RESOURCE SERIES 23
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GEOTHERMAL RESOURCE ASSESSMENT OF HOT SULPHUR SPRINGS, COLORADO

by
Richard Howard Pearl
Ted G. Zacharakis
Charles D. Ringrose

COLORADO GEOLOGICAL
SURVEY
DEPT. OF NATURAL
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Cover photo: Hot Sulphur Springs circa 1871. (Photo courtesy Colorado Historical Society).

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GEOTHERMAL RESOURCE ASSESSMENT OF HOT SULPHUR SPRINGS, COLORADO

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ABSTRACT

In 1979 The Colorado Geological Survey, in cooperation with the U.S. Dept. of Energy, initiated a program to evaluate the resource potential of those thermal areas in Colorado having potential for near term development. One of the areas investigated was Hot Sulphur Springs in northwest Colorado. Approximately 10 springs whose waters are used for recreation, steam baths and laundry purposes are located at Hot Sulphur Springs.

Estimated heat-flow at Hot Sulphur Springs is approximately 100 mW/m2, which is about normal for western Colorado. Recent work tends to show that surface and reduced heat flow in the mountains of northern Colorado could be high.

Hot Sulphur Springs is located approximately in the center of Middle Park, a large intermountain, synclinal basin located between the Front Range on the east and the Park-Gore Range on the west. Precambrian igneous and metamorphic rocks are exposed less than a mile southwest of the springs in Byers Canyon. Unconformably overlying these rocks and dipping to the northeast is a sequence of sedimentary rocks over 10,000 ft (3.1 km), thick ranging in age from Jurassic to Recent, which are deformed by two faults. The Mount Bross Thrust Fault is located within one-half mile northeast of the springs and a small normal fault is just west of the springs.

The thermal waters have an estimated discharge of 50 gpm, a temperature that ranges from 104°F (40°C) to a high of 111°F (44°C), and a total dissolved solid content of 1,200 mg/l. The waters are a sodium bicarbonate type with a large concentration of sulphate. It is estimated that the most likely reservoir temperature of this system ranges from 167°F (75°F) to 302°F (150°C) and that the areal extent of the system could encompass 1.35 sq mi (3.50 sq km) and could contain 0.698 Q's (10^{15} B.T.U.'s) of heat energy.

To aid in the evaluation of this system, soil mercury and electrical resistivity surveys were conducted. Unlike other areas of Colorado, the soil mercury survey proved less than satisfactory in helping to delineate the geological conditions controlling the occurrence of the thermal waters.

The geophysical survey delineated several areas of low resistivity associated with the north trending fault that passes just to the west of the spring area. It appears that this fault is saturated with thermal waters and may be the conduit along which the thermal waters are moving up from depth. From the evidence gathered, the Mount Bross Fault does not appear to control the occurrence of the springs.

While no deep hydrogeological information is available, it appears that the Hot Sulphur Springs thermal waters represent deep circulation of meteroric waters along numerous faults and fractures in an area of above normal heat flow. Recharge to the system probably occurs on the high ground to the east.

It is not possible to make any accurate predictions concerning required circulation depths due to the thick sequence of insulating Pierre shale found in the area. Due to the presence of this unit it is possible that low-to moderate-temperature waters 158°F-212°F, (70°C-100°C) could be found at its base.

The appendecies to this report include tables showing water temperatures required for various industrial processes, as well as dissolved minerals, trace elements and radioactivity levels found in the thermal waters. Also presented are a complete description of the factors affecting the electrical resistivity measurements, a description of the electrical resistivity equipment used, and the resistivity field procedures. Electrical resistivity calculations are also included in the appendecies.

INTRODUCTION

In 1979, the Colorado Geological Survey, in cooperation with the U.S. Department of Energy, Division of Geothermal Energy, initiated a program to delineate the geological features controlling the occurrence of those geothermal resources in Colorado believed to have a high potential for near term development. This effort consisted of a literature search, geologic and hydrogeological mapping, geophysical surveys, and soil mercury geochemical surveys. The areas evaluated under this program were: The Animas Valley, north of Durango; Canon City Area; Hartsel Hot Springs; Hot Sulphur Springs; Idaho Springs; Ouray; Ranger Hot Springs; Shaws Spring, western San Luis Valley; and Steamboat-Routt Hot Springs.

This report presents the geothermal resource assessment efforts conducted in and around the community of Hot Sulphur Springs in Grand County. Hot Sulphur Springs is a community of approximately 405 persons, located on the Colorado River 97 miles (156 km) northwest of Denver (Fig. 1). In this area there is a group of thermal springs located just to the northwest of the town on the north side of the Colorado River. (Fig. 2). The springs are privately owned and are used for swimming, steam baths and laundry purposes.

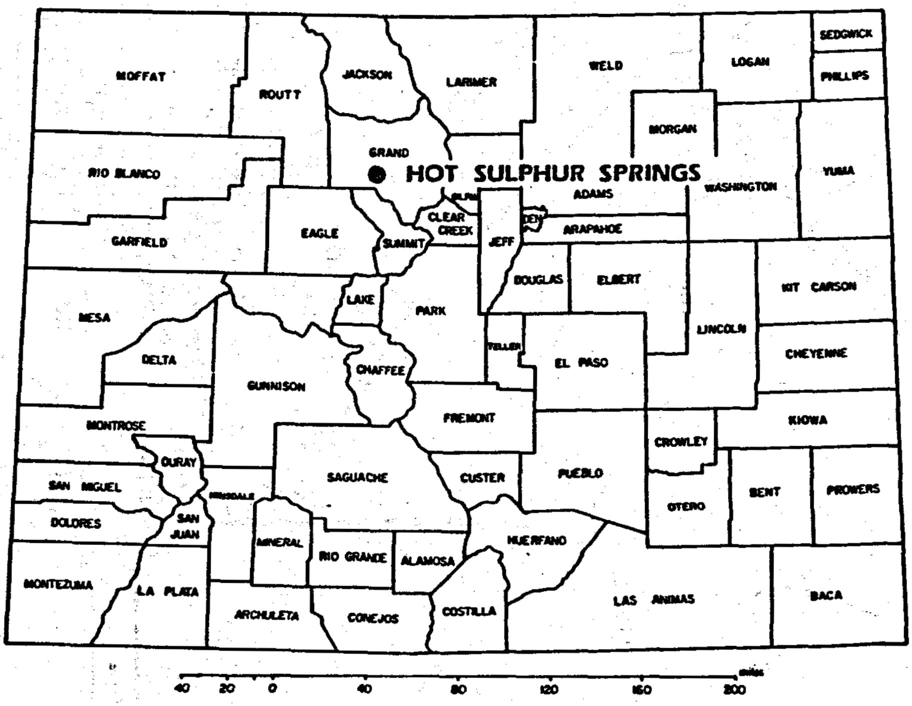
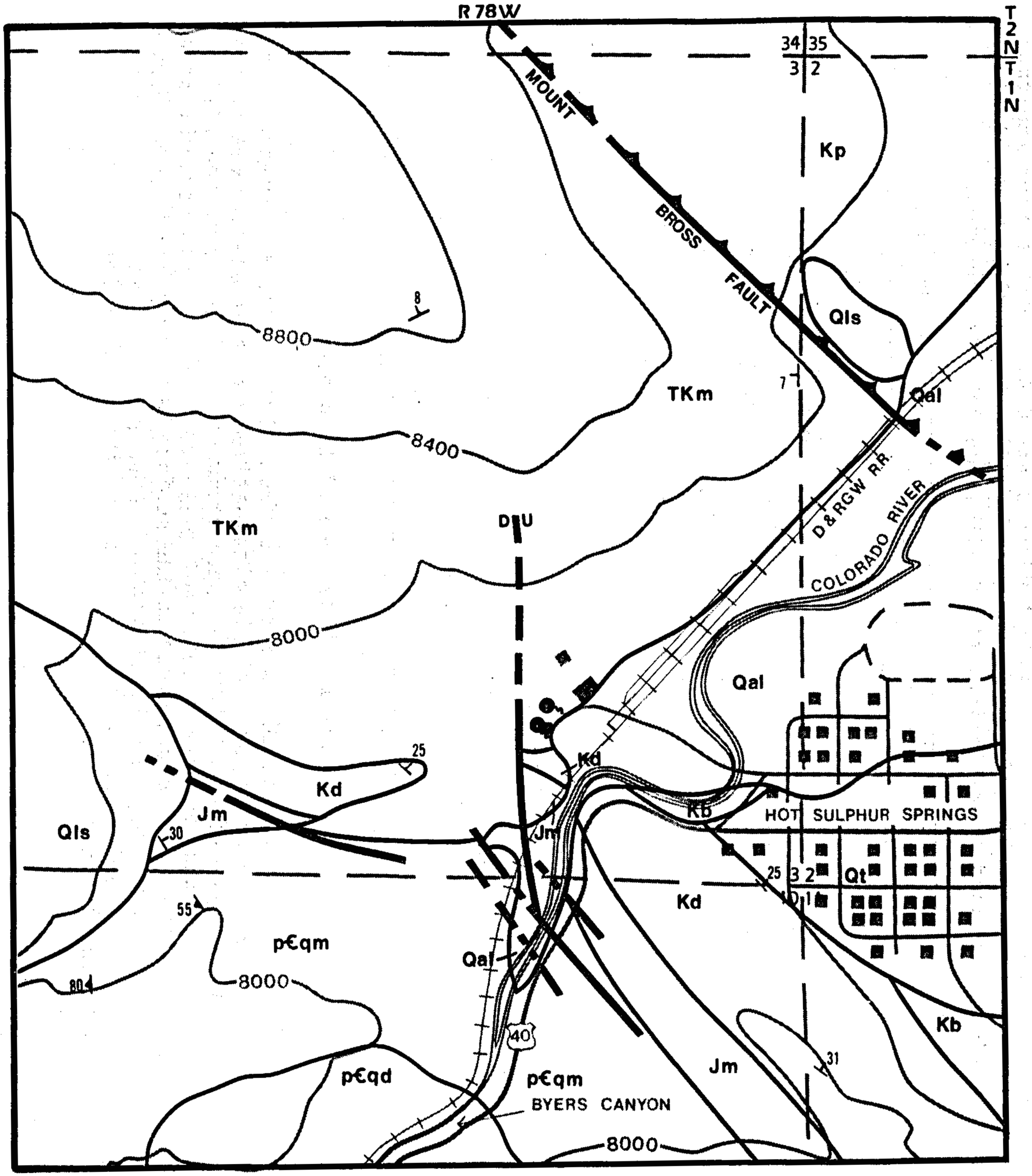


Figure 1. Index map of Colorado.

This study was necessitated by the fact that geothermal energy, the natural heat of the earth, is a viable alternative source of energy that can be put to a wide range of uses. Normally, geothermal energy is either too diffuse or found at depths too great to be of practical value. However, in some instances, where it is occurs close to the surface, it can be developed and put to practical use with readily available techniques and equipment. A brief description of geothermal energy and some of the uses it can be put to are presented in Appendix A.



EXPLANATION

Qal	Quaternary alluvium
Qls	Quaternary landslide
Qt	Quaternary terrace gravel
TKm	Tertiary-Cretaceous Middle Park Formation
Kp	Cretaceous Pierre Shale
Kn	Cretaceous Niobrara Fm.
Kb	Cretaceous Benton Shale
Kd	Cretaceous Dakota Group
Jm	Jurassic Morrison Fm.
p€qm	Precambrian quartz monzonite
p€qd	Precambrian quartz diorite
─	Geologic contact
━	Fault, dashed where inferred, dotted where concealed
━▲━	High angle reverse fault, sawteeth on upper plate, dashed where inferred, dotted where concealed
⊥ 5	Strike and dip of beds
▲ 7	Strike and dip of foliation
●	Hot spring

200 0 200 feet

N

Base modified from U.S.G.S. 7½' topographic quadrangle map.

Figure 2. Geology and thermal springs, Hot Sulphur Springs area (Geology modified from Izett and Hoover, 1963).

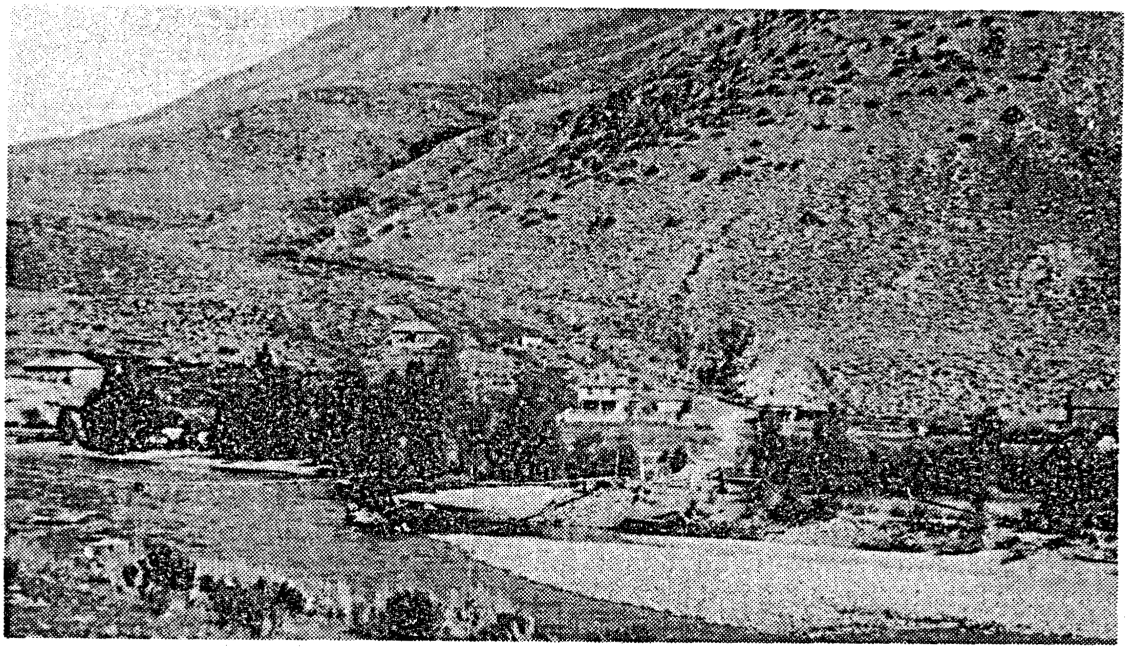


Figure 3. Hot Sulphur Springs circa 1899. Hot springs located at extreme left center of photo. (Photo courtesy of Colorado Historical Society.)

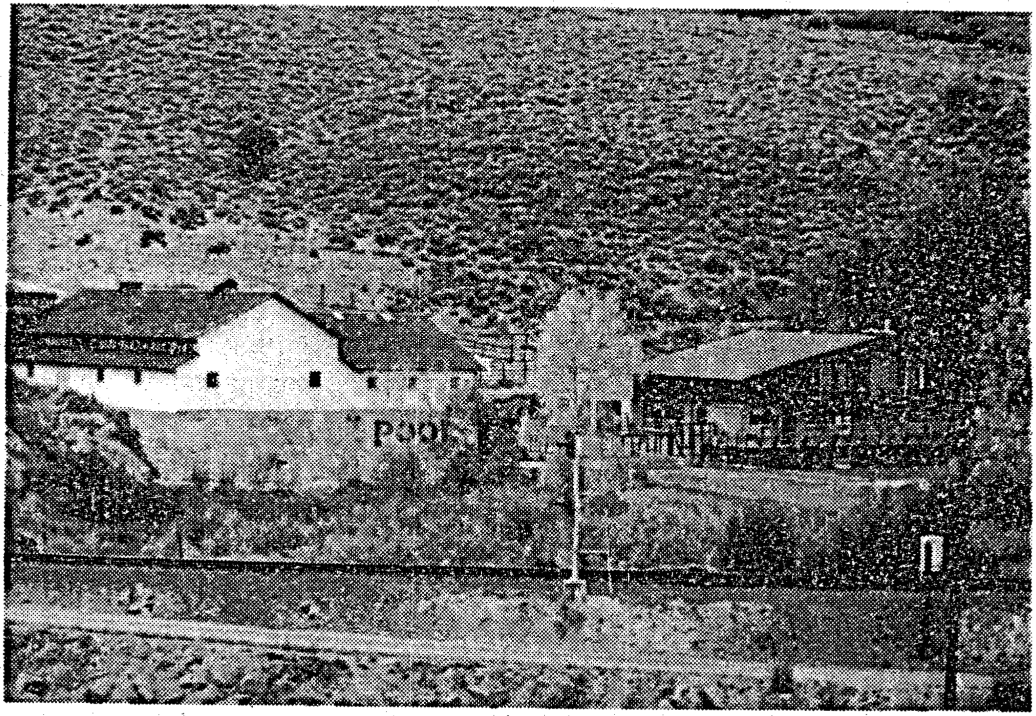


Figure 4. Hot Sulphur Springs circa 1976. Springs located to rear and left of white building.

THERMAL CONDITIONS OF THE HOT SULPHUR SPRINGS AREA

Thermal Waters

All the thermal waters in the Hot Sulphur Springs area are located at the resort across the Colorado River from the community by the same name. The springs issue from a large travertine mound north of the main resort buildings and in a marshy area to the west. The thermal waters range in temperature from 104°F (40°C) to 111°F (44°C). Due to modification of the spring's discharge point it is hard to determine accurately just how many springs exist, but there appear to be 5-10 individual springs.

Heat Flow

No measurements of heat-flow have been made in the vicinity of Hot Sulphur Springs, however the best estimate of the heat-flow in this region is the regional heat-flow map of Colorado prepared by Zacharakis (1981) (Fig. 3). This map, which is based on approximately 45 published heat-flow values, shows that the estimated heat-flow at Hot Sulphur Springs is approximately 100 mW/m2, which is normal for western Colorado.

While the Middle Park region of Colorado is not normally thought to have high heat-flow, recent work by Decker and others (1981) of the University of Wyoming showed that surface and reduced heat flow in the mountains of Wyoming along the Wyoming-Colorado border is low to normal, while that in the mountains of northern Colorado, including North and Middle Parks, is high.

Buelow (1980) noted that these parks could be a high heat-flow area similar to the Rio Grande Rift in southern New Mexico and west Texas. In attempting to explain this, Decker and others (1981) suggested two interpretations: "First, the unrealisticially high calculated temperatures suggests that the flux may be explained by transient conductive or nonconductive heat sources in the subsurface. Secondly, the heat sources that produce the excess flux must be in the crust because the depicted northern border of the anomaly is narrow (<50 km)". They (Decker and others, 1981) noted the cooling of a low density rock body at a depth between 16,404 and

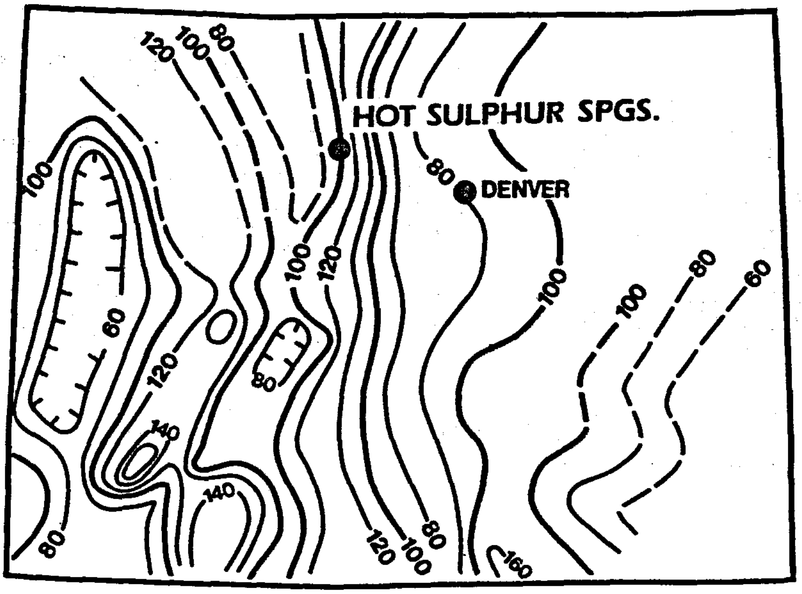


Figure 5. Preliminary heat flow map of Colorado (Adopted from Zacharakis, (1981.)

32,808 ft (5 and 10 km) in the upper crust would also explain the high heat flow if they were emplaced about 2 million years ago at intrusion temperatures of 1,112-1,292°F (600-700°C).

Decker and others (1981) stated that due to the following reasons high heat-flow might not be restricted to a simple north-south trending zone but might be found throughout the area: Late Miocene age volcanic rocks are found in the Elkhead Field; relatively young (>2 million year old) igneous rocks are found throughout the western and central parts of western Colorado in the Basalt Mountain-Flat Tops-State Bridge area; and the high heat flow at Hahn's Peak. They also pointed out that the high heat-flow of North and Middle Park suggest that these areas could be underalin by hot dry rock resources. (Decker and others, 1981). The most favorable area for these resources would be in the Basalt Mountain-Flat Top-State Bridge area southwest of the Hot Sulphur Springs area.

Decker and others (1981) felt that if the geological conditions were right that moderate to high temperature thermal waters suitable for the generation of electricity could be found in some parts of North and Middle Parks. They also believed that there was a good chance for the development of these higher temperature resources in the Basalt Mountain-Flat Top-State Bridge area, southwest of Hot Sulphur Springs.

GEOLOGY

Introduction

Hot Sulphur Springs is located approximately in the center of Middle Park, a large intermontaine basin just west of the Continental Divide (Fig. 4). Middle Park is bounded on the west by the Park-Gore Range, on the north by a low range of hills called the Rabitt Ears Range, which divides Middle Park from North Park, and on the east and south by the Contiental Divide. Unlike the other two large intermontaine basins in Colorado, North and South Parks, Middle Park from the ground appears to be quite irregular and rough. It is only from the air that the open nature of the land is apparent. When viewed from the air it appears that North and Middle Park are really one large basin, and they are often refered to as the North-Middle Park region.

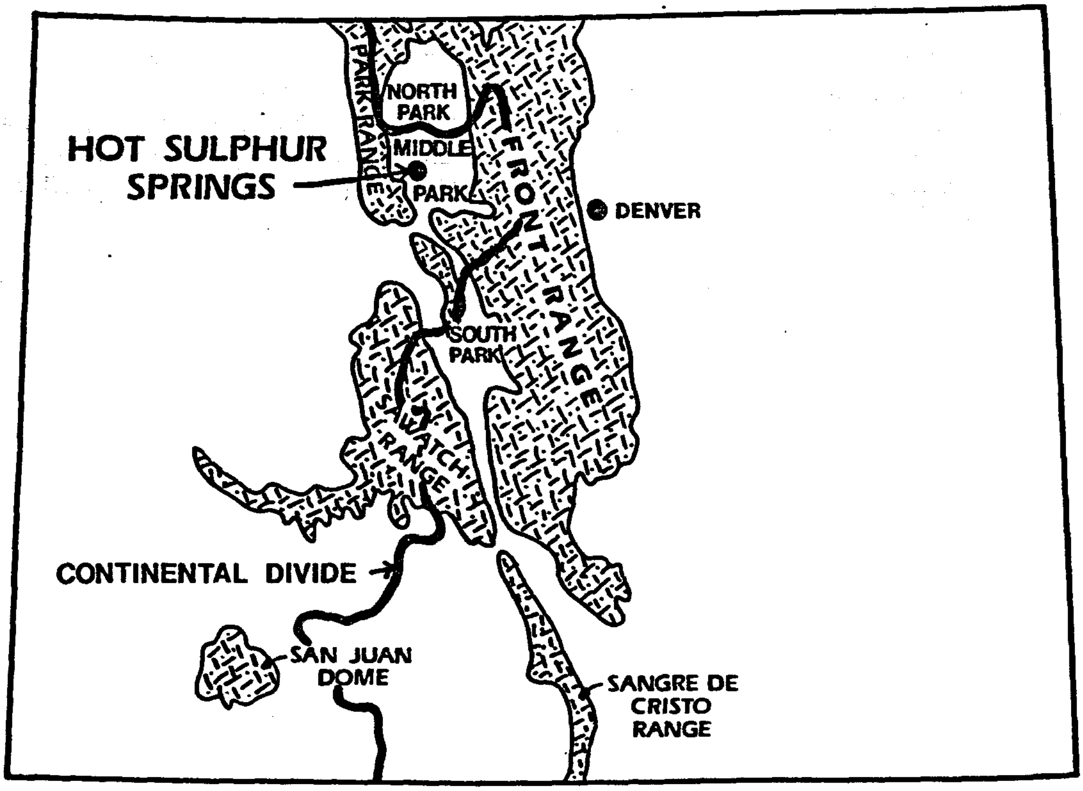


Figure 6. Index map showing basement complex, Colorado.

Several comprehensive papers have been written describing the geological conditions of the Hot Sulphur Springs region. Izett (1968 and 1975) and Izett and Hoover (1963) described the geological conditions of the Hot Sulphur Springs area in depth, while Steven (1975) described in general terms the volcanic rocks found in the area. Tweto (1975) presented a discussion on the tectonic development of the region. The following discussion is taken from these papers.

Middle Park, like many of the other structural features of western Colorado, developed as a result of mountain building forces during the Laramide Orogeny which extended from Late Cretaceous to early Tertiary time. The mountains and several major basins of northern Colorado and southern Wyoming developed on the site of the late Paleozoic Ancestral Front Range. One of these basins is the North-Middle Park basin, a synclinal basin between the Front Range on the east and the Park-Gore Range on the west. As this basin had little or no pre-Laramide expression, the sedimentary rock sequence in it is not exceptionally thick.

The low range of hills dividing North and Middle Parks, the Rabbit Ears Range, is capped by a sequence of mafic, intermediate, and silicic volcanic rocks that are cut by a series of volcanic necks and intrusive structures that mark the roots of ancient volcanoes (Steven, 1975). Most of the volcanic rocks have been dated as Oligocene and Miocene(?) age and are included in the Rabbit Ears Volcanics.

Stratigraphy

As shown on Fig. 2 Precambrian igneous and metamorphic rocks are exposed less than one mile southwest of town in Byers Canyon. Unconformably overlying these rocks and dipping to the northeast is a sequence of sedimentary sandstones, siltstones, shales, and limestones belonging in ascending order to the Morrison, Dakota, Benton, Niobrara, and Pierre Formations. Overlying these formations, with angular unconformity, is the Tertiary Middle Park Formation consisting of lava flows and associated siltstone and sandstones. Table 1 presents a brief description of the rock units found in the Hot Sulphur Springs area.

Structure

Less than one-half mile northeast of the hot springs is the Mount Bross Fault, a major high angle northwest-trending reverse fault. In the vicinity of the hot springs the Mount Bross Fault has brought Pierre Shale into contact with the Middle Park Formation. This fault does not appear to control the occurrence of the springs, since they are located just east of a small north trending normal fault (Fig. 2). This small fault is well exposed in a roadcut near the northern end of Byers Canyon where it cuts the Morrison Formation. The thermal waters may be ascending along this fault zone. Not shown on Figure 2 because it is off the map, is an east-west thrust fault which Izett (1968) shows terminating approximately one mile west of the springs.

Table 1. Rock units, Hot Sulphur Springs area
(Adapted from Izett, 1968 and Izett and Hoover, 1963)

System	Series	Formation	Thickness	Description
Quaternary				Alluvium, landslide deposits and terrace deposits.
	Miocene	Troublesome Fm.	0-400 ft (0-122 m)	Siltstone, tuffaceous, moderate, grayish-orange to light-brown. Conglomeratic lenses and stringers. Local thin beds of light-gray flaky volcanic glass.
Tertiary -?-?-?-?-?-?-	Paleocene	Middle Park Formation	+ 4,700 ft (1,433 m)	Micaceous siltstone, sandstone, and conglomerate all complexly interbedded, gray, brown, purple and green. Locally carbonaceous and impure coal beds and thin discontinuous limestone beds near base; local volcanic breccia and conglomerate beds.
			0-200 ft (0-61m)	Breccia of Marietta Creek: Andesite porphyry breccia, medium-gray to dark-gray and purplish-gray. Locally contains volcanic siltstone sandstone and conglomerate.
			0-1,100 ft (0-335m)	Windy Gap Volcanic Member. Andesite, medium to dark gray and purplish-gray. Trachyandesite porphyry breccia. Poorly sorted poorly stratified in lower and middle part. Upper part contains well bedded volcanic siltstone, sandstone, and conglomerate beds.
Cretaceous	Upper	Intrusive Rocks		Porphyritic trachyandesite. Very fine grained, dark-gray, augite, biotite, and hornblende phenocrysts Occurs as dikes and plugs. Porphyritic augite syenite, medium greenish-gray, fine-grained, occurs as dikes and plugs.
		Pierre shale	0 - 4,000 ft (0-1,219 m)	Shale, siltstone and claystone. Few ledge-forming siltstone and sandstone beds.
		Niobrara Formation	550 ft (168 m)	Claystone, limey, light to dark gray. Limey siltsone and impure limestone, light-gray, in lower part.
Cretaceous	Upper ? ? ? ?	Benton shale	450 ft (137 m)	Claystone, silty and clayey, medium to dark gray. Topmost beds contain very fine grained sandstone.
	Lower	Dakota sandstone	185 ft (56 m)	Sandstone, light-gray to light brown, locally conglomeratic. Lenticular conglomeratic sandstone and chert pebble conglomerate in lower part.
Jurassic	Upper	Morrison Formation	100-300 ft (30-91 m)	Claystone, variegated color, interbedded with siltsone and sandstone, few thin limestone beds.
Precambrian		Quartz monzonite, Biotite-quartz diorite, and Quartz gneiss.		

. HYDROGEOLOGICAL CONDITIONS OF THE HOT SULPHUR SPRINGS THERMAL WATERS

Introduction

All the thermal waters in the Hot Sulphur Springs area are found at the resort across the Colorado River from the town of Hot Sulphur Springs (Fig. 2). On the hillside behind the resort is a large deposit of grayish travertine approximately 200 ft (61 m) in diameter and perhaps 40 ft (12 m) thick. Some of the thermal waters issue from the travertine while others issue around the swimming pool building. Due to the construction of an extensive collection system through which the waters are piped into the resort buildings, it is impossible to accurately determine the exact number of springs present. However, it appears that there may be as many as 10 springs. The waters are used for a wide variety of purposes in the resort.

The following authors have discussed in detail one or more aspects of this thermal system: Barrett and Pearl (1976 and 1978); Berry and others (1980); George and others (1920); Lewis (1966); Mallory and Barnett (1973); Peale (1886); Pearl (1972 and 1979); and Waring (1965).

Water Quality

The springs have an estimated total discharge 50 gpm, a temperature that ranges from 104°F to 111°F (40°C to 44°C) and a total dissolved solid content of 1,200 mg/l. The waters are a sodium bicarbonate type with a large concentration of sulfate (Barrett and Pearl, 1976 and 1978). A complete list of all the dissolved mineral found in the thermal waters is presented in Appendix B. In addition, amounts of the various trace elements and radioactivity associated with the thermal waters are also presented in Appendix B. The waters appear to be coming from the underlying Dakota sandstone.

Estimated Size and Extent of Thermal System

Based on geothermometer analysis Barrett and Pearl (1978) estimated that the most likely reservoir temperature of this system ranges from 167°F to 302°F (75 to 150°C). Due to the chemical composition of the thermal waters they noted that these estimates should be questioned because many of the assumptions the models are based on are violated. Pearl (1979) estimated that the areal extent of the Hot Sulphur Springs thermal system could encompass 1.35 sq mi (3.50 sq km) and could contain 0.698 Q's (1 Q = 1,000,000,000,000,000 BTU's) of thermal energy at a temperature of 104°F (40°C).

SOIL MERCURY INVESTIGATIONS

Introduction

The majority of exploration methods used in geothermal exploration are the more common ones such as geology, geophysics, and hydrogeological mapping; however, new methods are beginning to be used. One of these, soil mercury surveys, has proven successful in a number of instances. For example Capuano and Bamford (1978), Cox and Cuff (1980), Klusman and others (1977), Klusman and Landress (1979), and Matlick and Buseck (1976) have demonstrated the use of soil mercury surveying as a geothermal exploration tool. Both Matlick and Buseck (1976), and more recently, Cox and Cuff (1980), have used soil mercury surveys on a regional scale. On a detailed scale, Klusman and Landress (1979) and Capuano and Bamford (1978) have shown how soil mercury surveys can delineate faults or permeable zones in geothermal areas. The association of mercury with geothermal deposits has been shown by White (1967). Matlick and Buseck (1976) stated that areas with known thermal activity, such as the Geysers, California; Wairakei, New Zealand; Geyser, Iceland; Larderello, Italy and Kamchatka, Russia contain mercury deposits.

Matlick and Buseck (1976), in presenting the geochemical theory behind the associations of mercury with geothermal deposits, noted that mercury has great volatility and the elevated temperatures of most geothermal systems tends to cause the element to migrate upward and away from the geothermal reservoir. In addition, they noted the work of White (1967), and White and others (1970) which showed that relative high concentrations of mercury are found in thermal waters. Matlick and Buseck (1976) then pointed out that soils in thermal areas should be enriched in mercury, with the mercury being trapped on the surfaces of clays and organic and organometallic compounds.

Matlick and Buseck (1976) presented 4 case studies where they used soil mercury concentrations as a exploration tool. Three of the four areas tested, Long Valley, California, Summer Lake, Oregon and Klamath Falls, Oregon, indicated positive anomalies. At the fourth area, East Mesa in the Imperial Valley of California, no anomaly was observed although isolated elevated values were recorded.

Klusman and others (1977) evaluated the soil mercury concentration at six geothermal areas in Colorado. These areas were Routt Hot Springs, Steamboat Hot Springs, Glenwood Springs, Cottonwood Hot Springs, Mt. Princeton Hot Springs, and Poncha Hot Springs. Their sampling and analysis procedures differ from Matlick and Buseck (1976) in that they first decomposed the soils using hydrogen peroxide and sulfuric acid; then a flameless atomic absorption procedure was used to determine the concentration of mercury. They presented the results for only one of the six areas sampled, Glenwood Springs. Their survey indicated anomalous zones but they noted that their data would require more analysis.

Soil Mercury surveys were run by Capuano and Bamford (1978) at the Roosevelt Hot Springs Known Geothermal Resource Area Utah. They analyzed the soil samples with a Jerome Instrument Corp. gold film mercury detector. The results of their investigation showed that mercury surveys can be useful for indentifying and mapping faults and other structures controlling the flow of thermal waters and for delineating areas overlying near-surface thermal activity.

Objectives

The aim of the geochemical sampling program by the Colorado Geological Survey was to evaluate those thermal areas deemed to have high commercial development potential. As the time alloted for this program was limited, the soil mercury surveys had to be preliminary in nature. The geochemical sampling program started in 1979 and continued into 1980. The surveys conducted during the summer of 1979 were aimed at determining the structural conditions controlling the hot springs. This approach was strongly influenced by the results of Capuano and Bamford (1978). During 1980 a slightly broader target was considered, rather than just sampling along traverses located over suspected faults; grid sampling patterns were used where possible. If anomalous mercury concentrations were detected, then follow-up samples were collected at a more detailed level. For those thermal areas where grid sampling was not possible due to lack of access, soil disturbance, or urban development, traverses were chosen in a similar method to the procedure used in 1979.

During the course of the investigations several restrictions became apparent. One of these was soil disturbance caused by urban development. One cannot really be sure whether the surface deposits in the back streets and lawns are original or have been brought in. Another problem occurred frequently in sampling alluvial and colluvial surficial deposits; such deposits because of their origin, age and mineral content tend to mask, dilute, and/or distort any anomalies.

Sampling Methods

At selected sample sites, one to eight samples were taken at points within 15 to 20 ft (4.6 m to 6.1 m) of each other. The notation of sampling locality is explained in Miesch (1976). The interval between sampling sites depends on the target being considered. For areas investigated, the sample site interval was either 100 ft, 200 ft or 400 ft. (30.5 m, 61 m or 122 m). When using a 400 ft (122 m) interval, the area in the immediate vicinity of the hot spring was considered the target rather than any particular fault. Sampling intervals of 200 ft (61 m) or less were used where attempts were made to delineate controlling faults. This spacing was used by Capuano and Bamford (1978). However, Klusman and Landress (1979) seem to think that the sample must be taken directly over the faulting for detection. Considering the empirical result of Capuano and Bamford (1978), it was believed that some anomalous mercury values should be encountered if a grid pattern encompassing the hot spring area was used. A definite structural pattern may be obvious, but if the study area is being influenced by geothermal activity, the trend should indicate that the hot springs area is entirely or partially high in mercury relative to the surrounding area.

The sampling procedure used during 1979 consisted of laying out a series of sample lines across suspected faults in the thermal areas. Samples were then collected at predetermined intervals (usually 100 ft) along the lines.

In most of the areas investigated during 1980, three or more samples were taken at random sample localities. This was done to get an estimate of how the variance between sample localities compared with the variance at a sample locality. If the comparison suggested that there is as much variance at a sample locality as there is between sample localites, then the data would be interpreted on a point to point basis. Contouring the data would more than likely lead to false interpretation.

Two rationales have been used for determining the sampling depth. The method recommended by Cupuano and Bamford (1978) is to determine the profile of mercury down to a depth of approximately 15 in (38 cm); the depth at which the profile peaks determines the sampling depth. The other method consistently samples a soil horizon, such as the A or B horizon. The problem with using the A horizon is that its normally high organic content has been shown to have strong secondary effects in controlling mercury in the soil. Also, the sampling depth in the A horizon may not be deep enough to avoid the "baking" effect of the sun.

The method used during 1979 consisted of using profiles to determine sampling depths. A sampling depth of approximately 6 in (15.2 cm), with an interval of about .4 in (1 cm), was used for most of the profiles. During 1980, each sample was taken over an interval of 5 to 7 in (13 to 18 cm). It was hoped that some of variance due to depth would be smoothed out by sampling over a wider interval. Also at that depth it was hoped that the sun would not be affecting the soil's ability to retain mercury.

To collect a sample, the ground was broken with a shovel to a depth of 8 to 10 in (20 to 25.4 cm). A spatula and metal cup were then used to collect approximately 100 grams of material. The contents of the cup were then put in a marked plastic bag. At the end of the day the material in each bag was laid out and allowed to dry over night. Sometimes it would take more than one night to dry. Normally, the following morning the dried material would be sieved down to an 80 mesh size, outside in a shaded area, and stored in 4 ml glass vials with screw caps. Within a period of 7 days, the samples were analyzed for mercury using the Model 301 Jerome gold film mercury detector.

Background vs Anomaly

For an accurate analysis of geochemical data it is necessary to differentiate between background and anomalous values. There are various statistical ways of accomplishing this. For those areas where the statistical sample approaches 100 samples and a lognormal distribution can be assumed, a method which looks for a break in the accumulative frequency plot of the mercury data can be used. Hopefully, the break distinguishes the two populations - the background and the geothermal induced population (Cupuano and Bamford, 1978; Lepelitor, 1969; Levinson, 1974).

For those instances where the data were analyzed using a cumulative frequency diagram, the following procedure was used.

1). Determine the number of class intervals by multiplying the logarithm of the sample by 10.

2). Determine the range of each class interval by dividing the maximum recorded value, determined above, by one less.

3). Determine logarithm of top end of each interval.

4). Determine class frequency by calculating the number of values in each class.

5). Determine relative frequency by dividing each class frequency value by total number of values.

6). Construct frequency distribution graph by plotting class frequency log values by cumulative frequency.

7). Note where break in slope of graph occurs.

For those cases where the data were sparce and the values were clustered near the lower detection limit of the instrument, with a few high values at the opposite extreme, a more empirical method was used. This method called for arranging the data in ascending numerical order then inspecting the data for any gaps. The anomalous values are differentiated from background values. For the lack of a proper sampling design and computer facilities, the gap between background and the anomaly was chosen subjectively, rather than using a statistical test as recommended by Miesh (1976). When background was determined in this manner, sometimes the anomaly criteria of four times typical background was used to see how it compared with the anomalous results of the ranking method.

As a further aid in determining background mercury values, sample localities were chosen within a mile or two of the study area. Care was taken to try to sample on the same parent material as in the study area. It was assumed that there were no extreme regional trends.

SOIL MERCURY SURVEYS HOT SULPHUR SPRINGS AREA

Introduction

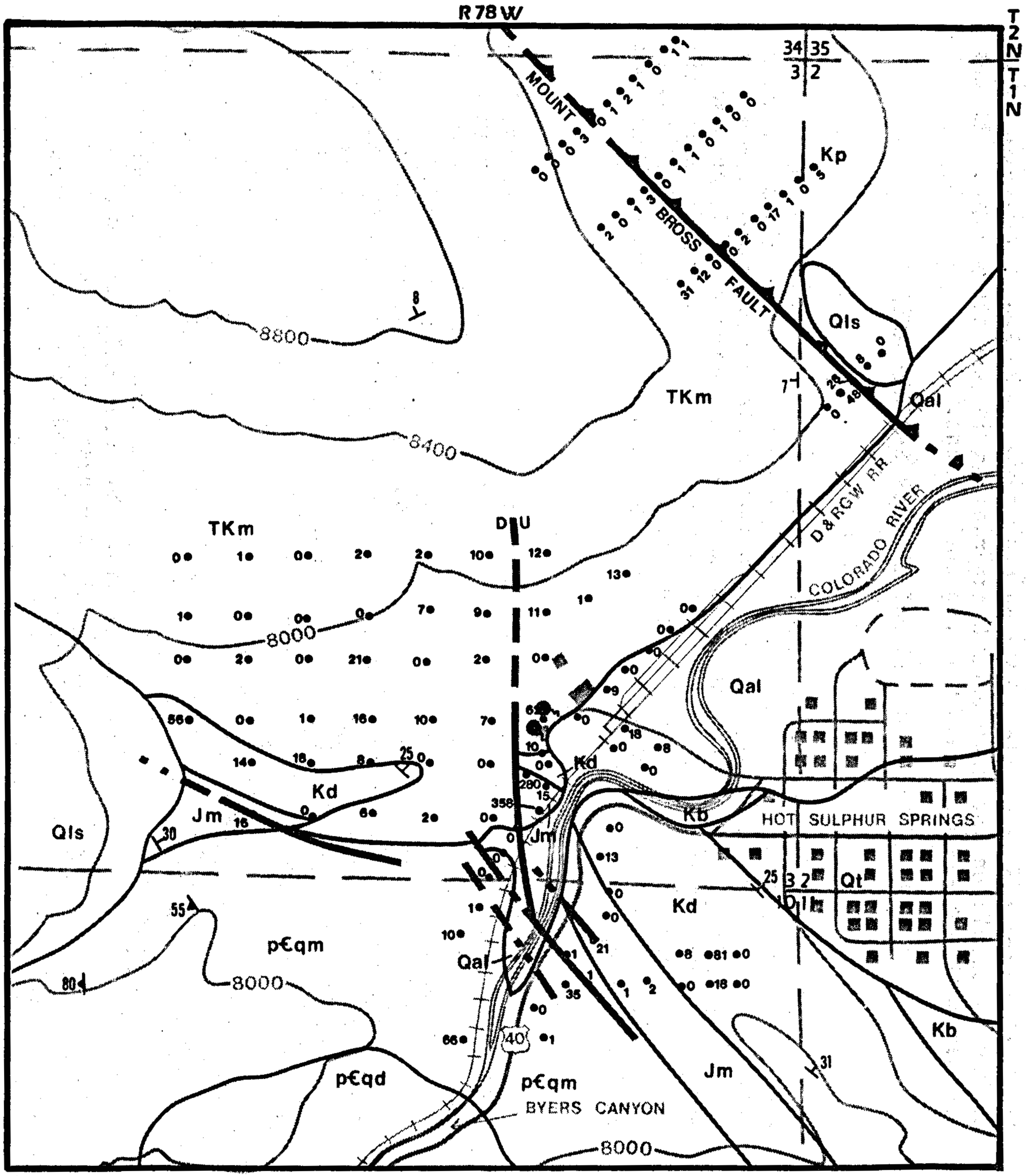
As part of the resource assessment program of the Hot Sulphur Springs area, 118 soil samples were collected and analyzed for mercury from two areas (Fig. 7). In first area samples were collected along four lines across the Mount Bross Fault. The second region encompassed a large geographic area south and west of Hot Sulphur Springs. Unlike some other areas in Colorado where this method was employed, the method proved less than satisfactory in helping to delineate the geological conditions controlling the occurrence of the Hot Sulphur Springs thermal waters.

Soil Description

On the hillside in back of the Hot Springs Motel, the soil appears to have formed from the Middle Park Formation. The B horizon, from which samples were taken, is light brown, unconsolidated, and sandy to clayey. The vegetation consists of a sparse cover of grasses and sage, on a slope averaging 15°. In the southern part of the study area where most of the faulting occurred, the soil appeared to have formed from the bed rock of the Dakota and Morrison Formations and the Precambrian granitics. The B horizon in this locataion has more variation in lithology, organic and clay matter. The vegetation is thicker, with lodge pole pine, juniper, scrub oak and aspen.

Mercury Surveys

The distribution of the analytical data does not lend itself to statistical methods for background and anomalous determinations. While analytical values ranged up to 358 ppb, 92% of the values are less than 21 ppb (Table 2 and Fig. 8). It is not possible to accurately determine what the background value are for the low values are near the detection limit of the instrument. Thus, it is quite probably that typical values could range as high as 20 ppb.



EXPLANATION

●1 Sampling locality with sample analysis in ppb of mercury

● Hot spring

See Figure 2 for geology explanation.

200 0 200 feet

N

Base modified from U.S.G.S. 7½' topographic quadrangle map.

Figure 7. Location of soil mercury sample sites, Hot Sulphur Springs area.

To determine background values, 37 soil samples were collected approximately 5 mi (8 km) from the study area across the Mount Bross Fault. Analytical values ranged from a low of 0 ppb to a high of 48 ppb with a median value of of 6 ppb mercury. With one exception there was no noticeable difference in the analytical data across the Mount Bross Fault. Thus, it is concluded that anomalous mercury values in the Hot Sulphur Springs area are above 40 to 50 ppb, based on subjective judgement as to where a break in the ranked data occurs.

Aside from the high mercury value found "in" the hot springs or in the immediate vicinity of the springs, there are only two or three values (Fig. 7) that might be considered anomalous. The values don't indicate any pattern and appear to be well away from any structure.

Table 2 Analytical mercury data* arranged in ascending rank. See Fig. 6 for location of sample points.

0	0	0	0	1	2	8	15	56
0	0	0	0	1	2	8	16	62
0	0	0	0	1	2	8	16	66
0	0	0	0	1	2	9	16	81
0	0	0	0	1	2	10	17	280
0	0	0	0	1	3	10	18	358
0	0	0	0	1	3	10	18	
0	0	0	1	1	5	10	18	
0	0	0	1	1	6	11	21	
0	0	0	1	2	6	12	21	
0	0	0	1	2	7	12	28	
0	0	0	1	2	7	13	31	
0	0	0	1	2	8	13	35	
0	0	0	1	2	8	14	48	

*Represents just one of the values at a sample locality.

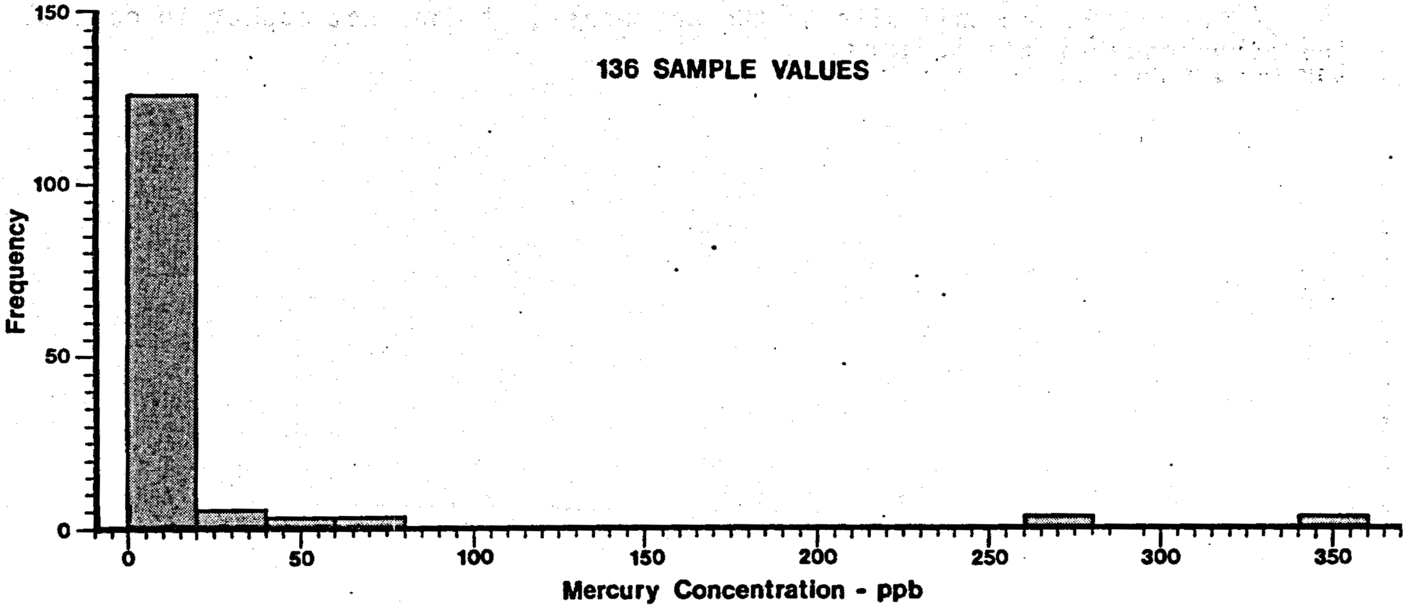


Figure 8. Soil mercury analytical frequency distribution.

ELECTRICAL GEOPHYSICAL RESISTIVITY SURVEYS

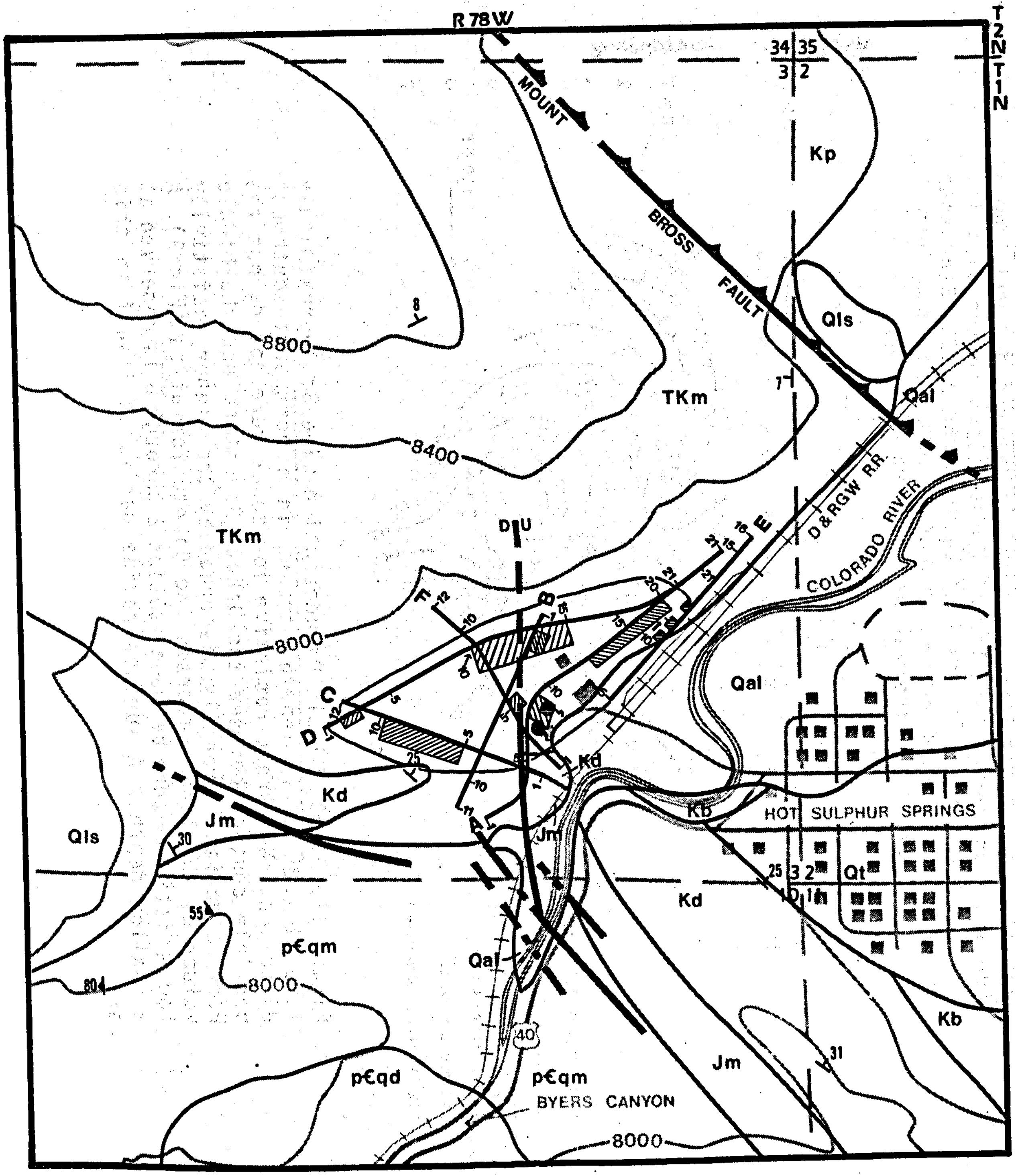
Introduction

Prior to this investigation no geophysical surveys had been conducted in and adjacent to the Hot Sulphur Springs geothermal area. As part of the assessment program dipole-dipole electrical resistivity measurements were made along six lines totaling 9,300 ft (2.83 Km) (Fig. 9) with a Scintrex RAC-8 electrical resistivity system. These measurements were made to detect areas of low resistivity. Areas of low resistivity, indicators of thermal reservoirs, are normally due to water saturation, higher than normal temperatures and a high clay matrix zone caused by faults. Due to combination of geological conditions plus equipment limitations it was not possible to acquire resistivity measurements below a depth of approximately 500 ft (152 m). A complete description of the various factors which might possibly affect electrical resistivity measurements is presented in Appendix C and a description of the equipment used is presented in Appendix D at the end of the paper.

One of the more common methods of portraying and interperating electrical resistivity data is through the use of pseudosections which are cross sections showing the resistivity values measured along each line. In their interpretation one must be aware that resistivity values obtained along the line of the traverse may be influenced by lateral variations in the subsurface geological conditions. Figures 10 to 15 are pseudosections drawn along the six traverse lines. An interperation of the geological conditions being measured by the resistivity data is presented on each figure.

Conclusions

Due to steep hillsides, canyon walls, the river, railroad, and homes dipole-dipole resistivity surveys were restricted in areal extent. From the low resistive zones delineated it is believed that the extent thermal system was outlined. Several areas of low resistivity appear to be associated with the north trending fault zone west of the hot springs. This suggests that the fault zone is saturated with thermal water and may well be the conduit along which the waters are moving up from depth. Although the large Mount Bross Fault, is located less than one half mile to the northeast, it does not appear to control the occurrence of the springs.



EXPLANATION

Resistivity line and station number

▨ Hachered area indicates low resistivity zones

Area of low resistivity

Hot spring

See Figure 2 for geology explanation.

Base modified from U.S.G.S. 7½' topographic quadrangle map.

Figure 9. Hot Sulphur Springs geophysical resistivity lines.

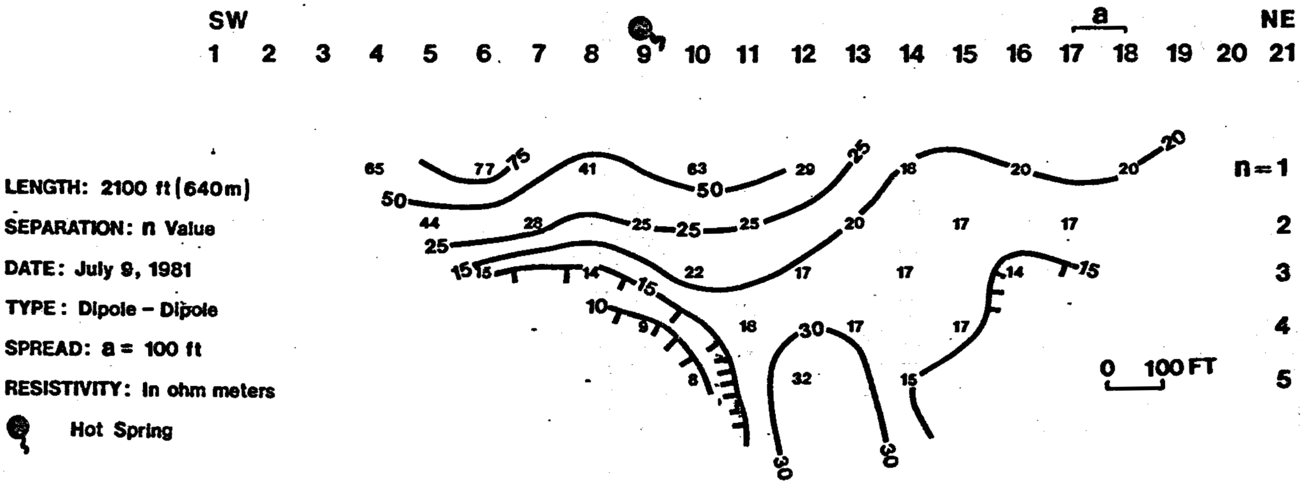


Figure 10. Dipole-Dipole Pseudosection Line A: Along this northeast- southwest line resistivities values dropped from a high of 77 ohm meter to a low of 7 ohm meters in the vicinity of the hot springs. The contact between the Dakota Sandstone and the Middle Park Formation was detected at stations 6 through 10 where the thermal waters were emerging.

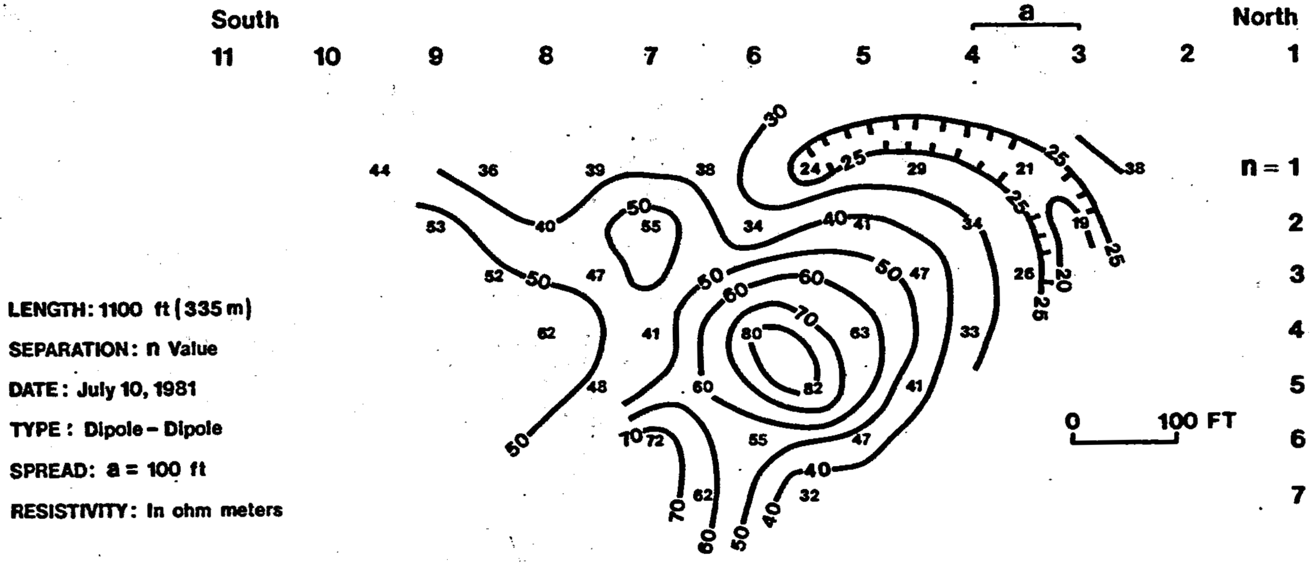


Figure 11. Dipole-Dipole Pseudosection Line B: Approximately 1100 ft (335 m) in length, trends in a northeast-southwest direction. No strong resistive low zones were noted, but the possible contact between the Dakota Sandstone and the Middle Park Formation is readily discerned by the higher resistivity values as the line traverses the Dakota formation (Fig 9). A low resistivity zone between station 2 through 6 is observed at a shallow depth. A surface ravine manifests itself in this area.

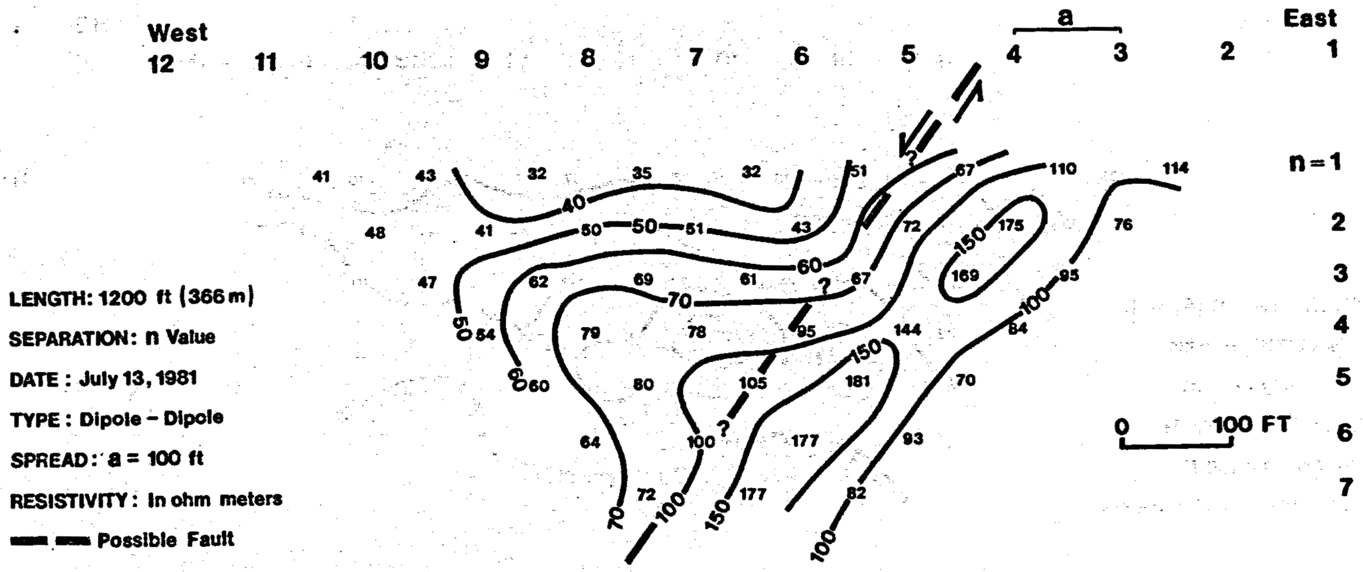


Figure 12. Dipole-Dipole Pseudosection Line C: A low resistivity zone was mapped between stations 5 and 8. A mapped fault is depicted on the section between stations 4 and 6 down thrown to the west. It is postulated that the mapped contact between the Dakota sandstone and the Middle Park Formation may be a fault contact as it occurs in the same area where there is a distinct change in resistivity.

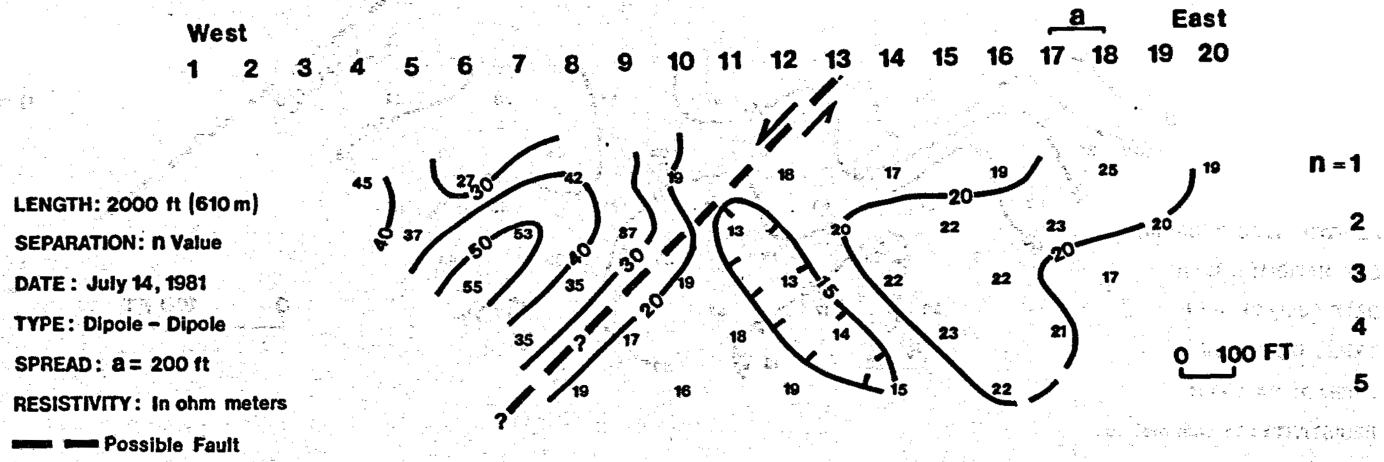


Figure 13. Dipole-Dipole Pseudosection Line D: This east-west line also demonstrates a very distinct resistivity low between stations 8 through 13. It is believed that this zone reflects varying resistivity values on either side of the mapped fault the line crossed.

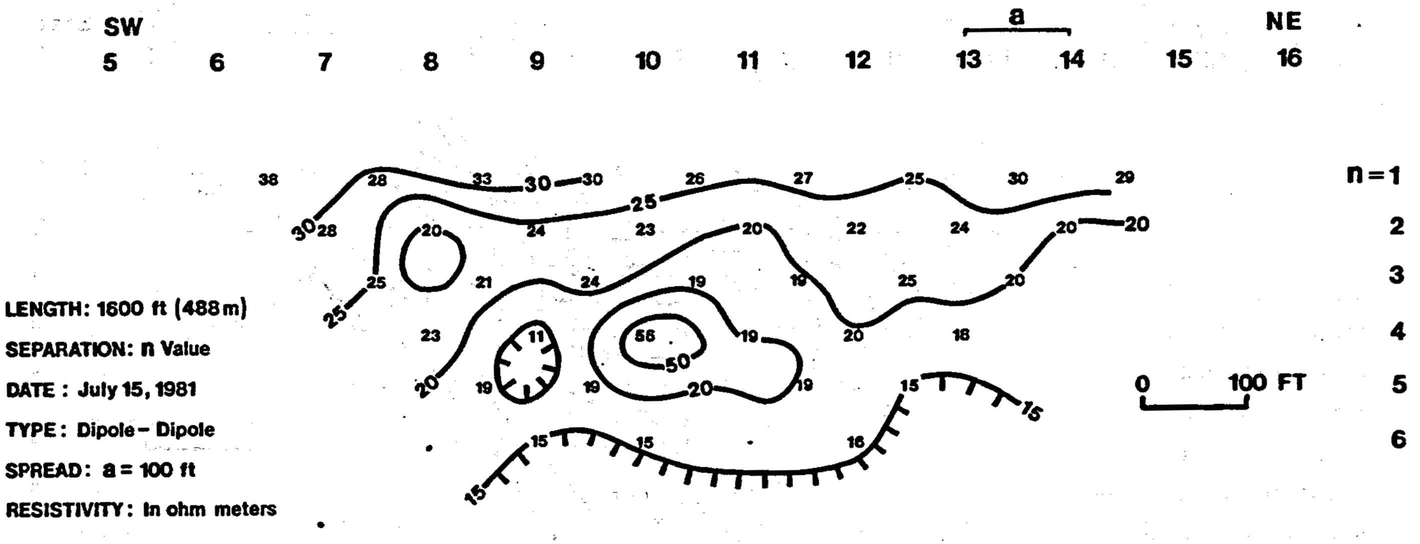


Figure 14. Dipole-Dipole Psuedosection Line E: No data were obtained from station 1 through 5 because of culture. A deep seated resistivity low exists the entire length of the line, however, structurally no features are apparent. This low zone may be due to the water saturated alluvium that underlay the line.

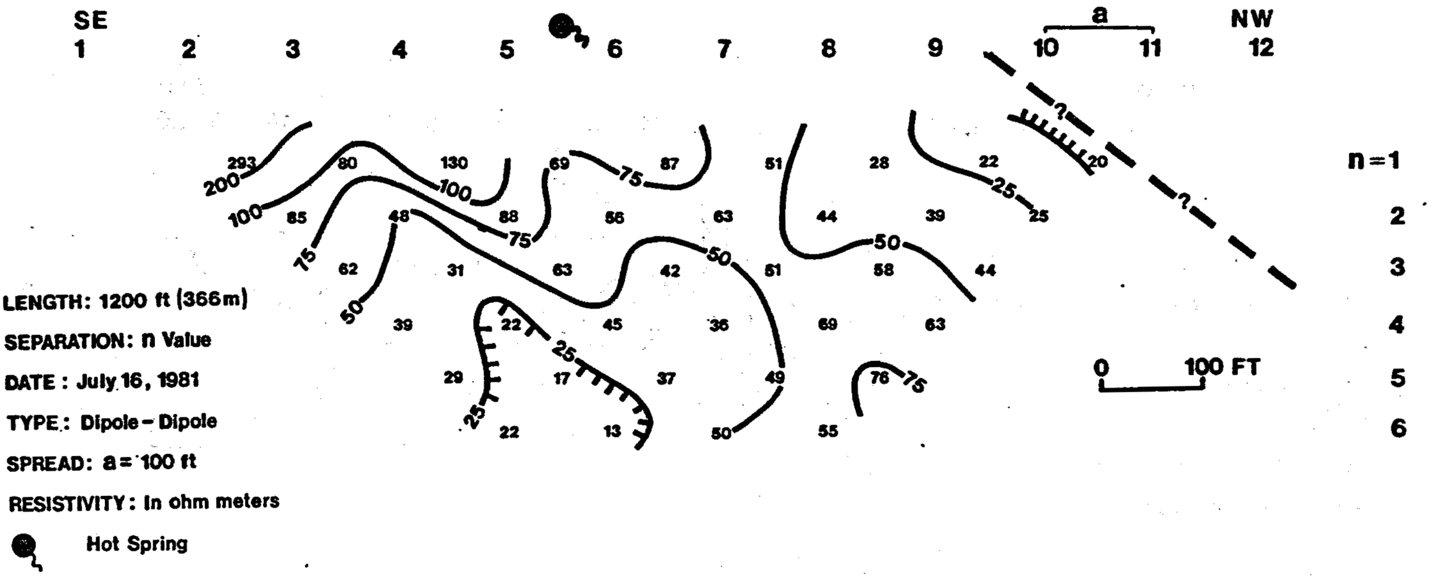


Figure 15. Dipole-Dipole Psuedosection Line F: Along this northwest- southwest trending line a deep seated low exists between stations 5 and 6 where the values decrease to 13 ohm-meter. This is probably due to the travertine deposits associated with the spring. Also the contact between the Dakota Sandstone and the Middle Park Formation is indicated at this area.

ORIGIN OF THE THERMAL WATERS

With the exception of this assessment program no other geological, geophysical or hydrogeological information pertaining to the thermal conditions of the area is available from which a meaningful interperation of the thermal conditions can be made. However, based on hydrogeological and geothermal conditions elsewhere, a working model of this system can be developed. This model will have await further exploration efforts to determine its accuracy.

Based on world wide occurrences, it has been determined that thermal waters are of three origins: meteoric, magmatic or a combination of the two. Meteroric waters are normal groundwaters which originated as precipitation falling on the surface of the land, some of which flowed downward along faults and fractures to a great depth where they became heated. The actual process by which these waters became heated is not known but is probably due to high heat-flow. Buelow (1980) and Decker and others (1981) have suggested that the heat flow of the Middle Park area may be higher than normal. Another possible heating mechanism could be heat given off by the disintegration of radioactive minerals. Wells (1960) showed that the concentration levels of radioactive minerals in the Tertiary age rocks of the Front Range are 15 to 25 times greater than that for average granitic rocks. No values are available on the radioactive mineral concentration levels for the granitic rocks in the Hot Sulphur Springs, but this could be a possible heat source.

Magmatic waters are those given off during the late cooling stages of a deep seated igneous rock body, like a batholith. Based on published geological information, no evidence has been given for the presence of such a feature in the Hot Sulphur Springs area. Therefore this origin is not considered a viable alternative.

Based on all available evidence the authors believe that the Hot Sulphur Springs thermal waters represent deep circulation of meteoric waters along numerous faults and fractures in an area of above normal heat flow. Recharge to the system probably occurs on the high ground to the east.

Due to the thick sequence of insulating Pierre shale found just to the east and south of the study area, it is not possible to make any accurate predictions on required circulation depths. Decker and others (1981) noted note that the high heat-flow values, late Cenozoic igneous activity and numerous hot springs all provide most compelling evidence that low to moderate temperature resources could exist at shallow depths in northwest Colorado. They noted that in areas where thick sequences of shale exist that low-to moderate-temperature waters (70-100°C (158°F-212°F)) could be found at their base.

SUMMARY AND CONCLUSIONS

The geothermal resources of the Hot Sulphur Springs area are restricted to a small area on the north side of the Colorado River in the community of Hot Sulphur Springs. In this area there are approximately 10 springs having a maximum temperature of 111°F (44°C), and a combined discharge of approximately 50 gpm. The waters are a sodium bicarbonate type.

As determined by geology and reconfirmed by geophysical surveys, the springs are associated with a small northeast trending fault. No evidence was gathered that would determine if they were or were not associated with the major Mount Bross fault located to the northeast.

While no data was collected to prove or disprove it, it is the authors belief that the thermal waters are normal meteoric ground waters that became heated due to deep circulation in an area of above normal heat flow. Pearl (1979) estimated that the areal extent of the Hot Sulphur Springs geothermal system could encompass approximately 1.35 sq mi (0.91 sq Km) and could contain 0.0698 Q's of heat energy at a temperature of 104°F (40°C). Pearl (1979) estimated that this system was bounded by the Mount Bross fault on the north. Evidence gathered during the course of this investigation did not support this conclusion. Therefore, it is here estimated that the Hot Sulphur Springs geothermal area does not encompass more than 1 sq mi (2.59 sq Km) and is primarily restricted to an area bounded on the west by the north trending fault. Due to the presence of a favorable impermeable, insulating caprock in the form of the Pierre shale, it is not possible to estimate depth of circulation. The presence of this caprock means that thermal waters may also be found at relatively shallow depths (<5,000 ft [1.52 km)] east of Hot Sulphur Springs. Decker and others (1981) belived that moderate to high temperature waters, adequate for the generation of electricity, could exist in some parts of North and Middle Parks if an adequate impermeable caprock exists. They noted that the most likely area for this occurrence would be in the Basalt Mountain-Flat Top-State Bridge area, southwest of the Hot Sulphur Springs area.

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APPENDIX A

GEOTHERMAL ENERGY AND ITS POSSIBLE USES

Geothermal energy, the heat generated by natural processes beneath the earth's surface, normally occurs at great depths. In some places, however it can be found close to or at the surface in the form of volcanoes, geysers or hot springs. Where it occurs near the surface it can be developed and put to beneficial use. Geothermal energy in the form of hot springs has been used by mankind for medicinal and cooking purposes since the earliest days of recorded history. In the last 100 years development of this energy source for other uses has occurred, and it is now used for such purposes as: Generation of electricity; heating and cooling of buildings; processing of food and other goods; heating cattle barns, greenhouses and fish ponds; milk pasteurization; and recreation and medicinal. Due to declining petroleum reserves It is anticipated that in years to come development of this energy source will increase. Figure 15 lists some of the uses geothermal energy could be put to and the temperatures required.

Coe (1978 and 1982) has presented a discussion on the possible uses, of geothermal energy development in Colorado and some of the problems associated with its development. If the reader is interested in learing more about geothermal enery and its possible development he/she is referred to papers by: Anderson and Lund (1979); Kruger and Otte (1973); Muffler (1979); and White and Williams (1975). Listed on the back cover is a complete listing of all papers and reports published by the Colorado Geological Survey relating to the geothermal resources of Colorado.

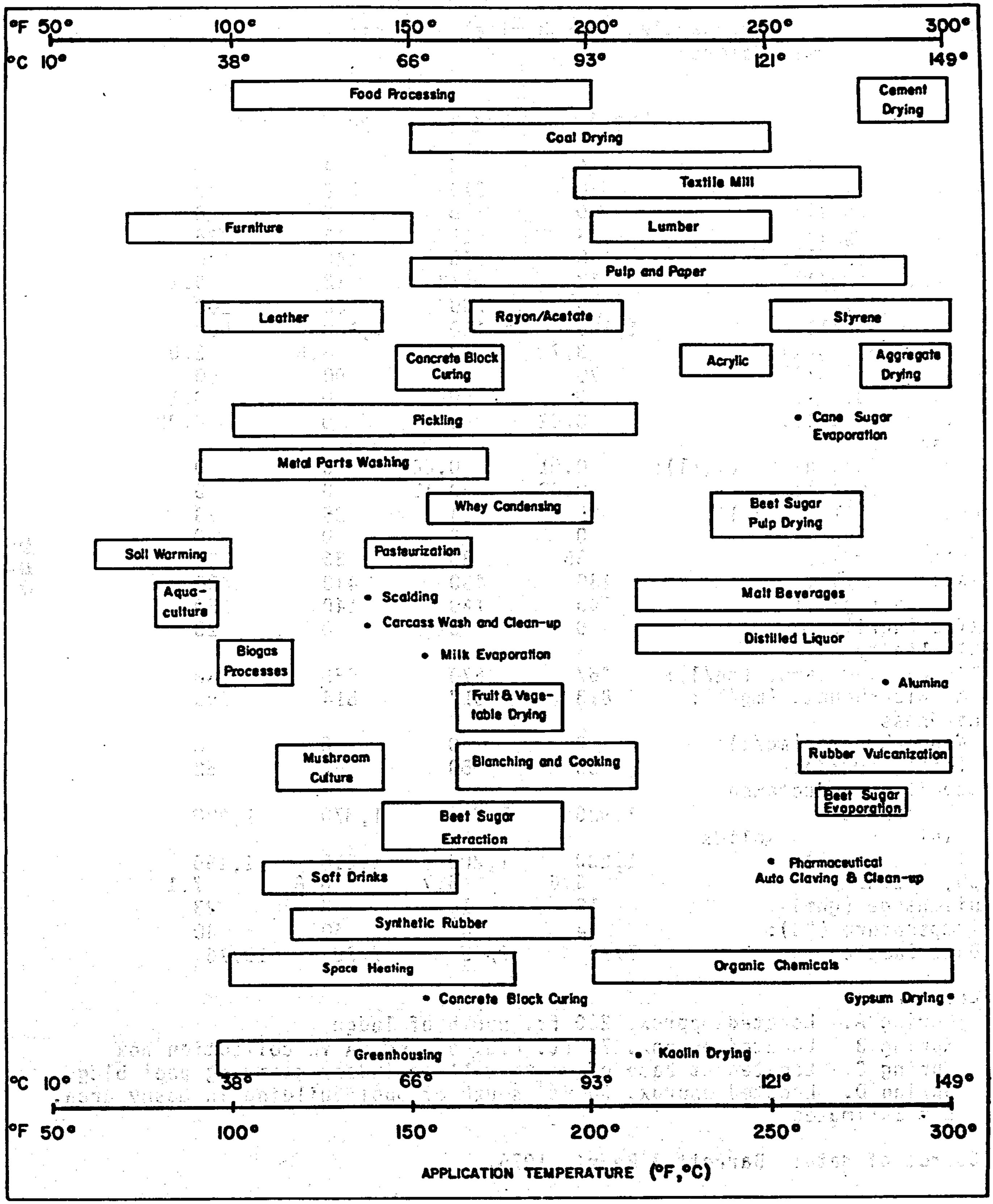


Figure 16. Temperature range for some direct uses of geothermal energy. (Adopted from Aderson and Lund, 1979, p.4-26.)

APPENDIX B

Table 3. Physical Properties and Chemical Analysis of Hot Sulphur Springs Thermal Waters.

	Spg A	Spg B	Spg C	Spg D
Arsenic (ug/l):	6	5	4	9
Boron (ug/l):	570	570	530	570
Cadmium (ug/l):	0	0	0	0
Calcium (mg/l):	14	15	15	16
Chloride (mg/l):	140	140	140	140
Fluoride (mg/l):	12	12	12	9.1
Iron (ug/l):	20	100	60	200
Lithium (ug/l):	1,100	1,100	1,100	1,500
Magnesium (mg/l):	3.7	3.1	3.5	3.0
Manganese (ug/l):	70	80	90	90
Mercury (ug/l):	0	0	0	0.1
Nitrogen (mg/l):	0.02	0	0.	0.02
Phosphate				
Ortho diss. as P, (mg/l):	0.01	0.04	0	0
Ortho, (mg/l):	0.03	0.12	0	0
Potassium (K), (mg/l):	25	24	25	23
Selenium (ug/l):	0	0	0	0
Silica (mg/l):	35	35	35	30
Sodium (mg/l):	430	430	440	430
Sulfate (mg/l):	140	140	140	150
Zinc (ug/l):	0	0	0	20
Alkalinity				
As Calcium Carb. (mg/l):	667	670	668	648
As Bicarbonate (mg/l):	813	817	814	790
Hardness				
Noncarbonate (mg/l):	0	0	0	0
Total, (mg/l):	50	50	52	52
Specific Conductance (Micromohs):	1,920	1,850	1,870	1,800
Total dissolved solids (TDS), (mg/l):	1,200	1,200	1,210	1,190
pH, Field	6.6	6.7	6.8	7.1
Discharge (gpm)	12	1E	3	23
Temperature (°C):	44	41	40	40
Date Sampled	7/75	7/75	7/75	10/75

Location:

Spring A. Located approx. 250 ft. north of lodge
Spring B. Located approx. 75 ft. n.e. of Spg. A in collection box.
Spring C. Located at base of north wall on indoor swimming pool bldg.
Spring D. Located approx. 50 ft. south of pool building in mashy area.
E = Estimated

Source of data: Barrett & Pearl, 1976.

TABLE 4. Trace Elements In Hot Sulphur Sprints Thermal Waters
Values reported in Micrograms/liter (UG/L)

	Spg A	Spg B
Aluminum	95	130
Barium	100	130
Beryllium	< 2	< 2
Bismuth	< 9	< 9
Chromium	< 9	< 9
Cobalt	< 9	< 9
Copper	3	2
Gallium	< 4	< 4
Germanium	< 9	< 9
Lead	< 9	< 9
Nickel	< 9	< 9
Silver	< 1	< 1
Strontium	630	790
Tin	< 9	< 9
Titanium	< 5	< 5
Vandium	< 9	< 9
Zirconium	<15	<15

Source of data: Barrett and Pearl (1976)

Table 5. Associated radioactivity, Hot Sulphur Springs thermal waters.
Spring B.
Values reported in Picocuries/liter (PCi/l)
Source: Barrett and Pearl (1976)

Rn-222	510. ± 51	U-235	< 0.01
Ra-226	3.2 ± 0.27	U-238	0.041 ± 0.021
Ra-228	N.A.	Th-230	< 0.0069
U-234	0.057 ± 0.024	Th-232	< 0.0085

APPENDIX C

FACTORS AFFECTING RESISTIVITY

Electrical resistivity geophysical methods used in geothermal exploration measure the electrical resistivity of rocks at various depths. Temperature, porosity, salinity of fluids, and the content of clays will normally be higher within the geothermal reservoir than in the surrounding subsurface rocks. Consequently, the electrical resistivity in thermal reservoirs is low compared to the surrounding rock. Basically, resistivity methods utilize manmade currents which enter the subsurface via two electrodes with the resultant potential measured at two other electrodes (Soil Test Inc., 1968).

The difficulty with interpretation stems from the fact that resistivity is a complicated function of the following parameters: temperature, porosity, salinity, and clay content. For example, a low temperature, highly saline ground water can provide the identical low resistivity anomaly as a high temperature, moderatately saline geothermal system. Therefore, to be most effective, this method should be used in conjuction with direct temperature gradient measurements and other types of data that are of value in determining the reason for the resistivity values obtained (Soil Test Inc., 1968).

Zones of low resistivity in a geothermal environment can be caused by a high dissolved solid content of thermal water versus ground water, higher clay content due to the hydrothermal alteration within the fault zones, and the higher temperature of the thermal fluids. Finally, the ability of the geophysicist to isolate any of the aforementioned factors and relate it to the object of the resistivity exploration program rests upon a combination of elimination process of constant or slowly varying factors from those that are most susceptible to change.

APPENDIX D

INSTRUMENTATION

Scintrex RAC-8 Low Frequency Resistivity System

The following description is taken from the Scintrex Manual (1971).

The Scintrex RAC-8 electrical resistivity equipment used by the Colorado Geological Survey is a very low frequency AC resistivity system with high sensitivity over a wide measuring range. The transmitter and receiver operate independent of each other, requiring no references wires between them. This allows a great deal of efficiency and flexibility in field procedures and eliminates any possibility of interference from current leakage or capacitive coupling within the system.

The transmitter produces a 5Hz square wave output at a preset electronically stabilized, constant current amplitude. The output current level is switch selectable at any one of five values ranging from 0.1 to 333 milliamps.

The receiver is a high sensitivity phase lock, synchronous detector which locks onto the transmitter signal to make the resistivity measurement. When set at the same current setting as the transmitter, the receiver gives a direct readout of V/I ratio.

The RAC-8, with a measuring range from .0001 to 10,000 ohms, high sensitivity to weight ratio gives fast accurate resistivity data. With the low AC operating frequency, good penetration may be obtained in excess of 1500 ft under favorable conditions. The system has an output voltage maximum of 1000 V peak to peak. However, the actual output voltage depends on the current level and load resistance. The output power under optimum conditions approaches 80 watts.

In areas of very low resistive lithology, the penetration power was reduced by a sizeable amount. Realizing the aforementioned constraint, the intent was to delineate gross potential differences in resistivity. In some areas where the lithology reflected small differences in resistivity, the RAC-8 system appeared to average the penetrated lithologic sequences rather than picking up distinct breaks. Considering cost and time constraints, the system performed as indicated and performed best in areas of high resistivity.

APPENDIX E

RESISTIVITY FIELD PROCEDURES

Before discussing the various electrode spreads used, it is necessary to consider what is actually measured by an array of current and potential electrodes. By measuring voltage (V) and current (I) and knowing the electrode configuration, a resistivity (p) is obtained. Over homogeneous isotropic ground this resistivity will be constant for any current and electrode arrangement. That is, if the current is maintained constant and the electrodes are moved around, the potential voltage (V) will adjust at each configuration to keep the ratio (V/I) constant (Sumner, 1976).

Apparent Resistivity:

$P_a = 2PIa \; V/I$ General Formula

a = Spread length
V/I = Voltage current ratio
Pa = apparent resistivity
2PI = 6.2

See Figure 17 for a schematic diagram for resistivity.

One of the most widely used electrical processing techniques for geothermal resource exploration is the resistivity profiling and sounding method. The method utilizes various arrays, but the most common are the Wenner, the Schlumberger and the Dipole-Dipole schemes. The Colorado Geological Survey extensively employed the latter method primarily because of the ease of use and also being able to obtain both horizontal and vertical sections.

If the ground is unhomogeneous, however, and the electrode spacing is varied, or the spacing remains fixed while the whole array is moved, then the ratio will in general change. This results in a different value of P for each measurement. Obviously the magnitude is intimately involved with the arrangement of electrodes.

This measured quantity is known as the apparent resistivity, Pa. Although it is diagnostic, to some extent, of the actual resistivity of a zone in the vicinity of the electrode array, this apparent resistivity is definitely not an average value. Only in the case of homogeneous ground is the apparent value equivalent to the actual resistivity (Sumner, 1976).

Wenner Array

In the Wenner Spread (Fig. 18) the electrodes are uniformly spaced in a line (Sumner, 1976).

In spite of the simple geometry, this arrangement is often quite inconvenient for field work and has some disadvantages from the theoretical point of view as well. For depth exploration using the Wenner Spread, the electrodes are expanded about a fixed center, increasing the spacing in steps. For lateral exploration or mapping the spacing remains constant and all four electrodes are moved along the line, then along another line, and so on. In mapping, the apparent resistivity for each array position is plotted against the center of the spread.

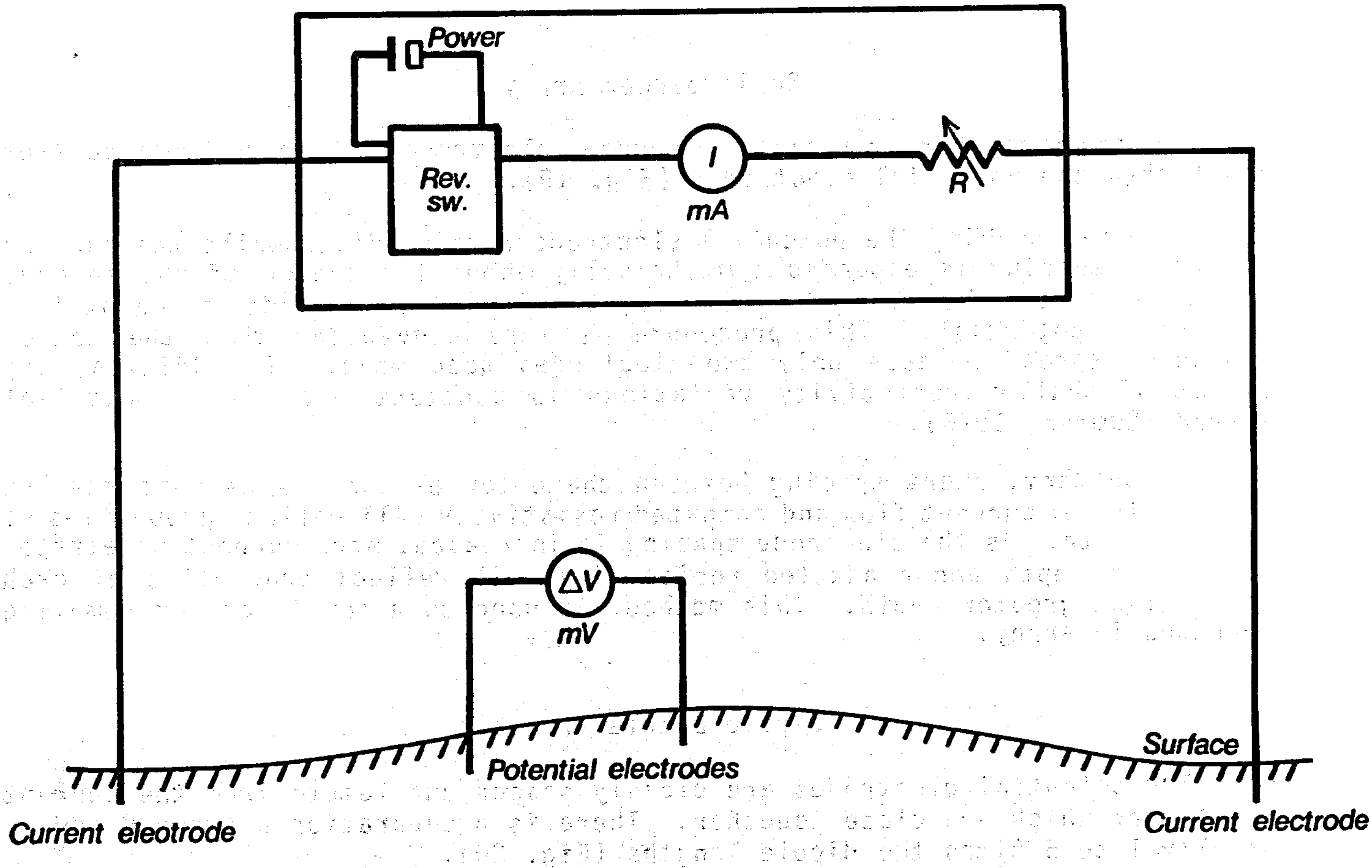
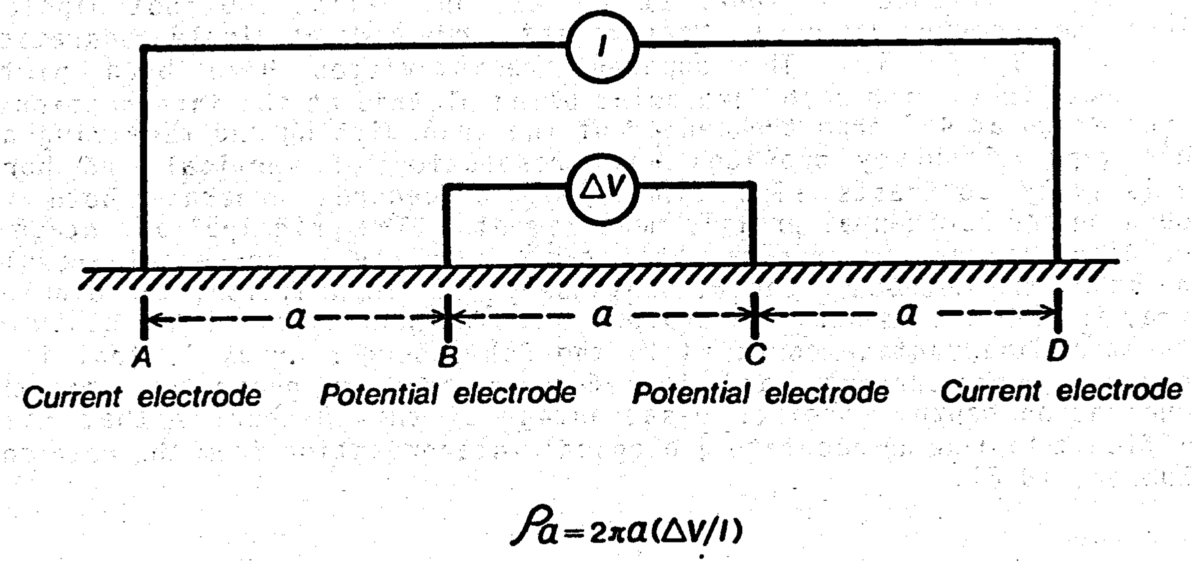


Figure 17. Schematic diagram for resistivity. (Adopted from Combs, 1980.)



$$\rho_a = 2\pi a(\Delta V/I)$$

Figure 18. Wenner array. (Adopted from Combs, 1980.)

Schlumberger Array

For the Schlumberger array, the current electrodes are spaced much further apart than the potential electrodes (Fig. 19).

In depth probing the potential electrode remains fixed while the current electrode spacing is expanded symmetrically about the center of the spread. For large values of L it may be necessary to increase 2l in order to maintain a measurable potential. This procedure is more convenient than the Wenner expanding spread because only two electrodes need move. In addition, the effect of shallow resistivity variations is constant with fixed potential spread (Sumner, 1976).

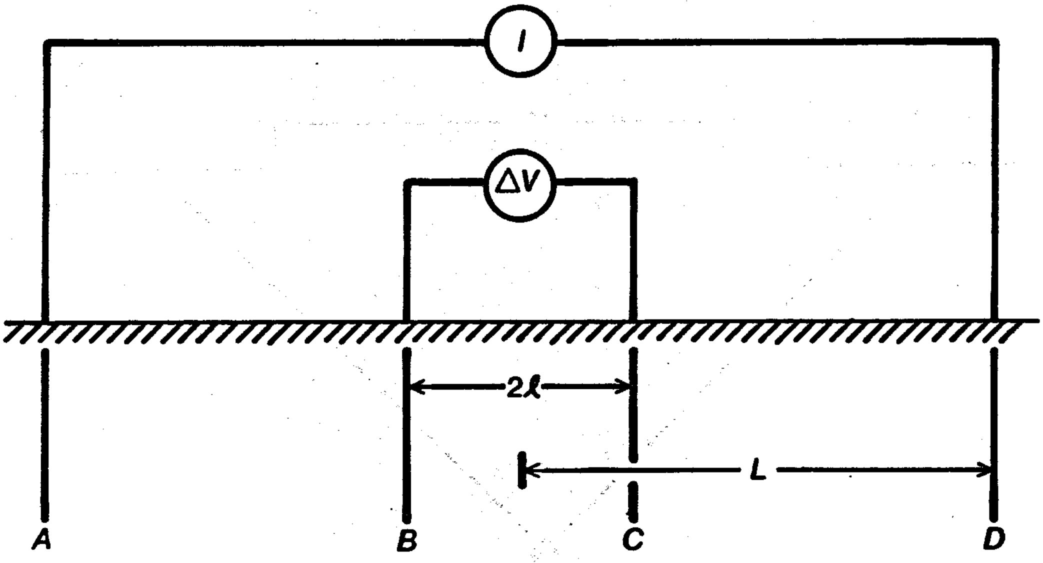
In summary, short spacing between the outer electrodes assumes shallow penetration of current flow and computed resistivity will reflect properties of shallow depth. As the electrode spacing is increased, more current penetrates to greater depth and conducted resistivity will reflect properties of each material at greater depth. This method was used on a few lines for sampling purposes in array.

Dipole-Dipole Array

The potential electrodes are closely spaced and remote from the current electrodes which are close together. There is a separation between C and A, usually 1 to 5 times the dipole lengths (Fig. 20).

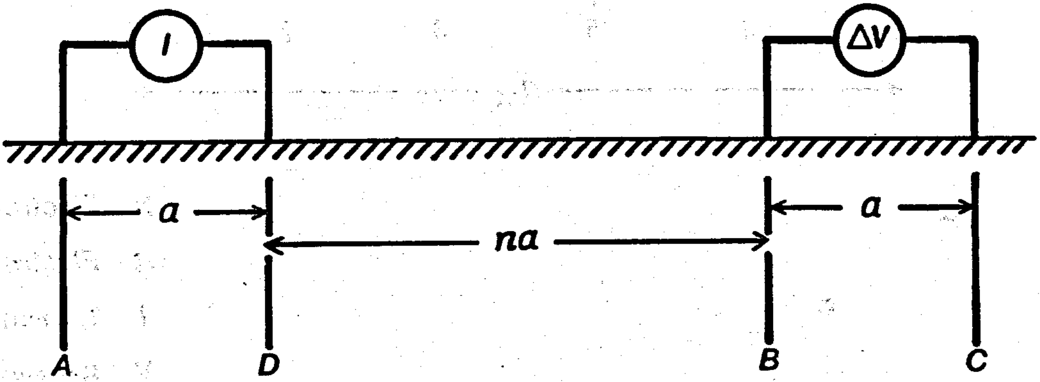
Inductive coupling between potential and current cables is reduced with this arrangement. This method was primarily used throughout all study areas because of reliability and ease of field operation. A diagram of this method is depicted in Figures 21 and Figure 22.

With reference to Figure 21 and 22, an in-line 100 foot dipole-dipole electrode geometry was used. Measurements were made at dipole separations of n = 1, 2, 3, 4, 5. The apparent resistivities have been plotted as pseudosections, with each data point being plotted at the intersections of two lines drawn at 45° from the center of the transmitting and receiving dipoles. This type of survey provides both resolution of vertical and horizontal resistivity contrasts since the field procedures generate both vertical sounding and horizontal profile measurements. The principal advantage of this technique is that it produces better geologically interpretable results than the other two methods (Wenner, Schlumberger). In addition, the dipole-dipole array is easier to maneuver in rugged terrain than either of the other methods. Its main disadvantage compared to the Schlumberger array is that it usually requires more current, and therefore a heavier generator for the same penetration depth. Another disadvantage of this method is that it is very difficult to make an accurate geological interpretation from the data collected (Sumner, 1976).



$$\rho_a = \frac{\pi L^2}{2\ell}(\Delta V/I)$$

Figure 19. Schlumberger array. (Adopted from Combs, 1980.)



$$\rho_a = \pi n(n+1)(n+2)a(\Delta V/I)$$

Figure 20. Dipole-dipole array. (Adopted from Combs, 1980.)

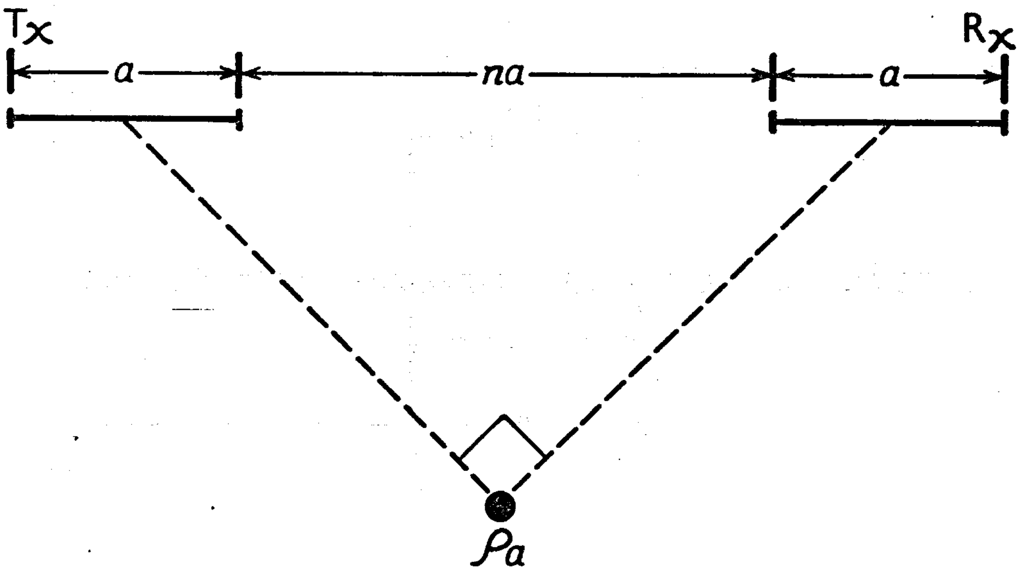


Figure 21. Data plotting scheme for dipole-dipole array. (Adopted from Combs, 1980.)

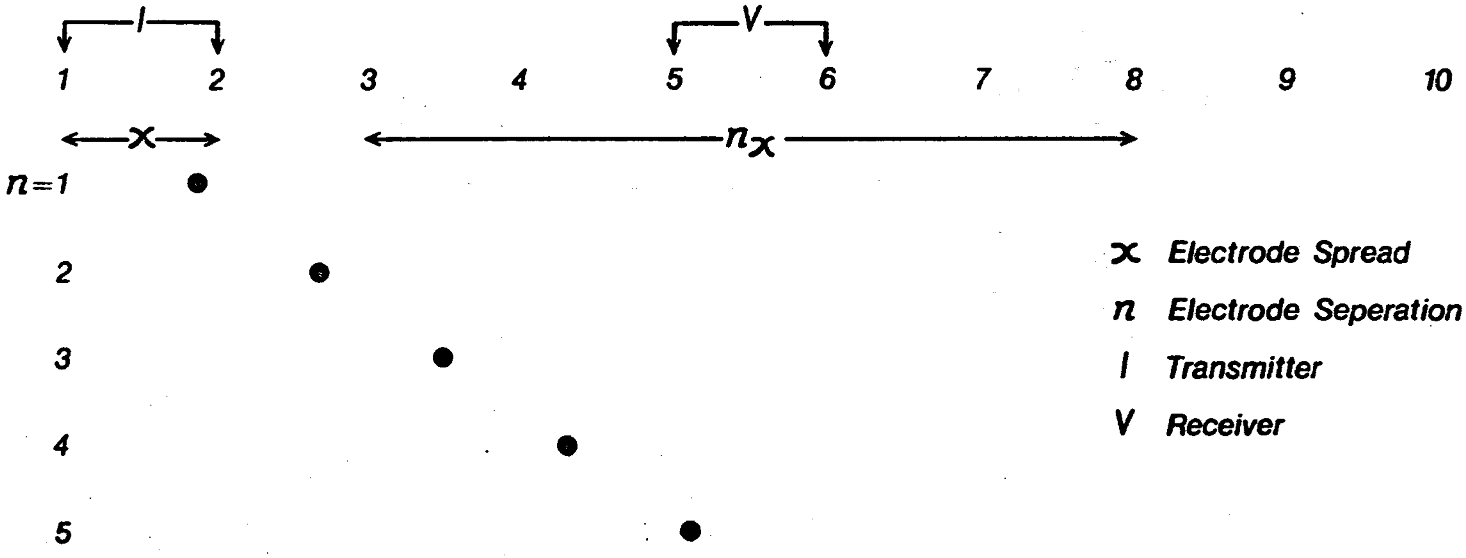


Figure 22. Typical dipole-dipole array. (Adopted from Combs, 1980.)

APPENDIX F. RESISTIVITY CALCULATIONS

TABLE 6. LINE A.

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Hot Sulphur Spgs.	Line A	9 July 1981
CHIEF OPERATOR	ASSISTANTS	METHOD
Robert Fargo	Memmi and Strong	Dipole-Dipole (Nx200')

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
1-3							
5-7	10	.01	66	0.57	0.057	1149	65.51
7-9	10	.001	66	0.89	0.0089	4997	44.48
9-11	1	.00031	133	4.15	0.0013	11493	14.94
11-13	1		225				N.R.
3-5							
7-9	100	.001	100	0.67	0.067	1149	77.00
9-11	1	.001	100	5.56	0.00556	4997	27.78
11-13	1	.00031	200	4.05	0.0012	11493	13.79
13-15	1	.00031	200	1.39	0.0004	22987	9.19
15-17	1	.00031	200	0.66	0.0002	40226	8.04
5-7							
9-11	10	.001	100	3.55	0.0355	1149	40.80
11-13	10	.001	100	0.58	0.0058	4997	24.99
13-15	10	.00031	200	0.61	0.0019	11493	21.84
15-17	1	.00031	200	2.44	0.0008	22987	18.39
17-19	1	.00031	200	2.76	0.0008	40226	32.18
7-9							
11-13	100	.00031	133	1.77	0.0549	1149	63.06
13-15	10	.00031	166	1.63	0.0050	4997	25.25
15-17	10	.00031	166	0.49	0.0015	11493	17.46
17-19	1	.00031	166	2.45	0.00076	22987	17.46
19-21	1	.00031	166	1.23	0.00038	40226	15.34

TABLE 6. LINE A (CONT.)

LOCATION	PROJECT	DATE
Hot Sulphur Spgs.	Line A	9 July 1981
CHIEF OPERATOR	ASSISTANTS	METHOD
Robert Fargo	Memmi and Strong	Dipole-Dipole (Nx200')

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
9-11							
13-15	10	.001	100	2.52	0.252	1149	28.96
15-17	1	.001	100	4.05	0.0040	4997	20.24
17-19	1	.001	100	1.45	0.00145	11493	16.66
19-21	1	.00031	166	2.33	0.00072	22987	16.60
11-13							
15-17	10	.00031	100	5.04	0.0156	1149	17.96
17-19	10	.00031	133	1.12	0.00347	4997	17.35
19-21	1	.00031	133	3.84	0.00119	11493	13.68
13-15							
17-19	100	.00031	100	0.55	0.0170	1149	19.60
19-21	10	.00031	100	1.12	0.00347	4997	17.35
15-17							
19-21	100	.00031	100	0.55	0.0170	1149	19.60

LEGEND: Range = Gain
MA = Dummy TX Current Switch
Vp = Balance Control to Null Meter
G.F. = Geometric Factor
Pa = Apparent Resistivity
DV/I = Range x MA x Vp

APPENDIX F. RESISTIVITY CALCULATIONS

TABLE 7. LINE B.

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Hot Sulphur Spgs.	Line B	10 July 1981
CHIEF OPERATOR	ASSISTANTS	METHOD
Robert Fargo	Memmi and Strong	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
11-10							
9-8	10	.01	66	0.77	0.077	575	44.25
8-7	1	.01		2.30	0.0230	2299	52.87
7-6	10	.001	100	0.98	0.0098	5747	51.72
6-5	10	.001		0.52	0.0054	11493	62.06
5-4	1	.001		2.38	0.00238	20113	47.87
4-3	1	.001		2.24	0.00224	32181	72.09
3-2	1	.001		1.30	0.00130	47698	62.01
10-9							
8-7	100	.001	66	0.62	0.062	575	35.63
7-6	10	.001	66	1.75	0.0175	2299	40.23
6-5	10	.001	66	0.82	0.0082	5747	47.12
5-4	1	.001	66	3.54	0.00354	11493	40.69
4-3	1	.001	66	3.01	0.00301	20113	60.54
3-2	1	.001	66	1.71	0.00171	32182	55.03
2-1	1	.001	66	0.68	0.00068	47698	32.42
9-8							
7-6	100	.001	66	0.68	0.0680	575	39.08
6-5	10	.001		2.40	0.0240	2299	55.17
5-4	10	.001		0.87	0.0087	5747	50.00
4-3	10	.001		0.70	0.0070	11493	80.45
3-2	10	.001		0.41	0.00415	20113	82.46
2-1	1	.001		1.46	0.00146	32182	46.98
8-7							
6-5	100	.001	66	0.66	0.066	575	37.93
5-4	10	.001		1.47	0.0147	2299	33.79
4-3	10	.001		1.05	0.0105	5747	60.34
3-2	10	.001		0.55	0.0055	11493	63.21
2-1	1	.001		2.02	0.0020	20113	40.63

TABLE 7. LINE B (CONT.)

LOCATION	PROJECT	DATE
Hot Sulphur Spgs.	Line B	10 July 1981
CHIEF OPERATOR	ASSISTANTS	METHOD
Robert Fargo	Memmi and Strong	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
7-6							
5-4	100	.001	66	0.41	0.041	575	23.56
4-3	10	.001		1.79	0.0179	2299	41.15
3-2	10	.001		0.82	0.0082	5747	47.12
2-1	1	.001		2.85	0.00285	11493	32.76
6-5							
4-3	100	.001	66	0.98	0.50	575	28.73
3-2	10	.001		1.49	0.0149	2299	34.25
2-1	10	.001		0.46	0.0046	5747	26.43
5-4							
3-2	10	.001	100	3.67	0.367	575	21.09
2-1	10	.001		0.84	0.0084	2299	19.31
4-3							
2-1	100	.001	100	0.67	0.067	575	38.50

LEGEND: Range = Gain
MA = Dummy TX Current Switch
Vp = Balance Control to Null Meter
G.F. = Geometric Factor
Pa = Apparent Resistivity
DV/I = Range x MA x Vp

APPENDIX F. RESISTIVITY CALCULATIONS

TABLE 8. LINE C.

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Hot Sulphur Spgs	Line C	13 July 1981
CHIEF OPERATOR	ASSISTANTS	METHOD
Robert Fargo	Memmi and Strong	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
1-2							
3-4	100	.001	133	1.99	0.1990	575	114.36
4-5	10	.001		3.31	0.0331	2299	76.09
5-6	10	.001		1.65	0.0165	5747	94.82
6-7	10	.001		0.73	0.0073	11493	83.90
7-8	10	.001	166	0.35	0.0035	20113	70.40
8-9	10	.001		0.29	0.0029	32181	93.33
9-10	1	.001		1.72	0.00172	47698	82.04
2-3							
4-5	100	.001	133	1.92	0.1925	574	110.34
5-6	100	.001		0.76	0.0765	2299	174.70
6-7	10	.001		2.95	0.0295	5747	169.53
7-8	10	.001		1.25	0.0125	11493	143.67
8-9	10	.001		0.90	0.0090	20113	181.02
9-10	10	.001	133	0.55	0.0550	32181.	177.00
10-11	1	.001		3.71	0.00371	47698	176.96
3-4							
5-6	100	.001	166	1.16	0.116	575	66.66
6-7	10	.001		3.15	0.0315	2299	72.41
7-8	10	.001	200	1.16	0.0116	5747	66.66
8-9	10	.001		0.83	0.0083	11493	95.39
9-10	10	.001		0.52	0.0052	20113	104.59
10-11	10	.001		0.31	0.0031	32182	99.76
11-12	10	.001		0.15*	0.0015	47697	71.55
4-5							
6-7	100	.001	166	0.88	0.088	575	50.57
7-8	10	.001		1.86	0.0186	2299	42.75
8-9	10	.001		1.06	0.0106	5747	60.91
9-10	10	.001		0.68	0.0068	11493	78.15
10-11	10	.001		0.40	0.0040	20113	80.45
11-12	10	.001	166	0.20	0.0020	32182	64.36

TABLE 8. LINE C (CONT.)

LOCATION	PROJECT	DATE
Hot Sulphur Spgs	Line C	13 July 1981
CHIEF OPERATOR	ASSISTANTS	METHOD
Robert Fargo	Memmi and Strong	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
5-6							
7-8	100	.001	133	0.55	0.055	575	31.61
8-9	10	.001		2.21	0.0221	2299	50.80
9-10	10	.001		1.20	0.0120	5747	68.96
10-11	10	.001		0.69	0.0069	11493	79.30
11-12	10	.001		0.30	0.0030	20113	60.34
6-7							
8-9	100	.001	133	0.61	0.0610	575	35.05
9-10	10	.001		2.16	0.0216	2299	49.65
10-11	10	.001		1.08	0.0108	5747	62.06
11-12	10	.001		0.47	0.0047	11493	54.02
7-8							
9-10	100	.001	100	0.56	0.0560	575	32.18
10-11	10	.001		1.80	0.0180	2299	41.38
11-12	10	.001		0.81	0.0081	5747	46.55
8-9							
10-11	100	.001		0.75	0.075	575	43.10
11-12	10	.001	100	2.11	0.0211	2299	48.50
9-10							
11-12	100	.001	100	0.71	0.071	575	40.80

LEGEND:

Range = Gain
MA = Dummy TX Current Switch
Vp = Balance Control to Null Meter
G.F. = Geometric Factor
Pa = Apparent Resistivity
DV/I = Range X MA x Vp

APPENDIX F. RESISTIVITY CALCULATIONS

TABLE 9. LINE D

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Hot Sulphur Spgs	Line D	14 July 1981
CHIEF OPERATOR	ASSISTANTS	METHOD
Robert Fargo	Memmi and Strong	Dipole-Dipole (Nx200')

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
1-3							
5-7	100	.001	66	0.39	0..039	1149	44.82
7-9	10	.001		0.75	0.0075	4997	37.48
9-11	10	.001		0.48	0.0048	1 493	55.17
11-13	10	.001		1.52	0.00152	22986	34.94
13-15	1	.00031	133	1.52	0.00047	40226	18.95
3-5							
7-9	10	.001	66	2.35	0.0235	1149	27.01
9-11	10	.001		0.07	0.0107	4997	53.47
11-13	10	.00031	100	0.98	0.00304	11493	34.94
13-15	1	.00031	100	2.51	0.00075	22986	17.31
15-17	1	.00031		1.28	0.00040	40226	15.97
5-7							
9-11	10	.001	66	3.65	0.0365	1149	41.95
11-13	10	.001		0.74	0.0074	4997	36.98
13-15	1	.001		1.62	0.00162	11493	18.62
15-17	1	.00031	100	2.60	0.00081	22986	18.53
17-19	1	.00031		1.56	0.00048	40226	19.47
7-9							
11-13	10	.001	100	1.65	0.0165	1149	18.96
13-15	1	.001		2.69	0.0027	4997	13.44
15-17	1	.00031	166	3.65	0.001135	11493	13.04
17-19	1	.00031	200	1.95	0.000605	22986	13.91
19-21	1	.00031		1.23	0.000381	40226	15.33
9-11							
13-15	10	.001	100	1.53	0.0153	1149	17.58
15-17	10	.001		0.41	0.0041	4997	20.49
17-19	1	.001		1.91	0.00191	11493	21.95
19-21	1	.00031	200	3.21	0.00100	22986	22.87
21-23	1	.00031		1.77	0.000549	40226	22.08

TABLE 9. LINE D (CONT.)

LOCATION	PROJECT	DATE
Hot Sulphur Spgs	Line D	14 July 1981
CHIEF OPERATOR	ASSISTANTS	METHOD
Robert Fargo	Memmi and Strong	Dipole-Dipole (Nx200')

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
11-13							
15-17	10	.001		1.45	0.0145	1149	16.66
17-19	10	.001		0.45	0.0045	4997	22.49
19-21	1	.001		1.94	0.00195	11493	22.41
21-23	1	.00031	200	2.88	0.000893	22986	20.53
13-15							
17-19	10	.001	66	1.63	0.0163	1149	18.73
19-21	10	.001		0.47	0.0047	4997	23.49
21-23	1	.001	66	1.52	0.00152	11493	17.47
15-17							
19-21	10	.001	66	2.17	0.0217	1149	24.94
21-23	10	.001		0.40	0.0040	4997	19.99
17-19							
21-23	10	.001	66	1.63	0.0163	1149	18.73

LEGEND: Range = Gain
MA = Dummy TX Current Switch
Vp = Balance Control to Null Meter
G.F. = Geometric Factor
Pa = Apparent Resistivity
DV/I = Range x MA x Vp

APPENDIX F. RESISTIVITY CALCULATIONS

TABLE 10. LINE E.

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Hot Sulphur Spgs	Line E	15 July 1981
CHIEF OPERATOR	ASSISTANTS	METHOD
Robert Fargo	Memmi and Strong	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage	V_P	DV/I	G.F.	P_a
5-6							
7-8	100	.001	200	0.66	0.066	574	38.13
8-9	10	.001		1.24	0.0124	2298	28.50
9-10	10	.001		0.44	0.0044	5746	25.29
10-11	1	.001		2.03	0.00203	20113	18.91
11-12	1	.001		0.94	0.00094	20113	18.91
12-13	1	.001		0.48	0.00048	32181	15.13
6-7							
8-9	10	.001	133	4.92	0.0492	574	28.27
9-10	10	.001		0.87	0.0087	2298	20.00
10-11	10	.001		0.37	0.0037	5746	21.26
11-12	1	.001		0.93	0.00093	11493	10.69
12-13	1	.001		0.94	0.00094	20113	18.91
13-14	1	.001		0.47	0.00047	32181	15.13
7-8							
9-10	100	.001	100	0.57	0.057	574	32.76
10-11	10	.001		1.04	0.0104	2298	23.91
11-12	10	.001		0.41	0.0041	5746	23.56
12-13	10	.001		0.49	0.0049	11493	56.32
13-14	10	.00031	200	3.22	0.000998	20113	20.07
8-9							
10-11	10	.001	66	5.28	0.0528	575	30.34
11-12	10	.001		1.00	0.0100	2299	22.99
12-13	10	.001		0.34	0.0034	5747	19.54
13-14	1	.001	66	1.67	0.00167	11493	19.19
14-15	10	.00031	133	0.30	0.00093	20113	18.71
15-16	1	.00031		1.57	0.00487	32181	15.67

TABLE 10. LINE E. (CONT.)

LOCATION	PROJECT	DATE
Hot Sulphur Spgs	Line E	15 July 1981
CHIEF OPERATOR	ASSISTANTS	METHOD
Robert Fargo	Memmi and Strong	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage	V_P	DV/I	G.F.	P_a
9-10							
11-12	10	.001	100	4.47	0.0447	575	25.69
12-13	10	.001		0.89	0.0089	2299	20.46
13-14	10	.001		3.28	0.00328	5747	18.85
14-15	10	.001		1.73	0.00173	11493	19.88
15-16	1	.001		0.75	0.00075	20113	15.09
10-11							
12-13	10	.001	133	4.74	0.0474	575	27.24
13-14	10	.001	133	0.96	0.0096	2299	22.07
14-15	10	.001	133	0.44	0.0044	5747	25.28
15-16	1	.001	133	1.56	0.00156	11493	17.93
11-12							
13-14	100	.001	100	0.44	0.044	575	25.28
14-15	10	.001		1.05	0.0105	2299	24.14
15-16	10	.001		0.35	0.0035	5747	20.11
12-13							
14-15	100	.001	100	0.53	0.053	575	30.46
15-16	10	.001		0.86	0.0086	2299	19.77
13-14							
15-16	100	.001	100	0.50	0.050	575	28.73

LEGEND: Range = Gain
MA = Dummy TX Current Switch
Vp = Balance Control to Null Meter
G.F. = Geometric Factor
Pa = Apparent Resistivity
DV/I = Range x MA x Vp

APPENDIX F. RESISTIVITY CALCULATIONS

TABLE 11. LINE F.

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Hot Sulphur Spgs	Line F	16 July 1981
CHIEF OPERATOR	ASSISTANTS	METHOD
Robert Fargo	Memmi and Strong	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage	V_P	DV/I	G.F.	P_a
1-2							
3-4	1,000	.001	100	0.511	0.51	574	293.01
4-5	10	.001		3.71	0.0371	2298	85.26
5-6	10	.001		1.08	0.0108	5745	62.05
6-7	1	.001		3.44	0.00344	11491	39.53
7-8	1	.001		1.44	0.00144	20109	28.96
8-9	1	.001		0.67	0.00067	32174	21.56
2-3							
4-5	100	.001	133	1.40	0.140	574	80.43
5-6	10	.001		2.11	0.0211	2298	48.49
6-7	10	.001		0.54	0.0054	5746	31.02
7-8	1	.001		1.94	0.00194	11491	22.29
8-9	1	.001	133	0.84	0.00084	20109	16.89
9-10	1	.001		0.41	0.00041	32174	13.19
3-4							
5-6	100	.001	133	2.26	0.226	574	129.93
6-7	10	.001		3.82	0.0382	2298	87.79
7-8	10	.001		1.09	0.0109	5746	62.62
8-9	10	.001		0.39	0.0039	11491	44.81
9-10	1	.001		1.82	0.00182	20119	36.60
10-11	1	.001		1.54	0.00154	32174	49.55
4-5							
6-7	100	.001	100	1.20	0.120	575	68.94
7-8	10	.001		2.44	0.0244	2299	56.07
8-9	10	.001		0.73	0.0073	5747	41.94
9-10	1	.001		3.10	0.00310	11491	35.62
10-11	1	.001	100	2.43	0.00243	20109	48.96
11-12	10	.00031	200	0.57	0.00171	32174	55.02

TABLE 11. LINE F. (CONT.)

LOCATION	PROJECT	DATE
Hot Sulphur Spgs	Line F	16 July 1981
CHIEF OPERATOR	ASSISTANTS	METHOD
Robert Fargo	Memmi and Strong	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
5-6							
7-8	100	.001	66	1.57	0.157	575	86.75
8-9	10	.001		2.73	0.0273	2299	62.74
9-10	10	.001		0.88	0.0088	5747	50.56
10-11	10	.001		0.60	0.0060	11491	68.94
11-12	10	.001		0.38	0.00385	20109	76.41
6-7							
8-9	100	.001	100	0.88	0.088	575	50.56
9-10	10	.001		1.92	0.0192	2299	44.12
10-11	10	.001		1.01	0.0101	5747	58.03
11-12	10	.001		0.55	0.0055	11491	63.20
7-8							
9-10	100	.001	100	0.49	0.049	575	28.15
10-11	10	.001		1.71	0.0171	2299	39.30
11-12	10	.001		0.76	0.0076	5747	43.66
8-9							
10-11	10	.001	100	3.80	0.038	575	21.83
11-12	10	.001		1.07	0.0107	2299	24.59
9-10							
11-12	10	.001	133	3.56	0.0356	575	20.45

LEGEND: Range = Gain
MA = Dummy TX Current Switch
Vp = Balance Control to Null Meter
G.F. = Geometric Factor
Pa = Apparent Resistivity
DV/I = Range x MA x Vp

Special Pub. 10, HYDROGEOLOGICAL AND GEOTHERMAL INVESTIGATIONS OF PAGOSA SPRINGS, COLORADO, by M.A. Galloway WITH A SECTION ON MINERALOGICAL AND PETROGRAPHIC INVESTIGATIONS OF SAMPLES FROM GEOTHERMAL WELLS O-1 AND P-1, PAGOSA SPRINGS, COLORADO, by W.W. Atkinson, 1980, 95 p. $10.00

Special Pub. 16, GEOTHERMAL RESOURCE ASSESSMENT OF WAUNITA HOT SPRINGS, COLORADO, ed. by T. G. Zacharakis, 1981, 69 p., Free over the counter.

Special Pub. 18, GROUNDWATER HEAT PUMPS IN COLORADO, AN EFFICIENT AND COST EFFECTIVE WAY TO HEAT AND COOL YOUR HOME, by K.L. Garing and F.R. Connor, 1981, 32 p., Free over the counter.

Map Series 14, GEOTHERMAL RESOURCES OF COLORADO, by R.H. Pearl, Scale 1:500,000, Free over the counter.

Map Series 18, REVISED HEAT FLOW MAP OF COLORADO, by T.G. Zacharakis, Scale 1:1,000,000, Free over the counter.

Map Series 20, GEOTHERMAL GRADIENT MAP OF COLORADO, by F.N. Repplier and R.L. Fargo, 1981, Scale 1: 1,000,000, Free over the counter.

Info. Series 4, MAP SHOWING THERMAL SPRINGS, WELLS, AND HEAT FLOW CONTOURS IN COLORADO, by J.K. Barrett, R.H. Pearl and A.J. Pennington, 1976, Scale 1:1,000,000, out of print.

Info. Series 6, HYDROGEOLOGICAL DATA OF THERMAL SPRINGS AND WELLS IN COLORADO, by J.K. Barrett and R.H. Pearl, 1976, 124 p. $4.00

Info. Series 9, GEOTHERMAL ENERGY DEVELOPMENT IN COLORADO, PROCESSES, PROMISES AND PROBLEMS, by B.A. Coe, 1978, 51 p., $3.00

Info. Series 15, REGULATION OF GEOTHERMAL ENERGY DEVELOPMENT IN COLORADO, by B.A. Coe and N.A. Forman, 1980, Free over the counter.

Open-File Report 80-10, GEOTHERMAL POTENTIAL IN CHAFFEE COUNTY, COLORADO, by. F.C. Healy, 47 p., Free over the counter.

Open-File Report 80-11, COMMUNITY DEVELOPMENT OF GEOTHERMAL ENERGY IN PAGOSA SPRINGS, COLORADO, by B.A. Coe, 1980, Free over the counter.

Open-File Report 80-12, TEMPERATURE-DEPTH PROFILES IN THE SAN LUIS VALLEY AND CANON CITY AREA, COLORADO, by C.D. Ringrose, Free over the counter.

Open-File Report 80-13, GEOTHERMAL ENERGY POTENTIAL IN THE SAN LUIS VALLEY, COLORADO, by B.A. Coe, 1980, 44 p., Free over the counter.

Open-File Report 81-2, GEOTHERMAL ENERGY OPPORTUNITIES AT FOUR COLORADO TOWNS, by B.A. Coe and Judy Zimmerman, 1981, Free over the counter.

Open-File Report 81-3, APPENDICES OF AN APPRAISAL FOR THE USE OF GEOTHERMAL ENERGY IN STATE-OWNED BUILDINGS IN COLORADO: SECTION A, Alamosa; SECTION B, BUENA VISTA; SECTION C, BURLINGTON: SECTION D, DURANGO; SECTION E, GLENWOOD SPRINGS; SECTION F, STEAMBOAT SPRINGS, 1981, $1.50 each or $8.00 for the set.

Pamphlet, GEOTHERMAL ENERGY-COLORADO'S UNTAPPED RESOURCE, Free over the counter.

In addition to the above charges there is an additional charge for all mail orders. Contact the Colorado Geol. Survey for exact amount. To order publications specify series and number, title and quantity desired. Prepayment is required. Make Checks payable to: Colorado Geological Survey, Rm. 715, 1313 Sherman St., Denver, Colorado 80203 (303/866-2611).

GEOTHERMAL ENERGY PUBLICATIONS

Following is a list of publications relating to the geothermal energy resources of Colorado published by the Colorado Geological Survey.

Bull. 11, MINERAL WATERS OF COLORADO, by R.D. George and others, 1920, 474 p., out of print.

Bull. 35, SUMMARY OF GEOLOGY OF COLORADO RELATED TO GEOTHERMAL ENERGY POTENTIAL, PROCEEDINGS OF A SYMPOSIUM ON GEOTHERMAL ENERGY AND COLORADO, ed. by R.H. Pearl, 1974, $3.00

Bull. 39, AN APPRAISAL OF COLORADO'S GEOTHERMAL RESOURCES, by J.K. Barrett and R.H. Pearl, 1978, 224 p., $7.00

Bull. 44, BIBLIOGRAPHY OF GEOTHERMAL REPORTS IN COLORADO, by R.H. Pearl, T.G. Zacharakis, F.N. Repplier and K.P. McCarthy, 1981, 24 p., $2.00.

Resource Ser. 6, COLORADO'S HYDROTHERMAL RESOURCE BASE--AN ASSESSMENT, by R.H. Pearl, 1979, 144 p., $2.00.

Resource Ser. 14, AN APPRAISAL FOR THE USE OF GEOTHERMAL ENERGY IN STATE OWNED BUILDINGS IN COLORADO, by R.T. Meyer, B.A. Coe and J.D. Dick, 1981, 63 p., $5.00.

Resource Ser. 15, GEOTHERMAL RESOURCE ASSESSMENT OF OURAY, COLORADO, by T.G. Zacharakis, C.D. Ringrose and R.H. Pearl, 1981, 70 p., Free over the counter.

Resource Ser. 16, GEOTHERMAL RESOURCE ASSESSMENT OF IDAHO SPRINGS, COLORADO. by F.N. Repplier, T.G. Zacharakis, and C.D. Ringrose, 1982, Free over the counter.

Resource Ser. 17, GEOTHERMAL RESOURCE ASSESSMENT OF THE ANIMAS VALLEY, COLORADO, by K.P. McCarthy, T.G. Zacharakis and C.D. Ringrose, 1982, Free over the counter.

Resource Ser. 18, GEOTHERMAL RESOURCE ASSESSMENT OF HARTSEL, COLORADO, by K.P. McCarthy, T.G. Zacharakis, and R.H. Pearl, 1982, Free over the counter.

Resource Ser. 19, GEOTHERMAL RESOURCE ASSESSMENT OF WESTERN SAN LUIS VALLEY, by T.G. Zahcarakis, R.H. Pearl and C.D. Ringrose, 1982, Free over the counter.

Resource Ser. 20, GEOTHERMAL RESOURCE ASSESSMENT OF CANON CITY AREA, COLORADO, BY T.G. Zacharakis and R.H. Pearl, 1982, Free over the counter.

Resource Ser. 22, GEOTHERMAL RESOURCE ASSESSMENT OF STEAMBOAT SPRINGS AREA, COLORADO, by R.H. Pearl, T.G. Zacharakis and C.D. Ringrose, 1982, Free over the counter.

Resource Ser. 23, GEOTHERMAL RESOURCE ASSESSMENT OF HOT SULPHUR SPRINGS, COLORADO, by R.H. Pearl, T.G. Zacharkis and C.D. Ringrose 1982, Free over the counter.

Resource Ser. 24, GEOTHERMAL RESOURCE ASSESSMENT OF RANGER HOT SPRINGS, COLORADO, by T.G. Zacharakis and R.H. Pearl, 1982, Free over the counter.

Special Pub. 2, GEOTHERMAL RESOURCES OF COLORADO, by R.H. Pearl, 1972, 54 p. $2.00.

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