mile of hot spring deposits in a broad valley through which Polecat Creek has cut. Love and others (1975) report that the majority of these deposits are siliceous sinter rather than the usual calcium carbonate travertine. This is shown by the high SiO_2 content of the analyzed water.

The springs actually surface through glacial deposits, but the subcrop is Pliestocene Lewis Canyon Rhyolite (Love, 1974). Amorphous silica found in rhyolites is more readily dissolved than is crystallized quartz, which explains the relatively high SiO_2 values for Huckleberry waters. The high mercury value is another indication of volcanic source rocks.

Since the Lewis Canyon Rhyolite is 600 or more feet thick (Love, 1974), it effectively masks earlier formations and structure, so the pre-volcanic geology is poorly known. Most likely, the origin of Huckleberry Hot Springs is similar to that of Yellowstone National Park features (see discussion of Geyser Basins, page 67).

JACKSON LAKE HOT SPRINGS

Photograph 43. Jackson Lake Hot Springs. Photo by J. D. Love, 1 September, 1977.

Location: Lat. 43°57′30″N
Long. 110°41′45″W
Elevation: 6772 feet
Quadrangle: Colter Bay
Ownership: National Park Service
Access: Across Jackson Lake from Arizona Island and U.S. 287
Temperature: 72° C maximum (J. D. Love, oral comm., 1977)
Flow: Undetermined (great)
Chemistry: Undetermined

These springs were described by Teton National Park Rangers in 1964 when abnormally low lake levels exposed vents on the shore. Wagner (1964) described a variety of small springs along 900 feet of shoreline. Temperature measurements were between 24° and 50° C. Flow is accompanied by some gas exsolution which can be seen as bubbles when high water covers the springs. Wagner described the local outcrop as "resistant but highly fractured." Love and Reed (1973) have mapped Madison Limestone at the site.

Structurally, the springs occur along the north-south trending Teton fault system. Behrendt and others (1968) claim that up to seven kilometers of vertical displacement has occurred along this fault, which is largely responsible for the magnificent east face of the Teton Mountains. Also converging at the spring site are two smaller northwest-southeast trending normal faults (Love and Reed, 1973).

The low water level during 1977 enabled J. D. Love to examine these springs further. He reports a maximum temperature of 72° C. Study by the U.S. Geological Survey is in progress.

KELLY WARM SPRING

Location: Sec.2baa, T.42N., R.115W.
Elevation: 6718 feet
Quadrangle: Shadow Mountain
Ownership: National Park Service
Access: One mile north of Kelly on Gros Ventre Road
Temperature: 27° C (9/21/76)
Flow: Undetermined
Chemistry: One analysis, page 65

Photograph 44. Kelly Warm Spring

Forming a deep pool covering approximately an acre, the Kelly Warm Spring provides a unique recreation spot to users of the National Park. Activities as diverse as swimming and warm water kayak practice constitute the principal use of the spring. The pool is up to eight feet deep, has a clean gravel bottom and is replenished through many gently bubbling vents. The sample site was a vent on the northeast shore of the pool. No hot spring deposits are associated with the present pool, but there is an abandoned travertine cone approximately 150 feet north of it.

The close association of this spring with the Teton Valley Warm Springs one mile south can be readily seen in their nearly identical chemistry. The Kelly site is mantled by alluvium and late Tertiary sediments which conceal the structure; but a fault pralleling the Gros Ventre River is mapped between the Kelly and Teton Valley sites. The Kelly site is in line with the trend of the Paleozoic rocks which outcrop to the south, but assignment of waters to the Madison Formation can only be based on chemical similarity at this time.

Chemically, the Kelly Warm Spring waters are within health standards, yet the National Park Service has erected a sign proclaiming them "unfit for drinking." This may indicate bacterialogical contamination or presence of some constituent not appearing in the analysis.

NORTH BUFFALO FORK SPRINGS

Location: Sec.32da, T.45N., R.111W.
Elevation: 7300 feet
Quadrangle: Joy Peak
Ownership: U.S. Forest Service
Access: 15 miles up Buffalo Fork River from Blackrock Ranger Station, at the Junction with Soda Fork

Temperature: 1. 33.5° C
2. 45° C
Flow: 1. 14 gpm
2. 200 gpm
Chemistry: Not Sampled

The authors did not visit these springs, and all information comes from the field notes of Dr. J. D. Love. The springs can be divided into two groups, for the temperature and flow data. The first group (1) occurs on the east side of the Buffalo Fork at its junction with Soda Fork. Several springs are described, "violently bubbling, strong sweetish, sodaish taste and a sulfur smell." The second group (2) is located directly west across the river, where "literally hundreds of gas seeps" occur in a 600-foot-diameter area. Also reported is a growth of red algae. A small patch of travertine has been mapped in the vicinity of the first springs by Love (1956).

Love's 1956 map of Teton County shows the outcrops in the springs area to be Precambrian crystallines. Two faults intersect near the springs site. One strikes east-west along Soda Fork and crosses a major north-south fault.

TETON VALLEY WARM SPRINGS

Photograph 45. Teton Valley Warm Springs

Location: Sec.11aa, T.42N., R.115W.
Elevation: 6680 feet
Quadrangle: Blue Miner Lake
Ownership: Private—Teton Valley Ranch
Access: One mile east of Kelly on the South side of the Gros Ventre River
Temperature: 18° C (9/23/76)
Flow: Undetermined
Chemistry: One analysis, page 65

These springs are used for irrigation and swimming. Through a system of ponds, dams, and ditches the springs now water the crops of the Teton Valley Ranch. Toward the upstream end of the spring area a large pond and dock have been constructed as part of a summer camp complex. The diffuse nature of the spring's flow make precise flow measurements unobtainable; but Phil Wilson, owner of the springs, claims they've been measured at 8600 gpm. He reports a range of 17° to 21° among individual vents but no variation through the year.

The springs consist of an extensive group of springs and seeps in an area approximately 150 feet by 1200 feet along the south river terrace. There are no associated travertine deposits, which is consistent with the springs' rather low mineralization (Total Dissolved Solids = 248 ppm).

The area of the springs is situated at the base of a long slope of deeply fractured Madison Limestone. A 197-foot well was drilled into the Madison at this site in 1972 and struck 19° C water of chemistry very similar to that of the springs (Cox, 1976). Faulting is the main structural control. The Paleozoic section east and south of the springs dips generally eastward. To the west the section ends against a north-south fault, and to the north against a complex of roughly east-west faults and late Tertiary sediments.

Table 18. Chemical analyses for Teton County

Spring	Temp	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3
Huckleberry	45	9.5	.7	200	8.6	0	380	11	120	.1
	61	11	.4	200	8.6		360	9.9	92	0
	61	14	2	197	14	0	375	14	101	
	71	12	1.1	201	7.8		372	12	102	.1
Teton Valley	18	49	16	7.0	1.6	0	180	62	2.0	.5
Kelly	27	54	18	7.6	3.0	0	180	78	3.1	.3
Abercrombie	27	35	17	7.6	2.6	0	190	20	2.9	1.9
Boyles Hill	30	430	120	28	13	0	160	1600	3.9	0
Astoria	37	170	43	120	13	0	300	520	97	0
Granite	41	32	6.4	180	8.8	0	200	150	140	.5
	39	32	5.8	160	8.6		182	120	130	.2

Spring	F	S	SiO_2	B	TDS	Cond	pH	Na%	Hard
Huckleberry	9.9	<.001	170	.74	688	950	7.8	92	27
	8.7		110	.46	613	950	7.4		30
			118		837				
	10		124				7.1		
Teton Valley	.6	<.001	11	.07	248	403	8.2	7.5	190
Kelly	.9	<.001	18	.05	284	450	8.2	7.2	210
Abercrombie	.6	<.001	14	.10	192	348	8.3	9.5	150
Boyles Hill	.5	6.0	26	.06	2480	2380	7.6	3.7	1600
Astoria	.4	.04	26	.17	1160	1550	7.8	29	590
Granite	6.0	<.001	49	.61	670	1050	8.3	77	110
	5.3		48	.53	597	1050	8.0		100

Spring	Tot CO_2	Date	Reference
Huckleberry	190	9/21/76	State Lab No. 7-2615
		10/2/73	Cox, 1976
			Allen & Day, 1935
			White, 1972
Teton Valley	88	9/23/76	State Lab No. 7-2442
Kelly	90	9/21/76	State Lab No. 7-2445
Abercrombie	93	9/23/76	State Lab No. 7-2564
Boyles Hill	76	9/23/76	State Lab No. 7-2446
Astoria	150	9/22/76	State Lab No. 7-2614
Granite	96	9/22/76	State Lab No. 7-2568
		7/27/73	Cox, 1976

Trace Element Analyses (mg/l)

	As	Cu	Fe	Mn	Zn	Ba	Cd	Cr	Pb	Se
Huckleberry	.10	<.01	0	.06	<.02	<.5	<.01	<.1	<.1	<.001
Abercrombie	<.05	<.01	0	<.05	<.02	<.5	<.01	<.1	<.1	.002
Astoria	<.05	<.01	0	<.05	.33	<.5	<.01	<.1	<.1	<.001
Granite	<.05	<.01	0	<.05	<.02	<.5	<.01	<.1	<.1	<.001

	Ag	Hg	Ni	Date	Reference
Huckleberry	<.5	.029	<.1	9/21/76	State Lab No. 7-2615
Abercrombie	<.5	<.001	<.1	9/23/76	State Lab No. 7-2564
Astoria	<.5	<.001	<.1	9/22/76	State Lab No. 7-2614
Granite	<.5	<.001	<.1	9/22/76	State Lab No. 7-2568

See Notes on the Chemical Analyses, page viii, for explanation of reported values.

Photograph 46. Teton Valley Pool

YELLOWSTONE NATIONAL PARK

Introduction

Yellowstone National Park covers 3472 square miles in the northwest corner of Wyoming. In size and variety of thermal features the Park is unsurpassed by any other area in the world. Since men first described the Yellowstone region, its hot springs and geysers have captured the imagination. Recognizing the uniqueness of the area, the Congress of the United States designated Yellowstone the nation's first National Park in 1872. Since then, the area has attracted the attention of explorers, scientists, and tourists in the millions. Yellowstone is probably the most thoroughly studied non-commercial geothermal area in the world, and a plentiful literature exists on it. Because of this, we have chosen to include only a brief synthesis of the literature on the area. Individual references are not made. The annotated bibliography at the end of this chapter will serve as a guide to more comprehensive treatments.

After the Lewis and Clark expedition of 1803, the upper Yellowstone slowly became familiar country to explorers and trappers. Increasingly credible stories appeared through succeeding years, leading the government to organize several exploratory expeditions in the 1870's. It was primarily as a result of these early surveys that the National Park was established. Early scientific work was devoted to describing and classifying the thermal and geologic features of the Park. The attempt has been made in more recent studies to define subsurface conditions and mechanisms using a wide variety of geochemical, geophysical and remote sensing techniques.

Certainly the most complete of the early studies was undertaken by Allen and Day from 1924 to 1935. While some of their ideas on spring origins have since been questioned, their monograph (1935) is unsurpassed as a descriptive work. The bulk of the following section is from that work.

Yellowstone National Park includes around 100 hot spring "groups" with individual thermal features estimated to number up to 10,000. Total flow from the entire system is around 49,000 gpm. Three hundred eighteen springs have been measured at over 90° C, and steam vents go as high as 138° C. Nearly 100 springs exhibit the phenomenon of superheating, water existing as a liquid up to three degrees centigrade above the boiling point. Surface expression of these thermal waters varies from isolated, superheated steam vents to the major geyser activity of the Old Faithful area. Values of pH from 1.9 to 8.9 are but one example of a similarly wide range in chemistry.

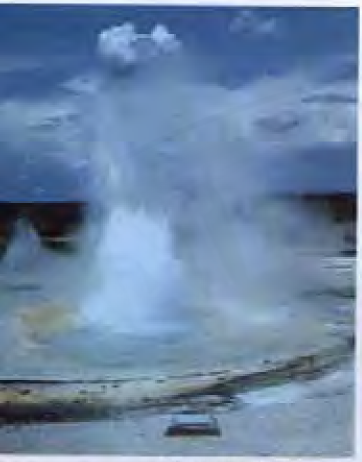
The Geyser Basins

The Upper Geyser Basin is described as the climax of thermal activity in the Park, surpassing any similar area on the globe. The Basin extends northwest from the geysers around Old Faithful down both sides of the Firehole River approximately three miles. It encloses 50 named hot springs and geysers, and discharges hot waters at a rate of 11,040 gpm.

Typical of all the geyser basins, springs here are deep and clear, and flow large quantities of near-boiling water. Names like Emerald Pool, Chromatic Spring, Morning Glory Pool and Sapphire Pool are indicative of their colorful beauty. The main attraction of the area is, of course, the geysers.

Including Old Faithful, Castle, Giant, and Riverside geysers, the Upper Geyser Basin presents an almost non-stop exhibition of eruptive activity. With very few exceptions the waters of the Basin are alkaline, carrying primarily chlorides and carbonates of sodium and potassium as well as substantial dissolved silica. The silica is readily precipitated producing broad sheets of silicous sinter throughout the Basin:

Geyser Hill, Upper Geyser Basin



Clepsydra Geyser

Doublet Pool

Fountain Paintpots

Miniature Sinter Cones

Plate 6. Yellowstone thermal areas I, geyser basins. The geyser basins are best known for their wide variety of eruptive phenomena, numerous deep clear pools, and large spring flows. Waters are abundant, dominantly alkaline, and precipitate sheets of sinter (siliceous) deposits dissolved from rhyolite country rock. The basin margins may contain acid springs. There are six typical geyser basins in Yellowstone: Upper, Midway, and Lower Geyser Basins, Shoshone Lake Basin, Heart Lake Basin, and West Thumb Basin. Norris Geyser Basin is a mixed area exhibiting characteristics of sinter, travertine, and acid types. *All photographs courtesy of the Wyoming Travel Commission*

Soda Butte, NE entrance

Opal Terrace, Mammoth

Travertine (carbonate) areas. Mammoth Hot Springs is the largest travertine area in the Park. Warm waters, laden with calcium carbonate from the solution of limestone, precipitate the intricate terrace and cone features. Spring vents and inlets are complex networks of tunnels dissolved in the carbonate rocks. Outside of Mammoth, only two travertine dominated systems occur, Chaulk Springs and Soda Butte.

Mud Volcano

Sulfur Caldron

Sulfate (acid) areas. Low flows, shallow mud pools, sulfurous gases, and fumaroles characterize the sulfate areas. Acid waters contain dissolved rock material and form unvegetated "frying pan" areas. Mud Volcano, Crater Hills, Mary Mountain, and Hot Springs Basin are the notable sulfate thermal areas. Scattered acid springs occur at the geyser basin fringes and in the northeast quarter of the Park in general.

Plate 7. Yellowstone thermal areas II, travertine and sulfate areas. All photographs courtesy of the Wyoming Travel Commission

one such layer has been measured at 20 feet thick. Sinter serves also to cement surface gravels and to line hot spring pools and geyser tubes.

A vast majority of the Basin's features, and all those described thus far, occur along the bottom of the Firehole Valley. Groundwater levels are quite high, and discharge is often directly into the river.

In contrast to these alkaline type springs, several acid springs in which sulphates and free sulphuric acid dominate exist on the fringes of the Basin. These springs flow very little and deposit only enough sinter and sulphur to give the ground a loose, crusty character. They are commonly associated with ridge and slope areas with poor surface water supply.

Downstream from the Upper Geyser Basin on the Firehole River is the Midway Geyser Basin. It contains 30 significant springs flowing over 4000 gpm along one mile of the river. Basically just a small-scale Upper Geyser Basin, Midway has the Park's largest hot pool, 370-foot-diameter Prismatic Lake, as well as numerous hot springs and geysers.

Next down the Firehole is the Lower Geyser Basin, the most extensive of all the geyser areas. Encompassing nearly 15 square miles, the basin discharges 10,500 gpm from 650 hot springs. It is second only to the Upper Geyser Basin in number of geysers and superheated springs. As further up the Firehole, these lower areas are characterized by large, deep springs and alkaline geysers. The surrounding slopes and ridges have sluggish acid springs. In contrast to the extensive sinter deposits covered with multi-colored algal mats and clear, fast-running streamlets of the geyser basin proper are the caked, lifeless tracts of white and dull yellow earth characteristic of the acid areas. Typical of such acid areas are the Fountain Paint Pots where spring waters are heavily laden with multicolored silt and clay.

Another typical geyser basin is located on the western shore of Shoshone Lake. Shoshone Geyser Basin is a small basin, flowing only 1050 gpm, but it exhibits many of the characteristic geyser basin features. The largest geyser in the group is Union Geyser which has erupted to a height of 114 feet. Deposits in the main basin are the silicious sinter commonly found with high-flow alkaline springs. A predominantly acid area is separated from the geyser basin proper by a low ridge: we can see side by side the two basic types of Yellowstone thermal areas.

West of Heart Lake, along two and one-half miles of Witch Creek, are 20 active geysers and a number of hot springs flowing 1650 gpm. All features of the Heart Lake Geyser Basin are of the alkaline type, following the pattern of the Upper Geyser Basin.

The sixth and last of the typical geyser basins is on the west bank of the West Thumb of Yellowstone Lake. West Thumb Geyser Basin contains two distinct groups of deep, clear, sinter-depositing springs and geysers discharging a total of 750 gpm. West Thumb has a few acid features, most notable of which are the Thumb Paint Pots, presenting a modest display of pink and white tints. Compared with the major geyser basins, West Thumb is somewhat cooler: of 39 temperatures recorded in 1928 only 12 exceeded 90° C.

There are several smaller groups of springs displaying the same type of thermal activity as the geyser basins, but on a much smaller scale. Such springs are found west and south of Lewis Lake and in the vicinity of the confluence of the Lewis and Snake Rivers. Springs of generally "alkaline" character with some chemical variations occur at Clearwater Springs south of Obsidian Cliff, at Terrace Springs on the Gibbon River south of Norris, on Alum and Violet Creeks west of the Hayden Valley, at Rainbow Springs 11 miles east-northeast of Canyon, and at several localities on Pelican Creek. Huckleberry Hot Springs, described in the Teton County section, are another example of this type of spring.

As spring chemistry changes so does the character of the area around the springs. One of the more obvious changes occurs as increased calcium carbonate content of the water results in travertine deposition. A number of springs in the Park are depositing both travertine and sinter. Among these are Firehole Lake in the Lower Geyser Basin and Hillside and Terrace Springs in the Gibbon area. Chemically, these springs represent the transition from the sinter-depositing silica geyser basins to the second major spring group, the travertine carbonate areas.

Mammoth Hot Springs

By far the largest travertine area in the Park, the Mammoth Hot Springs are aptly named. Located near the Park's northern boundary on the Gardner River, the Mammoth terraces cover over one-half square mile. Massive travertine cliffs and pools, streamers of multi-colored algae, and cascading sheets of 70° C water make Mammoth one of the most spectacular areas in the Park. Although total discharge is only 900 gpm, travertine terraces cover the hillside for nearly 400 feet above the lower portions of the system. There are no geysers in the Mammoth area; the springs quietly discharge clear water across the terraces. Typical of the calcium carbonate terrain, waters often flow into fissures and cavities and reappear elsewhere. The main outlet for the Mammoth system is believed to be the Hot River Spring, flowing nearly 10,000 gpm at 53° C from the base of a travertine cliff one and one-half miles northeast of the main Mammoth complex.

Outside the Mammoth area only two occurrences of travertine-dominated systems are known. The Chaulk Springs on the Snake River have built up a small travertine fan, and Soda Butte near the Park's northeast entrance is a large travertine cone. In the latter area, there are no thermal or mineralized waters flowing at present.

Sulfate Areas

The third major group of spring areas recognized by Allen and Day (1935) is the sulfate type. These areas show, in local dominance, the type of sulfate springs which occur individually at the fringes of the geyser basin. Typified by low flows, large quantities of sulfurous gases, murky and muddy waters, and minor deposits of sinter and sulfur, sulfate areas appear as barren as any in the Park. Where pools do form, their shallow and violently bubbling character has led to the name, "frying pans." Superheated waters are rare because of the abundant gases, but superheated steam commonly occurs in many fumaroles. Temperatures for sulfate areas are from 65° C to 130° C through water and steam phases.

In strong contrast to the geyser basins, even the largest sulfate areas rarely flow more than 50 gpm. Topographically these areas are generally confined to hillsides and uplands, following the pattern seen in the geyser basins. In contrast to the high silica, chloride, and carbonate content of the geyser basin waters, sulfate waters are generally low in chloride and rarely contain enough silica to form extensive deposits. These waters are high in sulfates, and frequently enough sulphur is present to form free sulfuric acid.

Sulfate springs areas are rarely as clearly defined as the alkaline springs of the geyser basins are, but several major systems can be distinguished. The most accessible, and therefore most studied, large sulfate tract is the Mud Volcano area on the west side of the Yellowstone River, eight miles north of Lake Junction. In this system are the most spectacular mudpots in the Park. Notable examples are Dragons Mouth, Black Dragons Caldron, Mud Geyser and Mud Volcano. Although the waters are only 68° C, the abundant gases produce a boiling appearance in the sediment-filled waters. Where the mud is viscous enough, larage bubbles throw mud clear of the spring, building up small "volcanoes."

A few miles north of the Mud Volcano group is a more dispersed area of sulfate thermal activity in the Crater Hills. Free sulfur deposits are common at this site, and gas flow is quite high. The Crater Hills area has one of the few geysers in a sulfate region. This geyser's water is alkaline with high chlorine, a characteristic of the geyser basin waters.

The Mary Mountain area, midway between Canyon Village and Old Faithful, has many acid areas consisting primarily of steaming sands and barren ground with little or no outflowing water. This area produces some of the most strongly acid waters in the Park, and sulfur deposits are quite common.

Many other sulfate springs occur in lesser concentrations throughout the Park. Such areas can often be recognized from afar by the white, unvegetated ground surrounding them. With very few exceptions, the entire northeast quadrant of the Park is the province of scattered acid springs. Largest of these areas is "Hot Springs Basin," covering one and one-half square miles with sulfurous pools, mudpots, "frying pans," and small fumaroles. Amphitheatre, White Rock, Roaring Mountain, and Sylvan Springs are the principal sulfate zones in the Gibbon-Norris area. East of Yellowstone Lake, sulfate waters occur at Turbid Lake, along Turbid Creek, and at Steamboat Point. The Steamboat Point emissions appear to be part of a larger system along the lake edge, venting superheated steam through the beach sands for several miles.

Mixed Areas

Thus far we have presented sulfate and alkaline hot springs as something of a dichotomy. As with the sinter-travertine transitional springs, however, there are a great many thermal features in Yellowstone which must be considered intermediate between typical alkaline and sulfate. Such areas are seen as mixtures of the two distinctive types of surface expression and as surface features connoting subsurface mixture of the two types of water. The prime example of a mixture is the Norris Geyser Basin. Covering about one square mile, it is a very heterogenous assortment of clear, deep springs; geysers; sandy, gaseous tracts; muddy springs; mudpots; vast sinter deposits; and loose, caky sulfur areas. Thirty-five geysers were erupting in the Norris Basin in 1926, and superheated steam vents have been measured at 138° C. Chemistry varies widely and has been found to change within a single spring between sampling periods. Flow from the basin varies between 600 and 2000 gpm, further revealing a far less stable system than the Firehole geyser basins.

Less extensive areas of mixed type occur south of Norris at Elk Park, Gibbon Hill, Artists Paint Pots, and Geyser Creek. Butte Springs, east of Yellowstone Lake, is primarily acid but includes two hot, deep, clear, sinter-lined alkaline springs. Violet Springs, west of Hayden Valley, deposits free sulfur, yet for a sulfate area has an abnormally high flow of 740 gpm. Below Tower Junction on the Yellowstone River are Calcite Springs flowing 40 gpm of high-sulfate and high-chloride waters.

Geology

Geologically, Yellowstone is made up of a thick series of volcanic rocks. The geyser basins are underlain entirely by rhyolitic rocks of Quaternary age. The most recent of these rocks were emplaced as few as 60,000 years ago, providing near-surface geothermal gradients up to one thousand times "normal."

Volcanically, Yellowstone is by no means an extinct area. From earliest Cenozoic time the Park has been the site of extensive, often violent volcanism. This supply of molten rock around 1000° C from deep within the earth makes Yellowstone one of the world's foremost geothermal areas.

The springs and geysers of the geyser basins actually issue from stream and glacial sediments derived from these rhyolites. In one section of the Upper Geyser Basin, for example, these sediments are over 220 feet thick. The high influx of thermal waters has modified the original sediments, in that mineral deposition has drastically reduced and concentrated permeable zones, and chemical exchange has changed sediment mineralogy.

The final control on spring and geyser occurrence is the thick blanket of sinter. The overall result is a sediment-filled basin, commonly steeply bounded by rhyolite hills. Drainage naturally provides such basins with a plentiful water supply, which in turn accounts for the tremendous output of thermal waters.

In the three travertine areas described in the previous section there are limestones present at shallow depths. In general, the areas are very similar to the geyser basins with chemical modifications occurring as water percolates through the carbonate sections. At Mammoth, the limestones of the Jurassic Ellis Group supply calcium carbonate to the springs, which is redeposited as travertine terraces. For the small groups mentioned from the Snake River and the extinct cone of Soda Butte, the well-known Madison Limestone is the formation which controls the mineralogy of the deposits.

The northeast section of the Park, where thermal features are generally less active and more acid, is covered with a thick section of older volcanics. These are primarily the Eocene andesites of the Absaroka Range. Quaternary volcanics are represented over much of the area by the Lava Creek Tuff, which apparently spread outward from the south central portion of the Park. Thermal features occur primarily in this tuff or through sediments covering it and, less commonly, in the older andesites.

Structurally the Park on the whole is rather simple. Volcanic flows tend to spread out horizontally, and the recent nature of the Park deposits has precluded any large scale post-depositional deformation. Layer upon layer of volcanics have built up a thick pile, locally covering older and structurally more complex rocks, as at Mammoth. Thus, none of the spring systems described appears to have a significant artesian component.

Structural control of spring occurrence does appear, however, to be under the influence of faults and fissures. Early workers failed to notice this relationship, but recent detailed mapping and definition of subtle lineaments on high altitude photographs have led to a correlation of spring occurrences with fractures. Faults are usually normal and follow the approximately north-south orientation of the regional stress pattern. Seismic Geyser in the Upper Geyser Basin, for example, first appeared following the 1959 Hebgen Lake earthquake. Although the earthquake epicenter was on a fault 38 kilometers away, the geyser appeared as part of a linear spring group parallel to the main fault.

Another fault system apparently controlling thermal feature distribution is the Yellowstone Caldera. Around 600,000 years ago, huge quantities of material were violently expelled from the central portion of the Park, which led to surface collapse over nearly 800 square miles. Subsidence occurred along a complex system of ring fractures which provided escape pathways for subsequent lava and tuff eruptions, as well as for the later hot springs.

Deeper sections of the Park are less well understood geologically, and consequently a variety of deep models has been proposed to explain the observed surface relationships. The most recent hypothesis (Truesdell and Fournier, 1976), based on thermal and geochemical data, is that one vast, slowly cooling magma body exists at depth. Presumed molten below six kilometers or so, this body is the ultimate heat source for the entire Yellowstone system in all its variations.

Hydrology

For the most part, hydrologic conditions of the Yellowstone system are interpreted from geochemistry. As was shown in the descriptive section, a chemical classification of the thermal waters closely follows their grouping on the basis of flow, topography, deposits, dimensions, types of features, and general appearance.

Thus, some strong genetic relationship logically must exist. Much evidence has been and is still being gathered as scientists attempt to explain the complex Yellowstone geothermal system. The following model represents current thought in this continuing investigation (Figure 11).

As stated above, a molten magma chamber is assumed to exist beneath most of the Park. Rock crystallization in this chamber produces two effects, the liberation of great quantities of heat and the expulsion of volatile components. Heat is transferred away from the source by conduction through previously solidified rock and by mass transfer of steam and carbon dioxide with lesser amounts of hydrogen sulfide and methane. Surface-derived waters circulate down through the volcanic pile to form a large, high pressure reservoir around three to five kilometers deep. As a result of constant cooling and addition of magmatic material, a heavily mineralized brine is created capable of remaining liquid at the inferred temperature of 340 to 390° C.

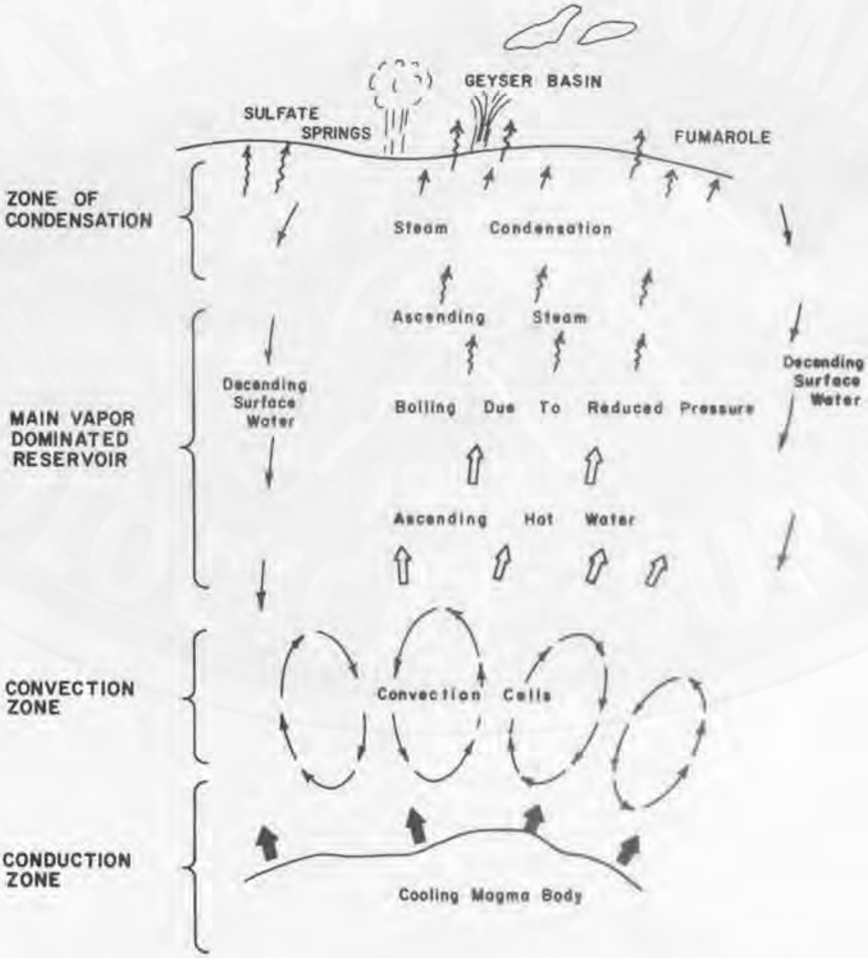


Figure 11. Schematic cross section of the Yellowstone geothermal system

This deep reservoir contains many strong convective cells transporting heat from below to higher levels where decreased pressure causes boiling. With the substantial cooling which accompanies steam formation, tremendous amounts of energy are rapidly moved upward through the system. Isotopic studies indicate that the actual addition of water from the magma is from zero to five percent of the total output, further supporting the model of a water supply primarily derived from the surface. The complete lack of seasonal variation in most areas indicates the presence of a reservoir large enough to buffer seasonal variation in supply.

As the convective mixture of steam and water rises toward the surface, rock permeabilities, water supply, and convection configuration are the variables which begin to affect surface expression. The steam-to-water proportions, for example, can readily be seen to depend on water supply. Rock permeability affects rate of flow and, by controlling pressure gradients, affects steam formation. As upward convection dominates the center of a system, the outlying areas supply the cooler return flow.

When mineralized waters boil, the volatile components, particularly hydrogen sulfide, concentrate in the steam fraction. If sufficient temperature is maintained, this steam will escape at the surface super-heated in proportion to its pressure of formation. If a shallow groundwater supply exists, atmospheric oxygen in the water will combine with the hydrogen sulfide to form sulfuric acid. The acid, in turn, works on the local rocks, reducing rhyolites to clay minerals. Thus, a classic sulfate area is formed.

Drill tests show that formation of acid generally occurs within ten feet of the surface and is most favored by loose, porous soils. The shallow and limited water supply is therefore critical in the development of these areas. Acid weathered rocks produce muddy waters and mudpots. Superheated steam produces fumaroles and "frying pans." Sinter deposition is slight because most of the silica remains in the parent water far below.

The Geyser Basins, then, represent the water portion of the system. Deep circulation of surface waters is enhanced by the low viscosity, low density and high silica solubilities in very hot waters. Steam fractionation of volatiles increases water alkalinity, decreases its rock weathering capabilities, and concentrates silica in it. Thus, these waters arrive at the surface in large volume, generally clear, and with a large load of silica. Because of the low gas content, superheated waters may occur.

Silica deposition in the higher portions of geyser systems forms their delicate plumbing. In many areas silica cementation of sediments near the surface is almost complete, creating an impermeable cap which in some cases contains pressures up to 147 percent of those possible in an open system. Such "self-sealing" is particularly common in the outlying sections of a hot spring system and frequently causes the death of the springs. The demise of many springs and geysers can be directly linked to the appearance of new vents nearby. Major earth movements may cause rearrangements in spring plumbing systems, as at Seismic Geyser. Imperial Geyser erupted so vigorously in the 1880's that it "cleared its throat" and became a quiet spring. More violent forms of this release of subsurface pressure can be seen in explosion craters up to 5000 feet in diameter. Pocket Basin in the Lower Geyser Basin is such a crater, formed when draining of a glacial lake rapidly decreased pressures, causing subsurface water to explode into steam.

Mammoth Hot Springs and the other travertine areas are readily explained, as the carbon dioxide-rich waters easily dissolve carbonate rocks. As the pressure and quantity of carbon dioxide decrease at the surface, calcium carbonate is precipitated. The maximum rate of precipitation measured at Mammoth is 22.2 inches per year. Travertine in non-limestone areas is less common, but may occur as calcium is leached from andesites and basalts.

Variations on these general patterns are common because a number of parameters are subject to change. The sulfate areas on the fringes of the geyser basins seem to represent a gaseous fraction derived from the primarily liquid system. In a basin like Norris, both types of springs are represented as well as mixtures of the two types.

Norris is also the most changeable of the hot spring areas, indicating a high rate of subsurface evolution. Various writers have developed ideas for the sequence of this evolution, but the most reasonable assumption seems to be that there is no clear pattern. The Mud Volcano area, for example, is currently a classic vapor dominated system, but old sinter deposits indicate earlier occurrence of high water flow. Given an abundant surface supply, water will gradually increase its deep circulation, which will result in geyser basin type springs. If heat supply changes relative to water supply, steam formation may increase and surface expression will change accordingly. Another example of the type of chemical variation represented at Mammoth is the high calcium and magnesium waters of Washburn Hot Springs, which rise through basaltic gravels rather than the usual rhyolites.

To summarize, Yellowstone National Park overlies a huge, slowly cooling magma body. Through rock conduction and convection of surface-derived waters in both water and steam phases, heat moves to the surface. Because the upper sections of this system are subject to variations in rock permeability, composition, and structure and in quantity of water supplied, a wide range of surface features results. These features number around 10,000, produce nearly 50,000 gpm of hot water, and make Yellowstone the world's most spectacular, if not its largest, geothermal system.

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GEOTHERMAL RESOURCES

Naturally occurring warm and hot waters have been used by mankind for thousands of years. Therapeutic, ceremonial, and recreational uses are probably the oldest, but hot spring waters were being diverted for space heating by the Romans as long as 2000 years ago.

As both the complexity and technological skills of society increase, energy demands prompt a corresponding increase in natural resource exploitation. Exploration of the Lardarello geothermal field in Italy led to the world's first geothermal powered electrical generation complex in 1904. Geothermal power has been the subject of local interest throughout this century, but has achieved national importance only in the last decade or so as a result of the energy and environmental "crises." Geothermal energy is currently being converted to electricity in Italy, New Zealand, Japan, Russia, Mexico and the United States. Additional use for industrial and space heating is being pursued in many countries of the world, particularly those with sparse fossil fuel resources and hydroelectric potential.

In the United States, geothermal resources are the object of a tremendous boom in interest. Small space heating projects date from the last century and The Geysers area in California has been producing electricity since 1960. Not until 1974 were federal lands made available for geothermal development leases. As soon as the Geothermal Steam Act went into effect, 2456 lease applications were filed in the 11 western states (Fuchs, 1975). By 1976, 133 Known Geothermal Resource Areas (KGRA's) were identified, covering 3,176,542 acres of western land. A total of 1,700,000 acres of federal land were leased for geothermal exploration in 1976 (U.S. Geological Survey, 1976).

So far, the majority of geothermal interest has been in California, Nevada and Oregon. Yellowstone National Park has been excluded from development, and Wyoming ranks near the bottom of the list of western states in recognized geothermal resources. Three leases have been filed on federal lands in Wyoming, all in Teton County. Lease applications for two tracts of state land in Fremont County and one in Teton County were turned down in 1973. Three leases have been granted on state lands in Lincoln County, adjacent to similar tracts in Idaho.

Only two areas of Wyoming outside Yellowstone are identified by the U.S. Geological Survey (Renner et. al., 1975) as having geochemically indicated subsurface temperatures in excess of 90° C: Huckleberry and Auburn hot springs. These are classified as "attractive for space and process heating," cooler waters being considered useful only under special circumstances. It must be pointed out, however, that little detailed investigation has been done in Wyoming, and the preceding is meant only as a statement of progress rather than the final word.

The highest ranking geothermal reservoirs are those producing superheated steam. This dry steam can be simply tapped and channeled through turbines to produce electricity. Such ideal systems are presently producing only at Lardarello, The Geysers, and Matsukawa, Japan. They are presumed to be rare.

Next in importance are very hot water systems in which a fraction of the water is flashed to steam to power turbines. This is the type of system producing electricity at Waireiki, New Zealand, and Cerro Preito, Mexico. Lower temperature systems are not currently being used for electrical generation, but development of two-stage heat exchange cycles involving isobutane may allow such use in the future.

Resources in the 90° to 150° C range are readily adapted to space heating and are used on a large scale at Boise, Idaho, and Klamath Falls, Oregon. As part of the Energy Research and Development Administration (ERDA) investigation of geothermal energy, the Idaho National Engineering Laboratory has undertaken a pilot project on the Raft River in which 149° C water will be used first to power isobutane turbines, then to supply heat to a variety of food processing plants, a feed lot, and a fish farm. As low-temperature utilization methods are developed, of course, the range of useful geothermal resources expands. Agriculture, fish culture, limited space heating, and processing heat are of particular relevance to Wyoming in that the bulk of her recognized geothermal resources are low rank.

Theoretically, any source of heat, no matter how small, can contribute its energy to our useable supply. For example, any water above 20° C could, in sufficient volume, be used for space heating. Through the use of heat pumps, energy could be extracted from natural waters of any temperature. Certainly, the highest ranking geothermal sources (dry steam) are the most valuable; but, as man continues to indulge himself in ever-increasing energy consumption, the full range of the earth's resources will have to be explored.

Wyoming's geothermal areas outside the Park occur as a result of overall warming with depth in the earth. The rate of warming (geothermal gradient) is primarily a function of the heat flow from deep within the earth.

For heat flow, the highest formally published values are 1.8 to 2.0 μcal/cm^2 sec in the Black Hills (Blackwell, 1969). Elsewhere, a single value near Meeteetse is 1.8 μcal/cm^2 sec (Blackwell, 1969), one in the Wind River Mts. is 1.2 μcal/cm^2 sec (Sass and others, 1971), and three in the Green River Basin are in the range 1.3 to 1.6 μcal/cm^2 sec (Blackwell, 1969; Sass and others, 1971). Inasmuch as the worldwide average is about 1.5 μcal/cm^2 sec, most of Wyoming would be defined as a zone of normal to slightly above normal heat flow.

As heat flows through the earth's crust a gradient is set up in response to many variables such as rock conductivity, structure, lithology, fluid content, and heat sources (e.g. radioactivity). As these parameters add and subtract effects, a locally enhanced gradient may result. Our thermal springs are examples. An anticlinal structure, for instance, might carry warm, deep rocks to higher positions. If fluid circulation is then naturally established with the surface, a thermal spring can result. Clearly, wells could artificially create such circulation, and so tap natural "concentrations" of heat.

In assessing structurally related geothermal resources one can take advantage of the parallel interests of the oil and gas industry. Bottom hole temperatures have been used to compile three gradient maps for Wyoming (Kehle, 1972; Hale, 1976). Since hydrocarbon exploration holes are not drilled primarily for thermal data, however, considerable discretion must be used in analyzing such data. Effects of drilling fluids, logging techniques, and nearby production, for example, are neither negligible nor constant.

Taken together, the gradient maps seem to confirm the generally low rank of Wyoming's non-Yellowstone geothermal resource. Most of the gradients are in the .4 to 1.2° C/100 feet range, (normal gradient is approximately 25° C/km or .76° C/100 feet, (Decker, 1976)). According to gradients (1.4 and 1.5° C/100 feet) presented by Blackwell (1969), northeast Wyoming may be hotter than the rest of the state, exclusive of Yellowstone.

The anomolous character of northeastern Wyoming is of particular significance in the present study, for that is the one section of the state without thermal springs. So again we see the connection of springs with structure, not with high values of heat flow or gradient. Similarly, Wyoming's thermal springs (outside of Yellowstone) are not closely related to Tertiary volcanism as they are through most of the West. Such volcanics occur in the Rattlesnake, Leucite, and Black hills, none of which are sites of significant thermal spring activity.

Another source of geothermal waters without surface expression occurs in geopressurized sedimentary basins. Water is trapped beneath impermeable rocks in such a system and becomes highly pressurized with succeeding sedimentation. This is the cause of spectacular oil well blowouts and may well induce flow of very deep, hot waters to the surface. The geopressurized resource is currently being investigated in the Gulf of Mexico. Its potential in Wyoming has not been studied, although many oil and gas fields in the state are known to be pressurized.

In conclusion, we first must emphasize that a study of thermal springs is not a comprehensive study of geothermal resources. Just as surface oil seeps represent only the most obvious and easily developed expression of a vastly larger resource, thermal springs are but one indication of geothermal potential. Nationwide, geothermal exploration today uses remote sensing, gravity and magnetic surveying, electrical and thermal well logging, and seismic techniques to evaluate the resource. Based on the thermal and geochemical data which are provided by thermal springs and on heat flow and gradient data, it must be concluded that, excluding the Park, Wyoming has little potential for development of very hot, electrical-generating-quality geothermal resources.

However, in terms of lower temperature waters valuable for space heating, industrial processing, and agriculture and livestock production, geothermal resources must be evaluated on a local scale. We have described many areas where warm and hot waters flow naturally at the surface. There are logically many more sites where hydrology and geology couple properly to provide such waters at depths easily accessible through drilling. With advances in geothermal technology and increased public interest, use of low temperature geothermal resources will inevitably result.

Since the physical, legal and economic aspects of geothermal development are particular to specific projects and sites, precise resource areas cannot be delineated at this time. However, Wyoming's geothermal resources may well assume an increasingly significant position in her overall energy supply, and we encourage further investigation and assessment of the resource.

VISITOR'S GUIDE

Since 1808, when John Colter described the hot springs of "Colter's Hell," attention has focused on Wyoming's thermal features. The Indians, of course, knew and used the springs for centuries. Chief Washakie of the Shoshone tribe is reported to have had a bathhouse erected over Black Sulfur Spring at Thermopolis, and the Steele Springs in Sublette County were frequently used as therapeutic baths.

White men "discovered" many of the springs early in the 19th century, following Colter's visit. Public interest in the preservation of the many spectacular thermal features in Wyoming's northwest corner led to the establishment of Yellowstone National Park, the nation's first, in 1872. Early travelers on the Oregon Trail stopped to wash clothes in a warm spring near Guernsey, giving it the name, "Immigrants' Washtub." The Thermopolis hot springs were incorporated into a State Park in 1897, and commercial development at the De Maris Springs near Cody began about the same time. Greatly increased interest in mineral waters for medicinal purposes, around the turn of the century, spurred more careful investigation of Wyoming's thermal springs, and prompted development of bathhouses and sanitariums at several sites.

Fifteen spring sites are now open to the public for a variety of activities: these sites are listed in Tables 19 and 20. All thermal springs listed in the Inventory are not presented because many occur on private land. Ownership status of these is listed in the Inventory and *all visitors must contact landowners before exploring*. Several of the undeveloped spring sites listed are under private lease or necessitate crossing private land for access. Visitors are urged to contact appropriate landowners in such cases and to respect their property at all times. The commercial springs, of course,

Table 19. Developed thermal springs

County	Name	Access	Temp. (°F)	Description
Carbon	Saratoga Hot Springs	on west bank of Platte River near south end of Saratoga	118	free public bathing pool, public swimming pool (fee), commercial pool and facilities at Saratoga Inn
Converse	Jackalope Plunge	7 mi. south of Douglas on Esterbrook Road	86	commercial swimming pool, accommodations in Douglas
Fremont	Washakie Hot Springs	3.5 mi. southwest of Ethete	111	commercial swimming pool, accommodations in Lander
Hot Springs	Hot Springs State Park	NE corner of Thermopolis	133	2 main springs, spectacular terraces, buffalo herd, State Bathhouse (free), several commercial pools, complete facilities on site
Park	Bronze Boot Spa	2 mi. west of Cody	90	commercial swimming pool, accommodations in Cody
Teton	Astoria Springs	17 mi. south of Jackson on U.S. 26	99	commercial swimming pool and bathhouses, food on site, accommodations in Jackson
Teton	Huckleberry Hot Springs	1.5 mi. west of U.S. 287 just north of Flagg Ranch	142	commercial swimming pool and laundry, food on site, accommodations at Flagg Ranch
Teton	Granite Hot Springs	26 mi. south of Jackson on U.S. 189, 12 miles up Granite Creek	106	small rustic commercial pool, accommodations in Jackson

Table 20. Undeveloped thermal springs on public lands

County	Name	Access	Temp. (°F)	Description
Big Horn	Little Sheep Mtn. Spring	S.off U.S. 14-A along W. bank at Bighorn River, ½ mile into little Sheep Canyon, at river level	68	two shallow pools in river
Fremont	Warm Springs Creek Spring	S. off U.S. 287, 5.1 mi. NW of Dubois; cross Wind River, then .6 mi. up warm Spring Creek, springs at creek and on south bluff	84	deep pool on bluff, many springs on creek, *land under BLM lease* to Wagon Bar Ranch (at creek mouth)
Platte	Immigrants Washtub	S. off U.S. 26 along west side of Platte R. near Guernsey, 2 mi. up 1st large drainage	70	2 small springs with shallow pools, *access crosses private land*
Sublette	Kendall Warm Springs	26 mi. north of Cora on Green River Lakes Road	85	many small springs and pools, *no swimming or bathing allowed* due to unique fish population
Teton	Kelly Warm Spring	1 mi. north of Kelly on Gros Ventre Road	81	1 large, natural pool
Teton	Abercrombie Warm Spring	4.7 mi. north of Jackson on U.S. 26, ¼ mi. west of road	86	several small springs, pool abandoned
Teton	Granite Falls Springs	26 miles south of Jackson on U.S. 189, 11 miles up Granite Creek, below falls	113	2 small springs on creek, 1 forming 20 ft. fall, no pools

require a use fee and are only open at certain times. Public springs are generally open all year.

When visiting hot springs areas, it is important to respect the natural aspects of the springs and to do nothing to destroy their beauty. Travertine cones and terraces take centuries to build up and the scars of a thoughtless footprint or a broken formation will not easily heal. Algae populations give the springs their brilliant colors and exist in a delicate equilibrium with the thermal waters. Algal mats are often poorly anchored and recover slowly from disruptions. Trash and coins thrown into pools and terraces become incorporated into the deposits and interrupt the natural processes. For example, Minute Geyser in Yellowstone stopped erupting when the vent tube was filled with rocks by ignorant tourists.

Temperatures cited are maximum, taken right at the spring. Waters will have cooled somewhat by the time they reach swimming pools or natural ponds. It has been our experience that while anything over 70° F (21° C) may feel warm to the touch, 85° F is a minimum for comfortable bathing.

The listed springs are arranged in two groups. In the first are those with developed swimming or bathing facilities. These have generally good access and commonly provide food and lodging concessions nearby. In the second group are those springs in a primitive state. These may or may not have natural pools, are frequently remote from main roads, and are generally of lower temperatures than those of the first group.

Fort Washakie Hot Springs

Granite Hot Springs

Huckleberry Hot Springs

Astoria Hot Springs

Hobo Pool, Saratoga Hot Springs

State Bathhouse, Hot Springs State Park, Thermopolis. *Wyoming Travel Commission Photo*

Plate 8. *Hot spring bathing.* Bathing in hot springs has long been a favorite activity for both health and recreation. The chemistry of hot spring mineral waters is complex, and has not been quantified with regard to health factors. A number of sites in Wyoming (see Visitor's Guide chapter) offer developed facilities for bathers.

Colored algae at Excelsior Geyser, Firehole River, Y.N.P. *Wyoming Travel Commission Photo*

Dying pines and colorful algae, Opalescent Pool, Y.N.P. *Wyoming Travel Commission Photo*

Mats of green and blue-green algae in warm pool, Y.N.P.

Monkey flowers thriving in hot springs along the Gibbon River, Y.N.P. *Wyoming Travel Commission Photo*

Plate 9. *Vegetation of thermal springs.* Hot springs often support abundant vegetation specially adapted to their seemingly hostile environment. Growth of more common plants in these areas may be enhanced by moderate winter temperatures or destroyed by the heat and chemicals. Four major types of organisms are commonly found in hot springs waters: bacteria, blue-green algae, green algae, and diatoms. Each one has a range of temperature and chemistry conditions in which it can grow. Much of the brilliant coloration associated with hot springs is due to the pigments of these organisms.

VEGETATION OF WYOMING THERMAL SPRINGS OUTSIDE OF YELLOWSTONE NATIONAL PARK

by
Terry T. Terrell*

Introduction

One of the most striking features of warm springs is the great variety and array of colors present. While some of these colors are due to mineral deposits, most result from aggregations of huge numbers of brightly colored microorganisms. These microorganisms range in color from white through reds, oranges, yellows, browns and purples, to deep greens and blue-greens. There are four main groups represented in most warm springs, the Bacteria (Schizophyta), Blue-green Algae (Cyanophyta), Green Algae (Chlorophyta) and Diatoms (Bacillariophyta). Occasionally, the Yellow-green Algae (Xanthophyta) occur peripherally to the hot springs in areas where the water temperature is near ambient. Seldom are they important components of hot springs systems. Each group has its characteristic colors and textures, so that the four main groups can be distinguished visually with a little practice.

Bacteria, Schizophyta

The bacteria are very primitive and simple one-celled organisms which lack a nucleus. Because of this simplicity, they can withstand higher temperatures than can members of the other groups, and some can live in boiling water (212° F, 100°). Bacteria growing at such high temperatures are highly adapted to this type of environment and cannot survive in cooler areas. Although the bacteria are microscopic, they aggregate in large numbers and have such characteristic colors and textures that they are easily identifiable with the naked eye. There are three main types—those that occur in long white streamers, those that occur in yellowish or whitish clumps, and those that are very bright pink-purple clumps or layers. While none of these bacteria photosynthesize (use the sun's energy for food production), the last two types, those occurring in whitish or yellowish clumps and those in pink-purple clumps or layers, can use sulfur available in many hot springs in their process of food production.

Blue-green Algae, Cyanophyta

The blue-green algae are a very old and primitive group. There is good fossil evidence that they were the first photosynthetic organisms to evolve on earth, and that they came into being over a billion years ago. While the blue-green algae are primitive in the sense that they lack a nucleus, they have developed photosynthetic pigments which give them very characteristic colors. As the name suggests, all members of the group have a blue pigment, phycocyanin, and a green pigment, chlorophyll (all photosynthetic organisms contain the green chlorophyll pigment). Many appear blue-green to the naked eye. Some are so dark blue-green that they appear black. Other pigments are present, too. These include phycoerythrin, a red pigment, and various carotenoids which are shades of yellow, brown and orange. When the conditions are right, these other pigments may combine with or mask the blue and green pigments to give a striking array of colors. Blue-green algae may appear

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*Department of Botany, University of Wyoming, Laramie, Wyoming 82071 red, reddish-brown, tan, olive green, orange, yellowish, or purplish as well as blue, blue-green, or black.

The group also has a distinctive array of textures which may help to distinguish it from the others. Members of the group may appear as a mass of fine filaments or threads interwined, as a solid sheet or mass resembling rubber, or as very coarse filaments.

If you wish to be certain you are looking at a blue-green alga, there is an excellent way to determine this. Take a small portion home, wash it carefully and place it in a plastic bag with a small amount of water in your home freezer. Remove the plastic bag from your freezer after a few days and allow it to thaw. If the water turns blue, the alga you collected was a blue-green, and you have just extracted its blue or phycocyanin pigments.

Blue-green algae are the most common and obvious inhabitants of warm springs. Some may only grow in the very warmest portions of the spring and be unable to survive at more moderate temperatures. Others can tolerate fairly high temperatures but grow best in cooler portions of the spring. In most hot springs, most of the vegetation is usually blue-green algae.

Green Algae, Chlorophyta

The green algae are unicellular, have a nucleus, and are very similar to higher plants in many respects. They are not inhabitants of the hottest portions of hot springs, but are very abundant in the coolor portions. These cooler portions of hot springs approximate the temperatures and conditions found in small ponds and lakes in the summer all over the world, and thus the inhabitants are similar to those found in such habitats. The character of hot springs, with their warm and fairly constant temperatures, allows these microscopic inhabitants to live in constant summer temperatures, and to reproduce in large numbers. They may remain unicellular or form in long chains or filaments and these filaments may become tangled into mats. Their chief pigment is the green chlorophyll and they are easily recognized by their bright grass green color.

Diatoms, Bacillariophyta

The diatoms are an extremely interesting group. Besides having a nucleus and chlorophyll, as well as some of the yellow, orange and brown carotenoid pigments, they have the unique ability to construct cell walls out of silicon, the same material used in making window glass. They are similar to the green algae in the sense that they are not true inhabitants of the hottest parts of hot springs. They also take advantage of the summerlike conditions of the cooler parts. They never grow in the great profusion witnessed among the other groups, and will be found as fine, feltlike, brownish-yellowish-green masses on rocks and twigs in warm springs.

List of Genera of Algae and Types of Bacteria Found in Hot Springs in Wyoming, Outside of Yellowstone National Park

Following is a list of the genera of algae and types of bacteria found in the various hot springs in the State of Wyoming, outside of Yellowstone National Park. Smith's *Freshwater Algae of the United States* is an excellent source of line drawings of the genera, and Copeland's "Yellowstone Thermal Myxophycaeae" an excellent source of descriptions of species of Cyanophyta which occur in hot springs, if you wish to go into much greater detail. For the general reader, *Life in the Geyser Basins* by Brock and Brock is a well written, simple description of the hot springs of Yellowstone National Park, and has several attractive color photographs.

HOT SPRING	GROUP	GENERA
Abercrombie Warm Springs (Teton)*	Chlorophyta	*Cladophora*
Astoria Springs (Teton)	Schizophyta	?
	Cyanophyta	*Lyngbya*
		Phormidium
Auburn Hot Springs (Lincoln)	Schizophyta	Purple Sulfur Bacteria
	Cyanophyta	*Lyngbya*
		Oscillatoria
		Spirulina
		Phormidium
	Chlorophyta	*Ulothrix*
	Bacillariophyta	*Denticula*
		Rhopalodia
		Cymatopleura
		Anomoeoneis
		Navicula
		Gomphonema
Big Fall Creek Springs (Sublette)	Bryophyta (Moss)	?
Big Spring, Thermopolis (Hot Springs)	Schizophyta	?
	Cyanophyta	*Phormidium*
		Mastigocladius
Boyles Hill Springs (Teton)	Schizophyta	Purple Sulfur Bacteria
	Cyanophyta	*Lyngbya*
		Phormidium
		Synechocystis
Conant Creek Springs (Fremont)	Cyanophyta	*Oscillatoria*
		Spirulina
De Maris Hot Springs (Park)	Schizophyta	?
	Cyanophyta	*Oscillatoria*
		Lyngbya
	Chlorophyta	*Spirogyra*
	Bacillariophyta	*Cymbella*
		Gomphonema
Douglas Warm Spring (Converse)	Cyanophyta	*Oscillatoria*
		Synechocystis
Granite Falls Hot Springs (Teton)	Schizophyta	Purple Sulfur Bacteria
		?
	Cyanophyta	*Oscillatoria*
	Bacillariophyta	?
Granite Hot Springs (Teton)	—	—
Immigrants Washtub (Platte)	Cyanophyta	*Lyngbya*
		Oscillatoria
	Chlorophyta	*Cladophora*
	Xanthophyta	*Tribonema*
	Bacillariophyta	*Navicula*
		Cymbella
		Diatoma

*The county in which it occurs follows each hot spring name.

HOT SPRING	GROUP	GENERA
Hobo Pool, Saratoga Hot Springs (Carbon)	Cyanophyta	*Spirulina*
		Phormidium
		Chroococcus
		Oscillatoria
		Rivularia ?
	Bacillariphyta	*Ceratoneis*
		Cymbella
Horse Creek Spring #1 (Natrona)	Cyanophyta	*Phormidium*
		Spirulina
		Oscillatoria
	Chlorophyta	*Spirogyra*
		Microspora
	Bacillariophyta	*Navicula*
Horse Creek Spring #2 (Natrona)	Chlorophyta	*Microspora*
		Spirogyra
	Xanthophyta	*Vaucheria*
	Bacillariophyta	*Rhopalodia*
		Gomphonema
		Navicula
Horse Creek Spring #3 (Natrona)	Chlorophyta	*Dichotomosiphon*
		Ankistrodesmus
Huckleberry Hot Springs (Teton)	Cyanophyta	*Anabaena*
		Oscillatoria
		Phormidium
		Spirulina
	Bacillariophyta	*Navicula*
		Pinnularia
		Surirella
		Rhopalodia
		Denticula
		Epithemia
		Camplodiscus
Kelly Warm Spring (Teton)	Chlorophyta	*Rhizoclonium*
	Bacillariophyta	*Amphora*
		Gomphonema
		Nitzchia
Kendall Warm Springs (Teton)	Cyanophyta	*Oscillatoria*
	Chlorophyta	*Spirogyra*
	Bacillariophyta	*Epithemia*
Little Sheep Mountain Spring (Big Horn)	Chlorophyta	*Spirogyra*
	Bacillariophyta	*Stauroneis*
		Melosira
		Frustulia
		Navicula
		Pinnularia
		Gyrosigma
		Surirella
Little Warm Spring (Fremont)	—	—

HOT SPRING	GROUP	GENERA
Sacajawea Well, Thermopolis (Hot Springs)	Schizophyta	?
	Cyanophyta	*Phormidium*
Sheep Mountain Springs (Big Horn)	Cyanophyta	*Oscillatoria* *Tolypothrix* *Scytonema* *Merismopedia ?*
	Bacillariophyta	*Epithemia* *Pinnularia* *Nitzchia* *Meridion* *Rhopaloida* *Cymbella* *Navicula* *Gomphonema*
Sweetwater Station Springs (Fremont)	Cyanophyta	*Oscillatoria* *Phormidium*
	Chlorophyta	*Spirogyra*
Teton Valley Warm Springs (Teton)	Chlorophyta	*Spirogyra* *Rhizoclonium*
	Bacillariophyta	*Gomphonema* *Synedra* *Amphora*
Warm Spring Creek Springs (Fremont)	—	—
White Sulphur Spring, Thermopolis (Hot Springs)	Schizophyta	?
	Cyanophyta	*Phormidium*
	Chlorophyta	*Spirogyra*
Wind River Canyon Spring (Hot Springs)	Cyanophyta	*Oscillatoria*
	Chlorophyta	*Spirogyra* *Zygnema* *Microspora*
	Xanthophyta	*Vaucheria*
	Bacillariophyta	*Cocconeis* *Navicula* *Synedra*

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GLOSSARY

ALLUVIUM—material deposited by recent streams and rivers, usually sand and gravel

ANDESITE—a volcanic rock of intermediate composition, commonly a deep reddish purple color in Yellowstone

ANTICLINE—an upwarped fold of rock layers, opposite: syncline (see Figure 2, page 4)

AQUIFER—a subsurface rock layer capable of producing water

BASALT—a dark, fine-grained volcanic rock, composed of calcium plagioclase and pyroxene

FAULT—fracture in the earth along which movement has occurred

GEOTHERMAL—heated by geologic processes or conditions

HYDROLOGY—the science relating to the water of the earth

HYDROSTATIC HEAD—the height to which water will rise in an open column by virtue of the pressure upon it

IGNEOUS—rocks formed by solidification from a molten state (magma)

IMPERMEABLE—not allowing passage of water

MAGMA—naturally occurring molten or partially molten rock

RHYOLITE—a light colored, fine-grained volcanic rock; compositional equivalent of granite

SECTION—in this paper usually the geologic section, the local sequence of rock layers (see Figure 12, page 101)

SINTER—a chemical sediment deposited by mineral springs, mostly silica (SiO_2)

SYNCLINE—a downwarped fold of rock layers, opposite: anticline

TDS—Total Dissolved Solids (chemical constituents); determined by addition of component parts or by direct measurement

THERMAL SPRING—a natural spring flowing at least 15° F above mean annual surface temperature

TRAVERTINE—a chemical sediment deposited by mineral springs, commonly calcium carbonate ($CaCO_3$)

VOLCANIC—coming from a volcano, pertaining to rocks erupted and solidified at the surface

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APPENDIX I, WYOMING ROCK COLUMN

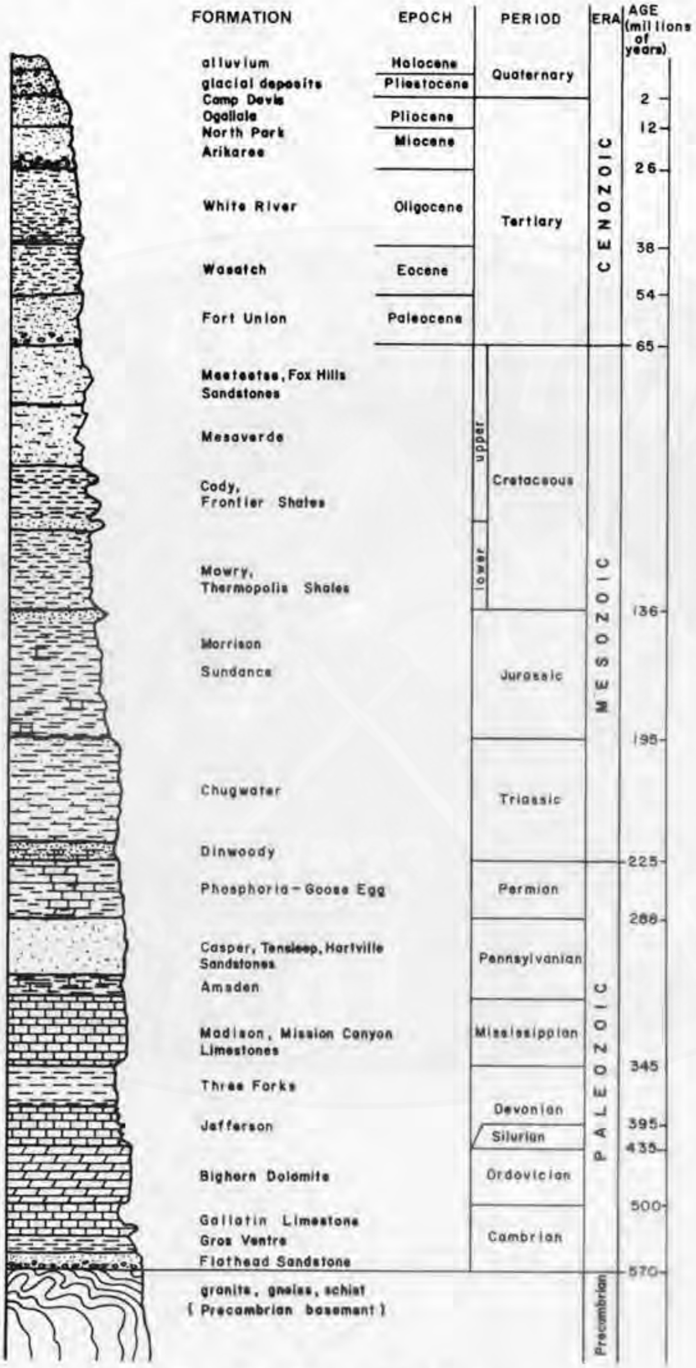

Figure 12. Wyoming rock column.

APPENDIX II, USEFUL TABLES

Table 21. Celsius—Fahrenheit conversions

(Rounded to nearest degree F — °C x 1.8 + 32 = °F)

°C	°F	°C	°F	°C	°F	°C	°F	°C	°F
7	45	21	70	35	95	49	120	63	145
8	46	22	72	36	97	50	122	64	147
9	48	23	73	37	99	51	124	65	149
10	50	24	75	38	100	52	126	66	151
11	52	25	77	39	102	53	127	67	153
12	54	26	79	40	104	54	129	68	154
13	55	27	81	41	106	55	131	69	156
14	57	28	82	42	108	56	133	70	158
15	59	29	84	43	109	57	135	71	160
16	61	30	86	44	111	58	136	72	162
17	63	31	88	45	113	59	138	73	163
18	64	32	90	46	115	60	140	74	165
19	66	33	91	47	117	61	142	75	167
20	68	34	93	48	118	62	144	76	169

Table 22. Flow conversions

Gallons/min	Cubic ft/sec	Gallons/day	Acre ft/yr
100	.223	144,000	161
448.8	1.000	646,272	724
696	1.550	1,000,000	1122
619	1.380	892,640	1000

Table 23. Gradient conversions

°C/100 ft	°C/km	°F/100 ft
1.000	32.8	1.800
.305	10.0	.549
.556	18.2	1.000

Table 24. U.S. Public Health Service Drinking Water Standards (1962)

Supply should be rejected where alternative is or can be made available if concentrations exceed (in mg/l):

As	.01	Mn	.05
Cl	250	NO_3	45
Cu	1.0	SO_4	250
F	.8-1.7*	Zn	5
Fe	.3	TDS	500

Supply should be rejected if concentrations exceed (in mg/l):

As	0.5	Pb	.05
Ba	1.0	Se	0.1
Cd	.01	Ag	.05
Hg	.002	F	1.6-3.4*

* F standard varies with amount consumed

INDEX OF HOT SPRING NAMES AND NAMES OF OTHER FEATURES