RESOURCE SERIES 22
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Geothermal Resource Assessment of the Steamboat-Routt Hot Springs Area, Colorado

by
Richard Howard Pearl
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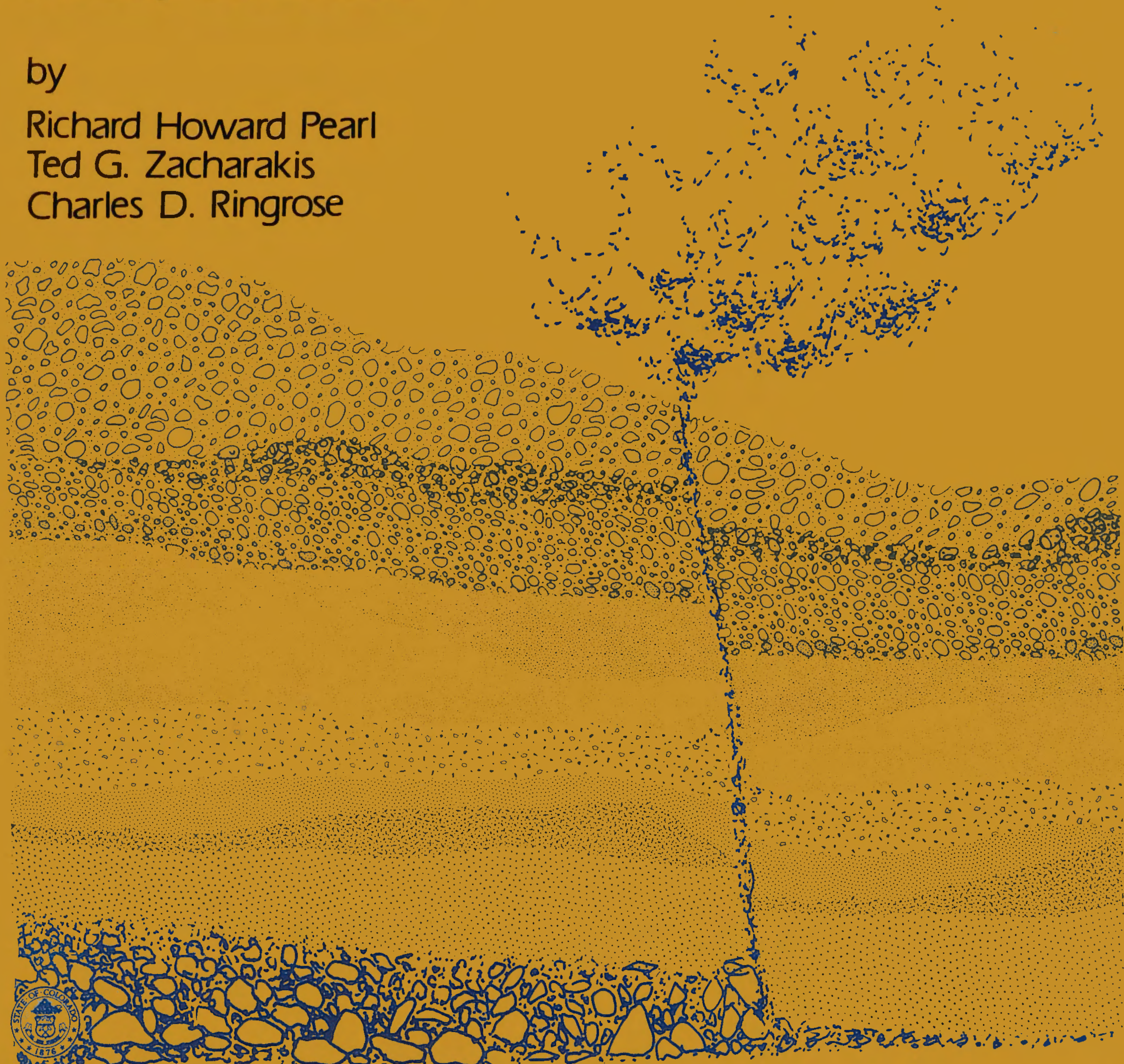

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NOTICE

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GEOTHERMAL RESOURCE ASSESSMENT OF THE STEAMBOAT-ROUTT HOT SPRINGS AREA, COLORADO

by

Richard Howard Pearl, Ted G. Zacharakis, and Charles D. Ringrose

ABSTRACT

As part of a state wide assessment program of those geothermal areas in Colorado believed to have a high potential for near term development, an assessment of the Steamboat Springs region in northwest Colorado was initiated and carried out in 1980 and 1981. The goal of this program was to delineate the geological features controlling the occurrence of the thermal waters (temperatues in excess of 68°F (20°C)) in this area at Steamboat Springs and 8 miles (12.8 km) north at Routt Hot Springs. Thermal waters from Heart Spring, the only developed thermal water source in the study area, are used in the municipal swimming pool in Steamboat Springs.

The assessment program was a fully integrated program consisting of: dipole-dipole, Audio-magnetotelluric, telluric, self potential and gravity geophysical surveys, soil mercury and soil helium geochemical surveys; shallow temperature measurements; and preparation of geological maps.

The investigation showed that all the thermal springs appear to be fault controlled. Based on the chemical composition of the thermal waters it appears that Heart Spring in Steamboat Springs is hydrologically related to the Routt Hot Springs. This relationship was further confirmed when it was reported that thermal waters were encountered during the construction of the new high school in Strawberry Park on the north side of Steamboat Springs. In addition, residents stated that Strawberry Park appears to be warmer than the surrounding country side. Geological mapping has determined that a major fault extends from the Routt Hot Springs area into Strawberry Park.

Based on presently available data, it is estimated that the Steamboat Springs system could have an areal extent of .52 sq. miles (.84 sq. Km) and contain .0487 Q's of heat energy. It was shown that the Routt Hot Springs system's minimum extent could be .50-.75 sq mi (.8-1.2 sq Km) and contain .1663 Q's of heat energy. For purposes of calculation it was not assumed that the two systems are hydrologically connected. If they are, then the estimates given are minimum estimates.

INTRODUCTION

In 1977, the Colorado Geological Survey in cooperation with the U.S. Department of Energy, Division of Geothermal Energy, under Contract No. DE-AS07-77-28365, initiated a program designed to determine the nature and extent of Colorado's geothermal resources. Priority was given to those areas with the greatest potential for near-term development 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 the Steamboat Springs-Routt Hot Springs area of northwestern Colorado. This publication reports the findings of the resource assessment program carried out in the Steamboat-Routt Hot Springs area in northwest Colorado. The evaluation program carried out consisted of a literature search, reconnaissance geologic and hydrogeologic mapping, electrical resistivity surveys, soil mercury and helium surveys, and a shallow temperature survey.

Steamboat Springs, a community of approximately 5,100 persons, is located along the Yampa River 170 miles northwest of Denver (Fig. 1). It is a growing community and is the trading and economic center for the surrounding region. Principal industries of the area are tourism and ranching. The internationally famous Steamboat Springs Ski Area is located south of the town.

While no local interest was expressed in 1980 for the development of the hydrothermal resources of the area, it was decided to undertake a full scale resource evaluation program of the region due to the increasing energy needs of the area. In years to come it is anticipated that alternative sources of energy such as geothermal energy will come to be an important local source of energy. Geothermal energy, the natural heat of the earth, normally is either too diffuse or found at such great depths to be of practical value. However, in some instances it occurs close to the surface, where it does it can be developed and put to practical use. A brief description of geothermal energy and some of the uses it can be put to are presented in Appendix A.

Located within the city limits of Steamboat Springs are three springs whose temperatures are above 68°F (20°C) and as such can be considered thermal (Fig. 2). In addition there are a number of other springs whose temperatures are just below 68°F. These springs are found in two distinct groups. The hottest spring, Heart Spring, located at the southeast end of town is the only spring in town which has been developed. The waters are used in the community swimming pool.

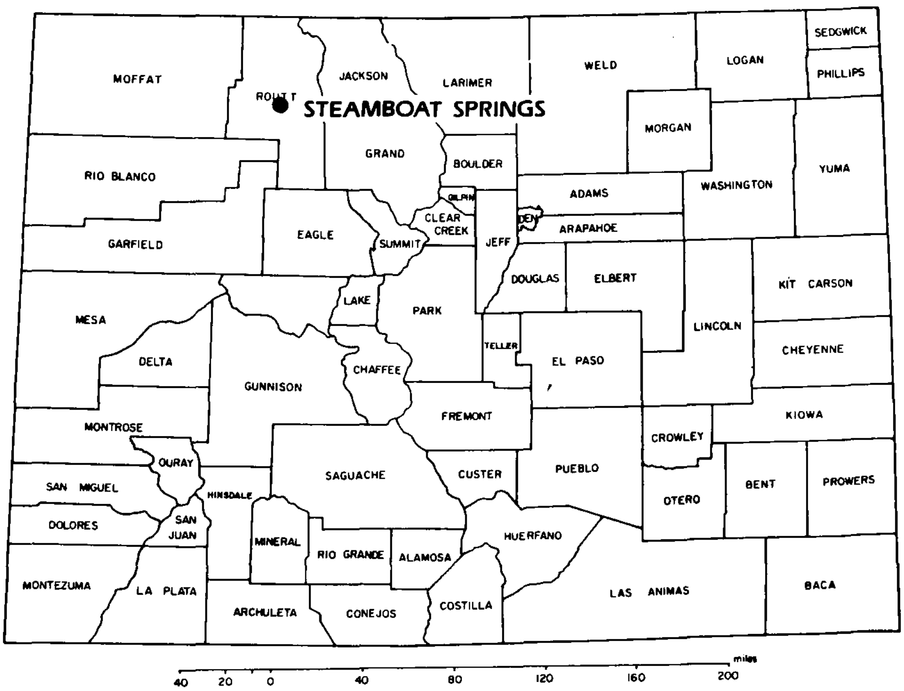


Figure 1. Index map of Colorado

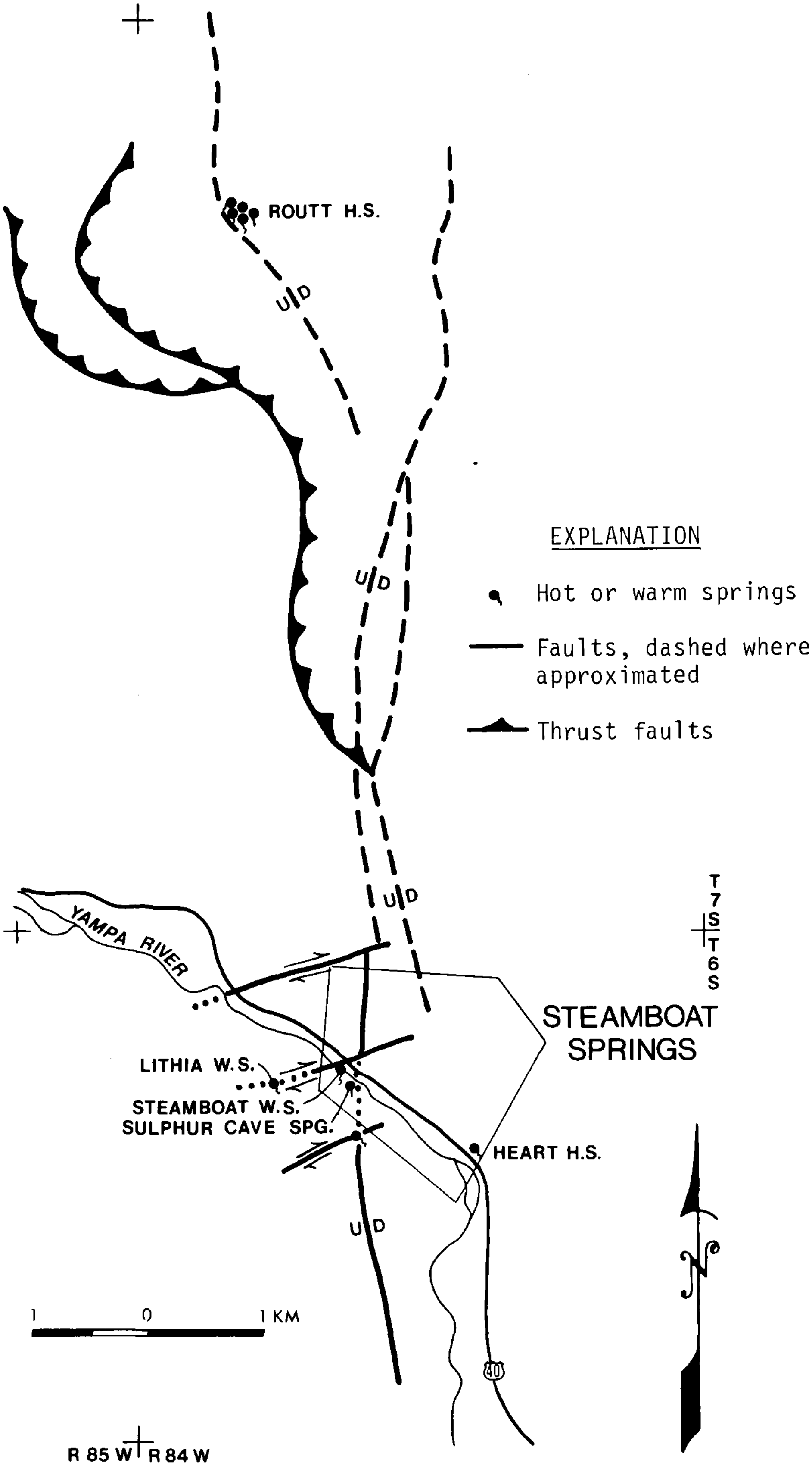


Figure 2. Map of Steamboat-Routt Hot Springs showing location of thermal springs. (Adopted from Christopherson, 1979).

At the northwest end of town there are two thermal springs and several cold springs distributed over a wide area. A large travertine mound known as the Sulphur Cave Spring (Fig. 2) is located approximately 80 ft (24.38 m) above the Yampa River northwest of the Howelsen Hill Ski Jump and approximately 0.75 mi (1.2 km) west, northwest of the Heart Spring. Another thermal spring located approximately 1,600 ft (488 m) northeast of the Sulphur Cave Spring is the original Steamboat Spring. This spring is just south of the bridge across the Yampa River next to the Denver and Rio Grande Railroad tracks (Figs 3).

Located in the City Park across U.S. Highway 40, north of the Steamboat Springs are a group of cold springs. As the temperature of these springs is below 68°F (20°C) they are not considered thermal and will not be discussed here.

A group of thermal springs known as the Routt Hot Springs (Fig. 2) or Strawberry Park Springs, are located approximately 8 miles (12.8 km) north of Steamboat Springs along Hot Springs Creek. At the time the field investigations for this report were being conducted these springs were undeveloped and were used for "skinny dipping". Since that time the springs have been sold and the new owner plans some type of commercial development around them.

Readers interested in the non-geologic history of the region are referred to Cahill (1982).

Figure 3. Photo of Steamboat and Sulphur Cave Warm Springs. View to the southwest from Colorado Alpine College. "A" Steamboat Warm Spring, "B" Sulphur Cave Warm Spring and small northeast trending fault.

THERMAL CONDITIONS OF THE STEAMBOAT-ROUTT HOT SPRINGS AREA

Thermal Waters

The thermal waters of the study area are found in two distinct groups. One group is within the city of Steamboat Springs and the other is approximately 8 miles (12.9 km) north along Hot Springs Creek. The northern group of springs--Routt Hot Springs--are the hottest, with the temperatures ranging from 124°F (51°C) to a high of 147°F (64°C). The temperature of the springs found within Steamboat Springs ranges from a low of 68°F (20°C) to a high of 102°F(39°C) (Barrett and Pearl, 1978). A complete description of the thermal waters of the Steamboat-Routt Hot Springs area is presented in Appendix B.

Heat Flow

No heat flow or gradient holes have been drilled in the study area. Based on regional data the heat-flow in the Steamboat-Routt Hot Springs thermal area is about 80 mw/m2, below the state wide average of 100 mw/m2 (Fig. 4). The geothermal gradient of the area, based on regional data and one well ranges between 1.9°F/100 ft to 2.6°F/100 ft (35°C/km to 47°C/km)(Christopherson, 1979, and Fargo and Repplier, 1981).

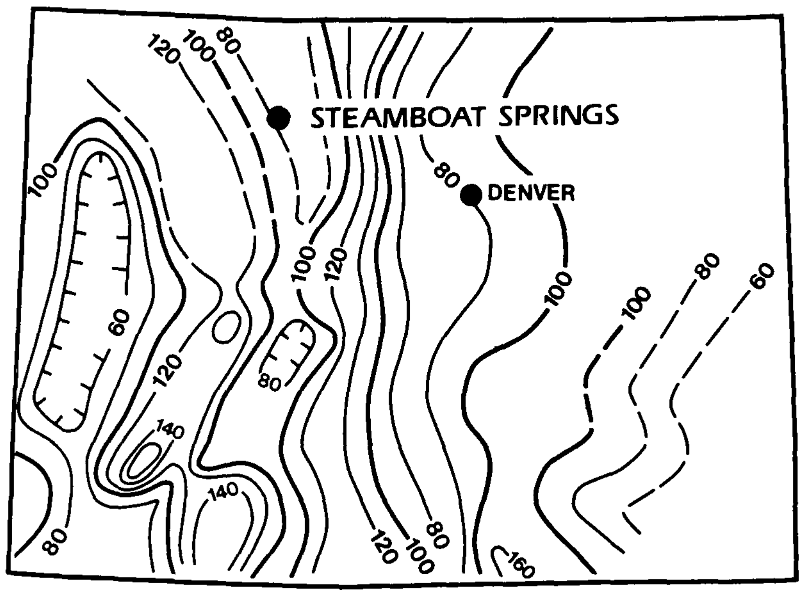


Figure 4. Heat flow map of Colorado.
(Adopted from Zacharakis, 1981).

While high heat-flow has not been measured in the Steamboat Springs region this does not mean that it may not exist. Decker and others (1981) have completed a regional study of the geothermal resource potential of northern Colorado and southern Wyoming through the use of heat flow, radioactivity, and gravity measurements. This study showed that the surface and reduced heat flow in the southern rockies in Wyoming is low to normal, while that in in North and Middle Parks of northern Colorado is high. They (Decker and others, 1981) noted that this high heat-flow might not be restricted to a simple north-south trending zone but could exist through much of northcentral and northwestern Colorado. Their conclusions were based on the following evidence: Young (<2 million year old) igneous rocks are found through out the western and central parts of western Colorado in Basalt Mountain-Flat Tops-State Bridge area south of the study area; Late Miocene age volcanics rocks are found in the Elkhead Field, northwest of Steamboat Springs; and high heat flow at Hahn's Peak northwest of Steamboat Springs.

Warm Areas

During the course of this investigation, the authors became aware that the area north of Steamboat Springs, known as Strawberry Park, appears to be warmer than the surrounding region and may contain undiscovered thermal resources. According to citizens of the area, snow does not remain long in this area and crops can be grown earlier in the spring. Prior to this investigation no thermal waters had been reported in this area. As will be noted later (see hydrology section), thermal waters were encountered during construction of the new high school located in Strawberry Park. In addition, a major north-south fault which extends from the vicinity of the Routt Hot Springs to possibly Heart Spring passes through the west side of this area. All the above evidence tends to indicate that the area warrents further investigation in the future.

GEOLOGY

Introduction

The Steamboat Springs-Routt Hot Springs area is located on the west side of the north trending Park Range. The Park Range, a large anticlinal structure, is part of a more or less continuous mountain chain stretching from Wyoming on the north to New Mexico on the south through the central part of western Colorado. The geological conditions of the region have been discussed and described by: Blackmer (1939); Larson (1955); Miller (1975); and Snyder (1977 and 1980). Tweto (1975 and 1980a&b) has discussed the structural development of Colorado and the Steamboat Springs-Routt Hot Springs area. The following discussion is taken from the above papers.

The Steamboat-Routt Hot Springs area is located on the east side of the Sand Wash Basin and on the west side of the Park Range. Overlying Precambrian age igneous and metamorphic rocks of the Park Range are up to 8,520 ft (2.6 Km) of sedimentary rocks ranging in age from Recent to Permo-Pennsylvania (Fig. 5) that dip into the basin.

The present topography and structure of the area developed throughout late Cretaceous and Cenozioc time. At the beginning of the Laramide Orogeny (late Cretaceous to early Tertiary time) the area, which was near sea level (Tweto, 1975) was uplifted from 2,000 to 3,000 ft (610 to 914 m) and much of the sedimentary rock covering the area were eroded away exposing the Precambrian age igneous and metamorphic rocks in the core of the range. Uplift and erosion continued intermittingly throughout the rest of Cenozoic time raising the area to its present elevation.

Stratigraphy

A brief description of the rock units found in the Steamboat Springs area adated from Christopherson (1979), Snyder (1977, 1980) and Tweto (1976) is presented below.

Quaternary:

Alluvium: Unconsolidated silts, clays, sands, gravels and cobbles found along the courses of the streams and rivers in the study area.

Terrace Gravels: Alluvial gravel, including alluvial fans

Terrace Deposits: Gravels in terraces from 0 to 361 (110 m) above flood plains.

Landslide Depoists: Jumbled rock and soil debris.

Tertiary:

Brown Park Formation: Consolidated and unconsolidated clays to sandstones, and conglomerates, loosely consolidated eolian sandstone with some volcanic ash. Maximum thickness 2,000 ft (610 m).

Cretaceous:

Mancos shale: Gray to dark gray shale with some sandstone units. Up to 2,400 ft (732 m) in thickness.

Niobrara Formation: Blue-gray, calcareous, platy, white-spotted shale. White thick-bedded glauconitic limestone near base. May be more than 1,200 ft (366 m) in thickness.

Benton shale: Black shale. Up to 1,800 ft (549 m) in thickness

Dakota sandstone: Massive, fine grained sandstone, with some interbedded dark shale and shaly sandstone. Forms prominent "hogback" ridge in places. Thickness about 150 ft (46 m).

Jurassic:

Morrison Formation: Variegated green, greenish-gray and maroon shale with some limestone and sandstone lenses, approximately 300 ft (91 m) thick.

Triassic:

Chinle Formation: Brownish- and purplish-red calcareous siltstone, mudstone and sandstone. Limestone-pellet conglomerate in lower part. sandstone member at base. Thickness about 234 ft (71 m).

Chugwater Formation: Red sandy shale, sandstone, siltstone and some greenish gray and yellow shales, approximately 536 ft (163 m) thick.

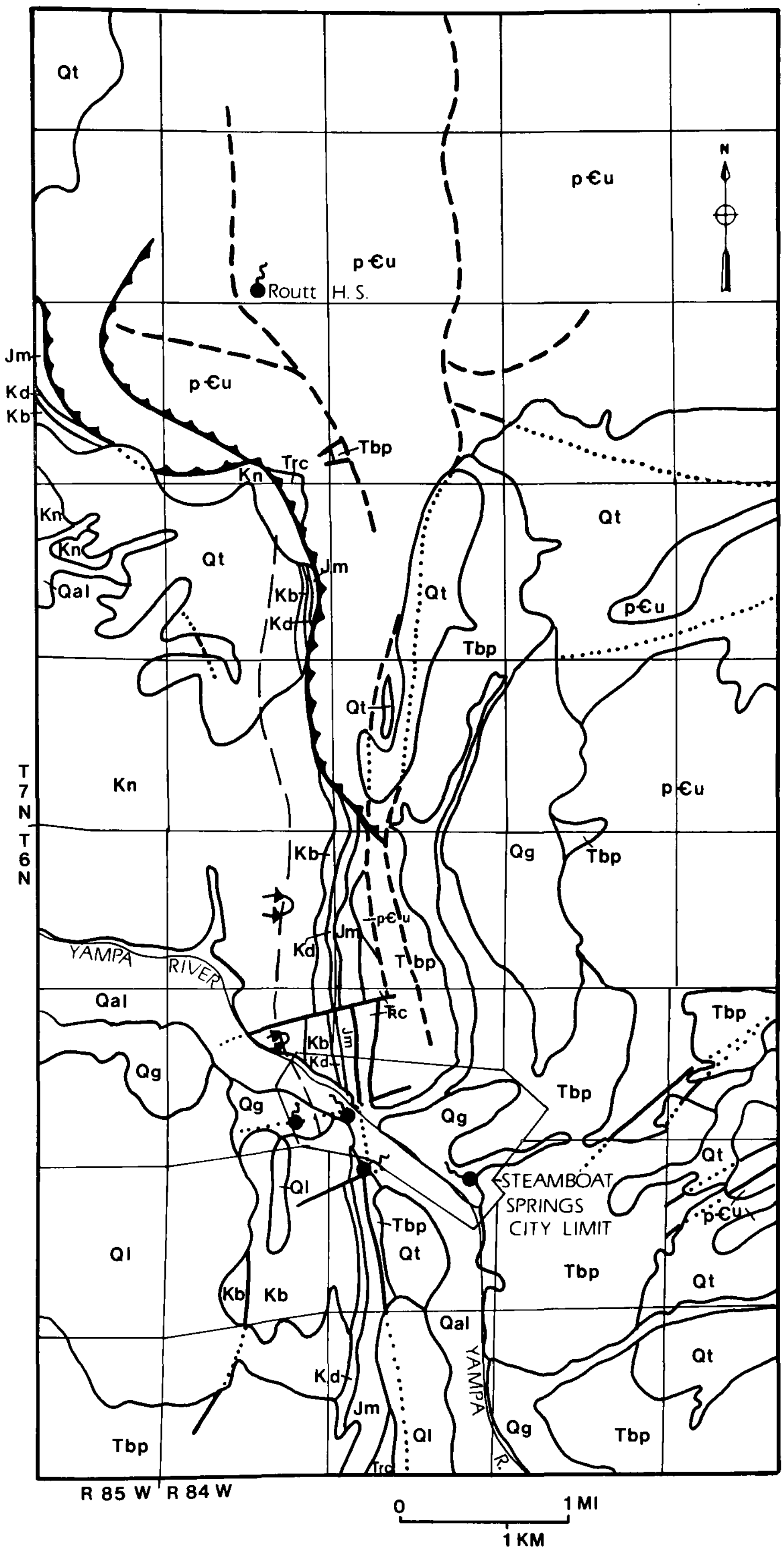
Precambrian:

Complex assemblage of igneous and metamorphic rocks consisting of quartz monzonite, pegmatite dikes, and gneisses.

Structure

There are no major folds in the study area, with the exception of one small syncline just west of Steamboat Springs. Several major north-south faults and one thrust fault are found in the study area (Fig. 5). Precambrian age rocks have been thrust over Jurassic and younger rocks along the thrust fault north of Steamboat Springs (Fig. 5). Tweto (1976) shows the continuous north-south normal fault cutting the area to be part of a fault system that extends for almost 50 miles along the west side of the Park and Gore Ranges. In the Steamboat Springs area, the Browns Park Formation has been downdropped along this fault into contact with the Morrison Formation. Detailed mapping by Snyder (1977 and 1980) has shown shown that in the study area this major north-south fault of Tweto consists of several smaller parallel faults (Fig. 5).

Geological mapping by Snyder (1977 and 1980) showed that the thermal springs on the north side of Steamboat Springs are the only ones directly associated with any faults.



GEOLOGY EXPLANATION FOR FIGURES 5, 10 AND 17

(symbol)	Hot or warm springs
(symbol)	Faults, dashes where approximated
(symbol)	Thrust fault
(symbol)	Geologic contact
Qal	Quaternary alluvium
Qg	Quaternary gravels
Ql	Quaternary landslide deposits
Qt	Quaternary terrace deposits
Tbp	Tertiary Browns Park Formation
Kn	Cretaceous Niobrara Fm.
Kb	Cretaceous Benton Sh.
Kd	Cretaceous Dakota Gp.
Jms	Jurassic Morrison and Sundance Fms., undivided
Ꞧc	Triassic Chinle and Chugwater Fms., undivided
p€u	Precambrian, undivided
Xgn	Precambrian metamorphic rocks
YXp	Precambrian pegmatite
Ya	Precambrian apalite
Yb	Precambrian monzonite

Figure 5. Geologic map of Steamboat Springs area. (Adopted from Christopherson, 1979).

From the geological evidence available it appears that the Routt Hot Springs are fracture controlled. Snyder (1980) in his geological mapping of the area did not locate any major faults in or near the Routt Hot Springs. He did show a north-south trending fault passing just to the west of the Routt Hot Springs, however he did not extend this fault far enough to the south to join with the main north-south normal fault of Tweto. Snyder (1980) showed that in the vicinity of the Routt Hot Springs the strike and dip of the metamorphic schistosity or igneous foliation is highly variable suggesting that the bedrock is highly fractured. Numerous fractures abound in the vicinity of the thermal springs. A north trending chlorite-epidote alteration zone can be found about one-half mile west of the hot springs along Hot Springs Creek.

The small northeast trending faults which cut the Dakota Sandstone in Steamboat Springs, warrant further discussion for they locally have a dramatic affect on the dip of the Dakota sandstone. North of the northeast trending fault which runs through the city park the Dakota Sandstone is overturned and dips to the east. Just a short distance to the south, at the northeast trending fault by the ski jump, the Dakota sandstone has been only slightly deformed and has normal westerly dip (Fig. 5). The thermal springs in this area are associated with these faults, especially the ones in the city park.

Due to cultural features it is not possible to accurately determine the structural conditions in much of Steamboat Springs. However, based on the mapped evidence it appears that the springs are fault controlled. Snyder (1977 and 1980) has shown that several shear zones could intersect in Steamboat Springs. Snyder (1977 & 1980) has mapped numerous faults extending southwest from the Park Range to within a short distance of Steamboat Springs. If these faults were to continue to the southwest they would intersect the north-south trending faults which extend into or pass through Steamboat Springs.

HYDROGEOLOGY OF THE STEAMBOAT-ROUTT THERMAL SYSTEMS

The thermal waters of the Steamboat-Routt Hot Springs area have been discussed and described by: Barrett and Pearl (1976 and 1978); Berry and others (1980); Boettcher (1972); George and others (1920); Lewis (1966); Lowther and Knowles (1910); Mallory and Barnett (1973); Pearl (1972 and 1979); and Waring (1965).

George and others (1920) made the first comprehensive appraisal of the thermal waters of Colorado and the medicinal values associated with them. Those readers interested in the historic treatment of this subject will find this report of immense value. In addition to reporting the chemical composition of the thermal waters, George and others (1920) listed such physical parameters as temperature, location, radioactivity, and location of the spring. Other authors have reported on various aspects of the Steamboat-Routt Hot Springs thermal waters. In 1978 Barrett and Pearl, following up on the work of George and others (1920), reevaluated the thermal waters of Colorado. They (Barrett and Pearl, 1978) relocated the thermal water sources, measured their temperature, pH, and other field parameters, and had a complete modern chemical analysis of the waters made. In addition they tried through the use of geochemical geothermometer models to estimate the subsurface reservoir temperatures. In 1979 Pearl carried this analysis one step futher and presented estimates of the size and extent of the thermal area.

Steamboat Springs

Within Steamboat Springs are three thermal springs (temperatures above 68°F, 20°C), plus a number of cooler springs. From north to south these three springs are: Steamboat Spring; Sulphur Cave Spring; and Heart Spring. The Steamboat Spring has a temperature of 79°F (26°C) and a discharge of 20 gpm. The waters are of a sodium bicarbonate type and contain 6,170 mg/l of dissolved solids. Sulphur Cave Spring has a temperature of 68°F (20°C) and a discharge of 10 gpm. The waters are a sodium bicarbonate type and contain 4,530 mg/l of dissolved mineral matter. Heart Spring, which is the hottest spring in town, with a temperature of 102°F (39°C) and a discharge of 140 gpm contains only 903 mg/l of dissolved solids. The waters are a sodium chloride type. A complete listing of all the minerals found in the thermal waters plus other information is listed in Tables 2-4 in Appendix B. The chemical composition of the Steamboat Springs thermal waters is presented in Fig. 6.

While Steamboat and Sulphur Cave Springs are associated with the Dakota Sandstone (Fig. 5) the waters are probably coming from depth along the nearby northeast trending faults which cut the Dakota Sandstone. No surface evidence can be found for any structural control of Heart Spring. Based on geological mapping by Snyder (1977) it can be hypothesized that Heart Spring is also fault controlled and lies on the southern extension of the north-south normal fault which is shown to terminate a short distance to the north.

In addition to the above thermal springs, during the course of this investigation the authors learned about the existence of other thermal waters in the Steamboat Springs area. Roy Steffen, Colorado Division of Water Resources, reported that in 1981 when the new high school was being built in

Sec. 9, T. 6 N., R. 84 W., along Butherknife Creek in Strawberry Park waters having an measured temperature of 102°F (39°C) were encountered at a depth of 25 ft (7.6 m). Steffen reported that the waters were not analyzed for dissolved minerals but they did not contain the characteristic hydrogen sulfide odor that some of the springs in town have. The authors were also informed about a well located in the SW,NW Sec. 1, NW, T. 6 N., R. 84 W. southeast of the airport, drilled in 1972 that encountered waters having an estimated temperature of approximately 100°F (37.8°C) (Bruce DeBrine, Colorado Div. of Water Resources and Scott Mefford, Willard Owens, Assoc. oral commun., 1981). The well flowed about 200 gpm from the Niobrara and Frontier Formations. The waters had a strong hydrogen sulfide odor, and they were not sampled or analyzed for dissolved mineral matter (Roy Steffen, oral commun., 1982).

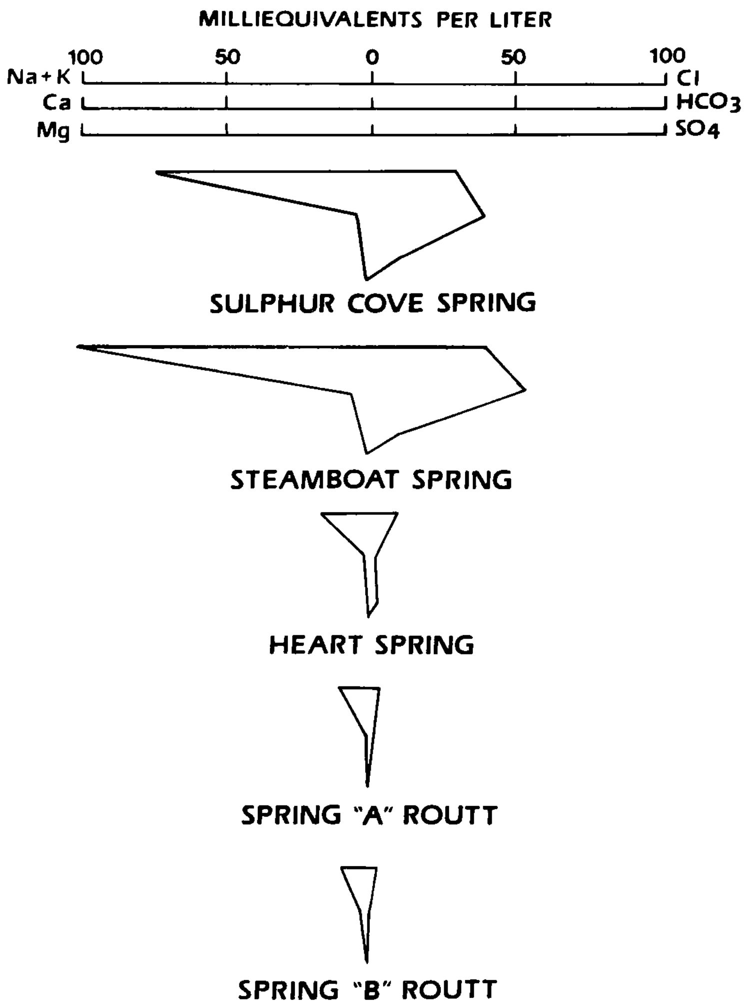


Figure 6. Water quality diagrams.

Routt Hot Springs

The temperature of the Routt Hot Springs thermal waters ranges from 124°F (51°C) to a high of 147°F (64°C). The dissolved solids found in the waters ranges from 500 to 900 mg/l and the waters are a sodium chloride-bicarbonate type (Fig 6). Aa complete description of the Routt Hot Springs, plus other information, can be found in tables 2-4 in Appendix B at the end of the paper. The springs emerge from fractured Precambrian metamorphic rocks (Fig. 5).

Resource Analysis

The temperature, size and aeral extent of the two thermal systems has been estimated by Barrett and Pearl (1978) and Pearl (1979). A summary of these estimates is presented below in Table 1.

Table 1. Resource analysis of Steamboat and Routt Hot Springs
Temp. in °C
(From Barrett and Pearl, 1978 and Pearl, 1979)

	Steamboat Springs			Routt	
	Heart	Sulphur Cave Spg.	Steamboat Spring	A	B
Geothermometer temperature estimates					
Silica:	101	60	66	130	65
Mixing Model:	179	79	93	200	230
Na-K:	148	181	176	167	170
Na-K-Ca:	141	188	187	155	159
Most likely temp.:	125-130	125-130	125-130	125-175	125-175
Aeral extent (sq. mi)	.52			.5-.72	
Heat energy	.0487 Q's			.1110 Q's	

(1 Q of heat energy = 1,000,000,000,000,000 B.T.U.'s)

Steamboat Springs

Barrett and Pearl (1978) noted that it was very difficult to make any precise estimate of the Steamboat Springs reservoir temperature due to the wide range of estimated temperatures and the unknown effects of the chemicals added to the Heart Spring thermal waters. They did state that the Na-K and Na-K-Ca geothermometer estimates are substantiated by the analysis of the Routt Hot Springs.

Based in part on geophysical surveys done in the Steamboat-Routt Hot Springs area by Christopherson (1979), Pearl (1979) estimated that the Steamboat Springs reservoir has an areal extent of .52 sq. mi (1.35 sq km) and contains 0.487 Q's of heat energy at an average temperature of 158°F (70°C).

Routt Hot Springs

Due to the close agreement between the mixing model and the Na-K-Ca geothermometer temperature estimates suggest that the Routt Hot Springs reservoir temperature probably ranges between 257°F and 347°F (125°C and 175°C) (Barrett and Pearl, 1978). Pearl (1979), based on Christopherson's (1979) geophysical work, plus the geological conditions of the area, estimated that this system's areal extent could range from .54 sq. mi (1.4 sq. km) to .75 sq mi (1.9 sq. km) and contain .1663 Q's of heat energy at an average temperature of 280°F (138°C).

GEOCHEMICAL SURVEYS

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. As part of the Steamboat-Routt Hot Springs resource assessment program soil mercury and soil helium geochemical surveys were conducted.

Soil Mercury Surveys

Introduction

Soil mercury surveys have proven successful in a number of instances. For example Capuano and Bamford (1978), Cox and Cuff (1980), Klusman and Landress, (1979), Klusman and others (1977), 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 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 identifying 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 to 200 ft or 400 ft (30.5 m to 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 fault 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 entirely or partially is high in mercury relative to 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 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 (38.1 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). Then a spatula and metal cup were 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 later, 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 number of the samples by 10.

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

3). Determine logarithm of the 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.

To demonstrate this method, assume that 90 samples had been collected and analyzed with analytical values ranging from 0 ppb to 900 ppb. 1) To determine the class interval, multiple the log of 90 by 10 (C.I. = 10 log 90 = 19 intervals). 2). To determine the range of each class interval divide 900/18. C.I. range = 50 ppb. 3) Determine log of each class interval: log 49 = 1.69; log 99 = 2.00 etc. for all 19 classes. 4). Arrange data in ascending numerical order. Determine number of values within each class interval. Assume that first class interval (0-49 ppb) contained 38 samples; and the second class interval (50-99 ppb) contained 24 samples. 5). Relative frequency of interval no. 1: 38/90 = .422. Relative frequency of interval no. 2: 24/90 = .267. 6) Construct cumulative frequency table by summing relative frequency values; .422, .422 + .267 =.689, etc. Plot relative frequency against cumulative frequency. 7). Note where break in slope occurs.

For those cases where the data was 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 in the Steamboat-Routt Hot Springs Area.

Steamboat Springs

Due to low level contamination of the soil by the activities of man it was not possible to determine soil mercury concentration levels in Steamboat Springs.

Routt Hot Springs Area

In the Routt Hot Springs area, soil samples were collected and analyzed for mercury concentration levels at 94 sites (Fig. 7). Most of the soil samples were collected on hillsides ranging in slope from 5° to 40° at an elevation of approximately 8,000 ft above sea level. Thick grasses and dense brush (spruce, pine, aspen, and oak) make up the vegetation. The soil profile gives the appearance that it is laying directly on the bedrock; with the depth to bedrock being generally less than 1 ft (0.3 m). The soil is generally light brown and unconsolidated, and tends to be rocky and/or sandy at the sampling depth of 5-7 in (12.7-17.8 cm).

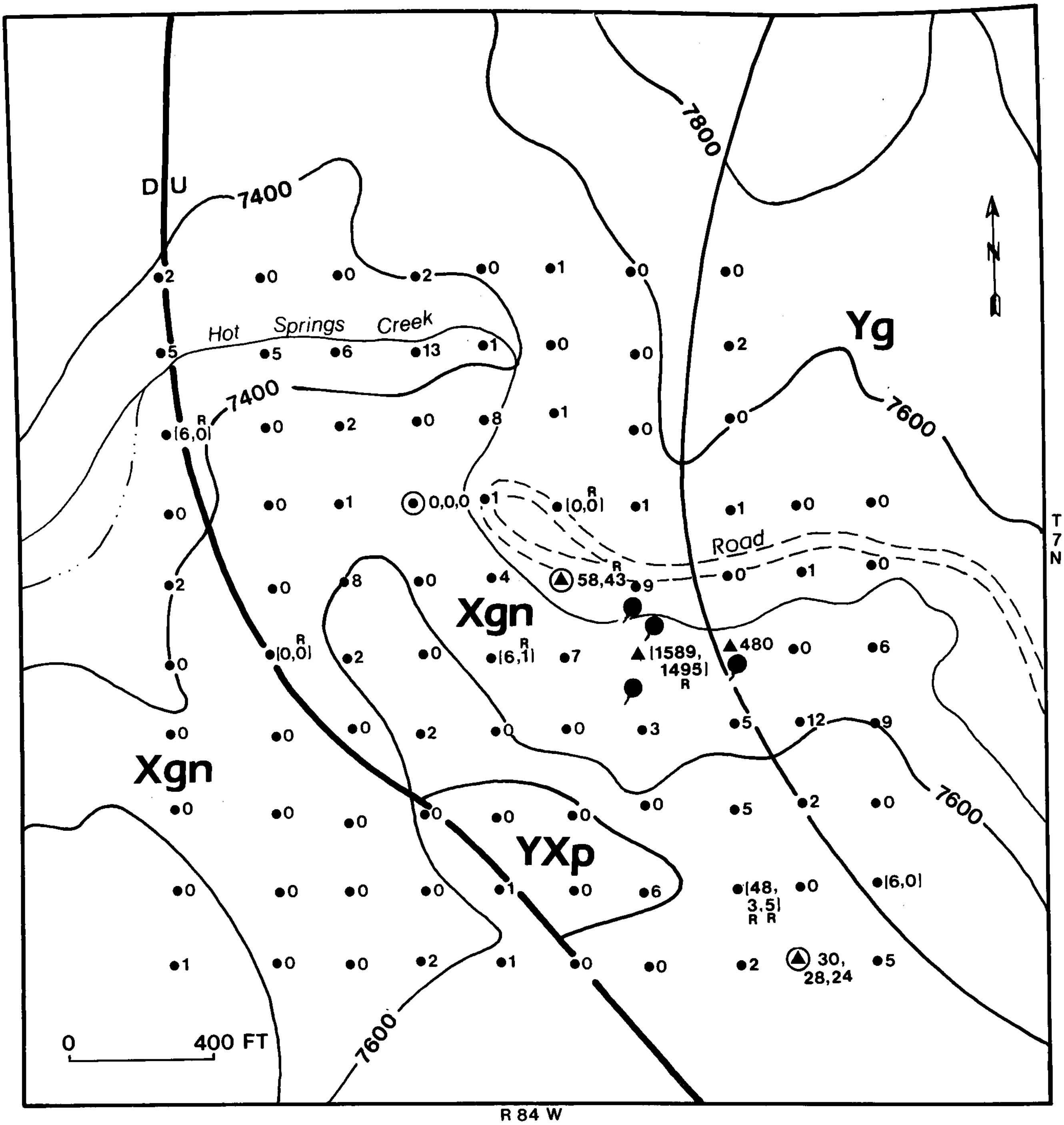
Mercury Anomalies

The distribution of the sample sites and their analytical values are shown in Figure 7. Analytical values ranged from a low of 0 ppb to a high of 1528 ppb (Table 2). For some sites duplicate analysis (Table 2). To determine variability of the sample sites, duplicate analysis of samples from 10 sites were performed. The replicated values suggest that a high percentage of the variance between localities is attributed to analytical variance.

An effective means for showing distribution of the analytical data and determination of background values is by the construction of a frequency distribution plot. Through the use of such a plot (Fig 8), for the Routt Hot Springs data it was decided that all values above 30 ppb should be considered anomalous. Upon examination of the data it is noted that only 4 sampling sites could be considered as containing anomalously high concentration levels of mercury (Fig. 7). Three of these sites are in the immediate vicinity of the hot springs and one is approximately 800 ft (244 m) south of the springs (Fig. 7).

Table 2. Mercury content of Routt Hot Springs Soil Samples. Arranged in ascending rank Values in ppb

0	0	0	0	0	1	2	3	6	48
0	0	0	0	0	1	2	4	6	58
0	0	0	0	0	1	2	5	6	480
0	0	0	0	0	1	2	5	7	1589
0	0	0	0	0	1	2	5	8	
0	0	0	0	0	1	2	5	8	
0	0	0	0	0	1	2	5	9	
0	0	0	0	0	1	2	6	9	
0	0	0	0	1	1	2	6	9	
0	0	0	0	1	2	3	6	30	



EXPLANATION

Sampling locality with mercury concentration in ppb, "R" indicates replicated lab analyses.

Triangle indicates sampling locality with anomalous mercury concentration, circle indicates more than one site

Hot spring

Geologic contact

Fault

Xgn Precambrian metamorphic rock

YXp Precambrian pegmatite

Yg Precambrian monzonite

Figure 7. Routt Hot Springs soil mercury survey.

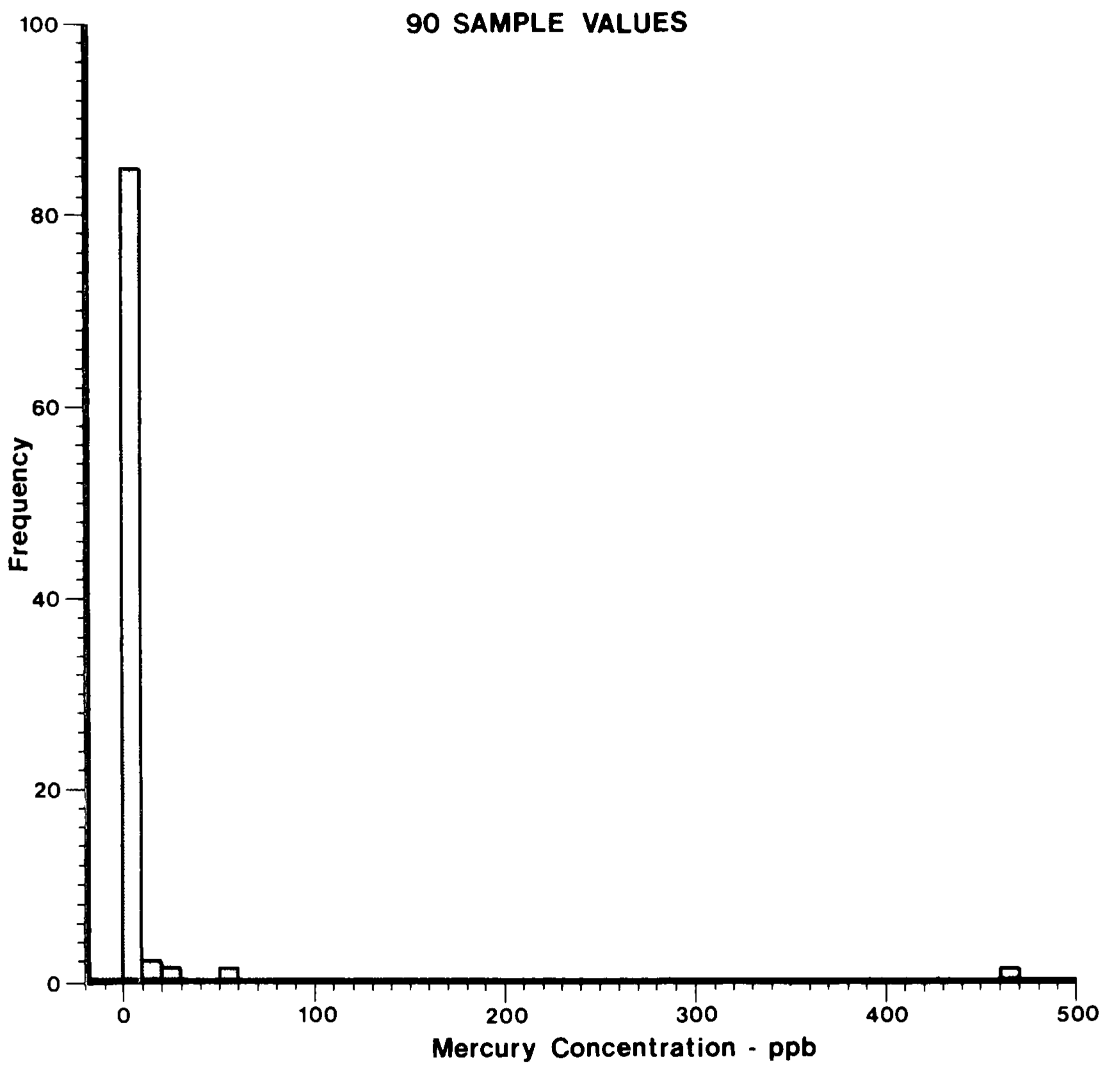


Figure 8. Freguency distribution, soil mercury analytical data.

Conclusions

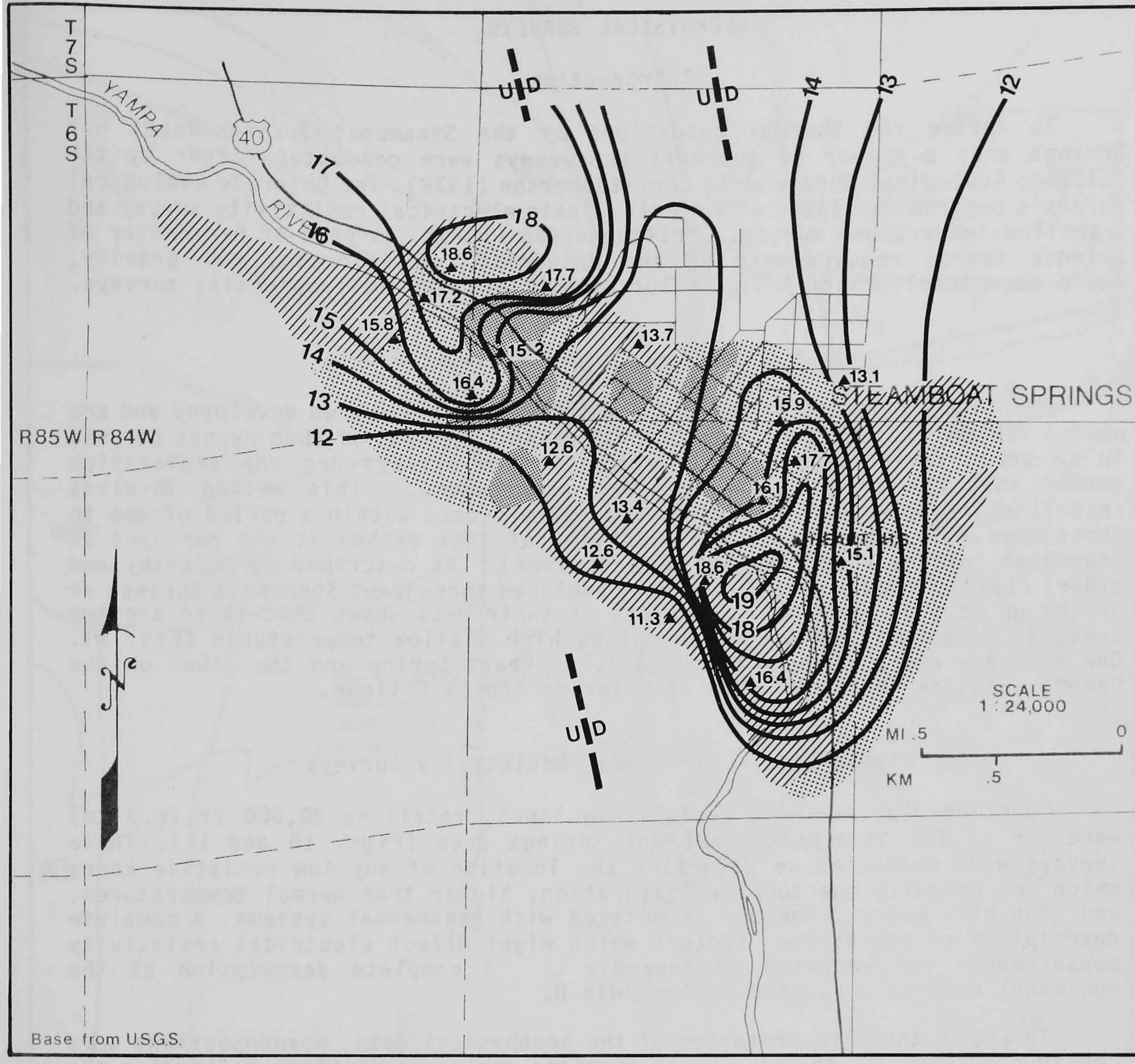
Choosing the upper limit for background as 30 ppb, only anomalous zones indicated are those in the immediate vicinity of the hot springs with the possible exception of the sample locality containing three samples ranging from 24 to 30 ppb. Thus, the soil mercury survey does not indicate any obvious trends that might be followed up with more detailed soil sampling. The mercury values that do stand out are probably caused by precipitation from the thermal waters. The rather sandy soil may also be a reason for the overall low mercury values.

Soil Helium Surveys

Anomalous concentrations of soil-helium gas may indicate the presence of a geothermal energy source (McCarthy and others, 1982). To test the viability of this method personnel from the U.S. Geological Survey during the summer of 1980 collected 62 soil helium samples in Steamboat Springs (McCarthy and others, 1982). Samples were collected approximately every 300 to 634 ft (91.4 to 200 m) apart throughout the city. Gas samples were collected by pounding a 2.46 ft (3/4 m) hollow probe into the ground and extracting a 4 in (10 cm) soil-gas sample with a disposable plastic syringe. The samples were then analyzed the same day by a mobile Dupont Spectrometer 120SSA helium "sniffer" mounted in a pickup truck (McCarthy and others, 1982).

Results

This survey showed that there were two anomalous zones within the City of Steamboat Springs (Fig. 9). The easternmost zone is northwest of Heart Spring while the western zone is east and north of the Colorado Alpine College. Both of these zones may be reflecting the presence of near by faults, especially the western zone. This zone is directly associated with the northeast and north trending faults. No faults have been mapped in the vicinity of the eastern zone but if the north-south trending fault which has been mapped as terminating a short distance to the north actually extends into the Heart Spring area then the anomalous helium zone would fall along its trace.



EXPLANATION

Helium (ppb) with respect to air (5240 ppb)

less than 40

40 to 100

greater than 100

Shallow temperature contour (^{o}C)

▲16.4 Shallow temperature sample site and value (^{o}C)

Inferred fault

Figure 9. Soil helium survey and shallow temperature surveys. (Adapted from McCarthy and others, 1982a)

GEOPHYSICAL SURVEYS

Introduction

To define the thermal conditions of the Steamboat Springs-Routt Hot Springs area a number of geophysical surveys were conducted either by the Colorado Geological Survey or by Christopherson (1979). The Colorado Geological Survey's program consisted of a dipole-dipole electrical resistivity survey and a shallow-temperature survey. Christopherson (1979), as part of her Master of Science degree requirements at the University of Colorado, ran gravity, audio-magnetotellurics (AMT), telluric profiling, and self-potential surveys.

Shallow Temperature Surveys

While many geophysical and geochemical methods have been developed and are useful for the exploration of geothermal resources, most of them cannot be used in an urban environment. Shallow temperature surveys are one exploration method that can be used in an urban environment. This method involves installing, reading and removing temperature probes within a period of one to three days. To demonstrate the viability of this method it was employed at Steamboat Springs (McCarthy and others, 1982). As described by McCarthy and others (1982), temperature probes were emplaced throughout Steamboat Springs at depths up to 5 ft (1.52 m). Analysis of their data shows that there are two areas in Steamboat Springs of anomalous high shallow temperatures (Fig. 9). One of these areas is just to the west of Heart Spring and the other on the Dakota sandstone hogback north of Colorado Alpine College.

Dipole-Dipole Electrical Resistivity Surveys

Fourteen dipole-dipole resistivity lines, totalling 20,600 ft (6.3 km) were run in the Steamboat-Routt Hot Springs area (Figs. 10 and 11). These surveys were conducted to determine the location of any low resistive zones which are normally due to water saturation, higher than normal temperatures, and high clay matrix, factors associated with geothermal systems. A complete description of the various factors which might affect electrical resistivity measurements is presented in Appendix C. A complete description of the equipment used is presented in Appendix D.

To aid in the interpretation of the geophysical data, pseudosections were constructed (Fig. 11 to 16). These sections are cross sections reflecting the shallow subsurface resistivity below the line of traverse. In the interpretation the pseudosection, it is easy to make the assumption that the measurements just represent the material immediately under the line of traverse. However this is not always the case and the interpretator must keep in mind that the measurements may be influenced by lateral variations in the geological conditions. Another method used to interpret electrical resistivity geophysical data are detailed computer models. This method was not employed.

The dipole-dipole measurements substantiated the presence of the north trending Steamboat Fault system. However, they did not show the east trending faults.

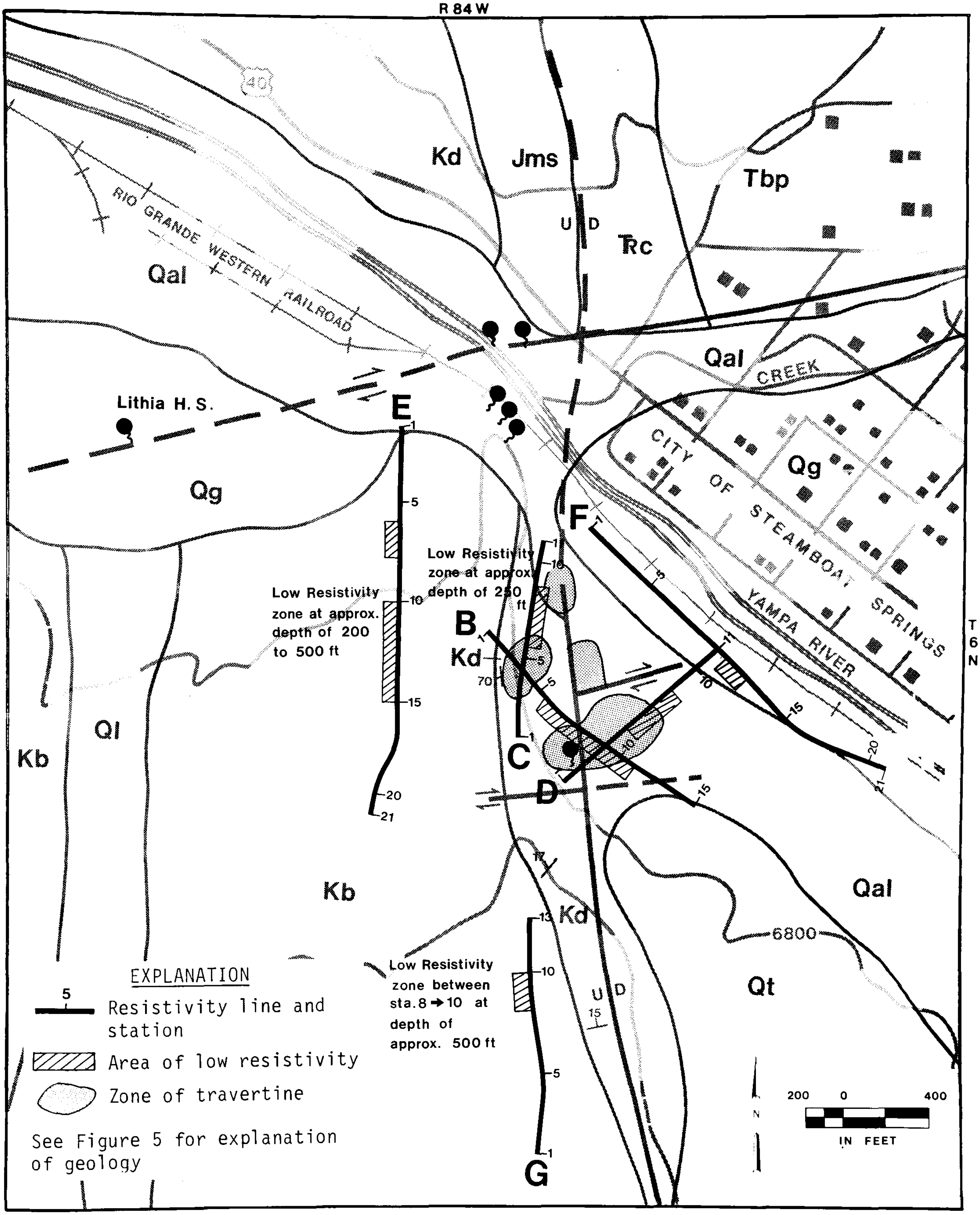
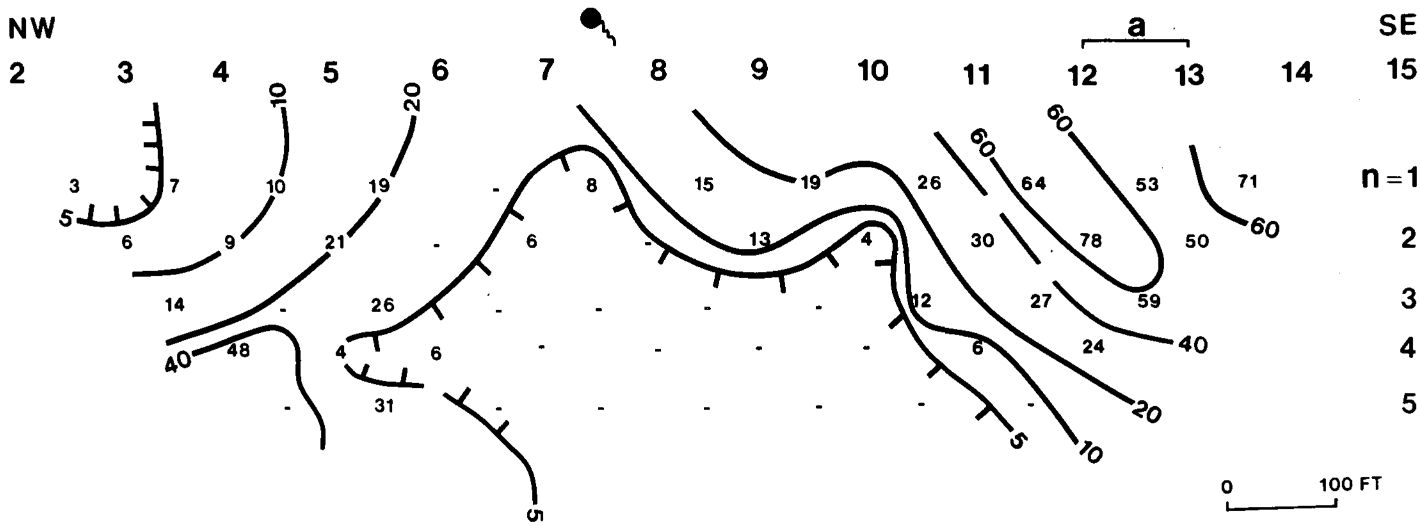


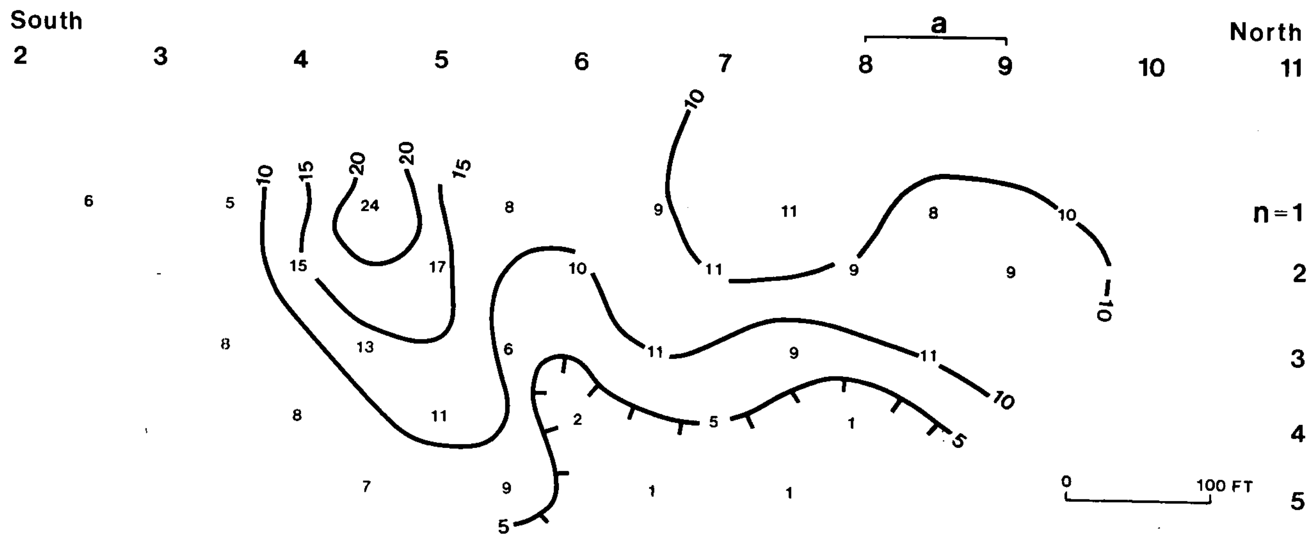
Figure 10. Dipole-dipole resistivity survey index map, Steamboat Springs.



A very low resistivity zone was noted between stations 5 to 11 at an approx. depth of 150 ft (76 m). Where obtained the measured values were less than 5 ohm meters and greater. This low zone is in the vicinity of mapped north-south fault downthrown to the east. Travertine mounds crop out nearby.

LENGTH: 1500 ft (457 m)
SEPARATION: n Value
DATE: 8/4/81
TYPE: Dipole-Dipole
SPREAD: a = 100 ft
RESISTIVITY: In ohm meters
HOT SPRING:

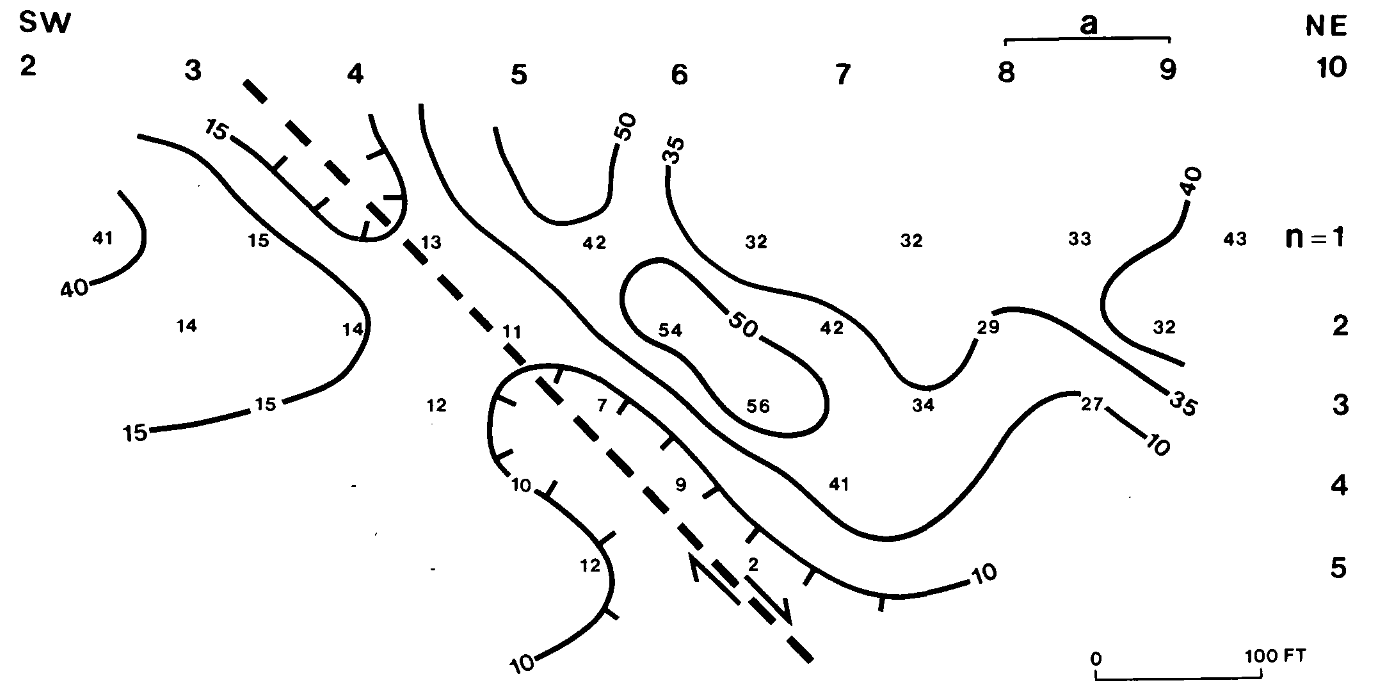
Figure 11. Dipole-dipole Pseudosection Line B, Steamboat Springs.



This line parallels the major north-south fault system (Fig. 10). It is believed that the resistivity zone mapped between stations 5 through 10 reflects the cavernous travertine which the line crossed.

LENGTH: 1100 ft (335 m)
SEPARATION: n Value
DATE: 8/6/81
TYPE: Dipole-Dipole
SPREAD: a = 100 ft
RESISTIVITY: In ohm meters

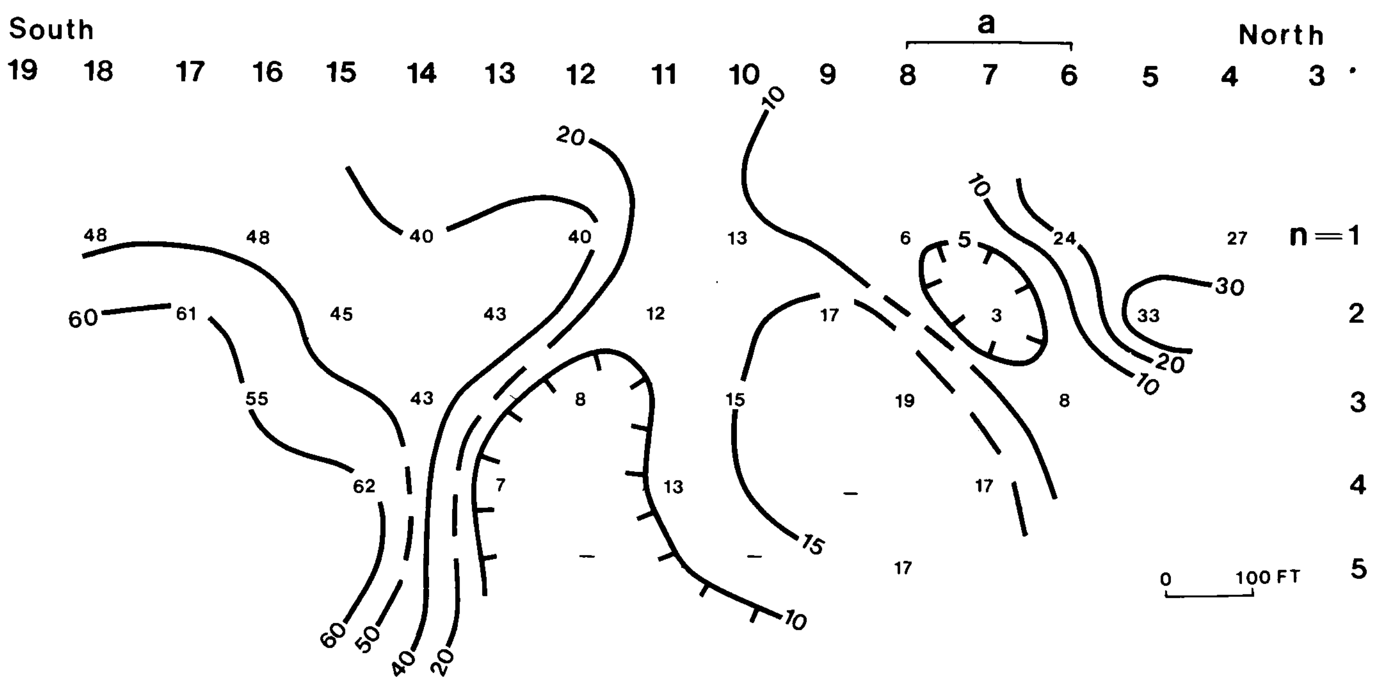
Figure 12. Dipole-dipole Pseudosection Line C, Steamboat Springs.



This northeast-southwest line crosses the major north-south fault (Fig. 10), which is noted by resistivity measurements as low as 2 ohm-meters. Thermal waters of the spring located along the strike of this fault are probably coming up the fault.

LENGTH: 1100 ft (335 m)
SEPARATION: n Value
DATE: 8/30/81
TYPE: Dipole-Dipole
SPREAD: a = 100 ft
RESISTIVITY: In ohm meters

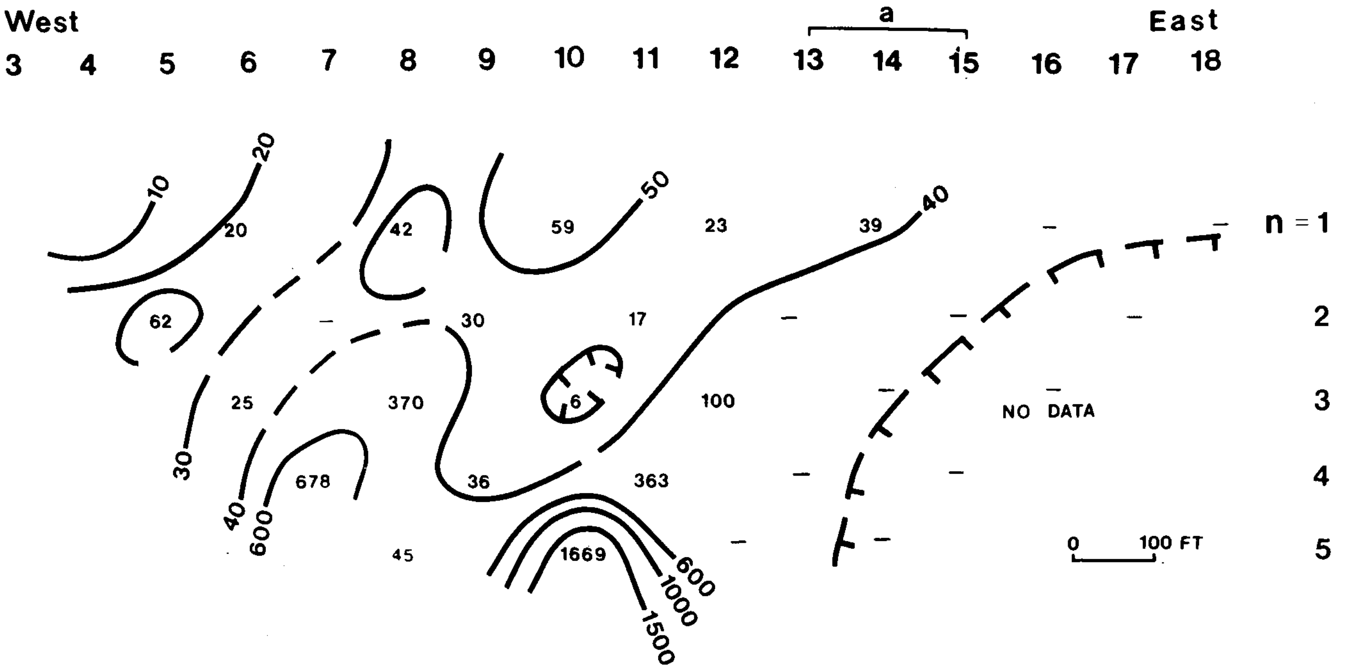
Figure 13. Dipole-dipole Pseudosection Line D, Steamboat Springs.



Low resistivity zones were mapped between stations 6 through 8 and 10 through 14 at depths of 200 and 500 ft. (61 and 152 m). From examination of the data no faults were apparent and these zones must be due to other causes.

LENGTH: 2100 ft (640 m)
SEPARATION: n Value
DATE: 8/6/81
TYPE: Dipole-Dipole
SPREAD: a = 200 ft
RESISTIVITY: In ohm meters

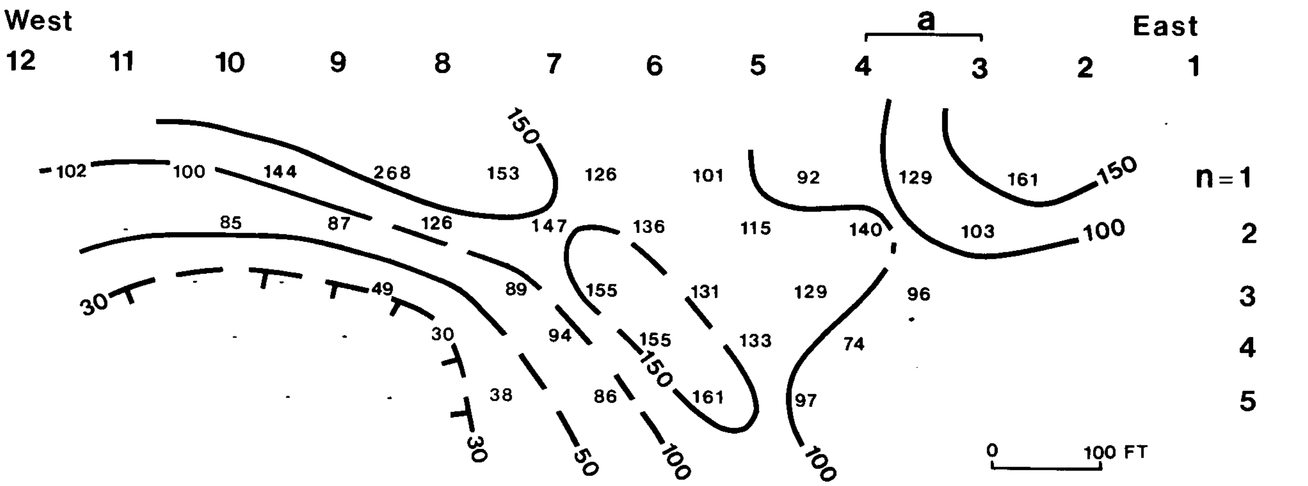
Figure 14. Dipole-dipole Pseudosection Line E, Steamboat Springs.



Alluvial gravels underly this line which parallels the Yampa River (Fig. 10). Only one low resistivity zone was mapped along this line. This zone at station 11 is aligned with the low resistivity zones on lines B and D. It was the intention that this line should be 2,100 ft (640 m) long however due to cultural obstacles the line was limited to a length of 1,800 ft (549 m)

LENGTH: 2100 ft (640 m)
SEPARATION: n Value
DATE: 8/8/81
TYPE: Dipole - Dipole
SPREAD: a = 200 ft
RESISTIVITY: In ohm meters

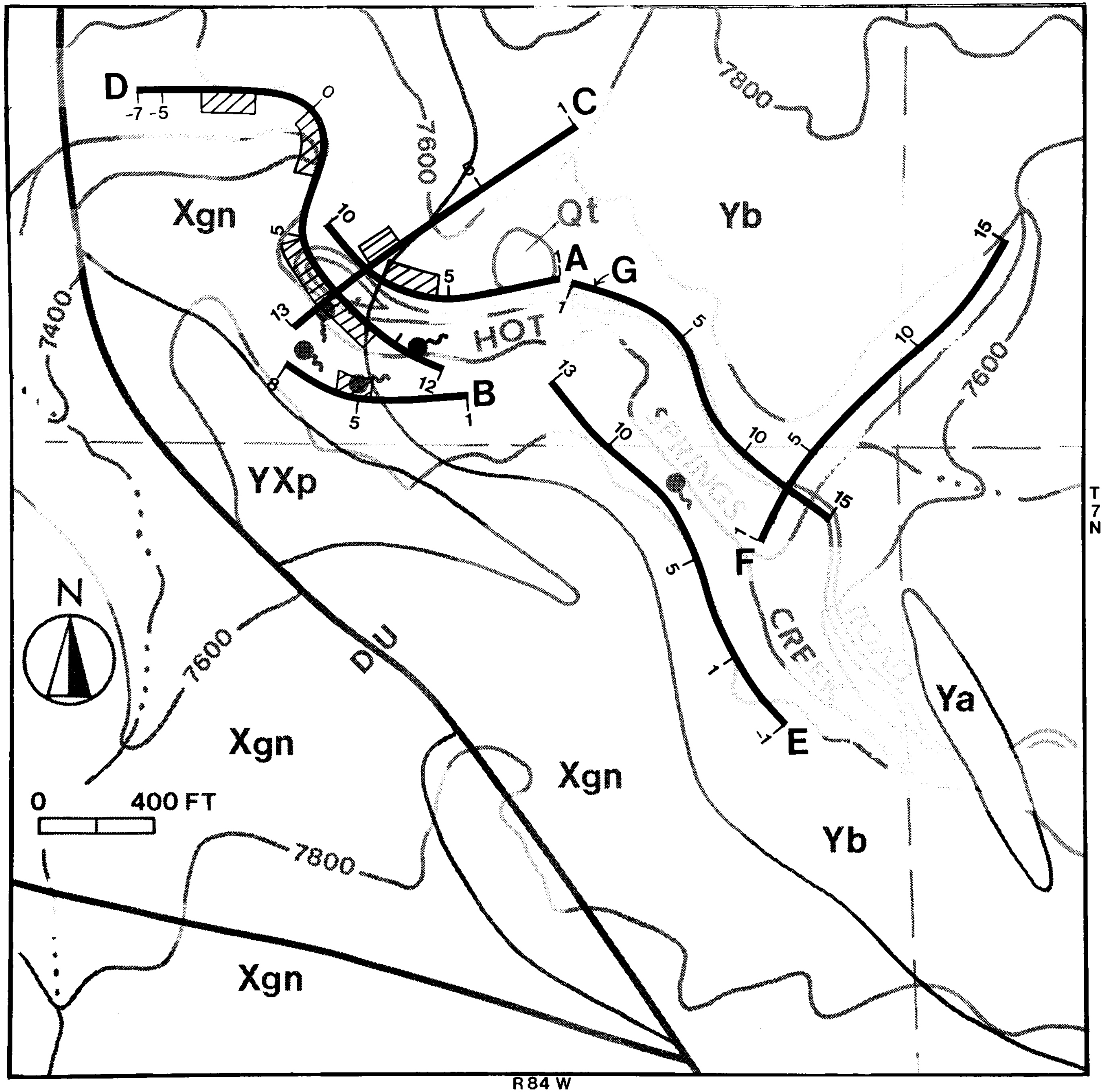
Figure 15. Dipole-dipole Pseudosection Line F, Steamboat Springs.



No evidence of faulting was observed along this north-south line parallel to the major north-south fault (Fig. 10). A low resistivity zone was measured at a depth of 500 ft (152 m) between stations 8 through 10.

LENGTH: 1300 ft (396 m)
SEPARATION: n Value
DATE: 8/6/81
TYPE: Dipole - Dipole
SPREAD: a = 100 ft
RESISTIVITY: In ohm meters

Figure 16. Dipole-dipole Pseudosection Line G, Steamboat Springs.



EXPLANATION

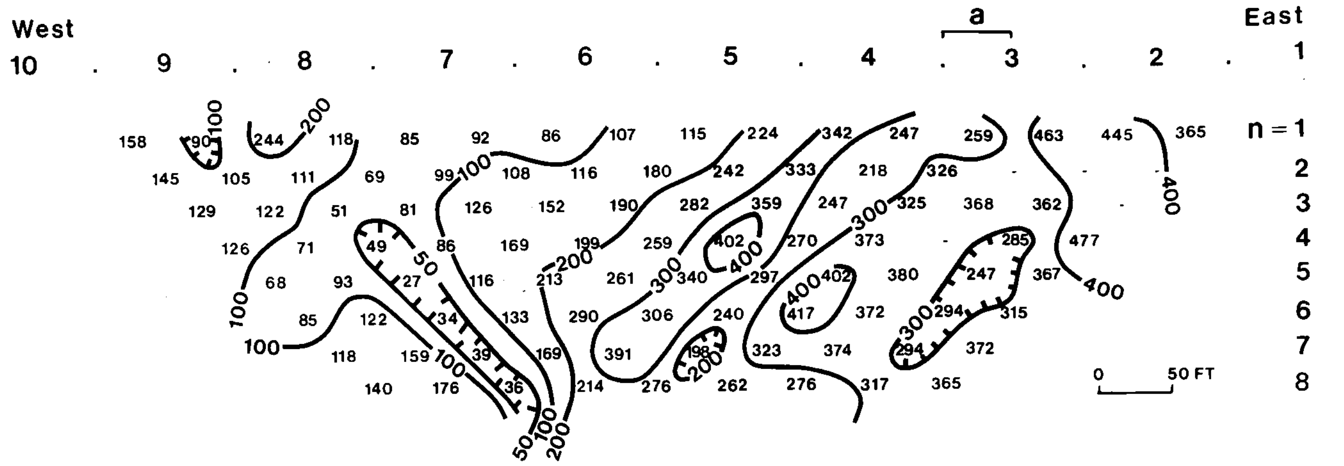
5

Resistivity line and station

Area of low resistivity

See Figure 5 for explanation of geology

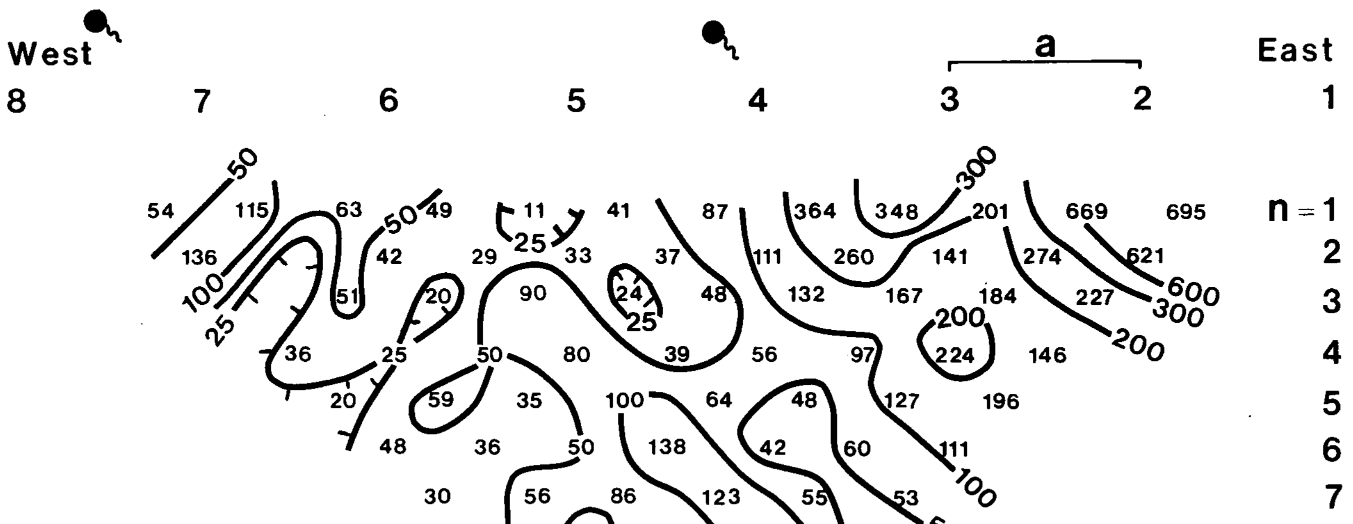
Figure 17. Dipole-dipole resistivity survey index map-Routt Hot Springs.



No faulting was observed along this line, however, a relative low resistivity zone was mapped between stations 7 through 8. While not apparent on the ground this zone may be the contact zone between two Precambrian age rock types. Generally, the resistivities increase to the east in the quartz monzonite bed rock (Fig. 17).

LENGTH: 1000 ft (304 m)
SEPARATION: n Value
DATE: 7/21/81
TYPE: Dipole - Dipole
SPREAD: a = 50 ft
RESISTIVITY: In ohm meters

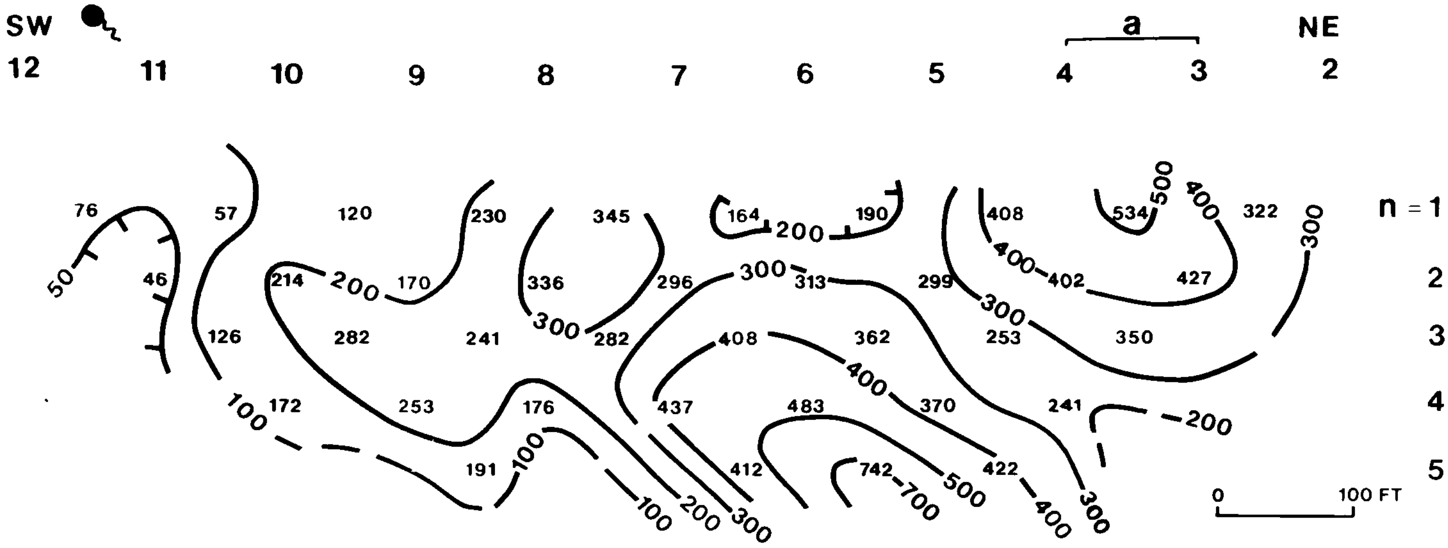
Figure 18. Dipole-dipole Pseudosection Line A, Routt Hot Springs.



This short line trends in a east-west direction (Fig. 17). Resistivity measurements decrease starting at about station 4 and continuing through the rest of the line. This decrease could be due to several causes: 1) Change in rock type, or 2) the hot springs which are located in this stretch.

LENGTH: 400 ft (122 m)
SEPARATION: n Value
DATE: 7/22/81
TYPE: Dipole - Dipole
SPREAD: a = 50 ft
RESISTIVITY: In ohm meters
HOT SPRING:

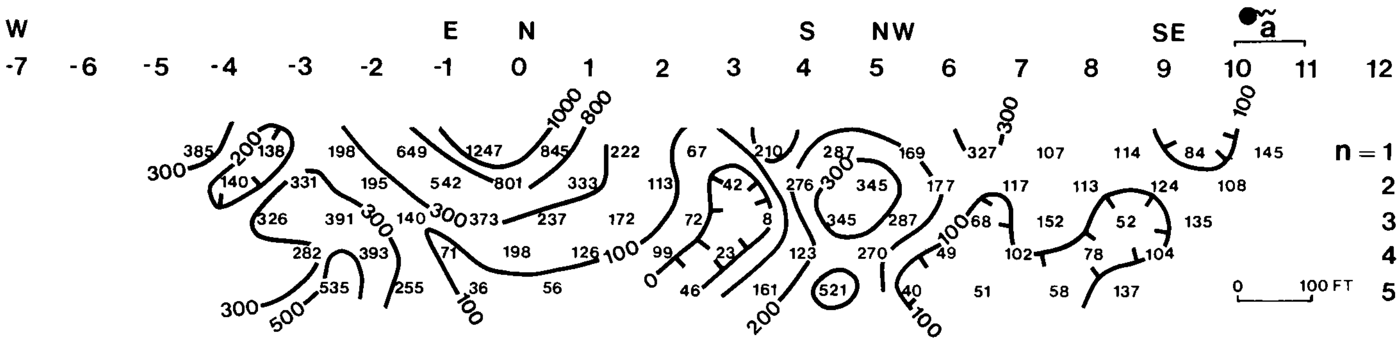
Figure 19. Dipole-dipole Pseudosection Line B, Routt Hot Springs.



Along the southwest part of the line, in the vicinity of the thermal area, the resistivity values are less than 50 ohm-meters, but to the northeast the values increase sharply denoting the charge in lithology encountered. The resistivity values in the quartz monzonite zone exceed 700 ohm-meter with depth (Fig. 17).

LENGTH: 1300 ft (396 m)
SEPARATION: n Value
DATE: 7/27/81
TYPE: Dipole-Dipole
SPREAD: a = 100 ft
RESISTIVITY: In ohm meters
HOT SPRING:

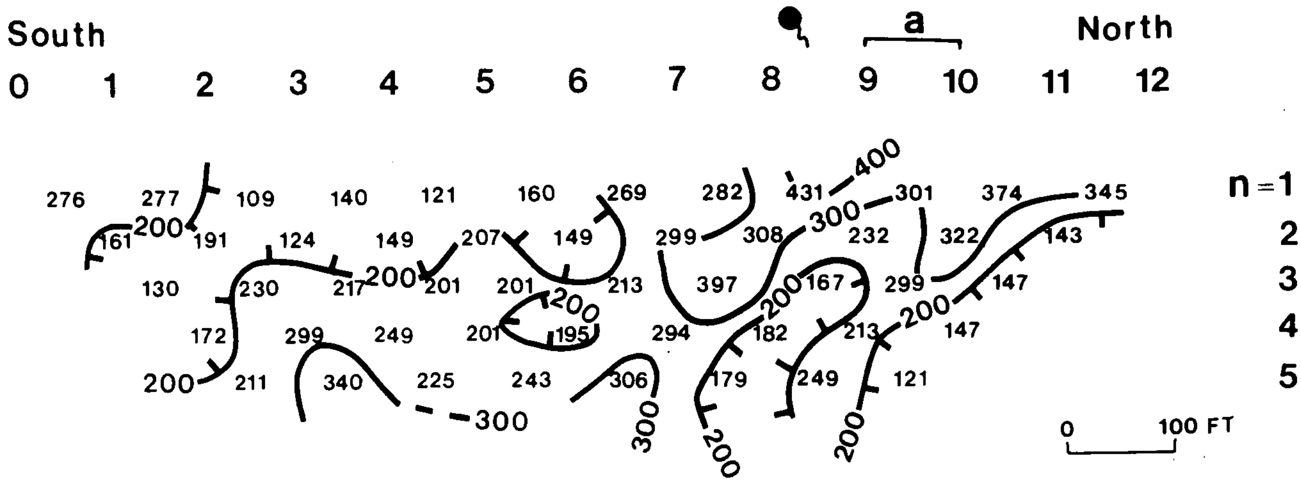
Figure 20. Dipole-dipole Pseudosection Line C, Routt Hot Springs.



This line is approximately 2,000 ft (607 m) in length and generally trends in a northwest-southeast direction, primarily following the drainage pattern (Fig. 17). Resistivity measurements varied widely over the length of the line. The variations were primarily due to a change in the bed rock type starting at station 0 and extending to station 8. Through this section the measurements may also have been influcenced by thermal water discharge from the near by hot springs. From examination of the data no faulting was apparent.

LENGTH: 1900 ft (579 m)
SEPARATION: n Value
DATE: 7/23/81
TYPE: Dipole-Dipole
SPREAD: a = 100 ft
RESISTIVITY: In ohm meters
HOT SPRING:

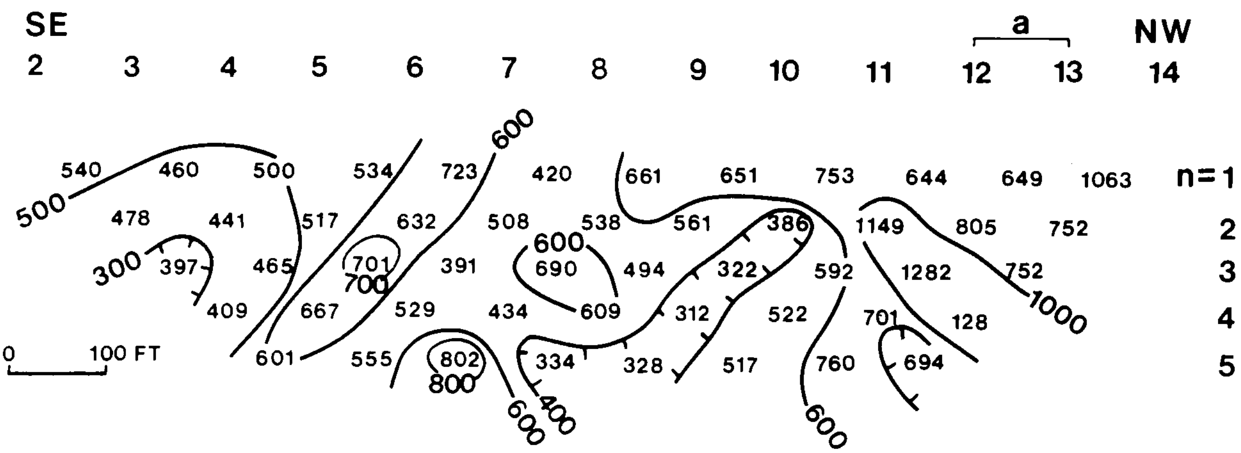
Figure 21. Dipole-dipole Pseudosection Line D, Routt Hot Springs.



This line parallels Hot Springs Creek, southeast of the Hot Springs (Fig. 17). There are no sharp changes of resistivity along the traverse of this line to indicate any features of interest. Another warm spring was located near Station 8. Measurements in this area showed resistivity values decreasing with depth.

LENGTH: 1300 ft (396 m)
SEPARATION: n Value
DATE: 7/28/81
TYPE: Dipole - Dipole
SPREAD: a = 100 ft
RESISTIVITY: In ohm meters
HOT SPRING:

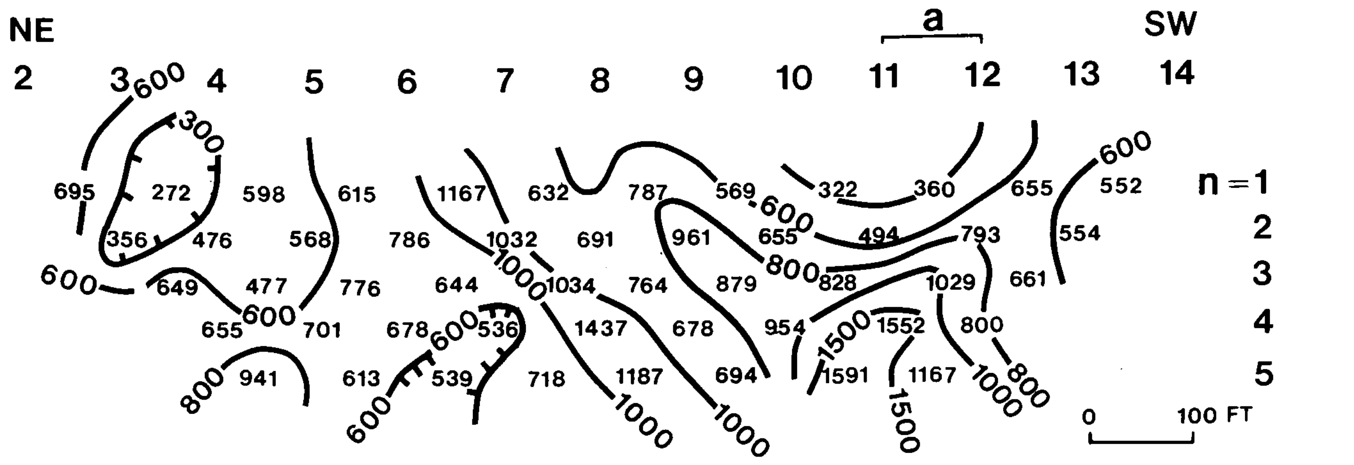
Figure 22. Dipole-dipole Pseudosection Line E, Routt Hot Springs.



Resistivity values measured along this line ranged from 300 to 1,500 ohm-meter with no significant features being apparent. An unmapped conglomeratic rock body was noted adjacent to station 5. The origin of this rock mass is unknown.

LENGTH: 1500 ft (457 m)
SEPARATION: n Value
DATE: 8/11/81
TYPE: Dipole - Dipole
SPREAD: a = 100 ft
RESISTIVITY: In ohm meters

Figure 23. Dipole-dipole Pseudosection Line F, Routt Hot Springs.



This line essentially is an extension of line A. Most of the resistivity values are high due to the quartz monzonite bed rock.

LENGTH: 1500 ft (457 m)
SEPARATION: n Value
DATE: 8 10 81
TYPE: Dipole-Dipole
SPREAD: a = 100 ft
RESISTIVITY: In ohm meters

Figure 24. Dipole-dipole Pseudosection Line G, Routt Hot Springs.

In the Routt Hot Springs area, dipole-dipole resistivity measurements were made along approximately 9,400 ft (2.9 km) of line (Fig. 17). Due to terrain obstacles, much diffuculty was encountered in making these measurements. However, by laying out the lines to take advantage of the terrain, measurements were made by which the areas of low resistivity were delineated. The measured values and the geologic interpretation are presented in Figures 18 to 24.

Other Geophysical Surveys

Attempting to delineate the geological conditions controlling the Steamboat-Routt Hot Springs, Christopherson (1979) ran gravity, audio-magnetotellurics (AMT), telluric profiling, and self-potential surveys. The location of each individual survey is shown on Figure 25. The following discussion is taken directly from her paper and represents her findings.

"All four geophysical methods were useful in determining the subsurface conditions of the Steamboat Springs area. The gravity map confirms the mapped geology and provides some idea of basement depth and subsurface trends. The -232 mgal contour follows the reverse fault front from south to north close to both spring areas, and other contours delineate the metamorphic-igneous rock contact near Routt Hot Springs. The gravity also suggests that an upfaulted block of basement lies just south of Steamboat Springs, which is not obvious from surface geology alone."

"The audio-magnetotelluric (AMT) method doesn't provide deep information but does point out electrical conditions which may be related to structural and lithological changes, determines absolute resistivity values, and shows the geothermal source to be relatively deep. A low resistivity zone of 300 to 800 ohm-meters exists from the surface to about 1000 meters depth at Routt Hot Springs which is significant since it may indicate altered or fractured rock and a probably low volume of water flow. The AMT also gives an indication of basement depth at some stations. For example, the three stations southwest of town show a sharp increase in resistivity at 1000 to 2000 meters depth."

"The telluric profiles are useful as a reconnaissance tool since they measure deep-seated resistivity changes. The southern traverse shows resistivity changes attributed to faults and lithologic changes. The northern profile suggests an altered zone about 750 meters wide coupled with an eighty per cent drop in relative voltage near Routt Hot Springs. The self-potential survey also proved to be a quick method of spotting low near-surface resistivity, measuring a 20 millivolt drop near Routt Hot Springs."

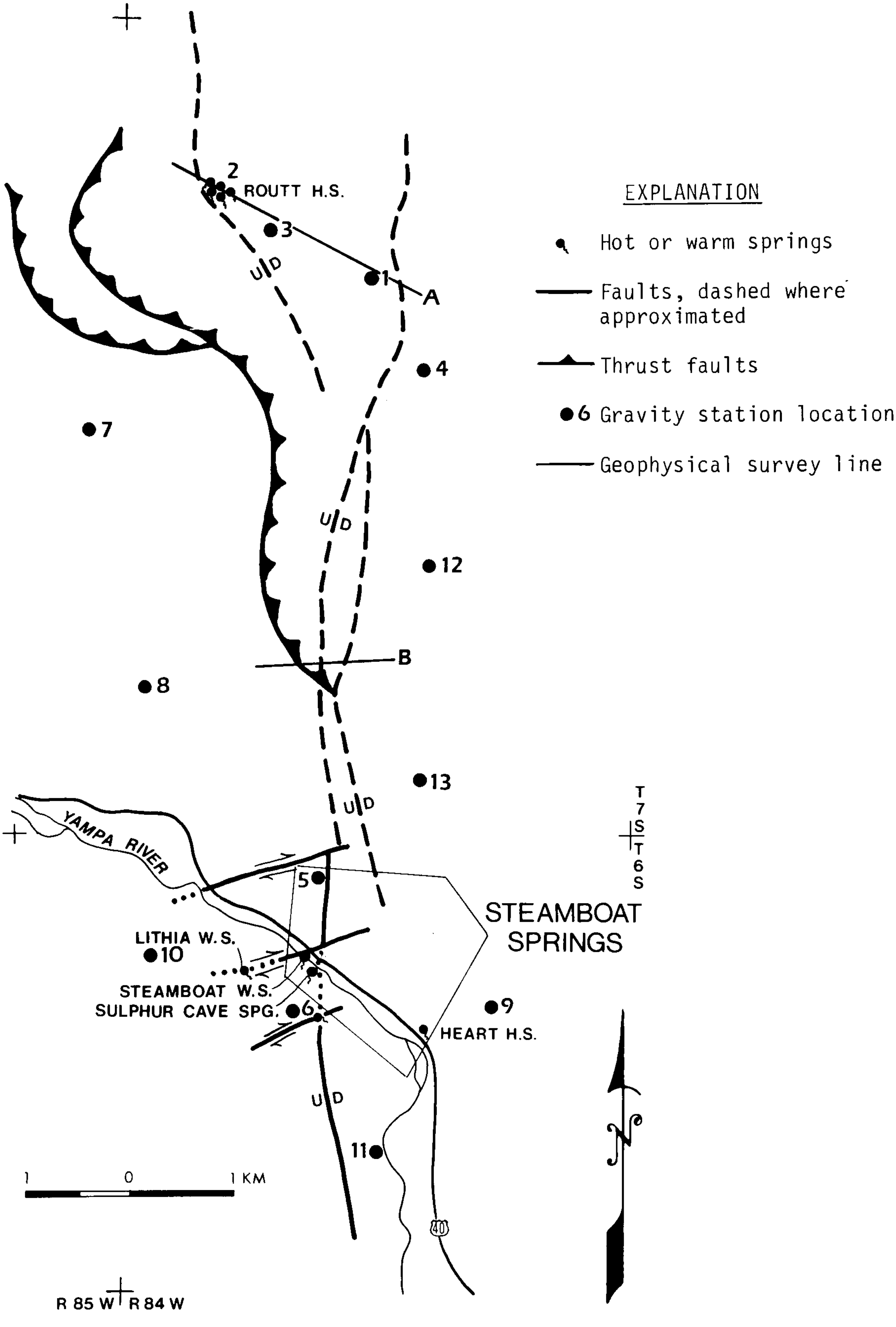


Figure 25. Location of other geophysical surveys, Steamboat-Routt Hot Springs area.

ORIGIN OF THE STEAMBOAT-ROUTT HOT SPRINGS THERMAL WATERS

Due to the lack of any deep water wells or water isotope data in the study area, the authors were limited in their efforts to fully evaluate the thermal conditions of the region and in the preparation of a working model of the thermal conditions. However, based on interpretation of the geologic conditions of the area and the known conditions at other thermal systems of the world, some basic assumptions can be made concerning the origin of the thermal waters of this system.

Thermal waters are of either magmatic or meteoric origin. Magmatic waters are waters driven off from a cooling igneous rock body, Meteoric waters are those which have fallen on the surface of the earth in the form of precipitation, then due to natural process have become part of the ground-water system. Craig (1961) and Craig and others (1956) have demonstrated that most thermal waters are of meteoric origin. To definitely prove that the thermal waters of the study area are of meteoric origin would necessitate sampling and analyzing the waters for various oxygen isotopes, which was not done or finding a buried igneous rock body. A search of the literature did not reveal reference to any buried molten igneous rock bodies in the area. Therefore, until proven otherwise, it will be assumed that the thermal waters of the study area are of meteoric origin.

As is normal, most of the precipitation falling upon the surface of the land in the form of snow or rain runs off and becomes part of the Yampa and other rivers and streams of the area. However, a small part of this precipitation flows into the earth and becomes part of the ground-water system. As this water circulates downward to depth along the many faults and fractures in the area it becomes heated.

One of the problems left unanswered by this investigation is the mechanism by which the ground waters are heated. There are several possible means by which the waters could become heated. 1) Tertiary age volcanic rocks are found throughout northwestern Colorado (Steven, 1975; Tweto, 1976), however these rocks are too old (>20 million years) to be the source of the heat. 2) The heating mechanism could be the regional heat-flow of the area. While no accurate heat-flow measurements have been made in the study area the regional heat flow of the area is about 80 mW/m^2 (Fig. 4). While not proven, Buelow (1980) and Decker and others (1981) have suggested that the occurrence of higher than normal heat-flow is possible in northwestern Colorado. This possibility will have to await further investigation to determine if it could be the heating mechanism of the Steamboat-Routt thermal waters. 3) Another possible source of heat is the disintegration of radioactive minerals. Wells (1960) has shown that Tertiary age rocks of the Colorado Mineral Belt in the Front Range are 15 to 25 times more radioactive than the average granitic rocks. While no values are available on the radioactive mineral concentration levels for the granitic rocks of the Park Range, Nelson-Moore and others (1978) have shown the presence of radioactive mineral deposits northeast of Steamboat Springs. Therefore it can be assumed that some heat could be contributed by decay of radioactive minerals in the basement rocks.

While no deep heat-flow or geothermal gradient wells have been drilled in the study area, some regional data are available. Christopherson (1979), noted that the only well data available gives a geothermal gradient of 2.6°F/100 ft

(47°C/km) in shale. She did not give the location of this well. Repplier and Fargo (1981), based on oil well bottom hole data, showed the geothermal gradient for the study area to be in excess of 1.9°F/100 ft (35°C/km). These values are higher than the world wide average of 1.6°F/100 ft (30°C/km).

As noted earlier it has been estimated that the most likely subsurface reservoir temperature for the Routt Hot Springs system is between 257°F and 347°F (125°C and 175°C) and for the Steamboat Springs system is 257°F and 266°F (125°C and 130°C). Assuming that the waters reach a temperature of 266°F (130°C) and that the geothermal gradient is 1.9°F/100 ft (35°C/km) it can be calculated that the waters would circulate to a depth of approximately 12,000 ft. (3.6 km) below the recharge area to reach these temperatures.

There is mixed evidence whether or not the two systems are hydrologically connected at depth. The regional geophysical studies by Christopherson (1979) gave no indication of a subsurface connection. Yet when the water chemistry of the two systems is analyzed (Fig. 6) it is quite apparent that the Heart Spring thermal waters are almost identical to the Routt Hot Springs thermal waters. In fact, there are more differences in the water chemistry between Heart Spring and the two other two springs in Steamboat Springs than between Heart and the Routt Hot Springs. Based on chemistry of the thermal waters a good argument could be made that Heart Spring is hydrologically related to the Routt Hot Springs and that Steamboat and Sulphur Cave Springs belong to another thermal system. Adding weight to the argument that Routt and Heart Spring are part of the same system is the fact that in Strawberry Park, located between the two areas, thermal waters were encountered during the construction of the new high school. This relationship could be caused by the faults extending from near Routt Hot Springs, through Strawberry Park towards Heart Spring. Further investigation will be required to full establish this relationship.

CONCLUSIONS

The thermal waters of the Steamboat-Routt Hot Springs area are assumed to be normal, deeply circulating ground waters of meteoric origin that have become heated by natural processes within the earth. Both thermal areas appear to be fault controlled. With the exception of Heart Spring, all of the springs lie on or near faults. While not proven, it is very likely that Heart Spring could lie on the extension of a north-trending normal fault. Routt Hot Springs is situated between a north-trending normal fault (to the west), a pegmatite dike (to the south), and the gneiss-quartz monzonite contact (to the east). This provides a fractured and altered zone perhaps 2,460 ft to 3,281 ft (750 to 1000 m) wide, for the upflow of geothermal waters. Since the eastern side of the fault was upthrown this zone probably dips steeply to the west.

The subsurface flow of water could be controlled by subhorizontal faults deep in the upper sheet of the reverse fault that runs the length of the study region. These faults could permit ground-water flow in fractured zones several kilometers below the surface (Christopherson, 1979).

There is some question about the level of seismicity in the Steamboat-Routt Hot Springs area. Historic seismicity locates 346 epicenters of earthquakes with magnitudes 1.0 to 4.5 (Richter scale) near Steamboat Springs during the years 1966 through 1971 (Simon, 1969, 1972), which is far above the state average for any one area. Kirkham and Rogers (1981) have shown that many of these earthquakes were manmade. Some of these quakes could be the result of mining, but Christopherson (1979) suggests the tensional strain suggested by these small quakes and the regional geology could provide the mechanisms to keep subsurface fractures open as permeable channels.

It has been estimated that the Routt Hot Springs system has an areal extent of .50-.75 sq. miles (.8-1.2 sq Km) and could contain 0.1663 Q's (1015 BTU's) of heat energy at an average temprature of 280°F (138°C) (Pearl, 1978). Pearl (1978) also estimated that the Steamboat Springs system could have an areal extent of .52 sq. miles and could contain .0487 Q's of heat energy at an average temperature of 158°F (70°C). Based on results of this investigation it is believed that these figures are minimum figures and that the size and energy content of the two systems is much greater. At the present time it is not possible to give any more precise estimate than Pearl did in 1978. If the two systems are connected at depth along the major north trending fault system then the system's areal extent could be much larger.

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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 purposes. Due to declining petroleum reserves It is anticipated that in years to come development of this energy source will increase. Figure 26 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 learning 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.

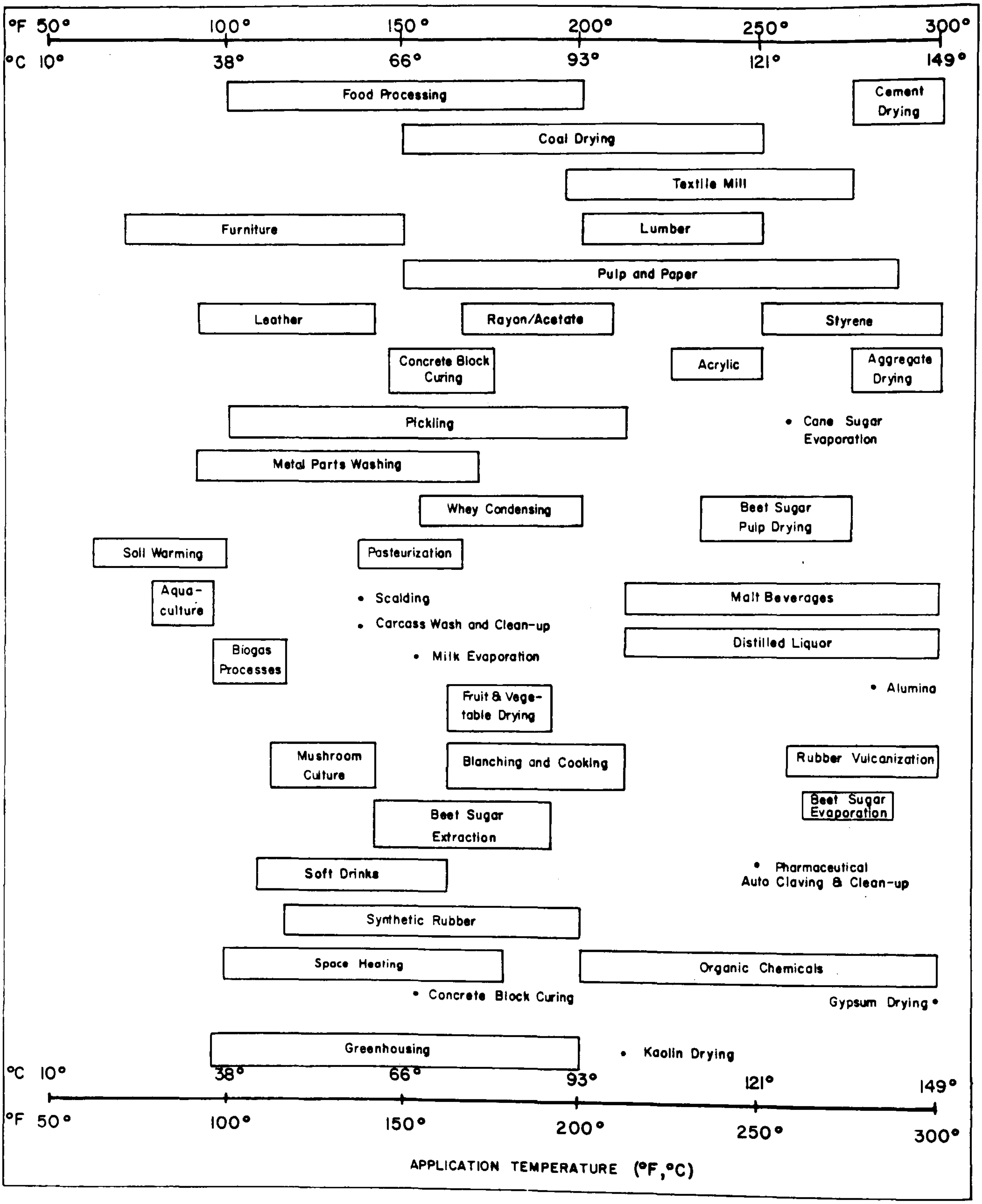


Figure 26. Temperature range for some direct uses of geothermal energy. (Adapted from Anderson and Lund, 1979, p. 4-26.)

APPENDIX B

Table 3. Physical Properties and Chemical Analysis of Steamboat-Routt Hot Springs Thermal Waters (From Barrett and Pearl, 1976).

	-----Steamboat Springs-----				
	Heart Spring	Sulphur Cave Spring	Steamboat Spring	Routt Spg A	Routt Spg. B
Arsenic (ug/l):	5	45	130	38	100
Boron (ug/l):	700	2,900	3,200	280	280
Cadmium (ug/l):	0	0	0	0	0
Calcium (mg/l):	18	90	110	13	7.8
Chloride (mg/l):	320	1,000	1,400	140	130
Fluoride (mg/l):	1.9	3.0	2.9	18	17
Iron (ug/l):	40	60	10	0	80
Lithium (ug/l):	350	3,000	3,700	290	310
Magnesium (mg/l):	1	24	31	0.4	0.5
Manganese (ug/l):	0	310	380	0	10
Mercury (ug/l):	0	0	0	0.	0 0.1
Nitrogen (mg/l :	0.04	0	0.16	0	0
Phosphate					
Ortho diss. as P, (mg/l):	0.02	0.06	0.07	0.01	0.02
Ortho, (mg/l :	0.06	0.18	0.21	0.03	0.06
Potassium (K), (mg/l :	11	110	140	9	9.1
Selenium (ug/l):	0	0	0	0	0
Silica (mg/l :	49	18	21	97	98
Sodium (mg/l):	300	1,600	2,200	160	160
Sulfate (mg/l):	150	490	590	47	49
Zinc (ug/l)	0	10	30	0	6
Alkalinity					
As Calcium Carb. (mg/l):	84	1,980	2,780	112	111
As Bicarbonate (mg/l):	103	2,420	3,390	136	135
Hardness					
Noncarbonate (mg/l):	0	0	0	0	0
Total, (mg/l):	49	320	400	34	22
Specific Conductance (Micromohs):	1,450	5,800	9,130	830	770
Total dissolved solids (TDS), (mg/l):	903	4,530	6,170	552	539
pH, Field	8.0	6.5	6.7	7.6	7.1
Discharge (gpm):	140	10	20	33	30
Temperature (°C):	39	20	26	64	62
Date Sampled	4/76	4/76	4/76	7/75	7/75

Location:
Heart Spring: NW, SE, NE, Sec. 17, T. 6 N., R. 84 W.
Sulphur Cave Spring: NW,SE,NW, Sec. 17, T. 6 N., R. 84 W.
Steamboat Spring: NE,SW,SW, Sec. 8, T. 6 N., R 84 W.
Routt Spring A: SW,SE, Sec. 18, T. 7 N., R. 84 W.
Routt Spring B: SW,SE, Sec. 18, T. 7 N., R. 84 W.

TABLE 4. Trace Elements In Routt Hot Springs Thermal Waters
Source of data: Barrett and Pearl (1976)

Values reported in Micrograms/liter (ug/l)

	Spg. A	Spg. B
Aluminum	70	150
Barium	16	20
Beryllium	< 1	< 1
Bismuth	< 4	< 4
Chromium	< 4	< 4
Cobalt	< 4	< 4
Copper	1	4
Gallium	< 2	< 2
Germanium	< 4	< 4
Lead	< 4	< 4
Nickel	< 4	< 4
Silver	0	0
Strontium	360	380
Tin	< 4	< 4
Titanium	< 2	< 2
Vanadium	< 4	< 4
Zirconium	< 5	< 5

Table 5. Associated radioactivity, Steamboat-Routt thermal waters.
Values reported in Picocuries/liter (PCi/l)
Source: Barrett and Pearl (1976)

Heart Spring:

Rn-222	150. ± 29	U-235	N.A.
Ra-226	1.8 ± 0.20	U-238	0.044 ± 0.024
Ra-228	N.A.	Th-230	< 0.01
U-234	0.084 ± 0.033	Th-232	< 0.0047

Routt Spring A:

Rn-222	530. ± 51	U-235	N.A.
Ra-226	0.13 ± 0.058	U-238	0.034 ± 0.023
Ra-228	N.A.	Th-230	0.019 ± 0.015
U-234	0.039 ± 0.03	Th-232	0.026 ± 0.015

APPENDIX C

FACTORS AFFECTING ELECTRICAL RESISTIVITY MEASUREMENTS

One of the more favorable techniques used in geothermal resource exploration are electrical geophysical surveys. The basic prinicipal behind this method is that the resistence of the subsurface rocks to the passage of an electrical current can be measured. The method used by the Colorado Geological Survey involves inducing a man made electrical current into the subsurface and measuring the resultant potential at two receiving electrodes (Soil Test Inc., 1968). A complete description of the equipment and field procedures used is presented in Appendices D and E.

The transmission of the electrical current is dependent upon such factors as: 1) subsurface temperature; porosity of the rocks; 2) salinity of fluids contained in the rocks; and 3) clay content of the rocks. As these factors tend to be higher in geothermal systems than non geothermal systems the geothermal systems are distinguished by lower resistence measurements than the surrounding areas. However, it must be kept in mind that under favorable conditions non thermal areas may be confused with thermal area. For example a low temperature, highly saline ground water can provide the same readings as a high temperature, moderately saline geothermal fluid. Therefore, to be most effective, electrical resistivity surveys should be used in conjuction with other methods, such as gradient temperature measurements, that are of value in determining the reason for the resistivity measurements recorded.

APPENDIX D

INSTRUMENTATION

Scintrex RAC-8 Low Frequence Resistivity System

The electrical geophysical equipment used by the Colorado Geological Survey during the course of this investigation was a Scintrex RAC-8 Low Frequency Resistivity System. The following description of this equipment is taken from the Scintrex Manual (1971).

The Scintrex RAC-8 electrical resistivity system 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 reference 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 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

Introduction

One of the most widely used electrical surveying methods used for geothermal resource exploration is resistivity profiling and sounding. This method utilizes various arrays with the most common being the Wenner, Schlumberger and Dipole-Dipole. During the course of this investigation the Dipole-Dipole method was extensively used because of the ease of use and also being able to obtain horizontal and vertical sections.

Before discussing the various methods used, it is necessary to consider what is actually measured by an array of current and potential electrodes (Fig. 27). By measuring (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).

If the ground is nonhomogeneous, 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 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).

The following formula is used by all methods to calculate the apparent resistivity at a site.

General Resistivity Formula

$$P_a = 2PIaV/I$$

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

See Figure 27 for a schematic diagram for resistivity.

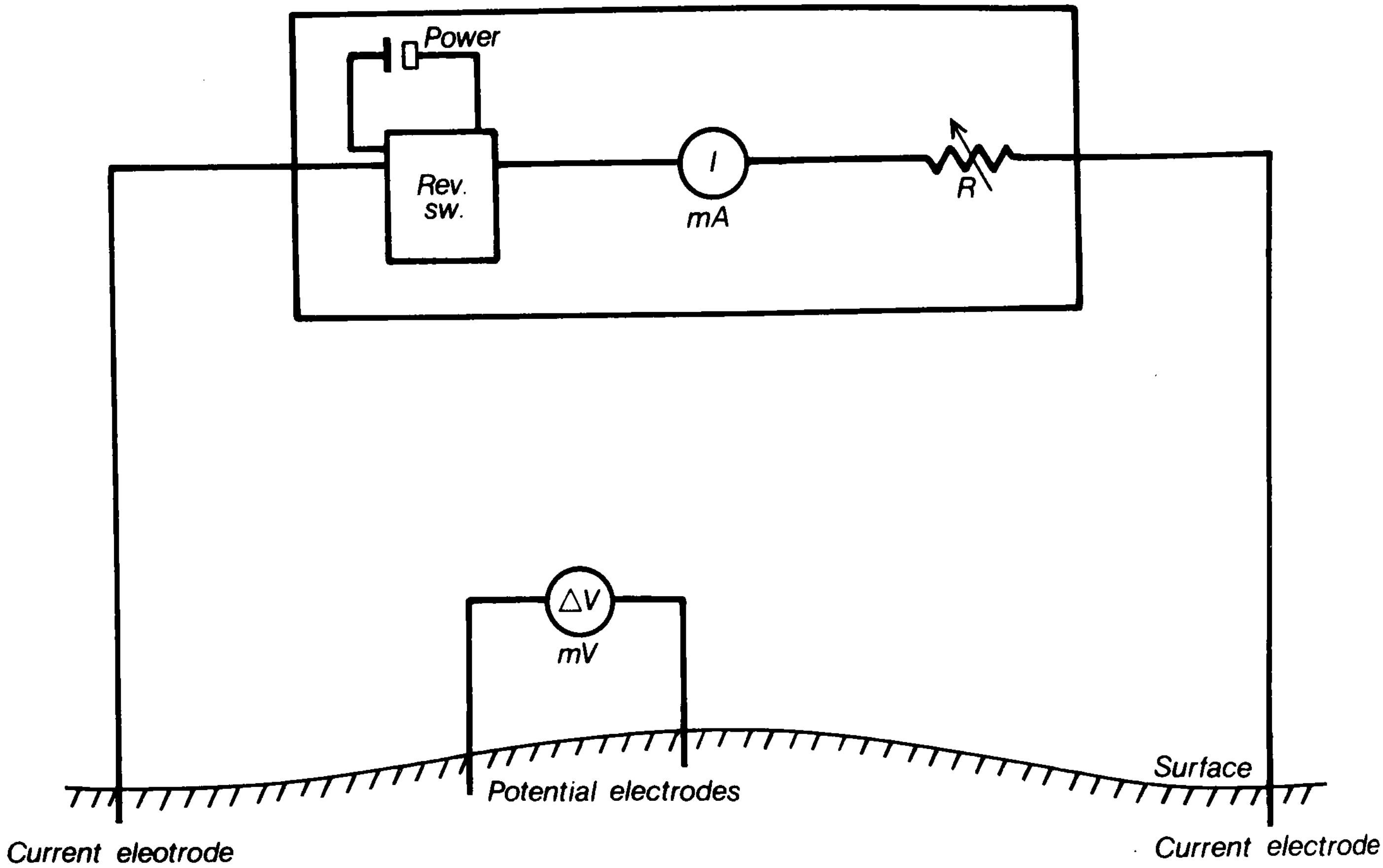
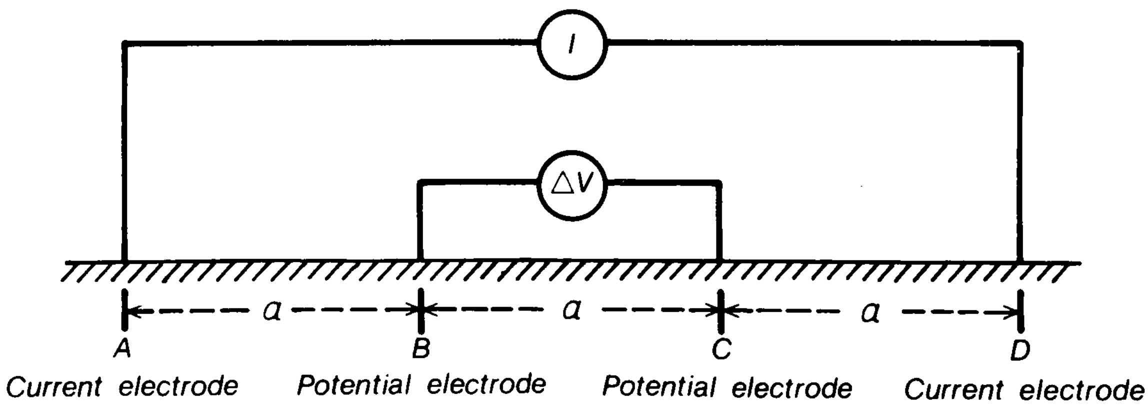


Figure 27. Schematic diagram for resistivity (Adopted from Combs, 1980).



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

Figure 28. Wenner array. (Adopted from Combs, 1980)

Wenner Array

In the Wenner array (Fig. 28) 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.

This method was not used in the study area due to steep terrain and access problems.

Schlumberger Array

For the Schlumberger array, the current electrodes are spaced much further apart than the potential electrodes (Fig. 29).

In depth probing the potential electrode remains fixed while the current elecrode spacing is expanded symmetrically about the center of the spread. For large values of L it may be necessary to increase 2l also 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).

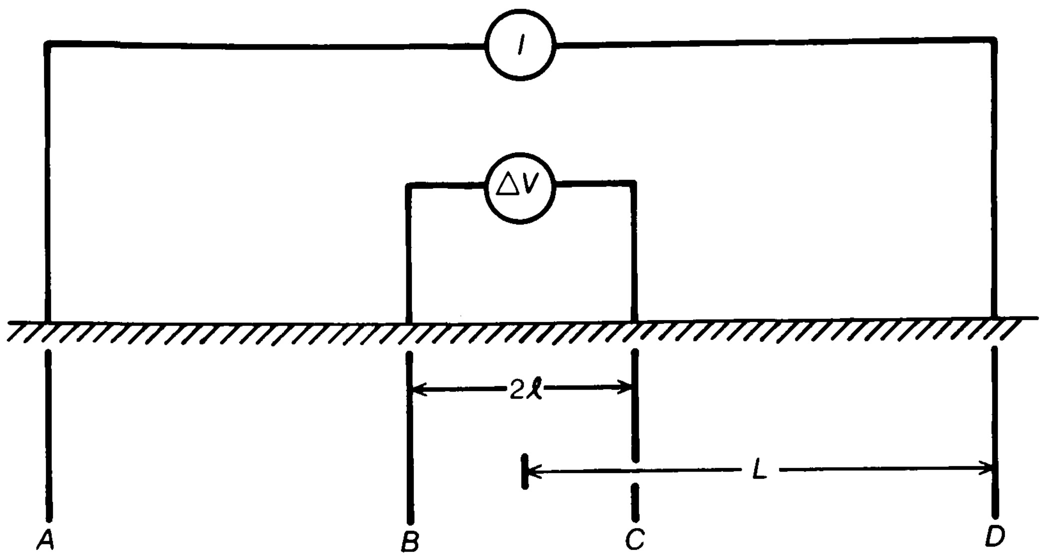
In summary, short spacing between the outer electrodes assumes shallow penetration of current flow and computed resistivity will reflect properties of shallow depth. As the electrode spacing is increased, more current penetrates to greater depth and conducted resistivity will reflect properties of each 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. 30).

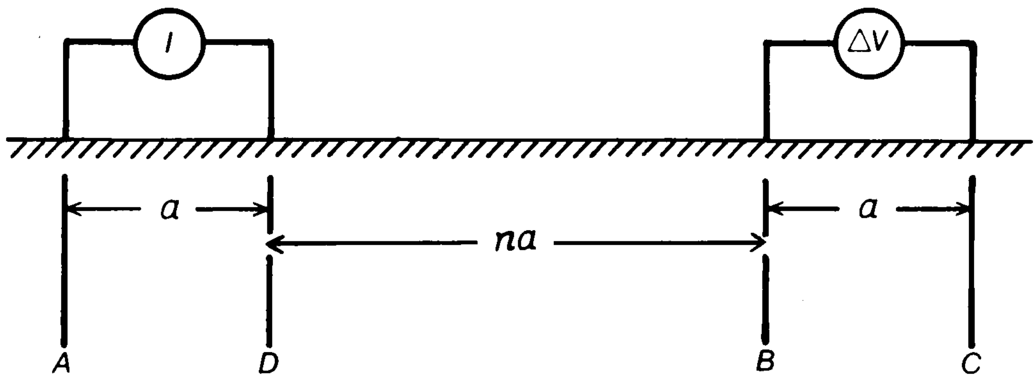
Inductive coupling between potential and current cables is reduced with this arrangement. This method was primarily used throughout all study areas because of reliability and ease of field operation. A diagram of this method is depicted in Figures 31 and Figure 32.

With reference to Figure 31 and 32, 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 is 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 interperation from the data collected (Sumner, 1976).



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

Figure 29. Schlumberger array. (Adopted from Combs, 1980).



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

Figure 30. Dipole-dipole array. (Adopted from Combs, 1980).

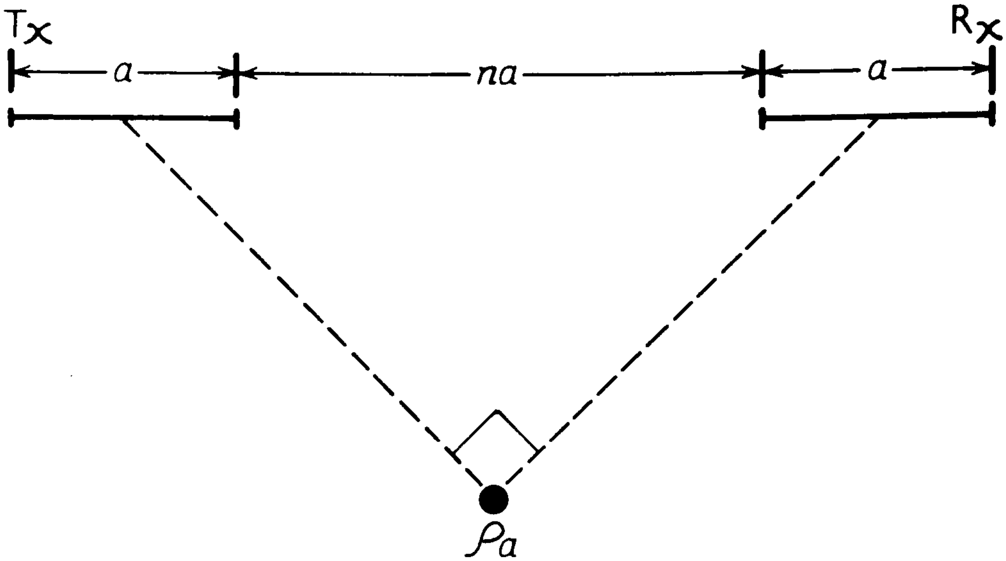


Figure 31. Data plotting scheme for dipole-dipole array. (Adopted from Combs, 1980).

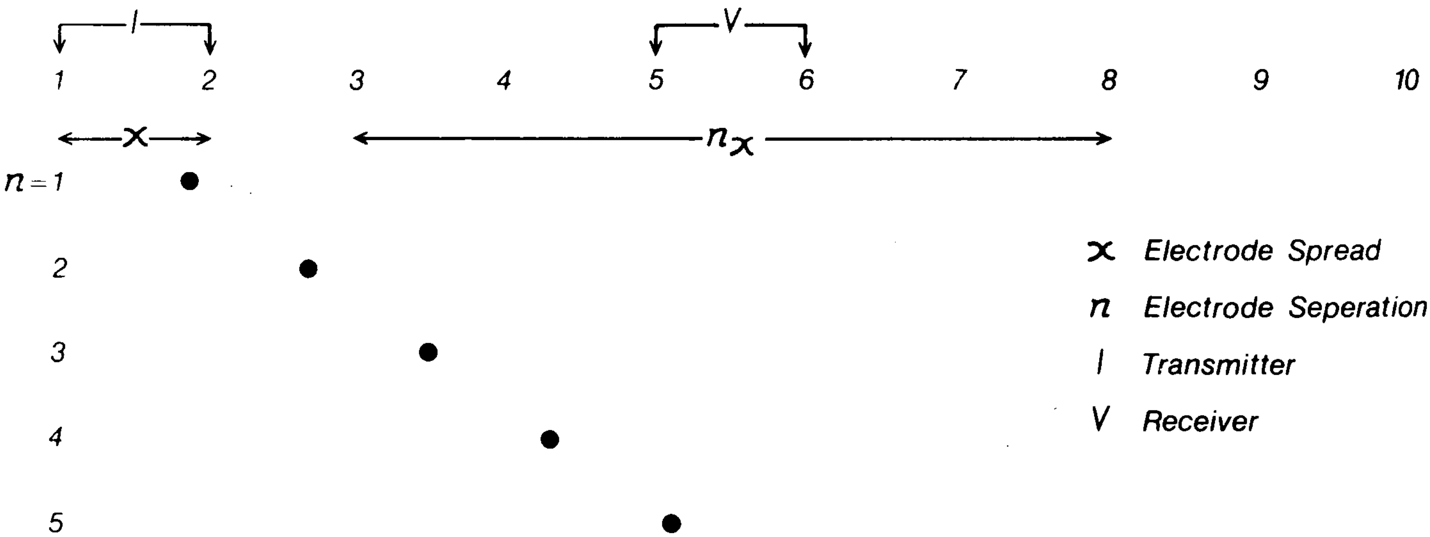


Figure 32. Typical dipole-dipole array. (Adopted from Combs, 1980).

TABLE 6. LINE A

MEASUREMENTS NOT TAKEN

TABLE 7. LINE B

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Steamboat Springs	Line B	4 August 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
C1-2							
3-4	10	.00031	200	1.68	.00520	574.53	2.99
4-5	10	.00031		.88	.00273	2298.14	6.27
5-6	10	.00031	225	.79	.00245	5745.34	14.08
6-7	10	.00031		1.35	.00419	11490.69	48.15
7-8		.00031	200			20108.71	-N.R.-
C2-3							
4-5	10	.00031	166	3.92	.01215	574.53	6.98
5-6	10	.00031	166	1.32	.00409	2298.14	9.40
6-7		.00031	166			5745.34	-N.R.-
7-8	10	.00031	225	.12 *	.00037 *	11490.69	4.25
8-9	10	.00031		.50 *	.00155 *	20108.71	31.17
C3-4							
5-6	10	.001	133	1.78	.0178	574.53	10.23
6-7	10	.001		.90	.0090	2298.14	20.68
7-8	10	.001		.45	.0045	5745.34	25.85
8-9	10	.001		.05 *	.0005 *	11490.69	5.74
9-10						20108.71	-N.R.-
C4-5							
6-7	10	.001	250	3.25	.0325	574.53	18.67
7-8		.001					-N.R.-
8-9		.001	250				-N.R.-
9-10	TX not producing high power settings						-N.R.-
10-11							-N.R.-
C5-6							
7-8		.001	333				-N.R.-
8-9	10	.001	333	.25	.0025	2298.14	5.74
9-10		.001					-N.R.-
10-11							-N.R.-
11-12							-N.R.-

TABLE 7. LINE B (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C6-7							
8-9	10	.001	250	1.33	.0133	574.53	7.64
9-10							-N.R.-
10-11							-N.R.-
11-12							-N.R.-
12-13							-N.R.-
C7-8							
9-10	10	.001	166	2.67	.0267	574.53	15.34
10-11	10	.001		.57	.0057	2298.14	13.10
11-12						5745.34	-N.R.-
12-13						11490.69	-N.R.-
13-14						20108.71	-N.R.-
C8-9							
10-11	10	.001	133	2.85	.0285	574.53	16.37
11-12	10	.001		.18 *	.0018	2298.14	4.14
12-13	10	.001		.21	.0021	5745.34	12.06
13-14	10	.001		.05 *	.0005	11490.69	5.74
14-15						20108.71	-N.R.-
C9-10							
11-12	100	.00031	166	1.47	.0456	574.53	26.18
12-13	10	.00031		4.22	.01308	2298.14	30.06
13-14	10	.00031	166	1.51	.00468	5745.34	26.89
14-15	10	.00031		.68	.00211	11490.69	24.24
C10-11							
12-13	100	.00031	166	3.61	.1119	574.53	64.29
13-14	100	.00031		1.10	.0341	2298.14	78.37
14-15	10	.00031		3.30	.01020	5745.34	58.60
C11-12							
13-14	100	.00031	166	2.98	.0923	574.53	53.03
14-15	100	.00031		.81	.0251	2298.14	57.68
C12-13							
14-15	100	.00031	166	4.01	.1243	574.53	71.41

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
N.R. = No Reading
* = Questionable Reading

TABLE 8. LINE C

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Steamboat Springs	Line C	6 August 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
C1-2							
3-4	10	.00031	200	1.68	.00520	574.53	2.99
4-5	10	.00031		.88	.00273	2298.14	6.27
5-6	10	.00031	225	.79	.00245	5745.34	14.08
6-7	10	.00031		1.35	.00419	11490.69	48.15
7-8		.00031	200			20108.71	-N.R.-
C2-3							
4-5	10	.00031	166	3.92	.01215	574.53	6.98
5-6	10	.00031	166	1.32	.00409	2298.14	9.40
6-7		.00031	166			5745.34	-N.R.-
7-8	10	.00031	225	.12 *	.00037 *	11490.69	4.25
8-9	10	.00031		.50 *	.00155 *	20108.71	31.17
C3-4							
5-6	10	.001	133	1.78	.0178	574.53	10.23
6-7	10	.001		.90	.0090	2298.14	20.68
7-8	10	.001		.45	.0045	5745.34	25.85
8-9	10	.001		.05 *	.0005 *	11490.69	5.74
9-10						20108.71	-N.R.-
C4-5							
6-7	10	.001	250	3.25	.0325	574.53	18.67
7-8		.001					-N.R.-
8-9		.001	250				-N.R.-
9-10		TX not producing high power settings					-N.R.-
10-11							-N.R.-

TABLE 8. LINE C (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C5-6							
7-8	10	.001	133	1.59	.0159	574.67	9.1
8-9	10	.001		.50	.005	2298.67	11.49
9-10	1	.001		1.65	.00165	5746.7	9.48
10-11	1	.001		.06	.00006	11493.4	.69
C6-7							
8-9	100	.00031	200	.61	.0189	574.67	10.86
9-10	10	.00031	200	1.24	.00384	2298.67	8.83
10-11	1	.00031	200	5.91	.001832	5746.7	10.53
C7-8							
9-10	10	.00031	200	4.42	.01370	574.67	7.87
10-11	10	.00031	200	1.30	.00403	2298.67	9.26
C8-9							
10-11	100	.00031	200	.55	.0171	574.67	9.83

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
- N.R. = No Reading
- * = Questionable Reading

APPENDIX F RESISTIVITY CALCULATIONS--STEAMBOAT SPRINGS

TABLE 9. LINE D.

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Steamboat Springs	Line D	30 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
C1-2								
3-4	100	.00031	166	2.30		.0713	574.53	40.96
4-5	10	.00031	166	1.92		.00595	2298.14	13.74
5-6	10	.00031	166	.83		.00257	5745.34	14.77
6-7							11490.69	-N.R.-
7-8							20108.71	-N.R.-
C2-3								
4-5	100	.00031	133	.83		.0257	574.53	14.77
5-6	0	.00031	133	2.04		.00613	2298.14	14.09
6-7	10	.00031	133	.67		.00208	5745.34	11.95
7-8	1	.00031	133	2.90		.00899	11490.69	10.23
8-9	1	.00031	100	1.95	*	.00605	20108.71	12.17
C3-4								
5-6	100	.00031	100	.77		.0234	574.53	13.44
6-7	10	.00031	100	1.61		.00499	2298.14	11.47
7-8	10	.00031	100	.40		.00124	5745.34	7.12
8-9	1	.00031	100	2.55		.00079	11490.69	9.08
9-10	1	.00031	66	.40	*	.000124	20108.71	2.49
C4-5								
6-7	100	.00031	100	2.35		.0728	574.53	41.83
7-8	100	.00031	133	.75		.0233	2298.14	53.55
8-9	10	.00031	133	3.13		.0097	5745.34	55.73
9-10	10	.00031	133	1.15		.00357	11490.69	41.02
10-11	10	.00031	100	.48		.0048	20108.71	-N.R.-
C5-6								
7-8	100	.001	100	.56		.056	574.53	32.17
8-9	10	.001	100	1.82		.0182	2298.14	41.83
9-10	10	.001	100	.59		.0059	5745.34	33.89
10-11		.001	100				11490.69	-N.R.-

TABLE 9. LINE D (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C6-7							
8-9	100	.001	100	.56	.056	574.53	32.17
9-10	10	.001	100	1.25	.0125	2298.14	28.73
10-11	10	.001	100	.47	.0047	5745.34	27.00
C7-8							
9 10	100	.001	100	.58	.058	574.53	33.32
10-11	10	.001	100	1.81	.0181	2298.14	41.60
C8-9							
10-11	100	.001	100	.75	.075	574.53	43.09

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
N.R. = No Reading
* = Questionable Reading

TABLE 10. LINE E.

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Steamboat Springs	Line D	30 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
C1-3							
5-7	10	.001	66	2.36	.0236	1149.33	27
7-9	10	.00031	133	2.14	.00663	4997.32	33
9-11	1	.00031		2.13 *	.000660	11493.3	7.6
11-13	1	.00031		2.41 *	.000747	22986.6	17.2
13-15	1	.00031		1.35 *	.000419	40226.55	16.85
C3-5							
7-9	100	.00031	100	.67	.0208	1149.33	23.91
9-11	10	.00031	100	.19 *	.00059	4997.32	2.95
11-13	10	.00031		.54	.00167	11493.3	19.2
13-15		.00031	133			22986.6	-N.R.-
15-17		.00031				40226.55	-N.R.-
C5-7							
9-11	10	.00031	200	1.79	.00555	1149.33	6.38
11-13	10	.00031		1.11	.00344	4997.32	17.19
13-15	10	.00031		.42	.00130	11493.3	14.94
15-17	1	.00031		1.82	.000564	22986.6	12.96
17-19		.00031				40226.55	-N.R.-
C7-9							
11-13	10	.00031	166	3.65	.01131	1149.33	13
13-15	10	.00031		.75	.00233	4997.32	11.64
15-17	1	.00031		2.29	.000710	11493.3	8.2
17-19	1	.00031	166	.95	.000305	22986.6	7.0
19-21	1	.00031		.06 **	.00002	40226.56	.8
C9-11							
13-15	10	.001	100	3.49	.0349	1149.33	40
15-17	10	.001		.87	.0087	4497.32	43.48
17-19	1	.001		3.73	.00373	11493.3	42.87
19-21	10	.00031	166	.87	.00270	22986.6	62

TABLE 10. LINE E. (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C11-13							
15-17	10	.001	100	3.52	.0352	1149.33	40.46
17-19	10	.001		.90	.009	4997.32	44.98
19-21	0	.001		.48	.0048	11493.3	55.17
C13-15							
17-19	100	.001		.42	.042	1149.33	48.27
19-21	10	.001		1.23	.0123	4997.32	61.47
C15-17							
19-21	100	.001		.42	.042	1149.33	48.27

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
N.R. = No Reading
* = Questionable Reading

TABLE 11. LINE F

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Steamboat Springs	Line F	8 August 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
C1-3							
5-7	10	.00031	66	.34	.00105	1149.33	1.21
7-9	100	.00031	66	.40	.0124	4997.32	61.97
9-11	10	.00031		.69	.00214	11493.3	24.59
11-13	100	.00031		.95	.0295	22986.6	678.10
13-15	10	.00031		.36	.00112	40226.55	45.05
C3-5							
7-9	100	.00031	66	.57	.0177	1149.33	20.34
9-11		.00031				4997.32	-N.R.-
11-13	100	.00031		1.04	.0322	11493.3	370.08
13-15	10	.00031		.51	.00158	22986.6	36.32
15-17	100	.00031		1.34	.0415	40226.55	1669.40
C5-7							
9-11	100	.00031	133	1.18	.0365	1149.33	41.95
11-13	10	.00031		1.94	.00601	4997.32	30.03
13-15	1	.00031		1.74 *	.000539	11493.3	6.19
1 -17	100	.00031		.51	.0158	22986.6	363.19
17-19		.00031				40226.55	-N.R.-
C7-9							
11-13	100	.00031	200	1.66	.0513	1149.33	58.96
13-15	10	.00031		1.09	.00338	4997.32	16.89
15-17	100	.00031		.28 *	.0087	11493.3	99.99
17-19		.00031				22986.6	-N.R.-
19-21		.00031				40226.55	-N.R.-
C9-11							
13-15	100	.00031	200	.65	.0202	1149.33	23.22
15-17		.00031	200				-N.R.-
17-19		.00031	200				-N.R.-
19-21		.00031					-N.R.-

TABLE 11. LINE F (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C11-13							
15-17	100	.001	200	.34	.034	1149.33	39.08
17-19		.001					-N.R.-
19-21		.001					-N.R.-
C13-15							
17-19							-N.R.-
19-21							-N.R.-
C15-17							
19-21							-N.R.-

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
N.R. = No Reading
* = Questionable Reading

APPENDIX F RESISTIVITY CALCULATIONS--STEAMBOAT SPRINGS

TABLE 12. LINE G

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Steamboat Springs	Line G	6 August 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
C1-2							
3-4	100	.001	200	2.80	.280	574.67	160.9
4-5	100	.001		.45	.045	2298.67	103.4
5-6	10	.001		1.67	.0167	5746.7	95.97
6-7	10	.001		.64	.0064	11493.4	73.56
7-8	10	.001		.48	.0048	20113.45	96.54
C2-3							
4-5	100	.001	133	2.25	.225	574.67	129.30
5-6	10	.001		6.10	.061	2298.67	140.22
6-7	10	.001		2.25	.0225	5746.7	129.30
7-8	10	.001		1.16	.0116	11493.4	133.32
8-9	1	.001		8.00	.008	20113.45	160.91
C3-4							
5-6	100	.001	133	1.60	.160	574.67	91.95
6-7	100	.001		.50	.050	2298.67	114.93
7-8	10	.001		2.28	.0228	5746.7	131.02
8-9	10	.001		1.35	.0135	11493.4	155.16
9-10	10	.001		.43	.0043	20113.45	86.49
C4-5							
6-7	100	.001	166	1.76	.176	574.67	101.14
7-8	100	.001		.59	.059	2298.67	135.62
8-9	100	.001		.27	.027	5746.7	155.16
9-10	10	.001		.82	.0082	11493.4	94.25
10-11	1	.001		1.88	.00188	20113.45	37.81
C5-6							
7-8	100	.001	166	2.20	.220	574.67	126.43
8-9	100	.001		.64	.064	2298.67	147.11
9-10	10	.001		1.55	.0155	5746.7	89.07
10-11	1	.001		2.63	.00263	11493.4	30.23
11-12	1	.001	200			20113.45	-N.R.-

TABLE 12. LINE G (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C6-7							
8-9	100	.001	200	2.66	.266	574.67	152.86
9-10	100	.001		.55	.055	2298.67	126.43
10-11	10	.001		.86	.0086	5746.7	49.42
11-12		.001				11493.4	-N.R.-
12-13		.001				20113.45	-N.R.-
C7-8							
9-10	100	.001	200	4.67	.467	574.67	268.37
10-11	10	.001		3.78	.0378	2298.67	86.89
11-12						5746.7	-N.R.-
12-13						11493.4	-N.R.-
C8-9							
10-11	100	.001	200	2.5	.25	574.67	143.67
11-12	10	.001		3.71 *	.0371	2298.67	85.28
12-13	10	.001				5746.7	-N.R.-
C9-10							
11-12	100	.001	225	1.74 *	.174	574.67	99.99
12-13		.001	225			2298.67	-N.R.-
C10-11							
12-13	100	.001	333	1.78 *	.178	574.67	102.29

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
- N.R. = No Reading
- * = Questionable Reading

APPENDIX G. RESISTIVITY CALCULATIONS--ROUTT HOT SPRINGS

TABLE 13. LINE A

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Routt Hot Springs	Line A	21 July 1981
CHIEF OPERATOR	ASSISTANTS	METHOD
Robert Fargo	Memmi and Strong	Dipole-Dipole (Nx50')

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C10-9.5							
9-8.5	100	.01	66	.55	.55	287.27	158.00
8.5-8	10	.01		1.26	.126	1149.07	144.78
8-7.5	10	.01		.45	.045	2872.67	129.27
7.5-7	10	.001	133	2.20	.022	5745.34	126.40
7-6.5	10	.001		.68	.0068	10054.35	68.37
6.5-6	10	.001		.53	.0053	16086.96	85.26
6-5.5	10	.001	166	.49	.0049	24130.45	118.24
5.5-5	1	.001		4.06	.00406	34472.07	139.96
C9.5-9							
8.5-8	10	.01	66	3.14	.314	287.27	90.20
8-7.5	10	.01		.91	.091	1149.07	104.56
7.5-7	10	.001	133	4.23	.0423	2872.67	121.51
7-6.5	10	.001	133	1.23	.0123	5745.34	70.67
6.5-6	10	.001		.92	.0092	10054.35	92.50
6-5.5	10	.001		.76	.0076	16086.96	122.26
5.5-5	10	.001	166	.66	.0066	24130.45	159.26
5-4.5	10	.001		.51	.0051	34472.07	175.81
C9-8.5							
8-7.5	100	.01	66	.85	.85	287.27	244.18
7.5-7	10	.01		.97	.097	1149.07	111.46
7-6.5	1	.01		1.76	.0176	2872.67	50.56
6.5-6	10	.001	133	.86	.0086	5745.34	49.41
6-5.5	1	.001		2.68	.00268	10054.35	26.95
5.5-5	1	.001		2.12	.00212	16086.96	34.10
5-4.5	1	.001		1.61	.00161	24130.45	38.85
4.5-4	1	.001		1.05	.00105	34472.07	36.19

TABLE 13. LINE A (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C8.5-8							
7.5-7	10	.01	66	4.12	.412	287.27	118.35
7-6.5	10	.01		.60	.060	1149.07	68.94
6.5-6	1	.01		2.83	.0283	2872.67	81.30
6-5.5	10	.001	166	1.50	.0150	5745.34	86.18
5.5-5	10	.001		1.15	.0115	10054.35	115.62
5-4.5	10	.001		.83	.0083	16086.96	133.52
4.5-4	10	.001	166	.70	.007	24130.45	168.91
4-3.5	10	.001		.62	.0062	34472.07	213.73
C8-7.5							
7-6.5	10	.01	66	2.97	.297	287.27	85.32
6.5-6	10	.01		.86	.086	1149.07	98.82
6-5.5	10	.01		.44	.044	2872.67	126.40
5.5-5	10	.001	133	2.95	.0295	5745.34	169.49
5-4.5	10	.001		2.12	.0212	10054.35	213.15
4.5-4	10	.001		1.80	.0180	16086.96	289.56
4-3.5	10	.001		1.62	.0162	24130.45	390.91
3.5-3	10	.001		.80	.0080	34472.07	275.78
C7.5-7							
6.5-6	10	.01	66	3.20	.320	2287.27	91.93
6-5.5	10	.01	66	.94	.094	1149.07	108.01
5.5-5	10	.01	66	.53	.053	2872.67	152.25
5-4.5	10	.001	100	3.46	.0346	5745.34	198.79
4.5-4	10	.001		2.60	.0260	10054.35	261.41
4-3.5	10	.001		1.90	.0190	16086.96	305.65
3.5-3	10	.001	100	.82	.0082	24130.45	197.87
3-2.5	1	.001		7.59	.00759	34472.07	261.64
C7-6.5							
6-5.5	10	.01	66	3.00	.30	287.27	86.18
5.5-5	10	.01		1.01	.101	1149.07	116.06
5-4.5	10	.01		.66	.066	2872.67	187.60
4.5-4	100	.001	100	.45	.045	5745.34	258.54
4-3.5	10	.001		3.38	.0338	10054.35	339.84
3.5-3	10	.001		1.49	.0149	16086.96	239.69
3-2.5	10	.001		1.34	.0134	24130.45	323.35
2.5-2	10	.001		.88	.0088	34472.07	275.78

TABLE 13. LINE A (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C6.5-6							
5.5-5	10	.01	66	3.71	.371	287.27	106.58
5-4.5	10	.01		1.57	.157	1149.07	180.40
4.5-4	10	.01		.98	.098	2872.67	281.52
4-3.5	100	.001	133	.70	.070	5745.34	402.17
3.5-3	10	.001		2.95	.0295	10054.35	296.60
3-2.5	10	.001		2.59	.0259	16086.96	416.65
2.5-2	10	.001		1.55	.0155	24130.45	374.02
2-1.5	10	.001		.92	.0092	34472.07	317.14
C6-5.5							
5-4.5	100	.01	66	.40	.40	287.27	114.91
4.5-4	10	.01		2.11	.211	1149.07	242.45
4-3.5	10	.01		1.25	.125	2872.67	359.08
3.5-3	10	.001	133	4.70	.047	5745.34	270.03
3-2.5	100	.001		.40	.040	10054.35	402.17
2.5-2	10	.001		2.31	.0231	16086.96	371.61
2-1.5	10	.001		1.22	.0122	24130.45	294.39
1.5-1	10	.001		1.06	.0106	34472.07	365.40
C5.5-5							
4.5-4	100	.01	66	.78	.78	287.27	224.07
4-3.5	10	.01		2.90	.290	1149.07	333.23
3.5-3	10	.01		.86	.086	2872.67	247.05
3-2.5	10	.01	66	.65	.065	5745.34	373.45
2.5-2	10	.001	100	3.78	.0378	10054.35	380.05
2-1.5	10	.001		1.83	.0183	16086.96	294.39
1.5-1	10	.001		1.54	.0154	24130.45	371.61
C5-4.5							
4-3.5	100	.01	66	1.19	1.19	287.27	341.85
3.5-3	10	.01		1.90	.190	1149.07	218.32
3-2.5	10	.01		1.13	.113	2872.67	324.61
2.5-2	100	.001	100			5745.34	-N.R.-
2-1.5	10	.001		2.46	.0246	10054.35	247.34
1.5-1	10	.001	133	1.96	.0196	16086.96	315.30
C4.5-4							
3.5-3	100	.01	66	.86	.86	287.27	247.05
3-2.5	10	.01		2.84	.284	1149.07	326.33
2.5-2	10	.01		1.28	.128*	2872.67	367.70
2-1.5	10	.001	133	4.96	.0496	5745.34	284.97
1.5-1	10	.001		3.65	.0365	10054.35	366.98

TABLE 13. LINE A (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C4-3.5							
3-2.5	100	.01	66	.90	.90	287.27	258.54
2.5-2	10	.01			.25 (?)	1149.07	287.27
2-1.5	100	.001	133	1.26	.126	2872.67	361.96
1.5-1	100	.001	133	.83	.083	5745.34	476.86
C3.5-3							
2.5-2	+10	.1	33	1.61	1.61*	287.27	462.50
2-1.5		.01				1149.07	-N.R.-
1.5-1		.001	200			2872.67	-N.R.-
C3-2.5							
2-1.5	100	.01	66	1.55	1.55	287.27	445.27
1.5-1						1149.07	-N.R.-

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
N.R. = No Reading
* = Questionabale Reading

APPENDIX G. RESISTIVITY CALCULATIONS--ROUTT HOT SPRINGS

TABLE 14. LINE B

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Routt Hot Springs	Line B	22 July 1981
CHIEF OPERATOR	ASSISTANTS	METHOD
Robert Fargo	Memmi and Strong	Dipole-Dipole (Nx50')

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C8-7.5							
7-6.5	10	.01	66	1.88	.188	287.27	54.01
6.5-6	10	.01		1.18	.118	1149.07	135.59
6-5.5	10	.001	133			2872.67	-N.R.-
5.5-5	10	.001		.62	.0062	5745.34	35.62
5-4.5	1	.001		2.02	.00202	10054.35	20.31
4.5-4	1	.001		2.96	.00296	16086.96	47.62
4-3.5	1	.001		1.25	.00125	24130.45	30.16
3.5-3	1	.001		1.26	.00127	34472.07	43.78
C7.5-7							
6.5-6	100	.01	66	.40	.40	287.27	114.91
6-5.5		.01				1149.07	-N.R.-
5.5-5	10	.001	133	1.76	.0176	2872.67	50.56
5-4.5	10	.001		.43	.0043	5745.34	24.71
4.5-4	10	.001		0.59	.0059	10054.35	59.32
4-3.5	1	.001		2.22	.00222	16086.96	35.71
3.5-3	1	.001		2.30	.00230	24130.45	55.50
3-2.5	1	.001		3.18	.00318	34472.07	109.62
C7-6.5							
6-5.5	10	.01	66	2.18	.218	287.27	62.62
5.5-5	1	.01		3.68	.0368	1149.07	42.29
5-4.5	1	.01		.68	.0068	2872.67	19.53
4.5-4	10	.001	133	.87	.0087	5745.34	49.98
4-3.5	1	.001		3.53	.00353	10054.35	35.49
3.5-3	1	.001		3.13	.00313	16086.96	50.35
3-2.5	1	.001		3.57	.00357	24130.45	86.15
2.5-2	1	.001		1.94	.00194	34472.07	66.88

TABLE 14. LINE B (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C6.5-6							
5.5-5	10	.01	66	1.72	.172	287.27	49.41
5-4.5	1	.01		2.53	.0253	1149.07	29.07
4.5-4	10	.001	166	3.12	.0312	2872.67	89.63
4-3.5	10	.001		1.39	.0139	5745.34	79.86
3.5-3	10	.001		.99	.0099	10054.35	99.54
3-2.5	10	.001		.86	.0086	16086.96	138.35
2.5-2	10	.001		.51	.0051	24130.45	123.06
2-1.5	10	.001		.42	.0042	34472.07	144.78
C6-5.5							
5-4.5	10	.01	66	.37	.037	287.27	10.63
4.5-4	1	.01		2.89	.0289	1149.07	33.21
4-3.5	1	.01		.84	.0084	2872.67	24.13
3.5-3	10	.001	166	.68	.0068	5745.34	39.07
3 2.5	10	.001		.64	.0064	10054.35	64.35
2.5-2	1	.001		2.64	.00264	16086.96	42.47
2-1.5	1	.001		2.26	.00226	24130.45	54.53
1.5-1	1	.001		1.30	.00130	34472.07	44.81
C5.5-5							
4.5-4	10	.01	66	1.42	.142	287.27	40.79
4-3.5	1	.01		3.24	.0324	1149.07	37.23
3.5-3	1	.01		1.66	.0166	2872.67	47.69
3-2.5	10	.001	133	.98	.0098	5745.34	56.30
2.5-2	10	.001		.48	.0048	10054.35	48.26
2-1.5	10	.001		.37	.0037	16086.96	59.52
1.5-1	1	.001		2.19	.00219	24130.45	52.84
C5-4.5							
4-3.5	10	.01	66	3.02	.302	287.27	86.76
3.5-3	10	.01		.97	.097	1149.07	111.46
3-2.5	10	.01		.46	.046	2872.67	132.14
2.5-2	10	.001	133	1.68	.0168	5745.34	96.52
2-1.5	10	.001		1.26	.0126	10054.35	126.68
1.5-1	10	.001		.69	.0069	16086.96	111.00
C4.5-4							
3.5-3	100	.01	66	.92	.92	287.27	264.29
3-2.5	10	.01		2.26	.226	1149.07	259.69
2.5-2	10	.01		.58	.058	2872.67	166.61
2-1.5	100	.001	133	.39	.039	5745.34	224.07
1.5-1	10	.001		1.95	.0195	10054.35	196.06

TABLE 14. LINE B (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C4-3.5							
3-2.5	100	.01	66	1.21	.121	287.27	347.60
2.5-2	10	.01		1.23	.123	1149.07	141.33
2-1.5	10	.01		.64	.064	2872.67	183.85
1.5-1	1	.01		2.54	.0254	5745.34	145.93
C3.5-3							
2.5-2	100	.01	66	.70	.70	287.27	201.09
2-1.5	10	.01		2.38	.238	1149.07	273.48
1.5-1	10	.01		.79	.079	2872.67	226.94
C3-2.5							
2-1.5	100	.01	66	2.33	2.33	287.27	669.34
1.5-1	100	.01		.54	.54	1149.07	620.50
C2.5-2							
1.5-1	100	.01	66	2.42	2.42	287.27	695.19

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
N.R. = No Reading
* = Questionabale Reading

TABLE 15. LINE C.

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Routt Hot Springs	Line C	27 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
C1-2							
3-4	100	.01	133	.56	.56	574.53	321.74
4-5	10	.01		1.86	.186	2298.14	427.45
5-6	10	.01		.61	.061	5745.34	350.47
6-7	10	.01		.21	.021*	11490.69	241.30
7-8	10	.01	100	.21	.021*	20108.71	422.28
C2-3							
4-5	100	.01	100	.93	.93	574.53	534.31
5-6	10	.01		1.75	.175	2298.14	402.17
6-7	10	.01		.44	.044	5745.34	252.79
7-8	1	.01	100	3.22	.0322	11490.69	370.00
8-9	1	.01		3.69	.0369*	20108.71	742.01
C3-4							
5-6	100	.01	133	.71	.71	574.53	407.92
6-7	10	.01		1.30	.130	2298.14	298.76
7-8	10	.01		.63	.063	5745.34	361.96
8-9	10	.01		.42	.042	11490.69	482.61
9 10	1	.01		2.05	.0205	20108.71	412.23
C4-5							
6-7	100	.01	100	.33	.33	584.53	189.59
7-8	10	.01		1.36	.136	2298.14	312.55
8-9	10	.01	100	.71	.071	5745.34	407.92
9-10	10	.01	100	.38	.038	11490.59	436.65
10-11	1	.01	100			20108.71	-N.R.-
C5-6							
7-8	10	.01	66	2.86	.286	574.53	164.32
8-9	100	.001	300	1.29	.129	2298.14	296.46
9-10	100	.001		.49	.049	5745.14	281.52
10-11	10	.001		1.53	.0153	11490.69	175.81
11-12	10	.001		.95	.0095	20108.71	191.03

TABLE 15. LINE C (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C6-7							
8-9	100	.01	100	.60	.60	574.53	344.72
9-10	10	.01		1.46	.146	2298.14	335.53
10-11	10	.01		.42	.042	5745.34	241.30
11-12	10	.01		.22	.022*	11490.69	252.80
12-13		.01				20108.71	-N.R.-
C7-8							
9-10	100	.01	100	.40	.402	574.53	229.81
10-11	10	.01		.74	.074	2298.14	170.06
11-12	10	.01		.49	.049	5745.34	281.52
12-13	10	.01		.15	.015*	11490.69	172.36
C8-9							
10-11	100	.001	250	2.08	.208	574.53	119.50
11-12	100	.001		.93	.093	2298.14	213.73
12-13	10	.001		2.22	.022	5745.34	126.40
C9-10							
11-12	100	.001	275	.99	.099	574.53	56.88
12-13	10	.001		1.99	.0199	2298.14	45.73
C10-11							
12-13	100	.001	275	1.33	.133	574.53	76.41

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
N.R. = No Reading
* = Questionabale Reading

TABLE 16. LINE D

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Routt Hot Springs	Line D	23 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
C6-7							
8-9	10	.01	66	1.86	.186	574.53	106.86
9-10	10	.01		.49	.049	2298.14	112.61
10-11	10	.001	100	.91	.0091	5745.34	52.28
11-12	10	.001		.90	.009	11490.69	103.43
C7-8							
9-10	10	.01		1.98	.198	574.53	113.76
10-11	10	.01	54	.54	.054	2298.14	124.10
11-12	10	.001	100	2.35	.0235	5745.34	135.01
C8-9							
10-11	10	.01	66	1.46	.146	574.53	83.88
11-12	10	.01		.47	.047	2298.14	108.01
C9-10							
11-12	10	.01	66	2.53	.253	574.53	143.36
C3-4							
5-6	100	.01	66	.50	.50	574.53	287.27
6-7	10	.01		1.50	.150	2298.14	344.77
7-8	100	.001	133	.50	.050	5745.34	287.27
8-9	10	.001	133	.43	.0043	11490.69	49.41
9-10	1	.001		2.54	.00254	20108.71	51.08
C4-5							
6-7	10	.01	66	2.94	.294	574.53	168.91
7-8	10	.01		.77	.077	2298.14	176.96
8-9	1	.01		1.18	.0118	5745.34	67.79
9-10	10	.001	133	.89	.0089	11490.69	102.27
10-11	1	.001		2.86	.00286	20108.71	57.51

TABLE 16. LINE D (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C5-6							
7-8	100	.01	66	.57	.57	574.53	327.48
8-9	10	.01		.51	.051	2298.14	117.21
9-10	10	.001	100	2.65	.0265	5745.34	152.25
10-11	10	.001	100	.68	.0068	11490.69	78.14
11-12	10	.001		.68	.0068	20108.71	136.74
C0-1							
2-3	10	.01	100	3.85	.385	574.53	221.94
3-4	10	.01		.49	.049	2298.14	112.61
4-5	1	.01		1.25	.0125	5745.34	71.82
5-6	1	.001	366	2.03	.00203	11490.69	23.33
6-7	10	.001		.80	.008	20108.71	160.87
C1-2							
3-4	10	.01	66	1.17	.117	574.53	67.22
4-5	1	.01		1.82	.0182	2298.14	41.83
5-6	1	.001	250	1.36	.00136	5745.34	7.81
6-7	10	.001	250	1.07	.0107	11490.69	122.95
7-8	10	.001		2.59	.0259	20108.71	520.82
C2-3							
4-5	10	.01	66	3.66	.366	574.53	210.28
5-6	10	.01		1.20	.120	2298.14	275.78
6-7	10	.01		.60	.060	5745.34	344.72
7-8	10	.001	166	2.35	.0235	11490.69	270.03
8-9	1	.001		1.99	.00199	20108.71	40.02
C3-2							
1-0	100	.01	66	1.13	1.13	574.53	649.22
0-1	10	.01		2.49	.249	2298.14	572.24
1-2	10	.01		.65	.065	5745.34	373.45
2-3	10	.001	133	1.72	.0172	11490.69	197.64
3-4	10	.001		.28	.0028*	20108.71	56.30
C2-1							
0-1	100	.01	66	2.17	2.17	574.53	1246.73
1-2	100	.01		.35	.35	2298.14	804.35
2-3	10	.01		.50	.050	5745.34	287.27
3-4	10	.001	166	1.10	.011	11490.69	126.40
4-5		.001				20108.71	-N.R.-

TABLE 16. LINE D (CONTD.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C1-0							
1-2	100	.01	66	1.47	1.47	574.53	844.56
2-3	10	.01		1.45	.145	2298.14	333.23
3-4	10	.01		.30	.030	5745.34	172.36
4-5	10	.001	333	.86	.0086	11490.69	98.82
5-6	1	.001		2.30	.0023	20108.71	46.25
C6-5							
4-3	100	.01	66	.67	.67	574.53	384.94
3-2	10	.01		.61	.061	2298.14	140.19
2-1	1	.01		5.67	.0567	5745.34	325.76
1-0	10	.001	225	2.45	.0245	11490.69	281.52
0-4	10	.001		2.66	.0266	20108.71	534.89
C5-4							
3-2	10	.01	66	2.41	.241	574.53	138.46
2-1	10	.01		1.44	.144	2298.14	330.93
1-0	10	.01		.68	.068	5745.34	390.68
0-1	10	.001	166	3.42	.0342	11490.69	392.98
1-2	10	.001		1.27	.0127	20108.71	255.38
C4-3							
2-1	10	.01	66	3.45	.345	574.53	198.21
1-0	10	.01		.85	.085	2298.14	195.34
0-1	1	.01		2.43	.0243	5745.34	139.61
1-2	10	.001	133	.62	.0062	11490.69	71.24
2-3	1	.001		1.78	.00178	20108.71	35.79

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
N.R. = No Reading
* = Questionabale Reading

APPENDIX G. RESISTIVITY CALCULATIONS--ROUTT HOT SPRINGS

TABLE 17. LINE E

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Routt Hot Springs	Line E	28 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
C1-0							
1-2	1000	.001	366	.48	.48	574.67	275.84
2-3	100	.001		.70	.070	2298.67	160.91
3-4	10	.001		2.26	.0226	5746.7	129.87
4-5	10	.001		1.50	.0150	11493.4	172.40
5-6	10	.001		1.05	.0105	20113.45	211.19
C0-1							
2-3	100	.001	433	4.82	.482	574.67	276.99
3-4	10	.001		8.35	.0835	2298.67	191.34
4-5	100	.001		.40	.040	5746.7	229.87
5-6	10	.001	433	2.60	.0260	11493.4	298.83
6-7	10	.001		1.69	.0169	20113.45	339.92
C1-2							
3-4	100	.001	366	1.90	.190	574.67	109.19
4-5	100	.001		.54	.054	2298.67	124.13
5-6	10	.001		3.78	.0378	5746.7	217.22
6-7	10	.001		2.17	.0217	11493.4	249.41
7-8	10	.001		1.12	.0112	20113.45	225.27
C2-3							
4-5	10	.01	100	2.44	.244	574.67	140.22
5-6	10	.01		.65	.065	2298.67	149.41
6-7	10	.01		.35	.035	5746.7	201.13
7-8	10	.001	500	1.75	.0175	11493.4	201.13
8-9	1	.01	100	1.21	.0121	20113.45	243.37

TABLE 17. LINE E (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C3-4							
5-6	10	.01	133	2.11	.211	574.67	121.25
6-7	10	.01		.90	.090	2298.67	206.88
7-8	10	.01		.35	.035	5746.7	201.13
8-9	10	.01		.17	.017*	11493.4	195.39
9-10	1	.01		1.52	.0152	20113.45	305.72
C4-5							
6-7	10	.01	133	2.79	.279	574.67	160.33
7-8	10	.01		.65	.065	2298.67	149.41
8-9	10	.01		.37	.037	5746.7	212.63
9-10	1	.01		2.56	.0256	11493.4	294.23
10-11	1	.01		.89	.0089	20113.45	179.01
C5-6							
7-8	10	.01	100	4.68	.468	574.67	268.95
8-9	10	.01		1.30	.130	2298.67	298.83
9-10	10	.01		.69	.069	5746.7	396.52
10-11	1	.01		1.58	.0158	11493.4	181.60
11-12	1	.01		1.24	.0124	20113.45	249.41
C6-7							
8-9	100	.01	100	.49	.49	574.67	281.59
9-10	10	.01		1.34	.134	2298.67	308.02
10-11	10	.001	333	2.90	.0290	5746.7	166.65
11-12	10	.001	333	1.85	.0185	11493.4	212.63
12-13	10	.001		.60	.006	20113.45	120.68
C8-9							
10-11	10	.01	100	5.24	.524	574.67	301.13
11-12	10	.01		1.40	.140	2298.67	321.81
12-13	10	.001	333	2.55	.0255	5746.7	146.54
				subsurface fault or collapsed elevator shaft			
C9-10							
11-12	100	.01	66	.65	.65	574.67	373.54
12-13	10	.01		.62	.062	2298.67	142.52
C10-11							
12-13	100	.01	100	.60	.60	574.67	344.80

LEGEND:

Range = Gain
VP = Balance Control to Null Meter
Pa = Apparent Resistivity
N.R. = No Reading
MA = Dummy TX Current Switch
G.F. = Geometric Factor
DV/I = Range x MA x Vp
* = Questionable Reading

APPENDIX G. RESISTIVITY CALCULATIONS--ROUTT HOT SPRINGS

TABLE 18. LINE F

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Routt Hot Springs	Line F	10 August 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
C1-2							
3-4	10	.1	66	1.21	1.210	574.67	695.35
4-8	1	.1		1.55	.155	2298.67	356.29
5-6	10	.01	133	1.12	.112	5746.7	643.63
6-7	10	.01		.57	.057	11493.4	655.12
7-8	1	.01		4.68	.0468	20113.45	941.31
C2-3							
4-5	10	.01	133	4.73	.473	574.67	271.82
5-6	10	.01		2.07	.207	2298.67	1475.82
6-7	10	.01		.83	.083	5746.7	476.98
7-8	10	.01	133	.61	.061	11493.4	
8-9	1	.01		3.05	.0305	20113.45	613.46
C3-4							
5-6	100	.01	66	1.04	1.04	574.67	597.66
6-7	10	.01		2.47	.247	2298.67	567.77
7-8	10	.01		1.35	.135	5746.7	775.80
8-9	10	.01		.59	.059	11493.4	678.11
9-10	10	.001	200	2.68	.0268	20113.45	539.04
C4-5							
6-7	100	.01	66	1.07	1.07	574.67	614.90
7-8	10	.01		3.42	.342	2298.67	786.14
8-9	10	.01		1.12	.112	5746.7	643.63
9-10	10	.001	225	4.66	.0466	11493.4	535.59
10-11	10	.001		3.57	.0357	20113.45	718.05
C5-6							
7-8	100	.01	66	2.03	2.03	574.67	1166.58
8-9	10	.01		4.49	.449	2298.67	1032.10
9-10	10	.01		1.80	.180	5746.7	1034.41
10-11	10	.01		1.25	.125	11493.4	1436.67
11-12	10	.01		.59	.059	20113.45	1186.69

TABLE 18. LINE F (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C6-7							
8-9	100	.01	66	1.10	1.10	574.67	632.14
9-10	10	.01		2.79	2.79	2298.67	641.33
10-11	10	.01		1.33	.133	5746.7	764.31
11-12	10	.01		.59	.059	11493.4	678.11
12-13	10	.001	275	3.45	.0345	20113.45	693.91
C7-8							
9-10	100	.01	66	1.37	1.37	574.67	787.30
10-11	10	.01		4.18	.418	2298.67	960.84
11-12	100	.001	200	1.53	.153	5746.7	879.24
12-13	100	.001		.83	.083	11493.4	953.95
13-14	10	.001		7.91	.0791	20113.45	1590.97
C8-9							
10-11	100	.01	66	.99	.99	574.67	568.92
11-12	10	.01		2.85	.285	2298.67	655.12
12-13	10	.01		1.44	.144	5746.7	827.52
13-14	100	.001	100	1.35	.135	11493.4	1551.61
14-15	100	.001		.58	.058	20113.45	1166.58
C9-10					Creek		
11-12	10	.01	66	5.60	.560	574.67	321.81
12-13	10	.01		2.06	.206	2298.67	473.53
13-14	10	.01		1.79	.179	5746.7	1028.66
14-15	10	.001	200	6.96	.0696	11493.4	799.94
C10-11							
12-13	10	.01	66	6.26	.626	574.67	359.74
13-14	10	.01		3.45	.345	2298.67	793.04
14-15	10	.01	66	1.15	.115	5746.7	660.87
C11-12							
13-14	100	.01	66	1.14	1.14	574.67	655.12
14-15	10	.01		2.41	.241	2298.67	553.98
C12-13							
14-15	10	.01	66	9.60	.960	574.67	551.68

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
- N.R. = No Reading
- * = Questionabale Reading

APPENDIX G. RESISTIVITY CALCULATIONS--ROUTT HOT SPRINGS

TABLE 19. LINE G

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Routt Hot Springs	Line G	11 August 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
C1-2							
3-4	100	.01	100	.94	.94	574.67	540.19
4-5	10	.01	66	2.08	.208	2298.67	478.12
5-6	10	.01		.69	.069	5746.7	396.52
6-7	1	.01		3.56	.0356	11493.4	409.16
7-8	10	.001	333	2.99	.0299	20113.45	601.39
C2-3							
4-5	100	.01	66	.80	.80	574.67	459.74
5-6	10	.01		1.92	.192	2298.67	441.34
6-7	10	.01		.81	.081	5746.7	465.48
7-8	100	.001	225	.58	.058	11493.4	666.62
8-9	10	.001		2.76	.0276	20113.45	555.13
C3-4							
5-6	100	.01	66	.87	.87	574.67	499.96
6-7	10	.01		2.25	.225	2298.67	517.20
7-8	10	.01		1.22	.122	5746.7	701.10
8-9	10	.01		.46	.046	11493.4	528.70
9-10	100	.001	166	.40	.040	20113.45	804.54
C4-5							
6-7	100	.01	66	.93	.93	574.67	534.44
7-8	10	.01		2.75	.275	2298.67	632.13
8-9	10	.01		.68	.068	5746.7	390.78
9-10	10	.001	200	3.78	.0378	11 93.4	434.35
10-11	10	.001		1.66	.0166	20113.45	333.88
C5-6							
7-8	100	.01	66	1.31	1.31	574.67	752.82
8-9	10	.01		2.21	.221	2298.67	508.01
9-10	10	.01		1.20	.120	5746.7	689.60
10-11	10	.01		.53	.053	11493.4	609.15
11-12	10	.001	275	1.78	.0178	20113.45	358.02

TABLE 19. LINE G (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C6-7							
8-9	100	.01	66	.73	.73	574.67	419.51
9-10	10	.01		2.34	.234	2298.67	537.89
10-11	10	.01		.86	.086	5746.7	494.22
1 -12	10	.001	333	2.74	.0274	11493.4	314.92
12-13	10	.001		2.57	.0257	20113.45	516.91
C7-8							
9-10	100	.01	66	1.15	1.15	574.67	660.87
10-11	10	.01		2.44	.244	2298.67	560.88
11-12	10	.01		.56	.056	5746.7	321.82
12-13	10	.01		.48	.048	11493.4	551.68
13-14	10	.001	333	3.78	.0378	20113.45	760.29
C8-9							
10-11	100	.01	66	1.08	1.08	574.67	620.64
11-12	10	.01		1.68	.168	2298.67	386.18
1 -13	10	.01		1.03	.103	5746.7	591.91
1 -14	100	.001	275	.61	.061	11493.4	701.10
14-15	10	.001		3.45	.0345	20113.45	693.91
C9-10							
11-12	100	.01	66	1.31	1.31	574.67	752.82
12-13	100	.01		.50	.50	2298.67	1149.33
13-14	10	.01		2.23	.223	5746.7	1281.51
14-15	10	.01		1.12	.112	11493.4	1287.26
C10-11							
12-13	100	.01	66	1.12	1.12	574.67	643.63
13-14	10	.01		3.49	.349	2298.67	802.23
14-15	10	.01		1.68	.168	5746.7	965.44
C11-12							
13-14	100	.01	66	1.13	1.13	574.67	649.38
14-15	10	.01		3.27	.327	2298.67	751.66
C12-13							
14-15	100	.01	66	1.85	1.85	574.67	1063.14

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
N.R. = No Reading
* = Questionabale Reading

APPENDIX H
GEOMETRIC FACTOR TABLES

TABLE 20 SCHLUMBERGER METHOD

2l (ft) / L(ft)	25	50	75	100	200	300
50	95.78	47.89	31.93	23.94	11.97	7.98
75	215.5	107.75	71.83	53.87	26.94	17.96
100	383.11	191.55	127.70	95.78	47.89	31.93
200	1532.44	766.22	510.81	383.11	191.56	127.70
300	3447.99	1724	1149.33	862	431	287.33
400	6129.87	3064.89	2043.26	1532.44	766.22	510.81
500	9577.77	4788.89	3192.59	2394.44	1197.22	798.15
600	1391.99	6896	4597.33	3447.99	1724	1149.33
700	18772.43	9386.22	6257.48	4693.11	2346.55	1564.37
800	24519.1	12259.54	8173.03	6129.77	3064.89	2043.26
900	31031.99	15515.99	10344	7758	3879	2586
1000	38311.1	19155.55	12770.36	9577.77	4788.89	3192.59
1100	46356.42	23178.21	15452.14	11589.11	5794.55	3863.04
1200	55167.97	27583.99	18389.32	13791.99	6896	4597.33
1300	64745.74	32372.87	21581.91	16186.44	8093.22	5395.48
1400	75083.74	37544.87	25029.91	18772.44	9386.22	6257.48
1500	86199.96	43099.98	28733.32	21548.98	10774.99	7183.3

TABLE 21. DIPOLE-DIPOLE GEOMETRIC FACTOR TABLE

n / a(ft)	25	50	100	150	200	300
1	143.67	287.33	574.67	862	1149.33	1724
2	574.67	1149.32	2298.67	3448	4597.32	6896
3	1436.7	2873.3	5746.7	8620	11493.3	17240
4	2873.4	5746.6	11493.4	17240	22986.6	3480
5	5028.45	1056.55	20113.45	30170	40226.55	60340
6	8045.52	16090.48	32181.52	48272	64362.48	96544
7	11924.61	23848.39	47697.61	71546	95394.39	143092
8	17240.4	34479.6	68960.4	103440	137913.6	206880
9	23705.55	47409.45	94820.55	14230	189639.45	284460
10	31607.4	63212.6	126429.4	189640	252852.6	379280

TABLE 22. WENNER GEOMETRIC FACTOR TABLE

2PI / a(ft)	25	50	100	200	300	400	500
6.2	157	314.16	628.32	1256.64	1884.64	2513.27	3141.6

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, 1983, Free over the counter.

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