Structural Geology and Geothermal Investigation of the White Sulphur Springs Area, Montana

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STRUCTURAL GEOLOGY AND GEOTHERMAL INVESTIGATION
OF THE WHITE SULPHUR SPRINGS AREA, MONTANA

by

William G. Gierke

A Thesis
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the
requirements for the
Degree of Master of Science
Department of Geology

Western Michigan University
Kalamazoo, Michigan
April 1987
Sevier thrusting in the White Sulphur Springs area was associated with left-lateral movement along the Lewis and Clark line. During Middle Miocene time, the Lewis and Clark line exhibited right-lateral movement, forming extensional features that either truncated Sevier structures or followed preexisting Sevier zones of weakness.

The Smith River Valley is a pull-apart basin that is filled with Tertiary volcanic ash and clay-rich sediments that are thermally nonconductive relative to surrounding rocks.

Hydrothermal activity in the area is associated with a structurally controlled circulation system accompanied by a high thermal gradient. Thermal discharge is constrained along the north-trending White Sulphur Springs normal fault. Calculated reservoir temperatures ranging from 52°C (Na-K-Ca-Mg) to 99°C (Quartz) indicates that variable degrees of mixing occur. The estimated reservoir temperature (72°C ± 10°C) limits thermal development in the area to space heating and recreational use.
ACKNOWLEDGEMENTS

I would like to acknowledge the following people who provided assistance during the formulation of this thesis. Foremost thanks go to Dr. John Sonderegger of the Montana Bureau of Mines and Geology (MBMG) for providing this thesis topic, field assistance, necessary literature, constructive criticism, and pleasant hospitality. I am obliged to the MBMG for financial support and analyses of water samples; Michael Stickney (MBMG) for contributing his gravity data and interpretations of the White Sulphur Springs area; John Gogas (Montana College of Mineral Science and Technology) for supplying his gravity maps, models, and interpretations of the area; S. L. Groff (MBMG, retired) for sharing his knowledge of the area studied; and Mitchell Reynolds (USGS) for his structural advice and geologic contributions of the area.

Special gratitude is given to my committee chairman Christopher J. Schmidt (Western Michigan University) for his assistance in the field and direction throughout this project; Western Michigan University professors Dr. W. Thomas Straw, Dr. William Sauck, Dr. John Grace, and Robert Havira for their support and contributions; and Mark Sheedlo (Western Michigan University) for his geologic advice and moral support.

I would like to thank Frank Murphy, Howard Zehtner, Mr. Bodell, Mr. and Mrs. Saunders, Bob Hanson, Ronald Jackson, and the people of White Sulphur Springs for their hospitality and kindness. Thanks
also to Sue Gibson for typing the thesis. Finally, I would like to thank my wife Suzanne for her steadfast support, motivation, and encouragement.

William G. Gierke
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Western Michigan University, 1987

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CHAPTER I

INTRODUCTION

Location and Description

The White Sulphur Springs area is located in west-central Montana east of the Big Belt Mountains, northwest of the Castle Mountains, and south of the Little Belt Mountains (Figure 1). U.S. Geological Survey quadrangle maps that encompass the map area include the White Sulphur Springs, Willow Creek, Manger Park, and the Catlin Springs Quadrangle. The study area encompasses approximately 103 square miles and extends from 110° 46' 45" to 110° 56' 52" W latitude and from 46° 24' 23" to 46° 37' 19" N longitude.

The hot spring, for which the town is named, is located near the intersection of U.S. Route 12-89 and Main street about seventy feet southeast of the Spa Motel. To the north and across the street from the Spa Motel is the thermal bank well (Plate 1).

Objective and Procedures

This study is part of an investigation by the Montana Bureau of Mines and Geology to determine the potential for thermal development in the vicinity of White Sulphur Springs. To assess the thermal potential of an area, the characteristics of the hydrothermal system must be identified. These features include the geologic controls on recharge-discharge patterns, geochemistry, hydrogeology, reservoir
Figure 1. Index map and general geographic setting of the White Sulphur Springs area.
characteristics, and the heat source of the thermal system. Field work in the area was designed to use various disciplines of geology in order to understand the system and its potential for development.

Field work was done in the White Sulphur Springs area during the summers of 1981 and 1982. Work accomplished the first season included detailed geologic mapping north and east of town, a well water inventory, static-water level measurements, and a water sampling program. In the second field season the following field work was done: reconnaissance gravity survey of the Smith River Valley, detailed geologic mapping south of town, and completion of the water sampling program with well waters from the Castle Mountain Lumber Company and the home of Ralph Jordon.

Geologic mapping was done on 1:20,000 twelve by twelve inch black and white aerial photos, and then transferred to 1:24,000 U.S. Geological Survey quadrangle maps. Existing geologic maps that were used included thesis maps by Dahl (1971) and Phelps (1969), and a reconnaissance map by Groff (1965). Sampling procedures and data acquisition for the water sampling program and gravity survey will be discussed in their designated chapters.

Previous and Related Works

Previous research on the origin and controls of thermal waters in the White Sulphur Springs area has been very limited; however, other types of geologic work, including mapping, stratigraphic interpretation, and petrology have been conducted in the area. Geologic work in the area was first done by Grinnell and Dana (1876), who
primarily studied Tertiary deposits in the Smith River Valley. The first geologic report of the Castle Mountain mining district was made by Weed and Pirsson (1896) and included lithology, petrology, and general geology of the area. Proterozoic Belt Supergroup rocks in the area were later named and described by Walcott (1899). Koerner (1939) mapped Tertiary deposits in detail and older rocks in a more general manner along the western margin of the Smith River Valley.

The first geologic map that included stratigraphic and structural detail of the area was done by Tanner (1949). Pardee (1950) briefly discussed the Smith River Valley in a paper in which he attributed the origin of the basin to the effects of crustal downwarping. A paper by Wolfe (1964) discussed the geomorphic history of the Smith River Valley. The paper related Late Cenozoic uplift of west-central Montana to the formation of mountains and intermontane basins.

Winters (1965) published a report on the geology and ore deposits of the Castle Mountain mining district. The district is located approximately 4 miles southeast of White Sulphur Springs.

Groff (1965) conducted a reconnaissance geologic and hydrologic study of Meagher County. The majority of his hydrologic study was concentrated around the White Sulphur Springs area. Master's theses in the area that were completed under the direction of S. L. Groff include Phelps (1969), Birkholz (1967), and Dahl (1971). The detailed map areas included within these theses are mainly north and west of White Sulphur Springs.

The first reservoir temperature and energy estimates of the White Sulphur Springs hydrothermal system were made by Renner, White,
and Williams (1975). Chemical data used for their derivations were obtained from the U.S. Geological Survey. Chemical analysis of thermal waters in White Sulphur Springs was done by Mariner, Presser, and Evans (1976). Water that was analyzed consisted of the Brewers spring (now Spa Motel well) area. A soil temperature survey was later completed by Chadwick, Galloway, and Weinheimer (1977) in an effort to determine the areal extent of thermal influence. The study was concentrated on the city block that includes the hospital and Spa Motel. In 1978, the First National Bank of White Sulphur Springs thermal well was drilled. A geologic report by Dunn (1978) presented hydrologic and lithologic data for the well. Pump tests, temperature profiles, geophysical logs, and drilling evaluation of the bank well was done by Stoker and Niemi (1978).

Reynolds (1979) was the first to identify the Smith River Valley as a fault-bounded basin. He discussed the tectonic origin of the valley and its relationship to thermal activity. A metallogenic map showing the general geology of the White Sulphur Springs Quadrangle was published by McClernan (1980). Woodward (1981) briefly discussed the Scout Camp-Willow Creek (now Moors Mountain) thrust zone and its relationship to the disturbed belt of west-central Montana.

Estimated reservoir temperatures and discharge values for the Spa Motel and bank wells were briefly discussed on the Geothermal Resources of Montana map (Sonderegger & Bergantino, 1981). A more detailed discussion of thermal activity in White Sulphur Springs was done by Sonderegger and Schmidt (1981). A resistivity survey involving Schlumberger soundings was done in 1981 by Montana Tech students.
under the direction of Charles Wideman. The purpose of the survey was to delineate areas of hydrothermal activity and associated stratigraphic controls.

Gogas (1984) conducted a gravity survey of the Smith River Valley. His paper includes interpretations regarding the structural geology and geometry of the Smith River Valley based on gravity data and two-dimensional modeling.
CHAPTER II

GEOLOGIC SETTING

Regional Setting

The White Sulphur Springs area is located at the margin of two major structural provinces in west-central Montana: the Late Cretaceous-Early Tertiary Montana disturbed belt and the Late Cenozoic Basin and Range Province. The eastern end of a regional linear structural element, the Lewis and Clark line or Montana lineament, is also located in the area (Figure 2). With exception of the Volcano Valley fault to the northeast, the Moors Mountain thrust in the White Sulphur Springs area is the easternmost thrust exposed in the Montana disturbed belt (Plate 1). The eastern margin of this belt corresponds closely with the eastern limit of Proterozoic Belt Supergroup deposition and with the western margin of the stable craton (for example, Harris 1957; Harrison, Griggs, & Wells, 1974; Mudge, 1970; and others). The Helena structural salient is a pronounced eastward bulge in the disturbed belt (Figure 2). The convex eastward geometry of the salient closely follows the Proterozoic depositional margin of the Belt trough or Helena embayment (Harrison et al., 1974). This embayment is bordered on the north and south by Archean gneisses and schists. Thrusts involving Beltian and Phanerozoic rocks appear to have impinged on these bounding basement rocks, accentuating the convex eastward shape of fold and thrust features in...
Figure 2. Structural provinces and regions of western Montana (modified from Schmidt & Hendrix, 1981).
the Helena salient. West of the craton's margin, Paleozoic and Mesozoic sediments comprise the Cordilleran miogeocline.

Basins and ranges in Montana are considered to be a northern continuation of extensional tectonism of the Great Basin region of Nevada, western Utah, and southeastern Idaho (Chadwick, 1981; Reynolds, 1979). The normal fault from which the White Sulphur thermal spring discharges occurs at the northeastern limit of basin and range faulting mapped in west-central Montana (Figure 3; Reynolds, 1979). The Smith River Valley may be a graben bounded by faults associated with extensional features south of the Lewis and Clark line (Reynolds, 1977, 1979). The range front fault along the eastern margin of the Smith River basin (Figure 3) corresponds with the eastern extension of the Lewis and Clark line (Reynolds, 1979).

The Smith River Valley is bounded by the Big Belt Mountains to the west, the Little Belt Mountains to the north-northeast, and the Castle Mountains to the east (Figure 1). The Big Belt Mountains form a broad, northwest-trending, doubly plunging arch. The Big Belt Mountains are probably a culmination of folded thrust faults that are mainly developed in Belt Supergroup rocks; however, in many portions of the arch, Beltian strata have been thrust over Paleozoic rocks (Lageson, Dresser, Schmidt, & Welker, 1982). Many thrusts in the northern Big Belt Mountains are intensely folded (Shaffer, 1971; Woodward, 1981) making regional correlation of thrusts difficult. On the southwestern flank of the arch a northwest-trending escarpment consisting of Beltian and younger sedimentary rocks are folded and thrusted (Lageson et al., 1982). Rocks as old as Chamberlain Shale
Figure 3. Locations of basins and ranges in western Montana and southeastern Idaho. (From Reynolds, 1979).
(Figure 4) may crop out near the center of the Big Belt Mountains indicating a thick Belt Supergroup sequence in the area (Reynolds, personal communication, 1982). Northeast of White Sulphur Springs the Little Belt Mountains form a broad east-west-trending arch (Figure 1). The Little Belt uplift exposes Belt Supergroup and Paleozoic rocks which are cored with Archean gneisses and schists that have been intruded by Tertiary plutons. Southeast of the Smith River Valley, the Early Miocene Castle Mountain stock truncates Paleocene (Laramide) folds and thrusts.

Local Stratigraphy

Introduction

Because the primary objective of this thesis is to define the geothermal potential and structural geology of the area, only a brief description of stratigraphy will be presented here. Detailed stratigraphic descriptions of the area were given by Birkholz (1967), Hruska (1967), Phelps (1969), and Dahl (1971), and on U.S. Geological Survey maps of the Ringling and Black Butte Quadrangles (McGrew, 1977a, 1977b). Detailed stratigraphic depositional and paleostructural history of rocks in the area were presented by Sloss (1950); Ross, Skipp, and Rezak (1963); McMannis (1965); Harrison (1972); Harrison et al. (1974); Suttner, Schwartz, and James (1981); and Peterson (1981).

Sedimentary rocks exposed in the White Sulphur Springs area range in age from Late Precambrian to Late Tertiary (Figure 4).
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<td>Quaternary Alluvium: Gravel, sand, silt, and clay in the Smith River Valley at elevations generally less than 500 ft. (152 m). Gravel may be well sorted, subrounded to rounded, and beach cobbles common.</td>
</tr>
<tr>
<td>LANDSLIDE DEPOSITS</td>
<td>Landslide Deposits (Ota): Debris flows and colluvium consisting of poorly sorted clay to boulder size material, locally found on the flanks of Castle Mountain.</td>
</tr>
<tr>
<td>TERTIARY SEDIMENTS UNDIVIDED</td>
<td>Tertiary Sediments Undivided (Ta): Fort Logan and Deep River Formations.</td>
</tr>
<tr>
<td>VOLCANO BUTTE BASALTS</td>
<td>Volcano Butte Basalts (Opb): Black basalt weathering brownish-gray; finely crystalline, occasionally vesicular.</td>
</tr>
<tr>
<td>RHYOLITE PORPHYRY</td>
<td>Rhyolite Porphyry (Tpp): Light-gray weathering to buff-gray with concentric red and orange staining. Fine-grained rhyolite porphyry with sandine and quartz phenocrysts (1-2 cm). Locally found in the vicinity of the Castle Mountain area.</td>
</tr>
<tr>
<td>CASTLE MOUNTAIN GRANITE AND SYENITE</td>
<td>Castle Mountain Granite and Syenite (Tcs): Fine to medium-grained granite and syenite that accompany faulting. Not abundant in the map area.</td>
</tr>
<tr>
<td>ANDESITE</td>
<td>Andesite (Tad): Dark grayish-brown fine-grained andesite. Locally found as sill that accompany faulting. Not abundant in the map area.</td>
</tr>
<tr>
<td>CRETACEOUS UNDIVIDED</td>
<td>Cretaceous Undivided (Km): Light-gray, white, tan, and gray mudstone, shale, and sandstone. Intermixed with black, gray, and green mudstone in the upper part. Thickness estimated 500-700 feet (152-213 m).</td>
</tr>
<tr>
<td>KOOTENAI FORMATION</td>
<td>Kootenai Formation (Kaa): Gray, red, and purple mudstone with white lines. Intermixed with light-gray sandstone, yellowish-orange siltstone, and gray mudstone. Thickness observed 200 feet (61 m).</td>
</tr>
<tr>
<td>MORRISON FORMATION</td>
<td>Morrison Formation (Kmm): Light-gray and yellowish-orange, calcareous mudstone and siltstone. Very fine-grained andesite with some red and yellow iron-stain banding. Thickness observed 150-200 feet (46-61 m).</td>
</tr>
<tr>
<td>QUADRANT QUARTZITE</td>
<td>Quadrant Quartzite (Kq): White to tan quartzite; extremely resistant-riptide forcer. Thickness 35 feet (11 m).</td>
</tr>
<tr>
<td>AMSDEN FORMATION</td>
<td>Amsden Formation (Kpa): Light-gray, weathering white to thin, thick bedded dolostone. Intermixed with pale-grayish-orange, fine-grained quartzitic sandstone in the upper part. Ped sandstone, siltstone, and mudstone interbedded with gray limestone in lower part. Thickness 320-600 feet (98-183 m).</td>
</tr>
<tr>
<td>TYLER SANDSTONE</td>
<td>Tyler Sandstone (Kpl): Tan to rusty-brown fine to medium-grained sandstone. Large scale cross-bedding with local lenticular pebble conglomerate. Total thickness 45 feet (14 m).</td>
</tr>
<tr>
<td>BIG SNOWY GROUP UNDIVIDED</td>
<td>Big Snowy Group: Undivided (Km): Mission Canyon Limestone, Oldman (middle), and Kootenai (lower).</td>
</tr>
<tr>
<td>MISSION CANYON LIMESTONE</td>
<td>Mission Canyon Limestone (Km): Gray to light-gray, shaly, massive limestone. Bedded limestone, some breccias, and black mudstone. Thickness 500-800 feet (152-244 m).</td>
</tr>
<tr>
<td>LODGEPOLE LIMESTONE</td>
<td>Lodgepole Limestone (Km): Gray to light-gray, shaly, massive limestone. Bedded limestone, some breccias, and black mudstone. Thickness 500-800 feet (152-244 m).</td>
</tr>
</tbody>
</table>
The total thickness of the section is approximately 15,220 ft (4634 m), excluding Quaternary sediments; however, Belt Supergroup strata and Paleozoic carbonates are the predominant rocks seen in the outcrop.

An outcrop of Chamberlain Shale and possibly Neihart Quartzite surrounds a pluton that cores Mt. Edith in the Big Belt Mountains (Reynolds, personal communication, 1982). Exposures of these older Belt Supergroup rocks (Plate 1) suggest that a thick Precambrian section exists below the Smith River Valley. Archean basement rocks are not exposed in the area. The nearest exposure of Archean rocks is about 27 mi (43 km) north of White Sulphur Springs, near the town of Neihart.

Precambrian Belt Supergroup

Belt Supergroup rocks in the area have a total thickness of approximately 9000 ft (2744 m) and consist of the Newland Limestone, Greyson Shale, and Spokane Shale. The thickness of the Newland Limestone is not precisely known because its lower contact has not been identified in the area. The Newland Limestone contains lenses of siltstone and locally thick beds of sandstone. The Greyson Shale conformably overlies the Newland Limestone. Its lithology ranges from micaceous shale (lower unit) to thin-to-medium bedded sandstone with interbeds of micaceous shale and irregular beds of dark gray limestone (upper unit).

The contact between the Greyson Shale and the overlying Spokane Shale is gradational. It is generally placed just below the first
thick reddish-purple shale layer which is the typical color of the Spokane Shale. The unconformity between the Precambrian Spokane Shale and Cambrian Flathead Sandstone is low-angle. A spectacular exposure of this contact can be seen at the Newlan dam, about 6 mi (9.3 km) north of White Sulphur Springs (Figure 5).

Harrison (1972) suggested that Belt strata were deposited in an intracratonic shallow marine basin that began to form about 1500 Ma ago; however, a nonmarine origin has been postulated for some of the units near the basin's margin (Boyce, 1975). Zieg (1986) described Belt strata of the Helena embayment as a complete transgressive-regressive depositional sequence. Structural controls on Belt deposition will be discussed in Chapter III.

Although low-grade metamorphism has made the Belt rocks dense and hard, Belt strata have a mechanical behavior similar to that of Paleozoic and Mesozoic carbonates and shales. Examples of this may be found in the Pinchout Creek (Plate 1) thrust fault just east of White Sulphur Springs which juxtaposes Greyson Shale against other Belt strata, and in the tight folding of Newland Limestone beds in portions of the Moors Mountain thrust sheet (NE 1/4 sec. 5, T.9N., R.7E.).

**Paleozoic Strata**

More than 3800 ft (1170 m) of Paleozoic rocks (Figure 4) overlie the Belt Supergroup in the study area. Paleozoic rocks are primarily limestones and micaceous shales with sandstones, dolomite, and siltstones. All of the Paleozoic rocks were formed from sediments deposited in a shallow marine environment with the possible exception
of the Tyler Formation. Maughan (1984) suggested that the Tyler Formation is a combination of fluvialacustrine, deltaic, and littoral marine deposits. The Tyler Formation in this area consists of the lower Stonehouse Canyon Member which was probably deposited in a delta near shore or fluvialacustrine environment (Maughan, 1984).

Ordovician, Silurian, and Lower Devonian rocks are nonexistent in this area as rocks of these ages are generally absent in western Montana. As is common in much of the disturbed belt, Paleozoic rocks in this region commonly form the footwall rocks of major thrust sheets.

**Mesozoic Strata**

Mesozoic sedimentary rocks (Figure 4) in the area are approximately 1650 ft (500 m) thick and are mainly associated with the
Willow Creek and Cottonwood Creek synclines (Plate 1). Because Upper Cretaceous rocks are only partially exposed in the extreme southeast corner of the map area, they were grouped into a single map unit.

Triassic rocks do not exist in the map area because the margin of Triassic deposition was about 80 mi (128 km) south of White Sulphur Springs (McMannis, 1965; Peterson, 1981). Middle to Upper Jurassic Ellis Group rocks are also absent from the study area. A large island mass which was part of the Big Belt Island complex occupied much of Meagher County and prevented the deposition of Ellis Group sediments in the area (McMannis, 1965; Meyers, 1981; Peterson, 1981). This island mass did not prevent deposition of Upper Jurassic Morrison sediments as approximately 150 ft (45 m) of Morrison Formation is present in the White Sulphur Springs area.

Tertiary Sediments

General Statement: Widespread deposition of Tertiary sediments in western Montana began by Late Eocene to Oligocene time (Kuenzi & Fields, 1971). The first terrigenous sediments were deposited in rather broad flat valleys, some of which were interconnected (Pardee, 1950; Wolfe, 1964). The Helena and Smith River Valleys were once a continuous area of deposition before Late Cenozoic basin and range tectonism uplifted the Big Belt Mountains (Reynolds, 1979; Wolfe, 1964). Evidence supporting this is the presence of Oligocene and Early Miocene strata on the flanks of the Big Belt Mountains (Koerner, 1939; Mertie, Fisher, & Hobbs, 1951; Reynolds, 1979; Wolfe, 1964). These exposures of volcanic ash, clay, silt, and isolated
conglomeratic deposits do not occur extensively at higher elevations in the Big Belts because of their high susceptibility to erosion. No evidence of extensional faulting in the area during or prior to the Oligocene is known.

Faulting that formed basins and ranges such as the Smith River basin and the Big Belt Mountains began in Middle Miocene time (Reynolds, 1979). During Middle Miocene time, erosion caused by regional uplift and a hiatus in volcanic activity prevented sediment deposition in western Montana (Rasmussen, 1973). This hiatus in deposition has been recognized in the White Sulphur Springs area (Koerner, 1939; Wolfe, 1964).

Tertiary deposits in the Smith River Valley consist of the Lower Miocene Fort Logan Formation and the Upper Miocene Deep River Formation. These units are separated by an unconformity that is related to the Middle Miocene hiatus. Because of the poor exposure of Tertiary sediments in the area, the Upper and Lower Miocene Formations were mapped as one unit. The exact thickness of both formations are unknown because they are poorly exposed. A gravity survey and modeling by Gogas (personal communication, 1983) gave an approximate maximum depth of 2000 ft (610 m) for the basin.

**Lower Miocene Fort Logan Formation**

The Fort Logan Formation is composed primarily of light tan-orange clay, sand, and conglomeratic tuffaceous siltstones interbedded with light gray volcanic ash, lake bed clays, and channel conglomerates. Coarse-grained components in the sandstones and
conglomerates include clasts derived from Belt Supergroup shales and sandstones, Paleozoic sandstones and limestones, and Tertiary porphyritic igneous rocks. A conglomerate containing these clasts is exposed in a roadcut two miles northeast of White Sulphur Springs.

Lake bed clays of the Fort Logan Formation form the eastern margin of Lower Miocene lake bed deposits in Montana (Reynolds, 1979). These lake bed clays were possibly deposited when uplift occurred more rapidly than erosional processes, producing ponded areas in the Smith River Valley (Wolfe, 1964). Kuenzi and Fields (1971) interpreted similar deposits in the Three Forks-Jefferson River basins as overbank deposits from sediment-choked water courses, and occasionally as lacustrine, deltaic, or paludal deposits.

Fields, Rasmussen, Tabrum, and Nichols (1985) suggested that the "Fort Logan Formation" is an informal name (name applied without designation of type section) and should probably be included in the Renova Formation. The Fort Logan beds are equivalent to the upper part of the Renova Formation, which is dominated by fresh volcanioclastics and montmorillonite mudstone.

**Upper Miocene Deep River Formation**

The Deep River Formation has a similar composition and unconformably overlies the Fort Logan Formation. Deep River beds are time equivalent to the lower part of the Sixmile Creek Formation (Fields et al., 1985). According to Koerner (1939), the Deep River Formation has larger glass fragments, more hornblende and plagioclase, is less well cemented, and has a darker brown color than the Fort
Logan Formation. He also recognized a greater abundance of stream channels in the Deep River.

Clay-rich deposits are common in both Miocene deposits. Many clay deposits are probably water-laid or ash fall tuffs that are partially altered to bentonite or montmorillonite. According to Pardee (1950), many "lake bed" deposits in western Montana basins are water-laid tuffs or volcanic ash mixed with terrigenous material that is partially or completely altered. Fields et al. (1985) identified Lower Miocene Renova Formation equivalents (Fort Logan beds) as being dominated by fresh volcaniclastic and montmorillonite mudstones, whereas Upper Miocene Sixmile Creek Formation equivalents (Deep River beds) are characterized by coarse clastics locally derived from developing fault-block mountains.

**Quaternary Alluvium**

A thin veneer of alluvial sediments cover a large area of the Smith River Valley and associated drainages (Plate 1). These sediments are primarily bedded stream deposits interbedded with flood plain silts and ponded clays. The alluvium may be associated with colluvial materials, especially near the margins of the basin. The presence of gravel, sand, silt, and clay in deposits of Quaternary age makes them extremely difficult to distinguish from Tertiary sediments in water well logs, primarily because many water well logs are exceptionally vague in their sediment descriptions. Therefore, the thickness of the Quaternary is not well defined in this area. On the basis of existing well data the writer estimates the maximum
thickness of Quaternary alluvium to be 125 ft to 150 ft; however, Tertiary sediments are generally encountered below 40 ft. Alluvium may exceed 150 ft in thickness west of White Sulphur Springs near the junction of the main Smith and North Fork of the Smith River. Deep wells do not exist nor are they necessary in this area due to the shallow water table and high specific yield of gravels.

Igneous Activity

Castle Mountain Stock and Related Volcanics

According to Reynolds (personal communication, 1982) the emplacement of the Castle Mountain stock occurred in Early Eocene time (~54 Ma). Late phase rhyolitic or rhyodacite extrusives that post-date the main intrusion have been dated at 47.6 Ma ± 1.8 Ma (Chadwick, 1980). These volcanics form lithic flow breccias and welded tuff deposits in the area (Phelps, 1969).

The stock intruded sedimentary rocks that range in age from Beltian to Late Cretaceous. Emplacement of the stock truncated Paleocene thrust belt structures such as the Moors Mountain thrust zone near the western margin of the intrusive. This margin has a fairly regular contact, dipping more than 60° to the west (Tanner, 1949).

The Castle Mountain stock is mainly composed of fine-to-medium grained granite and granite porphyry although other compositions include diorite, granodiorite, monzonite porphyry, and syenite porphyry (Dahl, 1971; Winters, 1965). Diorite and granodiorite are
the dominant rock types of the Blackhawk stock which predates and is
east of the Castle stock (Tanner, 1949; Winters, 1965). Granodiorite
also occurs in sills near the margin and within the Castle stock.
Syenites and monzonites are present in sills and near the intrusive
margin where the country rock is limestone or dolomite.

Because of the granitic composition of the Castle Mountains,
Chadwick (1972, 1981) associated the intrusive with alkalic rocks
derived from the foreland portion of the Idaho-Montana porphyry belt.
Many of these intrusives seem to be aligned zones that may be related
to deep-seated zones of weakness (Chadwick, 1981). Andesitic and
basaltic rocks commonly intrude fault zones in the White Sulphur
Springs area (Dahl, 1971; this paper). This fault-intrusive relation­
ship suggests that structures in the area may be deep seated.
Because these structures are probable extensions of the Lewis and
Clark line, the intrusives may be related to deep zones of weakness
controlled by this lineament.

Early Cenozoic igneous activity in west-central Montana may have
been related to the low angle of subduction associated with the
Laramide orogeny; hence, the low subduction angle may have caused
arc magmatism to occur farther inland where the subducted plate has
subsided deep enough for partial melting. Intrusives of west-central
Montana that have a similar age, composition, and eastern extent as
the Castle Mountain stock include various plutons in the Little Belt
Mountains (Marvin, Witkind, Keeker, & Mehnert, 1973), and a grano­
diorite intrusive in the Big Belts west of White Sulphur Springs
Metamorphism related to the Castle intrusion is generally restricted to the low-grade aureole near the margin of the stock. Limestones contain minor amounts of epidote and are marble near the contact of the stock. The Greyson Shale is the primary country rock in contact with the western flank of the Castle Mountains and is baked to a brittle hornfels near the contact. Chloritization and epidotization is common in Belt rocks near the stock.

Deformation of country rocks related to the Castle intrusion is restricted to the proximal area of the stock's margin. Emplacement of the stock has caused minor folding and small vertical offsets (.5 mm - 10 mm) in bedding laminae of the Greyson Shale. Many joint sets are also found in the baked Greyson Shale near the west margin of the stock.

**Basaltic Volcanism**

Three separate basalt flows are located northeast of White Sulphur Springs, the closest flow being 8 mi (13 km) from town. These flows were mapped by Tanner (1949) and Dahl (1971) and are named the Volcano Butte, Crater Lake, and Smoky Mountain basalt flows respectively. The small flow in the northeast corner of the map area (Plate 1) is part of the Volcano Butte basalt flow. This flow yielded a whole rock K-Ar date of 29.1 Ma (Chadwick, 1978); however, the sample was slightly chloritized with some filled vesicles, yielding some uncertainty to the date. This flow pre-dates the proposed Middle Miocene age (Reynolds, 1979) of basin-and-range faulting in the area. Basalts in the Big Belt Mountains
west of the map area are interpreted to be Pliocene in age as they lie unconformably on Miocene strata (Reynolds, 1979).

Oligocene basalt flows in the White Sulphur Springs area may represent the onset of extensional tectonism in the area. Further field work and additional radiometric dating is needed to determine the relationships between basalt flows and extensional tectonism in the area.
CHAPTER III

STRUCTURAL GEOLOGY

Precambrian Features

Belt Basin

The most prominent structural feature in western Montana during Precambrian (Proterozoic) time was the Belt basin. The tectonic history and origin of this basin is not completely understood, primarily due to the immense thickness of Belt and Phanerozoic rocks that still cover the old basin margin; therefore, exposures of pre- or syn-Belt basin structures are rare.

The general consensus is that the origin of the Belt basin is related to rifting of a proto-North American continent (Burchfiel & Davis, 1975; Kleinkopf, 1977; McMannis, 1963; Schmidt & Garihan, 1986); however, Harrison et al. (1974) suggested the Belt basin was not a great aulocogen, but was subsidence of a continental crustal block which was not necessarily a failed arm of a triple junction. Burchfiel and Davis (1975) suggested that two periods of rifting are responsible for the Belt-Purcell Supergroup and the Windemere Group. Regardless of the time of rifting, Belt sedimentation occurred between 1400-1500 Ma and 850 Ma (Burchfiel & Davis, 1975; Harrison, 1972; Harrison et al., 1974).

In west-central Montana the Belt basin has an eastward-trending embayment (Helena embayment) that was bordered on the north and south
by Archean crystalline rocks (Figure 6). The southern border of this embayment was an active tectonic zone during Late Precambrian time (Harrison, 1972; McMannis, 1963; Schmidt & Garihan, 1986), resulting in the deposition of the clastic northward-thinning Lahood Formation. The inferred basin-bounding feature responsible for this activation is called the Willow Creek fault (Harrison, 1972; Robinson, 1963).

The geometry of the Helena embayment and the presence of Archean crystalline rocks north and south of the embayment were dominant factors in controlling the extent and orientation of post-Belt structures in the Helena salient. Harris (1957) was the first to recognize the relationship between Belt sediment distribution and the scope of post-Beltian tectonic features. Other controlling factors of post-Beltian deformation may include the presence of Late Precambrian northwest-trending faults (Schmidt & Garihan, 1986; Schmidt & O'Neil, 1982). These previously established zones of weakness are found in the southwest Montana transverse zone near the southern margin of the Helena salient.

Winston (1986) attributed the formation of the Helena embayment to graben blocks that were offset from the inferred Townsend line, a northwest-trending Proterozoic fault line that extends from the north end of the Bridger Range, northwestward along the Townsend Valley. Winston (1986) inferred a west-northwest trending line, termed the Joco line, to be a dominant structural control near the northern margin of the Belt basin. The Joco line is interpreted to be a zone of Proterozoic growth faults that is evidenced by linear trends of abrupt stratigraphic thickening that coincide with separated loci of
Figure 6. General tectonic map showing the relationship between the Belt Basin, the Lahood Formation, and Late Precambrian faults. (Modified from Schmidt & Garihan, 1984.)
soft-sediment deformation. Similar basement controlling faults may be present near the northern margin of the Helena salient associated with the Lewis and Clark line.

**Lewis and Clark Line**

The Lewis and Clark line (Figure 2) has been a prominent structural feature, exhibiting movement from Precambrian through Holocene time (Reynolds, 1977, 1979). Sinistral movement occurred along the west-northwest-trending line from Late Cretaceous to Early Cenozoic time whereas dextral movement occurred during Late Cenozoic extensionalism (Reynolds, 1979). Cenozoic right lateral displacements associated with the Osborn and St. Marys fault segments of the line are estimated to be 26 km and 13 km respectively (Harrison et al., 1974). The relationship of the Lewis and Clark line to disturbed belt and basin and range features in the White Sulphur Springs area will be discussed in later sections.

**Fold and Thrust Belt Tectonic Setting**

The Laramide orogeny (~75-45 Ma) probably occurred when a more rapid westward motion of the North American plate accompanied an accelerated northeast-to-southwest convergence between the North American and Farallon plates (Coney, 1978; Dickinson, 1979). Compressional features in the White Sulphur Springs area are principally folds and thrusts of the Montana disturbed belt. The disturbed belt (Cohee, 1962; Mudge 1970) is a term used to designate the structural style of folds and thrusts between the Rocky Mountain...
foreland and the Cordilleran miogeosyncline in northwest and west-central Montana. Structures of the fold and thrust belt formed when supracrustal rocks in the geosyncline moved relatively eastward and impinged against the western margin of the foreland (Figure 2). Thrusts in the disturbed belt typically dip to the west or southwest and have a tectonic style that ranges from steep imbricate thrusts in the Sawtooth Range and northern Big Belt Mountains (Bregman, 1976; Mudge, 1970; Shaffer, 1971) to low angle thrusts such as the Eldorado thrust in the Beartooth Mountain area northeast of Helena. These thrusts have been interpreted to be listric in nature and possibly merge with a main or sole thrust (Mudge, 1970; Woodward, 1981).

The majority of disturbed belt thrusts in west-central Montana juxtapose Belt Supergroup strata (hanging wall) against Paleozoic and Mesozoic footwall rocks; however, some thrusts have Belt rocks in both the footwall and hanging wall (McGrew, 1977c, 1977d; Shaffer, 1971; and this paper). Ages determined for thrusting in the disturbed belt range from 72 Ma to 56 Ma (Hoffman, Hower, & Aronson, 1976).

The Helena or central Montana salient is a prominent eastward bulge in the disturbed belt (Figure 2). Fold and thrust features in the salient have a distinctive convex eastward geometry that was probably formed by a regional west to east compressive force. Controls on the geometry of the salient include the shape of the Precambrian Helena or Beltian embayment (Figure 6) and the buttressing effect of the stable foreland. Beutner (1977) associates salient features in the Wyoming and central Montana salient to foreland impingement. Both salients have reentrants of the foreland.
associated with them. The possibility of radial divergent gravity gliding produced by the emplacement of the Boulder batholith may have added to the kinematics of salient structures (Smedes & Schmidt, 1979); however, thrusts in the salient range in age from pre- to post-batholith time (78-68 Ma; Robinson, Klepper, & Obradovich, 1968) indicating the intrusion was not a primary influence in forming the Helena salient.

The northern boundary of the salient is part of the Lewis and Clark line, a suspected zone of left-lateral movement during thrusting (Reynolds, 1979; Smedes & Schmidt, 1979). The salient's southern boundary is part of the southwest Montana transverse zone which has a significant right-lateral strike-slip component (Schmidt, 1975; Schmidt & Hendrix, 1981; Schmidt & O'Neill, 1982). These structural margins appear to be oblique and lateral ramp zones respectively in the thrusts of the Helena salient (Schmidt & Garihan, 1986). According to these ideas, thrusts in the White Sulphur Springs area should display similar sinistral slip when parallel to the Lewis and Clark line.

Major thrusts in the salient are interpreted to merge into a decollement or sole fault that is near the base of Belt sediments (Birkholz, 1967; Schmidt & O'Neill, 1982; Shaffer, 1971; Woodward, 1981; and others). This decollement was formed when the Belt sedimentary prism, along with younger rocks, was detached from the pre-Belt basement floor and transported eastward approximately 15 km to 20 km (Schmidt & O'Neill, 1982). Resultant deformation was an imbricate fold and thrust system that merged into the major decollement. Mudge (1970) indicated that a similar decollement exists in
the disturbed belt north of the Helena salient. An expanded discussion of Laramide features in the White Sulphur Springs area is presented in the following section.

**Description of Thrust Faulting**

Statement regarding nomenclature: The thrust which was referred to as the Scout Camp-Willow Creek thrust fault by Birkholz (1967), Phelps (1969), Woodward (1981), and others is interpreted by Reynolds (personal communication, 1982) to be miscorrelated and is probably the Moors Mountain thrust by his nomenclature. Reynolds can demonstrate by mapping southeast from the northern Big Belt Mountains that previous workers miscorrelated the fault; therefore, the name Moors Mountain thrust fault will be used in this thesis.

**Moors Mountain Thrust Zone**

The Moors Mountain thrust zone was first mapped in the White Sulphur Springs area by Weed and Pirsson (1896) who called the thrust the Willow Creek Fault. Other portions of the fault zone were studied in greater detail by Tanner (1949), Hruska (1967), Birkholz (1967), Dahl (1971), Phelps (1969), Shaffer (1971), and Reynolds (unpublished mapping, U.S.G.S.). The Moors Mountain thrust zone in this area brings allochthonous Belt rocks (Newland Limestone and Greyson Shale) against Paleozoic strata. The trace of the thrust extends for approximately 55 mi (89 km) from the northwest corner of the Castle Mountains to the northern flank of the Big Belt Mountains. The thrust has an estimated minimum stratigraphic throw of 2.2 mi.
(3.5 km) and dips roughly 45° to the west and southwest at the surface. The steep dip is interpreted by the author to be from ramping of the thrust from a decollement fault at depth.

In the White Sulphur Springs area the Moors Mountain thrust changes trend from west-northwest to north-south at its eastern margin (see Figure 7) where it is truncated by the Early Eocene Castle Mountain stock (Plate 1). The change in trend occurs in a relatively short distance of 4 mi (2.5 km). A relationship between the trend of the Moors Mountain thrust and a minor change in slip direction seems evident. An oblique sinistral slip component possibly exists where the thrust trends west-northwest, and a predominant dip-slip component is present where the trend is more northerly. Evidence supporting left-lateral movement on the thrust was first recognized by Birkholz (1967). He measured minor folds in the hanging wall of the thrust and suggested that the northwest trend of the folds implied a left-lateral component for the west-northwest-trending thrust on the eastern flank of the Big Belt Mountains. A similar group of folds in the Newland Limestone north of White Sulphur Springs (NE\textsubscript{4}, sec. 5, T.9N., R.7E.) plunge 40° to the southwest (Appendix B, p. 99). This orientation indicates a possible minor left-lateral component as the fold axis is southwest and slightly oblique to the fault trace. Further evidence supporting a sinistral component of movement along the west-northwest-trending segment of the Moors Mountain thrust is scarce; however, predominant dip-slip movement may be inferred on the basis of field evidence for north-trending segments of the thrust. Such evidence includes the orientations of the overturned Willow
Figure 7. A - Photograph (looking northwest) of the Moors Mountain thrust zone and Pennsylvanian Quadrant klippens northeast of White Sulphur Springs.
B - Sketch of structural features in the photograph.
Rock units: Mz - Mesozoic rocks; p Eg - Precambrian Greyson Shale; Pq - Pennsylvanian Quadrant Formation; Pz - Paleozoic rocks; Ts - Tertiary sediments.
Greek syncline and minor folds in the Amsden Formation (see Plate 1) which comprise footwall strata.

The abrupt change in strike and the indication of predominant dip-slip movement for the north-trending thrust segment, suggests the west-northwest-trending thrust segment is an oblique ramp with some sinistral movement. If predominant dip-slip movement occurred along both fault segments, northeast extensional or dilational features should exist between the two segments (Figure 8). Northeast-trending normal faults do exist west (Birkholz, 1967) and south (see Plate 1) of White Sulphur Springs; however, such features are not evident near the expected zone of dilation. Predominant dip-slip movement along both thrust segments should not be ruled out as Tertiary and alluvial sediments cover much of the expected zone of extension.

Woodward (1981) reviewed information regarding the thrusts in the Helena salient, including the Moors Mountain and Scout Camp thrusts (Figure 9). He also suggested that a sinistral component exists where these thrusts trend west-northwest and a dominant dip-slip component where the trend is to the north. Similar interpretations have been made for the Montana transverse zone as the southern margin of the Helena salient, with the exception that strike-slip movement was dextral (Schmidt, 1975; Schmidt & O'Neill, 1982). Figure 9 is a diagrammatic sketch showing the relationship between the slip component to trends of faults in the Helena salient.

The Moors Mountain thrust is interpreted to be a possible folded thrust on the northern flank of the Big Belt Mountains (Shaffer, 1971). No evidence was found for folding of the Moors Mountain
Figure 8. A - Sketch showing a change in slip movement (oblique left-lateral when trending west-northwest and predominant dip-slip movement when trending north) which may be associated with convex-eastward thrust faults in west-central Montana. B - Sketch illustrating dilation or extensional features that would be expected if predominant dip-slip movement occurred along the length of a thrust that had an arcuate trace.
Figure 9. Diagrammatic sketch showing the outline of the Helena structural salient and inferred oblique slip. (Modified from Woodward, 1981).
thrust in this area; however, several Pennsylvanian Quadrant klippen in the southwest limb of the Willow Creek syncline (Plate 1) and the Fivemile Creek klippe to the east (Dahl, 1971) suggest that thrusts in the area become subhorizontal in dip and may be connected to a roof fault (see Figure 11).

Observed deformation in the hanging wall block is not extensive in the White Sulphur Springs area. The lack of observed deformation in the ramp portion of the thrust is probably related to minimal exposure of the hanging wall due to Tertiary normal faulting. Another less likely explanation is the removal of the more intensely deformed portion of the ramp by erosion; hence, the observer sees a lower structural level where deformation is generally minimal. Figure 10 uses the Lombard and Moors Mountain thrusts as examples for differences in observed deformation due to dissimilar levels of erosion. The fact that deformation of allochthonous rocks is greatest near the nose of the ramp region of a thrust was well documented by Morse (1977).

Upper Cretaceous (lower Colorado Group) rocks are involved in folding associated with the Moors Mountain thrust suggesting that thrusting occurred between Late Cretaceous and Early Eocene time (age of Castle Mountain stock). The thrust is probably late Paleocene in age (Reynolds, personal communication, 1982; Schmidt, personal communication, 1982). The age of thrusting in the disturbed belt of Montana ranges from Late Cretaceous to Late Paleocene time (Hoffman et al., 1976; Mehnert & Schmidt, 1971).
Figure 10. Diagrammatic sketches which illustrate that variations in the observed deformation of allochthonous thrust plates may be related to different erosional levels. Examples used include (A) the Lombard thrust near Toston and (B) the Moors Mountain thrust near White Sulphur Springs. Rock units: pG - Precambrian Greyson Shale; pS - Precambrian Spokane Shale; Kk - Cretaceous Kootenai Formation.
Sequential development of the Moors Mountain thrust zone along with the Pinchout Creek and Fourmile Creek thrusts is illustrated in Figure 11. This sequence and type of faulting explains the Quadrant klippens (Plate 1) and the Fivemile Creek kippe just east of the map area (Dahl, 1971). Imbrication and duplexing also explains the folded Moors Mountain thrust near the northern flank of the Big Belt Mountains (Shaffer, 1971). This sequence of thrusting is only a preliminary interpretation of local structures in the area as regional relationships must be known to accurately define the sequential development of thrusts; however, folding of the Moors Mountain thrust in the Big Belt Mountains (Shaffer, 1971) and klippens in the White Sulphur Springs area suggest that thrusting is not formed by the piling up of imbricate thrusts (Woodward, 1981) that appear progressively younger to the west, but is due to imbrication from duplexing (Figure 11), forming thrusts that may be progressively younger to the east.

Minor Faults. Two minor faults are associated with the Moors Mountain thrust zone within the map area. The first and more extensive of the two is a footwall splay of the Moors Mountain thrust zone that is along the western margin of the overturned Willow Creek syncline (see Plate 1). This thrust mainly places Amsden Formation and Madison Limestone against the Cretaceous Kootenai Formation. The inferred Craig thrust (Plate 1)—as designated by Phelps (1969)—causes repetition in Madison Group bedding in the northwestern corner of the area and may be a westward extension of this minor thrust.
Figure 11. Diagrammatic sketch of the sequence of faulting in the White Sulphur Springs area.
(1) Pre-tectonic setting with initial stratigraphic succession and trace of fault plane;
(2) Development of Horse Butte thrust fault and related roof fault near the Paleozoic-Mesozoic
contact; (3) Development of the Pinchout Creek thrust forming a decollement near the Greyson-
Spokane Shale contact with associated folding of the roof fault; (4) Development of the Moors
Mountain thrust with a large amount of crustal shortening along with folding of previous structures;
(5) Continuation of duplex imbrication and development of the Fourmile Creek thrust; (6) Present
erosional surface showing the possible relationship between thrust faults and listric normal faults.
SS, Southern Smith River basin; HB, Horse Butte thrust; NS, northern Smith River basin; PC, Pinchout
Creek thrust; MM, Moors Mountain thrust; FM, Fourmile Creek thrust; FMK, Fivemile Creek Klippe.
Rock units: Mz - Mesozoic rocks, Pz - Paleozoic rocks, S - Spokane Shale, G - Greyson Shale,
N - Newland Limestone, Ch - Chamberlain Shale, A - Archean basement and overlying Neihart Quartzite
(-700 ft).
Note: Each thrust sequence was shifted from right to left (NE to SW) to accommodate special
problems due to crustal shortening; therefore, the symbol X, is a point of reference for the
lateral shifting of each sequence.
fault. The trend of the thrust is similar to the Moors Mountain thrust, and the eastern margin of the fault is also truncated by the Castle Mountain stock. The thrust is relatively steep at the surface (45°-50° dip) and has a stratigraphic throw of approximately 350 ft (107 m). The inferred relationship of this fault to the Moors Mountain thrust is shown in Plate 2 (section B-B').

The second minor fault is located between the Moors Mountain and Craig thrusts 2.5 mi north of White Sulphur Springs. The trend of this fault ranges from northwest to northeast, and is interpreted to merge with the Moors Mountain thrust at its western margin and the Craig thrust at its eastern margin. The fault forms a connecting splay according to Boyer and Elliott's (1982) terminology. Movement on the fault is not well understood due to its poor exposure which may be related to later downdropping of the hanging wall of the Craig thrust. Evidence to support recurrent normal movement along the thrust plate includes the deposition of Tertiary sediments and colluvium over hanging wall strata, and two small exposures of Quadrant formation in contact with older Madison Group Limestone. This younger on older relationship may reflect later normal movement along the preexisting zone of weakness formed by the minor thrust fault. Therefore, downdrop symbols were placed on the thrust and the two Quadrant splays to indicate later downward movement (Plate 1).

A minor hanging-wall splay is inferred between the Moors Mountain and Pinchout Creek thrusts north of town (see Plate 1). This thrust explains the abnormally thin Belt Supergroup section present between the Moors Mountain and Pinchout Creek thrusts. The thrust
is probably near the Greyson Shale-Newland Limestone contact although
its presence is highly speculative.

**Pinchout Creek Thrust**

This fault has not been previously mapped in the area; therefore, the name Pinchout Creek thrust will be applied to this fault because it traverses a portion of the creek east of town. The existence of the thrust explains the close spatial relationship between the Spokane Shale-Flathead Sandstone outcrop on the north edge of town to the Greyson Shale penetrated in the bank thermal well at a depth of 35 ft, and in the roadcut just east of town (Reynolds, personal communication, 1983). The outcrop of Spokane Shale and Flathead Sandstone are inferred to be part of footwall rocks, with the Greyson Shale comprising hanging wall rocks (section A-A', Plate 2). Southeast of White Sulphur Springs the Greyson Shale forms both the hanging wall and the footwall of the thrust, accounting for the discordant attitudes in the eastern half of sec. 21, T.9N., R.7E. The fault has a convex-eastward shape that is similar to the Moors Mountain thrust zone. Due to the lack of exposure, the attitude of the thrust surface is not known. The lack of surface control and the indication that the fault is a bedding plane thrust makes a determination of the stratigraphic displacement difficult. The thrust may be a hanging-wall splay (see Figure 11) of the Moors Mountain sheet.
Mission Canyon Fault

The Mission Canyon thrust was first mapped by Tanner (1949) and was named the Fourmile fault. Phelps (1969) later named the fault the Mission Canyon thrust. Because the fault has a large left-lateral separation, the name Mission Canyon fault will be used. The fault lies in the northern portion of the map area and trends northeast (Plate 1). This fault is terminated by the Craig thrust to the southeast, and is interpreted to be a secondary tear in the thrust sheet north of the Fourmile Creek thrust. Apparent left-lateral separation along the fault is approximately 335 m, suggesting a significant sinistral component of movement. Based on map data (Dahl, 1971; Phelps, 1969), the fault appears to be steeply dipping (65°-75°). The eastern margin of the fault is covered by the Oligocene (Chadwick, 1978) Volcano Valley basalt flows.

Apparent separation along the fault may have increased during Cenozoic extension although conclusions regarding normal movement could not be made with existing data. More detailed study of the fault surface is needed to understand the kinematics and origin of the Mission Canyon fault.

Fourmile Creek Thrust

This thrust was named the Fourmile Creek fault by Tanner (1949) as it is well exposed in the Fourmile Creek area about 8 miles (12.8 km) east-northeast of White Sulphur Springs. It will be referred to as the Fourmile Creek thrust in this paper (see Plate 1). Using
Boyer and Elliott's (1982) terminology for thrusting, the Fourmile Creek thrust is interpreted to be a divergent splay. The existence of the thrust explains the discordant attitudes and apparent offset between the northern limb of the Willow Creek syncline which is cut by the North Fork of the Smith River. The fault trends westerly in this area, but bends to the south in the Fourmile Creek area, similar to the trend of the Moors Mountain thrust. The fault does not follow the North Fork of the Smith River as indicated by previous workers (Dahl, 1971; Tanner, 1949). The fact that the northwest-trending hinge of the Willow Creek syncline is not offset in the area (SE 4, sec. 34, T.9N., R.7E.) confirms this. Because this fault is hidden by Tertiary sediments, andesite, and Quaternary alluvium, its location is inferred.

**Horse Butte Thrust Zone**

Previous reconnaissance mapping in the southern portion of the study area was done by Weed and Pirsson (1896), Tanner (1949), and Groff (1965); but the majority of faults in the area were not identified or named. These northwest-trending faults can be traced to the southeast and correlated with the Horse Butte thrust zone in the Ringling Quadrangle (McGrew, 1977b). Because the correlation of these thrusts is very apparent, the name Horse Butte thrust zone will be used hereafter.

The Horse Butte thrust zone consists of five thrusts that generally trend northwest, although the main thrust changes trend from northwest to north-northwest further south. Total stratigraphic
throw based on cross section C-C' (Plate 2) is a minimum of 580 m for the entire zone. The Horse Butte thrust fault is the westernmost thrust of the fault zone, and where it trends northwest it places Precambrian Spokane and Cambrian strata against the Meagher Limestone. Further to the south (sec. 32, T.8N., R.7E.) the thrust changes trend to north-northwest, cutting the western limb of a small syncline and juxtaposing Cambrian Pilgrim Limestone against Upper Cambrian and Devonian strata. Stratigraphic throw is approximately 365 m to 430 m. Local topographic relief is not great enough for an accurate determination of dip by three-point problem, but the thrusts are estimated to dip about 45°-50° to the southwest. Slip direction along the thrust zone is predominantly dip slip as indicated by the parallel trends and shallow plunge of minor fold axes and the orientation of footwall anticlines and synclines.

Deformation within the Horse Butte thrust sheet is primarily restricted to the Spokane Formation, with the exception of a small dextral tear fault in Spokane Shale and Cambrian strata in the western half of sec. 32, T.8N., R.7E. Dips in the sparse outcrops of Spokane Shale are very diverse, indicating intense folding and possible shearing in the hanging wall.

The Horse Butte thrust zone is interpreted by McGrew (1977b) to be Late Paleocene in age. A Middle to Late Paleocene age for this thrust zone is reasonable as Upper Cretaceous rocks are involved in deformation related to thrusting.
Minor Faults. The four faults northeast of the main Horse Butte thrust are shear zones in the western limb of a footwall syncline (see section C-C', Plate 2). Using cross section C-C', stratigraphic throws of these minor imbricates range from less than 20 m to over 150 m. Field observations reveal the faults to be relatively steep, dipping 45°-60° to the southwest with northwest trends.

Because the displacement on these thrusts is much less than the main Horse Butte thrust, cross-section interpretation C-C' (Plate 2) suggests that the faults are imbricate thrusts in the footwall. These minor faults probably formed after and are structurally lower than the main Horse Butte thrust.

Description of Folding

General statement: Numerous folds with wavelengths ranging from 4 m to over 1 km are exposed within the map area. Major folds are represented as footwall synclines and anticlines associated with the Moors Mountain and Horse Butte thrust zone. Small wavelength parasitic folds are generally present within the fold limbs of major anticlines and synclines. Fold hinges are primarily parallel to the major thrusts, indicating predominantly dip-slip movement of hanging walls of adjacent thrusts. Stereographic analyses of folds within the White Sulphur Springs area are in Appendix B.

Willow Creek Syncline

The northeast-to-east verging Willow Creek syncline is a broad doubly plunging fold with smaller folds radiating from it. It is
associated with the footwall of the Moors Mountain thrust zone. The overturned western limb of the syncline ranges in strike from due north to N 70° W and dips roughly 50°-80° to the southwest. The overturned limb is well exposed in the NE¼ of section 10, T.9N., R.7E. (Plate 1). The northwestern part of the fold hinge gently plunges 10° to the southeast, and the southern fold hinge plunges 33° to the north-northwest. The northwestern hinge of the syncline is well exposed a few feet west of Highway 89, revealing the Pennsylvanian Tyler, Amsden, and Quadrant Formations (B-B’, Plates 1 and 2). The southern part of the hinge of the Willow Creek syncline is truncated roughly perpendicular to its axial trace by the Early-Middle Eocene Castle Mountain stock.

**Cottonwood Creek Syncline and Associated Folds**

The broad footwall syncline associated with the Horse Butte thrust zone was first mapped by Weed and Pirsson (1896) who called it the Cottonwood trough. It is herein referred to as the Cottonwood Creek syncline. The northeast limb of the syncline is marked by the concordant margin of the Castle Mountain stock that is in contact with Precambrian Greyson Shale. The southwest limb is associated with more tightly folded anticlines and synclines that are all related to the Horse Butte thrust fault zone to the southwest. Fold limbs on the Cottonwood syncline have gentle to moderate dips (10° to 60°), with an interlimb angle of roughly 110°. The hinge of the syncline plunges 20° to the north-northeast (Appendix B, p. 100).
An unbroken stratigraphic section from the Precambrian Greyson Shale to the Upper Cretaceous Colorado Group is exposed in the syncline.

The southwest limb of the Cottonwood Creek syncline becomes a more tightly folded anticline to the southwest. Minor folding within this anticline forms a minor anticlinal-syncline fold in section 23, T.8N., R.7E. (see Plate 1). Outcrops of these minor folds are sparse, hence, most of the contacts are inferred. The anticline exposes strata from Mission Canyon Limestone to Kootenai Sandstone and has a disharmonically folded hinge region which produces a W-shaped plunging anticline-syncline-anticline structure in the NW\(\frac{1}{4}\) of sec. 34, T.8N., R.7E. The southern hinge of the folded anticlinal nose plunges 30° to the southeast (Appendix B, p. 103) and is very well exposed at the Pennsylvanian Amsden-Quadrant contact near the hinge of the fold (Plate 1). The interlimb angle of the southern anticlinal nose is roughly 10°, revealing the tight nature of the fold.

The southwestern flank of the anticline becomes a very tightly folded syncline that is cut at its southwest limb by a thrust fault. This thrust is part of the Horse Butte thrust fault zone that juxtaposes Mississippian Mission Canyon Limestone against synclinal rocks that range from Mississippian to Late Cretaceous in age. The synclinal rocks are not exposed adjacent to the thrust to reveal if the syncline is overturned; however, sparse exposures of Kootenai Sandstone and Big Snowy Group in the trough of the syncline (NE\(\frac{1}{4}\), sec. 33, T.8N., R.7E.) reveal its tightly folded geometry (Plate 1).

Minor folds associated with the Horse Butte thrust zone are common. Figure 12 is a sketch illustrating the relationship of folds.
Figure 12. Sketch showing the relationship of folding to thrusting along the Horse Butte thrust zone (fold C is in the SW direction of section 29, T.8N., R.7E., Plate 1).

to faulting along the Horse Butte thrust zone. Minor folds shown in Figure 12 are within the Meagher Limestone located in the SW direction, sec. 29, T.8N., R.7E. (Plate 1).

Post-Fold and Thrust Belt Deformation in the White Sulphur Springs Area

Regional Setting and History

A marked change from compressional thrust-belt tectonics to extensional basin and range tectonics began in western Montana during Late Eocene time (Kuenzi & Fields, 1971). Crustal arching accompanied by regional extension produced basin and range features in western Montana that are similar to that of the Great Basin region. The tectonic style of such features in Montana have been interpreted by many workers (for example, Chadwick, 1981; Reynolds, 1979) to be a northern extension of the Great Basin region. Both areas have similar heat flow and structural margins to the east, along with
similar Cenozoic histories and structural characteristics; however, both areas are significantly different regarding their intensity of heat flow, degree of extension, and style of normal faulting.

The faults that formed the margins of basins in western Montana were established in Middle Miocene time (Reynolds, 1979); however, Tertiary sedimentation began in intermontane basins in Late Eocene to Early Oligocene time (Kuenzi & Fields, 1971; Pardee, 1950; Wolfe, 1964; and others). Many of these pre-Middle Miocene sediments can be found on the flanks of ranges such as the Big Belt Mountains, indicating their relative uplift in relation to downdropped valleys. Figure 3 shows the locations of basins and ranges in western Montana. Total horizontal extension that produced such features across western Montana is estimated to be a minimum of 10% to 15% (Reynolds, 1979). Extensional tectonism may still be active in the White Sulphur Springs area. Evidence suggesting this includes the Montana earthquake of 1925 which caused extensive damage in the White Sulphur Springs region (Pardee, 1926). The focus of the earthquake was along a post-Miocene fault that was located on the western margin of the Big Belt Mountains near the town of Lombard (Pardee, 1926). The earthquake activity suggests that the Big Belts are still being uplifted in relation to the Townsend and Smith River Valleys.

During Middle and Late Cenozoic extension the Lewis and Clark line exhibited a dextral component of movement that formed basins and ranges south of the major lineament (Reynolds, 1979). Figure 13 shows the relationship between the Lewis and Clark line to basins and
Figure 13. Generalized block diagrams illustrating the possible relationship between preexisting Laramide zones of weakness and Cenozoic basin-range extensional features at the eastern margin of the Lewis and Clark line.  
A - Undeformed block showing pre-extensional surface.  
B - Structures and extensional features of the Helena and White Sulphur Springs area.  
SR, Smith River Valley; SH, Spokane Hills; SG, Scratch-gravel Hills.  
Rock units:  
1) Cenozoic sedimentary rocks;  
2) Cretaceous intrusives;  
3) Paleozoic rocks;  
4) Precambrian Belt Supergroup strata.  
The probable complex structural culmination which forms the Big Belt Mountains is not illustrated.  
(Modified from Reynolds, 1979.)
ranges south of the lineament. The Smith River Valley is the eastern-, most basin formed by a dextral movement along this line.

The coincidence of the eastern margin of the Lewis and Clark line with the eastern limit of the fold and thrust belt suggests possible recurrent movement along preexisting zones of weakness. Basin-bounding faults may merge with thrust faults at depth, forming listric normal faults. Figure 14 illustrates the development of a listric normal fault in which thrust plates or portions of plates may exhibit reverse drag movement during post-Laramide extension. Evidence supporting listric normal faulting in the Smith River Valley includes the following: (a) Miocene sediments dip 4°-10° to the southeast (Wolfe, 1964) and may increase in dip near the valley's eastern basin-bounding fault; (b) the close relationship—in map view (Plate 1)—of normal faults and Tertiary sediments to the convex eastward Pinchout Creek thrust that passes through the north edge of town; (c) indications of recurrent downdropping of northwest-trending thrusts in the area; and (d) gravity data (Gogas, 1984; this paper) suggesting that the eastern basin margin is deeper and has a similar convex eastward geometry to that of thrusts in the area. Greater downward rotation along the eastern margin of the basin may be related to reverse drag of old thrust sheets.

The downwarping of Tertiary sediments is commonly associated with rotations of the downdropped block accompanying listric normal faulting (Anderson, Zoback, & Thompson, 1983). Figure 15 shows the possible relationship between thrust faults and basin-bounding faults in the Smith River Valley.
Figure 14. Schematic diagram showing A) Laramide fault geometry, B) extensional post-Laramide reverse drag forming a listric normal fault, and C) deposition and downwarping of post-Middle Miocene sediments. Rock units: 1) Precambrian Belt Supergroup; 2) Paleozoic-Mesozoic rocks; 3) pre-Middle Miocene Cenozoic rocks; 4) post-Middle Miocene Cenozoic rocks. (Modified from Hamblin, 1965.)
Figure 15. Generalized block diagram showing the possible relationship between Laramide thrust faulting and post-Laramide normal faulting in the Smith River Valley. Rock units: Ts - Tertiary rocks; Mz - Mesozoic rocks; Pz - Paleozoic rocks.
Description of Faulting

Much of the post-Laramide structural character of the Smith River Valley has been obscured by alluvial processes; consequently, the existence of normal faulting in the area (Plate 1) has been inferred primarily on the basis of well data, aerial photographs, mapping Tertiary sediments, and gravity studies (Gogas, 1984; and this paper).

Earlier work relating the Smith River Valley to normal faulting has been minimal. Koerner (1939) was the first to recognize that some normal faults in the area apparently follow previous zones of displacement. Pardee (1950) and Wolfe (1964) studied the deposition of Tertiary sediments in the Smith River Valley, but considered the valley to be a downwarped basin that was not associated with normal faulting. Birkholz (1967) mapped normal faults on the western margin of the valley but did not relate these features to basin development. Reynolds (1979) was the first to interpret the Smith River Valley as a graben. He mapped normal faults and Tertiary strata in the valley, and documented an offset of 1000 ft (305 m) for Lower Miocene lake beds that are found on the flanks of the Big Belt Mountains in White Sulphur Springs.

Normal faults in the area generally trend north, northwest, and northeast. These different fault trends combine to form a rhombic or zigzag pattern of faulting along the eastern margin of the Smith River Valley.
White Sulphur Springs Basin-Bounding Fault System

Gravity data (Gogas, 1984; this paper) and well log data indicate that a north-trending normal fault passes through the western margin of White Sulphur Springs. This fault is responsible for the discharge of thermal waters in town and will therefore be referred to as the White Sulphur Springs fault. The presence of this fault and its association with thermal activity in town was first recognized by Reynolds (1979). The fault trace is interpreted to merge with that of the northwest-trending Moors Mountain thrust approximately 2 miles (3.2 km) north of town (see Plate 1). The southern extent of the fault is open to interpretation as it is covered by Tertiary and alluvial sediments. Well log data are interpreted to suggest the fault passes through section 30, T.9N., R.7E., and may be continuous with the normal faults that cut the northwest hinge of Cottonwood Creek syncline to the south. The well log data includes the Bailey well (NW<sup>1/4</sup>, sec. 29, T.9N., R.7E.) which penetrated Belt shale at 125 ft (38 m), and the Hanson well (SE<sup>1/4</sup>, sec. 24, T.9N., R.6E.) one mile to the northwest which was completed in Tertiary sediments at a depth of 300 ft.

Because the fault is not exposed, a determination of dip and stratigraphic separation could not be made from field evidence. Gravity data (Plate 3) suggest the fault dips steeply (65°-85°) to the west. Minor synthetic faults may be associated with the major basin-bounding fault. Evidence supporting synthetic faults includes the presence of moderately thick (>200 ft in places) Tertiary
sediments such as Clay Butte, and associated gravity lows that are east of the main fault (see Plates 1 and 3). In the southern portion of the map area, minor synthetic faults have been inferred on the basis of aerial photograph interpretation, although the faults are virtually indistinguishable in the field.

Northwest-trending normal faults in the White Sulphur Springs area are apparently reactivated Laramide thrust faults that have exhibited reverse drag movement. The Moors Mountain thrust fault displays recurrent normal movement northeast of section 36, T.9N., R.7E. East of section 36 normal movement appears to be along a footwall splay associated with the Moors Mountain thrust system. The fresh fault scarps, marked change in topography, younger on older relationship of minor fault splays, and the sharp outline of Tertiary sediments associated with the faults is good evidence to support recurrent normal movement along these thrusts.

An inferred north-northwest-trending normal fault in the southern portion of the map area (Plate 1) has been interpreted to be a reactivated portion of the Horse Butte thrust zone. This fault is very apparent near Catlin Spring as one can clearly see that the spring's source is associated with the normal fault. The reactivated portion of this footwall splay changes trend to the northeast, cutting the northwest limb of the Cottonwood Creek syncline to the north, and truncating the Horse Butte thrust zone to the south. This change in trend produces a rhombic pattern of normal faulting in the southern portion of the map area. Gravity data (Gogas, 1984; this paper, Plate 3) suggest that a similar pattern may exist with the
White Sulphur Springs fault just south of town. A sharp deviation in gravity contours (Plate 3) near the southern margin of town suggests that the White Sulphur Springs fault may change its trend from north to northeast for a short distance. These different trends may represent the interaction between regional east-west extension and previously established compressional zones of weakness.

Various trends or patterns exhibited by normal faults in the area appear to be related to reactivation along the following thrusts or thrust-related features:

1. The northwest-trending normal fault segments may be associated with reactivation along the Moors Mountain and Horse Butte thrusts, and along the rejoining splay segments of the Craig and Moors Mountain thrusts.

2. Northeast-trending normal fault segments (i.e., at Catlin Spring) may follow cross-strike or transverse features that were transverse tear structures during thrusting and were later reactivated by normal faulting.

3. North-northeast trending normal fault segments, such as the White Sulphur Springs fault, may be following ramps in the thrust sheets. The White Sulphur Springs normal fault may follow the ramp of the Pinchout Creek thrust (Figure 11, sequence 6).
CHAPTER IV

RECONNAISSANCE GRAVITY SURVEY

Objective

The reconnaissance gravity survey was intended to provide a balanced exploration strategy for thermal activity in the White Sulphur Springs region. The principal goal of the survey was to identify structural features that may control hydrothermal circulation systems in the Smith River Valley, in particular, the geometry of the valley and associated basin-bounding faults. This survey was done without the knowledge of a more detailed gravity study of the same area by Gogas (1984); therefore, an overview of this survey will be done with frequent comparisons and references to the study by Gogas (1984).

Data Acquisition and Processing

In August 1982, eighty-three gravity stations (stns. 42-124 in Appendix C) were established by the author in the vicinity of White Sulphur Springs, Montana (Plate 3). These stations complemented 41 gravity stations that were previously established (summer, 1981) by Michael Stickney of the Montana Bureau of Mines and Geology (Appendix C). Gravity readings at stations 1-41 were done with a Worden Educator model gravimeter [dial constant .4017(8) mgals/div.], and stations 42-124 were done with a Worden model 944 gravimeter [dial...
constant .0970(6) mgals/div.]. Gravity data for stations 1-124 are listed in Appendix C and will be referred to as the data.

Data reduction was performed by using program GRVRED, a reduction program written by Dr. William Sauck of Western Michigan University to calculate Bouguer anomaly values. The density used was 2.67 g/cm$^3$ and sea level was used as the datum. Base station readings were not tied into a station of known gravity; therefore, an arbitrary observed gravity of 980,484.00 mgals was chosen for base station 1 to achieve positive Bouguer values with program GRVRED. The Bouguer anomaly contour map (Plate 3) shows relative changes in Bouguer gravity with respect to the observed gravity chosen for base 1. All latitudes and elevations were obtained from U.S. Geological Survey quadrangle maps on a scale of 1:24,000. Terrain corrections were not applied because the survey was primarily confined to the flat-lying valley.

A contour map of residual gravity indicated that residual values were biased because of an insufficient grid density; therefore, the contour map was not included. Residual values were computed by using program FORFIT (Ghatge, 1984), a modified version of a double Fourier fitting program written by James (1966). The program uses the least-squares method for calculating coefficients of the Fourier series.

Interpretation of the Bouguer Anomaly Map

Contours of relative Bouguer values (Plate 3) depicts the general geometry of major structural features in the White Sulphur Springs area. As expected, this map is very similar to the Bouguer gravity
map by Gogas (1984). The map suggests that the Smith River Valley is a northwest-trending fault-bounded basin with its depositional axis approximately .7 mi southwest of White Sulphur Springs. Modeling of Bouguer profiles by Gogas (1984) suggests the maximum basin depth is approximately 2000 ft (610 m) southwest of town; however, modeling of Bouguer values may not yield accurate results. Also, the Hanson well (NE1/4, NE1/4, sec. 9, T.9N., R.6E.) drilled near the basin's axis reportedly hit bedrock at approximately 1100 ft (335 m) (Groff, 1965) suggesting that the basin's depth may not be as great as 2000 ft.

The eastern margin of the basin is identified by a steep gradient of over 8 mgals/mi near the town of White Sulphur Springs. The sharp gradient indicates significant vertical displacement associated with the steeply dipping White Sulphur Springs fault. This fault has a northerly trend through the town but may change in trend to northeast near the southern margin of town. This change in trend would account for the pronounced northeast-trending gravity high ridge located in town.

The western margin of the Smith River basin appears to be bounded by a steeply dipping fault that is antithetic to the White Sulphur Springs fault. This fault changes trend from northwest to northeast in the SW1/4 of section 23, T.9N., R.6E. where it bounds a basin that is a southern extension of the Smith River Valley. A northwest-trending gravity high located near the White Sulphur Springs airport may represent a horst that divides the Smith River Valley into what Gogas (1984) calls the northern and southern basins. Gogas (1984)
interprets the maximum depth of the southern basin to be approximately 2000 ft (610 m). The southern basin may owe its origin to recurrent normal movement along the Horse Butte thrust whereas the northern basin may be related to normal movement along the Pinchout Creek and Moors Mountain thrusts (see Figure 11).
CHAPTER V

HYDROGEOLOGY

General Statement

In order to delineate and define the geothermal potential of an area, its hydrologic characteristics must be understood. Mixing of thermal waters with shallow cold ground water will dilute thermal brines and transport the plume downgradient in shallow aquifers. The plume will have a chemical composition and thermal expression that generally ranges between that of warm thermal brines and cold meteoric ground water. When using geothermal indicators and existing shallow water wells to identify the thermal potential of an area, the mixing and transport of thermal waters downgradient within shallow aquifers may create an erroneous area of thermal potential; therefore, a hydrologic study of the area should be made in conjunction with well-water inventories and water-sampling programs designed for geothermal exploration.

Drainage

Regional drainage of the White Sulphur Springs area is through the northerly flowing Smith River and its major tributaries. Local drainage near White Sulphur Springs is controlled by the southwest flowing North Fork of the Smith River which drains into the Smith River 3.4 mi (5.5 km) west of town. The North Fork and the main
course of the Smith River are gently meandering and have gradients of approximately 34 ft/mi and 13 ft/mi in the valley respectively. The Smith River Valley is a "graben-like" feature that has a gentle slope to the west, toward the Smith River. Many small drainage systems near the margins of the valley are caused by spring-fed and intermittent streams that have dissected Belt Supergroup and Tertiary rocks.

Aquifers

Aquifers in the area exist mainly in Quaternary alluvium and Tertiary sedimentary rocks, although many rock units (e.g., Mission Canyon Limestone) in the area are potential aquifers. Quaternary sand and gravel is the main source of ground water in the Smith River Valley as it provides better quality water, and wells in these materials have greater specific yields than most Tertiary and older rocks. Quaternary gravel aquifers are generally present within 40 ft (12.1 m) of the surface, although they are laterally discontinuous and may be interbedded with clays and silts (Appendix D). West of White Sulphur Springs near the Smith River, Quaternary gravel aquifers may be present at least 150 ft (45.4 m) below the surface; however, well data indicate that below 40 ft (12.1 m), the valley fill consists of Tertiary claystone and tuffaceous siltstone.

Tertiary stream channel deposits penetrated near the base of many wells (Appendix D) may yield large quantities of water. Wells with high yields in Tertiary stream bed deposits are generally deep, such as the Hanson well (previously Shearer well) located in SE^4 SE^4
SE¼ sec. 24, T.9N., R.6E. which has a pumping rate of 1200 gpm and is perforated at various intervals in Tertiary gravels to 220 ft (67 m); and the Townsend well (SW¼ SE¼ sec. 26, T.9N., R.6E.) which has a yield of 1850 gpm and is perforated to 250 ft (76 m) in Tertiary conglomerate and claystone. In the Smith River Valley, Tertiary channel deposits may be cemented by calcite and are laterally discontinuous in comparison to Quaternary gravels (Appendix D). A Tertiary stream channel lithic conglomerate interbedded with water-laid tuffs is exposed in a roadcut 2 miles east of town. This exposure exhibits calcite cementing in Tertiary gravels.

Bedrock aquifers are not widely used as a source of water in the area, although many Castle Mountain Ranch wells northeast of town draw water from Paleozoic limestones. Paleozoic carbonates, especially the Mississippian Mission Canyon Limestone, act as recharge areas for springs such as Trinity and Catlin Springs which discharge from fault zones. Paleozoic rocks, especially the Mission Canyon Limestone, are present in the footwalls of thrust zones north and northeast of town, and may act as recharge areas that transmit water to and along thrust faults that dip beneath the valley. A good example of the Mission Canyon Limestone's ability to transmit water is the Ringling petroleum test well 15 mi southeast of White Sulphur Springs. The well is completed in the Mission Canyon and discharges warm water (48°C) under artesian flow at a rate of 800 gpm.

Much of the valley floor is composed of Belt rocks that have low hydraulic conductivities and, where unfractured, have extremely low
permeabilities. Belt shales and limestones may transmit and yield significant volumes of water if highly fractured. Sandstones inter-bedded with the Greyson Shale and Newland Limestone may yield minor amounts of water, but extensive fracturing must be present for them to produce large volumes. A good example of a high yield well in fractured sandstone and shale within the Greyson Shale is the thermal bank well. A pump test of the bank well gave a calculated transmissibility of 103,000 gallons per-day-per-foot and an estimated safe yield of 50 gpm on a continuous basis (Sonderegger & Bergantino, 1981).

Ground Water Hydrology

The water table map of the White Sulphur Springs area (Plate 4) indicates that the local ground-water-flow direction is to the west-southwest. Minor variations in the flow direction and the hydraulic gradient are mainly related to changes in topography; however, the drawdown effects from pumping, lateral variations in permeability, and the depth to bedrock may contribute to such variations. In the vicinity of White Sulphur Springs, a sharp increase in hydraulic gradient and deviation in ground-water-flow direction is related to the following factors: (a) the sharp change in the depth to bedrock which ranges from less than 75 ft (23 m) in the eastern half of town to over 1200 ft (366 m) in the valley west of town; (b) the contrast in permeability between clay rich Tertiary rocks in the eastern portion of town to Quaternary gravels west of town; and (c) the presence of a topographic high in the eastern half of White Sulphur Springs.
All of these factors are related to the north-trending normal fault which transects the town of White Sulphur Springs (Plate 1).

An approximate value for the hydraulic gradient in the valley is $5.21 \times 10^{-3}$ ft/ft. This value was calculated from the distance between the 4900 foot and 5020 foot contour intervals in Plate 4 and is considered to be an approximation of the mean gradient for the area.

Ground-water flow velocities can be estimated with the use of hydraulic gradients (Plate 4) and representative hydraulic conductivities and porosities of Quaternary and Tertiary sediments. Because aquifers in the area exhibit an extremely wide range of hydraulic conductivities, effective porosities and hydraulic gradients, this thesis will not attempt to estimate ground-water flow velocities considering the data available.
CHAPTER VI

GEOCHEMICAL SURVEY

Objectives and Procedures

The water-chemistry program was undertaken to fulfill two objectives: (1) to aid in the delineation and assessment of thermal resources in the White Sulphur Springs area by the use of chemical indicators, and (2) to estimate the reservoir temperature of the geothermal system using geothermometers.

Twenty-six water samples were collected from wells in the area. Two of the samples were from wells developed for hydrothermal use (see Plate 4). Three 250 ml samples were collected at each well: one untreated sample to be kept chilled, one filtered (.45μ filter) sample kept chilled, and one sample filtered and acidified with nitric acid. All plastic storage bottles, caps, and filtering equipment were rinsed three times with sampled water (filtered or unfiltered) to help prevent cross-contamination. If pressure tanks were present, the pumping rate was measured and the well was pumped for a sufficient period of time to insure a representative sample. Field data collected at most stations included measurements of water temperature, pH, specific conductance, and static water level. All water samples were analyzed by the Montana Bureau of Mines and Geology lab and the results are listed in Appendix E (pp. 111-141).
Isoconcentration maps (Plates 6 and 7) of specific conductance and fluoride were constructed in hopes of delineating thermal waters or possible areas of hydrothermal discharge. Because the concentrations of most parameters increased exponentially from shallow meteoric to thermal fluids, a logarithmic contour interval was used. The contour interval was derived using the following formula:

$$\log \Delta = \frac{1}{x(0,1,2,3,4,\ldots,x)} \quad \text{or} \quad \Delta = \log^{-1} \frac{1}{x(0,1,2,3,\ldots,x)}$$

where $x$ equals the intervals per decade.

**Water Chemistry**

Chemical analyses of thermal, meteoric, and meteoric-thermally contaminated well waters are summarized in Table 1. The analyses show that thermal waters have significantly higher concentrations of $\text{Na}^+$, $\text{K}^+$, $\text{Cl}^-$, $\text{HCO}_3^-$, $\text{SO}_4^{2-}$, $\text{F}^-$, $\text{B}^{3+}$, $\text{Li}^+$, $\text{Sr}^{2+}$, and TDS than shallow meteoric waters. The only parameters that generally have lower concentrations in thermal waters are $\text{As}^{3+}$ and $\text{Mg}^{2+}$.

Evaluation of the bank thermal water analysis (Sonderegger, 1981) indicates that the water is supersaturated with respect to calcite, pyrite, fluorite, chalcedony, and quartz [log (IAP/KT) values of 0.92, 9.53, 0.25, 0.17, and 0.57]. Analysis of the Spa Motel thermal spring waters (Mariner et al., 1976) gave similar results, with the exception of calcite, which was undersaturated in the spring water [log (IAP/KT) = -0.33]. An equivalent Eh of -0.302 volts and a sulfide concentration of 2.5 mg/l for the bank well suggest the thermal waters are very reducing. Pyrite penetrated in fracture zones during
### Table 1

Chemical Analyses of Ground Water From Wells in the White Sulphur Springs Area, Montana

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Cations - mg/l</th>
<th>Anions - mg/l</th>
<th>Thermal Well Partial Mixing Water</th>
<th>Shallow Meteoric Well Water With Thermal-Brine Contamination$^b$</th>
<th>Shallow Meteoric Well Waters$^c$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
<td>Mean</td>
<td>STD deviation</td>
<td>Range</td>
<td>Mean</td>
</tr>
<tr>
<td>Sodium (Na)</td>
<td>433</td>
<td>449</td>
<td>2130</td>
<td>51.3 - 250</td>
<td>146.3</td>
</tr>
<tr>
<td>Silica (SiO₂)</td>
<td>43.7</td>
<td>47.9</td>
<td>44</td>
<td>19.0 - 79.7</td>
<td>57.3</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>41.0</td>
<td>41.7</td>
<td>2.5</td>
<td>1.7 - 101</td>
<td>57.6</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>9.5</td>
<td>9.5</td>
<td>3.4</td>
<td>0.5 - 18.5</td>
<td>11.9</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>17.5</td>
<td>17.4</td>
<td>19.0</td>
<td>0.9 - 18.3</td>
<td>9.7</td>
</tr>
<tr>
<td>Bicarbonate (HCO₃)</td>
<td>791</td>
<td>806</td>
<td>2533</td>
<td>317 - 445</td>
<td>362.3</td>
</tr>
<tr>
<td>Carbonate (CO₃)</td>
<td>0</td>
<td>0</td>
<td>66.4</td>
<td>0 - 51.8</td>
<td>13.0</td>
</tr>
<tr>
<td>Chloride (Cl)</td>
<td>147</td>
<td>186</td>
<td>827</td>
<td>9.5 - 177</td>
<td>66.1</td>
</tr>
<tr>
<td>Sulfate (SO₄)</td>
<td>211</td>
<td>253</td>
<td>1332</td>
<td>39.1 - 264</td>
<td>114.2</td>
</tr>
<tr>
<td>Fluoride (F)</td>
<td>6.3</td>
<td>7.07</td>
<td>7.7</td>
<td>0.14 - 2.28</td>
<td>0.9</td>
</tr>
</tbody>
</table>

**Parameter**

- Arsenic (As) μg/l
- Boron (B) mg/l
- Lithium (Li) mg/l
- Strontium (Sr) mg/l
- TDS - Lab
- Lab Spec. Cond. mhos/cm
- Lab pH
- Field Water Temp. °C

<table>
<thead>
<tr>
<th>Well Depths</th>
<th>Screened</th>
<th>Shallow flowing well</th>
<th>53.4 m TD</th>
<th>33.5 - 76.2 m</th>
<th>6.7 - 76.2 m</th>
</tr>
</thead>
</table>

$^a$The Jordon well (WSS-026) was intended for domestic use.

$^b$The four meteoric-thermally mixed domestic water wells were separated on the basis of isoconcentration maps (Plates 6-7) and chemical analysis data (Appendix E). The four wells include sample numbers WSS 010, 018, 022, and 025.

$^c$19 wells represented.
drilling of the thermal bank well (Dunn, 1978) (TD-273 m) also indicates reducing conditions and the supersaturation of pyrite in these thermal waters.

The dominant cation present in the thermal waters is Na\(^+\), which comprises more than 80\% (in equivalents) of the total cations whereas Ca\(^{2+}\) is the dominant cation in shallow meteoric waters. Sodium is generally the second most abundant cation in shallow well waters completed in Tertiary sediments, and Mg\(^{2+}\) is the second most abundant cation in well water pumped from Quaternary gravel and sand. Other elements that appear to have higher concentrations in Tertiary, rather than Quaternary aquifers, include As\(^{3+}\), K\(^+\), F\(^-\), and Sr\(^{2+}\). Higher concentrations of these elements are expected in Tertiary sediments because these sediments are mainly composed of volcanic ash and water-laid tuffs.

The dominant anion species in both thermal and shallow water wells is HCO\(_3^-\) which constitutes over 50\% of the total anions (in equivalents) for most well water sampled. The high concentrations of HCO\(_3^-\) and Mg\(^{2+}\) in well waters suggest dissolution of carbonate rocks. Therefore, meteoric and possibly thermal ground-water recharge areas are in carbonate terranes, or carbonate dissolution occurs in aquifers containing carbonate clasts or cement.

Water from the Jordan well (Appendix E, p. 137) has an extremely high Na\(^+\) content (2130 mg/l) which constitutes over 99\% of the total cations (in equivalents). The anomalously high observed temperature (15.3° C), brine-rich composition, and low Mg\(^{2+}\) content (3.5 mg/l) suggest that the Jordon well water represents a cooled thermal water.
with minor dilution. If the Jordon well water is chemically representative of the thermal reservoir, the bank and Spa Motel well waters comprise approximately 20%-25% thermal water, with the remaining component being cold meteoric water.

Some mixing of thermal and meteoric waters obviously occurs in shallow aquifers. Evidence that supports shallow mixing includes the increase in discharge temperature of the White Sulphur spring (~21°F) when a cement culvert (shallow dug well) was installed for the Spa Motel. Mixing at some intermediate depth is likely for the Spa Motel and bank well waters because they are nearly identical in chemical composition even though the bank well was completed in Greyson Shale (screened 27-104 m) and the Spa Motel well is in the top few feet of alluvium. These thermal waters are relatively dilute in comparison to the Jordon well, indicating a large mixing factor. This mixing may be caused by cold meteoric water moving through fractures related to the thrust zone north of town intersecting and mixing with thermal waters that ascend along the north-trending normal fault.

Progressive leaching of Tertiary sediments by thermal fluids could explain the brine-rich composition of the Jordon well; however, water analyses of cold meteoric waters indicate that the chemical difference between waters from Tertiary sediments and those from Quaternary alluvium is small; therefore, the differences in thermal water chemistry may be attributed to various degrees of mixing. The possibility of the Jordon thermal waters being derived from a separate, intermediate brine-rich reservoir within Tertiary sediments may be another explanation.
Isoconcentration maps (Plate 6 and 7) indicate that thermal waters discharge along a north-south-trending zone associated with the White Sulphur Springs fault. The length of the discharge area is less than a kilometer as thermal fluids move laterally down-gradient and are diluted by cold meteoric ground water. This meteoric-thermal brine mixture produces a plume of water that has a chemical composition between that of background meteoric and thermal water (Plates 6 and 7), with the exception of As and Mg, which generally have higher concentrations in the plume consisting of a meteoric ground water-thermal brine mixture (see Table 1). A resistivity low caused by the brine-rich contaminant plume can be identified as far west as the King Wilson sportman's lodge (Poor Farm) in the NW\(\frac{1}{4}\) of section 13, T.9N., R.6E. (Sonderegger, personal communication, 1983). Analysis of the Wilson well (sample #WSS018, p. 129) shows high concentrations of \(\text{Na}^+, \text{B}^{3+}\), and \(\text{As}^{3+}\), which confirms the mixing of thermal waters in the area. The areal extent of the plume caused by the ground-water transport of thermal brine to the west-southwest is identified by chemical isoconcentration maps (Plates 6 and 7). The westerly direction of contaminant movement shown by the maps correlates well with the west-southwest flow direction derived from the potentiometric surface map (Plate 4). It is important to note that some thermal fluids may move through lower confined aquifers in the Tertiary, and may not effectively mix with the shallow unconfined Quaternary gravel aquifer from which many wells were sampled.
Geochemical Thermometers

Dissolved silica and Na-K-Ca geothermometers are useful tools for determining the reservoir or base temperature of low to intermediate temperature hydrothermal systems. Calculated reservoir temperatures and related analytical data for thermal waters in the White Sulphur Springs area are listed in Table 2. Temperatures were calculated using the following chemical thermometers and equations (Fournier, 1981):

\[
\text{Quartz no steam loss} \quad t^\circ C = \frac{1309}{5.19 - \log C} - 273.15
\]

\[
t = 0 - 250^\circ C
\]

\[
\text{Na-K-Ca} \quad t^\circ C = \frac{1647}{\log(\text{Na}/\text{K}) + \beta[\log(\sqrt{\text{Ca}}/\text{Na}) + 2.06] + 2.47} - 273.15
\]

\[
t < 100^\circ C, \beta = \frac{4}{3}
\]

\[
t > 100^\circ C, \beta = \frac{1}{3}
\]

where C is concentration in mg/kg.

These geothermometers are accurate only when certain conditions are met. Factors that must be considered when using the silica geothermometer were discussed in detail by Fournier (1981) and include the following: (a) Temperature restrictions must be met; (b) chemical equilibrium must be established if mixing has occurred, otherwise calculated quartz temperatures will be low; (c) possible
# Table 2

**Calculated Reservoir Temperatures and Analytical Data for Thermal Well Waters in White Sulphur Springs (W.S.S.), Montana**

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Owner or Name</th>
<th>Temperature °C</th>
<th>Concentrations mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Observed</td>
<td>Quartz no steam loss</td>
</tr>
<tr>
<td>WSS-Bank</td>
<td>National Bank-W.S.S.</td>
<td>43.3</td>
<td>95.6</td>
</tr>
<tr>
<td>WSS-009</td>
<td>White Sulphur Springs - Spa Hotel</td>
<td>47.5</td>
<td>99.8</td>
</tr>
<tr>
<td>WSS-026</td>
<td>Ralph Jordon</td>
<td>15.3</td>
<td>95.9</td>
</tr>
</tbody>
</table>

Where $R = \frac{Mg}{(K + Ca + Mg)} \times 100$, with concentrations in equivalents (see Figure 16 for Mg correction).
polymerization or precipitation of silica may occur before sample collection; (d) polymerization of silica may occur after sample collection due to improper sample preservation; (e) the effects of steam separation must be considered—-not a factor for low temperature systems; (f) the effect of pH on quartz solubility must be considered; (g) the control of aqueous silica by solids other than quartz must be considered; and (h) water-rock reactions of thermal and mixing fluids with silica-rich fine-grained rocks causing silica enrichment must also be considered.

The following factors should be considered when using the Na-K-Ca geothermometer (Fournier, 1981): (a) The loss of aqueous Ca$^{2+}$ may occur as a result of boiling—-not a factor for low temperature systems, although calcite can precipitate if there is a rapid loss in CO$_2$ associated with a reduction in hydrostatic head (i.e., near a ground-water discharge point); (b) erroneous results may occur when the equation is applied to Mg$^{2+}$-rich waters; (c) low calculated values may result when Mg corrections are applied to thermal waters that gained Mg$^{2+}$ during ascension; and (d) mixing or dilution corrections should be applied for waters with a thermal component less than 20%-30%.

Calculated silica reservoir temperatures (Table 2) for the three thermal wells in the area range from 95.6° C to 99.8° C. These calculated temperatures are probably high as thermal waters are supersaturated with respect to quartz, and the mixing of silica-rich meteoric waters may cause silica enrichment. The mean silica concentration for water from 19 wells producing cold meteoric water is
38.3 mg/l (Table 1). This concentration yields a quartz reservoir temperature of 89.8° C even though the 19 wells had a mean observed temperature of 9.7° C. The supersaturation of silica in cold meteoric and possibly thermal waters may be attributed to the dissolution of fine grained silica-rich Tertiary ash deposits.

The Na-K-Ca geothermometers gave a temperature range of 122.5° C for the Jordon well and 144.9° C for the bank well (Table 2). These temperatures are higher than the actual reservoir temperature because Mg$^{2+}$ concentrations are elevated due to the mixing of thermal and cold meteoric water. When Mg$^{2+}$ corrections are applied (Figure 16), the calculated reservoir temperatures are significantly lowered and range from 53.5° C for the Jordon well to 73.4° C for the Spa Motel well. The 72.0° C and 73.4° C Na-K-Ca-Mg temperatures for the bank and Spa Motel wells correlate well with the 73° C chalcedony temperature derived for the bank well (Sonderegger, personal communication, 1984); however, the thermal waters are slightly supersaturated with respect to chalcedony, suggesting that the calculated temperature may be high. The 53.5° C Na-K-Ca-Mg temperature calculated for the Jordon well is very similar to the 52° C $\Delta^{18}O(SO_4 - H_2O)$ temperature (Sonderegger, personal communication, 1984) derived for the bank well. Both of these temperatures appear to be lower than the actual reservoir temperature. The 52° C $\Delta^{18}O(SO_4 - H_2O)$ temperature is obviously low as the maximum observed discharge temperature for the spring was 58° C (Sonderegger & Schmidt, 1981). The Mg$^{2+}$ corrected temperature (53.5° C) for the Jordon well may be adjusted too far
downward as the low Mg$^{2+}$ concentration (3.4 mg/l) and high TDS value (6986 mg/l) suggest mixing may be minor.

The wide range of calculated reservoir temperatures [$\Delta^{18}$O(SO$_4$ - H$_2$O), 52° C; Na-K-Ca-Mg, 53.5°, 72.0°, and 73.4° C; Chalcedony, 73° C; Quartz, 95.6-99.8° C], indicate that the thermal waters do not reach equilibrium at depth, and that variable degrees of mixing do occur. Considering the calculated reservoir temperatures and the chemical characteristics of the thermal waters, an estimated reservoir temperature of 72° C ± 10° C seems reasonable. Previously estimated base temperatures of 150° C (Renner et al., 1975) and 125° C (Sonderegger
& Bergantino, 1981; Sonderegger & Schmidt, 1981) appear to be optimistically high. The reservoir temperature estimate of Renner et al. (1975) was based on chemical thermometer temperatures of 103°C and 148°C for quartz and Na-K-Ca. The 150°C reservoir temperature was based on the assumption that most geochemical thermometers provide minimal estimates of subsurface temperatures. No magnesium corrections were applied for the 148°C Na-K-Ca temperature.
CHAPTER VII

WHITE SULPHUR SPRINGS HYDROTHERMAL SYSTEM

General Statement

To determine the geothermal potential of an area, the characteristics that govern the hydrothermal system must be understood. These characteristics include the reservoir temperature, heat sources, and the structural and lithologic controls of the circulation system. The characteristics of the White Sulphur Springs hydrothermal system will be discussed in hopes of determining potential areas for future geothermal development.

Thermal Gradient and Heat Source

According to Chadwick and Kaczmarek (1975), the normal geothermal gradient for western Montana is 1° C/100 ft (32.8° C/km). The AAPG geothermal gradient map of Montana (Kehle, 1972) indicates that the White Sulphur Springs region has a thermal gradient of 1.56° C/100 ft (51.2° C/km); however, the reliability of this value is low as the data control for this area was poor. The Ringling well (TD 2320 ft), 15 mi southeast of White Sulphur Springs, produces warm water at a flow rate of 800 gpm at a temperature of 48° C. Assuming a mean annual ambient temperature of 8° C, a thermal gradient of 1.7° C/100 ft (56.6° C/km) can be calculated for the area. This is a conservative estimate as the well's discharge temperature may not be
representative of the well's base temperature, and therefore, should be considered the minimum reservoir temperature. The Ringling well penetrated mainly Paleozoic carbonates and Mesozoic sandstones which had a thin (<30 m) Tertiary cover. The presence of a thicker (~610 m) thermally nonconductive (estimated \( K = 2 \) mcal/cm s °C) Tertiary blanket overlying the thick (~1220 m) Precambrian Greyson Shale (estimated \( K = 4 \) mcal/cm s °C) in the Smith River basin suggests that the thermal gradient in the valley is much greater than that calculated for the Ringling well, perhaps ranging from 2.0°-2.4° C/100 ft (66°-79° C/km). Anomalous gradients within this range are commonly present in basins of western Montana (Kehle, 1972).

Regional heat flow in the White Sulphur Springs area is approximately 65-71 milliwatts/m² or 1.1-1.2 HFU (Grim, Berry, Ikelman, Jackson, & Smith, 1979) although low conductivity Tertiary clays and Precambrian shales should create anomalous heat flow in the Smith River Valley. The temperature difference caused by low conductivity strata in the valley can be illustrated by calculating the change in temperature (\( \Delta T \)) between the low conductivity blanket and a higher background conductivity by using the formula (Diment et al., 1975):

\[
\Delta T = q\left[\frac{(K_1 - K_2)}{(K_1 \times K_2)}\right]Z
\]

where \( q \) is heat flow, estimated to be approximately 1.4 HFU in the Smith River Valley, \( K_1 \) and \( K_2 \) are the conductivities of each blanket or layer, and \( Z \) is the thickness of the low conductivity blanket (estimated to be ~1.83 km). A conductivity of 3.3 mcal/cm s °C was derived for the low conductivity blanket \( K_2 \) by taking the weighted
mean of the previously mentioned estimated conductivities and thick-
nesses of the Tertiary sediments and the Greyson Shale. A conduc-
tivity of 6 mcal/cm s °C ($K_1$) was used for comparison because it is
typical of igneous basement rocks (Diment et al., 1975). When
inserting the estimated conductivities, heat flow, and thickness
values into the previous formula, a temperature difference of 35° C
is calculated when $q = 1.4$ HFU (see Appendix A for conversion units)
and $Z = 1.83$ km. This temperature would be considerably higher if
the high conductivity value represented thick Paleozoic carbonates
which bound the northern margin of the valley. Even though the
temperature derivation is somewhat arbitrary, it illustrates that the
thermal effect caused by low conductivity strata in the Smith River
Valley is significant.

The heat source of the White Sulphur Springs hydrothermal system
is not related to recent plutonic activity. The small size and Early
Eocene age of the Castle Mountain stock suggest remnant heat from the
intrusive is negligible. Basaltic volcanism in the area is Late
Oligocene in age (Chadwick, 1978) and is not a significant heat
source. High regional heat flow in the area is attributed to exten-
sional tectonism which may still be locally active. Local anomalous
heat flow in the Smith River Valley is primarily related to thermally
nonconductive Tertiary clay and thick Precambrian Belt Supergroup
shale.
Circulation System

Thermal activity in the vicinity of White Sulphur Springs is a surface expression of a hot-water dominated hydrothermal convective system. Considering an estimated thermal gradient for the area (~65°-75° C/km), the shallow (~0.6 km max.) basin depth (Gogas, 1984; this paper), and the 72° C estimated reservoir temperature, the circulation of thermal waters should be deeper than the bottom of the basin (~1400-1600 ft). The generalized model of the White Sulphur Springs convective hydrothermal system (Figure 17) indicates that cold meteoric water descends along thrusts and fractures zones where it is heated by the anomalously high thermal gradient at depth. The heated water ascends along the north-trending White Sulphur Springs basin-bounding fault. During ascension mixing occurs at intermediate depths and also in near surface unconsolidated aquifers. Mixing of thermal-meteoric waters at depth may be controlled by fracture zones associated with the White Sulphur Springs fault and the Pinchout Creek thrust just north of town.

Some thermal water discharges as thermal springs (Spa Motel flowing well) while much of the water appears to flow laterally along permeable fracture zones and sandstones within the Greyson Shale (Dunn, 1978). In some areas, thermal water may be prevented from reaching near surface aquifers by Tertiary clay. This suggests that intermediate thermal reservoirs may be present in Tertiary bedded gravel deposits at depth. These reservoirs should have
Figure 17. Generalized diagrammatic sketch of the White Sulphur Springs hydrothermal circulation system. Rock units: pEn - Precambrian Newland Limestone; pEg - Precambrian Greyson Shale; pEs - Precambrian Spokane Shale; Cf - Cambrian Flathead Sandstone; Ts - Tertiary sediments.
different base temperatures and chemical compositions than water that is controlled by faults.

Rapid ascension of thermal water is likely because the discharge rate of the Spa Motel well (in alluvium) is 350 gpm. Pressure that drives the thermal system may be caused by the combination of head produced by the thermal expansion of rising hot water, and the hydraulic head caused by deep circulation of waters along a confined aquifer (e.g., fault zone).

Controls on Recharge-Discharge

Relatively impermeable Belt Supergroup shale that encompasses the area of thermal activity in town suggests that recharge-discharge patterns for the hydrothermal circulation system are structurally controlled. Recharge for the hypothesized circulation system may be predominantly controlled by thrust faulting in the area, although water may be directed toward faults by permeable Paleozoic carbonates which comprise footwall strata north and east of town. The carbonate unit with the best aquifer characteristics is the Mission Canyon Limestone. The Mission Canyon has paleokarst solution-breccia beds (Figure 18) near its upper surface and forms footwall rocks along the Moors Mountain thrust. The majority of water that is recharged through Paleozoic carbonates appears to circulate down the Moors Mountain thrust zone as the only major spring discharging from the thrust zone is Trinity spring. The majority of the thrust zone is topographically higher than streams in the area, indicating that recharge dominates along this zone.
Figure 18. Photograph of solution breccia in the upper member of the Mission Canyon Limestone. Northeast limb of the Willow Creek syncline, SW 4, sec. 35, T.10N., R.7E.

The area of greatest recharge will occur where thrust faults are covered by water saturated alluvium. Such an area is present north and northeast of town where the Moors Mountain thrust zone and the Pinchout Creek thrust are covered by alluvial sediments associated with the North Fork of the Smith River; however, geologic cross sections (Figure 11; Plate 2) suggest that a circulation system controlled by the Moors Mountain thrust zone should produce a reservoir base temperature that is greater than those calculated for thermal waters in town (Table 2). Therefore, the Pinchout Creek thrust and an associated splay fault may significantly control recharge for the hydrothermal system (Figure 17). Solution development in the Newland
Limestone may direct water toward the Pinchout Creek thrust north of town; however, extensive solutioning in the Newland Limestone has not been observed in the area. Other areas of possible recharge include fractures associated with the White Sulphur Springs normal fault and joints that are in rocks of the Belt Supergroup. Lateral movement of thermal water perpendicular to the White Sulphur Springs fault (i.e., thermal bank well) indicates that fracture zones associated with the fault are extensive. This also suggests that recharge may occur at higher elevations, north and south of White Sulphur Springs, along the fault zone. Recharge along joint sets in the Precambrian Greyson Shale should be insignificant as jointing is extensive only near the margin of the Castle stock.

As previously mentioned, the discharge of thermal waters is along the north-trending White Sulphur Springs normal fault. These thermal waters mix with cool meteoric water to form a plume that is transported downgradient to the west, along more permeable Quaternary and Tertiary sands and gravels. The geologic controls that restrict the discharge area to the immediate vicinity of town are open to interpretation.

Gravity data by Gogas (1984) and this paper (Plate 3) suggest that the White Sulphur Springs fault may change its trend from north to northeast near the southern margin of town. The fault trends northeast for a short distance (~1 mi) south of town and then returns to a northerly trend. This change in trend could be a controlling factor for the southern margin of thermal discharge, whereas the Pinchout Creek thrust may control the northern margin of discharge.
A water well that was reported to have encountered hot water in the western half of section 12, T.9N., R.7E. (Ronald Jackson, personal communication, 1981) suggests that thermal waters may discharge along the Pinchout Creek thrust west of town. Unfortunately, the well was not cased and was allowed to collapse.

The restriction of thermal waters to the vicinity of White Sulphur Springs is apparently related to the variation in the depth to bedrock caused by normal faulting. On the basis of well log data, the depth to bedrock is generally less than 75 ft (23 m) under the eastern half of town whereas bedrock is as deep as 2000 ft (610 m) in the downdropped valley just west of town. Data from wells south of town suggest that Tertiary sediments are more than 120 ft thick. The presence of thicker Tertiary clay south of town may prevent further ascension of thermal waters in this area.
CHAPTER VIII

THERMAL DEVELOPMENT

Present Development

Current geothermal use in the town of White Sulphur Springs consists of the First National Bank and Spa Motel thermal wells. The bank well supplies approximately 80% of the space heating required by the bank (Sonderegger & Bergantino, 1981). The well is drilled in Greyson Shale to a total depth of 273 m and is perforated from 27 m to 103.7 m (Dunn, 1978). Pump test data suggest the well can produce 48° C water with an estimated safe yield of 50 gpm (Sonderegger & Schmidt, 1981). Discharged warm water used by the bank is piped across the street and is used in conjunction with the Spa Motel well to heat a swimming pool and hot bath.

The Spa Motel well is a good example of a developed thermal spring (White Sulphur spring). Development of the spring consisted of the installation of a cement culvert (similar to a dug well) to decrease shallow ground water mixing. After the well's installation, the discharge temperature increased from approximately 46.1° C to 48° C with a flow rate of 350 gpm (Sonderegger & Schmidt, 1981).

Potential for Development

Development of hydrothermal resources in the White Sulphur Springs area will be limited to space heating and recreational uses.
due to the low temperature of thermal fluids (reservoir temperature 72° C ± 10° C). Plate 5 depicts an area where shallow ground water temperatures may be suitable for heat pump use. A standard water temperature of 10° C (Sonderegger & Schmidt, 1981) was used for the cutoff for heat pump use. It is important to note that Plate 5 shows water temperatures that were primarily measured from shallow wells; therefore, the isothermal map cannot be directly related to thermal potential at depth. Much of the area shown as suitable for heat use (Plate 5) is highly suspect because of the following factors: (a) Many wells measured were domestic wells with pressure tanks, (b) water temperatures were primarily measured in July, and (c) areas with marginal temperatures (10° - 15° C) may not yield sufficient quantities of ground water for development. Much of the area east and southeast of town may not yield adequate volumes because of the shallow depth to bedrock (Greyson Shale) and overlying Tertiary clays. The low conductivity (hydraulically and thermally) of strata east of town is the primary reason for slightly above normal water temperatures (10° - 12° C).

The area suitable for heat pump use just west and within the town of White Sulphur Springs is related to the discharge of thermal waters and their transport downgradient. Isoconcentration maps (Plates 6 and 7) indicate that the area of thermal discharge is restricted to the vicinity of town.

Potential for shallow thermal development—similar in temperature (48° - 58° C) to the bank and Spa Motel wells—occurs in a narrow north-trending zone that is controlled by the White Sulphur
Springs fault. This zone extends approximately 1.5 km to the south and less than a kilometer northwest of the bank well (see Plate 5). Evidence supporting the southern extension of this zone includes high water temperatures and concentrations of geothermal indicators found in shallow water wells (see Plates 6 and 7). This zone may extend further to the south as thicker Tertiary sediments overlying the White Sulphur Springs fault may restrict the ascension of thermal waters.

Evidence of thermal activity northwest of town is sparse. Wells sampled in this area do not have anomalous chemical concentrations; however, these wells are completed in shallow alluvial gravels near Fox Creek and the North Fork of the Smith River suggesting chemical indicators may not be useful. An unconfirmed report (Ronald Jackson, personal communication, 1981) of a 200 ft water well which produced warm water in the NW^4, SW^4, section 12, T.9N., R.6E. suggests thermal potential may exist a short distance northwest of town. This well was supposedly abandoned and allowed to collapse because it was not suitable for domestic or stock use.

Intermediate thermal aquifers may exist in permeable Tertiary stream bed gravels near the downdropped side of the White Sulphur Springs fault. Because Tertiary gravels are discontinuous in nature, such reservoirs would be limited in extent. Thermal reservoirs within Tertiary gravels may exist west and southwest of White Sulphur Springs, but such reservoirs would probably be low in temperature (15° C - 30° C) because of heat loss from dilution with cold ground water. Also, Tertiary gravels are often confined aquifers that may not have sufficient sustained yields.
In summary, the potential for thermal development in the White Sulphur Springs area is very limited in extent. The most promising area for future development is along the White Sulphur Springs fault south of the bank and Spa Motel thermal wells. Deeper wells (>200 ft) drilled near the downdropped margin of the fault may produce thermal waters in this area. The warm temperature (15.3° C) and brine rich composition of the Jordon well suggest the area just west of the high school is a potential zone for development; however, utilization of corrosive waters similar in composition to the Jordon well (TDS 6986 mg/l) may create operational problems.
CHAPTER IX

SUMMARY AND SYNTHESIS

Tectonic History

Structural relationships in the White Sulphur Springs area are related to various features that date back to Precambrian (Proterozoic) time. The following is a summary of the tectonic history of the White Sulphur Springs region:

1. The Phanerozoic Belt basin developed. This basin was possibly an aulocogen, failed arm of a triple junction (Burchfiel & Davis, 1975; Schmidt & Garihan, 1984), or a continental block-faulted region (Winston, 1987). The major transgressive-regressive sequence of Belt sediment deposition (-1500-850 Ma) was accompanied by regional arching and erosion along the basin margins (Winston, 1987). This thickest accumulation of young Belt deposits occurred in the Helena embayment, an eastward-trending arm of the Belt basin.

2. The Lewis and Clark line was established during Precambrian (probably Windermere) time (Harrison et al., 1974). This regional structural lineament is located near the northern margin of the Helena embayment.

3. Deposition of the transgressive sequence of Cambrian strata began during Middle Cambrian time. Renewed tectonic activity, perhaps related to the Antler orogeny, prevented deposition in the area from Ordovician through Lower Devonian time. Tectonic stability
returned with the deposition of the Late Devonian Maywood and Jefferson formations.

4. Deposition of stable shelf sediments with renewed periods of tectonic activity was perhaps related to the Sonoma orogeny (Late Paleozoic-Early Mesozoic) and the Nevadan orogeny (Middle to Late Mesozoic). Such activity resulted in nonmarine (Jurassic Morrison) and clastic (Cretaceous Kootenai) synorogenic deposits.

5. Initial development of Sevier east-west compressional features in the area began during Late Cretaceous to Paleocene time. Thrusting in the area was associated with left-lateral movement along the Lewis and Clark line (Reynolds, 1979). The convex eastward geometry of thrusting is related to the margin of Belt deposition (Helena embayment) and the buttressing effect of the stable foreland.

6. Fold and thrust features were truncated by the Early Eocene Castle Mountain stock.

7. Regional extension and associated uplift began in Late Eocene time (Kuenzi & Fields, 1971). Extension continued during Middle Miocene time, with associated right-lateral movement along the Lewis and Clark line. South of the Lewis and Clark line, basin and range extensional features such as the Smith River Valley were formed (Reynolds, 1979). Extensional features truncated many Sevier structures although some may have followed preexisting Sevier zones of weakness.
Hydrothermal activity in the White Sulphur Springs area is a surface expression of a structurally controlled circulation system. Meteoric water descends along fracture zones associated with faulting and is heated within a high thermal gradient regime that is related to low conductivity rocks (Belt shale and Tertiary clays) in the Smith River Valley and high regional heat flow. Recharge may predominate where water saturated alluvium provides a constant source of water to fault zones north of White Sulphur Springs.

The wide range of calculated reservoir temperatures \([\Delta^{18}O(SO_4 - H_2O), 52^\circ C; Na-K-Ca-Mg, 53.5^\circ, 72^\circ, \text{ and } 73.4^\circ C; \text{Chalcedony, } 73^\circ C; \text{Quartz, } 95.6^\circ-99.8^\circ C]\) for thermal waters indicates that variable degrees of mixing occur, and that thermal waters do not reach chemical equilibrium at depth. Mixing at intermediate depths may be related to recharge along faults that are at different structural levels.

Discharge of thermal water is along the north-trending White Sulphur Springs normal fault. The area of discharge is limited to a short linear zone (~2 km) which greatly constrains the potential for shallow thermal development in the area. The \(72^\circ C \pm 10^\circ C\) estimated reservoir temperature indicates that future thermal development in the area is limited to space heating and recreational use.
APPENDICES
Appendix A

Conversion Factors for Units Used in This Paper
CONVERSION FACTORS FOR UNITS USED IN THIS PAPER

Length:  
1 meter (m) = 3.281 ft  
1 kilometer (km) = .6214 mi = 3,281 ft

Area:  
1 km² = 10⁶ m² = 0.386 mi²

Volume:  
1 liter (l) = 0.2642 gal  
1 l/sec = 86.4 m³/day = 15.85 gal/min (gpm)

Temperature:  
°C = \frac{5}{9} (°F - 32);  °F = \frac{9}{5} (°C) + 32

Temperature gradient:  
1° C/100 ft = 32.8° C/km = 10⁻³ °C/m rate of temperature increase with depth

Pressure:  
1 bar = 0.9869 atm = 14.50 psi = 1.020 kg/cm² = 10⁶ dynes/cm²

Heat flow:  
1 x 10⁻⁶ cal/cm² sec = 4.19 x 10⁻² W/m² (Watts per square meter)  
1 heat flow unit (HFU) = 1 x 10⁶ cal/cm² sec

Thermal conductivity (K):  
1 x 10⁻³ cal/cm sec °C = .418 W/m °K

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Appendix B

Stereographic Analyses of Folds
A. Station WSS-81-38. S-pole diagram for fold in the Newland Limestone. Located in the NE\(^4\) sec. 5, T.9N., R.7E.

B. Station WSS-81-GSA. S-pole diagram for a minor fold and pressure solution features in the Newland Limestone. Located in the NE\(^4\) sec. 5, T.9N., R.7E.
A. Station WSS-82-77. S-pole diagram for a minor fold in the Jefferson Formation. Located in the N8 sec. 8, T.8N., R.7E.

B. Station WSS-82-78. S-pole diagram for the Cottonwood Creek syncline. Located in sec. 7 & 8, T.8N., R.7E.
A. Station WSS-82-97. S-pole diagram for a minor fold in the Meagher Limestone. Located in the SW<sub>8</sub> sec. 29, T.8N., R.7E.
B. Station WSS-82-108. S-pole diagram for a minor fold in the Pilgrim Limestone.
A. Station WSS-82-100-107. S-pole diagram for the Willow Creek syncline. Located in sec. 23 & 24, T.9N., R.7E.
B. Station WSS-82-91. S-pole diagram for a minor fold in the Pilgrim Limestone. Located in the NE¼ sec. 30, T.8N., R.7E.
A. Station WSS-82-177. S-pole diagram for a fold in the Amsden Formation. Located in sec. 33, T.9N., R.7E.

B. Station WSS-82-176. S-pole diagram for a fold in the Amsden Formation. Located in sec. 34, T.8N., R.7E.
Appendix C

Gravity Data
**WHITE SULPHUR SPRINGS, MONTANA GRAVITY SURVEY**

Area - Meagher Co., MT  
Observer - Michael Stickney (MBMG)  
Instrument - Worden Meter Educ. Model  
Density used in Bouguer correction factor - 2.670  
Datum - Base 1 - 980484.00

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### WHITE SULPHUR SPRINGS, MONTANA GRAVITY SURVEY

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**Area** - Meagher Co., MT

**Instrument** - Worden Meter No. 944

**Datum** - Base 1 - 980484.00

**Density used in Bouguer correction factor** - 2.670

**Date** - 7-19-82

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Date 7-20-82
### WHITE SULPHUR SPRINGS, MONTANA GRAVITY SURVEY

**Area:** Meagher Co., MT  
**Observer:** William Gierke (WMU)  
**Instrument:** Worden Mete  
**Density used in Bouguer correction factor:** 2.670  
**Datum:** Base 1 - 980484.00

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Appendix D

Stratigraphic Profiles
APPENDIX D. Stratigraphic profile A-A' (Plate 4). Vertical scale exaggerated.
APPENDIX D (Cont'd). Stratigraphic profile B-B' (Plate 4). Vertical scale exaggerated.
Appendix E

Chemical Analyses of Well Waters
Sample Number WSS001 - Cemetery Well

MONTANA BUREAU OF MINES AND GEOLOGY
WATER QUALITY ANALYSIS
STATE MONTANA
SAMPLE SITE WSS001 - CEMETARY Well
HONTANA BUREAU OF MINER AND GEOLOGY
BUTTE, MONTANA 59701

LATITUDE-LONGITUDE
UTM COORDINATES: Z12 NS151150 (490840)

STATION NO. 325253111013201

LATITUDE-LONGITUDE:
MONTANA 46°32'03"N 111°D19'33"W

SAMPLE HANDLING:
METHOD SAMPLED: WATER USE IRRIGATION

TOTAL CATIONS:
CALCIUM (Ca) 39.9 MEG/L 1.99 MEG/L
MAGNESIUM (Mg) 9.7 MEG/L 0.81 MEG/L
SODIUM (Na) 17.6 MEG/L 0.77 MEG/L
POTASSIUM (K) 1.3 MEG/L 0.14 MEG/L
IRON (Fe) .002 MEG/L 0.00 MEG/L
MANGANESE (Mn) .002 MEG/L 0.00 MEG/L
TOTAL ANIONS:
SILICA (SiO2) 59.1 MEG/L 0.2 MEG/L

STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA):
3.73

REMARKS:
WATER LEVEL TAKEN DURING PUMPING * 7" DW
NO TASTE OR ODOR *

EXPLANATION:
MILLIGRAMS PER LITER, MG/L = MICROGRAMS PER LITER, MEG/L = MILLIEQUIVALENTS PER LITER, FT = FEET, M = METERS, (R) = ESTIMATED, (E) = REPORTED, (T) = TOTAL RECOVERABLE, (S) = STANDARD DEVIATION.

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 8101112

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Sample Number WSS002 - Edwin Bodell

Montana Bureau of Mines and Geology
Butte, Montana 59701 (406) 496-4101

Water Quality Analysis
Lab No. 810113

State: Montana
County: Meagher
Latitude-Longitude: 44°34'14"N 110°54'10"W
Site Location: 2N SE 2 2ACC

Topographic Map: White Sulphur Springs 7.1
Station ID: 42341110561001

Sample Handling: Analyst
Date Analyzed: 8/15/81
Sample: Ejected

Agency + Sampler: Montana Bureau of Mines and Geology
Bottle Number: WSS002
Date Sampled: 20-JUL-81

Lateral Quality Analysis
Lab No. H101113

State
Latitude-Longitude
UTM Coordinates
Topographic Map
Geologic Source
Drainage Basin
Agency + Sampler
Bottle Number
Date Sampled
Time Sampled
Swl Above

Geologic Source
Geologic Source
Sample Handling
Laboratory Use

Sampling Site
Bodell, Edwin H
White Sulphur Springs

Sample Source
Calcium (Ca)
Magnesium (Mg)
Sodium (Na)
Potassium (K)
Iron (Fe)
Manganese (Mn)
Silica (SiO2)

Total Cations
Standard Deviation of Anion-Cation Balance (Sioma)

Parameter
Value

Parameter
Value

Remarks: Water has no odor or taste.
Send copy to Edwin Bodell, White Sulphur Springs.

Explanation: Mg/L = Milligrams Per Liter; ug/L = Micrograms Per Liter; meq/L = Milliequivalents Per Liter; ft = Feet; M = Meters; (H) = Measured, (E) = Estimated, (R) = Reported, TR = Total Recoverable, TOT = Total.

Other Available Data

Other File Numbers:

Project:
Last Edit Date: 16-SEP-81
Processing Program: P1703p V4 (9/26/80)
Printed: 16-SEP-81

Percent Meq/L (For Piper Plot)

Note: In Correspondence, please refer to Lab Number: 810113

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Sample Number WSS003 - Edwin Bodell

MONTANA BUREAU OF MINES AND GEOLGY
UTT, MONTANA 59701 (406) 496-4101

WATER QUALITY ANALYSIS

LATITUDE-LONGITUDE 46°33'06"N 110°05'22"W
UTM COORDINATES 219 W3D5130 E70376

TOPOGRAPHIC MAP WHITE SULPHUR SPRINGS 7.1

STATE MONTANA
COUNTY MEagher

TOPOGRAPHIC MAP WHITE SULPHUR SPRINGS 7.1

STATE LATITUDE-LONGITUDE
110W 6E 10 DDB

WATER QUALITY ANALYSIS
LA B NO. 1114

LATITUDE-LONGITUDE
46°33'06"N 110°05'22"W

UTM COORDINATES 219 W3D5130 E70376

SUSTAINED YIELD YIELD MEAS METHOD

DATE SAMPLED 20-JUL-81 TOTAL DEPTH OF WELL
TIME SAMPLED 17:45 HOURS SWL ABOVE (-) OR BELOW AS 14. FT (R)

LAB / ANALYST MDHOSNA CASING DIAMETER 7 IN

DATE ANALYZED

SAMPLE HANDLING 3120 COMPLETION TYPE 018
METHOD SAMPLED PUMPEO PERFORATION INTERVAL
WATER USE DOMESTIC

GEOLGIC SOURCE ALLUVIUM (QUATERNARY)

CALCIUM (CA) 0.74 4.36 BICARBONATE (HCO3) 359. 5.37
MAGNESIUM (Mg) 12.3 4.36 CARBONATE (CaO) 0.
SODIUM (Na) 0.31 1.07 CHLORIDE (Cl) 4.0 0.11
POTASSIUM (K) 1.5 0.05 SULFATE (SO4) 13.3 0.38
IRON (Fe) 0.002 NITRATE (NO3) 0.02 0.02
MANGANESE (Mn) 0.002 PHOSPHATE TOT (As P) 0.24 0.01
SILICA (SiO2) 20.1 6.16 TOTAL ANIONS 6.29

TOTAL CATIONS 6.16 TOTAL ANIONS 6.29

CALCULATED DISSOLVED LOADS 329.15 SODIUM ABSORPTION RATIO 0.18

SUM OF DISS. CONSTITUENT 509.80 RYZHAR STABILITY INDEX 6.34

LAD SPECIFIC MICROMHO/CM 577.6 LANGLIER SATURATION INDEX 0.75

PARAMETER VALUE PARAMETER VALUE

TEMPERATURE AIR (C) 79.0 CONDUCTIVITY FIELD MICROMHO 526.
FIELD PH 6.35 ALUMINUM DISS (MG/L-AL) <.03
LEAD DISS (MG/L AS Pb) 6.55 SILICUM DISS (MG/L-AS) <.03
STAINLESS DISS (MG/L-SS) 0.04 BORON DISS (MG/L-AB 01)
TITANIUM DISS (MG/L- Ti) 0.04 CERIUM DISS (MG/L-CR) <.02
NIABLEDISS (MG/L-AS) 0.04 COPPER DISS (MG/L-AS CU) <.02
ZINC DISS (MG/L-AZ) 0.04 MOLYBDENUM DISS (MG/L-MO) <.02
ARSENIC DISS (MG/L-AS) 1.2 LITHIUM DISS (MG/L-AS Li) <.02

REMARKS: WATER HAS NO ODOR OR PECULIAR TASTE. OWNER COMPLAINS OF MINERAL
DEPOSITS IN HOT WATER HEATER TANK (CACO3). MAIL COPY TO EDWIN BODELL,
WHITE SULPHUR SPRINGS, MT.

EXPLANATION: MG/L = MILLIGRAMS PER LITER; MG/L = MILLEQUIVALENCES PER LITER. FT = FEET, M = METERS. (P) = MEASURED. (E) =
ESTIMATED. (R) = REPORTED. TR = TOTAL RECOVERABLE. TOT = TOTAL.

OTHER AVAILABLE DATA
OTHER FILE NUMBERS:

PROJECT: 16-SEP-81 COST: TP 2MJT
PROCESSING PROGRAM: F1723P V2 (8/9/80) PRINTED: 16-SEP-81

OTHER AVAILABLE DATA
OTHER FILE NUMBERS:

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 8114114
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**Total Cations**: 4.81

**Total Anions**: 6.74

**Average**: 1.12

**Laboratory pH**: 7.64

**Field Water Temperature**: 49.0°F

**Total Hardness as CaCO₃**: 279.47

**Total Alkalinity as CaCO₃**: 202.14

**Sum of Diss. Constituent**: 329.38

**Ryznar Stability Index**: 6.61

**Laboratory pH**: 7.64

**Total Hardness as CaCO₃**: 279.47

**Total Alkalinity as CaCO₃**: 202.14

**Sum of Diss. Constituent**: 329.38

**Ryznar Stability Index**: 6.61

**Parameter**: **Value**

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**Remarks**: Water has no odor or taste.

**Explanation**: mg/L = milligrams per liter, ug/L = micrograms per liter, mg/L = milligrams per liter, ft = feet, m = meters, (m) = measured, (c) = calculated, (r) = reported, (t) = total recoverable, tot = total.

**Other Available Data**

**Project**: 14-SEP-81

**Cost**: 16-SEP-81

**Processing Program**: F1730P V2 (8/9/80)

**Percent mg/L (for Piper Plot)**

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**Note**: In correspondence, please refer to Lab Number: B1115.
Sample Number WSS005 - R. E. Saunders, Jr.

Montana Bureau of Mines and Geology
Butte, Montana 59701 (406) 476-4101

Water Quality Analysis

State: Montana

County: Meagher

Latitude-Longitude: 46°03'20"N 110°49'44"W

Longitude of Site Location: 7E 10 AGCA

U.S. Coordinate Map: T2J S15S R13 E31050

Elevation: 3015 ft

Geologic Source: Alluvium (Quaternary)

Drainable Basin: Willow Creek Reservoir

Land Surface Altitude: 5320 ft

Sample Handling: 312

Water Use: Domestic

Sampling Site: Saunders, R. E., Jr. & White Sulfur Springs

Geologic Source: Alluvium (Quaternary)

Calcium (Ca): 44.9 mg/L

Magnesium (Mg): 14.9 mg/L

Sodium (Na): 5.2 mg/L

Potassium (K): 0.4 mg/L

Iron (Fe): 0.03 mg/L

Manganese (Mn): 0.046 mg/L

Silica (SiO₂): 14.1 mg/L

Total Cations: 0.36 mg/L

Total Anions: 0.3 mg/L

Standard Deviation of Anion-Cation Balance (σ): 0.73

Laboratory pH: 7.91

Field Water Temperature: 49°F

Calculated Dissolved Solids: 201.00 mg/L

Sodium Adsorption Ratio: 0.17

Lab Spec. Cond. (Micromhos/cm): 358.0

Langlier Saturation Index: 0.26

Parameter: Value

Temperature, Air (°C): 80.0

Conductivity, Field Micromhos: 304.4

Aluminum, Diss (mg/L-L): < 0.03

Iron, Diss (mg/L-L): < 0.03

Boron, Diss (mg/L-L): < 0.02

Chromium, Diss (mg/L-L): < 0.02

Lithium, Diss (mg/L-L): < 0.02

Molybdenum, Diss (mg/L-L): < 0.1

Total Hardness as CaCO₃: 164.2 mg/L

Total Alkalinity as CaCO₃: 159.2 mg/L

Sustained Yield: 2.35 ft²

Sample Source: Surface Altitude: 3307 ft

Sustained YIELD: 0.5 ft

Casing Diameter: 4 in

Completion Type: Steel

Remarks: Water has no odor or taste. Owner says well runs dry in a short period of time. - About 5 Hr & # well test data from drill log & pumping level below LoD - 00 ft after 2 hrs pumping at 3 GPM & send copy to owner

Explanation: mg/L = milligrams per liter, µg/L = micrograms per liter, mg/L - estimated, (E) = estimated, (R) = reported, TR = total recoverable, TOT = total

Other Available Data:

Other File Numbers:

Project: 14-SEP-81

Processing Program: F730P V2

Cost:

Print Date: 09/20/80

Percent Hg/L (for Piper Plot):

Ca Na K Cl SO₄ HCO₃

41 31 6 0 6 8 4

Note: In correspondence, please refer to lab number: 0101116

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**Sample Number WSS006 - Dave Ellington**

### Montana Bureau of Mines and Geology

**WATER QUALITY ANALYSIS**

**LAB. NO.** 0101117

**STATE MONTANA**

**COUNTY MEAGHER**

**LATITUDE-LONGITUDE**

**N 46°52'54" W 109°57'46"**

**COORDINATE SYSTEM**

**WS 503479 E 503479**

**GEOLOGIC SOURCE**

**WILLow CREEK RESERVOIR**

**DATE SAMPLED**

**21-JUL-81**

**DATE ANALYZED**

**28-AUG-81**

**BOTTLE NUMBER**

**WSS006**

**TOTAL DEPTH OF WELL**

**130 FT**

**SAMPLE HANDLING**

**DOMESTIC USE**

**SAMPLE LOCATION**

**WHITE SULFUR SPRINGS, MT**

**EXPLANATION:**

- **pH** = **total hardness**
- **mg/l** = **milligrams per liter**
- **ug/l** = **micrograms per liter**
- **mg/l** = **milliequivalents per liter**
- **ft** = **feet**
- **m** = **meters**
- **h** = **measured**
- **c** = **reported**
- **tr** = **total recoverable**
- **tot** = **total**

**PARAMETER VALUE**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td><strong>Temperature</strong>, air (°C)</td>
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<tr>
<td><strong>Aluminum</strong>, mg/l (Al)</td>
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<tr>
<td><strong>Silicon</strong>, mg/l (SiO₂)</td>
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</tr>
<tr>
<td><strong>Boron</strong>, mg/l (B)</td>
<td>&lt; 0.02</td>
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<tr>
<td><strong>Chromium</strong>, mg/l (Cr)</td>
<td>&lt; 0.02</td>
</tr>
<tr>
<td><strong>Copper</strong>, mg/l (Cu)</td>
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<tr>
<td><strong>Lithium</strong>, mg/l (Li)</td>
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<tr>
<td><strong>Molybdenum</strong>, mg/l (Mo)</td>
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<tr>
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<tr>
<td><strong>Magnesium</strong>, mg/l (Mg)</td>
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<tr>
<td><strong>Sodium</strong>, mg/l (Na)</td>
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<tr>
<td><strong>Potassium</strong>, mg/l (K)</td>
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<tr>
<td><strong>Iron</strong>, mg/l (Fe)</td>
<td>&lt; 0.02</td>
</tr>
<tr>
<td><strong>Sulfate</strong>, mg/l (SO₄²⁻)</td>
<td>&lt; 0.02</td>
</tr>
<tr>
<td><strong>Bicarbonate</strong>, mg/l (HCO₃⁻)</td>
<td>&lt; 0.02</td>
</tr>
<tr>
<td><strong>Chloride</strong>, mg/l (Cl⁻)</td>
<td>&lt; 0.02</td>
</tr>
<tr>
<td><strong>Fluoride</strong>, mg/l (F⁻)</td>
<td>&lt; 0.02</td>
</tr>
<tr>
<td><strong>Silica</strong>, mg/l (SiO₂)</td>
<td>&lt; 0.02</td>
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</table>

**Standard Deviation of Anion-Cation Balance (Sigma)**

**TOTAL CATIONS**

<table>
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<tr>
<th>Parameter</th>
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<tr>
<td><strong>Phosphorus</strong>, mg/l (P)</td>
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**TOTAL ANIONS**

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<td><strong>Magnesium</strong>, mg/l (Mg)</td>
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<td><strong>Potassium</strong>, mg/l (K)</td>
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<tr>
<td><strong>Sulfate</strong>, mg/l (SO₄²⁻)</td>
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<tr>
<td><strong>Bicarbonate</strong>, mg/l (HCO₃⁻)</td>
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<tr>
<td><strong>Chloride</strong>, mg/l (Cl⁻)</td>
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</tr>
<tr>
<td><strong>Fluoride</strong>, mg/l (F⁻)</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>Silica</strong>, mg/l (SiO₂)</td>
<td>&lt; 0.002</td>
</tr>
<tr>
<td><strong>Sodium</strong>, mg/l (Na)</td>
<td>39.2</td>
</tr>
</tbody>
</table>

**Remarks:**

- Water has no odor or smell.
- PH meter out of order. Unable to measure static water level.
- 100% of the south side canal.

**Other Available Data:**

- **Project:**
- **Last Edit Date:** 10-SEP-81
- **Processing Program:** 10-SEP-V2 (8/9/80)
- **Percent MEO/L (for Piper plot):** NA
- **Note:** In correspondence, please refer to Lab Number: 0101117
Sample Number WSS007 - Herb Townsend

MONTANA BUREAU OF MINES AND GEOLOGY
WATER QUALITY ANALYSIS
Butte, Montana 59701 (406) 476-4101

STATE MONTANA
COUNTY MEASHEER

LATITUDE-LONGITUDE 44°50'20"N 110°06'05"W
UTM COORDINATES 212,919.06,113,990.10

GEOLOGIC SOURCE ALLUVIUM (QUATERNARY)
SAMPLE SOURCE WELL

DRAINAGE BASIN UC
LAND SURFACE ALTITUDE 4,947 FT < 10

AGENCY & SAMPLER HOMS6001
BOTTLE NUMBER WSS007

DATE SAMPLED 21-JUL-81
TOTAL DEPTH OF WELL 250 FT (R)

TIME SAMPLED 14:45 HOURS
SWL ABOVE+1 OC BELOW 15 FT (R)

LAB & ANALYST HOMS6001
CARING DIAMETER 16 IN (R)

SAMPLE HANDLING 312
COMPLETION TYPE 02302

METHOD SAMPLED PUMPED
PERFORATION INTERVAL 47 TO 250 (R)

WATER USE IRRIGATION

SAMPLE SITE TOWNSEND, HERB32.5 MI ON WHITE SULPHUR SPRINGS

GEOLOGIC SOURCE ALLUVIUM (QUATERNARY)

<table>
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<th>PARAMETER</th>
<th>VALUE</th>
<th>VALUE</th>
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<tr>
<td>TEMPERATURE, AIR (°C)</td>
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<td>CONDUCTIVITY FIELD MICROHMS</td>
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<tr>
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<td>&lt;.03</td>
<td>NICKEL, DISS (mg/L as Ni)</td>
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<tr>
<td>SILVER, DISS (mg/L as Ag)</td>
<td>&lt;.002</td>
<td>LEAD, DISS (mg/L as Pb)</td>
</tr>
<tr>
<td>BORON, DISS (mg/L as B)</td>
<td>&lt;.002</td>
<td>STRONTIUM, DISS (mg/L as Sr)</td>
</tr>
<tr>
<td>CADMIUM, DISS (mg/L as Cd)</td>
<td>&lt;.002</td>
<td>VANADIUM, DISS (mg/L as V)</td>
</tr>
<tr>
<td>CHROMIUM, DISS (mg/L as Cr)</td>
<td>&lt;.002</td>
<td>ZINC, DISS (mg/L as Zn)</td>
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<tr>
<td>LITHIUM, DISS (mg/L as Li)</td>
<td>&lt;.002</td>
<td>ZIRCONIUM, DISS (mg/L as Zr)</td>
</tr>
<tr>
<td>MOLYBDENUM, DISS (mg/L as Mo)</td>
<td>&lt;.1</td>
<td>ARSENIC, DISS (mg/L as As)</td>
</tr>
</tbody>
</table>

REMARKS: WATER HAS NO ODOUR OR SHELL & FILTER WAS VERY DIRTY. SILT & SAMPLE WAS COLLECTED IN A BUCKET FROM THE PUMP & SEND COPY TO PO BOX WHITE SULPHUR SPRINGS TO OTHERS PERF5 ON INVENTORY FORM 

EXPLANATION: mg/L = MILLIGRAMS PER LITER; µg/L = MICROGRAMS PER LITER; mg/L = MILLIEQUIVALENTS PER LITER; ft = FEET; MT = METERS; °C = MEASURED; (E) = ESTIMATED; (R) = REPORTED; TR = TOTAL RECOVERABLE; TOT = TOTAL.

OTHER AVAILABLE DATA

OTHER FILE NUMBERS:
PROJECT: 
LAST EDIT DATE: 16-SEP-81
PROCESSING PROGRAM: F173DP 02 (6/9/80)

PERCENT MG/L FOR PIPER PLOT:
<table>
<thead>
<tr>
<th>CA</th>
<th>Mg</th>
<th>Na</th>
<th>K</th>
<th>Cl</th>
<th>SO4</th>
<th>HCO3</th>
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<tbody>
<tr>
<td>29</td>
<td>29</td>
<td>11</td>
<td>1</td>
<td>21</td>
<td>17</td>
<td>55</td>
</tr>
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NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 8101118

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Sample Number WSS008 - Howard Zehntner

MONTANA DEPARTMENT OF MINES AND GEOLOGY
BUTTE, MONTANA 59701 (406) 476-4111

WATER QUALITY ANALYSIS
LAB NO. 0101119

Sample Handled By:

STATE: MONTANA
COUNTY: MEAGHER

WSS008

LATITUDE-LONGITUDE:

WATER QUALITY ANALYSIS

TOPOGRAPHIC MAP:
WILLOW CREEK RESERVOIR

STATE LOCALITY:

BUTTUE, MONTANA

OF MINES AND GEOLOGY

59701

QUALITY ANALYSIS

I.AE NO. 0101119

STATE

LATITUDE-LONGITUDE

UTM COORDINATE!

TOPOGRAPHIC MAP

GEOLOGIC SOURCE

DRAINAGE BASIN

AGENCY + SAMPLER

BOTTLE NUMBER WSS008

DATE SAMPLED 21-JUL-81

TOTAL DEPTH OF WEL: 22.5 FT (R)

LAB + ANALYST HOMESTEAD

DATE ANALYZED 08-AUG-81

CABIN DIAMETER 4 IN (H)

SAMPLE HANDLING 312

METHOD SAMPLED PERMANENT

WATER USE

SAMPLE SOURCE WELLS

METHOD SAMPLED PUMPED

WATER USE DOMESTIC

WATER USE USE DOMESTIC

TOTAL CATIONS 4.10

TOTAL ANIONS 4.28

STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA) 0.58

FIELD TEMPERATURE 7.64

TOTAL HARDNESS AS CaCO3 197.06

CALCULATED DISSOLVED SOLIDS 239.06

SODIUM ADSORPTION RATIO 0.20

SUM OF WATER USE SUMMARY 1.41

ATZMER SATURATION INDEX 0.17

LAB SPEC. COND. (MICROMOS/CM) 402.0

LAMBLER SATURATION INDEX 0.19

PARAMETER VALUE

PARAMETER VALUE

TEMPERATURE, AIR (C) 75.3

C N N O N T R Y , F I E L D M I C R O M O S 1000.

ALUMINUM, DISS (MG/L AS AL) 0.02

NICKEL, DISS (MG/L AS NI) < 0.01

Boron, DISS (MG/L AS B) < 0.02

LEAD, DISS (MG/L AS PU) < 0.04

CADMIUM, DISS (MG/L AS Cd) < 0.02

STIBIUM, DISS (MG/L AS Sb) 0.03

CHROMIUM, DISS (MG/L AS Cr) < 0.02

TITANIUM, DISS (MG/L AS Ti) 0.02

LITHIUM, DISS (MG/L AS Li) < 0.02

ZINC, DISS (MG/L AS Zn) 0.02

MOLYBDENUM, DISS (MG/L AS Mo) < 0.01

ARSENIC, DISS (MG/L AS As) < 0.01

PARAMETER VALUE

PARAMETER VALUE

CALCIUM (CA) 54.9

bicarbonate (HC03) 240.3

MAGNESIUM (MG) 13.6

CHLORIDE (CL) < 0.07

SODIUM (NA) 6.3

SULFATE (SO4) 0.34

POTASSIUM (K) 1.9

FLUORIDE (F) 0.27

IRON (FE) < 0.002

CHLORIDE (CL) 0.03

MANGANESE <HN> < 0.001

SULFATE (SO4) 0.01

SILICA (SiO2) 29.3

NITRATE (NO3) 0.02

TOTAL CATIONS 240.3

TOTAL ANIONS 0.07

STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA) 0.58

REMARKS:

WATER WAS NON ODOR OR SMELL 2 PH METER IS INOPERATIONAL 2

SEND COPY TO P. 0. BOX 534, WHITE SULPHUR SPRINGS, MT.

EXPLANATION: MG/L = MILLIGRAMS PER LITER; US/L = MICROGRAMS PER LITER; MEQ/L = MILLIEQUIVALENTS PER LITER; FT = FEET, MT = METERS; (C) = ESTIMATED; (R) = REPORTED; TR = TOTAL RECOVERABLE; TOT = TOTAL.

OTHER AVAILABLE DATA

OTHER FILE NUMBERS

PROJECT:

16-SEP-81

COST:

BY: TP 3MJT

PROCESSING PROGRAM: F1730P V2 (0/9/80) PRINTED: 16-SEP-81

PERCENT MEQ/L (FOR PIPER PLOT):

DE MEQ/L NA K CL SO4 HCO3

65 24 6 1 1 5 92

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 0101119

ANALYSIS NOT IN FILE!
Sample Number WSS009 - Spa Motel

MONTANA BUREAU OF MINES AND GEOLOGY
WATER QUALITY ANALYSIS
STATE: MONTANA COUNTY: MEAGHER
LATITUDE-LONGITUDE: N 43° 30’ 41” E 108° 46’ 52” SITE LOCATION: WSS009
UPM COORDINATES: Z 917295 E 208089 MONTANA BUREAU OF MINES AND GEOLOGY
TOPOGRAPHIC MAP: WHITE SULPHUR SPRINGS 7.1 STATION ID: WSS009
GROUNDWATER SOURCE: SPA MOTEL * SAMPLE SOURCE WELL
AGENCY + SAMPLER: MOMB JLS LAND SURFACE ALTITUDE
BOTTLE NUMBER: WSS009 SUSTAINED YIELD
SAMPLE DATE: 23-JUL-81 YIELD MEAS METHOD: GROSS
TIME SAMPLED: 0015 HOURS TOTAL DEPTH OF WELL: 36 IN (R)
LAB + ANALYST: WSS009 CARRYING DIAMETER: 36 IN (R)
SAMPLE HANDLING: 312 COMPLETION TYPE: 01
METHOD SAMPLED: PUMPED PERFORATION INTERVAL: WATER USE RECREATIONAL

SAMPLING SITE: SPA MOTEL * WHITE SULPHUR SPRINGS *
GEOLOGIC SOURCE: WHITE SULPHUR SPRINGS, MEAGHER COUNTY

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value (mg/L)</th>
<th>Value (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium (Ca)</td>
<td>41.7</td>
<td>2.06</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>9.5</td>
<td>0.20</td>
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<tr>
<td>Sodium (Na)</td>
<td>44.9</td>
<td>19.83</td>
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<tr>
<td>Potassium (K)</td>
<td>17.4</td>
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</tr>
<tr>
<td>Iron (Fe)</td>
<td>0.96</td>
<td>0.01</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>0.14</td>
<td>0.01</td>
</tr>
<tr>
<td>Silica (SiO2)</td>
<td>47.9</td>
<td>7.07</td>
</tr>
</tbody>
</table>

TOTAL CATIONS: 22.85 TOTAL ANIONS: 24.10

STANDARD DEVIATION OF ANION-CATION BALANCE (S.D.) 2.79

FIELD DATA:
- Field PH: 7.27
- Total Hardness (as CaCO3): 143.23
- Total Alkalinity (as CaCO3): 461.06
- Calculated Dissolved Solid: 1400.02
- Sodium Absorption Ratio: 16.33
- Sun of Diss. Constituent: 191.43
- Rainwater Saturation Index: 0.89
- Lab Spec. Cond. (microhos/cm): 2130.1
- Laboratory Saturation Index: 0.17
- Calcium (Ca) 41.7
- Magnesium (Mg) 9.5
- Sodium (Na) 44.9
- Potassium (K) 17.4
- Iron (Fe) 0.96
- Manganese (Mn) 0.14
- Silica (SiO2) 47.9

Remarking: Water is clear * H2S odor *
- Sampled at pool during filling & 250 gpm max. sustained yield *
- Lab: FC 43.1 mg/L, MO 10.1, MA of 469 and K of 17.4 gives .465
- Lab: Sigma *

Explanation: mg/L = milligrams per liter, ug/L = micrograms per liter, meq/L = milliequivalents per liter, feet = feet, meters. (M) = measured, (E) = estimated, (R) = reported. TR = total recoverable. TD = total.

OTHER AVAILABLE DATA:

PROJECT:
- Last Edit Date: 16-SEP-81
- Processing Program: F1750P V2 (8/9/80) PRINTED: 16-SEP-81
- Percent mg/L (for Piper Plot)

CA: 43.1 mg/L
NA: 10.1 mg/L
K: 469 mg/L

Note: In correspondence, please refer to lab number: 0101120

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Sample Number WSS010 - Cow Palace

**Montana Bureau of Mines and Geology**

**State Montana**

**Location:**

- **Latitude:** 40°5'37.2"N
- **Longitude:** 110°5'4.2"W
- **Elevation:** 715.3950 ft
- **UTM Coordinates:** W5153950 E7027250
- **Map:** White Sulphur Springs 7.1
- **Drainage Basin:** Knowsite W5201

**Quality Analysis Lab No. U 010121**

**Sample Source:**

- **GEOLOGIC SOURCE:** Alluvium (Quaternary)
- **DRAINAGE BASIN:** Meagher
- **AGENCY + SAMPLER:** Montana Bureau of Mines and Geology
- **BOTTLE NUMBER:** WSS010
- **SAMPLE NUMBER:** WSS010
- **SAMPLE SITE:** Cow Palace 3
- **SAMPLE SOURCE:** Alluvium (Quaternary)
- **STATE:** Montana
- **SITE LOCATION:** BS0M03 LS04
- **LATITUDE-LONGITUDE:** N 515.3950 E 7027.2500
- **UTM COORDINATES:** 7153950 7027250

**Sampling Site:**

- **DATE SAMPLED:** 25-JUL-81
- **TIME SAMPLED:** 11:00 hours
- **LAB + ANALYST:** MBMN 03U 00-AUG-81
- **DATE ANALYZED:** 00-AUG-01
- **METHOD SAMPLED:** Pumped Domestic
- **SAMPLE HANDLING:** Perforation interval 80 to 110 ft (R)
- **DATE:** 22-JUL-81
- **TIME:** 11:00 hours
- **LAB:** MBMN 03U 00-AUG-01
- **ANALYST:** 00-AUG-01
- **BOTTLE NUMBER:** WSS010
- **SAMPLE SITE:** Cow Palace 3
- **AGENCY + SAMPLER:** Montana Bureau of Mines and Geology
- **STATE:** Montana

**Water Quality Analysis**

**Calcium (Ca)**: 101.0 mg/L
**Magnesium (Mg)**: 18.5 mg/L
**Sodium (Na)**: 29.0 mg/L
**Potassium (K)**: 10.3 mg/L
**Iron (Fe)**: 0.11 mg/L
**Silica (SiO2)**: 79.7 mg/L
**Total Cations**: 179.1 mg/L

**Dicarbonate (HCO3)**: 50.4 mg/L
**Carbonate (CO3)**: 10.0 mg/L
**Chloride (Cl)**: 0.5 mg/L
**Sulfate (SO4)**: 0.0 mg/L
**Fluoride (F)**: 0.01 mg/L
**Phosphate (PO4)**: 17.9 mg/L
**Total Anions**: 18.07 mg/L

**Standard Deviation of Anion-Cation Balance (SIGMA)**: 0.43

**Laboratory Ph**: 7.67
**Field Water Temperature**: 7.67°F
**Total Hardness as CaCO3**: 320.3 mg/L
**Total Alkalinity as CaCO3**: 364.9 mg/L
**Sodium Adsorption Ratio**: 4.00
**Sum of Diss. Constituent**: 1317.54 mg/L
**Ryznar Stability Index**: 0.20

**Parameter**

<table>
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<th>Parameter</th>
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<tbody>
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<tr>
<td>Silver (mg/L)</td>
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<td>Boron (mg/L)</td>
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<tr>
<td>Cadmium (mg/L)</td>
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<tr>
<td>Chromium (mg/L)</td>
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</tr>
<tr>
<td>Copper (mg/L)</td>
<td>&lt;0.002</td>
</tr>
<tr>
<td>Nickel (mg/L)</td>
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<tr>
<td>Lead (mg/L)</td>
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<td>Lithium (mg/L)</td>
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<td>Calcium Absorption</td>
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<tr>
<td>Magnesium Absorption</td>
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</tr>
<tr>
<td>Nickel Absorption</td>
<td>0.01</td>
</tr>
<tr>
<td>Lead Absorption</td>
<td>0.04</td>
</tr>
<tr>
<td>Lithium Absorption</td>
<td>0.01</td>
</tr>
<tr>
<td>Sodium Absorption</td>
<td>0.00</td>
</tr>
<tr>
<td>Magnesium Absorption</td>
<td>0.00</td>
</tr>
<tr>
<td>Nickel Absorption</td>
<td>0.00</td>
</tr>
<tr>
<td>Lead Absorption</td>
<td>0.00</td>
</tr>
<tr>
<td>Lithium Absorption</td>
<td>0.01</td>
</tr>
</tbody>
</table>

**Remarks:**

- Water Level Measured While Pumping
- Temperature Reading is Not Accurate ± 2°F
- Send Copy to: Box 660, White Sulphur Springs, MT.

**Explanation:**

- **mg/L = Milligrams per Liter**
- **ug/L = Micrograms per Liter**
- **MEASURED**
- **ESTIMATED**
- **TOTAL RECOVERABLE**
- **TOTAL**

**Other Available Data:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium (Ca)</td>
<td>101.0</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>18.5</td>
</tr>
<tr>
<td>Sodium (Na)</td>
<td>29.0</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>10.3</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>0.11</td>
</tr>
<tr>
<td>Silica (SiO2)</td>
<td>79.7</td>
</tr>
<tr>
<td>Total Cations</td>
<td>179.1</td>
</tr>
<tr>
<td>Total Anions</td>
<td>18.07</td>
</tr>
</tbody>
</table>

**Note:** In correspondence, please refer to Lab Number: 010121

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**Sample Number WSS011 - James Lind**

**Montana Bureau of Mines and Geology**

**Latitude-Longitude:** 46°03'06"N 110°53'05"W  
**Site Location:** 207E 8 C3GC  
**UTM Coordinates:** 212 W 115250 2984910  
**Hand Site:** WSS011  
**Topographic Map:** White Sulphur Springs 7 1  
**Station ID:** 463309110530201  
**Geologic Source:** Alluvium (Quaternary)  
**Sample Source:** Well  
**Land Surface Altitude:** 5065 ft  
**Sampling Site:** James Lind  
**Geologic Source:** Alluvium (Quaternary)

### Water Quality Analysis

#### Parameters

<table>
<thead>
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<td>Calcium (Ca)</td>
<td>41.7</td>
<td>5.00</td>
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<tr>
<td>Magnesium (Mg)</td>
<td>15.3</td>
<td>1.43</td>
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<tr>
<td>Sodium (Na)</td>
<td>19.7</td>
<td>0.96</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>5.0</td>
<td>1.43</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>&lt;0.02</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>&lt;0.02</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td>Silica (SiO2)</td>
<td>4.67</td>
<td>2.20</td>
</tr>
<tr>
<td>Total Cations</td>
<td>5.36</td>
<td>Total Anions 5.44</td>
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<tr>
<td>Standard Deviation of Anion-Cation Balance (Sigma)</td>
<td>0.48</td>
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#### Standard Laboratory Parameters

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<tr>
<td>Temperature: Air (°C)</td>
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</tr>
<tr>
<td>Total Hardness (mg/L)</td>
<td>210.69</td>
</tr>
<tr>
<td>Sodium Absorption Ratio</td>
<td>0.57</td>
</tr>
<tr>
<td>Ryznar Stability Index</td>
<td>7.07</td>
</tr>
<tr>
<td>Lab Specific Conductivity (μS/cm)</td>
<td>109.0</td>
</tr>
</tbody>
</table>

#### Remarks

- Water has no color or odor.  
- Water heater and washing machine deposits in washing machine and hot water heater.  
- Send copy to TSP.  
- White Sulphur Springs, MT.

**Explanation:**  
- **MO/L = Milligrams per liter; mg/L = Milligrams per liter; MEQ/L = Milliequivalents per liter; ft = Feet.**  
- **Sample:**  
- **W:** Water, **W:** Well.  
- **ANID:** Analyzed.  
- **DISS:** Dissolved.  
- **TOTAL:** Total recovered.  
- **TR:** TR = Total Recoverable.  
- **MT:** Montana.

**Other Available Data**

- **Y:** Yes  
- **N:** No  
- **W:** Wa  
- **S:** S  
- **P:** P  
- **M:** M  
- **W:** W  
- **P:** P  
- **Y:** Y

**Other Fill Numbers**

- **Project:** 16-SEP-91  
- **COST:** By: TP ENJ

**Processing Program:** F1730P V2 (0/9/00)  
**Printed:** 16-SEP-91

**Percent MEQ/L (for Piper Plot)**

<table>
<thead>
<tr>
<th>Cation</th>
<th>Na</th>
<th>K</th>
<th>Mg</th>
<th>Ca</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>15</td>
<td>2</td>
<td>7</td>
<td>15</td>
</tr>
</tbody>
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**Note:** In correspondence, please refer to Lab Number: 0101122

---

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Sample Number WSS013 - Bill Skelton

MONTANA BUREAU OF MINES AND GEOLOGY
WATER QUALITY ANALYSIS
BUTTE, MONTANA 59701 (406) 474-4101

STATE MONTANA
COUNTY MEAGHER
LATITUDE-LONGITUDE 46°30'24"N 110°57'23"W

LATITUDE: 46°30.40 N
LONGITUDE: 110°57.39 W
UTM COORDINATES 212, 5900170 E 5903750 N
MBNG SITE WSS013

TOPOGRAPHIC MAP WHITE SULPHUR SPRINGS 7.5
SITE LOCATION 9N 3E 27 DCBC

GEOLoGIC SOURCE WHITE SULPHUR SPRINGS
SAMPLE SOURCE WELL

AGENCY & SAMPLER MANGER & HALL
BOTTLE NUMBER WSS013
YIELD MEANS METHOD

DATE SAMPLED: 20-JUL-81
TOTAL DEPTH OF WELL: 22.7 FT (R)
TIME SAMPLED: 1300 HOURS
SWL ABOVE GROUND: 47.6 FT (R)

LAB & ANALYST MANAGER
CASING DIAMETER: 36 IN (E)

DATE ANALYZED: 08-AUG-81
SAMPLE HANDLING: PUMPED
METHOD SAMPLED: PUMPED
PERFORATION INTERVAL: 01%

WATER USE: PUMPED

COUNTY MEAGHER
UTM COORDINATES 212, 5900170 E 5903750 N
MBNG SITE WSS013

TOPOGRAPHIC MAP WHITE SULPHUR SPRINGS 7.5
SITE LOCATION 9N 3E 27 DCBC

GEOLoGIC SOURCE WHITE SULPHUR SPRINGS
SAMPLE SOURCE WELL

AGENCY & SAMPLER MANGER & HALL
BOTTLE NUMBER WSS013
YIELD MEANS METHOD

DATE SAMPLED: 20-JUL-81
TOTAL DEPTH OF WELL: 22.7 FT (R)
TIME SAMPLED: 1300 HOURS
SWL ABOVE GROUND: 47.6 FT (R)

LAB & ANALYST MANAGER
CASING DIAMETER: 36 IN (E)

DATE ANALYZED: 08-AUG-81
SAMPLE HANDLING: PUMPED
METHOD SAMPLED: PUMPED
PERFORATION INTERVAL: 01%

WATER USE: PUMPED

SAMPLE SITE: BILL & RANCH 4 MI SW OF TOWN

GEOLoGIC SOURCE

<table>
<thead>
<tr>
<th>Parameter</th>
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<th>Value</th>
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</thead>
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<tr>
<td>Calcium (Ca)</td>
<td>52.8</td>
<td>2.63</td>
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<tr>
<td>Magnesium (Mg)</td>
<td>14.2</td>
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<tr>
<td>Sodium (Na)</td>
<td>15.2</td>
<td>2.97</td>
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<tr>
<td>Potassium (K)</td>
<td>2.15</td>
<td>0.50</td>
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<tr>
<td>Manganese (Mn)</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Silica (SiO2)</td>
<td>21.0</td>
<td>0.01</td>
</tr>
</tbody>
</table>

TOTAL ANIONS: 4.67

TOTAL CATIONS: 4.55

STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA): 0.67

LABORATORY PH: 7.37
TOTAL HARDNESS AS CaCO3: 109.00
TOTAL ALKALINITY AS CaCO3: 103.69
SODIUM ABSORPTION RATIO: 0.51
RYZNAR STABILITY INDEX: 7.93
LANGLIER SATURATION INDEX: -0.20

FIELD WATER TEMPERATURE: 9.0

FIELD PH: 7.37
TOTAL HARDNESS AS CaCO3: 109.00
TOTAL ALKALINITY AS CaCO3: 103.69
SODIUM ABSORPTION RATIO: 0.51
RYZNAR STABILITY INDEX: 7.93
LANGLIER SATURATION INDEX: -0.20

CALCULATED DISSOLVED SOLIDS: 263.17
SODIUM ABSORPTION RATIO: 0.51
RYZNAR STABILITY INDEX: 7.93
LANGLIER SATURATION INDEX: -0.20

REMARKS: WATER IS CLEAR, NO COLOR OR TASTE NOTED.
OWNER DOES NOT WANT MILLILETHERS MEASURED, SAMPLED AT OUTSIDE HYDRANT THROUGH HOLE IN LAND SURFACE IN SPRING.

EXPLANATION: MG/L = MILLIGRAM PER LITER; MG/L = MICROGRAMS PER LITER; MG/L = MILLIGRAMS PER LITER; FT = FEET; MT = METERS; (R) = ESTIMATED; (E) = ESTIMATED; (R) = REPORTED; TOTAL = TOTAL RECOVERABLE.

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 0101123

OTHER AVAILABLE DATA

OTHER FILE NUMBERS:

PROJECT: OTHER

PROCESSING PROGRAM: TIT2.09
PRINTED: 16-SEP-81

PERCENT MG/L FOR PIPER PLOT:

GEOLOGIC SOURCE:

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 0101123

OTHER FILE NUMBERS:

PROJECT: OTHER

PROCESSING PROGRAM: TIT2.09
PRINTED: 16-SEP-81

PERCENT MG/L FOR PIPER PLOT:

GEOLOGIC SOURCE:

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 0101123

OTHER FILE NUMBERS:

PROJECT: OTHER

PROCESSING PROGRAM: TIT2.09
PRINTED: 16-SEP-81

PERCENT MG/L FOR PIPER PLOT:

GEOLOGIC SOURCE:

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 0101123

OTHER FILE NUMBERS:

PROJECT: OTHER

PROCESSING PROGRAM: TIT2.09
PRINTED: 16-SEP-81

PERCENT MG/L FOR PIPER PLOT:

GEOLOGIC SOURCE:

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 0101123

OTHER FILE NUMBERS:

PROJECT: OTHER

PROCESSING PROGRAM: TIT2.09
PRINTED: 16-SEP-81

PERCENT MG/L FOR PIPER PLOT:

GEOLOGIC SOURCE:

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 0101123

OTHER FILE NUMBERS:

PROJECT: OTHER

PROCESSING PROGRAM: TIT2.09
PRINTED: 16-SEP-81

PERCENT MG/L FOR PIPER PLOT:

GEOLOGIC SOURCE:

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 0101123

OTHER FILE NUMBERS:

PROJECT: OTHER

PROCESSING PROGRAM: TIT2.09
PRINTED: 16-SEP-81

PERCENT MG/L FOR PIPER PLOT:

GEOLOGIC SOURCE:

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 0101123

OTHER FILE NUMBERS:

PROJECT: OTHER

PROCESSING PROGRAM: TIT2.09
PRINTED: 16-SEP-81

PERCENT MG/L FOR PIPER PLOT:

GEOLOGIC SOURCE:

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 0101123

OTHER FILE NUMBERS:

PROJECT: OTHER

PROCESSING PROGRAM: TIT2.09
PRINTED: 16-SEP-81

PERCENT MG/L FOR PIPER PLOT:

GEOLOGIC SOURCE:

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 0101123

OTHER FILE NUMBERS:

PROJECT: OTHER

PROCESSING PROGRAM: TIT2.09
PRINTED: 16-SEP-81

PERCENT MG/L FOR PIPER PLOT:

GEOLOGIC SOURCE:

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 0101123

OTHER FILE NUMBERS:
Sample Number WSS014A - Bill Corkill - Trailer Well

MONTANA BUREAU OF MINES AND GEOLOGY
BUTTE, MONTANA 59701 (406) 496-4105

STATE MONTANA
COUNTY MCAFEE

LATITUDE 46°30'18"N 110°44'55"W SITE LOCATION ON SE 25 BND
LONGITUDE 112°51'52"E 406°24'14"W HANG SITE WSS014A

TOPOGRAPHIC MAP WILLOW CREEK RESERVOIR STATION IN 46°51'110445501

GEOL O GIC SOURCE ALLUVIUM (TERTURY) II SAMPLE SOURCE WELL
BRAINAGE BASIN US LAND SURFACE ALTITUDE 5033, FT < 10

AGENCY I SAMPLER HWX30LS DATE SAMPLED 26-JUL-81 YIELD MEASUREMENT
BOTTLE NUMBER WSS014A TOTAL DEPTH OF WEL 34, FT (R)
TIME SAMPLED 19:00 HOURS SWL ABOVE (-) OR BELOW AB 35.17 FT
LAB I ANALYST HWX30FN DATE ANALYZED 00-OCT-81
GEOLOGIC SOURCE ALLUVIUM (QUATERNARY) COMPLETION TYPE
METHOD SAMPLED PUMPED WATER USE INDUSTRIAL
SAMPLING SITE CORILL. BILL & sampling INTERVAL
GEOL O GIC SOURCE ALLUVIUM (QUATERNARY)

<table>
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<th>PARAMETER VALUE</th>
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<tbody>
<tr>
<td>CALCIUM (CA) 54.7</td>
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<tr>
<td>MAGNESIUM (Mg) 7.4</td>
</tr>
<tr>
<td>SODIUM (Na) 2.2</td>
</tr>
<tr>
<td>POTASSIUM (K) 0.66</td>
</tr>
<tr>
<td>SILICA (SiO2) 35.6</td>
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</tbody>
</table>

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>RICARDATE (HC03) 2.01</td>
</tr>
<tr>
<td>CARBONATE (CO3) 0.33</td>
</tr>
<tr>
<td>CHLORIDE (Cl-) 0.08</td>
</tr>
<tr>
<td>BICARBONATE (HCO3) 0.34</td>
</tr>
<tr>
<td>SULFATE (SO4) 0.73</td>
</tr>
</tbody>
</table>

| TOTAL CATIONS 3.93 |
| TOTAL ANIONS 4.02 |

| STANDARD DEVIATION OF AMON-CATION BALANCE (SIGMA) 0.03 |

| LABORATORY PH 7.74 |
| TOTAL HARDNESS AS CaCO3 176.90 |
| TOTAL ALKALITY AS CaCO3 167.07 |

| FIELD TEMPERATURE 9.0 C |
| SUM OF DISS. CONSTITUENT 341.73 |

<table>
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<tbody>
<tr>
<td>CNHICYL: FIELD MICRONHG 392</td>
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<tr>
<td>ALUMINUM (Al) 0.03</td>
</tr>
<tr>
<td>SILVER (Ag) 0.01</td>
</tr>
<tr>
<td>BORON (B) 0.02</td>
</tr>
<tr>
<td>COPPER (Cu) 0.0007</td>
</tr>
<tr>
<td>HOLE (H) 0.004</td>
</tr>
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</table>

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>FIELD PH 7.74</td>
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<tr>
<td>MICROG/L AS MG 0.01</td>
</tr>
<tr>
<td>FIELD DISS MG/L 0.04</td>
</tr>
<tr>
<td>STRONTIUM DISS (MG/L-RR) 0.04</td>
</tr>
<tr>
<td>TITANIUM DISS (MG/L-RR) 0.001</td>
</tr>
<tr>
<td>ZINC DISS (MG/L) 0.0004</td>
</tr>
</tbody>
</table>

| SEMIC. DISS (MG/L) 0.3 |
| ARGENTI.DISS (MG/L-RR) 0.004 |

| LAB SPEC. COND. (MICRONHG/CM) 394.6 |
| WAT. SATURATION INDEX 0.32 |

| REMARKS: WATER IS TASSY, NO ODOR OR TASTE CHARACTERISTICS |
| 1ST TRAILER BY BILL |

EXPLANATION: MG/L = MILLIGRAMS PER LITER, UG/L = MICROGRAMS PER LITER, MG/E = MILLIEQUIVALENTS PER LITER, FT = FEET, M = METERS, (R) = ESTIMATED, (E) = REPORTED. TOTAL RECOVERABLE. TOTAL = TOTAL.

OTHER AVAILABLE DATA:

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<thead>
<tr>
<th>COST:</th>
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</thead>
<tbody>
<tr>
<td>PRINTED:</td>
</tr>
</tbody>
</table>

| PERCENT MED/L (FOR PIPER PLOT) |
| CA MEO/L NA K K CL SO4 HC03 |
| 71 17 1 3 9 |

| NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 0191135 |

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Sample Number WSS014B - Bill Corkill - Welding School

Montana Bureau of Mines and Geology
Butte, Montana 59701 (406) 496-4101

Locus No. B010114

State-Water Quality Analysis

Sample Number W S S 014B - B ill Corkill - Welding School

Montana Bureau of Mines and Geology
Butte, Montana

Drainage Basin: White Sulphur Springs 71

Geographic Source: 110TRC2

Agency: Sampled Montana Bureau of Mines and Geology

Bottle Number: W 15014B

Sampled to: Yield Test Method

Date Sampled: 20-JUL-01

Sampled for: Total Depth of Well

Time Sampled: 19,000 Hours

Lab & Analyst: Hamilton

Sampled by: CORILL, DILL X GEOLOGIC SOURCE: TERRACE DEPOSITS (QUATERNARY)

Sampling Site: CORILL, DILL X WELDING SCHOOL

Geologic Source: TERRACE DEPOSITS (QUATERNARY)

Latitude-Longitude: 46.00'10"N 110.00'20"W

U TM Coordinates: 2 7 2 1 4 1 0 1

H R /L MEQ/L

Calcium (Ca) .57 2 2 .05 Magnesium (Mg) .0 0 6 0 7 1 Sodium (Na) 7 .9 .0 3 4 Potassium (K) 5 .4 0 .0 6 Iron (Fe) 4 .0 0 7 Manganese (Mn) .0 0 1 Silica (SiO2) 3 5 .5

Field Water Temperature: 9 .0 C

Laboratory PH: 7 .6 7

Total Cations: 3 .9 7

Standard Deviation of Anion-Cation Balance (S10MA): 170 .2 3

Field Conductivity: 395

Lithium (Li) .0 0 2

Molybdenum (Mo) .0 0 2

Total Hardness as CaCO3: 170.23

Total Alkalinity as CaCO3: 0 .2 6

Sodium Absorption Ratio: 0 .2 6

Leach Saturation Index: 1 .7

Remarks: Water is clear. No odor or taste characteristics. X

Collected from bathroom at Welding School. X Pump was running.

Explanation: Milligrams per liter. ug/l = micrograms per liter. mg/l = milliequivalents per liter. FT = Feet, MT = Meters. (M) = Measured. (E) = Estimated. (R) = Reported. TR = Total Recoverable. TOT = Total.

Other Available Data:

Other File Numbers:

Project:

Last Edit Date: 14-SEP-01

Processing Program: F72DP 92

Percentage mg/l (for Piper Plot):

Cost:

IP 3MHT

Printed: 16-SEP-01

Note: In Correspondence, please refer to Lab Number: B010114

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Sample Number WSS015 - Deters House

MONTANA BUREAU OF MINES AND GEOLOGY
WATER QUALITY ANALYSIS
LAB NO. 0101124

STATE MONTANA
COUNTY MEADIER

LATITUDE-LONGITUDE 46°29'45"N 110°35'32"W SITE LOCATION 9N OF 24 ADR
UTM COORDINATED 011592775 E 0109917 N STATION ID 46314510542201

TOPOGRAPHIC MAP WHITE SULPHUR SPRINGS 7 1

GEOLOGIC SOURCE 110ALUM1210TRR 1 SAMPLE SOURCE ROLL

AGENCY = SAMPLED MAMO2LS LAND SURFACE ALTITUDE 5038. FT < 10

BOTTLE NUMBER WSS015 YIELD MEAS METHOD REPORTED

DATE SAMPLED 21-JUL-01 TOTAL DEPTH OF WELL 80. FT (R)

LAB + ANALYST MAMO2LS TOTAL NUMBER CASING DIAMETER 6 IN (M)

DATE ANALYZED 08-AUG-01 COMPLETION TYPE STEEL

SAMPLE HANDLING 04K PERFORATION INTERVAL 77 TO 88 FT

WATER USE DOMESTIC

SAMPLING SITE DETERS HOUSE . S M WHITE SULPHUR SPRINGS

GEOLOGIC SOURCE ALLUVIUM
CALCIUM (CA) 7.28 3.75 DISSOLVED SOLIDS (HC03) 291.8 1.78
MAGNESIUM (MG) 18.4 1.84 CARBONATE (CO3) 0.16 0.87
SODIUM (NA) 18.4 1.10 CHLORIDE (Cl) 30.7 0.70
POTASSIUM (K) 5.7 0.12 SULFATE (SO4) 43.1 0.71
IRON (FE) .016 0.02 NITRATE (N03) 2.2 0.15
MANGANESE (MN) .001 0.00 FLUORIDE (F) 0.01 0.01
SILICA (SiO2) 44.0 PHOSPHATE TOT (AS P) 6.84

TOTAL CATIONS 6.84 TOT-AL ANIONS 6.73

STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA) 0.58

POH 7.77 TOTAL HARDNESS AG CACO3 277.00
FIELD WATER TEMPERATURE 9.2°C TOTAL ALKALINITY AG CACO3 239.53
CALCULATED DISSOLVED SOLIDS 329.00 SODIUM ABSORPTION RATIO 0.66
SUM OF DISS. CONSTITUENT 641.04 LANGNAR STABILITY INDEX 4.70
LAR SPEC. COND. (MICROMHO/CM) 650.5 LANGNAR SATURATION INDEX 0.54

PARAMETER VALUE PARAMETER VALUE
CONDUCTIVITY FIELD MICROHMS 647 FIELD PH 7.64
ALUMINUM (AS) <.03 NICKEL (Nl) (MG/L AG) <.01
SILVER (AG) <.002 BISMUTH (As) (MG/L AG) 1 <.02
Boron (BO3) <.002 TITANIUM (Ti) (MG/L AG) <.01
CADMIUM (Cu) <.002 VANADIUM (V) (MG/L AG) <.004
CHROMIUM (Cr) <.002 ZINC (Zn) (MG/L AG) <.004
COPPER (Cu) <.002 ZIRCONIUM (Z) (MG/L AG) 2.3
LITHIUM (Li) <.002 MOLYBDENUM (AS) (MG/L AG) <.004
MAGNESIUM (Me) <.004 POTASSIUM (K) (MG/L AG) 0.01

REMARKS: WATER IS CLEAR - HAS A TRACE OF SAND *
NO ONE HOME = NO WL = SAMPLED THROUGH HOSE *

EXPLANATION: MG/L = MILLIGRAMS PER LITER, UG/L = MICROGRAMS PER LITER, MEQ/L = MILLIEQUIVALENTS PER LITER, FT = FEET, MT = METERS. (M) = MEASURED, (E) = ESTIMATED, (R) = REPORTED, TR = TOTAL RECOVERABLE, TOT = TOTAL.

OTHER AVAILABLE DATA

OTHER FILE NUMBERS:

PROJECT: 16-SEP-01 COST:
PROCESSING PROGRAM: F1730P V2 (0/9/00) PRINTED: 16-SEP-01

PERCENT MEQ/L (FOR PIPER PLOT) 61.9 56.4 2.5 3.2 10.7 71.2

NOTE: IN CORRESPONDENCE PLEASE REFER TO LAB NUMBER: 0101124

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**Sample Number WSS016 - Ronald Jackson - Trailer Well**

**MONTANA BUREAU OF MINES AND GEOLOGY**

**WATER QUALITY ANALYSIS**

**WELL DATA**

- **Sample Number:** WSS016
- **Agency:** MONTANA BUREAU OF MINES AND GEOLOGY
- **State:** MONTANA
- **County:** MEAGHER
- **Latitude-Longitude:** 44° 32' 34" N 118° 7.1' W
- **UTM Coordinates:** 212 NS154450 P004435
- **Topographic Map:** WHITE SULPHUR SPRINGS 7-1
- **Geologic Source:** ALLUVIUM (QUATERNARY)
- **Drainage Basin:** WHITE SULPHUR SPRINGS
- **Land Surface Altitude:** 4943' GHD
- **Site Location:** N 4 E 11 C/32
- **Site #:** WSS014
- **SPRINGS STATION ID:** 443254110543201
- **Remarks:** Water is clear, has no odor or gas, slightly degassed

**Sample Details**

- **Land Use:** DOMESTIC
- **Agency/Sample:** MONTANA BUREAU OF MINES AND GEOLOGY
- **Bottle Number:** 0101120
- **Date Sampled:** 21 JUL-81
- **Time Sampled:** 6:15 hours SWL
- **SWL Above or Below:** 45 FT (R)
- **Sample Handling:** 1120
- **Method Sampled:** WATER USE DOMESTIC
- **Sampling Site:** JACKSON, RONALD & TRAILER WELL

**Water Quality Analysis**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Value</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parameter</strong></td>
<td><strong>Value</strong></td>
<td><strong>Parameter</strong></td>
<td><strong>Value</strong></td>
</tr>
<tr>
<td>CONDUCTIVITY,FIELD Mhos/cm</td>
<td>492</td>
<td><strong>FIELD PH</strong></td>
<td>7.72</td>
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<tr>
<td>SILVER,BADG (MG/L AS AG)</td>
<td>&lt;.002</td>
<td>LEAD,BADG (MG/L AS PB)</td>
<td>&lt;.04</td>
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<tr>
<td>BORON, BBADG (MG/L AS B)</td>
<td>&lt;.002</td>
<td>STRONTIUM,BADG (MG/L AS Ba)</td>
<td>&lt;.24</td>
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<tr>
<td>CHROMIUM,BADG (MG/L AS Cr)</td>
<td>&lt;.002</td>
<td>TITANIUM,BADG (MG/L AS Ti)</td>
<td>&lt;.010</td>
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<tr>
<td>LITHIUM,BADG (MG/L AS Li)</td>
<td>&lt;.002</td>
<td>ZIRCONIUM,BADG (MG/L AS Zr)</td>
<td>&lt;.004</td>
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<tr>
<td>MOLYBDENUM,BADG (MG/L-HNO)</td>
<td>&lt;.1</td>
<td>ARSENIC,BADG (MG/L AS Ag)</td>
<td>1.7</td>
</tr>
</tbody>
</table>

**Standard Deviation of Anion-Cation Balance (SIGMA):** 0.37

**Laboratory PH:** 7.72

**Total Hardness As CaCO3:** 234.78

**Total Alkalinity As CaCO3:** 234.16

**Sodium Adsorption Ratio:** 0.37

**Langelier Saturation Index:** 0.43

**Remarks:**

- Water is clear, has no odor or gas, slightly degassed
- Filetless adapter & no WI, measurement & new well (sandy) & sampled through hose 1.5 ft new white sulphur springs, MT.

**Explanation:**

- MG/L = MILLIGRAMS PER LITER
- MG/AL = MILLIGRAMS PER LITER
- MG/CR = MILLIGRAMS PER LITER
- FT = FEET
- M = METERS
- (M) = MEASURED
- (E) = ESTIMATED
- (R) = REPORTED
- TR = TOTAL RECOVERABLE
- TG = TOTAL

**Other Available Data:**

- **Cost:**
- **Last Edit Date:** 14-SEP-01
- **Processing Program:** F1730P V2 (8/9/00)
- **Printed:** 14-SEP-01
- **Percent Meq/L (For Piper Plot):**
  - CA MAG NA K CI SO4 HCO3
  - 40 24 6 0 2 5 21

**Notes:** In correspondence, please refer to LAB NUMBER: 0101125

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Sample Number WSS017 - Wallace Bailey - House Well

**MONTANA BUREAU OF MINES AND GEOLOGY**

**WATER QUALITY ANALYSIS**

**BUTTE, MONTANA 59701 (406) 476-4101**

**LAB NO. 8101126**

**STATE**

**MONTANA**

**COUNTY**

**MEagher**

**LATTITUDE-LONGITUDE**

46°31'16"N 110°45'32.7"W

**SITE LOCATION**

24 26 19 DDCB

**WATER QUALITY ANALYSIS**

**LAB NO. 0101126**

**WATER USE**

DOMESTIC AND COUNTY MEagher

**BOTTLE NUMBER**

WSS017

**DATE SAMPLED**

25-JUL-81

**TOTAL DEPTH OF WELL**

104. FT (R)

**SAMPLE HANDLING**

PUMPED

**TIME SAMPLED**

16:30 HOURS

**METHOD SAMPLED**

DOMESTIC AND COUNTY MEagher

**DATE ANALYZED**

08-AUG-81

**SAMPLE SOURCE WELL**

WATER QUALITY ANALYSIS

**LAND SURFACE ALTITUDE**

9150. FT < 10

**TOPOGRAPHIC MAP**

WHITE SULPHUR SPRINGS 7 1 STATION ID 46316610531901

**MOUNTAIN BASE OF MINER AND GEOLOGY**

BUTTE, MONTANA 59701 (406) 496-4101

**BOTTLE NUMBER**

WSS017

**SAMPLE SITE**

BAILEY, WALLACE L. & HOUSE WELL

**GEOLOGIC SOURCE**

CALCIUM (CA)

MAGNESIUM (MG)

SODIUM (NA)

SILICA (Si02)

TOTAL CATIONS

MG/L

52.2

16.7

40.2

59.3

5.87

TOTAL ANIONS

MG/L

2.60

1.37

1.75

0.66

5.98

**STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA)**

0.53

**LABORATORY PH**

7.40

**TOTAL HARDNESS AS CAC03**

197.08

**FIELD WATER TEMPERATURE**

11. C

**TOTAL ALKALINITY AS CAC03**

96.84

**CALCULATED DISSOLVED SOLIDS**

404.48

**SODIUM ABSORPTION RATIO**

1.94

**ATMOSPHERIC COND.**

44.41

**LANGLIER SATURATION INDEX**

7.94

**LANGLIER SATURATION INDEX**

-0.20

**PARAMETER VALUE**

**VALUE**

CANDYTV/FIELD HCRMONH03

631.

FIELD PH

7.96

ALUMINUM, DISS (M0/L-AL)

<.03

NICKEL, DISS (MG/L AS NI)

<.01

Boron, DISS (MG/L AS BR)

<.002

BROMINE, DISS (MG/L BR)

<.002

CHROMIUM, DISS (MG/L-CHR)

<.002

COPPER, DISS (MG/L AS CU)

<.002

LITHIUM, DISS (MG/L AS LI)

<.002

MOLYBDENUM, DISS (MG/L-MO)

<.1

LEAD, DISS (MG/L AS PD)

199.08

96.86

1.24

7.99

7.96

<.01

.35

.007

.004

.089

.004

2.2

REMARKS: WATER IS CLEAR

SAMPLED FROM HYDRANT BY CORRAL (WESTSIDE)

STEEL CAGING TO 127' PVC 127 TO 104

PERHAPS PERFORATED WITH A DRILL IN THE PVC 3 PVC DIAMETER UNKNOWN

**EXPLANATION:**

MG/L = MILLIGRAMS PER LITER, MG/EQ/L = MILLIEQUIVALENTS PER LITER, FT = FEET, FT = FEET, MT = METERS, (M) = MEASURED, (E) = ESTIMATED, (R) = REPORTED, TR = TOTAL RECOVERABLE, TO = TOTAL

**OTHER AVAILABLE DATA**

**PROJECT:**

16-SEP-81

**COST:**

TP 39

**PROCESSING PROGRAM:**

F1303D 82 (8/9/80)

**PRINTED:** 16-SEP-81

**PERCENT MG/EQ/L (FOR PIPER PLOT):**

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<thead>
<tr>
<th>CA</th>
<th>MG</th>
<th>NA</th>
<th>K</th>
<th>CL</th>
<th>HCO3</th>
</tr>
</thead>
<tbody>
<tr>
<td>44</td>
<td>23</td>
<td>29</td>
<td>2</td>
<td>25</td>
<td>41</td>
</tr>
</tbody>
</table>

**NOTE:** IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 8101126

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Sample Number WSS018 - King Wilson - Poor Farm - Sportsmans Lodge

Montana Bureau of Mines and Geology

WATER QUALITY ANALYSIS
LAB NO. B110127

Sample Number WSS018 - King Wilson - Poor Farm - Sportsmans Lodge

State: Montana
County: Meagher

Latitude-Longitude: 40°32'27"N 110°55'14"W
Site Location: 9N 16E 13 RCDA

Topographic Map: White Sulphur Springs 7.1
Station ID: 44233110551401

Geologic Source: White Sulphur Springs

Agency + Sampler: Montana Bureau of Mines and Geology

Date Sampled: 21-Jul-81
Time Sampled: 11:45 hours

Lab + Analyst: Montana Bureau of Mines and Geology

Date Analyzed: 08-Aug-81

Sample Handling: Performed by Public Supply

Water Use: Public Supply

Geologic Source:
- Montana
- Lat: 44°32'33"N
- Long: 110°55'14"W
- UTM Coordinates: X: 712410, Y: 440720
- Topographic Map: White Sulphur Springs 7.1
- Geologic Source: White Sulphur Springs
- Drainage Basin: Montana
- Agency: Montana Bureau of Mines and Geology
- Sampler: Montana Bureau of Mines and Geology
- Bottle Number: WSS018
- Date Sampled: 21-Jul-81
- Time Sampled: 11:45 hours
- Lab: Montana Bureau of Mines and Geology
- Analyst: Montana Bureau of Mines and Geology
- Date Analyzed: 08-Aug-81
- Sample Handling: Performed by Public Supply

Sample Site:
- Wilson, King, Poor Farm, Sportsman's Lodge

Geologic Source:
- Calcium (Ca): 1.7 mg/l
- Magnesium (Mg): 0.04 mg/l
- Sodium (Na): 100 mg/l
- Potassium (K): 0.02 mg/l
- Iron (Fe): <0.002 mg/l
- Manganese (Mn): 0.001 mg/l
- Silica (SiO2): 19.0 mg/l

Total Cations:
- Mg/L: 1.7 mg/l
- Ca/L: 0.04 mg/l
- Na/L: 100 mg/l
- K/L: 0.02 mg/l

Total Anions:
- Mg/L: 3.24 mg/l
- Ca/L: 0.55 mg/l
- Na/L: 1.00 mg/l
- K/L: 0.34 mg/l

Standard Deviation of Anion-Cation Balance (Sigma): 1.35

Laboratory PH: 9.20
Field Water Temperature: 11.4°C
CALCULATED DISSOLVED SOLIDS (TDS): 443.51
SUM OF D I S S . CONSTITUENT: 0.92
LAB SPEC. COND. (MICROMHOES/CM): 800.2
TOTAL HARDNESS AS CaCo3: 6.30
TOTAL ALKALINITY AS CaCO3: 35.77
SODIUM ADSORPTION RATIO (SAR): 0.24

Parameter: Calcium, Magnesium, Sodium, Potassium, Iron, Manganese, Silica
Value: 1.7, 0.04, 100, 0.02, <0.002, 0.001, 19.0

Other Available Data:
- Project: WWS018
- Last Edit Date: 14-Sep-81
- Processing Program: F172D5 V2 (9/9/80)
- Printed: 14-Sep-81
- Percent Meg/L (for Piper Plot):
  - Ca: 1
  - Mg: 0
  - Na: 0
  - K: 3
  - Cl: 9
  - SO4: 44

Note: In correspondence, please refer to Lab Number: B110127

Remarks:
- Water is very gasy, high CO2.
- Mail copy to PO Box 452, White Sulphur Springs, MT.
- New (1976) well in old well house.

Explanation:
- Nm/L = Milligrams per Liter, ug/L = Micrograms per Liter, mg/L = Milligrams per Liter, ft = Feet, mi = Miles, (m) = Measured, (E) = Estimated, (R) = Reported. Ta = Total Recoverable. Tot = Total.

Other File Numbers:
- Project: WWS018
- Last Edit Date: 14-Sep-81
- Processing Program: F172D5 V2 (9/9/80)
- Printed: 14-Sep-81
- Percent Meg/L (for Piper Plot):
  - Ca: 1
  - Mg: 0
  - Na: 0
  - K: 3
  - Cl: 9
  - SO4: 44

Note: In correspondence, please refer to Lab Number: B110127

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Sample Number WSS019 - Gordon Doig - House Well

MONTANA DEPARTMENT OF MINES AND GEOLOGY
WATER QUALITY ANALYSIS
LAB NO. 010128

STATE MONTANA
COUNTY MEAD
LATITUDE-LONGITUDE 46°32'21"N 110°53'53"W
UTM COORDINATES 12S X613780 E607025
HANG SITE WSS019
UTM MAP INSIDE WHITE SULPHUR SPRINGS 71
STATION ID 46221110525501

MONTANA BUREAU OF MINER AND GEOLOGY
BUTTE, MONTANA 59701 (406) 494-4101

WATER QUALITY ANALYSIS
LAB NO. S1R1128

STATE LATITUDE-LONGITUDE
UTM COORDINATES
TOPOGRAPHIC MAP
GEOLOGIC SOURCE
DRAINAGE BASIN
AGENCY + SAMPLER
BOTTLE NUMBER
DATE SAMPLED
TIME SAMPLED
LAB + ANALYST
DATE ANALYZED
SAMPLE HANDLING
METHOD SAMPLED
DATE ANALYZED
COMPLETION TYPE STEEL
BOTTLE NUMBER WSS019
SAMPLE SOURCE
COUNTY
SITE LOCATION
E 507G 23 MSNG SITE
SPRINGS
STATION ID
SAMPLE SOURCE
LAND SURFACE ALTITUDE
SUSTAINED YIELD
YIELD MEAS METHOD
TOTAL DEPTH OF WELL
ABOVE OR BELOW OS
Casing Diameter ft.
PERFORATION INTERVAL
SAMPING SITE DOIG, GORDON + HOUSE
GEOLOGIC SOURCE
CALCIUM (CA) 40.2
MAGNESIUM (MG) 12.9
SODIUM (NA) 30.5
POTASSIUM (K) 4.8
IRON (FE) <.002
MANGANESE (MN) <.001
SILICA (SiO2) 40.6
TOTAL CATIONS 5.02
TOTAL ANIONS 5.08
STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA) 0.32

LABORATORY PH 7.99
TOTAL HARDNESS AS CACO3 173.45
TOTAL ALKALINITY AS CACO3 180.13
CALCULATED DISSOLVED SOLIDS 353.02
NITRATE NITRITE RATIO 1.01
SODIUM ABDORPTION RATIO 1.02
LAB SPEC. COND. (MICROMHO/CM) 300.2
LAMBERT SATURATION INDEX 0.37

PARAMETER
TEMPERATURE, AIR (C)
FIELD PH
FIELD TEMPERATURE
NICKEL DISS (MG/L AS N)
LEAD DISS (MG/L AS Pb)
STRONTIUM DISS (MG/L AS Sr)
TITANIUM DISS (MG/L AS Ti)
VANADIUM DISS (MG/L AS V)
ZINC DISS (MG/L AS ZN)
ZIRCONIUM DISS (MG/L AS ZR)
ARSENIC DISS (MG/L AS AS)
VALUE
27
7.94
0.1
0.01
0.04
0.39
0.003
0.004
0.004
0.04
0.03
0.0

REMARKS: WATER IS CLEAR + HAS MINOR GAS BUBBLES +
STEEL CASING 0-90 FEET + PVC 90-160 FEET + DRILLED HOLE
1/2" X 1/2" IN PVC 

EXPLANATION: MG/L = MILLIGRAMS PER LITER; UG/L = MICROGRAMS PER LITER; MEG/L = MILLIEQUIVALENTS PER LITER; TR = TOTAL RECOVERABLE; (C) = MEASURED; (E) = ESTIMATED; (R) = REPORTED; FT = FEET; (M) = MEASURED; (C) = CALCULATED; (R) = REPORTED; TR = TOTAL RECOVERABLE; TOT = TOTAL.

OTHER AVAILABLE DATA
OTHER FILE NUMBERS:

PROJECT:
LAST EDIT DATE: 16-SEP-01
PROCESSING PROGRAM: F1730P V2 (8/9/00)
PRINTED: 16-SEP-01
PERCENT MEG/L (FOR PIPER PLOT)

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 010128

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**Sample Number WSS020 - Fox - Stock Well**

**State**: Montana  
**County**: Meagher  
**Latitude-Longitude**: 46°43'10"N 110°25'01"W  
**UTM Coordinates**: 71U 1505605 2924406  
**Geologic Source**: 1104LUM  
**Drainage Basin**:  
**Agency + Sampler**: Montana BLM  
**Sample Source**: Stock Well  
**Sample Site**: Stock Well at Fox  
**County**: Meagher  
**Latitude**: 46°43'10"N  
**Longitude**: 110°25'01"W  
**UTM Coordinates**: 71U 1505605 2924406  
**Geologic Source**:  
**Drainage Basin**:  
**Agency + Sampler**: Montana BLM  
**Sample Source**: Stock Well  
**Sample Site**: Stock Well at Fox  
**County**: Meagher  

<table>
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<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Water Temperature</td>
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<tr>
<td>Total Hardness (CaCO3)</td>
<td>239.48 Mg/L</td>
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<tr>
<td>Alkalinity (CaCO3)</td>
<td>267.88 Mg/L</td>
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<tr>
<td>Conductivity (MicroMhos/Cm)</td>
<td>572.1</td>
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<tr>
<td>pH</td>
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<tr>
<td>Sodium (Na)</td>
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<td>Chloride (Cl)</td>
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<td>Potassium (K)</td>
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<tr>
<td>Calcium (Ca)</td>
<td>66.4</td>
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<tr>
<td>Magnesium (Mg)</td>
<td>18.2</td>
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<td>Sulfate (SO4)</td>
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<tr>
<td>Iron (Fe)</td>
<td>2.48</td>
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<tr>
<td>Manganese (Mn)</td>
<td>1.89</td>
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<tr>
<td>Silica (SiO2)</td>
<td>30.0</td>
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<tr>
<td>Iron Stain on Filter</td>
<td>1.09</td>
</tr>
<tr>
<td>Stainless Stain on Filter</td>
<td>0.002</td>
</tr>
</tbody>
</table>

**Remarks**: Water is clear. Iron stain on filter.

**Explanation**: Mg/L = Milligrams per liter, ug/L = Micrograms per liter, Meq/L = Milliequivalents per liter, FT = Measured, (M) = Measured, (E) = Estimated, (R) = Reported, TR = Total Recoverable, Tot = Total.

**Other Available Data**

**Cost**:  
**Processing Program**:  
**Percent Meq/L (for Piper Plot)**

**Note**: In correspondence, please refer to Lab Number: 0101129
Sample Number WSS021 - Ivan Bodell - Ranch House

MONTANA BUREAU OF MINES AND GEOLOGY
BUTTE, MONTANA 59701 (406) 496-4101

WATER QUALITY ANALYSIS
LAB NO. 0101130

STATE MONTANA
COUNTY MEAGER

LATTITUDE-LONGITUDE 46°03'24"N 110°55'52"W
SITE LOCATION 10N 66 29 CRD

9TH COORDINATE 641605.1331 264720.5007
WATER SOURCE WHITE SPRINGS 71

GEOLIGIC SOURCE LAND SURFACE ALTITUDE 5035. FT < 10

AGENCY + SNPLER BOTTLE NUMBER
DATE SAMPLED 21-JUL-01
TIME SAMPLED 10120 HOURS
LAB. + ANALYST BOTTLE EIAPIYI
DATE ANALYZED 09-SEP-01

SAMPLE SITE BODELL, IVAN & RANCH HOUSE
METHOD SAMPLED PUMPED
WATER USE DOMESTIC AND STOCK

GEOLOGIC SOURCE
CALCIUM (CA) 33.1 1.65 DICARBOXATE (HCO3) 156.9 2.57
MAGNESIUM (MG) 15.0 1.30 CARBONATE (CO3) < 0.1
SODIUM (NA) 17.2 0.73 CHLORIDE (Cl) 19.0 0.54
POTASSIUM (K) 8.8 0.23 SULFATE (SO4) 28.1 0.59
IRON (Fe) 0.01 0.00 NITRATE (AS N) < 0.001
MANGANESE (Mn) < 0.001 FLUMURATE (AS P) < 0.001
PHOSPHATE (AS PH) 0.001
TOTAL CATIONS 4.92 TOTAL ANIONS 3.92

STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA) - 0.08

LABORATORY PH 7.00 TOTAl HARDNESS AS CaCO3 147.68
FIELD WATER TEMPERATURE 11.9 C TOTAL ALKALINITY AS CaCO3 129.68
CALCULATED DISSOLVED SOLIDS 240.94 SODIUM ADOPTION INDEX 8.8
SUM OF DISS. CONSTITUENT 320.95 LANGLIER SATURATION INDEX 0.01
LAB SPEC.COMP.(MICROMHOS/CM) 304.8 LANGMIUR SATURATION INDEX 0.01

PARAMETER VALUE PARAMETER VALUE
TEMPERATURE, AIR (C) 25.0 CONDUCTIVITY, FIELD MICROHOS 359.
FIELD pH 8.0 ALUMINUM, DISS (MG/L-AL) < 0.03
NICKEL, DISS (MG/L-AG-HI) 0.01 COPPER, DISS (MG/L-AG) < 0.002
LEAD, DISS (MG/L-AG PB) < 0.04 BORON, DISS (MG/L-AG PB) < 0.02
STRONIUM, DISS (MG/L-SR) < 0.27 CARBON, DISS (MG/L-C) < 0.002
TITANIUM, DISS (MG/L-TI) < 0.01 CHROMIUM, DISS (MG/L-CH) < 0.002
VANADIUM, DISS (MG/L-V) < 0.01 COPPER, DISS (MG/L-CU) < 0.004
ZINC, DISS (MG/L-ZN) < 0.005 MANGANESE, DISS (MG/L-AG) < 0.002
ZIRCONIUM, DISS (MG/L-ZR) < 0.004 LITHIUM, DISS (MG/L-LI) < 0.1
ARSENIC, DISS (MG/L-AR) 4.4 MOLYBDENUM, DISS (MG/L-MO) < 0.001

REMARKS: WATER IS CLEAR *
SON OF EDWIN BODELL *
WATER SAMPLED THROUGH HOSE *

EXPLANATION: MG/L = MILLIGRAMS PER LITER, MU/L = MICROGRAMS PER LITER, MG/L = MILLIGRAMS PER LITER, FT = FEET, AT = METERS, (E) = ESTIMATED, (R) = REPORTED, TR = TOTAL RECOVERABLE, TOT = TOTAL

OTHER AVAILABLE DATA
OTHER FILE NUMBERS:

PROJECT:
LAST EDIT DATE: 16-SEP-01 COST:
PROCESSING PROGRAM: PRINTED:
PERCENT MG/L (FOR PIPER PLOT):
NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 0101130

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### Water Quality Analysis

#### Sampling Site
- **Name:** Jeff Kennick
- **Location:** 0.5 mi S White Sulphur Spr
- **Geologic Source:**
  - **Type:**
  - **Depth:**

#### Geologic Source
- **Latitude-Longitude:**
- **UTM Coordinates:**
- **Topographic Map:**
- **Drainage Basin:**
- **Sample Source Well:**
- **Agency + Sampler:**
- **Bottle Number:**
- **Date Sampled:**
- **Time Sampled:**
- **LAB + Analyst:**
- **Date Analyzed:**
- **Sample Handling:**
- **Water Use:**

#### Geology
- **County:**
- **State:**
- **Latitude:**
- **Longitude:**
- **UTM E:\ N:**
- **Topographic Map:**
- **Drainage Basin:**

#### Sample Information
- **Sample Handling:**
- **Water Use:**

#### Laboratory and Field Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium (Ca)</td>
<td>31.3 mg/L</td>
<td>Magnesium (Mg)</td>
<td>1.09 mg/L</td>
</tr>
<tr>
<td>Sodium (Na)</td>
<td>104.5 mg/L</td>
<td>Potassium (K)</td>
<td>4.66 mg/L</td>
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<td>Iron (Fe)</td>
<td>0.002 mg/L</td>
<td>Hafnium (Hf)</td>
<td>0.001 mg/L</td>
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<tr>
<td>Silicon (Si)</td>
<td>58.3 mg/L</td>
<td>Fluoride (F)</td>
<td>0.06 mg/L</td>
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</table>

#### Calculated Dissolved solids
- **Total Cations:** 8.37 mg/L
- **Total Anions:** 0.59 mg/L

#### Anion-Cation Balance
- **Standard Deviation of Anion-Cation Balance:** 0.97 mg/L

#### Field Water Temperature
- **Total Hardness as CaCO3:** 192.0 mg/L

#### Other Available Data
- **Remarks:**
- **Send Copy To:**
- **Lab:**
- **Explanations:**
- **Other Available Data:**

#### Other File Numbers
- **Project:**
- **Last Edit Date:**
- **Processing Program:**
- **Percent Meq/L (for Piper Plot):**

**Note:** In correspondence, please refer to Lab Number: 0101131

---

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Sample Number WSS023 - Ronald Jackson

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<td>TOTAL HARDNESS AS CACO3 164.35</td>
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<td>MANGANESE (Mn)</td>
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<td>FLUORIDE (F)</td>
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<tr>
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<td>TOTAL CATIONS</td>
<td>3.99</td>
<td>TOTAL ANIONS 4.12</td>
<td>0.79</td>
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OTHER AVAILABLE DATA

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<td>STRONTIUM Dis (mg/l AS Sr)</td>
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<td>CHROMIUM Dis (mg/l AS Cr)</td>
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REMARKS: WATER IS CLEAR * 1 MI NW WHITE SULPHUR SPRINGS *

EXPLANATION: MG/L = MILLIGRAMS PER LITER, UD/L = MICROGRAMS PER LITER, MEQ/L = MILLIEQUIVALENTS PER LITER, FT = METER, M = METER, FM = FEET, M = METER, (M) = MEASURED, (E) = ESTIMATED, (R) = REPORTED. TR = TOTAL RECOVERABLE; TOT = TOTAL.

OTHER AVAILABLE DATA

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<td>NICKEL Dis (mg/l AS Ni)</td>
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<td>SILVER Dis (mg/l AS Ag)</td>
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<td>BORON Dis (mg/l AS B)</td>
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<td>STRONTIUM Dis (mg/l AS Sr)</td>
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<td>CHROMIUM Dis (mg/l AS Cr)</td>
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<td>TITANIUM Dis (mg/l AS Ti)</td>
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<td>COPPER Dis (mg/l AS Cu)</td>
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<td>VANADIUM Dis (mg/l AS V)</td>
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<tr>
<td>LITHIUM Dis (mg/l AS Li)</td>
<td>&lt;0.002</td>
<td>ZINC Dis (mg/l AS Zn)</td>
<td>0.028</td>
</tr>
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<td>MOLYBDENUM Dis (mg/l AS Mo)</td>
<td>&lt;0.1</td>
<td>ZIRCONIUM Dis (mg/l AS Zr)</td>
<td>0.004</td>
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NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 0101152

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Sample Number WSS024 - Bob Hanson - Irrigation Well

WATER QUALITY ANALYSIS
LAB NO. 82G0040

STATE MONTANA
COUNTY MEAGHER

LATTITUDE-LONGITUDE 46031'17"N 110054'10"W SITE LOCATION 09W 06E 24 DDRA

TOTAL PRACTICABLES 27 MH 336.07 MT, 250 FT AHD SITE WSS024 4.25

WATER QUALITY ANALYSIS LAB NO. 82G0040

GEOLOGIC SOURCE MEAGHER ALLUVIUM (QUATERNARY)

CALCULATED RESOLVED SOLIDS 344.41 SODIUM ABSORPTION RATIO 4.40

REPORTED RECOVERABLE 32 UOU FLOW

CALCULATED DISSOLVED SOLIDS 344.41 SODIUM ABSORPTION RATIO 4.40

TOTAL RECOVERABLE, TOT = TOTAL.

PARAMETER VALUE PARAMETER VALUE

ALUMINUM DIS (MG/L AL) .53 DIC (HL/L AS Al) .03
IRON DIS (MG/L Fe) <.002 NICKEL DIS (MG/L AS Ni) .02
MAGNESIUM DIS (MG/L MG) .12 CADMIUM DIS (MG/L AS Cd) <.002
MANGANESE DIS (MG/L Mn) .004 LEAD DIS (MG/L AS Pb) .09
CALCIUM DIS (MG/L Ca) .14 CHROMIUM DIS (MG/L AS Cr) <.002
SODIUM DIS (MG/L Na) .12 COPPER DIS (MG/L AS Cu) .007
CHLORIDE (MG/L Cl) 32.1 FLUORIDE W Q (MG/L AS F) <.002
SULFATE (MG/L SO4) 1.64 ARSENIC W Q (MG/L AS As) 2.0
POTASSIUM (MG/L K) .44 TOTAL = 0.33
CALCIUM (MG/L Ca) .08 TOTAL ANIONS
MAGNESIUM (MG/L Mg) .04 LAB SPEC. COND. (mg/1) 513.3
SODIUM (MG/L Na) .44 LANGLEY SATURATION INDEX 0.79
MOTOR (MG/L K) .01
CALCULATED DISSOLVED SOLIDS 344.41 ODIXE DISSOLVED EXPLANATION MG/L = MILLIGRAMS PER LITER, UM/L = MICROGRAMS PER LITER, GCA/L = MILLIEQUIVALENTS PER LITER, FT = FEET, AT = DEGREES, (R) = REPORTED, (M) = MEASURED, (E) = ESTIMATED.

OTHER AVAILABLE DATA

OTHER FILE NUMBERS

PROJECT:

LAST EDIT DATE: 13-OCT-02
PROCESSING PROGRAM: F1309 02 (11/3/01) PRINTED 13-OCT-02
PERCENT NBD/ (FOR PIPER PLOT)

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 82G0040

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Sample Number WSS025 - Castle Mtn. Lumber Co. - Fire Protection Well

MONTANA BUREAU of MINERALS AND GEOLOGY
WATER QUALITY ANALYSIS
LAB. NO. 8290096

STATE: MONTANA
COUNTY: MEAGHER
LATITUDE-LONGITUDE: 40°35'21"N  110°54'27"W
SITE LOCATION: ONsite 13 WAGA
WATER QUALITY ANALYSIS
WITTE. MONTANA 59701 (406) 242-5860

WATER use ANALYST: LAW. NO. 02000/1

WATER USE: FIRE PROTECTION

SAMPLE HANDLING: 312
LABORATORY PH: 7.83
FIELD WATER TEMPERATURE: 54°F

POST SAMPLED: 04-FEB-03
PERFORMANCE INTERVAL: 5 TO 131 FT

SAMPLE SITE: CASTLE MTN LUMBER CO FIRE PROTECTION WELL

GEOLOGIC SOURCE: ALLUVIUM (QUATERNARY)

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<th>Value</th>
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<td>Mg (Mg/l)</td>
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<td>Ca (Mg/l)</td>
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<td>Na (Mg/l)</td>
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<td>HCO₃ (Mg/l)</td>
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<td>NO₃ (Mg/l)</td>
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<td>SiO₂ (Mg/l)</td>
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<td>Ca (Mg/l)</td>
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STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA): 2.92

LABORATORY PH: 7.83
TOTAL HARDNESS: 252.92
TOTAL ALKALINITY: 250.99
CALCULATED DISWELL: 307.33
GROWTH ABSORPTION INDEX: 1.40

PARAMETER: VALUE
TEMPERATURE (°C): 70
LEAD (Mg/l): 0.01
NICKEL (Mg/l): 0.01
COPPER (Mg/l): 0.01
CROMIUM (Mg/l): 0.01
ZINC (Mg/l): 0.01
BARIUM (Mg/l): 0.01
ARSENIC (Mg/l): 0.01
SILVER (Mg/l): 0.01
ALUMINUM (MG/L): 0.01
Boron (MG/L): 0.01
SODIUM (MG/L): 0.01
TITANIUM (MG/L): 0.01
ZIRCON (MG/L): 0.01
MOLYBDENUM (MG/L): 0.01

REMARKS: GAS BURSTING 10 FT TURBINE PUMP; 2 LARGE PRESSURE TANKS (*150 GAL)
LAB. BU: 50.1 MG/L ANIONS & CATIONS VERIFIED

PROJECT: 17-FEB-03
COST:
LAST EDIT DATE: TP-2955
PROCESSING PROGRAM: F1730P V2 (11/2/01)
PERCENT MG/L (FOR PIPER PLOT): 95

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER 8290096

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**Sample Number WSS026 - Ralph Jordan**

**MONTANA BUREAU OF MINES AND GEOLOGY**

**WATER QUALITY ANALYSIS**

**Site Location**

- *Butte, Montana*
- *State: Montana*
- *County: Meagher*
- *Latitude-Longitude: 40°32'40"N 110°04'22"W*

**Geologic Source**

- *Topographic Map: Sulfur Springs 7-1 Station 41*
- *Geologic Source: Sulfur Springs*

**Sample Handling**

- *Date Sampled: 04-FEB-83*
- *Time Sampled: 1 Hour*
- *Sample Source: Water Sampled*

**Water Use**

- *County: Meagher*
- *State: Montana*

**Sample Analysis**

- *Water Quality:
  - Calcium (Ca): 2.5 mg/L
  - Magnesium (Mg): 3.4 mg/L
  - Sodium (Na): 213.0 mg/L
  - Potassium (K): 1.9 mg/L
  - Iron (Fe): 0.009 mg/L
  - Manganese (Mn): 0.007 mg/L
  - Silica (SiO2): 44.0 mg/L

- *Total Cations:
  - Total Mg/L: 2.5 mg/L
  - Total Na/L: 3.4 mg/L
  - Total Ca/L: 213.0 mg/L
  - Total K/L: 1.9 mg/L
  - Total Fe/L: 0.009 mg/L
  - Total Mn/L: 0.007 mg/L
  - Total SiO2/L: 44.0 mg/L

- *Total Anions:
  - Total HCO3/L: 253.3 mg/L
  - Total Cl/L: 0.4 mg/L
  - Total SO4/L: 827.8 mg/L
  - Total NO3/L: 1332.0 mg/L
  - Total PO4/L: 34.3 mg/L
  - Total F/L: 7.7 mg/L

**Remarks:**

- Water foams when agitated. Yellowish suspended clay or silt. No pressure tank. Well has been used very little since installation in April 1982. Owner claims the water is killing his tree. Subpump 12 gph.

**Other Available Data**

- *Last Edit Date: 02-MAR-83*
- *Processing Program: P1730 V2 (11/3/01) PRINTED 02-MAR-03*

**Percent Meq/L (For Piper Plot)**

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<td>Lead</td>
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<td>Strontium</td>
<td>0.24 Meq/L</td>
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<tr>
<td>Titanium</td>
<td>0.003 Meq/L</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.004 Meq/L</td>
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<td>Arsenic</td>
<td>0.004 Meq/L</td>
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**Explanation:** Meq/L = milliequivalents per liter, mg/L = milligrams per liter, μg/L = micrograms per liter. (P) = measured, (E) = estimated, (R) = reported, (T) = total recoverable. (E) = total. 

**Note:** In correspondence, please refer to Lab Number: 0200062
Sample Number WSSBANK - Bank Thermal Well

**Latitute Longtude:** 40° 44' 34" N, 110° 43' 18" W

**GEOLOGIC SOURCE:** White Sulphur Springs - Bank Thermal Well

**Drainage Basin:** SUSTAINED YIELD 50.0 GPM

**Remarks:** Water collected from heat exchanger - no pH or EC

**Other Available Data:**

- **Quantities:**
  - **Project:** 138
  - **Edit Date:** 19-DEC-82
  - **Program:** 19-DEC-82
  - **SOURCE:** 19-DEC-82
  - **Date:** 9.1.82
  - **Number:** 0.015
  - **Month:** 9
  - **Date:** 7.82
  - **Quality:**
    - **TDS (mg/l):** 21.12
    - **Total Anions:** 21.04

**Standard Deviation of Anion-Cation Balance (Sigma):** 0.08

**LABORATORY PH:** 7.62

**Field Water Temperature:** 110.6 °F

**Sodium Absorption Ratio:** 13.84

**LAB SPEC COMP. (MICROMOS/CM):** 216.7

**Langler Saturation Index:** 0.74

**VALUE**

- **PARAMETER**
  - **TEMPERATURE-AIR (C):** 35.0
  - **CAlCIUM (CA):** 41.0
  - **MAGNESIUM (MG):** 19.5
  - **SODIUM (Na):** 143.3
  - **MOLYBDENUM (M):** 1.0
  - **CHROMIUM (Cr):** 1.0
  - **ZINC (Zn):** 0.3
  - **COPPER (Cu):** 0.4
  - **BISMUTH (Bi):** 0.0
  - **LEAD (Pb):** 0.0
  - **MERCURY (Hg):** 0.0
  - **FERRUM (Fe):** 0.0
  - **IRON (Fe):** 1.0
  - **TITANIUM (Ti):** 0.0
  - **ALUMINUM (AI):** 0.0
  - **Boron (B):** 0.0
  - **SILICON (Si):** 43.9
  - **SULFATE (SO4):** 0.0
  - **BICARBONATE (HCO3):** 21.1
  - **CARBONATE (CO3):** 19.5
  - **CHLORIDE (Cl):** 147.0
  - **SULFIDE (S):** 0.0
  - **PHOSPHATE (PO4):** 10.0
  - **FlUORIDE (F):** 1.0
  - **ZINC (Zn):** 0.0
  - **COPPER (Cu):** 0.0
  - **GOLD (Au):** 0.0
  - **SILVER (Ag):** 0.0
  - **CADMIUM (Cd):** 0.0
  - **LEAD (Pb):** 0.0
  - **CASSITE (CH3):** 0.0
  - **LABORATORY PH:** 7.62
  - **TOTAL HARDNESS AS CACO3:** 141.48
  - **SODIUM ABSORPTION RATIO:** 13.84
  - **TOTAL ALKALINITY AS CACO3:** 640.76
  - **TOTAL HARDNESS AS CACO3:** 141.48
  - **TOTAL SOFTNESS:** 110.6
  - **TOTAL ANIONS:** 21.04

**Remarks:** Water collected from heat exchanger - no pH or EC

**Explanation:** M/G/L = MILLIGRAMS PER LITER; UG/L = MICROGRAMS PER LITER; MG/L = MILLICELLS PER LITER; FT = FEET; M = METERS; (P) = ESTIMATED; (R) = REPORTED; TR = TOTAL RECOVERED; 10T = TOTAL.

**Other Available Data:**

- **Quantities:**
  - **Project:** 138
  - **Edit Date:** 19-DEC-82
  - **Program:** 19-DEC-82
  - **SOURCE:** 19-DEC-82
  - **Date:** 9.1.82
  - **Number:** 0.015
  - **Month:** 9
  - **Date:** 7.82
  - **Quality:**
    - **TDS (mg/l):** 21.12
    - **Total Anions:** 21.04

**Standard Deviation of Anion-Cation Balance (Sigma):** 0.08
WHITE SULPHUR SPRINGS BANK WELL; 81Q2053

INITIAL SOLUTION

TEMPERATURE = 45.00 DEGREES C  PH = 7.820  ANALYTICAL pH = 22.202  ANALYTICAL Eh = 21.772

### OXIDATION - REDUCTION ###

DISCHARGED OXYGEN = 0.0000 NO/L

MEASURED WITH CALOMEL = 0.0000 VOLTS

REACHED Eh OF ZEBELL SOLUTION = 0.0000 VOLTS

CORRECTED Eh = 0.0000 VOLTS

FE COMPUTED FROM CORRECTED Eh = 0.0000

### TOTAL CONCENTRATIONS OF INPUT SPECIES ###

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<th>TOTAL NO/LITRE</th>
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WHITE SULPHUR SPRINGS BANK WELL; 81Q2053

### DESCRIPTION OF SOLUTION ###

ANALYTICAL COMPUTED  pH  ELECTRONEutrality EN = 0.9993

EHCAT 22.202  21.417  7.120  FECOMPUTED = 4.4310E+02  IDSCOMPUTED = 1.0914

EPM1 21.772  20.700  TEMPERATURE  EN = 9.7510E-07

OM1 = 1.203111E+01  REDOX = 4.701  PE = -4.701

In computing the distribution of species: PE = -4.701  EQUIVALENT EN = -0.302 VOLTS

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### Reproduction of White Sulphur Springs Bank Well (continued)

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#### WHITE SULPHUR SPRINGS BANK WELL DEC053

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BIBLIOGRAPHY


Harrison, J. E. (1977a). Geometry and sedimentation of the Late Precambrian Belt basin. Geological Society of America (Rocky Mountain Section) Abstracts With Programs, 9, 730.


GEOLOGIC MAP OF

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EXPLANATION

Quaternary alluvium
Landslide deposits
Tertiary sediments
Volcano Butte basalts
Rhyolite porphyry
Castle Mountain granite and syenite

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granite and syenite
Andesite

Cretaceous (undivided) - Mowry and Thermopolis Shales; Frontier Formation

Kootenai Formation
Morrison Formation
Quadrant Formation
Amsden Formation
Tyler Formation
Big Snowy Group
Madison Group - undivided
Mission Canyon Limestone
Lodgepole Limestone
Three Forks Formation
Jefferson Formation
Red Lion - Maywood Formations
Pilgrim Limestone
Park Shale
Meagher Limestone
Wolsey Shale
Flathead Sandstone
Spokane Shale
Greyson Shale
Newland Limestone
INDEX MAP SHOWING LOCATION OF AREA

Modified from Gardar G. Dahl, Jr. (1971) and George B. Phelps (1969)

PLATE I

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Flathead Sandstone
Spokane Shale
Greyson Shale
Newland Limestone

Formation contact—dashed where approximate
Fault contact—dashed where approximate
Fault—showing relative lateral movement sense
Thrust fault—teeth on upthrown side, dashed where approximate
Normal fault—barbells on downthrown side, dashed where approximate
Normal fault reactivated along previous Laramide thrust, dashed where approximate
Anticline showing trend and plunge of axis
Overturned anticline
Syncline
Overturned syncline
Minor fold showing trend and plunge of axis
d dip of beds
Inclined
Vertical
Overturned
Horizontal
SECTIONS OF THE WHITE SULPHUR SPRINGS AREA, MONTANA

By
William G. Gierke
1986

Moors Mountain thrust

Tod-

Craig thrust

Willow Creek syncline

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Observed Gravity at Base Station I (980484.00) was chosen arbitrarily to achieve positive relative Bouguer values with the reduction program used.

Note: No terrain corrections applied

PLATE 3

By
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1986

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PLATE 4

By
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Contour Interval 10 intervals per decade, °C

- Well location with water temperature in °C
- Thermal well
- Thermal spring

Area with ground water temperatures suitable for heat pump use.

PLATE 5

By
William G. Gierke
1986
JULPHUR SPRINGS, MONTANA

CONTOUR INTERVAL 5 intervals per decade,
mg/l FLUORIDE

.29 o
.35 0
.44 0
.56 0

well location with fluoride concentration (mg/l)

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CONTOUR INTERVAL 5 intervals per decade, mg/l FLUORIDE

well location with fluoride concentration (mg/l)

- Thermal well
- Thermal spring

PLATE 6

By William G. Gierke
1986

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