RESOURCE SERIES 20
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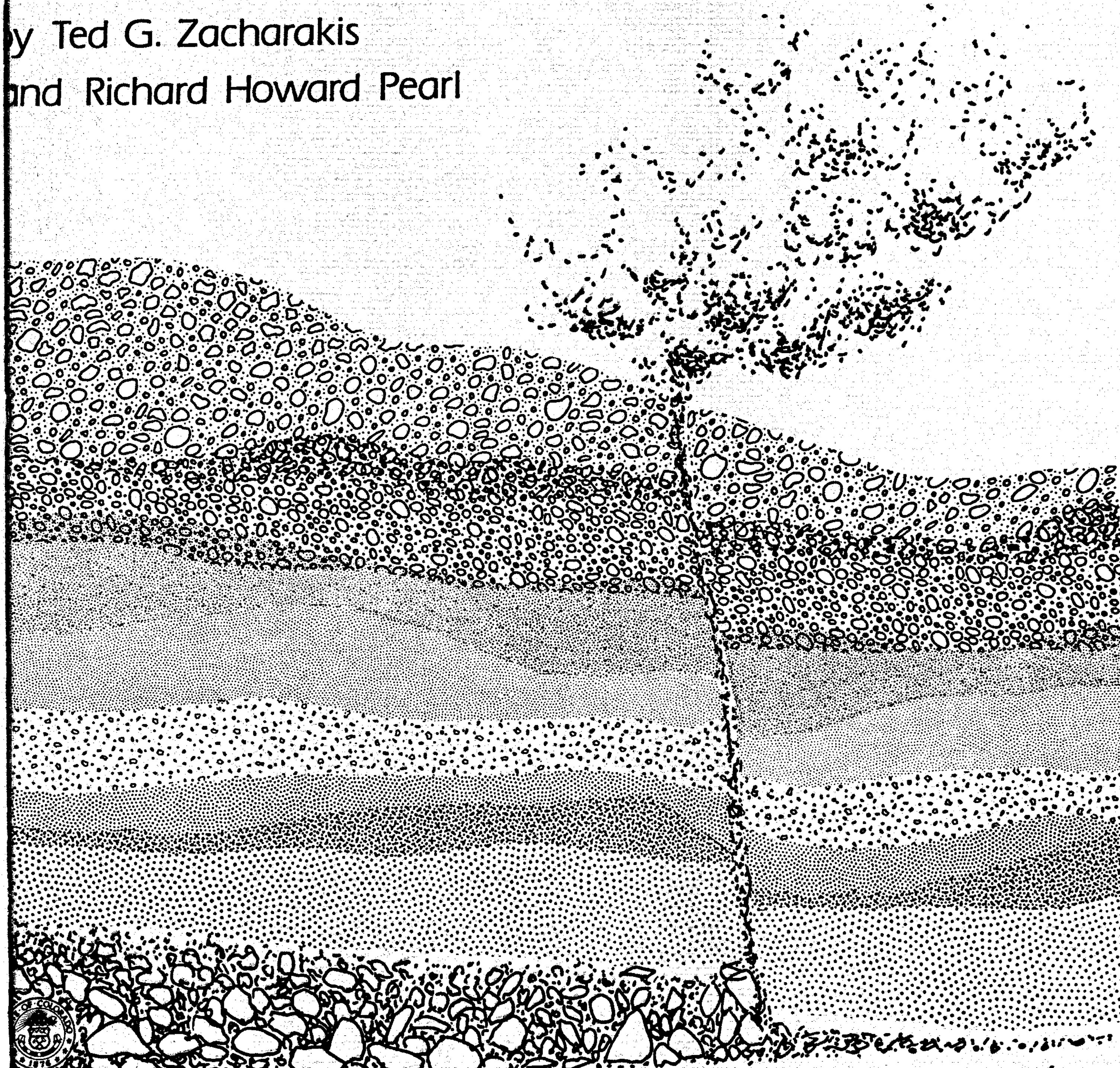
Geothermal Resource Assessment of Cañon City, Colorado Area

by Ted G. Zacharakis
and Richard Howard Pearl



Colorado Geological Survey / Department of Natural Resources / Denver, Colorado / 1982

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GEOTHERMAL RESOURCE ASSESSMENT OF CANON CITY, COLORADO AREA

by

Ted G. Zacharakis
Richard Howard Pearl

Prepared by the
COLORADO GEOLOGICAL SURVEY
in cooperation with the
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Colorado Geological Survey
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NOTICE

NOTICE

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GEOTHERMAL RESOURCE ASSESSMENT OF CANON CITY, COLORADO AREA

by
Ted G. Zacharakis and Richard Howard Pearl

ABSTRACT

In 1979 a program was initiated to fully define the geothermal conditions of an area east of Canon City, bounded by the mountains on the north and west, the Arkansas River on the south and Colorado Highway 115 on the east. Within this area are a number of thermal springs and wells in two distinct groups. The eastern group consists of 5 thermal artesian wells located within one mile of Colorado Highway 115 from Penrose on the north to the Arkansas River on the south. The western group, located in and adjacent to Canon City, consists of one thermal spring on the south bank of the Arkansas River on the west side of Canon City, a thermal well in the northeast corner of Canon City, another well along the banks of Four Mile Creek east of Canon City and a well north of Canon City on Four Mile Creek.

All the thermal waters in the Canon City Embayment, of which the study area is part of, are found in the study area. The thermal waters unlike the cold ground waters of the Canon City Embayment, are a calcium-bicarbonate type and range in temperature from 79°F (26°C) to a high of 108°F (42°C). The total combined surface discharge of all the thermal water in the study area is in excess of 532 acre feet (A.F.) per year.

Gradients in 11 temperature gradient holes ranged from 2.17°F/100 ft (21.8°C/km) to a high of 4.92°F/100 ft (89.7°C/km). The highest gradients were measured in the southeast part of the study area on the Brush Hollow Anticline. No heat flow measurements were made as part of the study. However the regional heat flow map of Colorado shows that the study area has a heat flow of 90mW/m2, about normal for the Colorado Front Range.

A thick sequence of sedimentary, granitic and metamorphic rocks ranging in age from Precambrian to Recent are found in the study area. The Canon City Embayment is a south-southeastward plunging syncline and within the embayment are a number of smaller synclines and anticlines. The most prominent anticline, is the north trending Brush Hollow Anticline located on the east side of the study area. Preliminary subsurface geological and geophysical evidence suggests that this structure is a faulted horst block. The margins of the embayment are cut by numerous faults and fractures with some minor surface faulting within the basin.

The prinicpal thermal water bearing bedrock aquifers in the study area are the Dakota Group and the Morrison Formation.

During the course of this investigation the following geophysical investigations were conducted: Electrial resistivity; telluric; augio-magnetotelluric; and seismic. The electrical resistivity surveys were effective in delineating the near surface parts of the Canon City Hot Springs reservoir. Due to limitations of the equipment these surveys were less than satisfactory in the deeper eastern artesian thermal well area. The telluric surveys were useful in further defining the structural conditions of the Brush Hollow Anticline (Horst?). The Audio-magnetotelluric survey indicated two possible geothermal systems, one in the vicinity of Canon City and the other in the Penrose area. The seismic surveys turned up evidence of a deep geological

structure. It was suggested that this structure could be of several origins: an overthrust with subsequent movement; a sub-basement reflection within the basement; or a deep geothermal front.

The soil mercury geochemical sampling program was conducted in three areas: Around the Penrose Artesian Thermal Well; on the grounds of the Colorado Dept. of Corrections; and adjacent to the Canon City Hot Springs. Due to unfavorable geological conditions and contamination of the surface by the activities of man these surveys were unsatisfactory in defining the geothermal conditions of the study area.

Examination of geological and hydrogeological data suggests that the origin of the thermal waters is due to a combination of favorable geological conditions plus decay of radiaoctive minerals. The thermal ground waters of the study area contain large amounts of radioactive mineral deposits. Overlying these aquifers is a thick sequence of Pierre Shale, a good insulating blanket. This unit traps and retains the heat given off by decaying radioactive minerals which then heats the recharging ground waters.

The thermal resources of the Canon City area appear to be large. It is calculated that in excess of 532 Acre Feet (A.F.)/year of thermal waters are currently being discharged to the surface. In addition it is estimated that there are approximately 264,000 A.F. of thermal waters that could be recovered in the study area. While these resources are large their development will be limited by the depth at which they are found. In some parts of the study area, especially the eastern part, the waters are found at shallow depth, while in others they are found at great depths.

Presented in the appendices are tables showing the dissolved minerals, trace elements and radioactivty levels found in the thermal waters of the study area. Also presented are a complete description of the factors affecting the electrical resistivity measurements, a description of the electrical resistivity equipment used, and the resistivity field procedures. Electrical resistivity calculations are also enclosed. Complete copies of two reports detailing findings of the telluric and seismic geophysical studies are also enclosed.

INTRODUCTION

In 1979, the Colorado Geological Survey, in cooperation with the U.S. Dept. of Energy, Division of Geothermal Energy, under Contract No. DE-AS07-77ET28365, initiated a program to delineate the geological features controlling the occurrence of those geothermal resources in Colorado believed to have a high potential for near term development. This effort consisted of a literature search, geologic and hydrogeological mapping, geophysical and geochemical surveys, and drilling of temperature gradient holes.

One of the regions investigated was the Canon City Area, located in central Fremont County (Fig. 1). The Canon City Area, which is part of the Canon City Embayment, is bounded by the mountains on the north and west, the Arkansas River on the south and Colorado State Highway 115 on the east (Fig 2). This area is named for the community of Canon City situated at the western edge of the area. Within this area are a number of thermal springs and wells, found in two distinct groups. The eastern group consists of 5 thermal artesian wells, located within one mile of Colorado State Highway 115 from Penrose on the north to the Arkansas River on the south (Fig. 2).

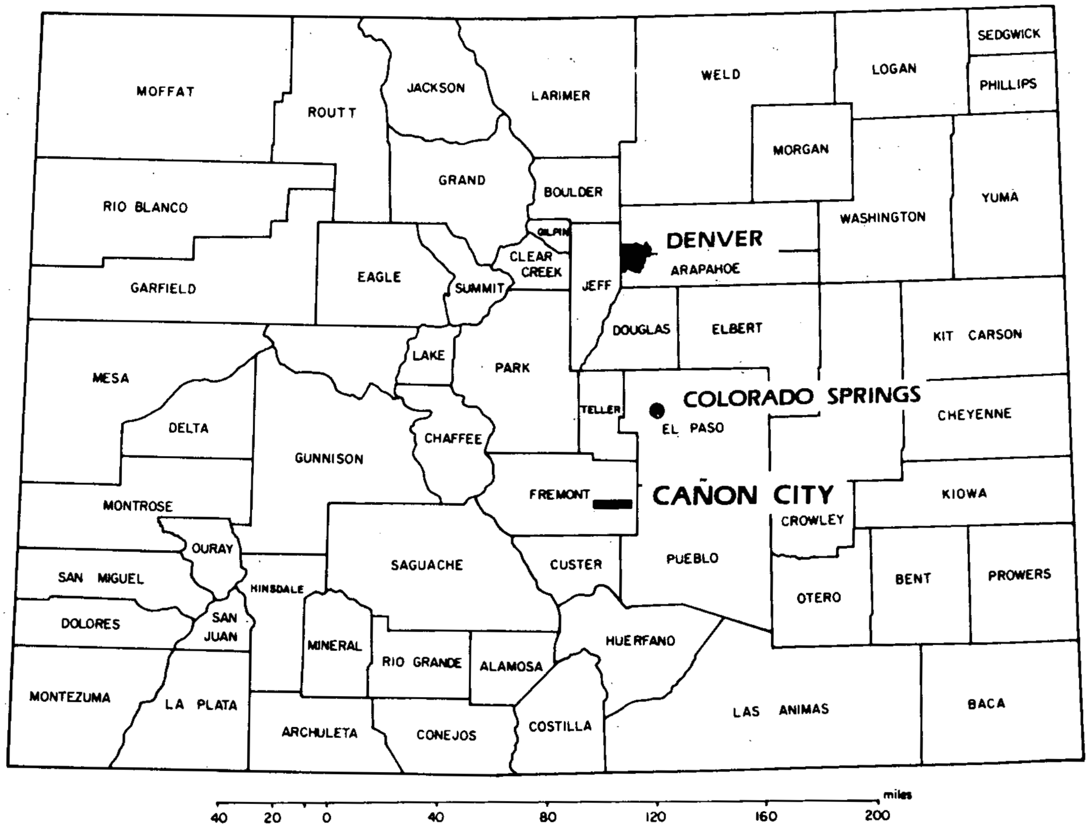


Figure 1. Index map.

The second thermal area is in and adjacent to Canon City (Fig. 2). This area consists of one spring along the banks of the Arkansas River on the west side of Canon City, a thermal well in the northeast corner of Canon City, another well along the banks of Four Mile Creek east of Canon City and a well north of Canon City on Four Mile Creek (Fig. 2).

Geothermal energy, the natural heat of the earth is a viable alternative source of energy that can be put to a wide range of uses. Geothermal energy, normally is either too diffuse or found at such great depths to be of practical value. However, in some instances it is occurs close to the surface, where it does it can be developed and put to practical use. The techniques and equipment for developing and using geothermal energy are readily available. A brief description of geothermal energy and some of the uses it can be put to are presented in Appendix A at the end of the paper.

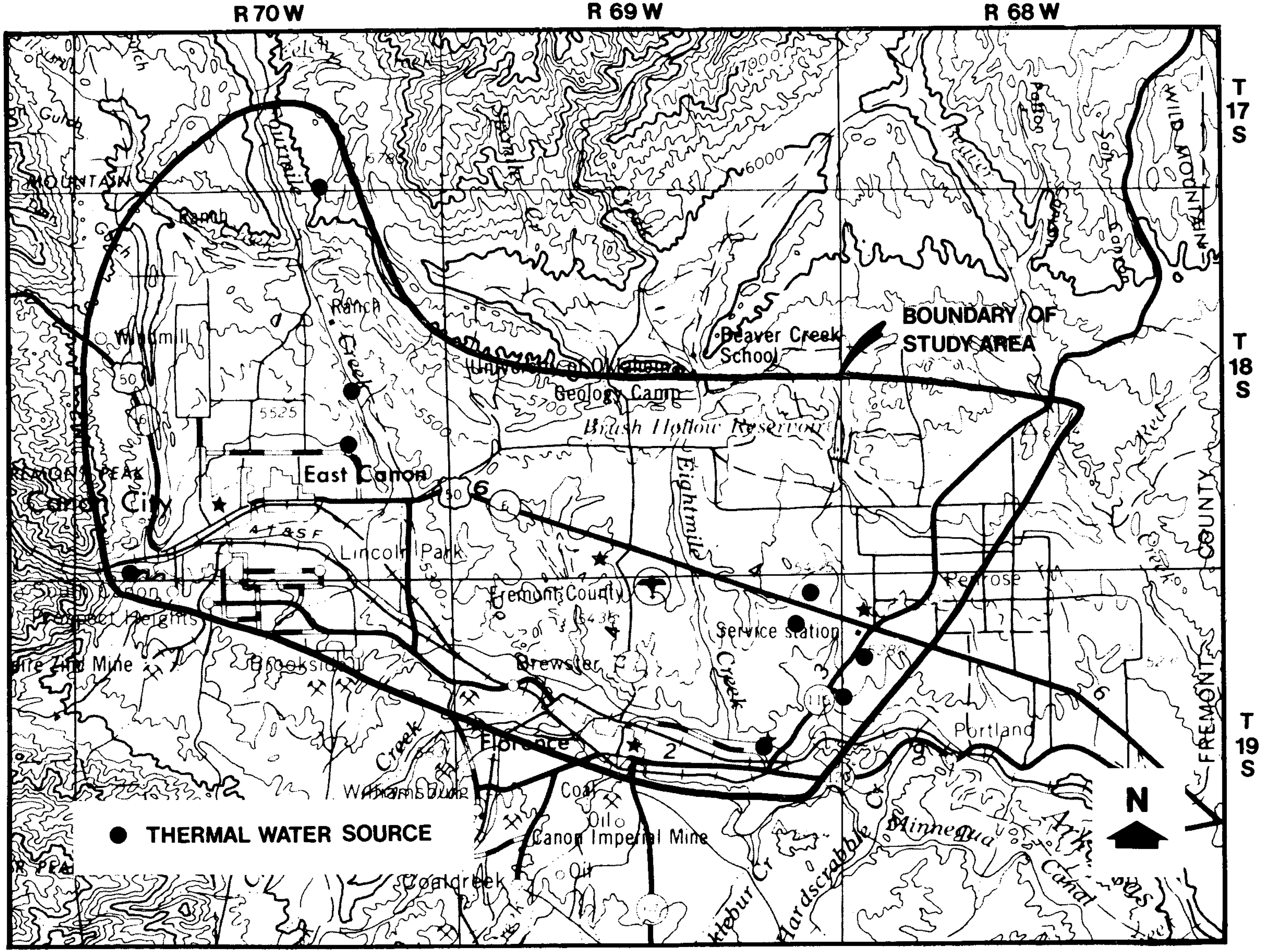


Figure 2. Canon City study area.

THERMAL CONDITIONS OF THE CANON CITY AREA

Thermal Waters

Introduction

With a few exceptions, all the thermal waters found in Fremont and Pueblo Counties are restricted to the study area. Vinckier (1978 and 1982) in his hydrogeological study of the Canon City Embayment in Fremont and Pueblo Counties noted that thermal waters are only found north of the Arkansas River and west of Penrose.

The thermal conditions of the Canon City area have been discussed and described by George and others (1920), Barrett and Pearl (1976 and 1978), Berry and others (1980), Lewis (1966), Mallory and Barnett (1973), Pearl (1972 and 1979), Vinckier (1978 and 1982), and Waring (1965).

Canon City Vicinity

The only true hot spring in the study area, the Canon City Hot Spring, is located at 1400 Riverside Drive on the south bank of the Arkansas River at the west side of Canon City (Fig. 2). The spring, located next to an abandoned swimming pool, is cased with 6-in pipe to a depth of 50 ft (15 m) (Barrett and Pearl, 1978). The thermal waters are presently not being used, but the owners have stated that they are going to renovate the existing pool and utilize the waters for recreation and space heating their home. The spring has a discharge of 5 gpm (gallons per minute) and a temperature of 104°F (40°C) (Barrett and Pearl, 1976). A complete chemical analysis of the dissolved mineral matter contained in the Canon City Hot Spring is presented in Appendix B at the end of the paper.

Geologically, the spring is located at the contact between the easterly dipping Fremont limestone and the overlying Fountain Formation. While no faults are apparent or have been mapped in the vicinity of the spring a vertical fault is shown by Taylor and others (1975), on an east-west cross section approximately 1,500 ft (457 m) south of the spring. This fault, which does not extend to the surface, truncates the downdip side of the Fremont limestone. While this fault has no surface expression it is possible that it does extend to the surface, because a thick cover of alluvial and colluvial deposits blankets the area.

During the course of this investigation another possible hot springs was brought to the authors attention by the owner of the spring. However, no evidence of this spring could be found. The springs reported location is north of, and across the Arkansas River, from the Canon City Hot Springs. Due to it location it could also be associated with the postulated fault.

East of the mountain front other thermal waters in the vicinity of Canon City are coming from deep water wells. The Fremont Natatorium Artesian Thermal Well described by Barrett and Pearl (1978) as being 1,800 ft (549 m) deep is located at 3095 Central Ave. The waters have a temperature of 95°F (35°C) and a discharge of 20 gpm (Appendix B). At one time the thermal waters were used in a swimming pool but are currently unused.

The Valle Cuatro Millas Artesian Well, is located approximately one mile northeast of the Fremont Natatorium well along Four Mile Creek in NE, NW, Sec. 23, T. 18 S., R. 70 W. The well is found just south of the golf course clubhouse. The water, which has a temperature of 79°F (26°C), is used for space heating at the ranch house approximately one-half mile to the south and on the golf course (Pearl, 1979).

A third deep artesian thermal well is located north of Canon City along Four Mile Creek, in SW, SW, Sec 34, T. 17 S., R. 70 W. This well is owned by a water district and the waters are reportedly used for domestic purposes.

Penrose Area

According to a rancher in the area, warm artesian waters have been found in this area for many years, with the waters being primarly used for cattle watering.

The following wells are found along Colorado Highway 115 east of Canon City: Penrose, Brush Hollow, Higgins, American Nauheim and the Ideal Cement Co. wells (Fig. 2).

The Penrose Artesian Well (formerly known as the Florence Artesian Well), according to Barrett and Pearl (1978) is of unknown depth. The well is located approximately one-quarter mile southeast of the intersection of U.S. Highway 50 and Colorado 115 (Fig. 3) in SW, NE, NW, Sec. 7, T. 19 S., R. 68 W. The waters have a temperature of 82°F (28°C) and discharge of 130 gpm (Pearl, 1979).

Approximately one-quarter to one-half mile west of the intersection of U.S. 50 and Colorado 115 are two wells. One well, the Brush Hollow Creek Thermal Well, is located just north of U.S. 50, and the other well, the Higgins Artesian Thermal Well, is south of U.S. 50 (Fig. 3). The Brush Hollow Creek Thermal well is located in NE, NE, SE, Sec. 1 T. 19 S., R. 69 W. and the Higgins Artesian Thermal Well is located in SE, SW, SE, Sec. 1, T. 19 S., R. 69 W.

The depth of the Brush Hollow Creek well is unknown. The waters have a temperature of 90°F (32°C) and an estimated discharge of 100 gpm (Pearl, 1979). The Higgins Artesian Thermal Well waters have a temperature of 108°F (42°C). These waters are used by a private swimming club in their swimming pool and to heat a house. The well is reported to have been drilled in 1924 to a depth of 1,875 ft (572 m) (Pearl, 1979).

Waters from the American Nauheim Artesian Thermal Well, located one-half mile north of the intersection of Colorado 115 and Colorado 120 east of Florence, have a temperature of 81°F (27°C). Pearl (1979) reported the depth of this well to be approximately 1,400 ft (427 m). At one time according to Mr. George Goodwin, the well had a dischage of 200 gpm but now is much less than that now (Pearl, 1979). The City of Florence recently constructed a sewage treatment facility in the vicinity of this well, and destroyed the well's surface structure.

During the course of the field investigations for this report another warm artesian well was located one-half mile southeast of the Penrose Artesian Well in NE, SW, SW, Sec. 7, T. 19 S., R. 68 W. The well is here named the Ideal Cement Co. Thermal Artesian Well. The waters from this well have a surface temperature of 90°F (32°C) and an estimated discharge in excess of 100 gpm. The waters are used for irrigation of crops. The depth of the well is unknown.

Geothermal Gradient and Temperature Maps

To help in delineating the thermal conditions of the Canon City area, in 1979-80 eleven temperature gradient holes were drilled (Fig. 3). Ten of the holes had an approximate depth of 328 ft (100 m) and one drilled on the Colorado Department of Corrections land had a depth of 1,706 ft (520 m) (Ringrose, 1980). In order that a complete and representive measurement of the geothermal gradients could be made, unperforated, two inch diameter, black iron pipe was installed in the holes to total depth. The annular space was backfilled with drill cuttings to the surface and the pipe was filled with water and allowed a minimum of two weeks to reach equilibrium temperature conditions before temperature measurements were made. As shown on Figure 3 gradients measured in these holes ranged from 2.17°F/100 ft (21.8°C/km) to a high of 4.92°F/100ft (89.7°C/km)(Ringrose, 1980). Figure 4 shows the disribution of the measured temperatures at a depth of 262 ft (80 m). When this map is compared with gradient map (Fig. 3) it is noted that the two maps are quite similar, with the highest gradient and temperature being in the southeast part of the area.

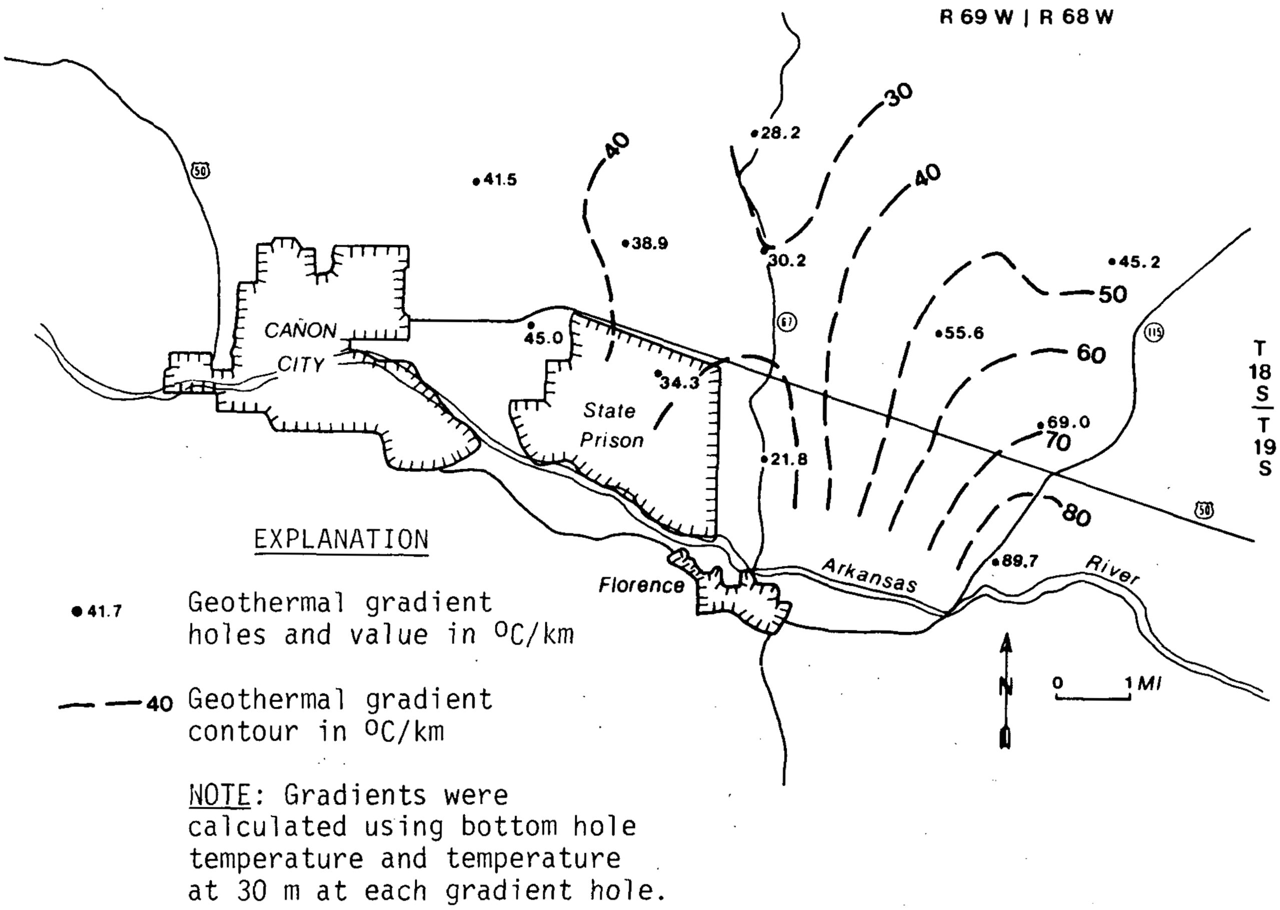


Figure 3. Geothermal gradient holes and measured values. (from Ringrose, 1980)

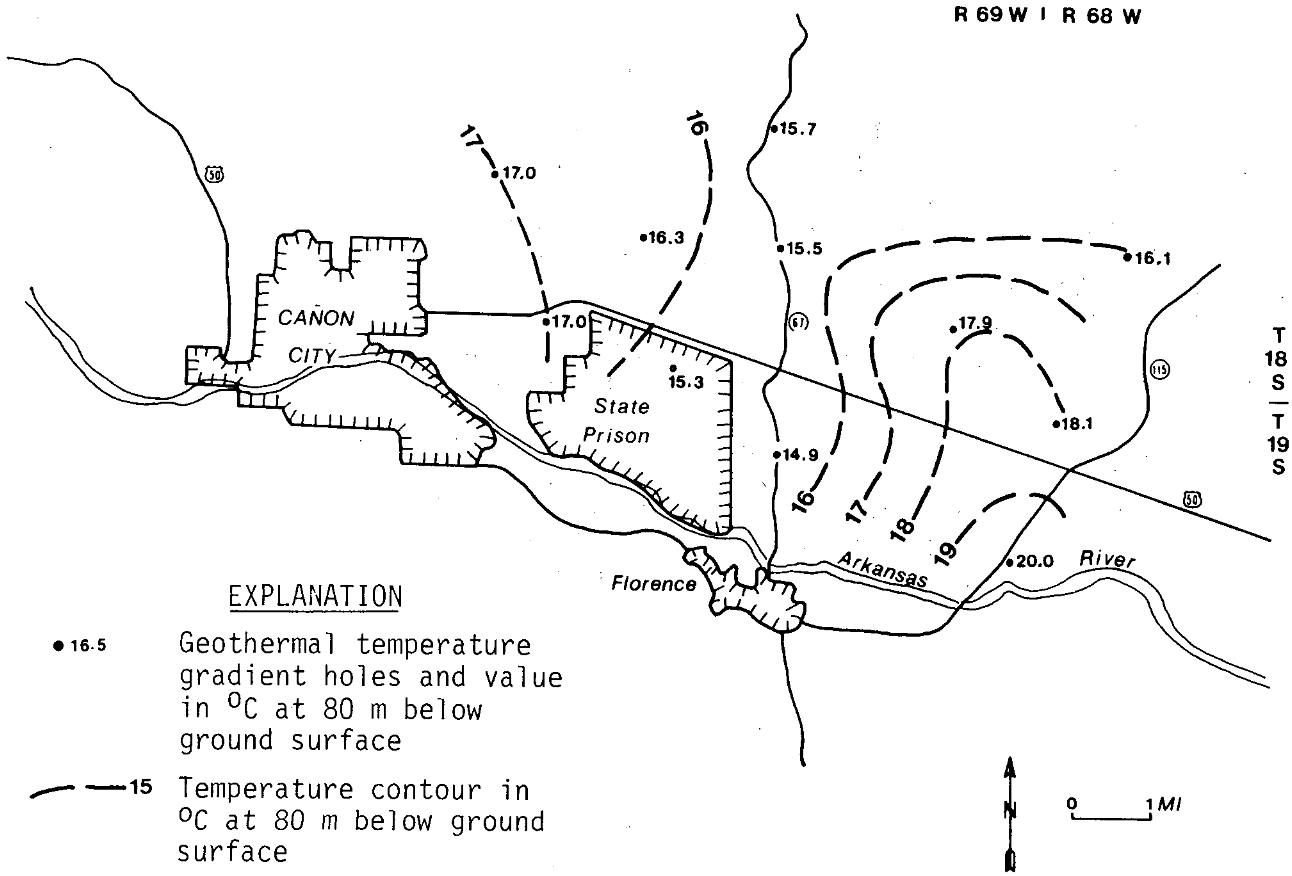


Figure 4. Temperatures at a depth of 80 meters.

The instrument used to measure the temperatures in the 328 ft (100 m) deep holes was built by Fluid Dynamics, Golden, Colo. and was calibrated to an accuracy of ± 0.1°C with a resolution of at least .01°C. The 1,706 ft (520 m) hole was logged by personnel from the Dept. of Geology, University of Wyoming under the supervision of Dr. E.R. Decker.

During the summer of 1981, Ms Cindy Gwinn of Southern Methodist University, remeasured the temperatures in these holes and calculated both the geothermal gradient and heat flow. Her measurements showed that the gradients ranged from 1.24°F/100 ft (22.6°C/Km) to 4.67°F/100 ft (85.1°C/Km) (Cindy Gwinn, unpublished report, 1981). The heat-flow map prepared by C. Gwinn (Fig. 5) demonstrates good correlation with the regional heat-flow map of Colorado (Zacharakis, 1981). The main difference observed is that Gwinn's values are somewhat lower, which can be explained by the lower Pierre shale thermal conductivity values used.

Zacharakis (1981), has shown that the Canon City area has a heat flow of $90 mW/m^2$. This value is somewhat above the national average but is about normal for the Colorado Front Range area.

Using bottom hole temperature measurements from oil wells, plus other data, Repplier and Fargo (1981) have shown that the average geothermal gradient in the Canon City area is 2.90°F/100 ft (35°C/Km).

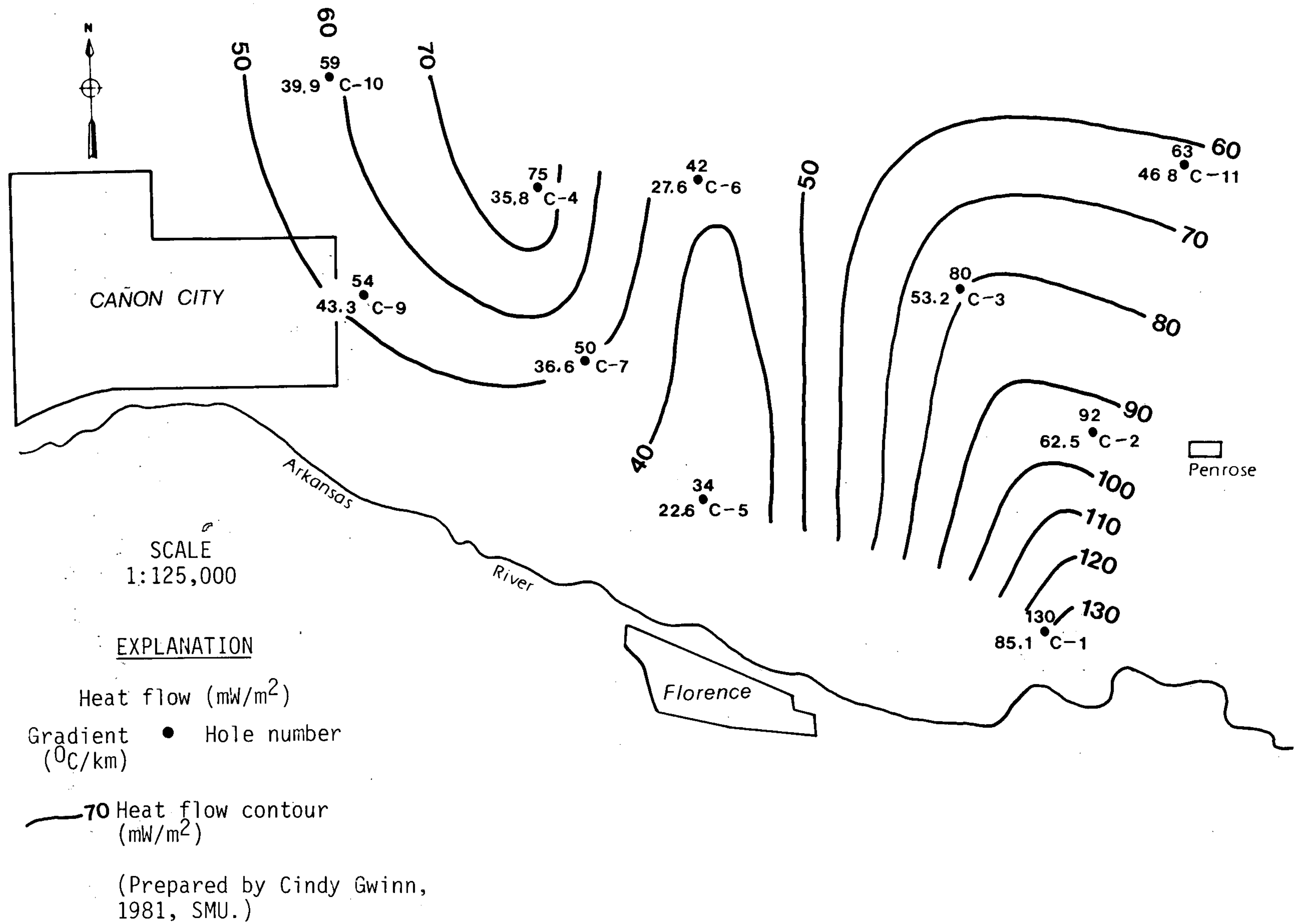


Figure 5. Heat flow map, Canon City Area.
(from Gwinn, 1981)

GEOLOGY

Introduction

The geological conditions of the Canon City Embayment area, of which the Canon City area is part of, have been described by Boos and Boos (1957); Gerhard (1967); Scott (1977); Scott and others (1978); Taylor and otheres (1975); and Vinckier (1978 and 1982). The following descriptions are taken from the above papers.

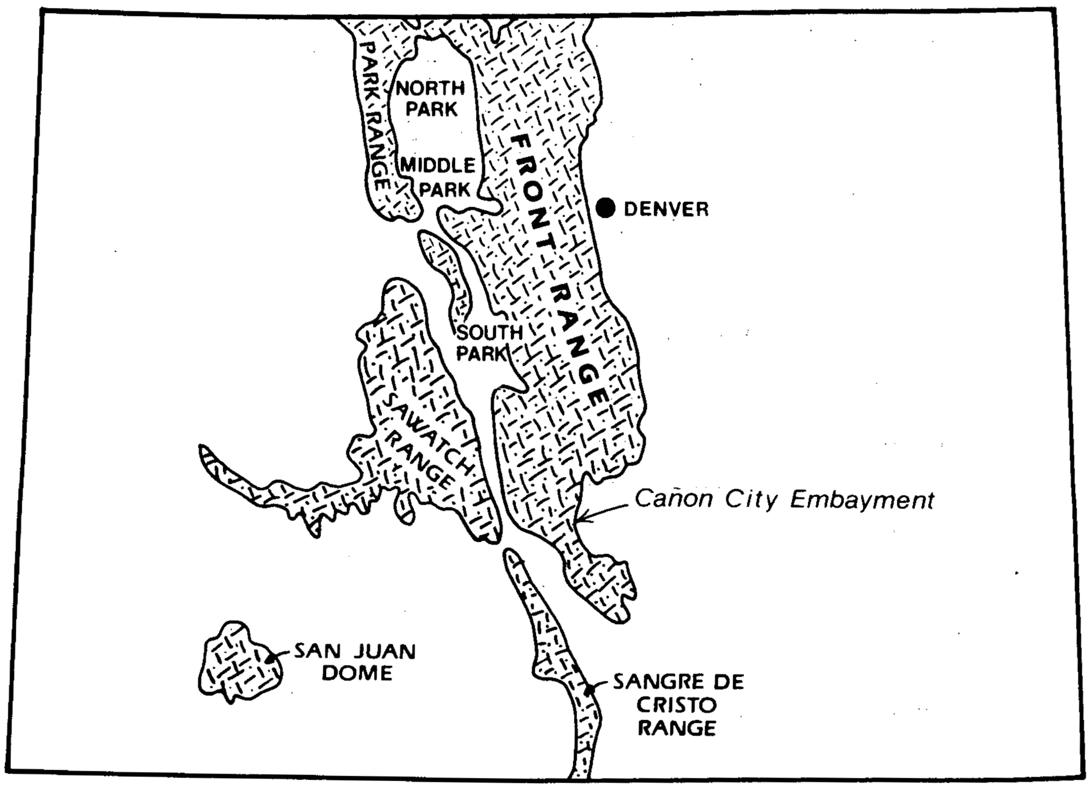


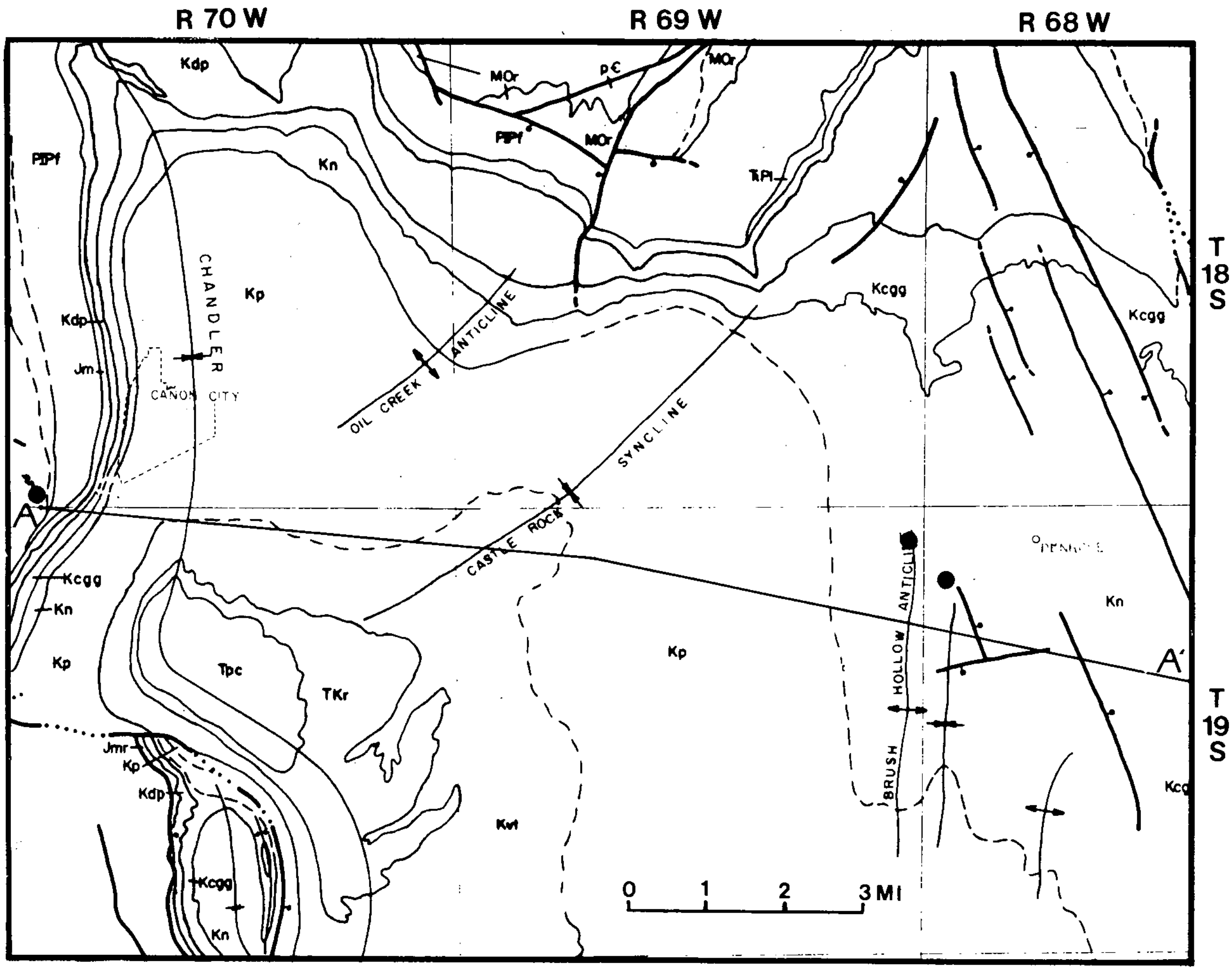
Figure 6. Basement complex map of Colorado.

Stratigraphy

The Embayment contains a thick sequence of Paleozoic, Mesozoic, and a thin section of Cenozoic age sedimentary rocks with some Quaternary deposits in the vicinity of the Arkansas River valley. Table 1 below presents a brief summary of the various rock units found in the Canon City area.

Structure

The Canon City Embayment, of which the Canon City area is part of, is bounded on the south and west by the Wet Mountains, on the north by the southern end of the Front Range and opens toward the southeast (Fig. 6). The Embayment may be considered a south-southeastward-plunging synclinal basin with steeply dipping limbs that lie between the southern limits of the Front Range and the east flank of the Wet Mountains. Along the west side of the Embayment the sedimentary rocks are steeply upturned against the Precambrian crystalline rocks of the Wet Mountains and dip steeply eastward into the Chandler Syncline (Fig. 7). The north margin of the Embayment is characterized by locally faulted hogback ridges.



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EXPLANATION

	Hot spring
	Warm artesian well
	Fault, ball on downthrown side
Jmr	Jurassic Morrison and Ralston Creek Formations
TPl	Triassic-Permian Lykins Fm.
Ply	Permian Lyons Formation
PIPf	Permian-Pennsylvanian Fountain Formation
MOr	Mississippian, Devonian, and Ordovician rocks
pЄ	Precambrian crystalline rocks
	Anticline
	Syncline
A——A′	Cross section line
Tpc	Tertiary Poison Canyon Formation
TKr	Tertiary-Cretaceous Raton Fm.
Kvt	Cretaceous Vermejo Fm. and Trinidad Sandstone
Kp	Cretaceous Pierre Shale
Kn	Cretaceous Niobrara Fm.
Kcgg	Cretaceous Carlile Shale, Greenhorn Limestone and Graneros Shale
Kdp	Cretaceous Dakota Sandstone and Purgatoire Fm.-Dakota Gp.

Figure 7. Geology and thermal springs of Canon City area. (Geology adopted from Vinckier, 1982)

Table 1. Generalized section of geologic formations, Canon City area.

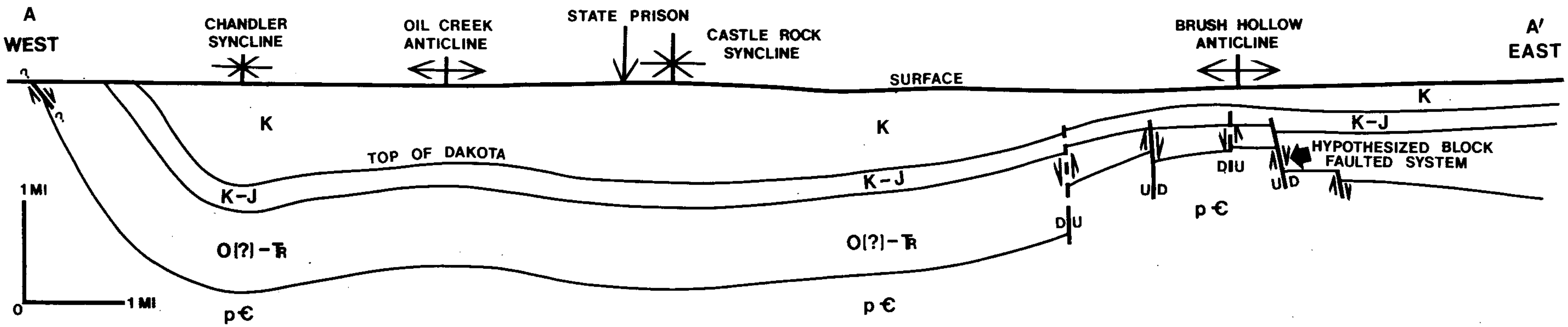
System	Series	Formation	Thickness	Description
Quaternary				Alluvial and colluvial deposits along rivers and creeks and as cover on hillsides.
Tertiary		Poison Canyon	265m (840ft)	Claystone, silstone, and sandstone. Yellow to brown.
	Paleocene	Raton	73-152m (240-500 ft)	Sandstone, yellowish-gray to yellowish-brown, medium to coarse grained, forms cliffs.
		Vermejo	30m (100 ft)	Sandstone, light-gray to yellowish-orange, fine to medium-grained. Some interbedded shale and coal beds.
		Trinidad	12-27m (40-90ft)	Sandstone, light gray to yellowish-gray, friable, fine grained. Some interbedded shale. Dark, reddish-brown calcareous concretions project from weathered surfaces.
		Pierre	1189m (3900ft)	Shale, gray to black, with some bentonite beds, iron and limestone concretions, fossiliferous. Some sandstone members.
	Upper	Niobrara	180-185m (590-610ft)	Smoky Hill shale, yellowish-brown slightly fossiliferous, 173m (570 ft) thick. Some interbedded ls. Fort Hays limestone--white, fossiliferous limestone 6-12 m (20-40ft) thick, unconformable on Carlile shale. Forms ridges
		Benton Group	82-107m (270-350 ft)	Carlile shale-gray to black shale approx. 53-61m (175-200ft) thick. Codel sandstone member .9-12m 3-40ft) thick at top. Forms a persistent outcrop. Greehorn limestone--white limestone with some interbedded gray shale, 8-24m (25-80ft) thick. Conformable with Graneros shale. Graneros shale--gray to black, fissile, approx. 21m (70m thick).

Cretaceous	Lower	Dakota Gp	46m (150 ft)	Sandstone and shale. Upper and lower sandstone units separated by a shale and sandstone member. Forms "hogback" ridges.
		Purgatoire	40m (130 ft)	Glencairn member--sandstone and shale, gray and brown. Forms grass coverd bench. Lytle sandstone member at base. Sandstone, white, cross bedded 58 m (190ft) thick.
Jurassic	Upper	Morrison	98m(320ft)	Shale, sandstone and limestone variegated color
	Middle?	Ralston Creek	46m(150ft)	Sandstones and evaporites with some gypsum
Triassic	Lower	Lykins	46m (150 ft)	Shale and silstone, red. "Crinkly" limestone member occurs about 30m(100ft) above base.
Permian	Middle?			
Permian	Lower	Fountain	762m (2500 ft)	Sandstone, silstone, shale, conglomerate, few limestone beds.
Pennsylvanian	Lower			
Mississippian	Lower	Williams Canyon	18m(60ft)	Limestone, white to gray, with calcareous shale and few sandstone beds.
Devonian	Upper			
Ordovician	Upper Middle	Fremont	86m (283 ft)	Limestone, Light gray, fossiliferous, with bedded chert.
	Lower	Harding	48m (157 ft)	Sandstone, fine grained, yellow with some shale, slightly calcareous.
		Manitou	61m (200 ft)	Dolomite, light gray to purplish pink, cherty in lower part.
Precambrian		Migmatite biotite gneiss		

According to Weimer (1980), the structure in the Penrose area is dominated by a north-south trending horst block called the Brush Hollow Anticline. As shown by Weimer (1980) this structure is an east-tilted horst block with a fault zone on the west side that extends from the basement. Recurring movement on these faults throughout geologic time caused thinning and draping of the sediments over the structure. Geophysical studies done by the U.S. Geological Survey as part of this project (See Geophysical Investigations Sec.) confirmed Weimers (1980) structural model of the basin.

It appears that this anticlinal structure continues to the south. For a seismic survey conducted in 1978 approximately 5 miles (8 km) south of the study area showed a north trending faulted anticline (horst?) in the area (Brown, 1978).

Fig. 8, an east-west cross section depiciting the structural conditions of the Canon City area, extends approximately 15 miles (24 Km) east from the mountains at Canon City to the Penrose area. The Brush Hollow Anticline (Horst?) is more fully detailed because of the various geophysical surveys conducted in the area. The anticline is interpreted from telluric geophysical data (Appendix I) as a block-faulted horst structure in which normal faults extending from the Precambrian rocks penetrate the Dakota Group before dying out.



EXPLANATION

K	Upper Cretaceous undivided
K-J	Jurassic and lower Cretaceous
O ? TR	Ordovician -- Triassic
pЄ	Precambrian

Figure 8. East-west Cross section, Canon City Area.

HYDROGEOLOGICAL CONDITIONS OF THE CANON CITY AREA

Introduction

Alluvial deposits along the Arkansas River and some of the larger creeks yield large quantities of water to wells; however, as they yield no thermal waters they will not be discussed here.

While other bedrock units may yield water to wells, the prinicipal water bearing bedrock aquifers in the Canon City Area are the sandstones of the Dakota Group, and Morrison Formation and the Precambrian granitic rocks. These formations are exposed along the mountain flanks on the north and west side of the basin and dip into the basin where they are deformed by a series of anticlines and synclines and cut by numerous faults (Fig. 7). While not specifically addressing the Canon City-Penrose area, Vinckier (1978 and 1982) showed that the regional potentiometric surface of the Dakota Group aquifer in the Canon City Embayment slopes to the east towards Pueblo. Assuming the thermal waters in the Fremont Natatorium well are coming from the Dakota Group, the elevation of the Dakota Group potentiometric surface in the Canon City area would be 5400 ft. In the Pueblo area the elevation of the potentiometric surface is 4700 ft (Vinckier, (1978 and 1982). The elevation of the potentiometric surface thus has an average slope of 20 ft/mi (3.87 m/Km) to the east in the Canon City-Penrose-Pueblo area.

Water Quality

The thermal waters in the Canon City Area are essentially a sodium-bicarbonate type (Fig. 9) and chemically are not like ground waters found elsewhere in the Canon City Embayment. Vinckier (1978 and 1982) noted that the ground waters from the Dakota Group aquifer in the southwest part of the Canon City Embayment are a calcium bicarbonate type, with high Ca/Na ratios of 1.95 to 4.65, while the waters in the Canon City study area have Ca/Na ratios of 0.66 to 1.00. Vinckier (1978 and 1982) also noted that the ground waters in the Canon City area contain more dissolved solids than the ground waters elsewhere in the embayment area. He was not able to explain the difference in water chemistry between the two areas but did present several possible origins. He (Vinckier, 1978 and 1982) suggested that the origin of the waters could be: 1) Connate waters coming from the Dakota Group aquifer, 2) ground water entering the aquifer as leakage from adjacent semiconfining strata, 3) deeply circulated meteoric ground water, or 4) hydrothermal fluids purged from the crystalline basement rocks. As will be shown later explanation number 3 is probably the most likely explanation for the difference in water quality throughout the region. A complete chemical analyis of the dissolved mineral matter found in the thermal waters in presented in Appendix B at the end of the paper.

While Vinckier's (1978 and 1982) report described the quality and hydrogeological conditions surrounding the ground waters in the Canon City area, the main thrust of his report dealt with the high level of radioactive elements found associated with ground waters. Vinckier (1978 and 1982) noted that 67% of the 117 wells he sampled contained Ra-226 levels above recommended drinking water standards. Vinckier's (1978 and 1982) study was limited to concentration levels of Ra-226 and therefore he did not analyze for other radioactive elements that might be present.

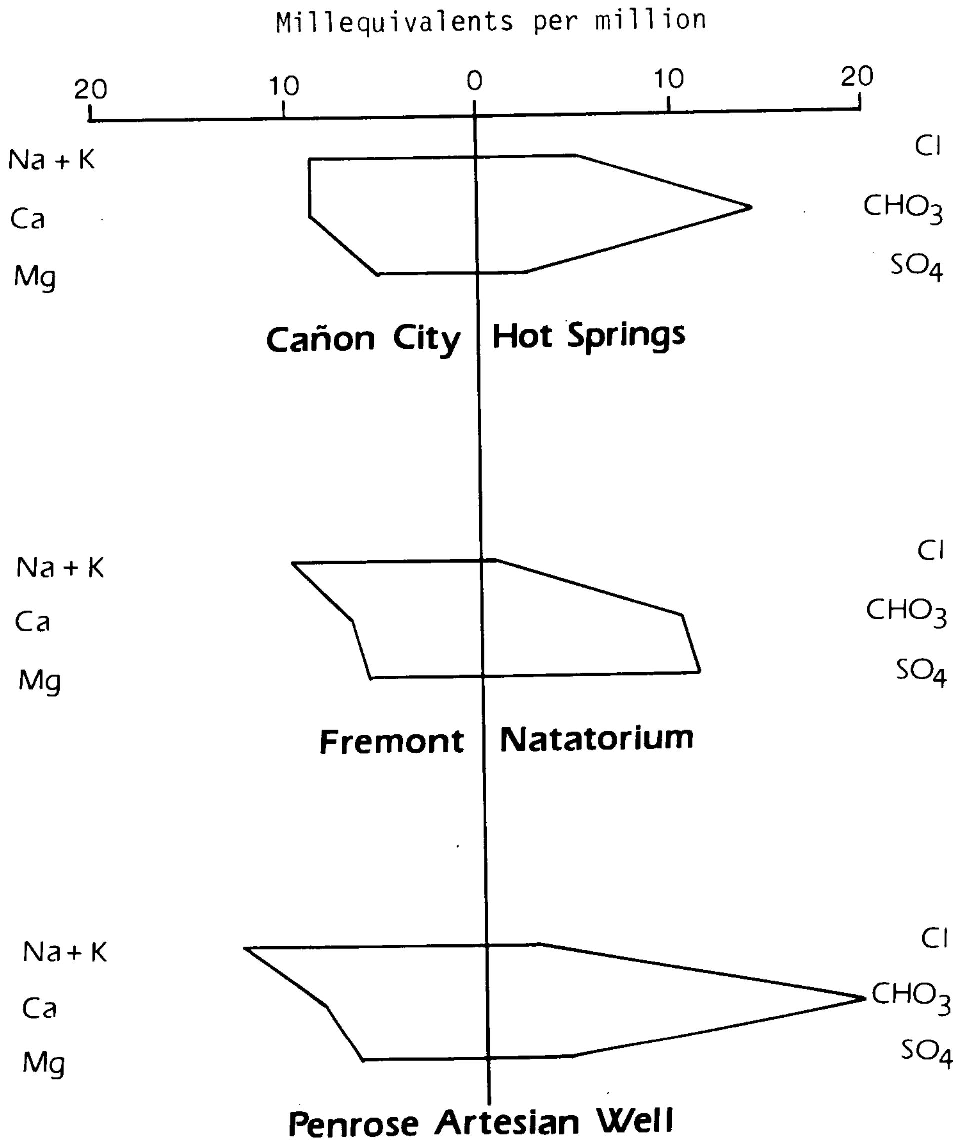


Figure 9. Water quality diagram.

GEOPHYSICAL SURVEYS

Introduction

In order to define the extent of the geothermal resource in the Canon City area the following geophysical surveys were conducted: Tellurics, seismic, electrical resistivity and audio-magnetotelluric. These surveys, with the exception of the seismic, were quite valuable in the interperation of the subsurface structural conditions of the study area.

Electrical Geophysical Resistivity Surveys

To define the thermal conditions of the Canon City Area, electrical resistivity surveys were conducted to determine the location of any low resistive zones in the area. Low resistivity is normally due to water saturation, higher than normal temperatures, and high clay matrix zones. For a complete description of the factors which might affect electrical resistivity measurements, the reader is referred to Appendix C.

Using a Scintrex RAC-8 electrical resistivity system, a total of four dipole-dipole resistivity survey lines were run totalling 5,500 ft in the vicinity of both thermal areas (Figs 10 & 11). A complete description of the RAC-8 system is presented in Appendix D.

In the Brush Hollow area, two dipole-dipole lines approximately 3,800 ft (1,158 m) long were run in the vicinity of the artesian well (Fig. 10). However, in the Penrose Artesian Well area it was not possible to conduct DC resistivity surveys. The reason being the heavy overhead power or buried phone cables which interfered with the transmitter signal prevented the receiver from locking onto the signal. However, other geophysical exploration methods were successfully used. The U.S. Geological Survey ran three telluric lines and an Audio-magnetiotelluric (AMT) survey in this area. In addition, the Colorado School of Mines ran a 3-mile seismic line to coincide with the telluric survey. The results of these surveys will be presented in later sections of this report.

In the thermal area west of Canon City, two dipole-dipole resistivity survey lines on both sides of the Arkansas River and adjacent to the two hot springs were run (Fig. 11). Due to terraine obstacles and cultural conditions, additional resistivity lines were not run that may have further delineated possible faulting in the area. Appendix E presents a complete description of the field procedures pertaining to the various arrays employed.

To aid in the interperation of electrical resistivity data preudosections are constructed. These sections are cross sections reflecting the shallow subsurface resistivity below the line of traverse. Figures 12-15 are pseudosection cross sections constructed for the four traverses ran in the study area. In the interperation of any dipole-dipole pseudosection, one must be cognizant of the fact that resistivity values obtained along the line of traverse may be influenced by lateral variations of three dimensional features at depth. This may be the case in the Penrose area where the Brush Hollow Anticline (Horst?) exists.

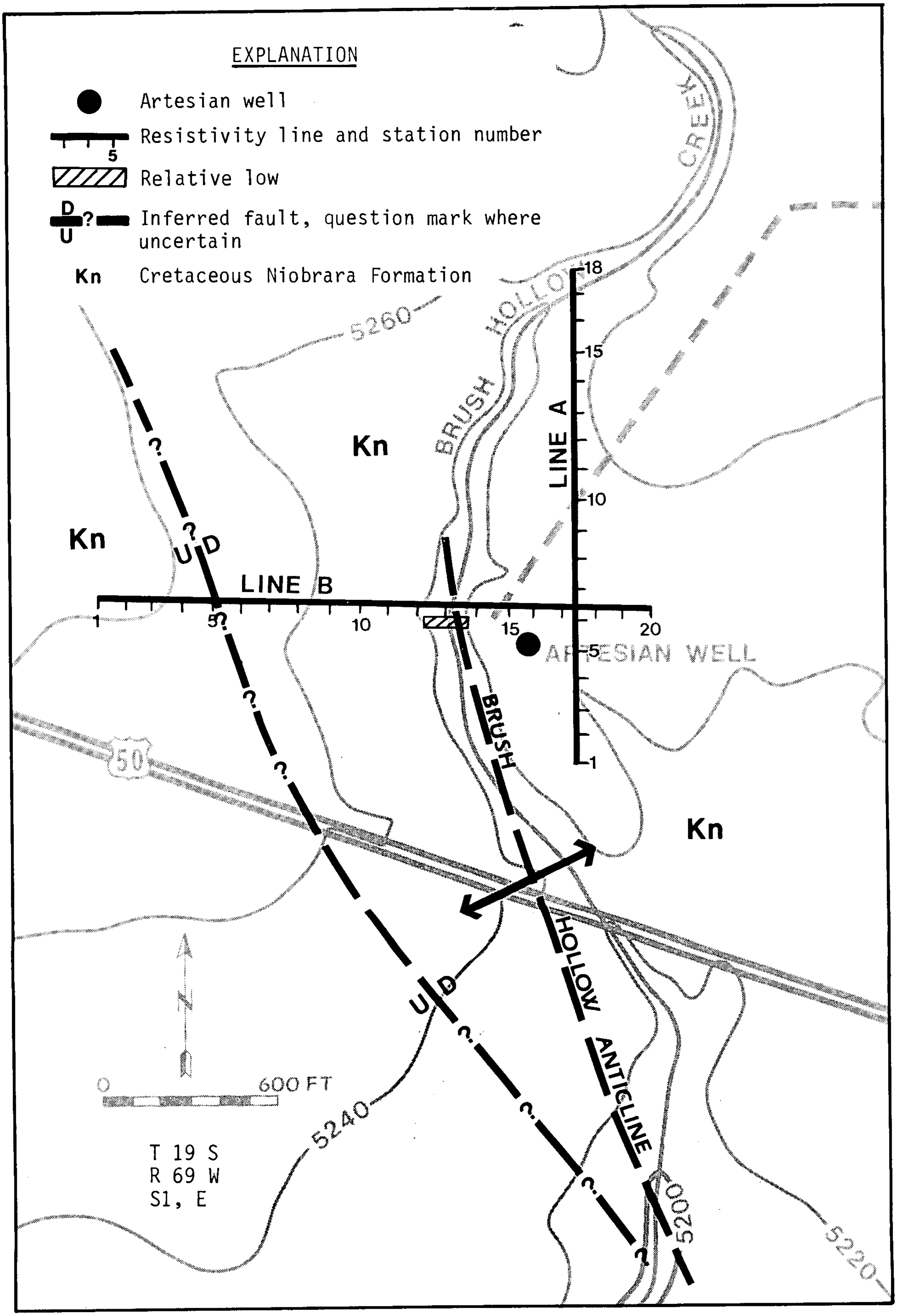


Figure 10. Electrical resistivity survey lines, Penrose/Brush Hollow area. (Geology adopted from Vinckier, 1982).

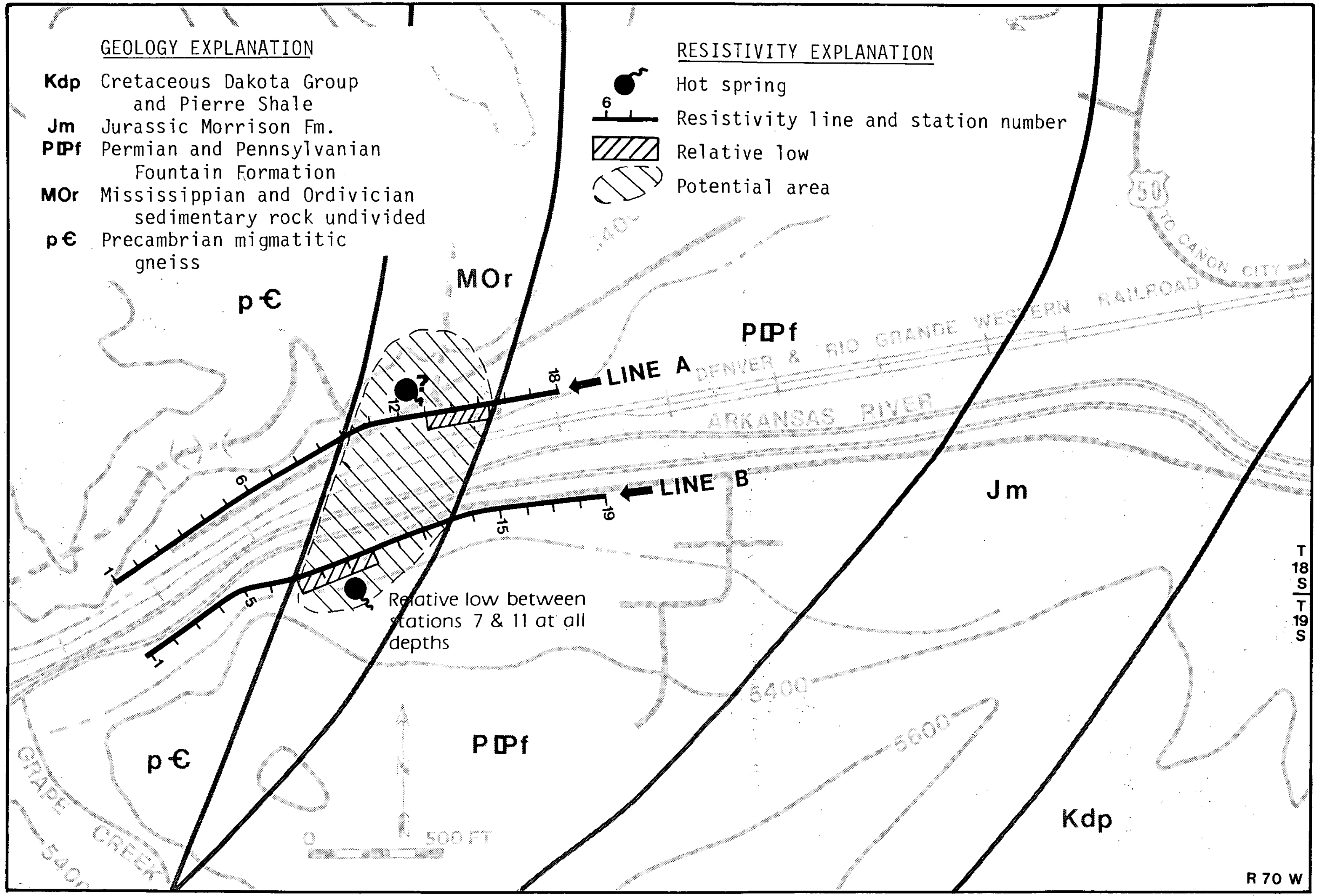


Figure 11. Location of resistivity survey lines, Canon City area. (Geology adopted from Taylor and others, 1975)

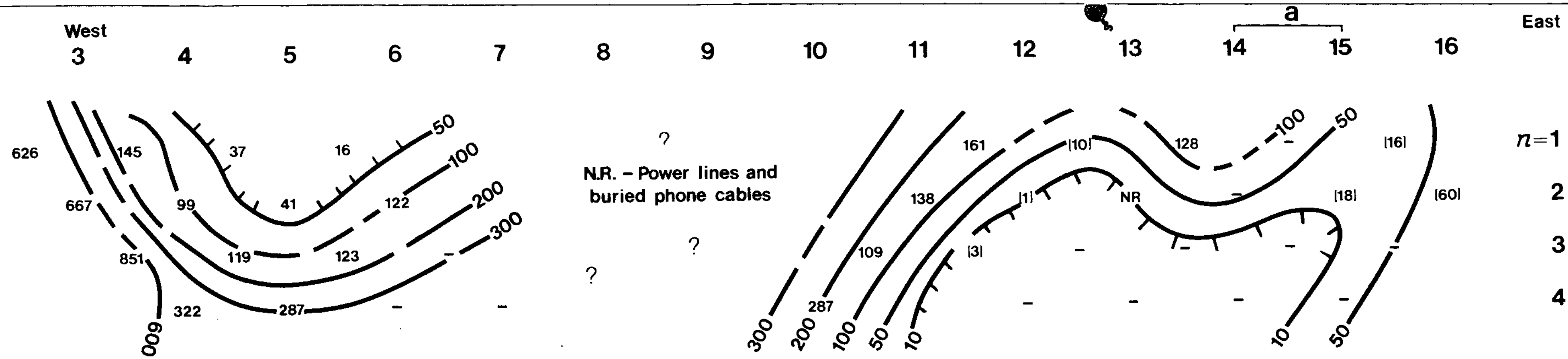


Figure 12. Line A - This resistivity dipole-dipole line is 200 ft east of the Brush Hollow artesian well and trends in a north-south direction (Fig. 10). No faulting was evident. While no relative sharp differences in resistivity were noted, a low resistive zone was mapped between stations 13 through 15. The bedrock geology traversed was the Niobrara Formation, namely the Fort Hays limestone. The only thing that was evident from this line is the averaging effect of the limestone sediments penetrated. Table 5 (Appendix E) tabulates the resistivity calculations for line A.

LENGTH: 1600 ft [488 m]
SEPARATION: n Value
DATE. June 5, 1980
TYPE: Dipole - Dipole
SPREAD: a = 100 Feet
RESISTIVITY: In ohm-meters
Hot Springs
0 200 ft

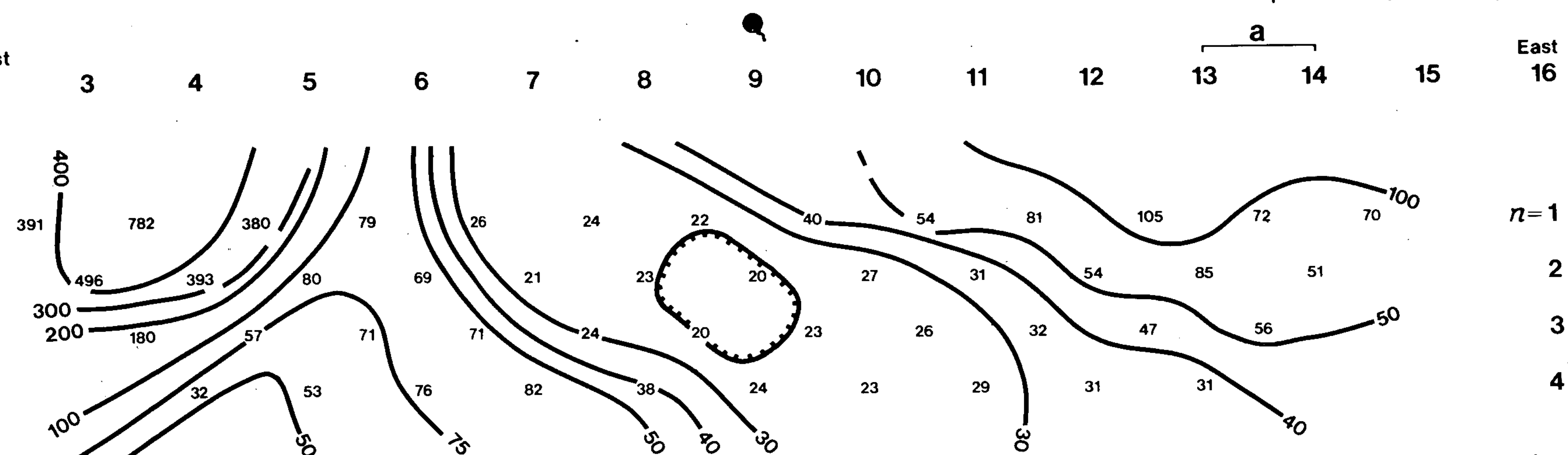


Figure 13. Line B - This resistivity line lies just north of the Brush Hollow artesian well and trends in an east-west direction (Fig. 10). A low resistive zone between stations 15 and 17 was encountered as an arroyo was crossed in the vicinity of the artesian well. These lower values may be attributed to water saturation in the creek bed and adjacent area. A sharp change in resistivity occurred between Station 4 and 6 which could be faulting or a lithologic sequence change. It cannot be determined from the dipole-dipole data with any degree of reliability that faulting exists in the immediate area primarily because of the shallow penetration and the averaging effect in resistivity values encountered in the Niobrara section. As a result it was difficult to delineate a reservoir in this section. Table 6 (Appendix E) tabulates the resistivity calculations for line B.

LENGTH: 1600 ft [488 m]
SEPARATION: n Value
DATE: June 5, 1980
TYPE: Dipole - Dipole
SPREAD: a = 100
RESISTIVITY: In ohm-meters
Hot Springs
0 200 ft

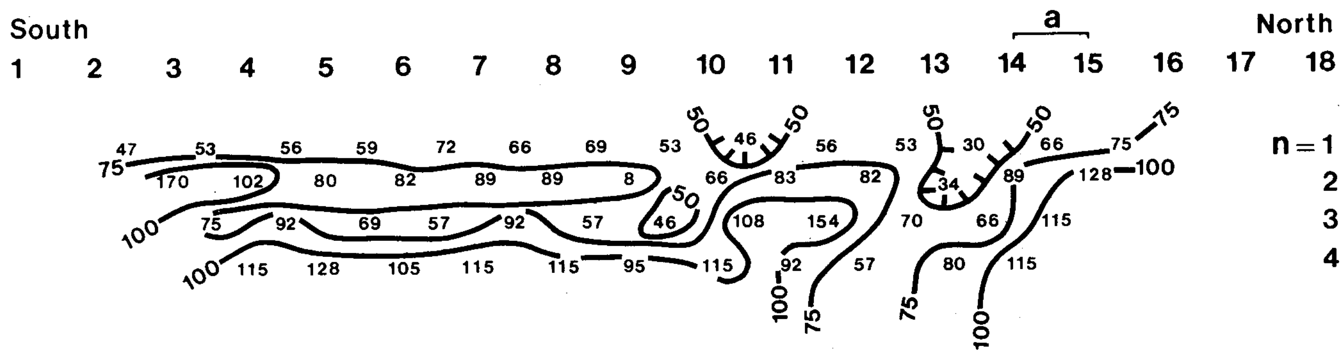


Figure 14. Line A - This dipole-dipole resistivity line was located on the north side of the Arkansas River adjacent to a plugged unnamed hot spring (Fig. 11). Much difficulty was encountered in procuring stable data due to heavy culture, such as buried phone cables, water mains, and overhead power lines. However, the Precambrian-Paleozoic age sedimentary rock contact towards the western portion of the line between stations 3 and 4 was noted. It is perceived that the unnamed spring and the one on the south side of the river may have the same geothermal reservoir source for resistive lows were measured on both lines opposite each other. Table 7 (Appendix F) tabulates the resistivity.

LENGTH: 1800 ft [549 m]

SEPARATION: n Value

DATE: May 29, 1980

TYPE: Dipole – Dipole

SPREAD: a = 100 ft

RESISTIVITY: In ohm meters

0 200 ft

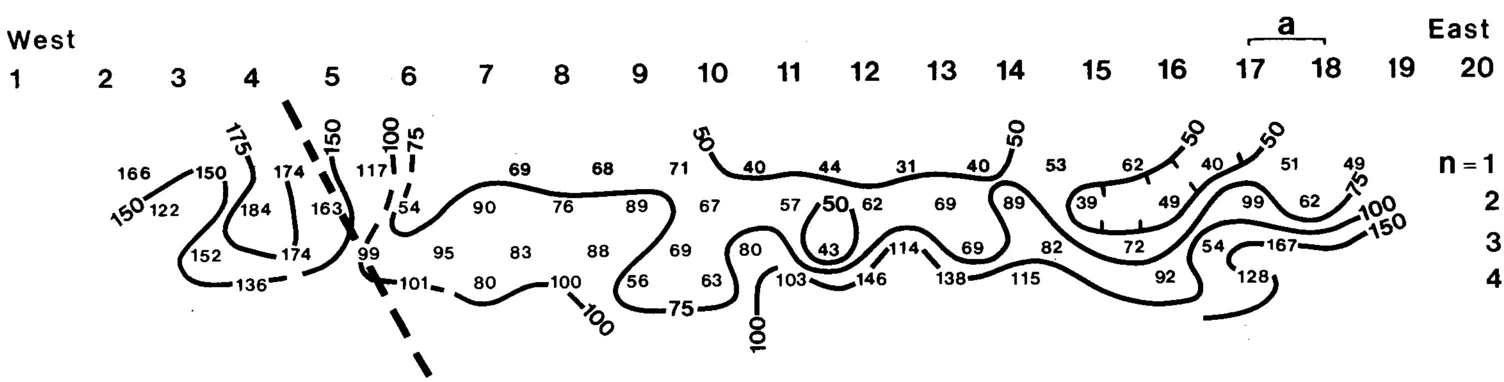


Figure 15. Line B - This dipole-dipole line was located on the south side of the Arkansas River adjacent to the existing hot spring (Fig. 11). The resistivity data shows a definite low adjacent to the hot spring area with values ranging down to 20 ohm-meters. This low resistive zone appears to persist with depth between Stations 7 through 10. Immediately to the west of this low zone, the resistivities increase dramatically to over 700 ohm-meters. This change corresponds to a lithologic contact between the lower Paleozoic limestones and the Precambrian migmatite gneisses. It is postulated that this contact could be a fault contact concealed at the surface by colluvial and alluvial deposits. Table 8 (Appendix F) tabulates the resistivity calculations for line B.

LENGTH: 2000 ft [610 m]

SEPARATION: n Value

DATE: June 2, 1980

TYPE: Dipole – Dipole

SPREAD: a = 100 ft

RESISTIVITY: In ohm meters

— — Possible fault

0 200 ft

Appendix H presents the geometric factor tables used to calculate the resistivity values in Appendices F and G.

Summary

Due to the culture and terraine obstacles around the Canon City Hot Springs, the dipole-dipole electrical resistivity surveys were limited to the proximity of the hot springs. From the low restivity zones mapped it appears that both hot springs belong to the same reservoir. The steeply dipping Paleozoic limestones in contact with the Precambrian migmatite gneiss could be a fault conduit along which the warm thermal waters are migrating to the surface. No surface expression of faulting is apparent, mainly because of alluvial and colluvial deposits covering the surface.

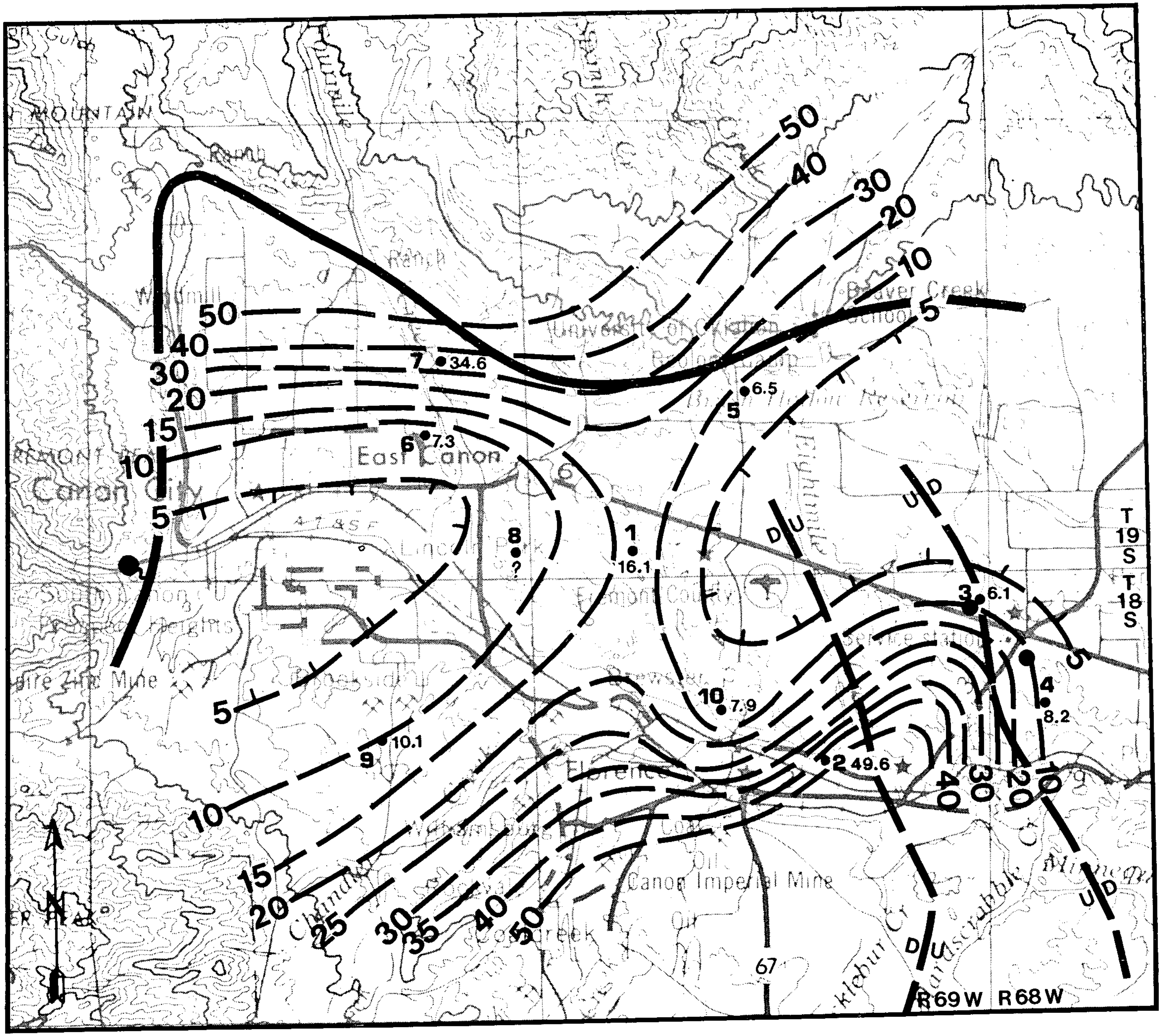
The two resistivity dipole-dipole lines conducted in the Penrose area did not indicate a geothermal reservoir. There were no distinct differences in resistivity encountered along these lines. This may have been caused by the averaging affect of the Fort Hays limestone section penetrated. Due to equipment and geological limitations, the signal was only able to reach to depths of 250 to 350 ft (76 to 107 m). Additional resistivity lines were desired for more structural control, but due to the urbanization of the area, it was not possible.

Audio-magnetotelluric Resistivity Survey

Personnel from the United States Geological Survey and the Colorado Geological Survey ran an Audio-magnetotelluric resistivity survey (AMT) in the Canon City area during September 19 and 20, 1979. Readings were taken at ten AMT stations in the vicinity of Canon City (Fig. 16). The area encompassed was approximately 50 square miles, thereby allowing for a density of one setup every 5 square miles.

The AMT System developed by the United States Geological Survey (Hoover and Long, 1975; and Hoover and others, 1976), measures natural and artificial electromagnetic waves at 12 frequencies from 7.5 to 18,600 hertz. As contrasted to the D.C. resistivity systems AMT and telluric systems depend upon the natural electromagnetic waves of the earth, whereas D.C. resistivity systems induce man-made electrical currents into the earth and measures the potential difference in voltage caused by the induced wave. The AMT method has proven to be a fairly effective reconnaissance tool in other geothermal areas where used for resistivity mapping. For each station the electric (E) and magnetic (H) fields are measured in orthogonal directions at each frequency. Two simultaneous soundings are made with a 100-meter electric field lines (using copper-clad steel stakes as electrodes) and the coils oriented east-west and north-south (Hoover and Long, 1975). For a complete description of the Audio-magnetotelluric method the reader is referred to Hoover and Long (1975).

The 7.5 htz contour map (Fig. 16) indicates a low resistive zone though the central part of the mapped area. The gradient is more exaggerated, primarily because lower frequency level indicates greater penetration of the sedimentary rock sequences. The low resistivities are probably the result of the thick Pierre shale. The steep resistivity gradient in the to the north may be attributed to the thinning the Pierre shale and possible penetrating the higher Paleozoic resistive beds. The steep gradient to the southwest may also be attributed to some thinning of the Pierre shale.



EXPLANATION

Hot spring

Warm artesian well

7 Station number
• Station location
7.8 Value in ohm-meters

40 — D/U — Contour interval in ohm-meters

Inferred fault

Dakota Hogback

Frequency = 7.5 hertz

SCALE

½in. = 1 mi.

Figure 16. Audio-magnetotelluric survey

The Dakota aquifer may have been penetrated in the east and northeastern portion of the area, primarily because the Dakota sandstone on the Brush Hollow Anticline (Horst?) is less than 1500 ft (457 m) below the surface. Any thermal waters in the Dakota could have contributed to the resistive low.

While the resistivity low to the west cannot be readily explained there are several possible explanations for it. 1) It may be associated with the thermal waters found along the west side of the study area. 2) It may be related to the shallowing of the lower resistive rocks along the west side of the basin. or 3) a combination of the above two.

Seismic Survey

A Vibroseis survey was conducted by the Exploration Research Laboratory, Colorado School of Mines in the Penrose area (Append. J). The survey line, which was laid out over the top of the Brush Hollow Anticline, did not extend far enough west to show the steep dips on the west side of the anticline. While the data was of good quality the author was unable to reach any definitive conclusions regarding the subsurface structure. The author did note a reflecting surface at a depth in excess of 13,000 ft (3.962 km). With the available data the author was not able to explain this surface, other than it might be a deep thrust fault, or some structure within the basement.

Conclusions

The telluric surveys conducted by the U.S. Geological Survey in the Penrose area confirmed Wiemer's (1980) geological analysis of the area. These surveys showed that the Brush Hollow Anticline (Horst?) is faulted on both sides with steep westerly dip (Christopherson, 1980, and Appendix I this volume).

No definitive conclusions can be drawn about the geological conditions from the seismic survey data. Applegate (Appendix J), indicates that the deep geological structure of the Penrose area could have resulted from the following: Post-Ordovician overthrusting with subsequent movement as theorized by Weimer (1980); the deep structure is not of sedimentary origin but rather a sub-basement reflection within the basement; or a geothermal front exists at depth.

The dipole-dipole electrical resistivity surveys conducted by the Colorado Geological Survey delineated the Canon City Hot Springs system quite well but were less satisfactory in the eastern thermal artesian well area due to the averaging effect of the sedimentary rock sequence.

The AMT survey indicated two possible geothermal systems one in the vicinity of the Canon City Area and the other to the east in the Penrose area.

SOIL MERCURY 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. One of these, soil mercury surveys, has proven successful in a number of instances. For example, Capuano and Bamford (1978); Cox and Cuff (1980); Klusman and others, (1977); Klusman and Landress, (1979); and Matlick and Buseck (1976) have demonstrated the use of soil mercury surveying as a geothermal exploration tool. Both Matlick and Buseck (1976), and more recently, Cox and Cuff, (1980), have used soil mercury surveys on a regional scale. On a detailed scale, 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: Geysers, California; Wairakei, New Zealand; Geyser, Iceland; Larderello, Italy; and Kamchatka, Russia all 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 that 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 relatively 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 four case studies where they used soil mercury concentrations as an 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 six areas sampled, Glenwood Springs. Their survey indicated anomalous zones at Glenwood Springs.

Soil Mercury surveys were run by Capuano and Bamford (1978) at the Roosevelt Utah Hot Springs Known Geothermal Resource Area. 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.

Strategy and Methodology

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 allotted 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 work of Capuano and Bamford (1978). In 1980 a broader sampling target was selected. Rather than just sampling along traverses located over suspected faults, grid sampling patterns were used. 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 the following restrictions became apparent: urban development; alluvial and colluvial deposits; and mining areas. In urban developments one cannot really be sure whether the surface deposits in the back streets and lawns are original or have been brought in. 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. In old mining area the problem becomes whether the mercury concentrations found are caused by mineralization or by geothermal actitivty.

Sampling Methods

At selected sample sites, one to eight samples were taken at points within 15 to 20 ft 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 m to 61 m or 122 m). When using a 400 ft (122 m) interval, the area in the immediate vincinity of the hot spring was considered the target rather than any particular fault. Sampling intervals of 200 ft (61 m) or less were used where attempts were made to delineate controlling faults. This spacing was used by Capuano and Bamford (1978). However, Klusman and Landress (1979) seem to think that the sample must be taken directly over the faulting for detection. Considering the empirical result of Capuano and Bamford (1978), it was believed that some anomalous mercury values should be encountered if a grid pattern encompassing the hot spring area was used. A definite structural pattern may be obvious, but if the study area is being influenced by geothermal activity, the trend should indicate that the hot sprins 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 samples 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 than likely lead to false interpretation.

Two rationales have been used for determining the sampling depth. The method recommended by Capuano and Bamford (1978) is to determine the profile of mercury down to a depth of approximately 16 in (40 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 cm), with an interval of about 0.4 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 9 to 10 in (20 to 25 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 overnight. 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 seven days later, the samples were analyzed for mercury using the Model 301 Jerome gold film mercury detector.

Analysis

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 cumulative frequency plot of the mercury data can be used. Hopefully, the break distinguishes the two populations -- the background and the geothermal induced population (Capuano and Bamford, 1978; Lepelitor, 1969; and Levinson, 1974).

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

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

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

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

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

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

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

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

For those cases where the data 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 development. This effort consisted of a literature search, and geologic mapping.

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, CANON CITY AREA

Introduction

Unlike most of the other thermal areas in Colorado investigated during the course of this program, the Canon City area encompassed vast acreage (approximately 110 sq. mi). The large size of the study area presented problems in designing a soil mercury sampling program. Normally lines would be laid over suspected faults or in proximity to thermal springs and tied together. This was not possible in the Canon City Area. Therefore, it was decided to collect geochemical samples in three areas: Around the Penrose Artestian Thermal Well; on the grounds of the correctional complex east of Canon City; and in the Canon City Hot Springs region (Fig. 17).

These areas were chosen for the following reasons: Penrose Artesian Thermal Well-- Other than the well, no surface expression of thermal conditions was evident. It was hoped that some indication of the deep thermal conditions would be found and that the geochemical sampling program could then be expanded to other parts of the study area.

Dept. of Corrections land: On this land a number of facilities exist: A minimum security facility, a new maximum security facility, and the prison farm. Prior to the start of this investigation the Dept. of Corrections stated that they would be able to use any and all thermal waters found in close proximity to the prison facilities. In addition, the complex is located in what appeared to be the junction of several geologic structures. It is noted on Figure 7, that the Chandler Syncline, located to the west, has a north-south trend, while the Oil Creek Anticline to the north and the Castle Rock Syncline to the northeast have a northeast-southwest trend. It was believed that the bedrock of the correctional complex could be fractured allowing the escape of mercury rich gases from the thermal system at depth.

Canon City Hot Spring-- In addition to being the only true thermal spring in the area, this site was sampled to try and determine any controlling structures.

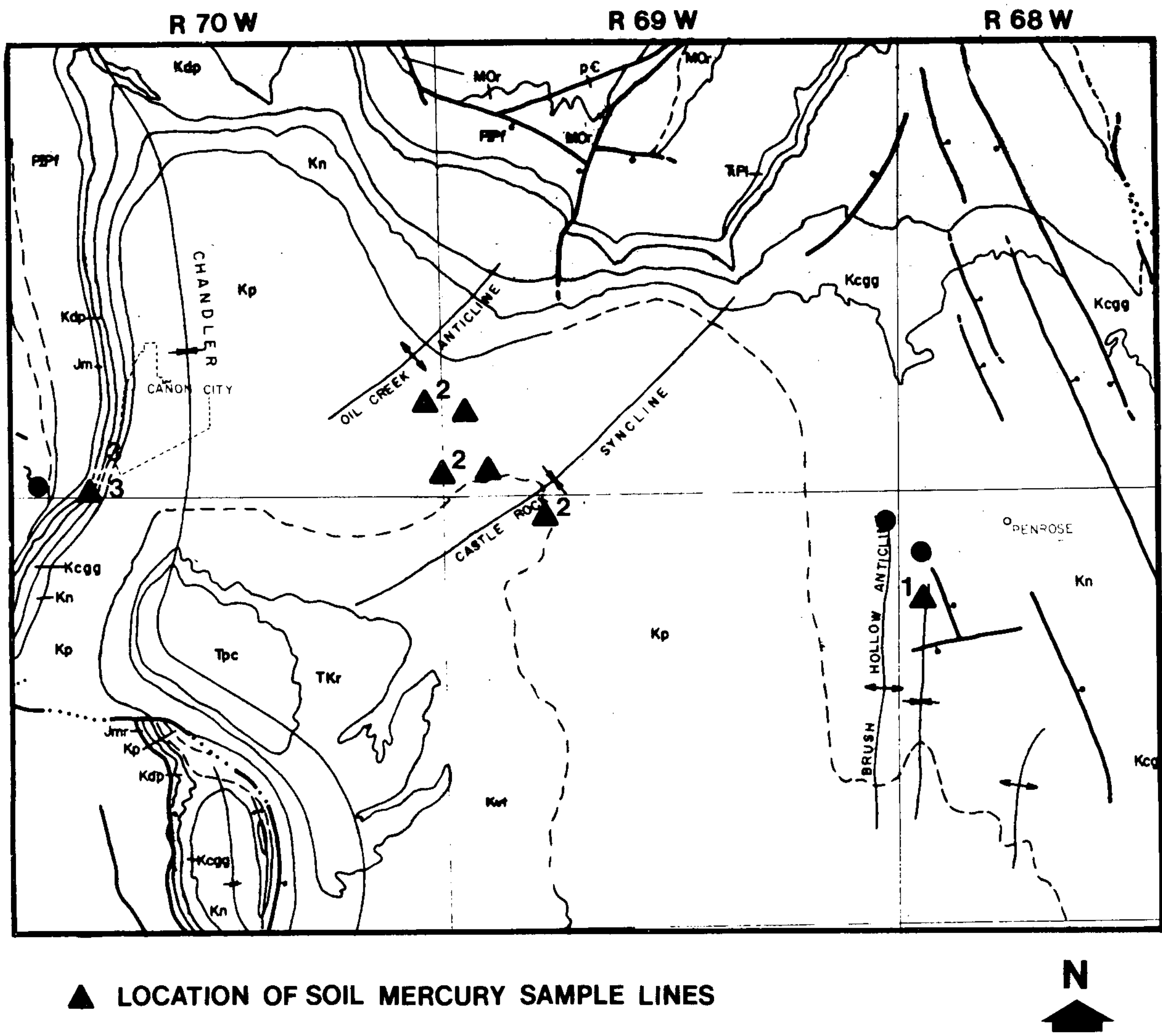


Figure 17. Location of soil mercury sample sites (Geology adapted from Vinckier, 1978 - see p. 11 for explanation).

Soils

The soils in the area sampled were derived from the underlying bedrock or alluvial and colluvial deposits. In the Penrose area the soils were derived from the underlying Niobrara Formation, in the correctional complex area the soils were either derived from the Pierre shale bedrock or alluvial terrace deposits. In the Canon City hot Springs area the soils were essentially alluvial and colluvial deposits.

Soil Mercury Surveys

Penrose Area

15 samples were collected at 100 ft (30 m) intervals along 6 sample lines around the Penrose Artesian Thermal Well (Fig. 18). Mercury concentration levels measured along these lines ranged from a low of 12 ppb to a high of 101 ppb. with an average value of 38 ppb (Fig. 19). While the area north of the well has high values no noticeable anomalous zones were readily apparent.

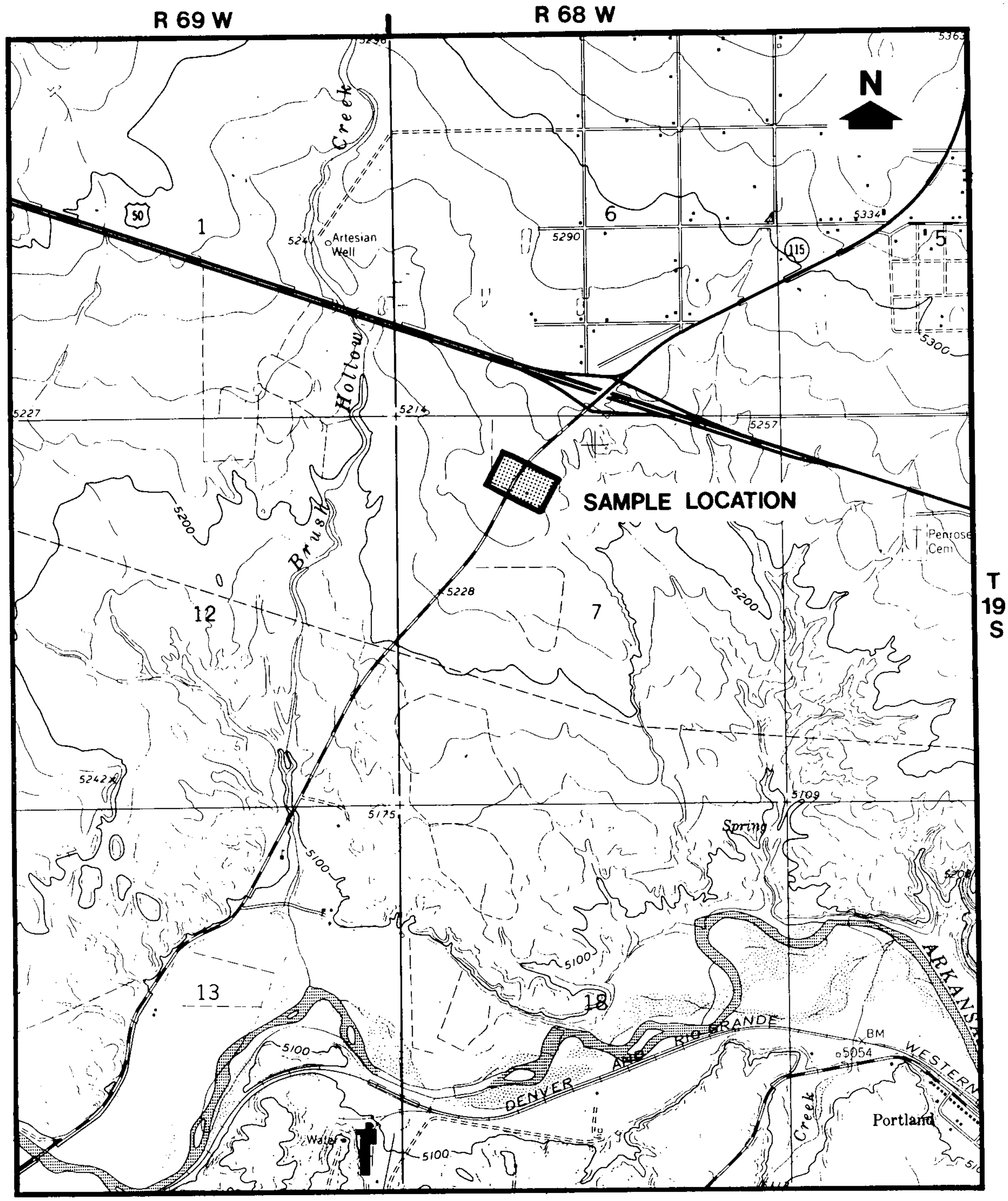
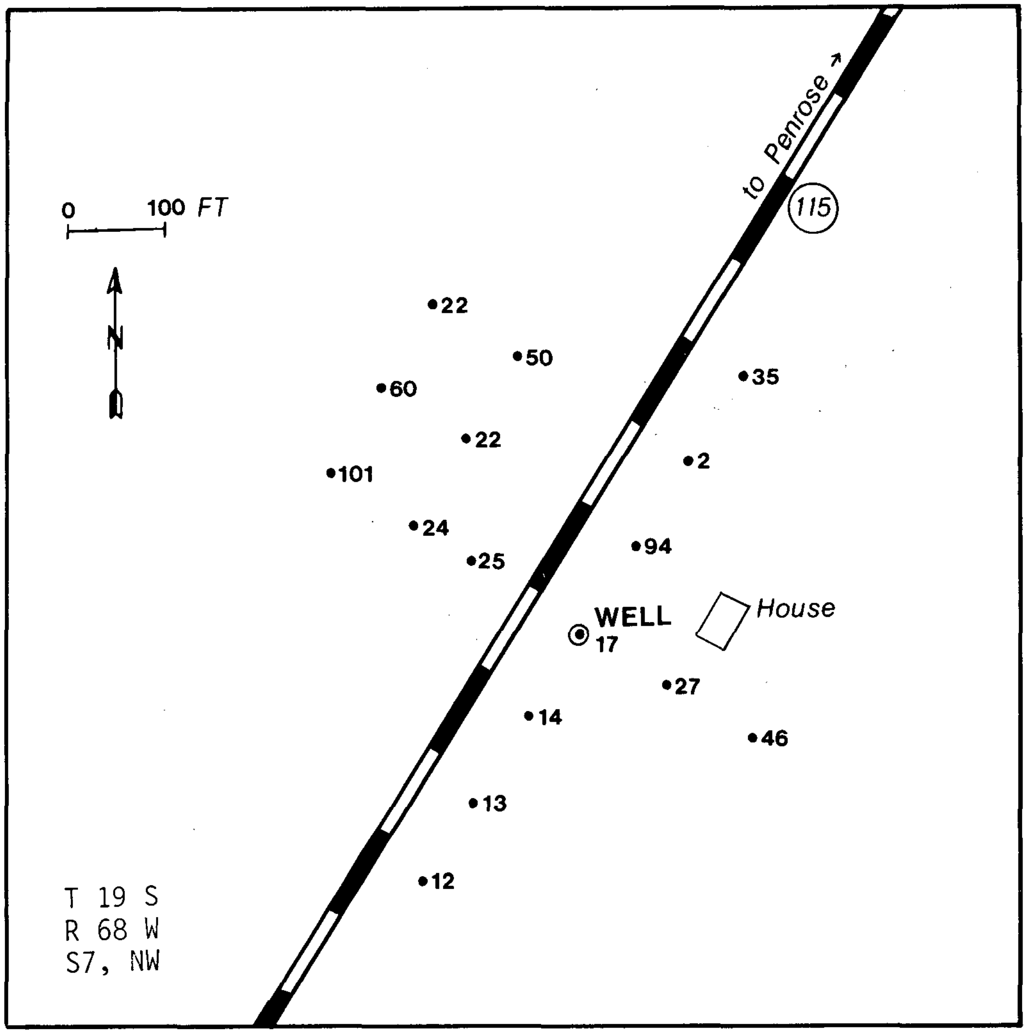


Figure 18. Penrose soil mercury sample area.



EXPLANATION

• 22 Location of sampling site, number indicates mercury concentration in ppb

Figure 19. Penrose artesian well soil mercury sample sites.

Correctional Complex

At the Colorado Dept. of Corrections complex east of Canon City samples were collected along 5 lines (Fig. 20). Mercury concentrations values ranged from a low of 06 ppb to a high of 115 ppb. When the data was arranged in descending order it was noted that there was a significant break in the values between the 69 ppb and 83 ppb level. From this it was decided that any value above 69 ppb would be considered anomalous. To show the variability of the analytical data the soil mercury analytical values have been plotted in profile form in Figures 21 to 25.

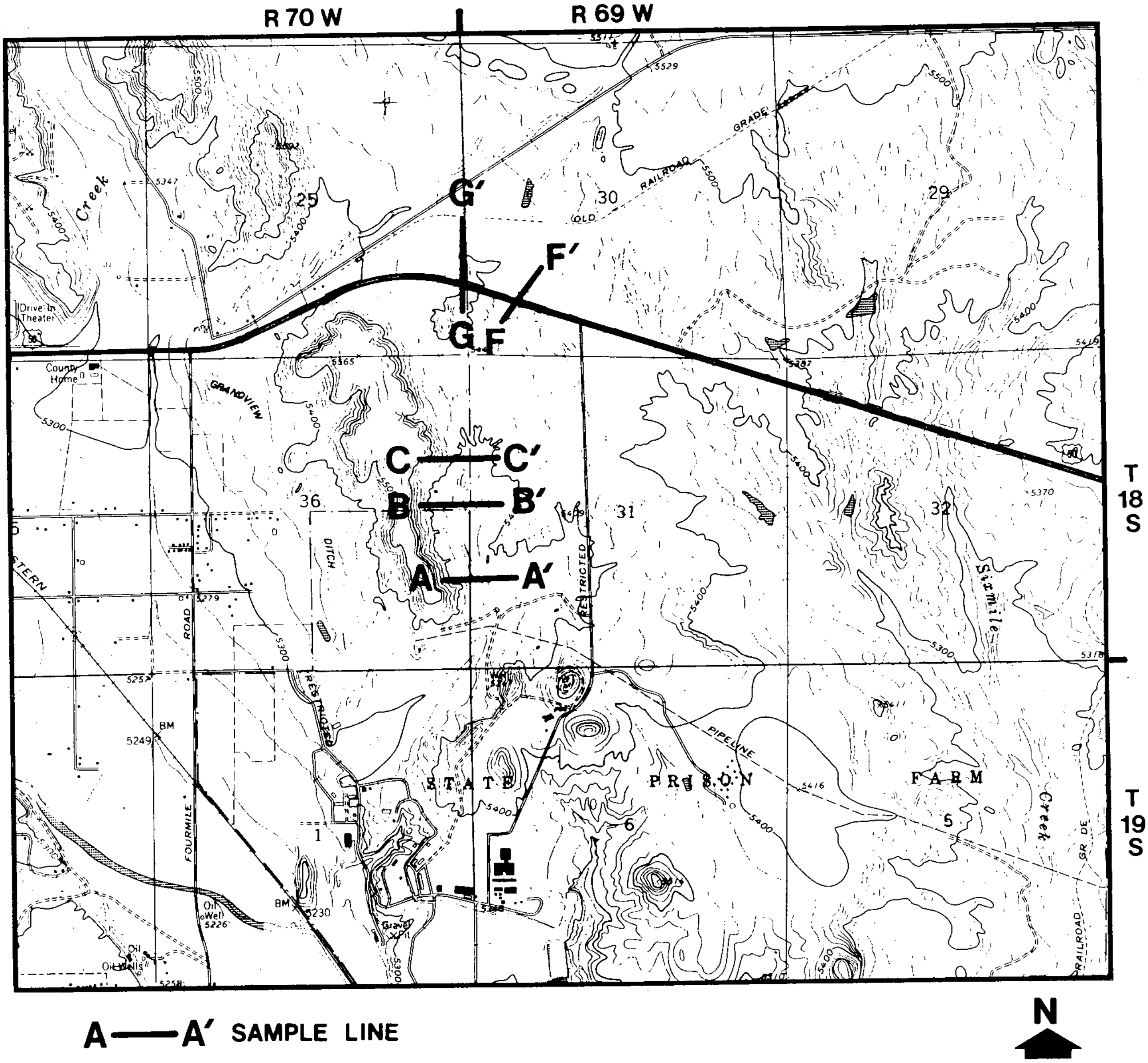


Figure 20. Location of soil mercury lines adjancent to correctional complex.

Samples were collected along three lines traversing the eastern slope of the mesa to the west of the new maximum security facility (Fig. 29). Anomalously high values were recorded on lines A-A' and C-C'. No significant structural or thermal features were noted along either of these two lines. The significance of these high values is not known at the present, but they may represent fracturing of the Pierre shale bedrock.

High mercury concentration values were recorded along lines D-D' and E-E' (Figs. 24 and 25). Both of these lines cross U.S. 50 and run close to an old railroad grade. Both of these features could be sources of contamination. Therefore from examination of the data it appeared that no meaningful trends were observed in the soil mercury concentrations in this area.

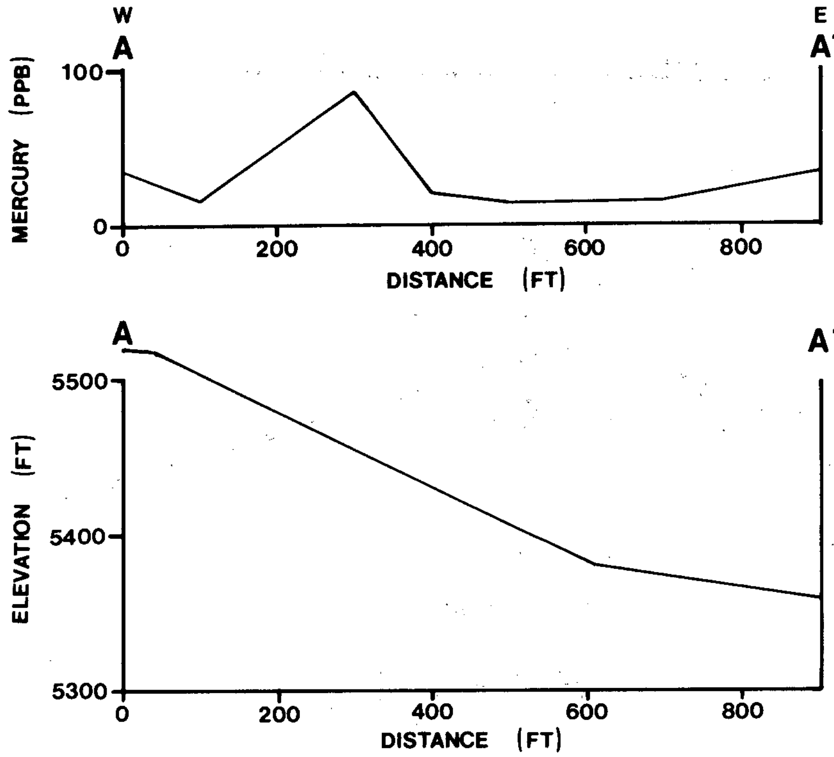


Figure 21. Soil mercury traverse A-A' and surface topography profile, State Penitentiary.

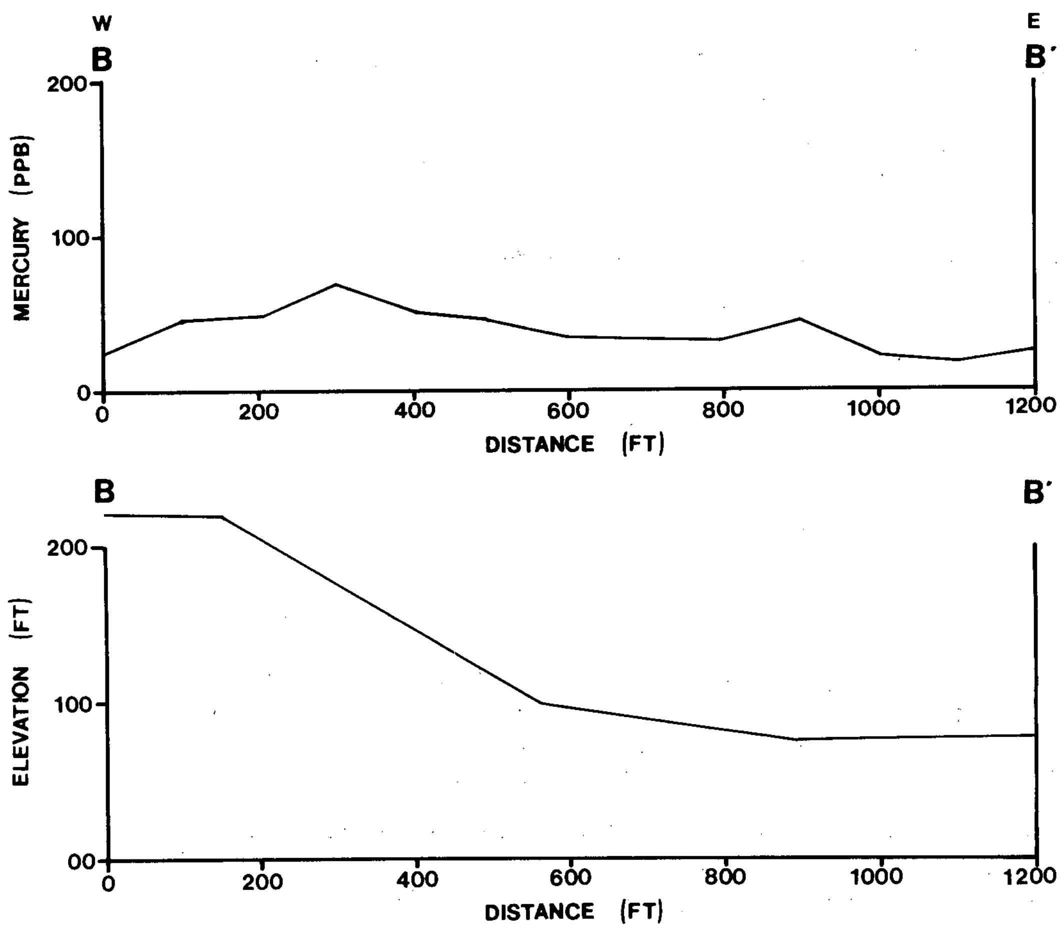


Figure 22. Soil mercury traverse B-B' and surface topography profile, State Penitentiary.

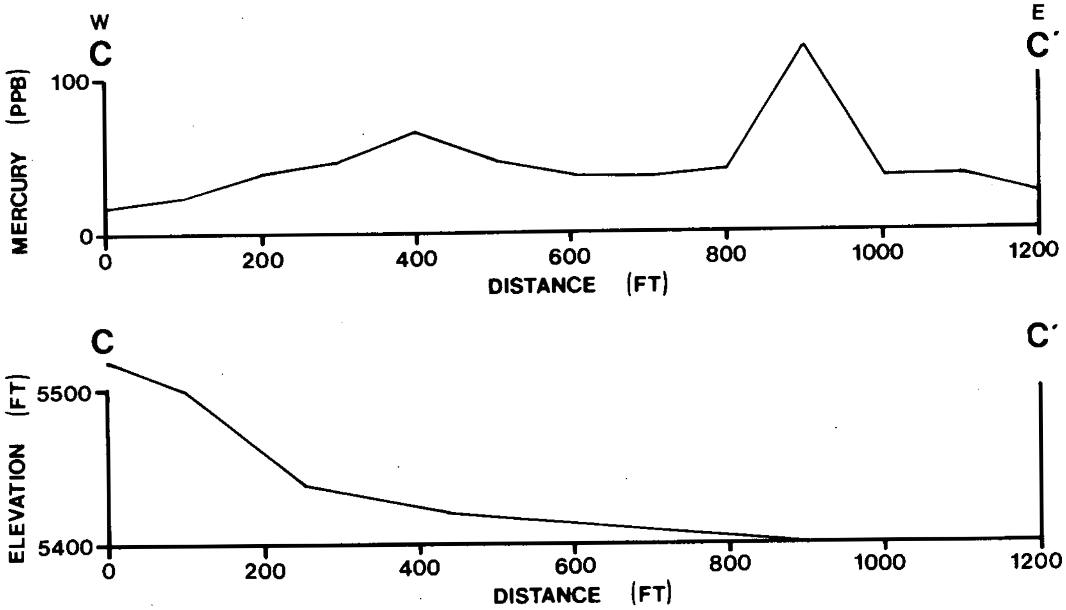


Figure 23. Soil mercury traverse C-C' and surface topography profile, State Penitentiary.

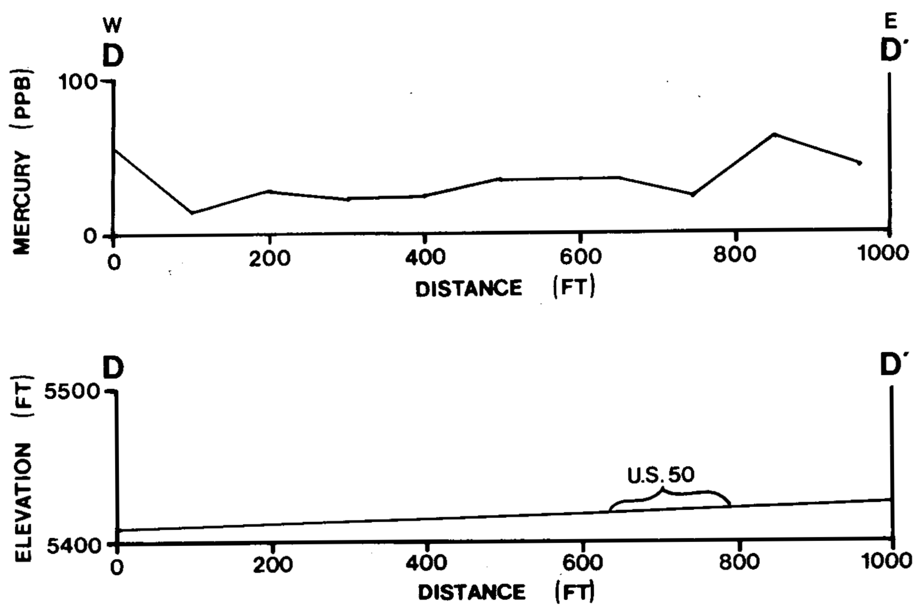


Figure 24. Soil mercury traverse D-D' and surface topography profile, State Penitentiary.

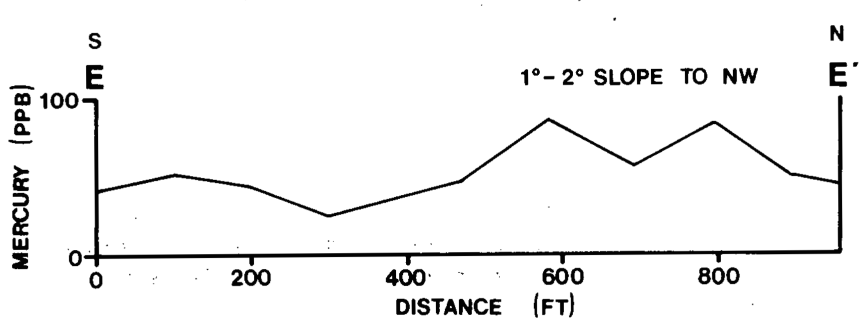


Figure 25. Soil mercury traverse E-E', State Penitentiary.

Canon City Hot Springs Area

Two short lines were laid out south of the hot springs and 14 samples were collected (Fig. 26). Concentration of mercury along these lines ranged from a low of 11 ppb to a high of 769ppb. The high value represents contamination by the cinders used as fill in the area. As can be noted no apparent anomalous concentration levels of soil mercury were detected.

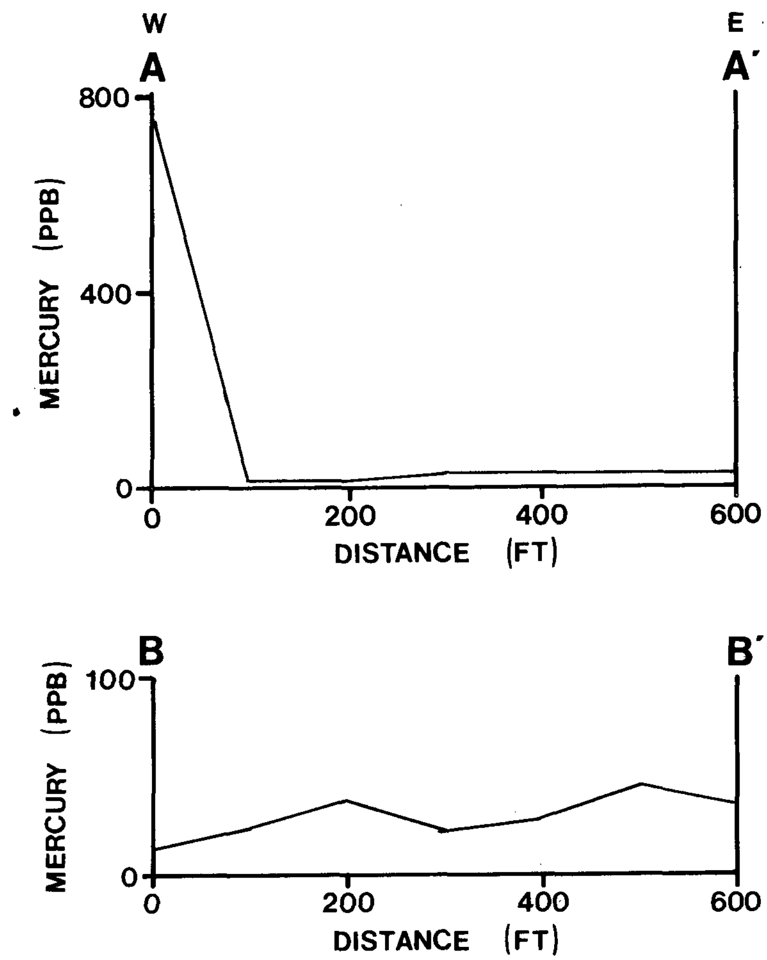


Figure 26. Soil mercury traverses A-A' and B-B', Canon City Hot Springs.

Conclusion

Due to the large size of the study area it was decided that the geochemical sampling program should be designed to locate any controling structural features. Therefore sample lines were laid out in the vicinity of a thermal wells and the hot spring area. In addition the Colorado Dept. of Corrections land east of Canon City was sampled. Analysis of the analytical data showed a few anomalously high values, in all areas, however no readily apparent trend was observed.

ORIGIN OF CANON CITY AREA THERMAL WATERS

Introduction

The thermal waters of the Canon City area appear to have originated under two distinct hydrogeological environments. However, examination of the geological conditions indicates that all the thermal waters could be of the same origin and may explained by the combination of decay of radioactive minerals and favorable geological conditions.

While the thermal waters may be a product of hydrothermal solutions being driven off from the basement rocks (Vinckier, 1978 and 1982) or are due to higher than normal gradients and heat flow (Repplier and Fargo, 1981, and Zacharakis, 1981) it is believed that the most logical explanation is related to the high levels of radioactive minerals associated with the ground waters. This association has been studied and reported on by Felmlee and Cadigan (1979) and Vinckier (1978 and 1982).

Nelson-Moore and others (1978) have shown that economic concentrations of radioactive minerals exist to the northwest, west and southwest of Canon City in Precambrian and Tertiary age rocks. Fig. 7 shows the Precambrian age rocks around the basin being cut by numerous faults which essentially strike into the basin. These faults for the most part terminate at the base of the sedimentary rock sequence.

Vinckier (1978 and 1982) noted that some of the highest levels of radioactive decay in the Dakota Group and Morrison Formation in the southwest part of the Canon City Embayment are found in close proximity to major faults. He (Vinckier, 1978 and 1982) made the assumption that the radioactivity is migrating up from depth along the faults with recharging groundwaters.

It can be postulated that radioactive minerals found in the radioactive rich mineral deposits and rocks to the west are being eroded and leached by normal ground-waters. These radioactive rich ground waters then migrate down, through and along the numerous fault and fracture zones into the Canon City area where they move upward along fault and fracture zones into the Morrison and Dakota aquifers. The radioactive minerals are then precipitated out near the fault zones (Vinckier, 1978 and 1982). The heat given off by the decaying radioactive elements is then trapped by the thick insulating blanket of shales, which overlies the Dakota Group thus heating the ground waters.

Any other explanation must be able to account for the fact that there is very little change in the temperature of the thermal waters across the study area. This can only be accounted for by an area wide heat source.

Canon City Area

From the locaton of the two hot springs it is perceived that the hot water may emerge through the Fremont limestone along a covered fault plane from fractured Precambrian migmatitic rocks underlying the limestone beds. The recharge area for these springs is probably to the north, west, and south along the flanks of the Canon City embayment.

Penrose Area

All the wells in the Penrose area, which are located on the asymetric Brush Hollow Anticline appear to be associated with the Dakota Sandstone. Geological and geophysical data has shown that the Brush Hollow Anticline is cut by faults that extend from Precambrian into the Cretaceous age formations. The faults could be the conduit by which the radioactive rich thermal waters are moving from depth into the Dakota sandstone.

Size and Extent of Canon City Thermal System

As noted before, with few exception, all the thermal waters found in the larger Canon City Embayment are restricted to the study area. This is an area of approximately 110 sq mi (284.9 sq km) containing waters with an estimated average temperature of 90°F (32°C). The present total discharge from the thermal reservoir through springs and wells in excess of 400 gallons per minute, or 532 acre feet per year (A.F./yr) (1 A.F. = 325,900 gallons). It can be assumed that the present conditions nearly represent hydrogeological equilibrium conditions and much of this presently unused water could used for commercial development without seriously affecting the reservoir. In addition if it is assumed that all the thermal waters are restricted to the Dakota aquifer and the Dakota aquifer has an average permeability of .15 (15%), and an average thickness of 85 ft (26 m) (Vinckier, 1982) the amount of thermal water in storage can be calculated to be 881,280 A.F. The amount of drainable thermal water is estimated to be approximately 264,000 A.F. This amount is in addition to the 532 A.F/yr already flowing from the aquifer.

An estimate of the energy available from the Canon City Area thermal system can be made using the current thermal water discharge of 532 A.F./yr. If 20°F (11°C) of heat is extracted from the discharge 35,100,000,000 B.T.U's/yr of heat energy will be obtained. At 1982 price of natural gas of $ 4.50/MCF this is a gross savings of $15,795/yr.

Unfortunately, while it appears that there are large quantities of low to moderate temperature thermal waters available for development throughout the study area, the depth at which these waters occur will prevent their development throughout much of the area. In the study area there are four major geologic structures, from west to east they are: Chandler Syncline, Oil Creek Anticline, Castle Rock Syncline and the Brush Hollow Anticline (Fig. 7). These structures determine at what depth the water bearing units will be found. On synclines rock units which on anticlines are found close to the surface will be found at depth. Vinckier (1978 and 1982) showed that the Dakota aquifer in the Chandler Syncline in the western part of the study area is more than 6,000 ft (1,829 m) below the surface. The depth to the aquifer shallows from there to the east, where just west of the Brush Hollow Anticline the depth is approximately 1,200 ft (366 m). On the crest of the Brush Hollow Anticline the top of the Dakota Group is approximately 700 ft (213 m) below the surface.

SUMMARY AND CONCLUSIONS

Found within the Canon City Embayment, located on the southern end of the Front Range, are one thermal spring and 8 thermal water wells of low to moderate temperature (<108°F). Examination of the occurrence of the thermal waters has determined that the thermal waters are essentially restricted to an area north of the Arkansas River, and south and east of the mountains.

To fully define the size, extent, occurrence and other factors relating to this resource, a program was initiated in 1979 to evaluate the geothermal resource potential of this area. This program consisted of: literature search; reconnaissance geological mapping; test drilling; soil mercury geochemical sampling; and electrical resistivity, seismic, telluric, and audio-magnetotelluric geophysical surveys.

The Canon City Embayment is a large south-southeast plunging syncline on the east side of the Southern Rocky Mountains with the basin reaching a maximum depth of over 6,000 ft (1.83 Km). south of Canon City. Within the basin are a number of smaller synclines and anticlines. Preliminary subsurface work by Weimer (198), and later confirmed by geophysical surveys conducted as part of this program, showed that the eastern margin of the study area is bounded by the Brush Hollow Anticline. Preliminary evidence tends to show this structure is a horst block and not a true anticline.

Examination of the hydrogeological conditions of the study area determined that the thermal waters are found associated with the Morrison and Dakota aquifers and range in temperature from a low of 79°F (26°C) to a high of 108°F (42°C). Vinckier (1978 and 1982) noted that the thermal waters are a sodium-bicarbonate type while the non thermal ground-waters are a calcium-bicarbonate type. Vinckier also noted that the ground waters of the Canon City Embayment contain high levels of radioactive minerals.

The radioactive minerals plays an important role in the origin of the thermal waters for it is postulated that the large amount of heat given off by the decaying minerals is trapped by the thick sequence of the overlying Pierre shale. The heat then warms the ground waters found in the Morrison and Dakota aquifers.

The geothermal resources of the Canon City area appear to be large. Under present conditions over 532 acre feet per year of thermal water are discharging at the surface. In addition it is conservatively estimated that there are an additional 264,000 acre feet of recoverable thermal waters in the study area. 35,100,000,000 B.T.U.'s of heat energy/year could be obtained if the temperature of the 532 A.F./yr was lowered 20°F (11°C) for a saving of almost $16,000/yr.

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APPENDIX A

GEOTHERMAL ENERGY AND ITS POSSIBLE USES

Geothermal energy, the heat generated by natural processes beneath the earth's surface normally occurs at great depths. In some places, however it can be found close to or at the surface in the form of volcanoes, geysers or hot springs. Where it occurs near the surface it can be developed and put to beneficial use. Geothermal energy in the form of hot springs has been used by mankind for medicinal and cooking purposes since the earliest days of recorded history. In the last 100 years development of this energy source for other uses has occurred, and it is now used for such purposes as: Generation of electricity; heating and cooling of buildings; processing of food and other goods; heating cattle barns, greenhouses and fish ponds; milk pasteurization; and recreation and medicinal. Due to declining petroleum reserves It is anticipated that in years to come development of this energy source will increase. Figure 27 lists some of the uses geothermal energy could be put to and the temperatures required.

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

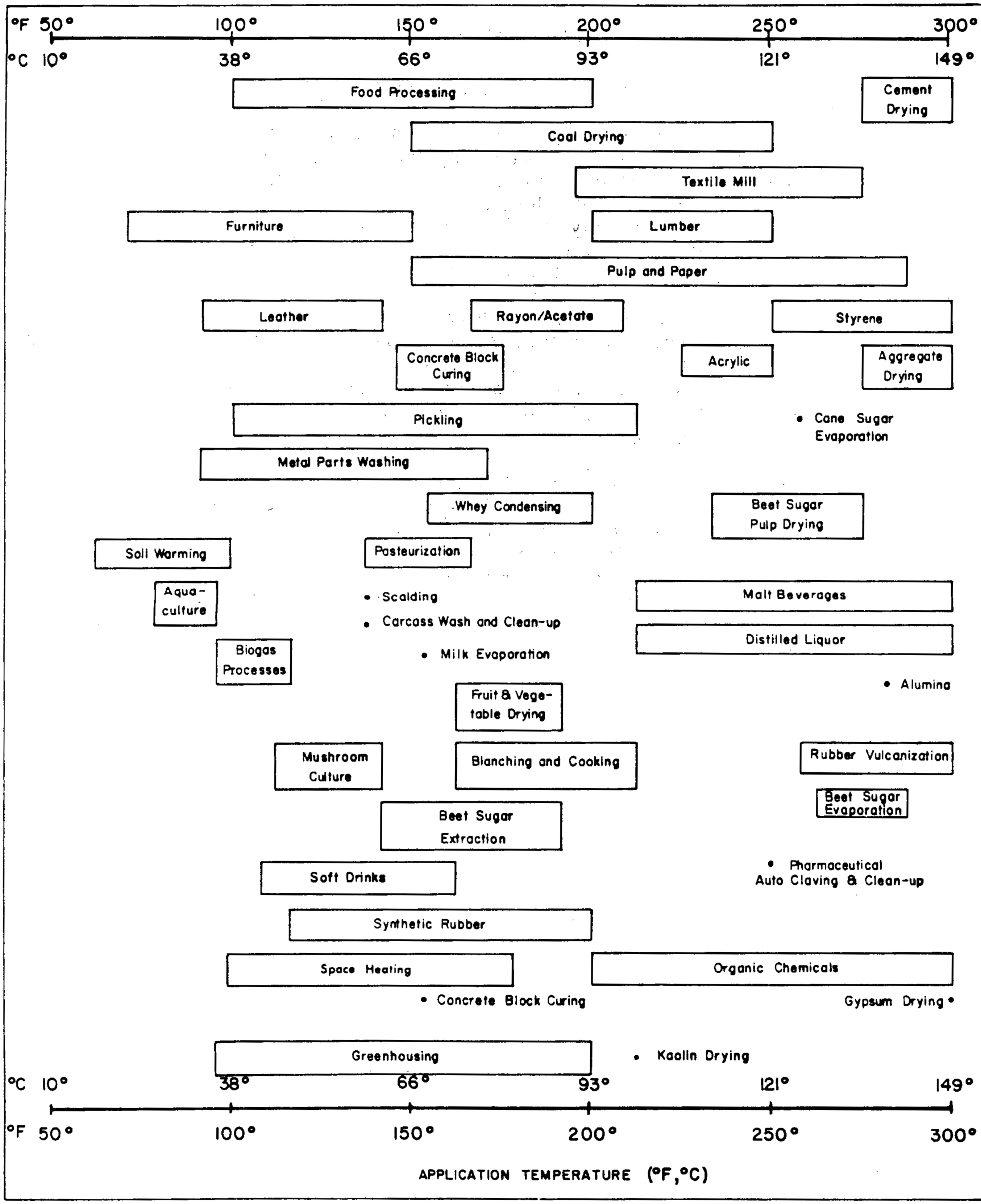


Figure 27. Temperature range for some direct uses of geothermal energy. Adapted from: Geothermal Resources Council Special Report #7.

APPENDIX B. CANON CITY AREA THERMAL WATERS

Table 2. Physical properties and chemical analysis of Canon City Area thermal waters.

	Canon City Hot Spg.	Fremont Natatorium	Penrose Artesian Well*
Arsenic, (UG/L)	11	0	1
Boron, (UG/L)	190	90	160
Cadium, (UG/L)	0	1	0
Calcium, (MG/L)	190	150	180
Chloride, (MG/L)	180	36	98
Fluoride, (MG/L)	1.5	0.5	1.1
Iron, (UG/L)	30	880	500
Lithium, (UG/L)	230	120	240
Magnesium, (MG/L)	62	70	78
Manganese, (UG/L)	10	50	50
Mercury, (UG/L)	0	0.1	0
Nitrogen, (MG/L)	0.55	0.03	0.01
Phosphate			
Ortho diss. as P, (MG/L)	0.73	0	0.01
Ortho, (MG/L)	2.22	0	0.03
Potassium, (MG/L)	15	13	32
Selenium, (UG/L)	1	0	0
Silica, (MG/L)	22	16	21
Sodium, (MG/L)	190	220	270
Sulfate, (MG/L)	130	550	210
Zinc, (UG/L)	10	10	10
Alkalinity			
As Calcium Carb., (MG/L)	728	515	984
As Bicarbonate, (MG/L)	887	628	1,200
Hardness			
Noncarbonate, (MG/L)	2	150	0
Total, (MG/L)	730	660	770
Specific Conductance (Micromohs)	1,900	1,900	2,200
Total Dissolved Solids (MG/L)	1,230	1,330	1,480
ph, Field	6.3	6.9	6.3
Discharge (gpm)	5	20	130
Temperature (°C)	40	35	28
Date Sampled	9/75	9/75	9/75
Remarks			*

* Formerly called the Florence Artesian Well.

Source of data: Barrett and Pearl (1976)

TABLE 3. Trace Elements In Thermal Waters of the Canon City Area
Values reported in Micrograms/liter (UG/L)

	Canon City Hot Spg.	Fremont Natatorium	Penrose Artesian Well*
Aluminum	20	30	30
Barium	100	30	60
Beryllium	< 2	< 2	< 3
Bismuth	< 9	< 10	< 10
Chromium	< 9	< 9	< 10
Cobalt	< 9	< 9	< 10
Copper	< 2	< 2	3
Gallium	< 4	< 4	< 5
Germanium	<20	< 20	< 20
Lead	< 9	< 9	< 10
Nickel	< 9	< 9	< 10
Silver	< 1	< 1	< 1
Strontium	1,000	1,700	2,900
Tin	<10	< 10	< 13
Titanium	< 5	< 5	< 5
Vandium	< 5	< 5	< 5
Zirconium	<20	< 20	< 20

Source of data: Barrett and Pearl (1976)

Table 4. Radioactivity associated with Canon City area thermal waters.
Values reported in Picocuries/liter (PCi/l)
Source: Barrett and Pearl (1976)

	Canon City Hot Spg.	Fremont Natatorium	Penrose Artesian Well*
226Ra	0.39 ± 0.99	12.0 ± 0.52	31.0 ± 0.83
228Ra	2.8 ± 0.75	36.0 ± 1.9	8.8 ± 1.1
234U	15.0 ± 1.6	0.56 ± 0.10	15.0 ± 1.9
235U	.25 ± .076	< .013	.19 ± 0.079
238U	6.5 ± .73	0.051 ± 0.029	4.8 ± 0.67
230Th	<.027	< .033	0.026 ± 0.023
232Th	<0.19	< .019	< 0.011

APPENDIX C

FACTORS AFFECTING RESISTIVITY

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

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

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

APPENDIX D

SCINTREX RAC-8 LOW FREQUENCY RESISTIVITY SYSTEM

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

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

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

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

The RAC-8, with a measuring range from .0001 to 10,000 ohms, high sensitivity to weight ratio, gives fast, accurate resistivity data. With the low AC operating frequency, good penetration may be obtained in excess of 1500 ft under favorable conditions. The system has an output voltage maximum 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

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

Before discussing the various electrode methods used, it is necessary to consider what is actually measured by an array of current and potential electrodes (Fig. 28). 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

Wenner Array

In the Wenner Spread (Fig. 29) the electrodes are uniformly spaced in a line (Sumner, 1976). In spite of the simple geometry, this arrangement is often quite inconvenient for field work and has some disadvantages from the theoretical point of view as well. For depth exploration using the Wenner Spread, the electrodes are expanded about a fixed center, increasing the spacing in steps. For lateral exploration or mapping the spacing remains constant and all four electrodes are moved along the line, then along another line, and so on. In mapping, the apparent resistivity for each array position is plotted against the center of the spread.

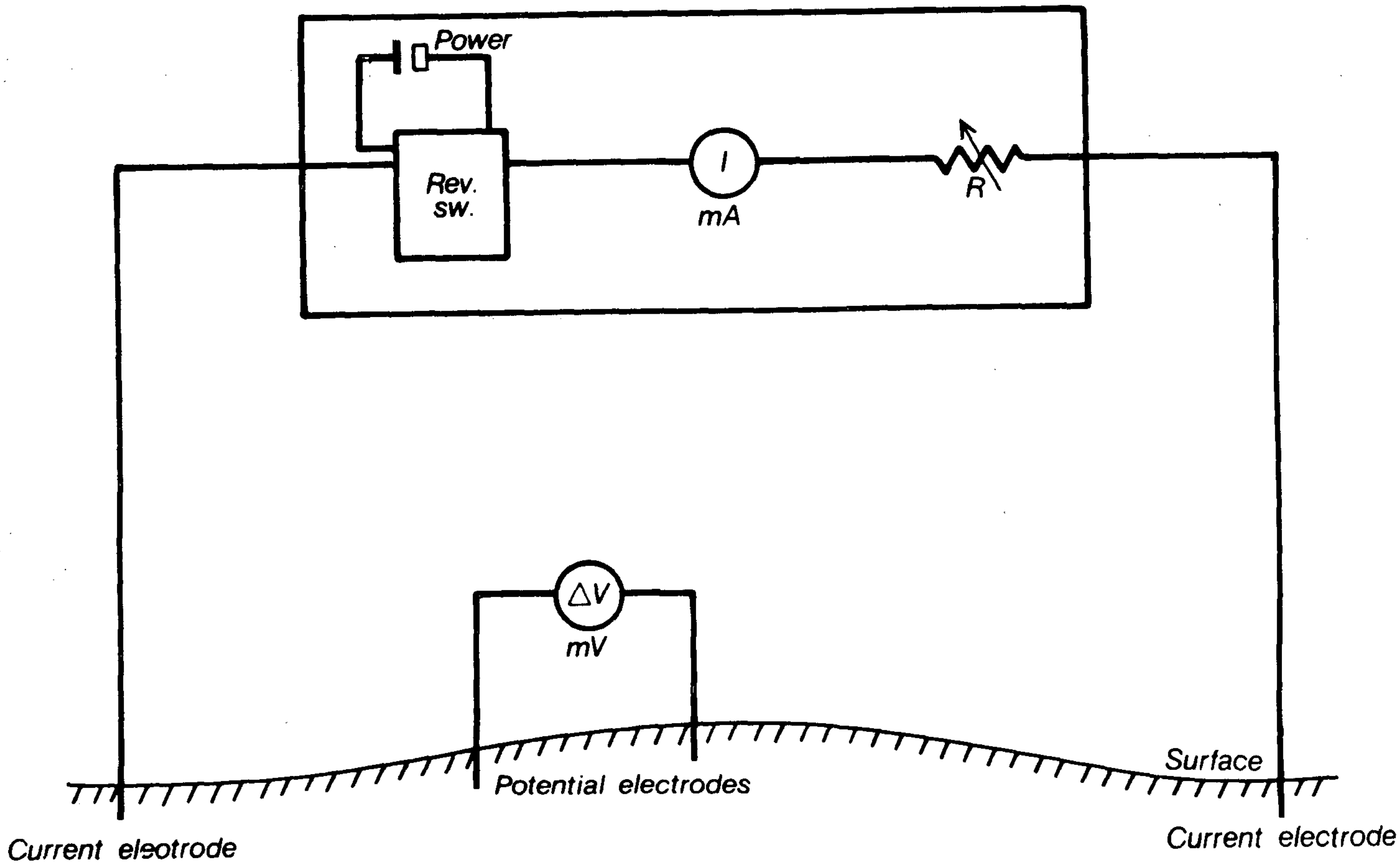
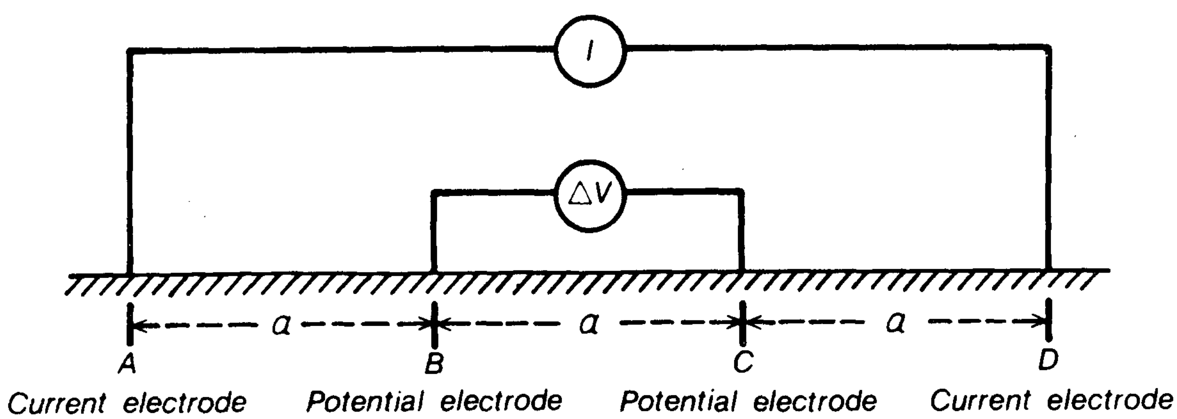


Figure 28. Schematic diagram for resistivity (from J. Combs, 1980).



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

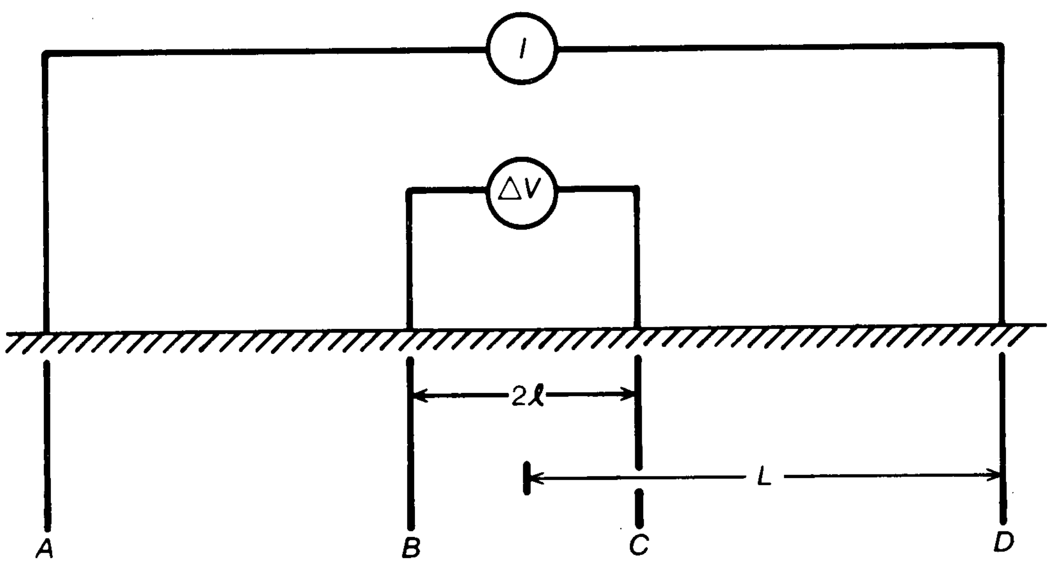
Figure 29. Wenner array (from J. Combs, 1980).

Schlumberger Array

For the Schlumberger array, the current electrodes are spaced much further apart than the potential electrodes (Fig. 30).

In depth probing the potential electrode remains fixed while the current electrode spacing is expanded symmetrically about the center of the spread. For large values of L it may be necessary to increase 2 x 1 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.



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

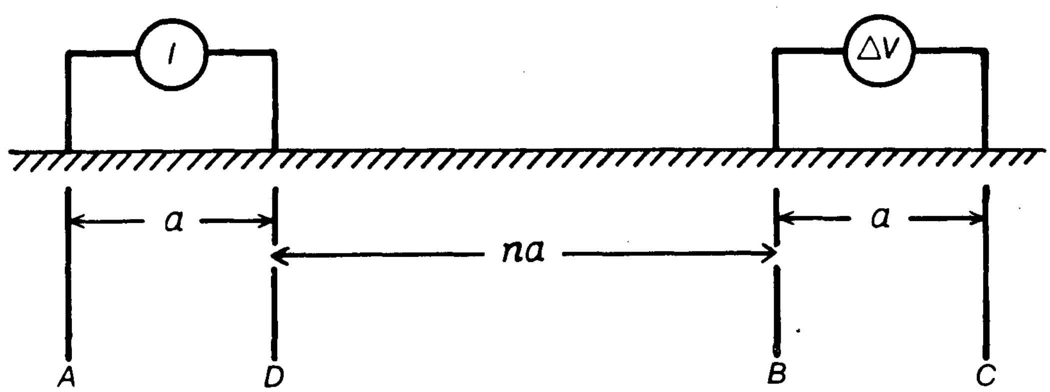
Figure 30. Schlumberger array (from J. Combs, 1980)

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 P, usually 1 to 5 times the dipole lengths (Fig. 31).

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 32 and 33.

With reference to Figures 32 and 33, 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. However, this advantage is not sufficient compensation for the difficulties encountered in making geologic interpretation from the resulting data (Sumner, 1976).



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

Figure 31. Dipole-dipole array (from J. Combs, 1980).

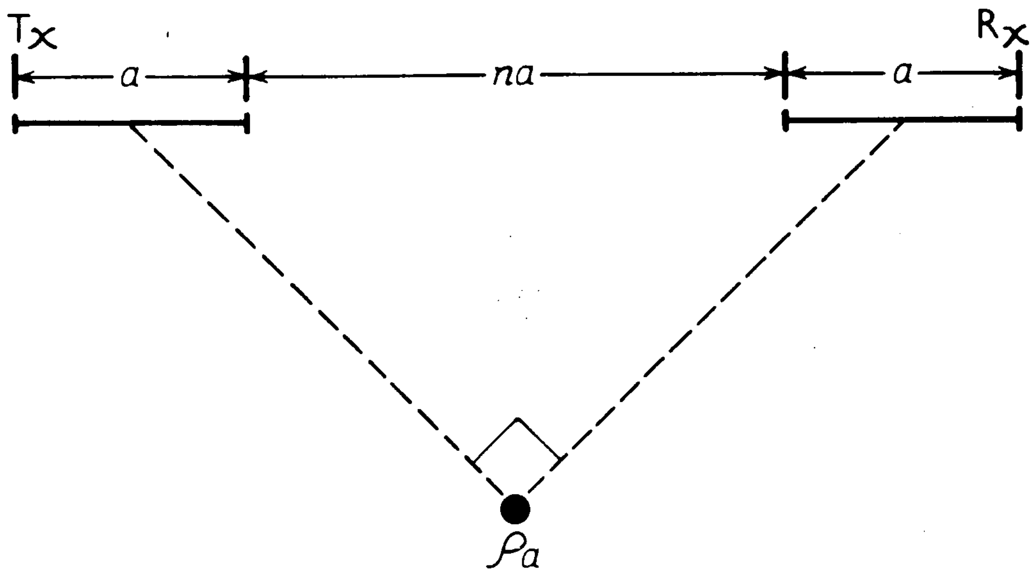


Figure 32. Data plotting scheme for dipole-dipole array (from J. Combs,)

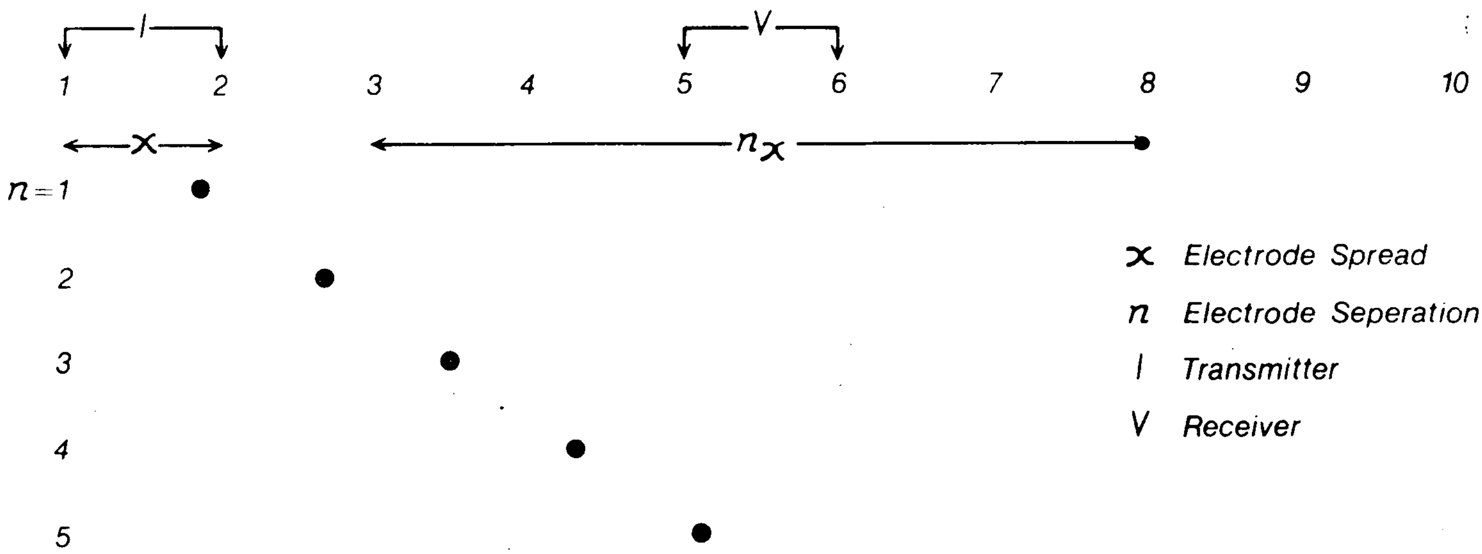


Figure 33. Typical dipole-dipole array (from J. Combs, 1980).

APPENDIX F. RESISTIVITY CALCULATIONS--BRUSH HOLLOW AREA

TABLE 5. LINE A.

LOCATION	PROJECT	DATE
Brush Hollow, Colo.	Line A	29 May 1980
CHIEF OPERATOR	ASSISTANTS	METHOD
Jay Jones	Fargo and Treska	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
7-6							
5-4	10	.01	33	1.04	.104	575	59
4-3	1	.01	33	3.46	.035	2298	80
3-2	1	.01	33	1.56	.016	5747	92
2-1	1	.01	33	1.00	.010	11493	115
6-5							
4-3	10	.01	33	.98	.098	575	56
3-2	10	.01	33	.44	.044	2298	102
2-1	1	.01	33	1.33	.013	5747	75
5-4							
3-2	10	.01	33	.89	.089	575	53
2-1	1	.01	33	3.05	.030	2298	170
4-3							
2-1	10	.01	33	.82	.082	575	47
11-10							
9-8	10	.01	33	.93	.093	575	53
8-7	10	.01	33	.35	.035	2298	82
7-6	1	.01	33	1.02	.010	5747	57.4
6-5	1	.01	33	1.03	.010	11493	115
10-9							
8-7	10	.01	33	1.19	.119	575	69
7-6	10	.01	33	.39	.039	2298	89
6-5	1	.01	33	1.15	.016	5747	92
5-4	1	.001	33	1.04	.010	11493	115
9-8							
7-6	10	.01	33	1.13	.113	575	66
6-5	10	.01	33	.38	.038	2298	89
5-4	1	.01	33	1.03	.010	5747	57
4-3	1	.01	33	.94	.009	11493	105
8-7							
6-5	10	.01	33	1.25	.125	575	72
5-4	10	.01	33	.36	.036	2298	82
4-3	1	.01	33	1.24	.012	5747	69
3-2	1	.01	33	1.14	.011	11493	128

TABLE 5. LINE A (CONT.)

Sta.	Range	MA	Voltage	V_P	DV/I	G.F.	P_a
15-14							
13-12	1	.01	33	5.15	.051	575	29.5
12-11	1	.01	33	1.48	.015	2298	34.4
11-10	1	.01	33	1.18	.012	5747	70
10-9	1	.01	33	.54	.005	11493	57.4
14-13							
12-11	10	.01	33	.9	.090	575	52.5
11-10	10	.01	33	3.61	.036	2298	82.0
10-9	1	.01	33	2.71	.027	5747	154
9-8	1	.01	33	.81	.008	11493	92
13-12							
11-10	10	.01	33	0.98	.098	575	56
10-9	1	.01	33	3.575	.036	2298	83
9-8	1	.01	33	1.88	.019	5747	108
8-7	1	.01	33	1.09	.010	11493	115
12-11							
10-9	1	.01	33	.80	.080	575	46
9-8	1	.01	33	2.89	.029	2298	66
8-7	1	.01	33	.79	.0079	5747	46
7-6	1	.01	33	.83	.0083	11493	95
18-17							
16-15	1	.1	33	1.31	0.131	575	75
15-14	10	.01	33	.560	0.056	2298	128
14-13	1	.01	33	2.04	0.024(4)	5747	115
13-12	1	.01	33	1.04	0.010(4)	11493	115
17-16							
15-14	10	.01	33	1.17	0.117	575	66
14-13	1	.01	33	3.85	0.0385	2298	89
13-12	1	.01	33	1.13	0.0113	5747	66
12-11	1	.01	33	0.70	0.007	11493	80
16-15							
14-13	10	.01	33	0.60	0.060	575	36
13-12	1	.01	33	1.43	0.0143	2298	38
12-11	1	.01	33	0.86	0.0086	5747	49
11-10	1	.01	33	0.41	0.0041	11493	46

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

APPENDIX F. RESISTIVITY CALCULATIONS--BRUSH HOLLOW AREA

TABLE 6. LINE B.

LOCATION	PROJECT	DATE
Brush Hollow, Colo	Line A	30 May 1980
CHIEF OPERATOR	ASSISTANTS	METHOD
Jay Jones	Fargo and Treska	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
20-19							
17-18	10	.01	33	0.87	.087	575	49
16-17	1	.01	33	2.72	.027	2299	62
15-16	1	.01	33	2.87	.029	5747	167
14-15	1	.01	33	1.12	.011	11493	128
19-18							
16-17	10	.01	33	0.88	.088	575	51
15-16	1	.01	33	4.31	.043	2299	99
14-15	1	.01	33	2.70	.027	5747	154
13-14	1	.01	33	0.81	.008	11493	92
18-17							
15-16	10	.01	33	0.70	.070	575	40
14-15	1	.01	33	2.11	.0211	2299	49
13-14	1	.01	33	1.24	.0124	5747	72
12-13	10	.01	33	.1			
17-16							
15-14	10	.01	33	1.08	.108	575	62
14-13	1	.01	33	1.74	.017	2299	39
13-12	1	.01	33	1.40	.014	5747	82
12-11	1	.01	33	1.01	.010	11493	115
16-15							
13-14	10	.01	33	0.94	0.94	575	53
12-13	1	.01	33	3.85	.039	2299	89
11-12	1	.01	33	1.23	.012	5747	69
10-11	1	.01	33	1.23	.012	11493	138
15-14							
13-12	10	.01	33	.70	.070	575	40
12-11	1	.01	33	3.00	.030	2299	69
11-10	1	.01	33	1.98	.0198	5747	114
10-9	1	.01	33	1.27	.0127	11483	146

TABLE 6. LINE B. (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
14-13							
12-11	1	.01	33	5.42	.054	575	31
11-10	1	.01	33	2.73	.027	2299	62
10-9	1	.01	33	0.75	.007(5)	5747	43
9-8	1	.01	33	0.90	.009	11493	103
13-12							
11-10	10	.01	33	0.77	.077	575	44
10-9	1	.01	33	2.47	.025	2299	57
9-8	1	.01	33	1.43	.014	5747	80
8-7	1	.01	33	0.55	.0055	11493	63
12-11							
10-9	1	.01	33	7.07	.070	575	40
9-8	1	.01	33	2.89	.029	2299	67
8-7	1	.01	33	1.24	.012	5747	69
706	1	.01	33	0.49	.0049	11493	56
11-10							
9-8	10	.01	33	1.23	.123	575	71
8-7	1	.01	33	3.88	.0388	2299	89
7-6	1	.01	33	1.53	.0153	5747	88
6-5	1	.01	33	0.87	.0087	11493	100
10-9							
8-7	10	.01	33	1.18	.118	575	68
7-6	1	.01	33	3.29	.0329	2299	76
6-5	1	.01	33	1.45	.0145	5747	83
5-4	1	.01	33	0.70	.007	11493	80
9-8							
7-6	10	.01	33	1.20	.120	575	69
6-5	1	.01	33	3.90	.039	2299	90
5-4	1	.01	33	1.65	.0165	5747	95
4-3	1	.01	33	0.88	.0088	11493	101

TABLE 6. LINE B. (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
8-7							
6-5	1	.01	33	1-5		575	
5-4	1	.01	33	3.26	.0326	2298	54
4-3	1	.01	33	1.73	.0173	5747	99
3-2							
7-6							
5-4	10	.01	33	2.04	.204	575	117
4-3	10	.01	33	0.71	.071	2298	163
3-2	1	.01	33	3.02	.0302	5747	174
2-1	1	.01	33	1.18	.0118	11493	136
6-5							
4-3	10	.01	66	3.03	.303	575	174
3-2	10	.01	66	0.80	.080	2298	184
2-1	1	.01	66	2.65	.0265	5747	152
5-4							
3-2	10	.01	66	2.60	.260	575	150
2-1	10	.01	66	0.53	.053	2298	122
4-3							
2-1	10	.01	66	2.88	.288	575	166

LEGEND: Range = Gain

Range = Gain
MA = Dummy TX Current Switch
Vp = Balance Control to Null Meter

G.F. = Geometric Factor
Pa = Apparent Resistivity
DV/I = Range x MA x Vp

APPENDIX G. RESISTIVITY CALCULATIONS--CANON CITY HOT SPRINGS

TABLE 7. LINE A.

LOCATION	PROJECT	DATE
Canon City Hot Springs	Line A	4 June 1980
CHIEF OPERATOR	ASSISTANTS	METHOD
Jay Jones	Fargo and Treska	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
1-2							
2-3	100	.01	33	1.09	1.09	575	626.4
3-4	10	.01	66	2.9	.29	2299	666.6
4-5	10	.01	66	1.48	.148	5747	850.5
5-6	10	.01	66	0.28	.028	11493	321.8
2-3							
4-5	10	.01	66	2.53	.253	575	145.4
5-6	10	.01	66	0.43	.043	2299	98.8
	1	.01	66	2.07	.0207		
6-7	10	.01	66	.22	.022	5747	118.9
	1	.01	66	2.38			
7-8	10	.01	66	.25	.025	11493	287.3
3-4							
5-6	10	.01	66	0.65	.065	575	37.4
	1	.01	66	1.5			
6-7	10	.01	66	0.18	.018	2299	41.3
	10				.27		
7-8	1	.01	66	2.15	.0215	5747	123.5
4-5							
6-7	10	.01	66	0.27	.027	575	15.5
7-8	10	.01	66	0.53	.053	2299	121.8
12-11							
10-9	10	.01	66	1.96	.196	575	112.6
9-8	10	.01	66	0.70	.070	2299	160.9
8-7		no reading					
7-6		no reading					

TABLE 7. LINE A (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
11-10							
9-8	10	.01	66	2.80	.280	575	161.0
8-7	10	.01	66	.16	.016	2299	36.8
7-6		no reading					
6-5		no reading					
13-12							
11-10	10	.01	66	1.01	.101	575	58.0
10-9	10	.01	66	0.60	.060	2299	137.9
9-8	10	.01	66	.19	.019	5747	109.2
8-7	10	.01	66	.25	.025	11493	287.4
14-13							
12-11	10	.01	66	0.17	.017	575	9.8
11-10	1	.01	66	0.04	.0004	2299	.9
10-9	1	.01	66	0.55	.00055	5747	3.16
9-8		no reading					
15-14							
13-12	10	.01	66	2.23	.223	575	128.1
12-11	1	.01	66	.04	.004	2299	9.2
11-10		no reading					
10-9		no reading					
16-17							
14-13	10	.01	66	.28	.028	575	16.1
12-13	10	.01	66	.08	.008	2299	18
11-12				.04			
10-11		no reading					
17-18							
16-15		no reading					
15-14	10	.01	66	.26	.026	2299	59.8
14-13		no reading					
13-12		no reading					

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

RESISTIVITY CALCULATIONS--CANON CITY HOT SPRINGS

TABLE 8. LINE B.

LOCATION	PROJECT	DATE
Canon City Hot Springs	Line B	5 June 1980
CHIEF OPERATOR	ASSISTANTS	METHOD
Jay Jones	Fargo and Treska	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
10-11							
8-9	10	.01	66	.69	.069	575	39.68
7-8	1	.01	66	.88	.0088	2299	20.22
6-7	1	.01	66	.35	.0035	5747	20.11
5-6	1	.01	100	3.33	.033	11493	379.28
11-12							
10-9	100	.001	66	.95	.095	575	54.63
9-8	10	.001	66	1.19	.0119	2229	27.35
8-7	1	.001	66	3.94	.00394	5747	22.64
7-6	1	.001	66	2.10	.0021	11493	24.14
12-13							
10-11	100	.001	66	1.41	.141	575	8.10
9-10	10	.001	66	1.34	.0134	2299	30.79
8-9	10	.001	66	0.46	.0046	5747	26.44
7-8	1	.001	66	2.04	.0020	11493	22.98
14-13							
12-11	100	.001	66	1.82	.182	575	104.65
11-10	10	.001	66	2.33	.0233	2299	53.54
10-9	1	.001	66	5.55	.0055	5747	31.61
9-8	1	.001	'66	2.51	.0025	11493	28.73
14-15							
13-12	100	.001	66	1.26	.126	575	72.45
12-11	10	.001	66	3.71	.037	2299	85.03
11-10	10	.001	66	0.81	.0081	5747	46.56
10-9	1	.001	66	2.66	.0027	11493	31.03
16-15							
14-13	100	.001	66	1.21	.121	575	69.6
13-12	10	.001	66	2.17	.022	2299	50.56
12-11	10	.001	66	0.98	.0098	5747	56.32
11-10	1	.001	66	2.73	.0027	11493	31.03

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
8-7							
6-5	10	.01	66	0.42			
5-4							
4-3							
3-2							
9-10							
8-7	1	.01	66	3.74	.0374	575	21.5
7-6	10	.001	66	.99	.0099	2299	22.75
6-5	10	.001	100	.41	.0041	5747	23.56
5-4	10	.001	100	.71	.0071	11493	81.66
8-9							
7-6	100	.001	100	.41	.041	575	23.58
6-5	10	.001	100	.91	.0091	2299	20.91
5-4	10	.001	100	1.23	.0123	5747	70.68
4-3	10	.001	100	.66	.0066	11493	75.8
8-7							
6-5	100	.001	100	.46	.046	575	26.45
5-4	10	.001	100	3.0	.030	2299	68.94
4-3	10	.001	100	1.23	.0123	5747	70.68
3-2	10	.001	100	.46	.0046	11493	52.86
7-6							
5-4	1	.1	66	1.38	.138	575	79.35
4-3	1	.1	66	.35	0.035	2299	80.43
3-2	10	.001	100	1.09	0.010	5747	57.47
2-1	1	.001	100	2.77	0.0028	11493	32.18
6-5							
4-3	100	.01	66	.66	.66	575	379.5
3-2	10	.01	66	1.71	0.171	2299	392.9
2-1	10	.01	66	3.14	0.0314	5747	180.4
5-4							
3-2	1000	.001	66	1.36	1.36	575	788
2-1	100	.001	66	2.16	0.216	2299	496.4

TABLE 8. LINE B (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
4-3							
2-1	1000	.001	66	.68	0.68	575	391
1-2							
2-3	100	.01	33 V	1.09	1.09	575	626.4
3-4	10	.01	66	2.9	.29	2299	666.6
4-5	10	.01	66	1.48	.148	5747	850.5
2-3							
4-5	10	.01	66	2.53	.253	575	145.4
5-6	10	.01	66	0.43	.043	2299	98.8
	1	.01	66	2.07	.0207		
6-7	10	.01	66	.22	.022	5747	118.9
	1	.01	66	2.38			
7-8	10	.01	66	.25	0.25	11493	287.3
3-4							
5-6	10	.01	66	0.65	.065	575	37.4
	1	.01	66	1.5			
6-7	10	.01	66	0.18	.018	2299	41.3
	10			.27			
7-8	1	.01	66	2.15	.0215	5747	123.5
4-5							
6-7	10	.01	66	0.27	.027	575	15.5
7-8	10	.01	66	0.53	.053	2299	121.8

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

APPENDIX H

TABLE 9
GEOMETRIC FACTOR TABLE
SCHLUMBERGER METHOD

L(ft) \ 2l (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 10. 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 11. 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

APPENDIX I

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

TELLURIC PROFILING STUDIES IN THE PENROSE AREA, COLORADO

by
Karen R. Christopherson, Kevin H. Nervick, William D. Heran

Open File Report 81-461

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During 1980, the U.S. Geological Survey conducted geophysical studies east of Canon City, Colorado, as part of a geothermal evaluation program. The work was done in cooperation with the Colorado Geological Survey.

Three E-field-ratio telluric profiles were made approximately 13 kilometers east of Canon City, and 3 kilometers southwest of Penrose, Colorado (Fig. 1). The traverses were between 5 and 13 kilometers in length and trended west-northwest to west. The purpose of the traverses was to locate major north-trending faults that displace the Precambrian bedrock but have little or no surficial expression. These faults could provide channels for the upflow of geothermal waters. Warm water (25°C) has been found in several wells drilled in the region.

The geology of the area has been mapped regionally (Scott and others, 1978) and some detailed work has been done by Weimer (1980). The study area lies within the Canon City embayment, just south of the southern terminus of the Front Range. The sedimentary section has been folded resulting in thickening of the Mesozoic and Paleozoic sedimentary rocks above the Precambrian bedrock. No major faults have been mapped, but well data suggest that north-trending faults associated with anticlines and synclines create horst and graben structures in the subsurface (Weimer, 1980). A few kilometers south of the study are (east of Florence), the sedimentary section thickens from 1100 meters (4.5 kilometers south of station 4E, line 3) to 2700 meters (6 kilometers south of state 14W, line 3) over a horizontal distance of 4500 meters (see figure 2 for station locations). Weimer has attributed the thickening to a zone of "steep dip" associated with faulting in the basement on the flanks of the Brush Hollow anticline (Fig. 2). This zone has created a deep (2500-meter) basin between the Brush Hollow anticline and Canon City.

None of the faulting has obvious surficial expression; the local terrain is fairly flat, dipping slightly to the east. The surface exposures are mostly Quaternary alluvium and the Cretaceous Pierre and Niobrara Shales.

The locations of telluric traverses are shown in figure 2. The profiles, which show the relative telluric voltage at a period of 30 seconds referenced to dipole 0-1 on each line, are given in figures 3 through 5. These figures plot the relative voltage changes (proportional to the square root of resistivity) along the traverses.

The telluric instrumentation and method have been described by Beyer (1977). For this survey the bandwidth of the recording system was 20-40 seconds (0.025-0.05) hertz) which results in a maximum depth of exploration (skin depth) of many kilometers in normal earth material. As a rule of thumb, changes in resistivity can be detected at about 1/2 a skin depth. In 20 ohmmeter material the skin depth is 13 kilometers.

Along traverse 1 (fig. 3) there is an increase in voltage (resistivity) westward from station 7 as the contact between the Niobrara and Pierre is approached. This increase could be caused by either a lithology change or an upfaulted basement block to the west. East of station 7 the profile is quite flat, although two lows with an approximate 10% decrease in voltage occur between stations 3 and 4 near station 6. These could be expressions of faulting. There appears to be no reflection of the Brush Hollow anticline in the data at its inferred location near station 2, although there is an increase in voltage eastward from station 3, which may be attributed to it.

Traverse 2 (fig. 4) shows two low-voltage zones, one between stations 2 and 6 and another west of station 8. These again could be indicative of faulting with upthrown blocks between stations 6 and 8 and east of station 2. The eastern low may also be an expression of the syncline shown on figure 2.

Traverse 3 was located south of lines 1 and 2 and extended west into the zone of steep dip proposed by Weimer. The changes in voltage along the profile (fig. 5) are large, varying by almost one order of magnitude. The voltage drops indicate three low-resistivity zones: one west of station 8W, one between stations 4W and 1E, and one east of station 4E. These zones probably represent downthrown and tilted fault blocks, with the largest displacement occurring in the eastern and western lows. These possible faults could be located approximately at stations 4E, 0 4W, and 8W with downthrown sides toward the telluric lows. The voltage changes could also be the result of folding and thickening in the sedimentary section. The low centered between station 6 and 8 east coincides with the inferred mapped syncline axis, and the shallower high between stations 2E and 4E coincides with the Brush Hollow anticline. The zone of steep dip extends west from station 8W and may reflect thickening of the Pierre.

Combining the results from the three profiles, locations of inferred major faults are plotted on Figure 2. The faults can be projected from line to line, revealing the northward trends shown. The major faults lie on the flanks of the anticline and on the edge of the zone of steep dip. Extensions of the two westernmost inferred faults aline with faults located by two seismic lines to the south (Zacharakis, 1980). The two faults between the Brush Hollow anticline and the syncline are probably part of a complex structure. At station 3E on line 3, the axis of the telluric ellipse was rotated 90° from its normal trend, signifying 3-dimensional structure at depth.

It should be noted that these interpretations are speculative and based on geophysical data alone, since the goelogy of the are is not well mapped and all structures and contacts are approximate.

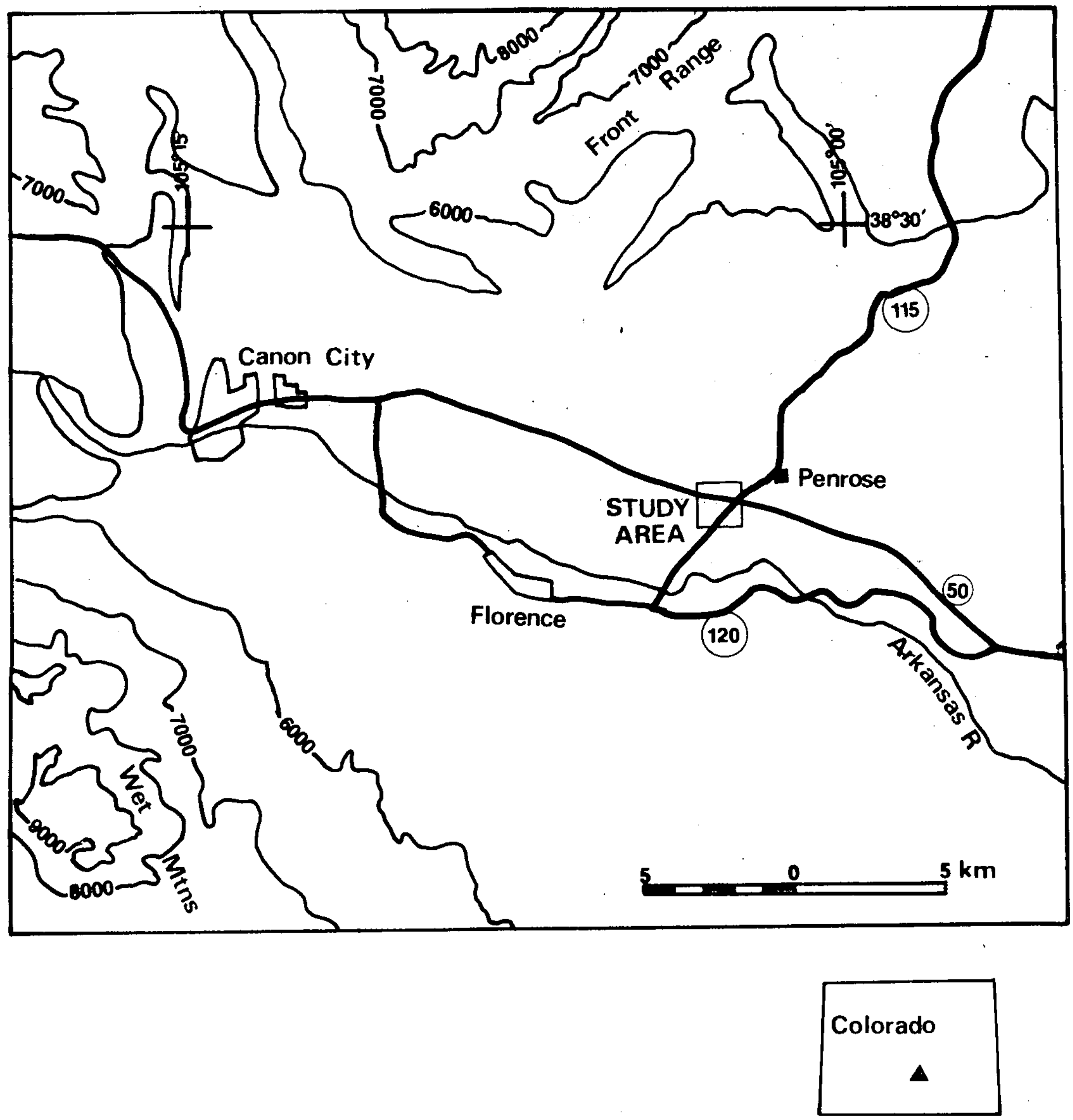

Figure 1. Location of study area. Contour interval 1000 ft (305 m).

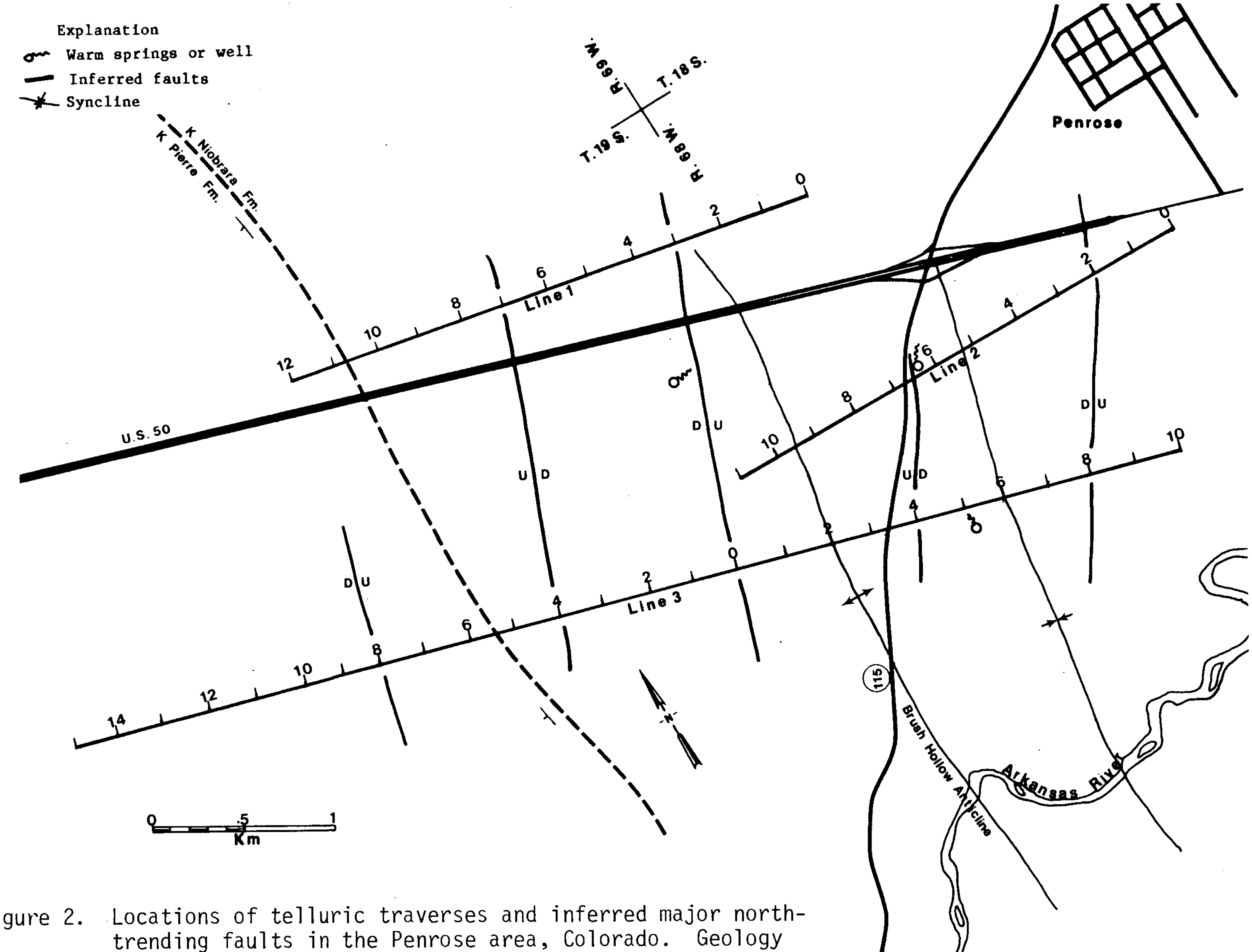

Figure 2. Locations of telluric traverses and inferred major north-trending faults in the Penrose area, Colorado. Geology (except faults) from Scott and others, 1978.

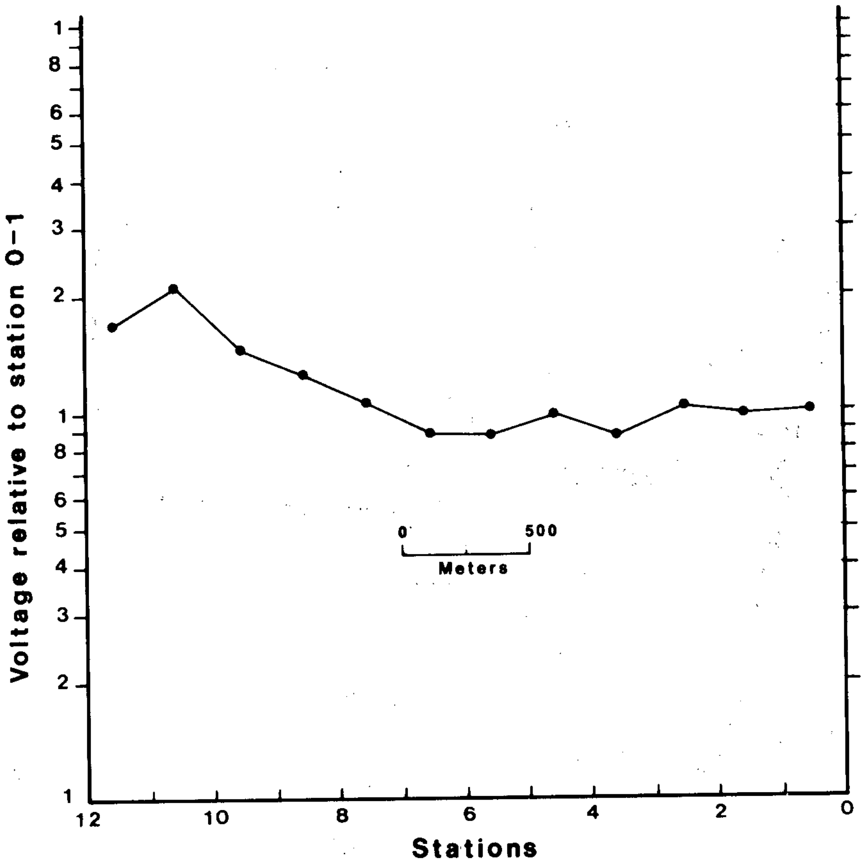

Figure 3. Penrose area, telluric traverse 1.

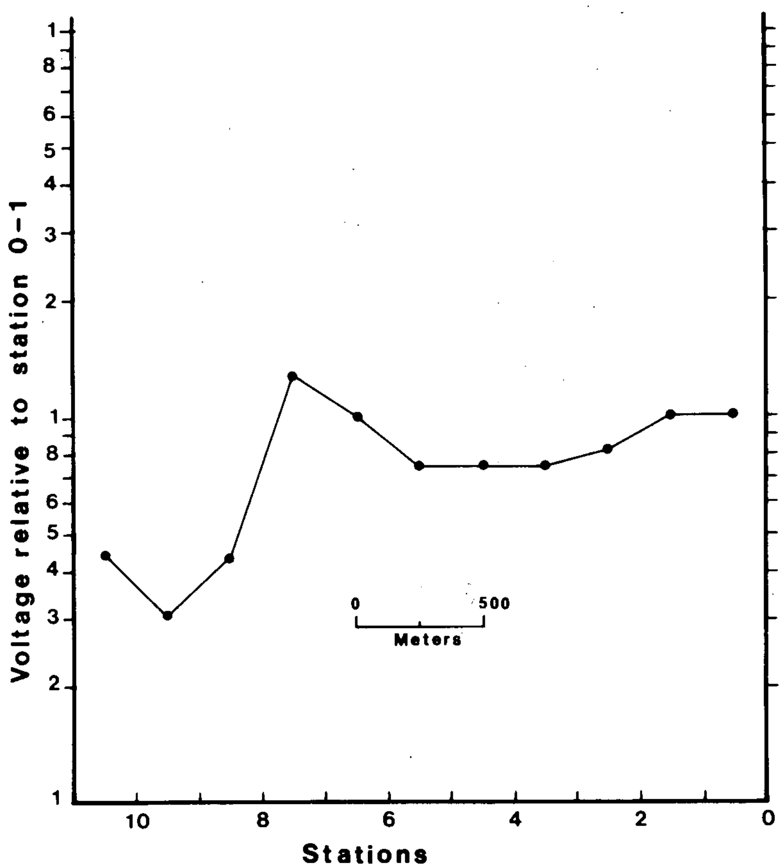

Figure 4. Penrose area, telluric traverse 2.

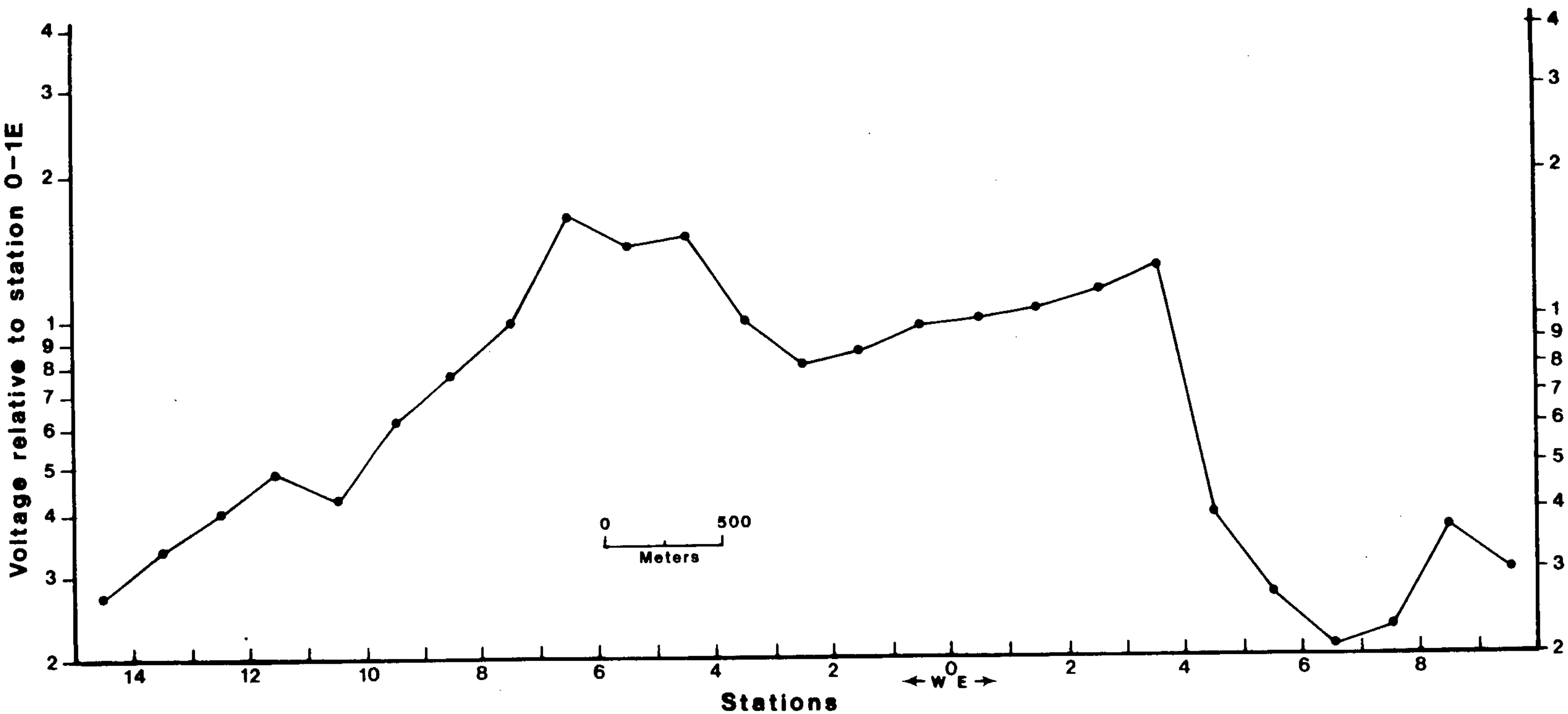

Figure 5. Penrose area, telluric traverse 3.

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APPENDIX J

SEISMIC REFLECTION SURVEY IN THE VICINITY OF CANON CITY, COLORADO

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February, 1981

by
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CANON CITY STUDY

The seismic data in the Canon City study was acquired east of Canon City and north of Florence. The location of the seismic line is indicated in Fig. 1. The study was along a line approximately three miles in length near which additional geophysical data were acquired in the past and orthogonal to the trend of the postulated Brush Hollow anticline.

Data Acquisition

Seismic data in the area were acquired by the Exploration Research Laboratory of the Colorado School of Mines. Data acquisitiion was undertaken using a Litton, Model 311, vertical vibrator and the data were recorded utilizing a Texas Instruments DFS V recording system. The geophone groups were spaced at 100-ft intervals and one string of geophones was used for each group. The string of geophones was stretched over the 100-ft interval. The seismic data were acquired using a sample rate of 4 milliseconds and a Vibroseis sweep of 58 to 11.5 hz. The sweep length was 12 seconds and the listen time was 3 seconds. The data were recorded 24-fold. The seismic data were recorded on conventional magnetic tape for subsequent computer processing.

Data Processing

Data processing was undertaken first on the Exploration Research Laboratory TIMAP seismic computing sytem. On this machine the field tapes were demultiplexed, cross-correlated, vertically stacked, and sorted. Subsequent processing is undertaken on the Exploration Research Labortaory Control Data Corporation CYBER 720 running GeoDigit (CGG) software. The processing undertaken on the CYBER included deconvolution to sharpen the signal, velocity analysis to determine the appropriate stacking velocities for the various reflectors, and static corrections to compensate for variations in elevation and the near surface. The final step in processing was migration to attempt to place the events in their proper relationship within the plane of the seismic section. The processing flow is shown in Table 1.

Data Interpretation

The Canon City area appears to be an embayment of the Denver Julesburg Basin. This area had Niobrara and Pierre rocks on the surface and is immediately underlined by Cretaceous Dakota. Within the section there are, in parts of the area, Ordovician limestone rocks and rocks of Pennsylvanian age (Weimer, 1980). The anticipated structure in the area is dominated by the Brush Hollow anticline which trends approximately north/south, orthogonal to the seismic line. This trend is projected from other studies to the south by Weimer (1980) and by geological mapping by others. To the west of the line, there is an apparent drape fold that drops very strongly to the west. Additional seismic data south of the Arkansas River acquired by Petroleum Geophysics Corporation (PGC) and interpreted by Weimer (1980) provides some useful information when coupled with the limited drill hole data.

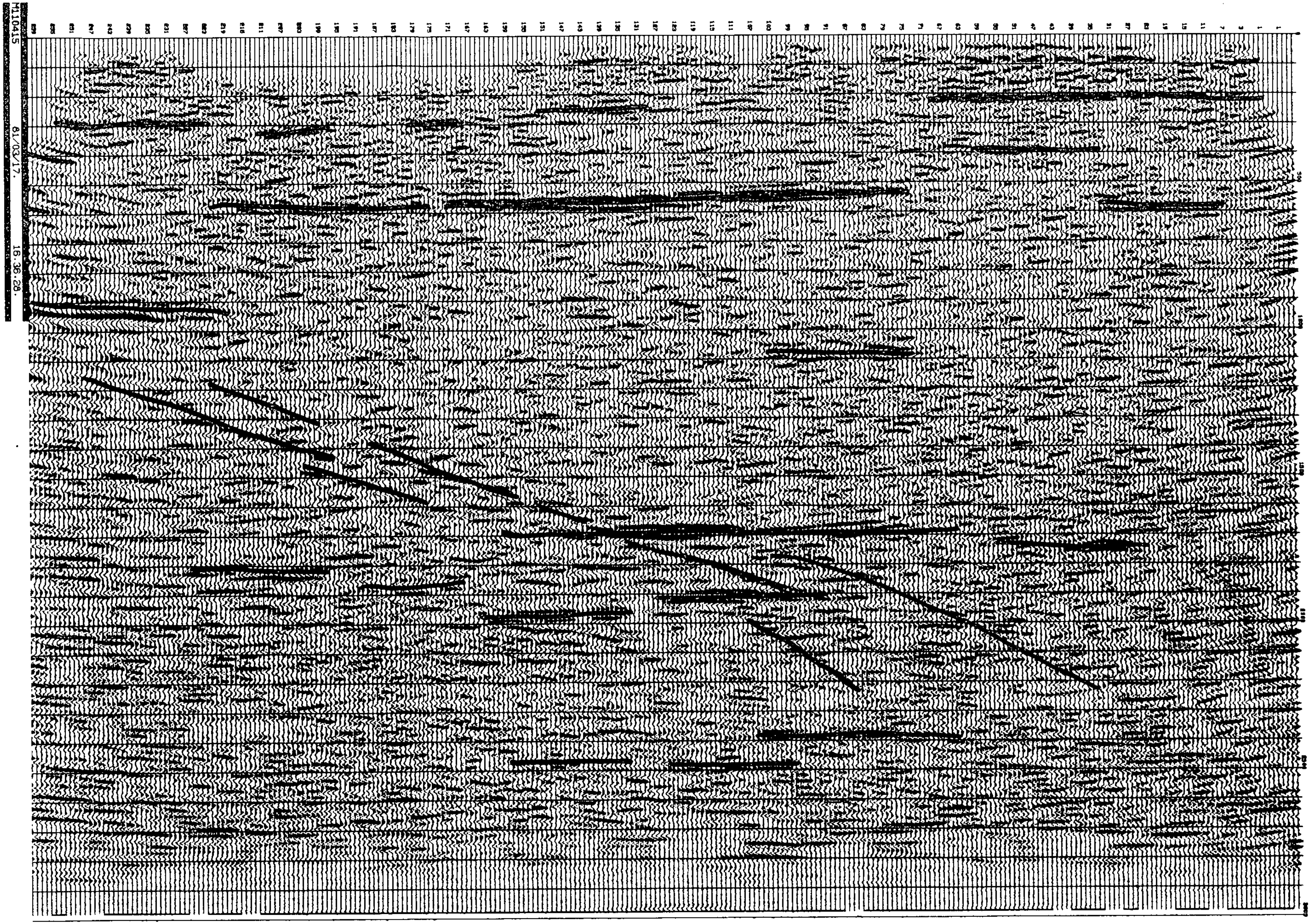

Figure 1. Interpreted seismic section - Canon City.

TABLE I

PROCESSING SEQUENCE

Demultiplex
Cross Correlate
Vertical Stack
Common Midpoint Gathers
Partial Velocity Scan and Near-Trace Stack
Deconvolution Test
Deconvolution and Statics
Complete Velocity Scan
Mute Test
Automatic Residual Statics
Fan Filter
Migration

The new data (Fig. 2) acquired for this study appears to be very close to the crest of the Brush Hollow anticline. The shallow data, at a time of approximately 0.2 seconds may represent the Dakota. The Dakota would be at a depth of 900 to 1,000 ft below the surface. The unit at 0.55 seconds (3,000-3,500 ft deep) on the seismic section is postulated to be the basement reflector. This is based on personal communications from Weimer (1981). Weimer's observation is that the reflectivity of the basement is controlled in part by the presence or absence of Ordovician limestone. The presence of the Ordovician limestones tends to give a very strong reflector, while in those areas where the Ordovician limestone is absent and the arkose of the Fountain lies directly on the basement, the reflection quality is very poor.

Based on this analysis, it would appear that, within the center of the seismic section, there is a strong argument for there being a significant Ordovician limestone unit on top of the basement. The depth to the limestone/basement complex is approximately 3,500 ft below seismic datum (the surface). This fits very well with Weimer's observations from his analysis of the seismic data to the south. The new seismic line did not reach far enough to the west (to the vicinity of Eight-Mile Creek) to see the postulated very strong dips of the western flank of the Brush Hollow anticline. In that area, one would anticipate that the basement rocks would dip very strongly to the west as is illustrated on the seismic data to the south.

An interesting feature on the new seismic section is the dominant reflector at a time of approximately 1.7 seconds (Fig. 4) which is in excess of 13,00-ft deep. This sub-basement reflector which, at first glance, appears to be an enigma is clearly evident on the other seismic line to the south. This feature could have great significance for understanding the geology of the area. Several interpretations are possible. Perhaps there is an east-dipping thrust in which the Brush Hollow draped-anticline represents a wedge of the basement and shallower sediments over the top of a deeper slice of sediments.

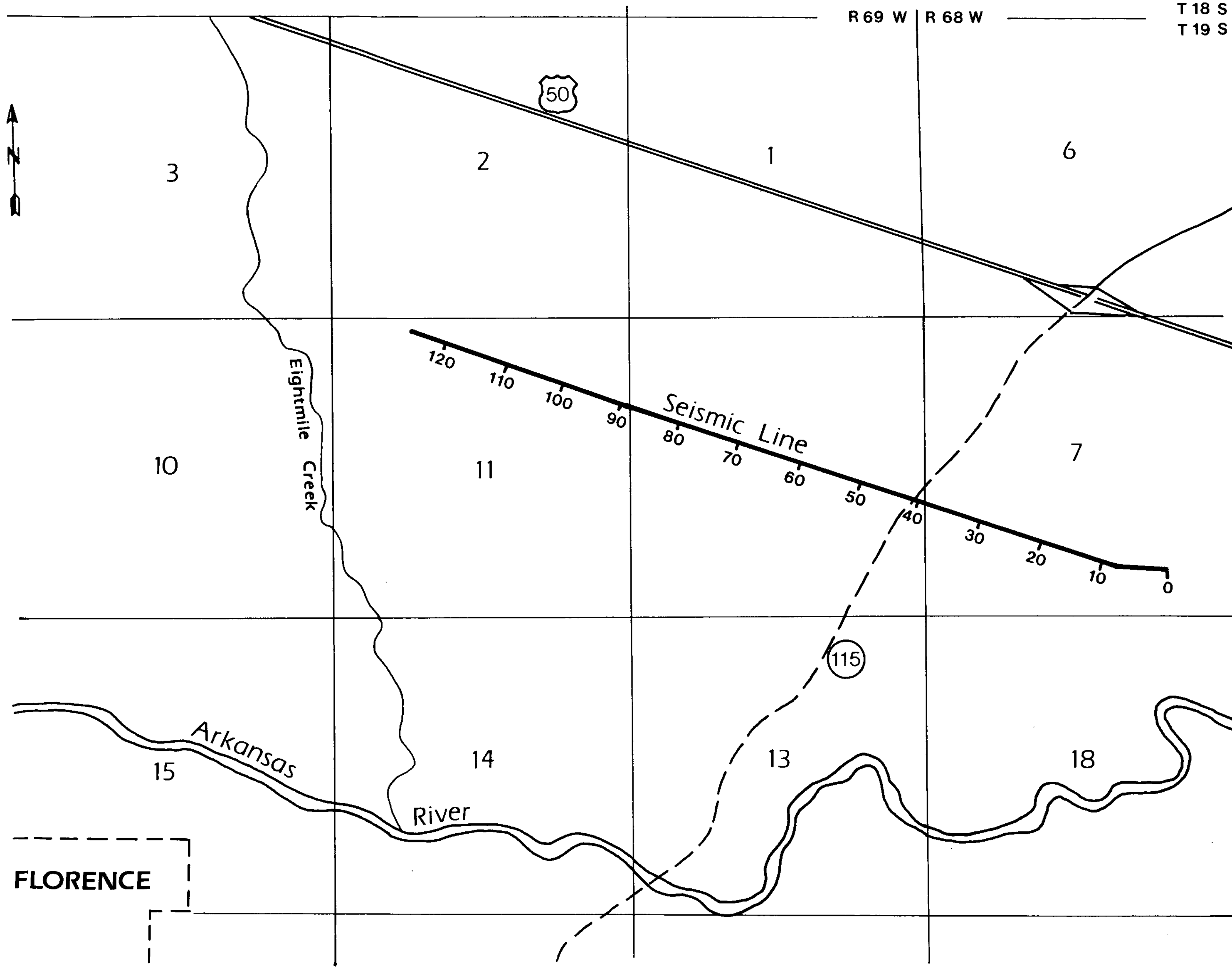

Figure 2. Detailed map of the Canon City--Florence seismic line.

This thrusting would thrust basement rocks over older material such as the Ordovician limestones. This would account for the presence and the approximate location of the deep reflectors on both the southern seismic line and the newly acquired seismic line to the south indicates significant structure and reversals of dip within this deeper section. This may represent folding of the deeper structure concurrent with the overthrusting of the upper plate.

Other interpretations for this deep reflection are, of course, possible. A simple interpretation would be to argue that this data is coming from outside the plane of the section and, hence, the geological interpretation is not nearly as complicated as we are attempting to make it. The argument against this hypothesis is that the complex structure shows up on two seismic lines separated by several miles. It is postulated that the deep structure is a multiple by others. However, the stacking velocity, the divergence of dip directions, and the inconsistent travel times argue against this contention.

Another hypothesis is that the deep structure is not of sedimentary origin but rather is one of the seldom explained sub-basement reflectors. One could postulate that perhaps this sub-basement reflector is a surface within the basement. Perhaps this surface in the basement could represent a subsequent intrusion and, hence, a source of heat and, in fact, this reflection we are seeing is a thermal effect or a thermal front rather than a distinct rock type change.

Conclusions

The seismic data in the area is of good quality. The geological model (Fig. 3) is somewhat more complex. With our seismic line alone, it is almost impossible to reach any definitive conclusions. However, when coupled with the work of other investigators in the area and other seismic data such as the seismic data acquired south of the current study area, it is possible to speculate on various geological models. The most plausible model is that the deep structure results from an overthrust occuring in post-Ordovician time. Subsequent deposition and recurrent movement, as postulated by Weimer (1980), could thus account for the draping of the sediments over this fold.

However, with the newly acquired seismic data and the old seismic data, it is still impossible to draw any definitive interpretations. Other options, as mentioned above, are perhaps viable. Additional information is necessary to assess all of these hypotheses.

Recommendations

The structure of the Brush Hollow anticline and related geological features could be much more clearly understood with the acquisition of significant amounts of additional seismic reflection data in the area. A broadly-spaced grid comprising 20 to 30 miles of additional seismic data would be very helpful in better understanding the structure. This study would provide a great deal of useful information on not only the geothermal potential in the area and significant faults that may control the circulation of waters to significant depths for heating and subsequent recirculation to the surface, but would also provide very useful information on the possibility of structures beneath the "overthrust" that may have petroleum potential. The deep structure, if it is either sediments or the alternative alteration/thermal front could also have strong implications for geothermal. By drilling to those

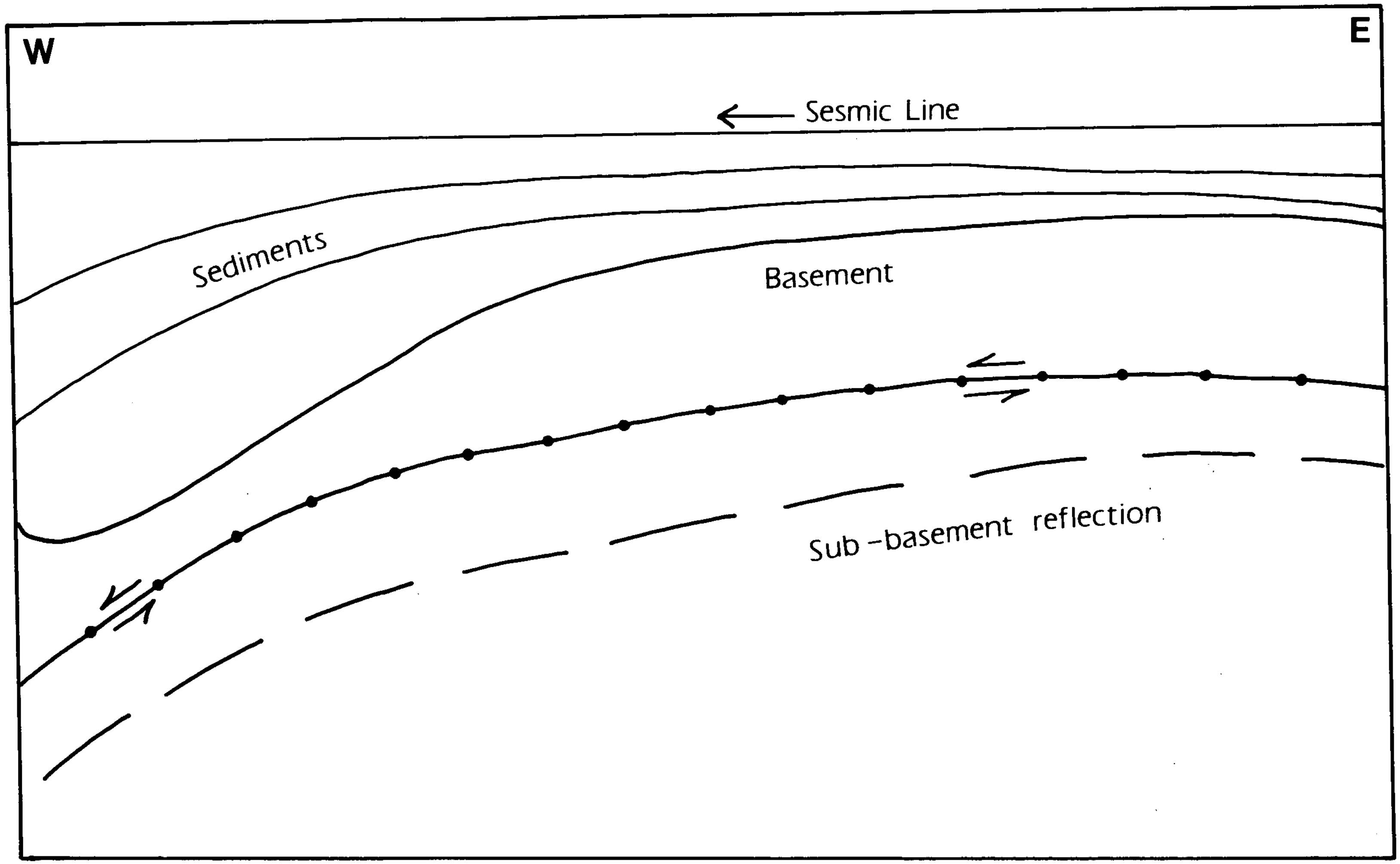

Figure 3. Sketch of the geological interpretation of Figure 1.

depths, one could take advantage of the apparent high thermal gradient in the area and penetrate a sedimentary aquifer at depth that could produce geothermal fluids. Also one could drill close enough to the front, if it is a thermal front, to reach a zone of high temperatures and through a circulation system involving two wells generate energy using the concepts expounded in the hot dry rock project.

SUMMARY

The Canon City seismic study was useful in confirming information that had been suggested by work done by Weimer (1980) and others. It also emphasized that the geology is significantly more complex than one may have postulated. In fact, there are geological features that are very poorly understood on the seismic sections. It is thus important that if one is to understand the structure of the area, the shallow faulting, the Brush Hollow anticline and the deeper structure present on the seismic sections, that one must acquire additional seismic data.

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