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GEOTHERMAL RESOURCE ASSESSMENT OF HARTSEL, COLORADO

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COLORADO GEOLOGICAL SURVEY
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The cover, "A view of South Park from Kenosah Hill" is from A Gripsack Guide to Colorado, recently republished by Johnson publishing.

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Kevin P. McCarthy, Ted G. Zacharakis and Richard H. Pearl

ABSTRACT

Two unused hot springs of moderate temperature issue from the Morrison Formation at Hartsel, Colorado, in South Park. The Colorado Geological Survey chose this site for study as part of a statewide geothermal resource assessment project. Exploration activities conducted by the Survey during 1980 and 1981 included soil mercury and electrical resistivity surveys and shallow temperature measurements.

South Park is a structural basin formed during uplift of the Front Range and Sawatch Mountains during Laramide time. The Precambrian basement was tilted to the east, then broken by northwest trending faults. Widespread Tertiary volcanism and renewed faulting later altered drainage and governed the depositional history of the basin.

Results of the exploration suggest that the Santa Maria fault passing through Hartsel serves as a conduit for warm water coming from the east. Hot water from depth may be forced upward due to an impermeable horst block adjacent to the fault. Other data indicates that warm water exists in the thick Paleozoic sediments to the west, but this is probably a separate system. Any further exploration should focus upon the Santa Maria Fault, the Dakota Sandstone aquifer, or the Precambrian rocks beneath Glendiver Dome to the east.

INTRODUCTION

In 1979, the Colorado Geological Survey, in cooperation with the U.S. Department of Energy/Division of Geothermal Energy, under Contract No. DE-AS07-77-28635, initiated a program designed to determine the nature and extent of Colorado's geothermal resources. Priority was given to those areas with the greatest potential for near-term development. The project has included geologic and hydrogeologic mapping, and geophysical, and geochemical surveys.

One of the thermal areas investigated was Hartsel Hot Springs, located in the South Park Basin on U.S. Highway 24, 66 miles west of Colorado Springs, Colorado (Fig 1). The two hot springs, which have a temperature of 54°C (130°F) are located in a swampy area among decaying resort buildings on the south side of Hartsel, Colorado. One spring flows out from under an old bath house and is presently unused, while the more westerly spring bubbles up in a shack, where a bath tub exists for occassional users. The resort has not been operated for at least 30 years and the property is now owned by a local grazing association.

The Hartsel Hot Springs are located in the south central part of South Park, a large, intermontane basin bounded by the Sawatch Mountains on the west, the Continental Divide on the north, and the Front Range on the east (Fig. 2). Several large north-northwest trending faults traverse the basin. The springs emerge from the Morrison Formation, which overlies a large outcrop of the Garo Sandstone and Precambrian granitic rocks. General geology of the study area is shown in Figure 3.

Figure 1. Index map of Colorado.

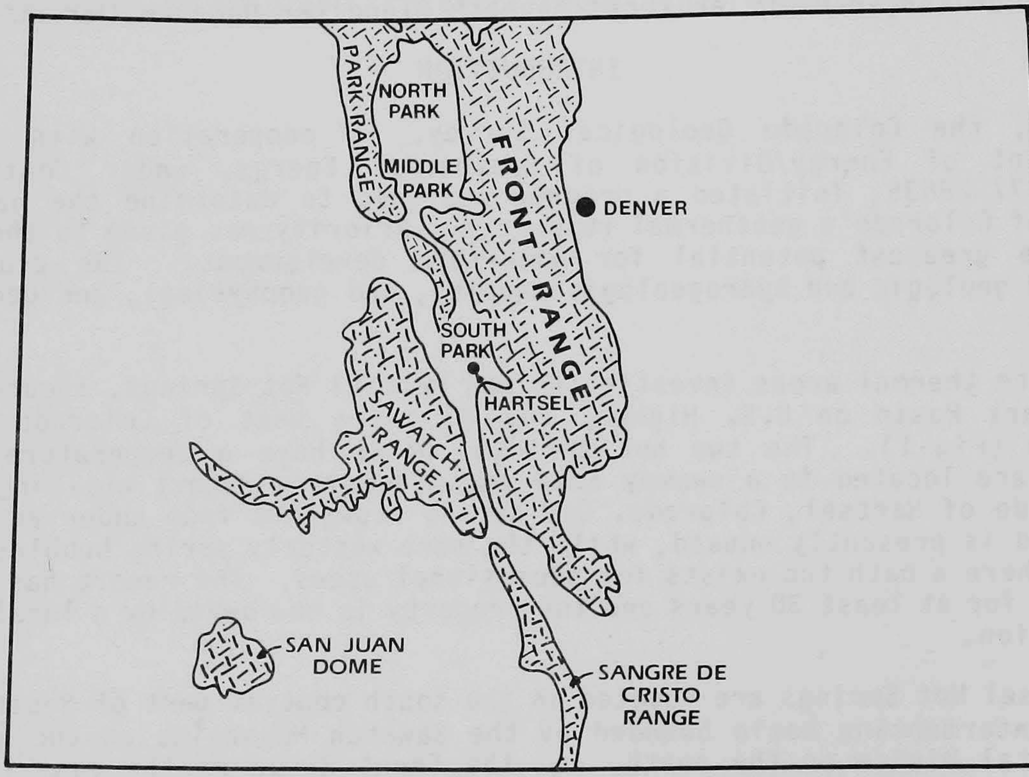


Figure 2. Index maps showing basement complex, Colorado.

The thermal conditions of the Hartsel Hot Springs area have been discussed by George (1920), Barrett and Pearl (1976 and 1978), Berry and others (1980), Lewis (1966), Mallory and Barrett (1973), Pearl (1979), and Waring and others (1965). Based on geothermometer model analysis, Barrett and Pearl (1978), concluded that the most likely subsurface temperature average is approximately 70°C (158°F). Several general assumptions about the size and total energy of the resource were made by Pearl (1979). The reservoir was interpreted to be a faulted, fracture type, which could encompass an aerial extent of 1.00 square miles and contain .0470 Q's of heat energy at an average temperature of 70°C.

During the summers of 1980 and 1981, the Colorado Geological Survey ran geophysical and soil mercury surveys in the Hartsel area to more fully define the thermal conditions. The geophysical surveys consisted of shallow temperature measurements and electrical resistivity surveys.

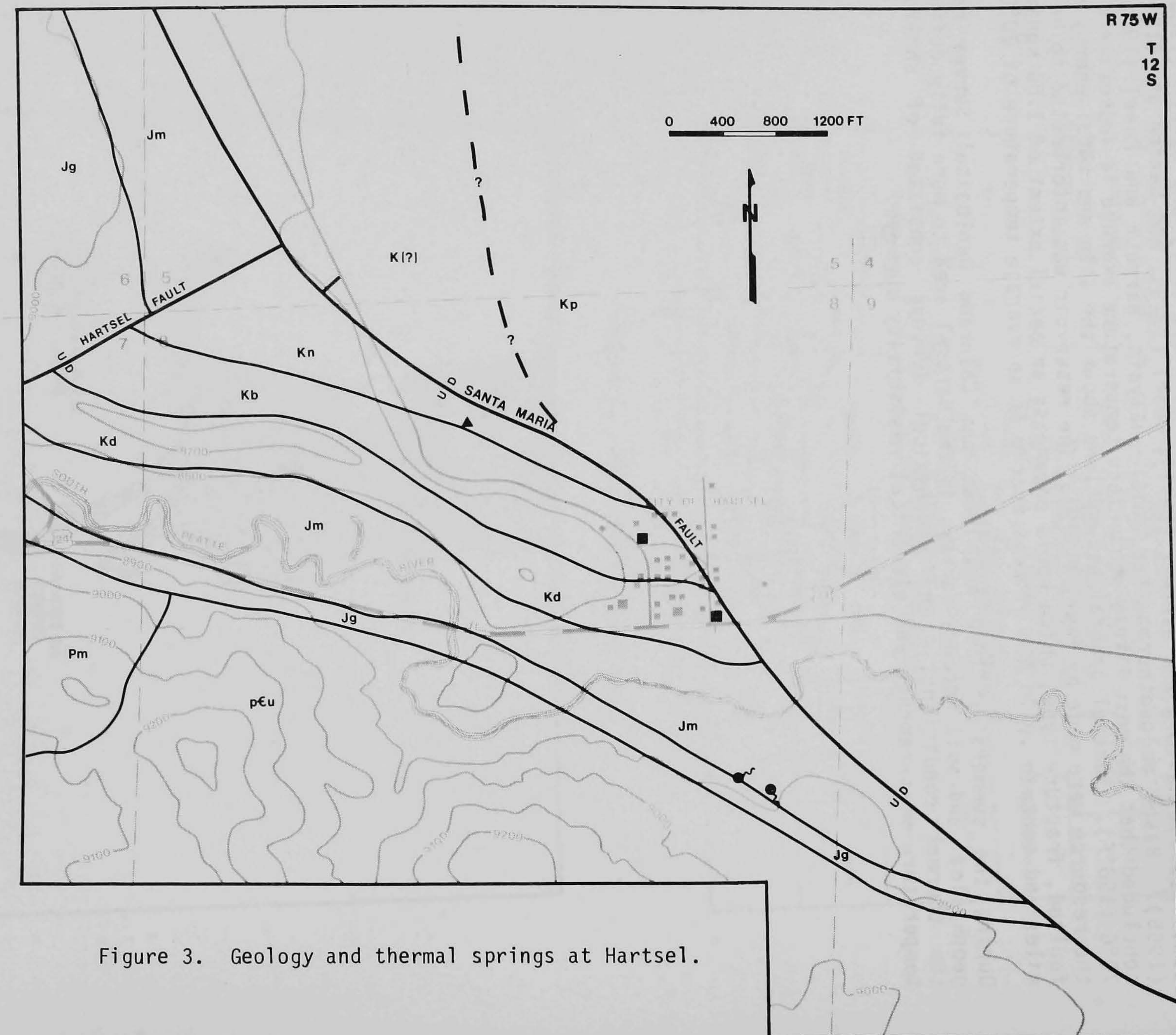


Figure 3. Geology and thermal springs at Hartsel.

FIGURE 3 EXPLANATION

● (hot spring symbol)	Hot spring
■	Warm shallow well
▲	Cold spring

K (?)	Undifferentiated	Cretaceous
Kp	Pierre Formation	Cretaceous
Kb	Benton Formation	Cretaceous
Kn	Niobrara Formation	Cretaceous
Kd	Dakota Formation	Cretaceous
Jm	Morrison Formation	Jurassic
Jg	Garo Formation	Jurassic
Pm	Maroon Formation	Permian
p€u	Undifferentiated	Precambrian

Normal fault, dashed where inferred, U - upthrown side, D - downthrown side

GEOLOGY

Introduction

Much of the initial geologic studies of the South Park region were concerned with placer gold deposits in the valley and small mines in the mountainous periphery. More recent investigations have evaluated the potential for oil and gas production in the area, but significant reserves have not been found.

Very general geologic reports of South Park were published by Bechler (1877), Hayden (1873), Peale (1874) and Stevenson (1875). Washburne (1910) published a report on local coal fields which included a map showing the major structural features of South Park. The stratigraphy of the region was described by Gould (1935) and Johnson (1933, 1934 a, b, & c). The most complete discussion of the stratigraphy, structure, and geologic history of the entire park can by found in Stark and others (1949). More specific work in southern South Park has been done by students at the Colorado School of Mines. This group of work includes theses by Beggs (1976), DeVoto (1961), Ettinger (1959), Lozano (1965) and Sawatzky (1967). Sanders (1975) discussed the volcanic history of the Buffalo Peaks to the west. Epis and others (1980) detail central Colorado volcanism and tectonics.

South Park is a structural basin formed during uplift of the Front Range and Sawatch Mountains during Laramide time. North and northwest trending faults developed in Paleozoic times and were reactivated during the Laramide Orogeny (Beggs, 1976). This fault movement, along with Tertiary volcanism to the west and south, controlled the depositional history of the basin.

Tectonics and Volcanism

South Park is structurally continuous with the Mosquito Range (a branch of the Sawatch Mountains) to the west via an easterly dipping monocline. This large monoclinal structure is bounded by two easterly dipping faults: The Elkhorn Thrust to the east, and the Mosquito reverse fault to the west (Ettinger, 1956). The feature is modified by a northwest trending sequence of synclines and anticlines broken by basement faulting. Minor northeast trending faults alter some of these trends. The exposed sediments are older to the west, while overthrust Precambrian rocks predominate east of the Elkhorn Thrust Fault. Higher pediments and ridges are capped with Tertiary volcanic sediments, especially to the south.

The basement was tilted to the east, then broken by northwest trending high angle reverse faults, with the east side upthrown (Lozano, 1965). This structural trend is normal to the primary Laramide stress direction, while minor, northeast-trending faults were formed from a secondary force. South Park was gradually elevated during Eocene - Oligocene volcanism, with minor folding continuing into late Tertiary time (Lozano, 1965). The relatively flat topography of the area today represents three subsequent pediment surfaces (Stark and others, 1949).

The South Park-Santa Maria fault system is the predominant structure of the study area, but is not completely understood. All previous investigators have mapped a northwest trending fault passing through Hartsel, although there is considerable discrepancy regarding the character and name of this fault. Stark and others (1949) mapped it as an easterly dipping reverse fault that extends far north along Chalmer Ridge. In this interpretation, the fault (called the South Park fault) splits in two at the northwest corner of section 30, T11S, R75W, and rejoins in the middle of section 10, T12S, R75W, east of town. The eastern limb was thought to have an opposite dip and throw to that of the fault further north. The fault is shown to separate again as it dies out to the southeast. Ettinger (1959) more carefully defined the fault split north of Hartsel and placed the eastern limb further west than Stark and others (1949). In this interpretation, the fault diverges between the Santa Maria Ranch, about 5 Km (3 mi.) north of town, and a point northeast of the hogback, about .3 Km (.2 mi.) north of Hartsel. An upthrust block was postulated to exist between the opposing reverse faults. The easterly dipping reverse fault style of the northern portion of the fault was thought to be manifested in the western limb; while the opposite was theorized for the southern portion and the eastern limb. Lozano (1965) also shows the eastern limb in roughly the same position, but the main fault is shown as a westerly dipping reverse fault. Further, the fault was not projected further north than the Santa Maria Ranch, and was called the Santa Maria fault. Clement and Dolton (1970) gave the name South Park fault to a thrust fault further to the east, approximately where others have identified the McDannald thrust fault. A westerly dipping reverse fault is shown east of the hogback north of town, but is interpreted to turn to the southeast, in the location of the Hartsel fault identified by others. Finally, Beggs (1976) interpreted 90 (Km) (56 mi.) of seismic reflection data in a large area north of Hartsel. The data is interpreted to show a north-trending horst block, called the Santa Maria horst, in the Chalmer Ridge-Bald Hill area. The buried horst block is a major feature of the Chalmer-Bald Hill anticline (Figure 4). This is bounded on the east by the Santa Maria fault, which extends through Hartsel as shown by Lozano (1965). This fault is shown on the data as a nearly vertical easterly dipping normal fault. The South Park fault is shown as a westerly dipping normal fault on the west side of this horst.

It is impossible to interpret the geology of this area with any accuracy strictly from the sparce surface evidence. For the purposes of this report, the northwesterly trending fault traversing the study area will be called the Santa Maria fault (Fig. 4). The subsurface data of Beggs (1976) is considered the most accurate representation of the complex structure in the study area. In light of this work, the Santa Maria fault is shown in this report to be a high angle normal fault. The eastern fault limb north of town as interpreted by Ettinger (1959) is shown as dashed in Fig. 3, although it did not show up on a reflection line through the area. The subsurface data is sparce, however, and some geomorphic evidence suggests that this fault trace may exist.

The Hartsel fault is the most prominent tranverse fault in the study area, cutting the Dakota Hogback north of town at right angles. The dip slip movement shown is based upon the tectonic style postulated by Beggs (1976) regarding the Chalmer-Bald Hill anticline, although a right lateral strike slip component probably exists. Stark and others (1949) suggest that this feature may be a hinge or rip fault developed as stress relief between intensely folded sedimentary rock and stable granite islands to the south.

The nature of the faults to the northeast has been subject to debate. These several northwest trending faults just west of the Elkhorn thrust can only be postulated here to be a complex system of easterly dipping normal, reverse, and thrust faults. These include the McDonnald, Hartsel Anticline, and San Isabel faults (Fig. 4).

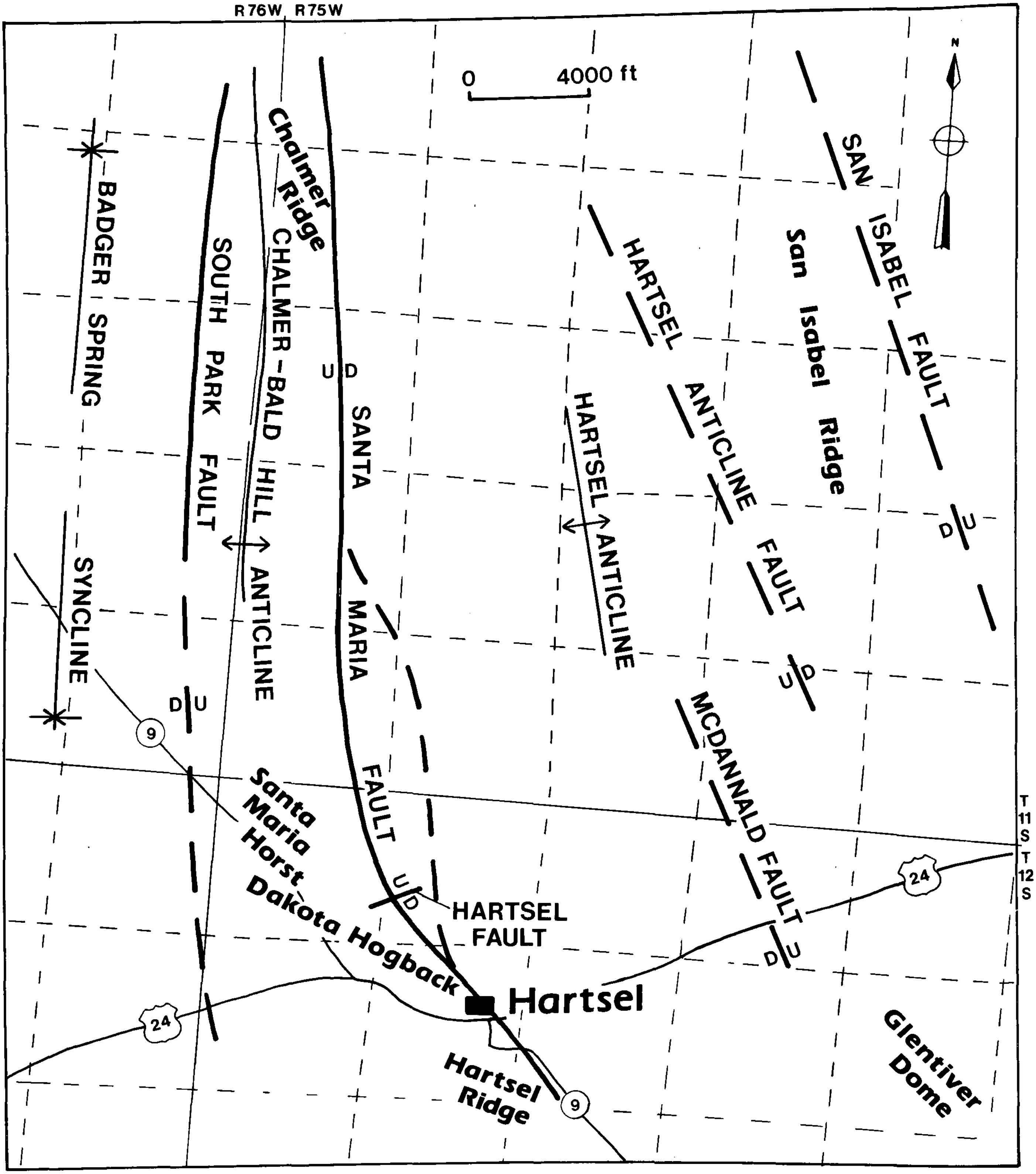


Figure 4. Structure and surface features, Hartsel area.

There are some other major structures in the Hartsel area. The Hartsel anticline to the northeast is a prominent feature, but Beggs (1976) contends that the structure is not continuous at depth. This could simply be a shallow feature of the Pierre Shale on the eastern flank of the Chalmer-Bald Hill anticline. Hartsel Ridge is an abrupt Precambrian high just south of town that was probably a paleohill, now part of the Santa Maria Horst. West of here, a thick sequence of sediments lie in a series of synclines. Figure 5 shows a generalized cross-section, normal to the most fault trends, through Hartsel.

The most important geologic event regionally was widespread Tertiary volcanism, of which the Thirtynine Mile field is only a remnant. This activity is most responsible for the current geomorphology of South Park. Thirty-nine Mile volcanism began southwest of the study area in early Oligocene time. Ash flows were extruded from near Mount Aetna in the Sawatch Mountains and spread from South Park south to the Wet Mountain Valley, and eastward across the Front Range to the plains (Epis and others, 1980). Andesitic and rhyodacitic volcanism from various centers continued until at least 28 million years ago (Epis and others, 1980). Much of the erupted material came from just west of the Buffalo Peaks; west of the study area. This ejecta combined with active faulting in in separating the South Platte and Arkansas drainages.

Stratigraphy

The sedimentary rocks in the Hartsel area range from Permian to Holocene in age. The Paleozoic sediments present are much thicker to the west than they are east of the South Park-Santa Maria fault system. Two nonconformities are present in the area south of US 24 and west of Hartsel. Here the Permian Maroon Formation overlies Precambrian rocks, while further west, the Jurassic Garo overlies the Maroon and is in contact with the Precambrian granitics. The following description of the stratigraphy of the Hartsel, Colorado area is taken from DeVoto (1964) and Ettinger (1959).

Precambrian

Quartz monzonite rocks, high in biotite minerals, crop out at Hartsel Ridge, south of town (Fig. 3). These rocks are cut by pegmatite dikes composed of quartz, orthoclase, and mica, which trend N. 30°W., and N. 55°E.

Permian System

Maroon Formation - Red shales, siltstones, sandstone, conglomerate, and a few limestone beds at least 5,000 ft thick. Ettinger (1959) indicated that an angular unconformity occurs between the Maroon and the overlying Garo Sandstone, although Lozano (1965) showed the contact to be conformable.

Jurassic System

Garo Formation - A gray, well sorted sandstone about 80-110 ft (24-34 m) thick near the hot springs. The Jurassic age of the unit is in question. Lozano (1965) dated the formation late Permian.

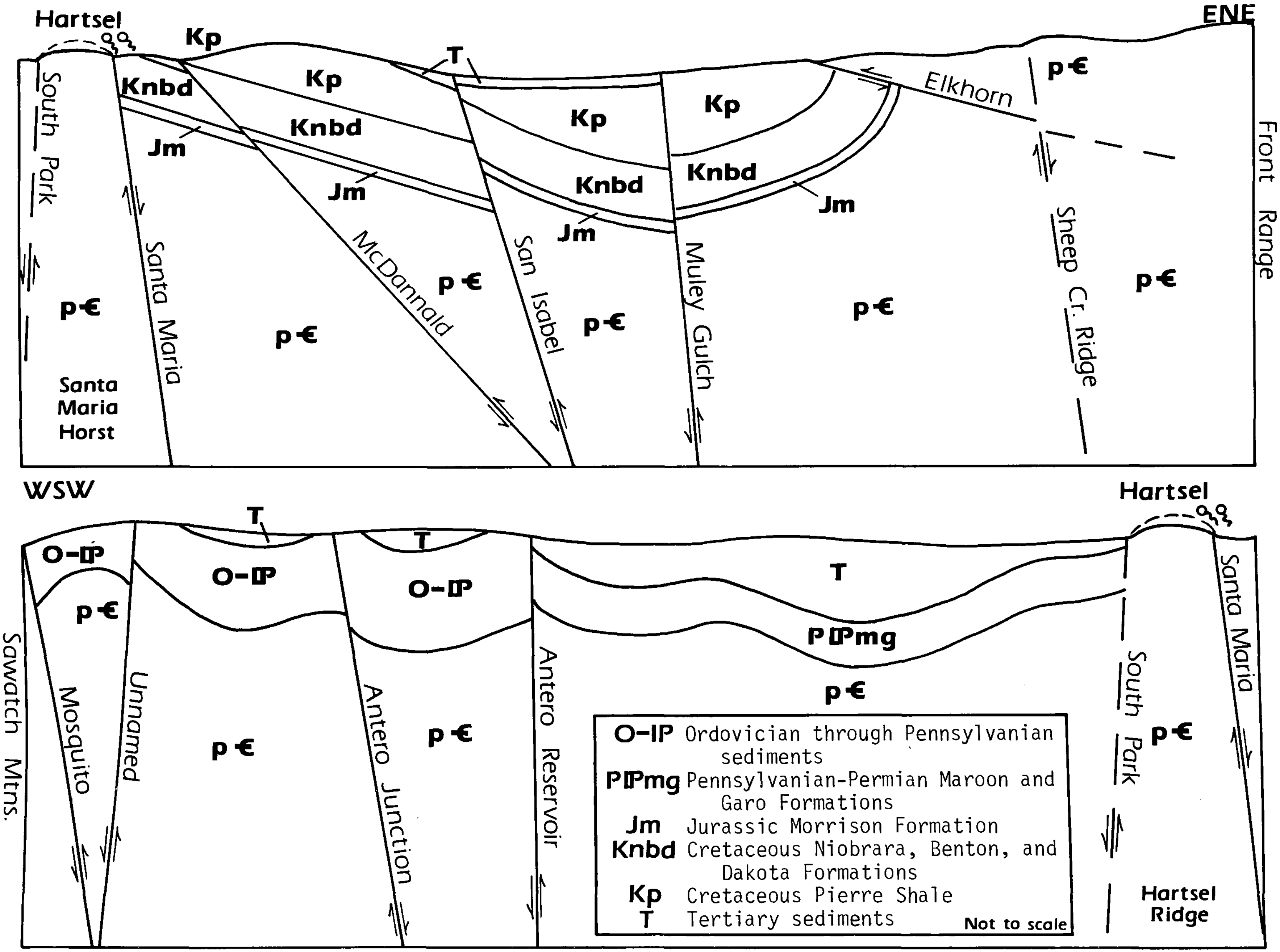


Figure 5. Generalized cross section through Hartsel (ENE-WSW).

Morrison Formation - Overlying the Garo Sandstone are 200 ft (61m) of red, gray, and purple shale, siltstone, mudstone, limestone, and calcareous sandstones called the Morrison Formation. An unconformity may exist at the base.

Cretaceous System

Dakota Formation - Tan to buff, medium to well sorted arkosic sandstone to quartzite; fine to medium grained, highly resistant. Forms hogbacks. Thickness averages approximately 240 ft (73m) in the study area.

Benton Formation - Black to dark gray, fissile shale with some limestone units and thin beds of bentonite. Some calcareous sandstone present. Thickness ranges from 220 ft (67m) to approximately 300 ft (91m).

Niobrara Formation - Consists of a lower limestone member and an upper calcareous shale member. May form small ridges. Thickness of this unit in the study area ranges from 180 ft (55m) to 260 ft (79m).

Pierre Formation - Consists of very dark gray to black fissle shale with some sandy and calcareous beds. The Pierre is about 3,600 ft (1,098m) thick in the Hartsel area.

Fox Hills Formation - Thickness of the Fox Hills is undetermined. It consists of yellow to light gray, fine grained, friable sandstone. In the northwest portion of the study area, the Fox Hills is absent and the Denver Formation rests unconformably on the Pierre Shale.

Tertiary System

Denver Formation - An angular, unconformity separates the Denver from underlying Cretaceous age sediments. This unit consists of more than 400 ft (122m) of red to yellow arkosic conglomerates and sandstones, and white, gray, and yellow tuffs. Correlation with the Denver Formation east of the Front Range is tenuous, so this name used in South Park may be incorrect.

Antero Formation- The Antero Formation is composed of up to 3,000 ft (915m) of fluvial and lacustrine limestones, tuffaceous sandstones, conglomerates and gravels; thickening to the east.

Quaternary System

Alluvial and colluvial deposits are found along the courses of the major rivers and streams. Colluvial deposits are found covering slopes of hills.

HYDROGEOLOGY

Introduction

As noted earlier there are two unused and undeveloped thermal springs located just to the south of Hartsel, Colorado (Fig. 3). The eastern spring (Spring A) flows out from under the eastern side of an unused building. The western spring (Spring B) is located in a small wooden shed at the southeast edge of the swampy area. Table 1, below lists some of the physical parameters of these springs. The complete list of physical parameters and chemical analysis of the Hartsel Thermal waters is presented in Appendix A, at the end of the paper.

Table 1. Hartsel Hot Springs

	Discharge		TDS	T	
	(gpm)	(l/s)	(Mg/l)	(°C)	(°F)
Spring A (West)	--	--	2280	54	130
Spring B (East)	50	3.15	2330	54	130

Source of data: Barrett and Pearl (1976)

The hydrogeological conditions of these springs have been described by Barrett and Pearl (1976, 1978); George and others (1920); Lewis (1966); Mallory and Barrett (1973); and Pearl (1972 and 1979). Barrett and Pearl (1978) and Pearl (1979) attempted to estimate the subsurface temperatures of the thermal waters and to explain the origin of the springs.

In addition to the two thermal springs, some of the deeper water wells in town (greater than 60 ft (18 m)) have encountered waters having a temperature between 20°C and 29°C (68°F and 84°F). At least two of these are flowing artesian wells. At one time, the hotel, which was located on the west side of town, had a deep hot water well (Dorothy Canterberry, oral comm., 1982). The hotel and well have been destroyed. From this evidence it appears that there may be a confined warm water aquifer at a depth of 60 ft (18 m) below Hartsel.

Other warm waters have been encountered along the west side of South Park, between Antero Junction and Fairplay. In 1967, the Geary Oil Company drilled an exploration hole in SW/4, NW/4, Sec. 11, T13S, R66W, just west of Antero Junction. At a depth of 235 m (771 ft), the Leadville Limestone was encountered, which yielded gas and hot, fresh water. Another well was drilled by Geary in S/2, Sec. 18, T13S, R76W. The Leadville formation was encountered at a depth of 372 m (1,220 ft), where circulation was lost, and the sound of running water could be heard at depth (DeVoto, 1971). The former drill site is just west of the London reverse fault, while the latter is near the Antero Junction fault. Hot water may be stored in the cavernous Leadville formation, west of the study area.

The northern extension of the Antero Junction fault runs just east of the old salt works near Antero Junction. Hayden (1874) reported a hill composed of gypsiferous marls and tufa about .5 Km east of the salt works. Springs, warm or cold, were probably extruded along the fault here. Rhodes Warm Springs occur in a faulted area about 15 Km (9.3 mi) southwest of Fairplay, along Four Mile Creek. Another warm spring is referred to by Stark, et al. (1949, p. 128) as being located in Sec. 33, T11S, R77W, on the London Fault. Thermal springs are apparently controlled by faulting west of the study area.

GEOPHYSICS

Introduction

The best estimate of heat flow in the Hartsel area was shown by Zacharakis (1981) as approximately 100 mW/m2 in a revised heat flow map of Colorado. No data points were available for South Park, however, so this estimate has yet to be substantiated.

Several oil wells drilled in the area provide some clues to the subsurface conditions. Table 2 shows some data from those wells.

Table 2. Data from oil wells near Hartsel

Name	Location	Total Depth (meters)	Unit Bottomed In	Gradient
Tennessee Gas Teter 1	SW SE NW Sec. 11 T8S, R76W Spud 8-57, P&A 8-56	7475 ft (2279 m)	Kp	2.1°F/100 ft (22°C/Km)
Shell Oil Federal 4285-1	SE NE NE Sec. 28 T11S, R75W Spud 6-56, P&A 8-56	8489 ft (2588 m)	Jm	2.1°F/100 ft (22°C/Km)
Shell Oil McDannald 1	C NW NW Sec. 32 T11S, R75W Spud P-56, P&A 10-56	3558 ft (1085 m)	PC	2.3°F/100 ft (24°C/Km)
Shell Oil State 4343-1	C NW SW Sec. 36 T11S, R75W Spud 8-56, P&A 9-56	5350 ft (1631 m)	PC	2.3°F/100 ft (24°C/Km)
Shell Oil Federal 4337-1	C SE SE Sec. 4 T12S, R74W Spud 8-56, P&A 9-56	571 ft (174 m)	PC	7.6°F/100 ft (121°C/Km)
Shell Oil State 4340-1	C NW NE Sec. 7 T12S, R74W Spud 10-56, P&A 11-56	3906 ft (1191 m)	Jm	26°F/100 ft (29°C/Km)
Shell Oil Govt. 4553-1	SW SW NE Sec. 34 T12S, R74W Spud 11-56, 12-56	4444 ft (1355 m)	Jm	2.3°F/100 ft (24°C/Km)
McDannald Federal 1	SW SE SE Sec. 1 T12S, R75W Spud 3-49, P&A 8-49	7098 ft (2164 m)	Kp	2.2°F/100 ft (23°C/Km)

From Clement and Colton, 1970, and Oil & Gas Conservation Commission data.

As can be seen in Table 2, recorded bottom hole temperatures (of questionable reliability) do not reflect a high geothermal gradient in the area, except for the one anomaly of 121°C/Km (7.6°F/100 ft). This well is among the furthest of the group from Hartsel, about 15 Km (9 mi.) east, on Glentiver Dome. Higher gradients in granite may represent conduction from a basement heat source. Trobe Grose (in Pearl, 1979), described "heat lensing" as a possible mechanism for thermal accumulation in igneous rocks overlain by a sedimentary sequence. He noted that since sedimentary rocks have lower specific heat content than igneous rocks, heat is drawn to and concentrated in the underlying metamorphic and igneous rocks.

To help delineate the thermal reservoir in the Hartsel area, two geophysical methods were employed: a shallow temperature survey, and an electrical resistivity survey.

Near surface temperature measurements

Introduction

It is theoretically possible to determine spacial distribution of a subsurface heat source by near surface temperature measurements. This procedure has proven useful in delineating the extent of a secondary heat source in areas of near surface convective geothermal systems. Kitzinger (1956) reported excellent results in mapping temperatures measured at a depth of 1 m (3.3 ft) in Lordsburg, New Mexico for defining a hot ground water system. Olmsted (1977) had good results from 1 m (3.3 ft) deep temperature measurements in an area of near surface steam in Nevada. Friedman and Norton (1981) were able to define areas of anomalous heat flow at Yellowstone National Park by using the Pallman method of temperature determination at 2 m (6.6 ft) depth. Flynn and others (1980) reported good correlation between 2 m (6.6 ft) deep isotherms, local fault trends, and temperature measurements from thermal wells.

Several extraneous factors may influence near surface earth temperature. These factors include diurnal surface temperature effects, seasonal flux, erratic climate anomalies, micro climate (micro geography), soil and rock type, groundwater damping effects, and vegetation. These factors may be dealt with qualitatively either by technique or subsequent analysis. Other, more subtle (in most areas of interest) temperature effects such as near surface oxidizing of sulphides, other exothermic reactions, or thermal pollution are interpreted as true heat source values.

It is generally agreed that the effects of daily surface temperature flux are negligible below 1 m (3.3 ft) (Friedman and Norton, 1981; Lovering and Goode, 1963; Olmsted, 1977; and Thompson, 1960). Installing, reading, and removing temperature probes in 1 to 3 days effectively mitigates the effects of seasonal or erratic climate variance. Micro-climate and other factors can be dealt with somewhat by recording surface temperature, slope orientation, elevation, soil type, geology, and vegetation present at each site. Correlation of each of these effects to results of the survey can be made to modify the interperation if necessary.

Probably the greatest single factor distorting shallow temperature data is groundwater. Shallow, unconfined aquifers are generally warmer than dry soil in the winter, and cooler in the summer. Ground water considerably dampens temperature drift. Cartwright (1968) reported as much as a 2°C (3.6°F) temperature anomaly attributed to shallow groundwater during shallow short term temperature surveys. Parsons (1970) found groundwater in a permeable esker warmer than groundwater from adjacent clay and till. The usefulness of shallow temperature measurements to locate groundwater was demonstrated by Birman (1969), who concluded that increasing temperature is proportional to increasing depth to groundwater. This temperature change could be considered negligible where depth to groundwater is very consistent, or greater than 75 m (225 ft). The effect of this variable can be determined where local well data is available.

The shallow temperature survey is more an effective measure of geothermal convection, rather than conduction. Most successful results have been obtained near fault zones and high temperature surface features. Ideally, the best area to apply this technique should have high temperature surface manifestations present, uniform soil type, geology, and vegetation, a deep groundwater table, relatively flat topography, and invariable climate. Olmsted (1977) considers near surface heat flow of at least several thousand times background to be ideal. Basin and Range-type geothermal sites in the southwestern United States are well suited to this procedure.

Temperature survey at Hartsel

A shallow temperature probe survey was conducted at Hartsel. The temperature probes used consist of thermistors epoxied to tapered 1.94 cm (0.75 in) diameter maple dowels. The 3.08 cm (2 in) long dowels are fastened to 1.52 m (5 ft) PvC pipe. This probe construction was advised by the Nevada Bureau of Mines and Geology (Tom Flynn, oral comm., 1981).

Initial station intervals were approximately .2 Km (656 ft), but closer spacing was used later around warmer areas. The probes were emplaced by augering a 5 cm (2 in) hole to 1.52 m (5 ft) with a soil auger. Packed dirt was used to fill in the space around the probes. Many initial sites had to be abandoned or moved due to rocky soil and a few probes were emplaced as shallow as 1.22 m (4 ft). Most probes were left in the ground for 24 hours while some were left in the ground for up to 72 hours to determine if further temperature change would occur with time.

Temperatures were recorded to an accuracy of ± .1°C with an Electrotherm IT 610 digital thermometer. For each site, the following were recorded: probe depth, geology, elevation, slope orientation, time emplaced, thermistor reading, and other remarks. Soil type, vegetation present, surface temperature, and estimated soil moisture should also be recorded at each site.

Temperatures ranged from 10.4°C to 35.5°C (51°F to 96°F) (Table 3). Probes left emplaced for 72 hours showed a maximum temperature change of ± .2°C. Most of the higher temperatures occurred in the Morrison Formation, from which the hot springs issue, but this was not considered significant since more of the probes were emplaced in the Morrison than any other formation. Four probes left at depths of less than 1.2 m (4 ft) were considered inaccurate, and this data was not used. Groundwater effects probably distorted the data, but this variable could not be quantified within the constraints of this study. Elevations, slope orientation, and time the probes were emplaced (up to 72 hours) apparently had negligible effect upon the results of this survey.

Table 3. Hartsel temperature values

1.	10.4	19.	13.0
2.	10.6	20.	13.2
3.	10.7	21.	13.4
4.	10.8	22.	13.6
5.	10.9	23.	13.9
6.	10.9	24.	14.1
7.	10.9	25.	14.1
8.	11.1	26.	14.2
9.	11.2	27.	14.2
10.	11.3	28.	14.3
11.	11.4	29.	14.4
12.	11.6	30.	15.7
13.	11.7	31.	15.7
14.	11.7	32.	16.0
15.	11.9	X (1-32) = 12.6	
16.	11.9	s (1-32) = 2.1	
17.	11.9	33.	31.4
18.	12.8	34.	35.5

Figure 6 shows temperature contours and structure of the area. The highest temperatures were within 50 m (164 ft) of the hot springs. Temperatures decreased at a much slower rate away from the springs to the southeast. The temperature contours suggest that the Santa Maria fault passing near the hot springs provides permeability for warm water migration.

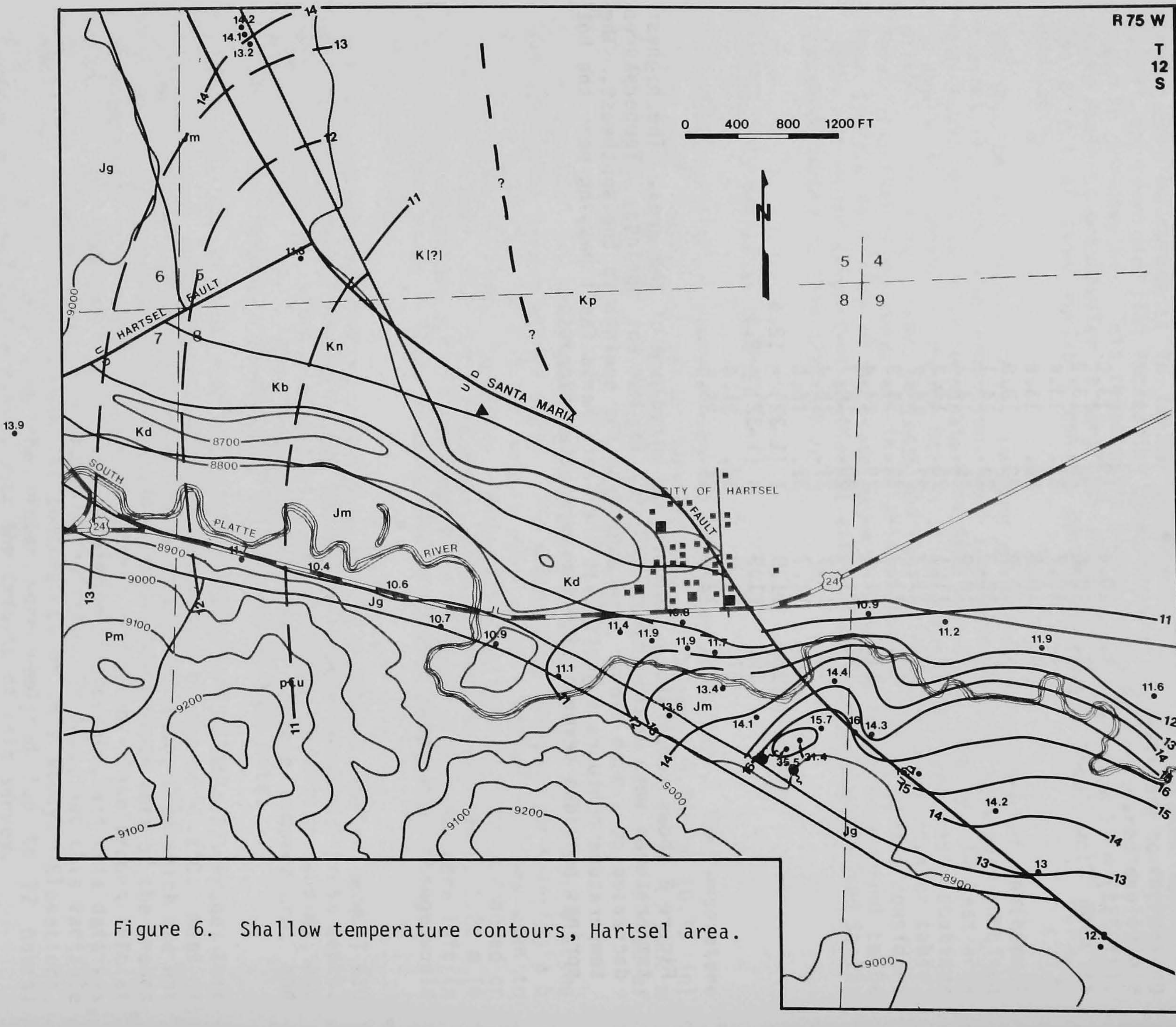


Figure 6. Shallow temperature contours, Hartsel area.

FIGURE 6 EXPLANATION

- Hot spring
- Warm shallow well
- Cold spring
- —15 Temperature contour (°C)
- 14.1 • Data point and temperature (°C)

K(?)	Undifferentiated	Cretaceous
Kp	Pierre Formation	Cretaceous
Kb	Benton Formation	Cretaceous
Kn	Niobrara Formation	Cretaceous
Kd	Dakota Formation	Cretaceous
Jm	Morrison Formation	Jurassic
Jg	Garo Formation	Jurassic
Pm	Maroon Formation	Permain
p€u	Undifferentiated	Precambrian

Normal fault, dashed where inferred, U - upthrown side, D - downthrown side

Electrical resistivity surveys

During the summer of 1980, electrical geophysical surveys were run in the Hartsel area to try and delineate the reservoir limits. It was decided to employ the electrical resistivity method because geothermal reservoir areas normally indicate low resistive zones. Low resistivity is normally due to water saturation, higher than normal temperatures, and high clay matrix zones caused by faults. Therefore, the mission was to determine the location of low resistive zones. A complete description of the factors which may affect the electrical resistivity measurements is presented in Appendix B.

To make these measurements, a Scintrex RAC-8 Electrical Resistivity System was used. A total of 9 dipole-dipole resistivity lines and a gradient array were run totalling 25,000 ft (7.62 km) in the vicinity of the thermal area of Hartsel (Fig. 7). A complete description of this system is presented in Appendix C. Appendix D presents a discussion of the field procedures employed pertaining to the various arrays utilized.

In the target area, a major feature is the Precambrian quartz monzonite that makes an unconformable contact with the Garo Sandstone. The resistivity survey was able to detect the contact between the Precambrian granite and the Garo Sandstone by a noticeable change in the resistivity values. Resistivity calculations for all the lines are presented in Appendix E. Appendix F presents the geometric factor table used to calculate the resistivity values in Appendix E. Figures 8 through 17 are pseudosections constructed from resistivity data.

The electrical resistivity data indicated a low resistive zone paralleling the mapped faults and structural features. This zone trended in a north-northwest direction and encompassed an area 1,000 ft (305 m) wide by 6,000 ft (1,829 m) in length (Fig. 7).

The dipole-dipole resistivity surveys were only able to ascertain resistivity values from the surface to an approximate depth of 500 ft, therefore, what is actually occurring at depths greater than 500 ft is not known with the present geophysical data.

Most electrical resistivity surveys are represented by pseudosections, which are cross sections reflecting the shallow subsurface resistivity below the line of traverse. In the interpretation of any dipole-dipole pseudosection, one must be aware of the fact that values obtained along the line of the traverse may be influenced by lateral variations of three dimensional features.

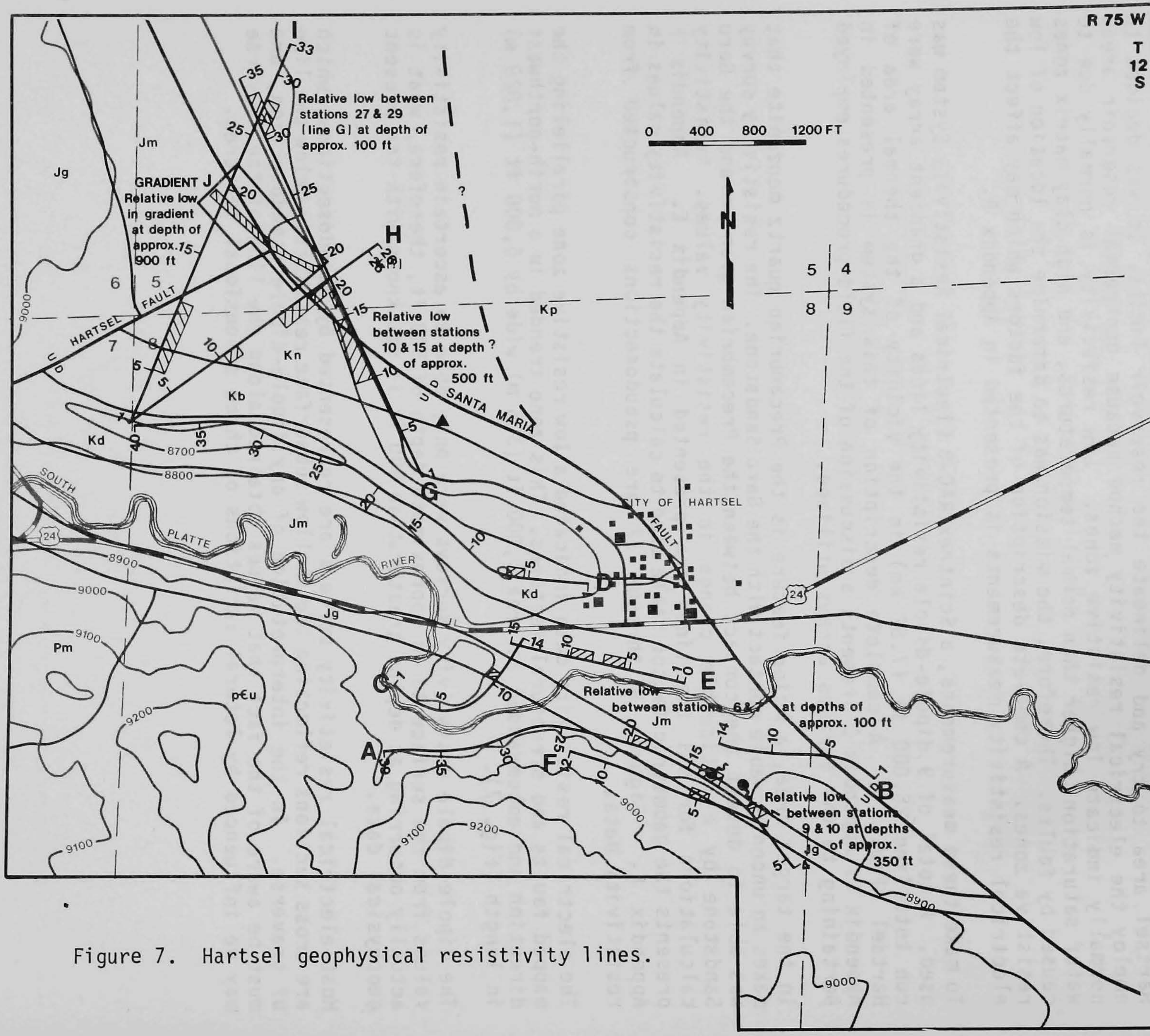


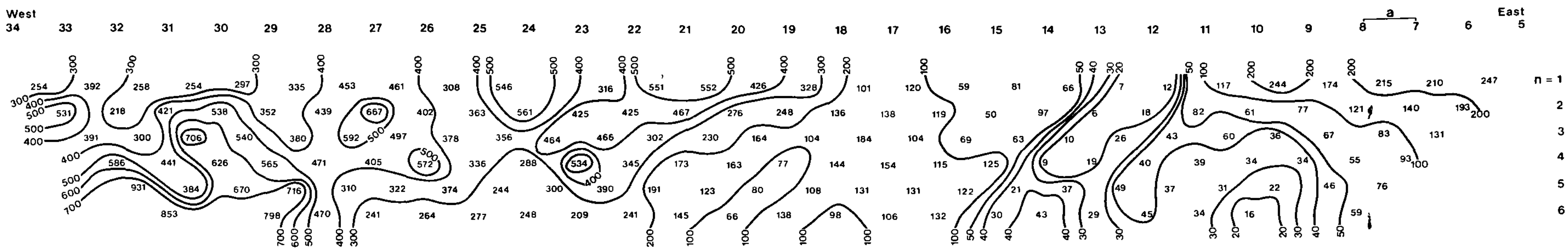
Figure 7. Hartsel geophysical resistivity lines.

FIGURE 7 EXPLANATION

- Hot spring
- Warm shallow well
- Cold spring
- Resistivity line and station
- Area of low resistivity

K(?)	Undifferentiated	Cretaceous
Kp	Pierre Formation	
Kb	Benton Formation	
Kn	Niobrara Formation	
Kd	Dakota Formation	
Jm	Morrison Formation	Jurassic
Jg	Garo Formation	
Jm	Maroon Formation	Permian
p€u	Undifferentiated	Precambrian

Normal fault, dashed where inferred, U - upthrown side, D - downthrown side

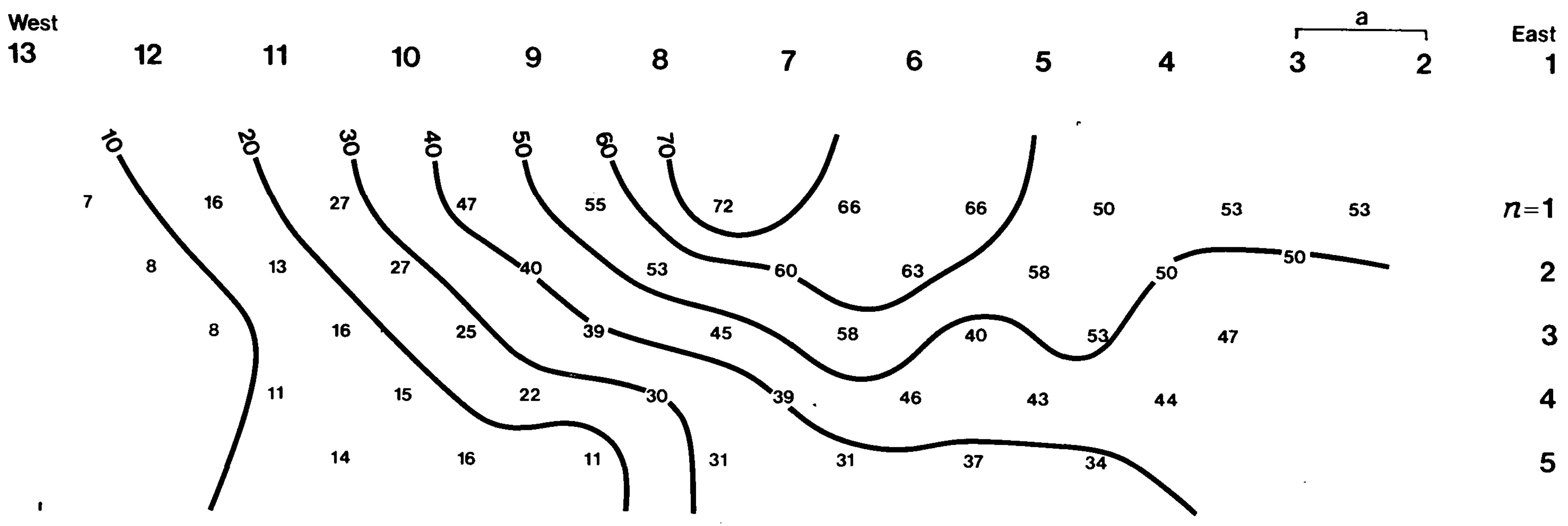


This line, approximately 3,400 ft (1037 m) in length trends primarily in an east-west direction (Fig. 7). Three low resistive zones are indicated; the first one at station 19 which is the geologic contact between the Garo Sandstone and the Precambrian granites; the second zone between stations 13-15 is probably due to the proximity of the hot springs. The third zone between stations 9 and 10 is probably due to being close to the Garo Sandstone and Morrison contact which appear to obtain lower values because of the clay content. Generally, this line reflected resistivity values varying from 700 ohm meters to 7 ohm meters, most of the changes being due to traversing several lithologic sequences of strata.

LENGTH: 3400 ft (1037m)
SEPARATION: n value
DATE: June 20, 1980
TYPE: Dipole - Dipole
SPREAD: a = 100 ft
RESISTIVITY: In ohm-meters

0 200 ft

Figure 8. Dipole-dipole pseudosection line A.



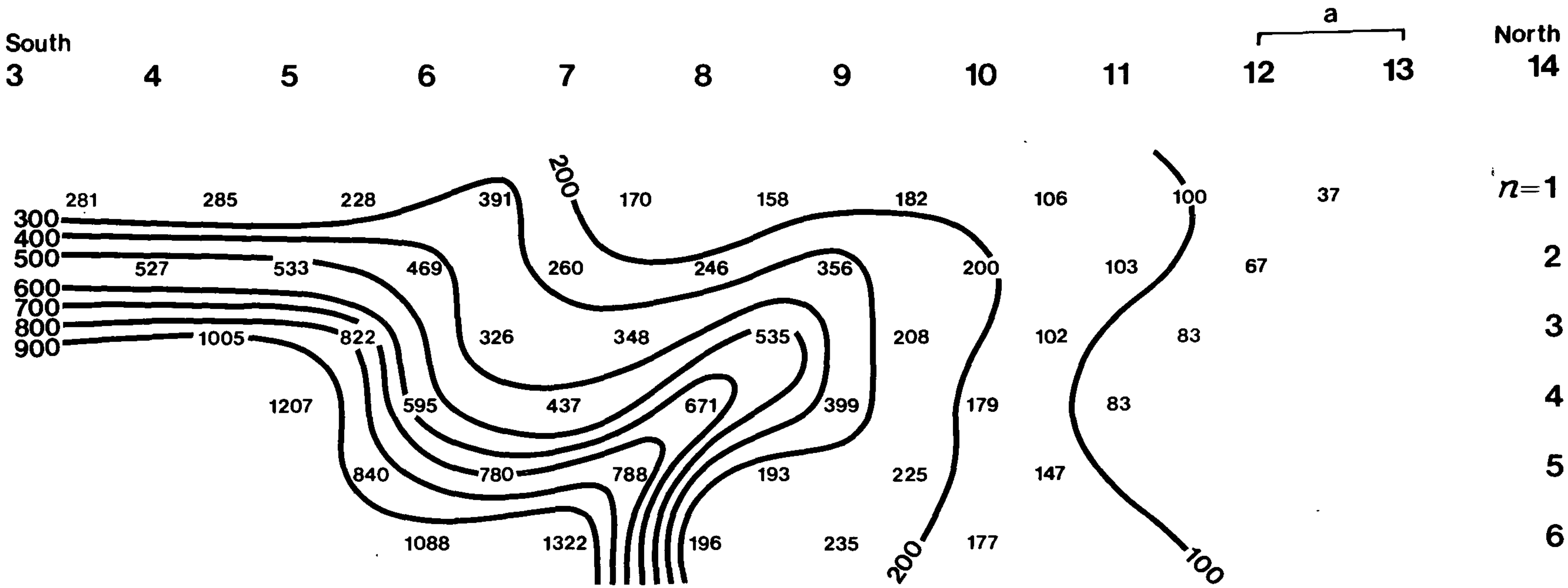
This line 1,300 ft (396 m) long exhibits resistivity values ranging from 7 to 70 ohm-meters (Fig. 7). The low values are shown in the proximity of the hot spring area along the western portion of the line. In general, lower resistivity values are indicated with depth of section.

The mapped fault shown transecting this line on Figure 7 is not reflected on the dipole pseudo section. The only conclusion that may be drawn from this section is that the resistivity values in the Morrison shale are much lower than the values to the east of the fault which may be in the Pierre Shale.

LENGTH: 1300 ft (396m)
SEPARATION: n value
DATE: June 24, 1980
TYPE: Dipole-Dipole
SPREAD: a = 100 ft
RESISTIVITY: In ohm-meters

0 100 ft

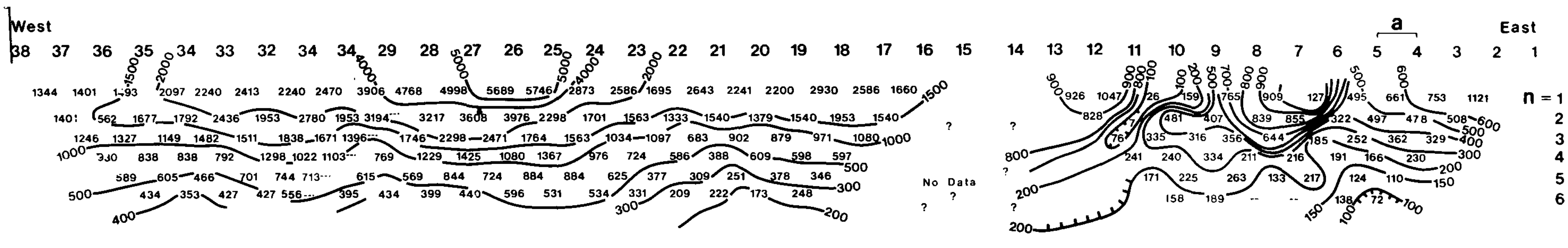
Figure 9. Dipole-dipole pseudosection line B.



Line C is a 1,300 ft (396 m) section that crosses three lithologic sections (Fig. 7). The resistivity values illustrate the changes in rock type very well. From the pseudosection, it is very obvious that the traverse goes from the Precambrian into the Garo Sandstone between station 9 and 10 and from the Garo into the Morrison Formation between station 12 and 14. The resistivity values vary from west to east, from 1,300 ohm-meters to approximately 40 ohm-meters, which is a dramatic change.

LENGTH: 1300 ft (396 m)
SEPARATION: n value
DATE: June 24, 1980
TYPE: Dipole – Dipole
SPREAD: a = 100 ft
RESISTIVITY: In ohm – meters
0 100 ft

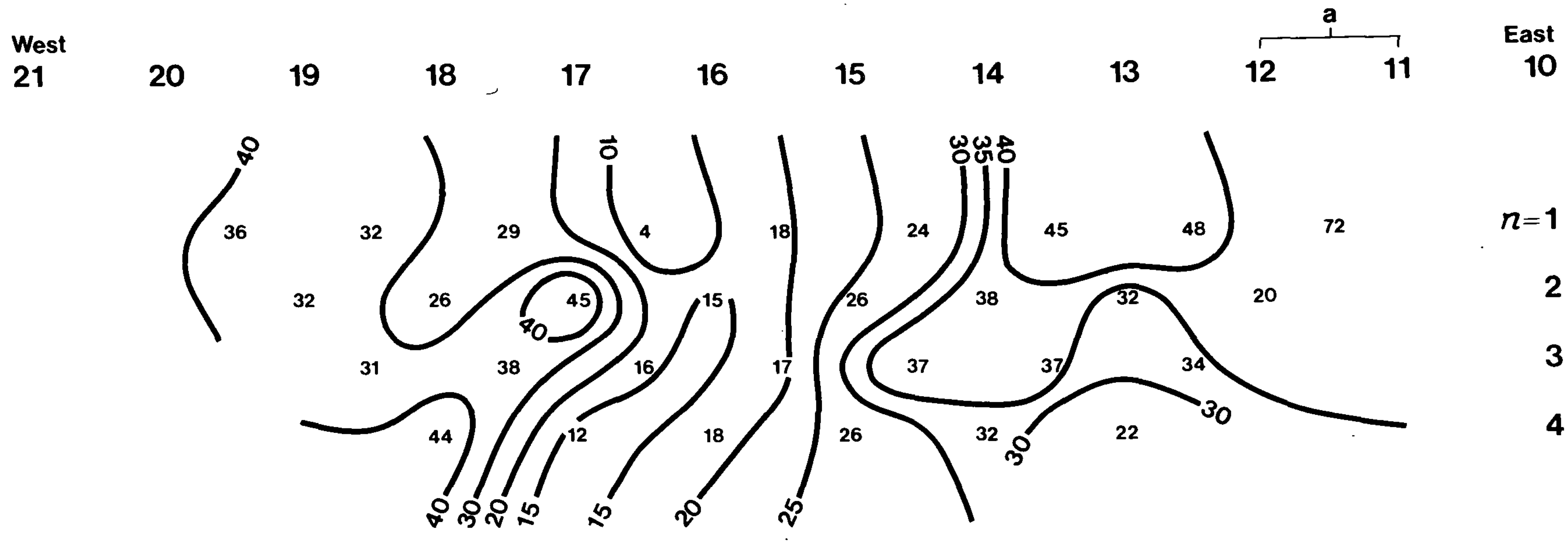
Figure 10. Dipole-dipole pseudosection line C.



This line, approximately 3,900 ft (1,189 m) in length is underlain by the Dakota sandstone (Fig. 7). Low resistivity values were measured between stations 4 and 5. No faults or springs are present in this area. The resistivity values also decrease with depths, suggesting that that the Benton shale was penetrated. In addition, a low resistivity zone exists below stations 10 and 15 at depth. This is based on the fact that the RAC-8 system was not able to lock onto the power induced into the ground. The possible warm water could account for this between the Dakota Sandstone and the Benton Shale, or could be due to the shallow thermal waters found at a 60 foot depth in the vicinity of the old hotel that has since been destroyed.

LENGTH: 3900 ft (1189 m)
SEPARATION: n value
DATE: June 24, 1980
TYPE: Dipole - Dipole
SPREAD: a = 100 ft
RESISTIVITY: In ohm-meters
0 300 ft

Figure 11. Dipole-dipole pseudosection line D.

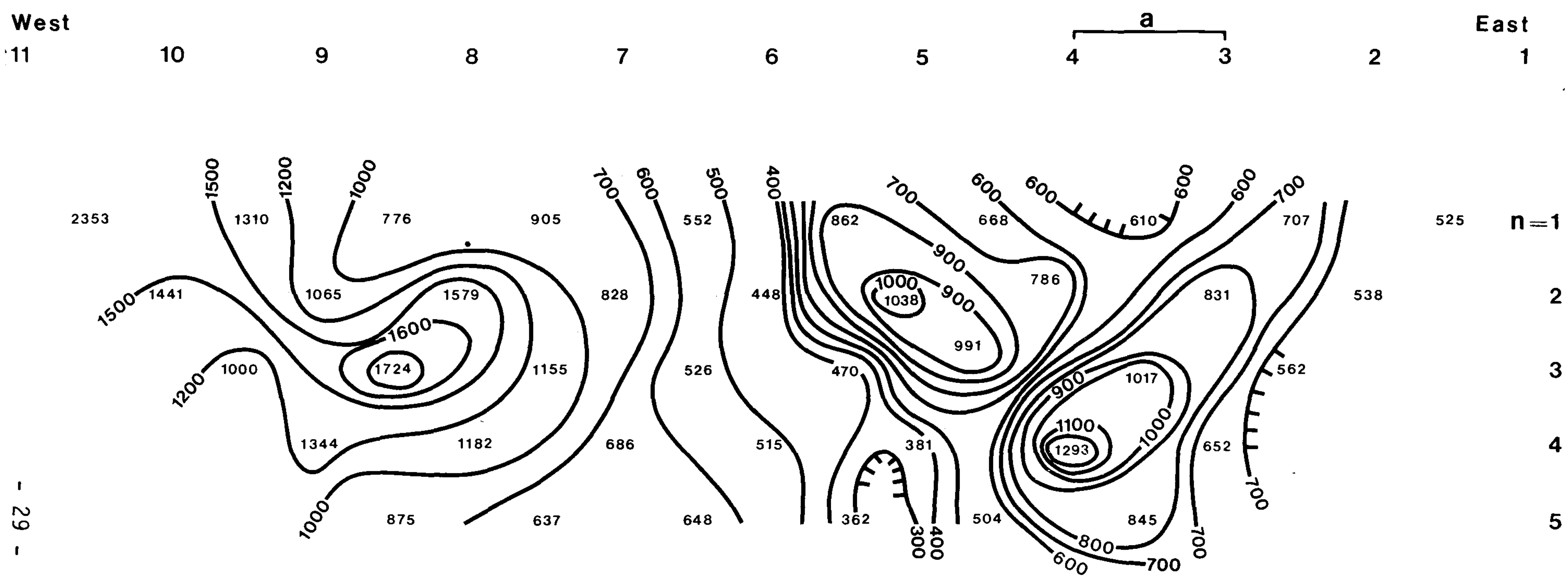


LENGTH: 1200 ft [366 m]
SEPARATION: n value
DATE: June 25, 1980
TYPE: Dipole – Dipole
SPREAD: a = 100 ft
RESISTIVITY: In ohm-meters

0 100 ft

The line is approximately 1,200 ft (366 m) and is entirely in the Morrison Formation (Fig. 7). In general the resistivity values are all in the low range from 15 to 70 ohm-meters. One relative low area exists between station 16 and 17 and this is probably due to the water saturated alluvium in the immediate area.

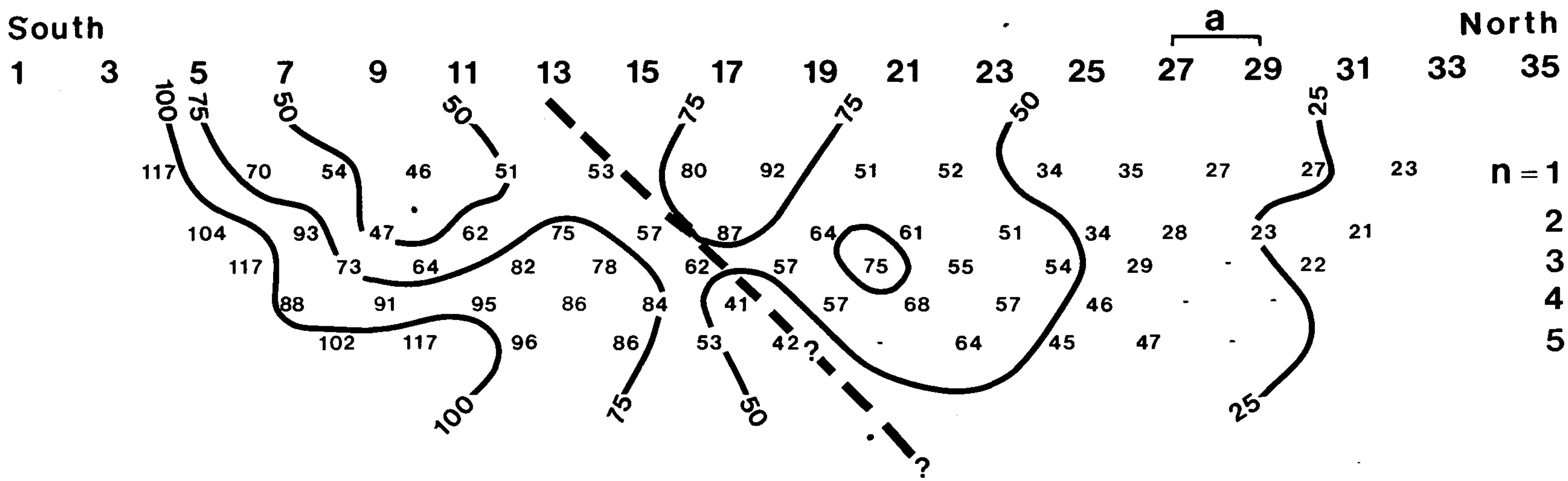
Figure 12. Dipole-dipole pseudosection line E.



This line is located on the hill above the hot springs (Fig. 7) on Precambrian rocks. The line is approximately 1,200 ft (366 m) long. Measured resistivity values are very high, ranging from 2,300 ohm-meters to about 400 ohm-meters. The low values between 330 and 400 ohm-meters are between station 5 and 6, which is adjacent and above the hot springs area.

LENGTH: 1200 ft [366m]
SEPARATION: n value
DATE: June 26, 1980
TYPE: Dipole-Dipole
SPREAD: a = 100 ft
RESISTIVITY: In ohm-meters
0 100 ft

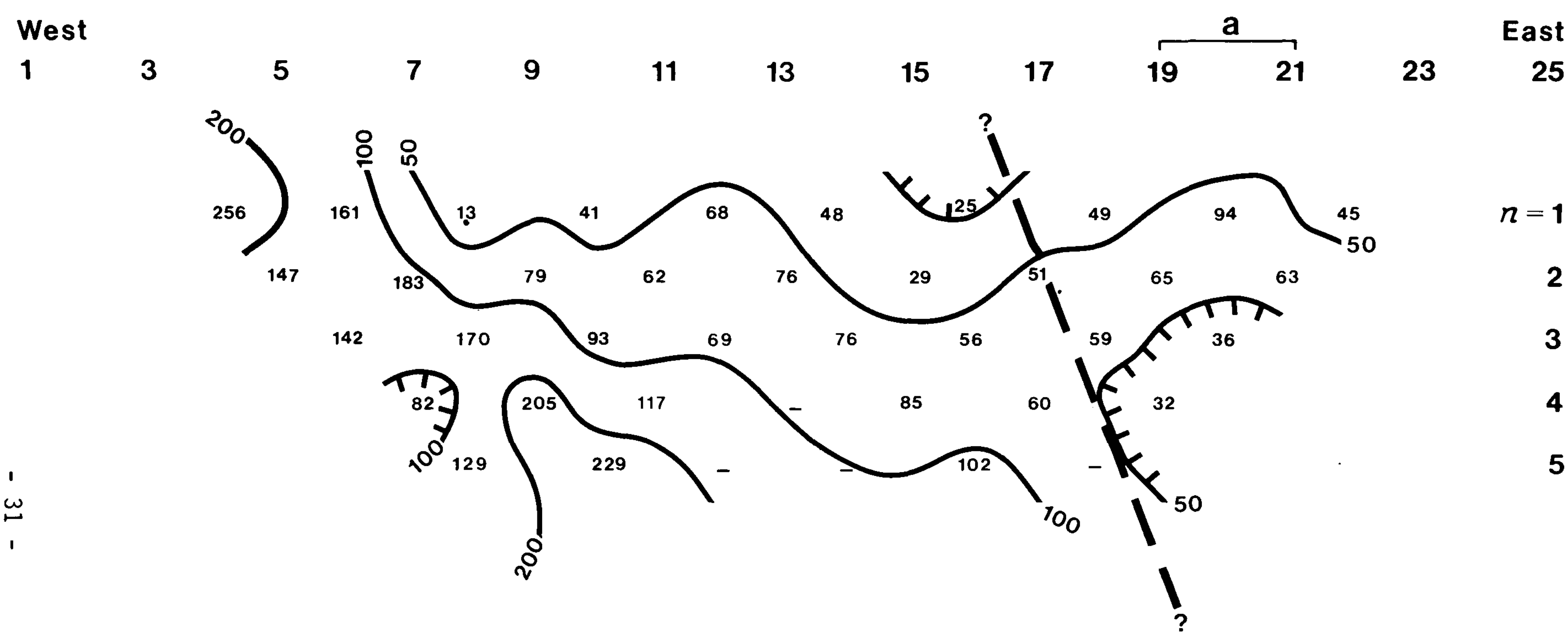
Figure 13. Dipole-dipole pseudosection line F.



Dipole-Dipole Resistivity Line G is approximately 3,500 ft (1,067 m) in length and trends northwest-southeast (Fig. 7). Two low resistive zones are displayed on this line. The first zone exists between station 10 and 15 at a depth of approximately 500 ft. There is also a mapped fault in this area that could attribute to the low resistivity. The second low zone exists at a shallow depth of 200 ft between station 27 and 33. No faults are evident in this area except that this area lies in a wedge zone between two thrust plates. Most of the northern portion of this line lies in the Maroon Formation which, because of its lithologic characteristics, could be water saturated.

LENGTH: 3500 ft [1067 m]
SEPARATION: n value
DATE: June 30, 1981
TYPE: Dipole – Dipole
SPREAD: a = 200 ft
RESISTIVITY: In ohm-meters
▬ ▬ ▬ Possible fault
0 400 ft

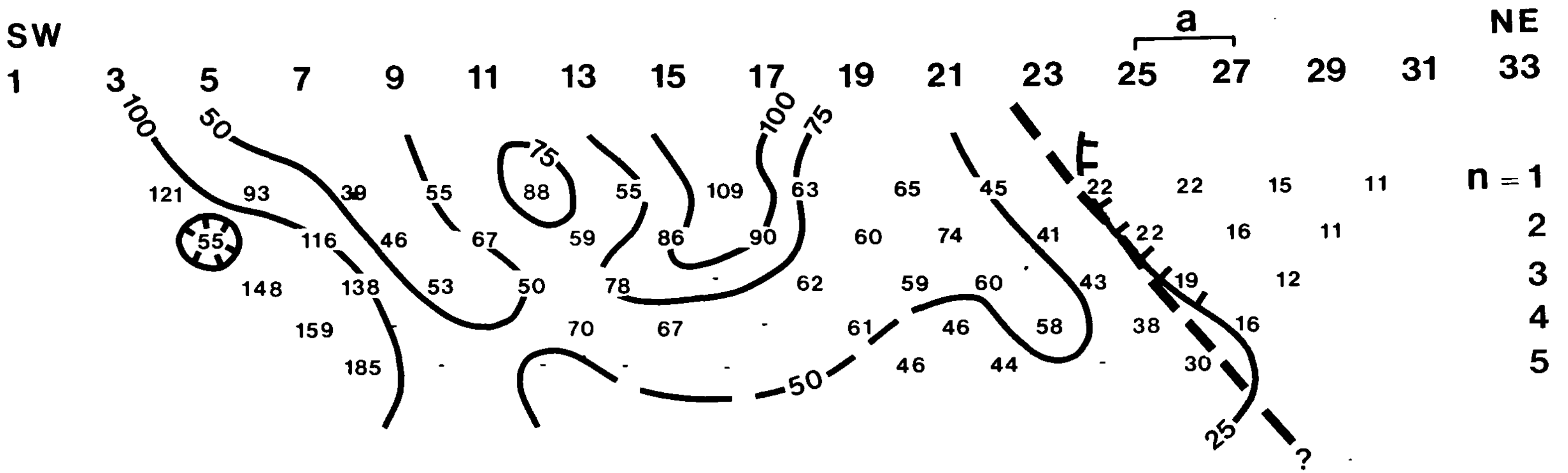
Figure 14. Dipole-dipole pseudosection line G.



Resistivity Line H is approximately 2,600 ft (793 m) in length and trends in a northeast-southwest direction (Fig. 7). Two low resistive zones are demonstrated on this line, one at station 10 and another between stations 15-18. Coincidentally, the latter low resistive zone is where a mapped thrust fault intersects the dipole-dipole line. The first low resistive zone is at the proximity of the Benton and Niobrara Formation contacts. Neither of these features shows up distinctly on the dipole-dipole pseudosection.

LENGTH: 2600 ft (793 m)
SEPARATION: n value
DATE: July 1, 1981
TYPE: Dipole - Dipole
SPREAD: a = 200 ft
RESISTIVITY: In ohm-meters
▬ ▬ Possible fault
0 200 ft

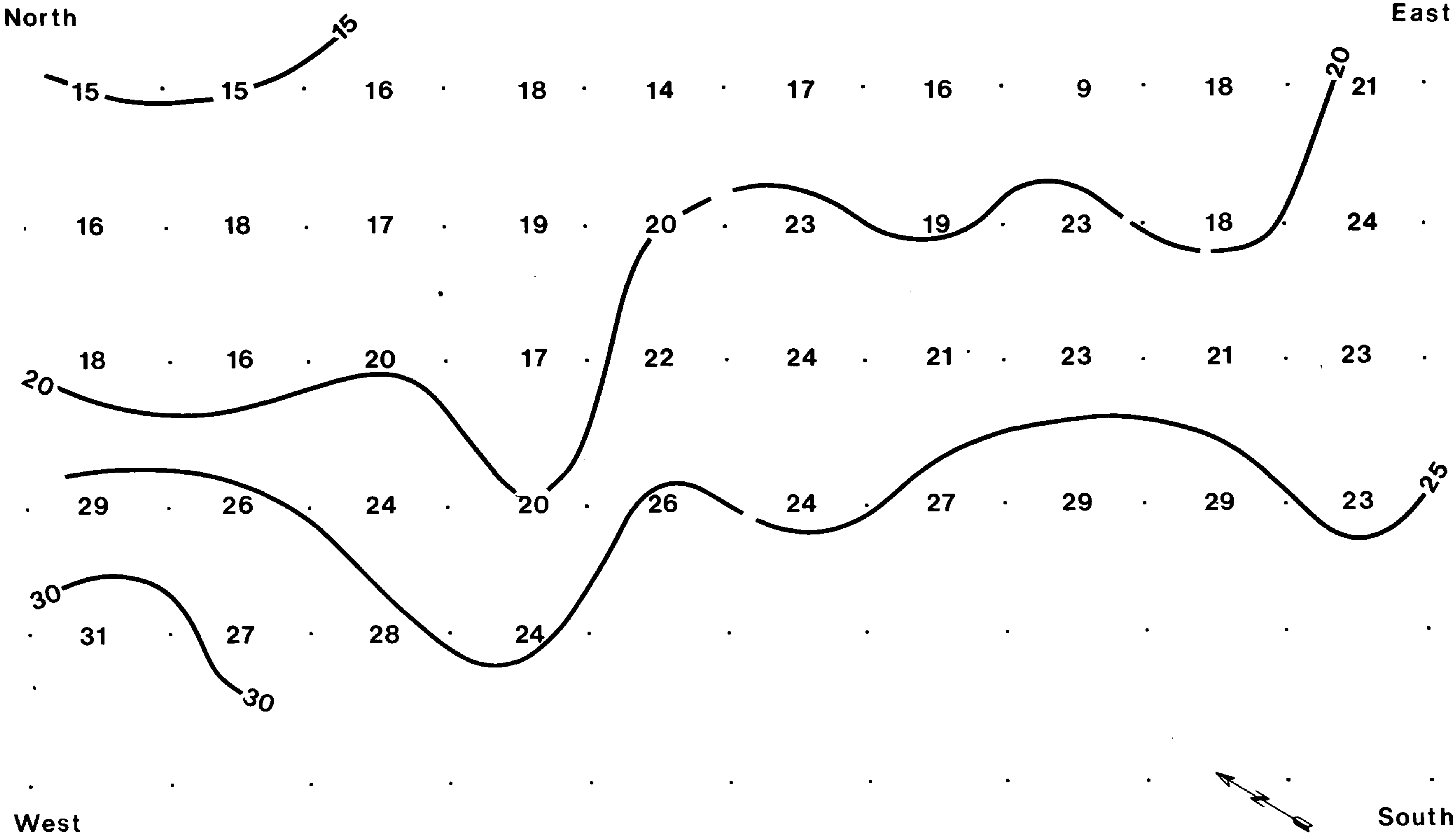
Figure 15. Dipole-dipole pseudosection line H.



Dipole-Dipole Resistivity Line I is approximately 3,300 ft (1,006 m) length and trends in a northeast-southwest direction (Fig. 7). A low resistive zone is evident at the southwest portion of the line between station 5 through 11. The other low zone exists at the northeast portion of the line on the east side of the thrust fault. In addition, there is some evidence from the psuedosection that the thrust fault intersects the line in the vicinity of station 21. Therefore there seems to be a fair ammount of correlation pertaining to the faulting with respect to dipole-dipole lines G, H, and I.

LENGTH: 3300 ft (1006 m)
SEPARATION: n value
DATE: July 1, 1981
TYPE: Dipole - Dipole
SPREAD: a = 200 ft
RESISTIVITY: In ohm-meters
▬ ▬ Possible fault
0 300 ft

Figure 16. Dipole-dipole pseudosection line I.



A partial gradient array was conducted in the vicinity of the thrust plate northwest of the town of Hartsel (Fig. 7). The faulting was not obvious from the resistivity information obtained. The resistivity values decreased to the northeast and increased to the southwest. The only inference that could be drawn from the data contours is that within the fault wedge lower resistive readings were obtained.

LENGTH: 900 ft (273m)
DATE: July 2, 1981
TYPE: Gradient array
SPREAD: a = 100 ft
RESISTIVITY: In ohm–meters
0 100 ft

Figure 17. Gradient array.

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, Klusman and Landress (1979) and Capuano and Bamford (1978) have shown how soil mercury surveys can delineate faults or permeable zones in geothermal areas. The association of mercury with geothermal deposits has been shown by White (1967). Matlick and Buseck (1976) stated that areas with known thermal activity, such as: Geysers in California; Wairakei, New Zealand; Geyser, Iceland; Larderello, Italy; and Kamchatka, Russia contain mercury deposits.

Matlick and Buseck (1976), in presenting the geochemical theory behind the associations of mercury with geothermal deposits, noted that mercury has great volatility, and 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 vicinity of the hot spring was considered the target rather than any particular fault. Sampling intervals of 200 ft (61 m) or less were used where attempts were made to delineate controlling faults. This spacing was used by Capuano and Bamford (1978). However, Klusman and Landress (1979) seem to think that the sample must be taken directly over the faulting for detection. Considering the empirical result of Capuano and Bamford (1978), it was believed that some anomalous mercury values should be encountered if a grid pattern encompassing the hot spring area was used. A definite structural pattern may be obvious, but if the study area is being influenced by geothermal activity, the trend should indicate that the hot springs area entirely or partially is high in mercury relative to surrounding area.

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

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

Two rationals 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 with the anomalous results of the ranking method.

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

Hartsel Area Soil Mercury Surveys

As part of the resource evaluation program of the Hartsel area 84 soil samples were collected in three areas and analyzed for their soil mercury concentrations (Fig 18). Preliminary examination of the field data suggested that the Hartsel Hot Springs are fault controlled, so the sample lines were laid out to cross previously mapped faults. Two of the areas sampled were north of Hartsel and one was south of Hartsel in the vicinity of the hot springs. Values of mercury contained in the soil samples ranged from a low of 0 ppb to a high of 105 ppb with an average value of 12 ppb (Table 4).

TABLE 4. Soil Mercury Values, Hartsel Area

Lines: A - A'	B - B'	B - C	D - D'	E - E'	F - F'
105,41,10	45	15	4	1,3,4	0
41,41	8,7	5	4	4	1
101	7	8	10	0	1
28	15	9	20*	3	7
4	4,10	20*	22,23 ***	1	15,2
22	5	38	37 ***	14	21
3	0	38	0 ***	7	6
18,16	12,22	4,11 ***	4	1	6
4	0	9			14,12
1	2	40**			22
2	12**	2,5,6***			
1	19**	1			
7	5,8	5			
4	6.3				
4	7				
4,8,13					
23					
3					
8					

* Sample common to two lines
** Fault zone
*** Samples from same area. Average value plotted on Fig. 18.

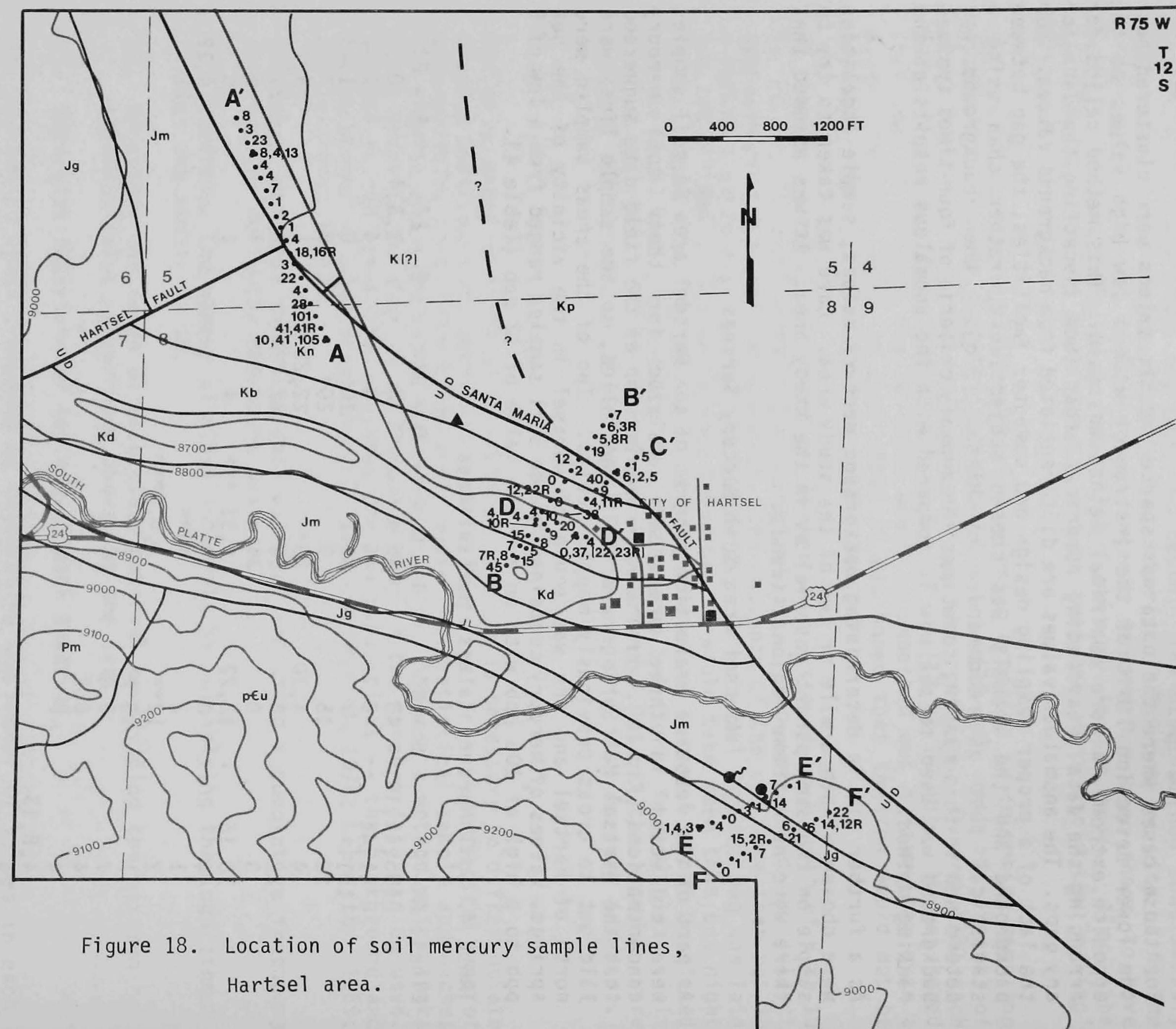


Figure 18. Location of soil mercury sample lines, Hartsel area.

FIGURE 18 EXPLANATION

Hot spring

Warm shallow well

Cold spring

23,22R Each value indicates the analysis of a single sample in ppb of mercury. "R" denotes replicated sample value. Values in parentheses indicate more than one analysis of a single sample.

K(?)	Undifferentiated	Cretaceous
Kp	Pierre Formation	
Kb	Benton Formation	
Kn	Niobrara Formation	
Kd	Dakota Formation	
Jm	Morrison Formation	Jurassic
Jg	Garo Formation	
Pm	Maroon Formation	Permian
p€u	Undifferentiated	Precambrian

U/D Normal fault, dashed where inferred, U - upthrown side, D - downthrown side

To determine soil mercury background values eighteen samples were randomly collected away from the hot springs, but in the Hartsel area. Analysis of these samples determined that the mean background value was 4 ppb of mercury. Using the analytical method of values greater than 4x mean value, described before it was decided that all values above 20 ppb could be considered anomalous.

The area north of Hartsel was sampled in two location to determine if the major north-south trending fault could be detected. While there was no evidence of any thermal activity along this fault, mercury values on lines A-A', B-B' and B-C did peak near the fault (Figs. 19 & 20).

The area to the east and south of the hot springs was sampled to see if any controlling structure could be located (Fig. 18). Analysis of the analytical data for samples collected along line E-E' showed one higher value, when compared with other values, on the line. On Line F-F' two anomalmous areas were noted. These high values could indicate the presence of a fault passing through the hill, but no fault was observed. These anomalous areas were also noted by the electrical resistivity surveys (Fig. 8, Line A-A').

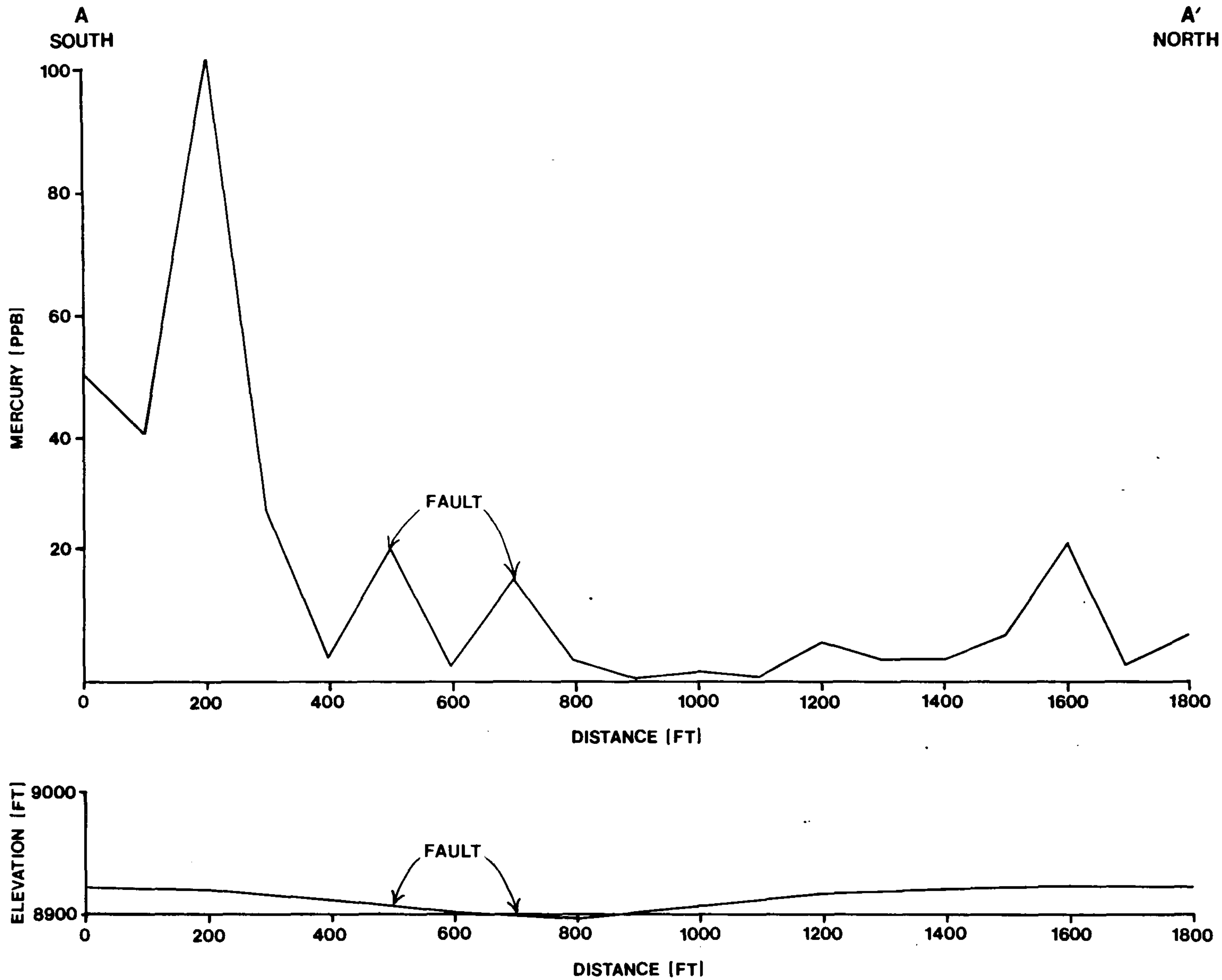


Figure 19. Soil mercury profile line A.

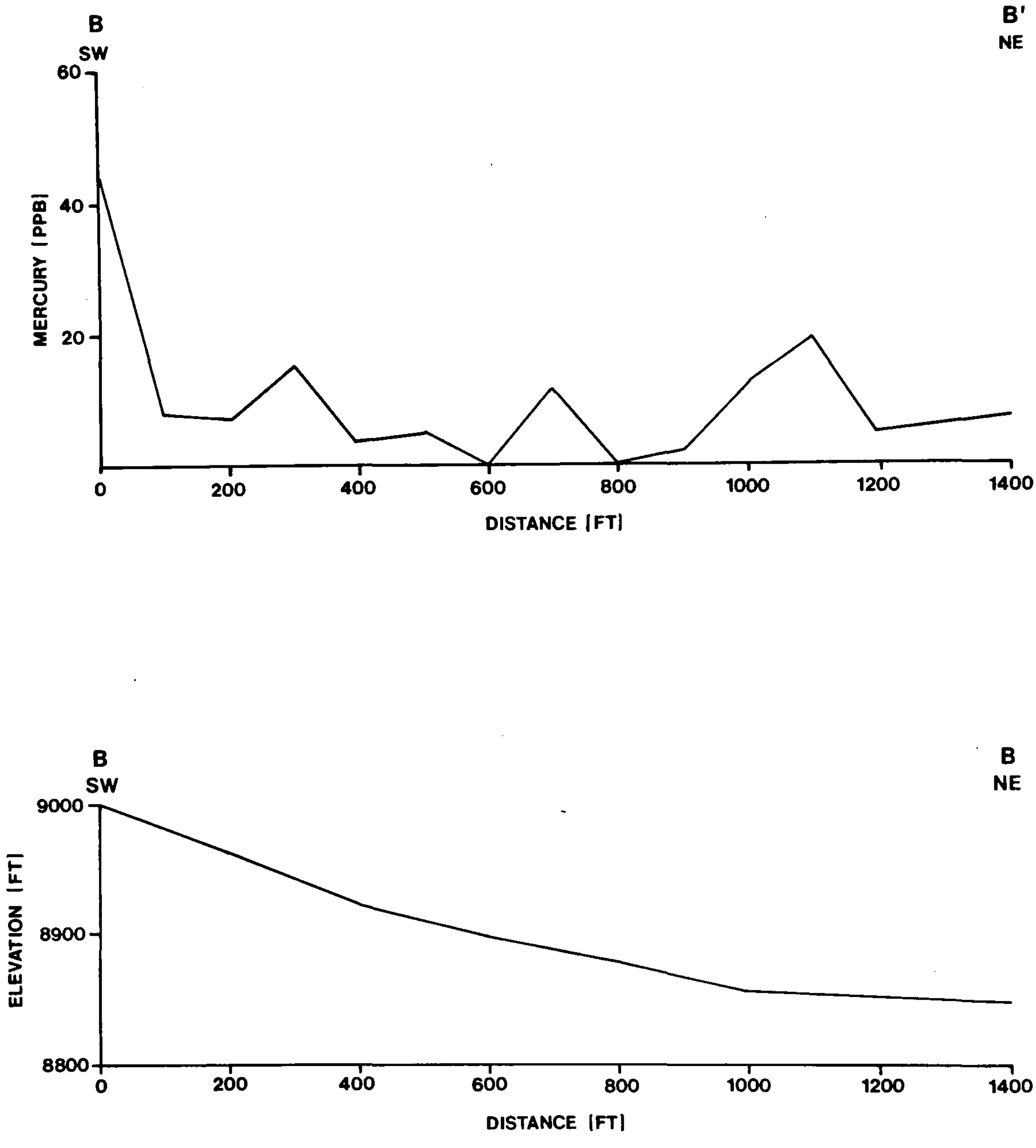


Figure 20. Soil mercury profile line B.

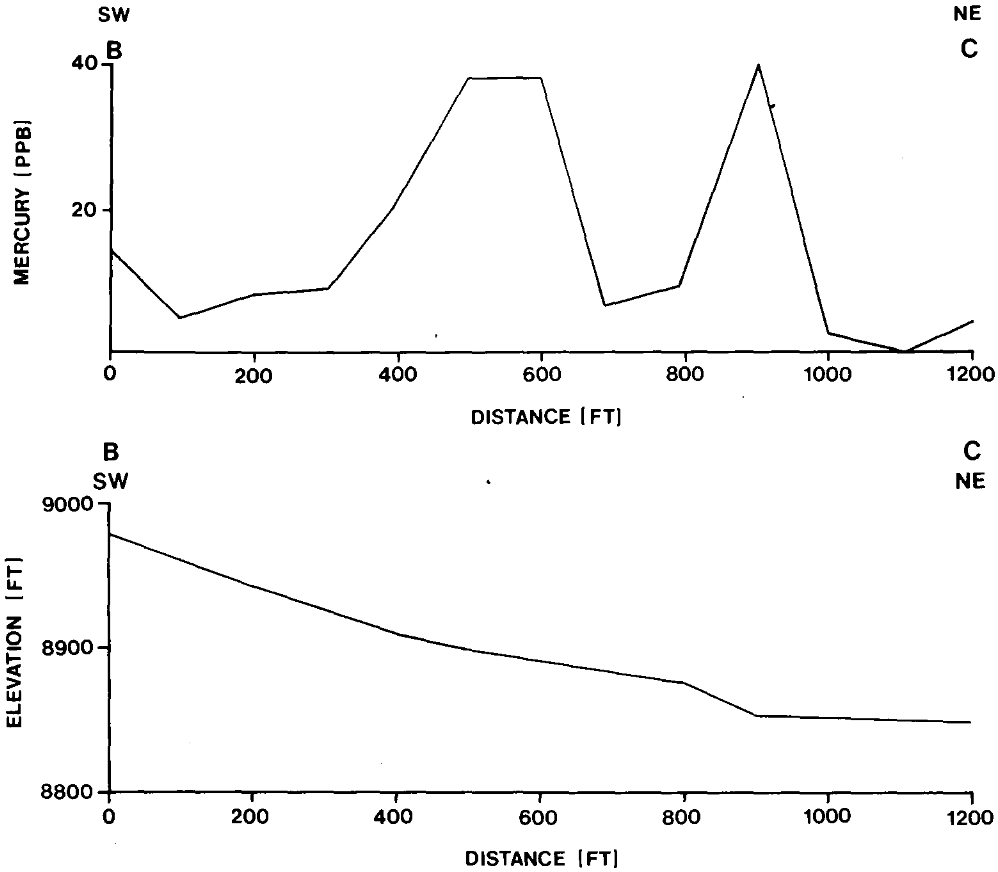


Figure 21. Soil mercury profile line B-C.

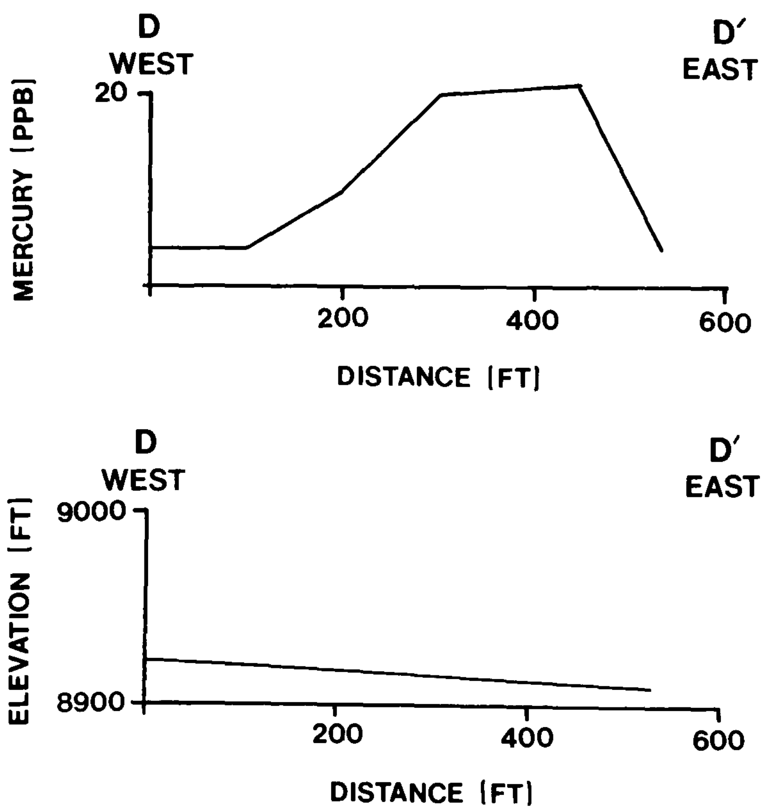


Figure 22. Soil mercury profile line D.

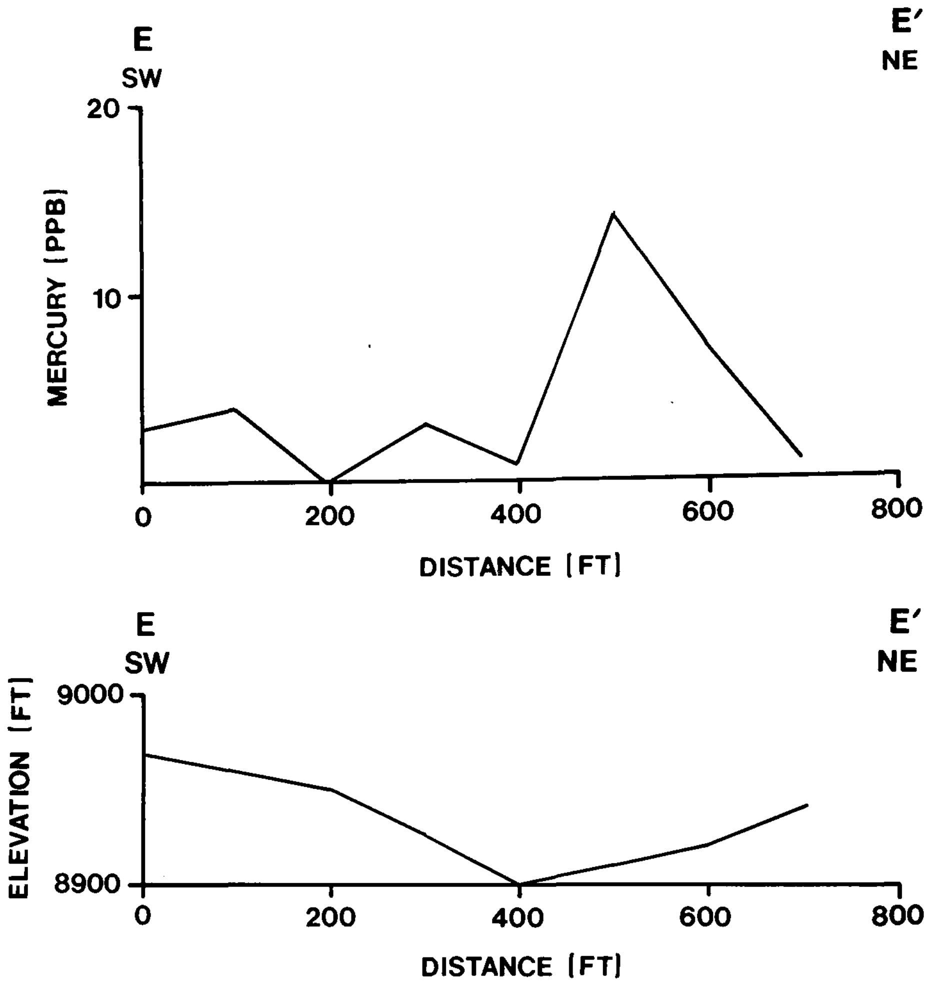


Figure 23. Soil mercury profile line E.

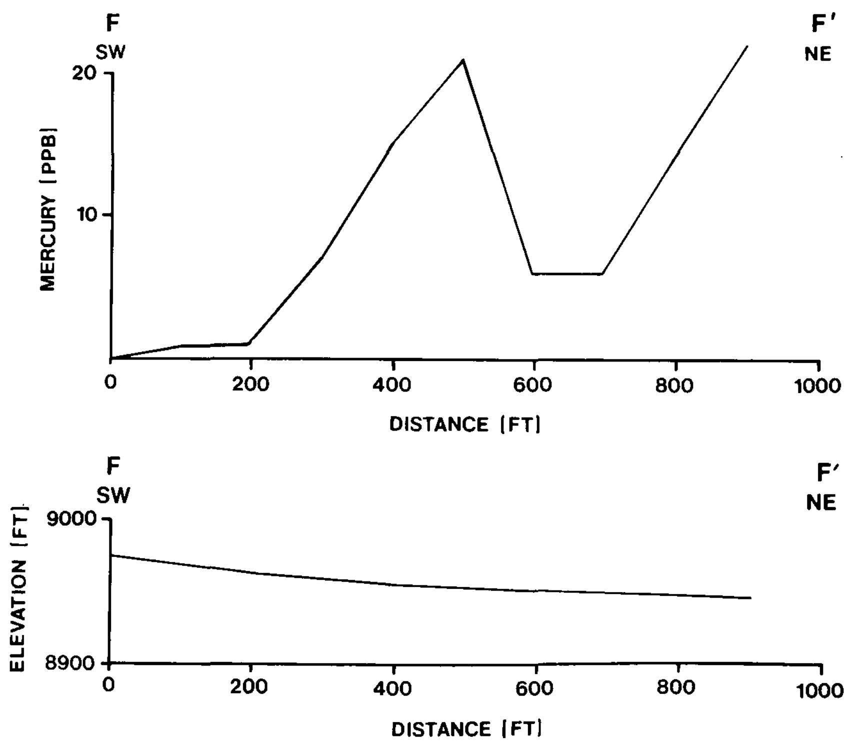


Figure 24. Soil mercury profile line F.

ORIGIN OF THE THERMAL WATERS

The anomalous gradient found in the granite at Glentiver dome suggest the heat source may be the Precambrian basement rocks in the study area. Meteoric water may be heated by shallow granite storing heat, and insulated by overlying sediments. The granite may be heated by decay of radioactive elements since Wells (1960) has shown that Tertiary igneous rocks in the Colorado Front Range are considerably more radioactive than normal. High geothermal gradients may explain the lack of hydrocarbons in the area, as any accumulation may have been driven off by the heat.

The water may simply be heated by normal geothermal gradient via deep circulation along faults. Since basement faulting is the dominant structural feature in the area, this is a likely mechanism for the hot water present. Assuming an average annual surface temperature of 2°C (36°F), a conservative geothermal gradient of 22°C/km, and some heat loss, groundwater would need to penetrate to a depth of approximately 3 Km (1.8 mi) to attain the observed temperature, which is well within the probable depth of faulting.

The resistivity, shallow temperature and soil mercury surveys all showed trends in a northwesterly direction along or adjacent to the Santa Maria Fault at Hartsel. Thermal water probably reaches the surface via fault permeability along the Santa Maria Fault. If the interperation shown in the ENE cross-section in Figure 4 is correct, the Santa Maria Horst (of which Hartsel Ridge is a part) is an inpermeable barrier to deep groundwater movement, although warm water exists in the shallow sediments overlying basement rocks in Hartsel. From the recharge area east of the Elkhorn Thrust Fault, meteoric water may move to depth via fault permeability. Cold springs along the low angle Elkhorn Thrust attest to hydraulic pressure at depth to the east. The heated water could then move up-dip through a sedimentary aquifer to Hartsel Ridge, being forced to the surface via the Santa Maria Fault. Although a few formations may be thermal aquifers, the Dakota Sandstone is the most probable, since it is highly permeable, and a common geothermal aquifer in Colorado.

The hot water encountered west of Hartsel is probably a separate system (see Hydrogeology section). Preliminary indications are that this resource area is extensive, and fault controlled with some hot water migration occurring in the Leadville limestone, although the resource dynamics are not fully known.

SUMMARY AND CONCLUSIONS

Geophysical and geochemical surveys conducted by the Colorado Geological Survey at Hartsel, Colorado were useful in determining the nature and extent of the local geothermal resource. Due to lack of deep subsurface hydrogeological data it is not possible to accurately model this thermal system. However, based on interperation of existing geological data it appears that the hot waters are most likely migrating upward along the Santa Maria Fault, on the east side of an impermeable horst block. Recharge to the thermal system probably occurs to the east in the form of precipitation, which moves into the subsurface along faults and fractures. The water, heated at depth, may then move westward (updip) via sedimentary aquifers, probably the Dakota Sandstone primarily. The heat source is most likely Precambrian granite, which is responsible for a high gradient in the area. Hot water encountered further to the west is probably a separate system.

Any futher exploration or drilling should focus upon the Santa Maria Fault, the Dakota Sandstone aquifer, or the Precambrian rocks beneath Glentiver Dome to the east. The Leadville Limestone aquifer and major faults are probably good targets to the west, in the Antero Junction area, but more research is required to substantiate this.

REFERENCES

Barrett, J. K. and Pearl, R. H., 1976, Hydrogeological data of thermal springs and wells in Colorado: Colorado Geol. Survey Info. Series 6, 124 p.

______1978, An apparaisal of Colorado's geothermal resources: Colorado Geol. Survey Bull. 39, 229 p.

Belcher, G.A., 1877, Report of Gustavus R. Belcher, topographer: U.S. Geol. and Geog. Survey Territories, 9th Ann. Rept. for 1875, pp. 379-431.

Beggs, G., 1976, Interpretation of seismic reflection data from the Hartsel and Sulphur Mountain Quadrangles, Park County, Colorado: Colorado School Mines Master Sci. Thesis T-1880, 55p.

Berry, G. W., Grim, P. J., and Ikelman, J. A., 1980, Thermal springs list for the United States: Nat. Oceanic and Atmospheric Administration, Key to Geophysical Records Documentation No. 12, Boulder, Colorado, 59 p.

Birman, J. H., 1969, Geothermal exploration for ground water: Geol. Soc. America Bull., v. 80, p. 617-630.

Cartwright, K., 1968, Temperature prospecting for shallow glacial and alluvial aquifers in Illinois: Illinois State Geol. Survey Circ. 433, 41 p.

Capuano, R. M., and Bamford, R. W., 1978, Initial Investigation of Soil Mercury Geochemistry as an Aid to Drill Site Selection in Geothermal Systems, Contract: EG-78-C-07-1701, Earth Science Laboratory, University of Utah Research Institute, Salt Lake City, Utah.

Clement, J. H., and Dolton, G. T., 1970, Chronicle of exploration in South Park Basin, Park County, Colorado: Mountain Geologist, v. 7, no. 3, p. 205-218.

Colorado State Planning Division, 1957, Colorado precipitation map, climatological, population and economic data: Colorado State Planning Div., scale 1 = 20 miles.

Combs, Jim, 1980, Geothermal Exploration Strategy and Techniques, Geothermal Services Inc., San Diego, CA, 41 p.

Cox, M. E., and Cuff, K. G., 1980, Rn and Hg Surveys: Geothermal exploration in N.E. Maui Hawaii, in Geothermal: Energy for the Eighties, Transactions Geothermal Resources Council Annual Meeting, Salt Lake City, UT: Geothermal Res. Council, Davis, CA, p. 451-454.

Craig, Harmon, 1961, Isotopic variations in meteoric waters: Science, v. 133, pp. 1702-2703.

DeVoto, R.H., 1971, Geologic history of South Park and geology of the Antero Reservoir Quadrangle, Colorado: Colorado School Mines Quart., v. 67, no. 4, pp. 139-185.

Epis, R.C., Scott, G.R., Taylor, R.B. and Chapin, C.E., (1980), Summary of Cenozoic geomorphic volcanic, and tectonic features of Central Colorado and adjoining areas, in Kent, H.C. and Porter, K.W., Colorado Geology: Rocky Mountain Assoc. of Geologists, pp 135-156.

Ettinger, M.I., 1959, The geology of the Hartsel area, South Park, Park County, Colorado: Colorado School Mines Master Sci. Thesis T-897, 99p.

Flynn, T., Koenig, B. A., Trexler, D. T., and Bruce, J. L., 1980, Area specific investigations of three low- to moderate-temperature geothermal resource areas in Nevada, in Geothermal Energy for the Eighties: Transactions of the Geothermal Resources Council Annual Meeting, Salt Lake City, Utah: Geothermal Resources Council, Davis, CA, p. 41-45.

Friedman, I., and Norton, D. R., 1981, Ground temperatures in and near Yellowstone National Park, in Ground Temperature Measurements: U.S. Geol. Survey Prof. Paper 1203, p. 23-29.

Gould, D.B., 1935, Stratigraphy and structure of Pennsylvanian and Permian rocks in the Salt Creek area, Mosquito Range, Colorado: American Assoc. Pet. Geologists Bull. v. 19, pp. 971-1009.

George, R. D., Curtis, H. A., Lester, O. C., Crook, J. K., and Yeo, J. M., 1920, Mineral waters of Colorado: Colorado Geol. Survey Bull. 11, 474 p.

Hayden, F.V., 1873, Annual reports 1-3 for 1867,1868, 1869: U.S. Geol. Survey Territories, pp. 175-181.

Johnson, J.H., 1934a, Paleozoic formations of the Mosquito Range, Colorado: U.S. Geol. Survey Prof. Paper 185B, pp. 15-43.

______1934b, Stratigraphy of South Park (abs): Geol. Soc. America Proc. p. 86.

______1934c, Stratigraphy of northeastern and east-central parts of South Park, Colorado: Geol. Soc. America Bull., v. 48, pp. 1227-1235.

Kintzinger, 1956, Geothermal survey of hot ground near Lordsburg, New Mexico: Science, v. 124, p. 629.

Klusman, R. W. and Landress, R. A., 1979, Mercury in soils of the Long Valley, California, geothermal system: Jour. Volcanology, Geothermal Res., v. 5, pp. 49-65.

Klusman, R. W., Cowling, S., Culvey, B., Roberts, C., and Schwab, A. P., 1977, Preliminary evaluation of secondary controls on mercury in soils of geothermal districts: Geothermics, v. 6, pp. 1-8.

Lepeltier, Claude, 1969, A simplified statistical treatment of geochemical data by graphical representation: Economic Geology, v. 64, pp. 538-550.

Levinson, A. A., 1974, Introduction to exploration geochemistry, Applied Publishing Ltd., Calgary, pp. 561-568.

Lewis, E. L., 1966, The thermal springs of Colorado--A resource appraisal: Univ. of Colorado Dept. Geography, Master Sci. Thesis, 91 p.

Lovering, T. S., and Goode, H. D., 1963, Measuring geothermal gradients in drill holes less than 60 feet deep, East Tintic district, Utah: U.S. Geol. Survey Bull. 1172, 48 p.

Lozana, E., 1965, Geology of the southwestern Garo area, South Park, Park County, Colorado: Colorado School Mines Master Sci. Thesis T-1880, 91 p.

Mallory, E. C., Jr., and Barrett, P. R., 1973, Chemistry and spectrochemical analysis of selected groundwaters in Colorado: U.S. Geol. Survey Open-file Report, 47 p.

Matlick, J. S. III, and Buseck, P. R., 1976, Exploration for geothermal areas using mercury - a new geochemical technique, in Proceedings Second United Nations Symposium on the Development and Use of Geothermal Resources, San Francisco, CA.: U.S. Gov. Printing Office, v. 1, pp. 785-792.

Miesh, A. T., 1976, Sampling designs for geochemical surveys - syllabus for a short course: U.S. Geol. Surv. Open-file Report 76-772.

Olmsted, F. H., 1977, Use of temperature surveys at a depth of 1 meter in geothermal exploration in Nevada: U.S. Geol. Survey Prof. Paper 1044-B, 25 p.

Parsons, M. L., 1970, Ground water thermal regime in a glacial complex: Water Resources Research, v. 6, no. 6, p. 1701-1720.

Peale, A.C., 1874, Report of the South Park division: U.S. Geol. and Geog. Survey Territories, 7th Ann. Rept. for 1873, pp. 211-225.

Pearl, R. H., 1972, Geothermal resources of Colorado: Colorado Geol. Survey Spec. Pub. 2, 54 p.

______1979, Colorado's hydrothermal resource base--An assessment: Colorado Geol. Survey Resource Series 6, 144 p.

Sanders, G.F., 1975, Geology of the Buffalo Peaks, Park and Chaffee Counties, Colorado: Colorado School Mines Master Sci. Thesis.

Sawatzky, D.L., 1967, Tectonic style along the Elkhorn Thrust, eastern South Park and western Front Range, Park County, Colorado: Colo. School Mines PhD dissertation T-1044, 206 p.

Scintrex, 1971, RAC-8 low frequency A.C. resistivity system operation manual: Concord, Ontario, Canada, 22 p.

Soil Test Inc., 1968, Earth resistivity manual: Evanston, Illinois, 52 p.

Stark, J.T., Johnson, J.H., Behre, C.H., Jr., Powers, W.E., Howland, A.D. and Gould, D.B., 1949, Geology and origin of South Park, Colorado: Geol. Soc. America Memoir 33, 188 p.

Stevenson, J.T., 1875, Geology of a portion of Colorado explored and surveyed in 1873: U.S. Geol. and Geol. exploration and survey, west of the one-hundreth meridian, vol. 3, pp. 389-390

Sumner, J. S., 1976, Principles of induced polarization for geophysical exploration: Elsevier Scientific Publishing Co., pp. 1-47

Thompson, W., 1860, On the reduction of observations of underground temperature; with application to Professor Forbes' Edinburgh Observations, and the continued Carlton Hill Series, in Transactions of the Royal Society of Edinburgh, v. 22, p. 405-427.

Waring, G. A., 1965, Thermal springs of the United States and other countries of the world - A summary, revised by R. F. Blankenship and Ray Bentall: U.S. Geol. Survey Prof. Paper 492, 383 p.

Wells, J.D., 1960, Petrography of radioactive Tertiary igneous rocks, Front Range Mineral Belt, Colorado: U.S. Geol. Survey Bull. 1032-E, p pp. 223-272.

White, D. E., 1967, Mercury and base-metal deposits with associated thermal and mineral waters, in Barnes, H. L., ed., Geochemistry of hydrothermal ore deposits: New York, Holt, Rinehart and Winston, pp. 575-631.

White, D. E., Hinkle, L. G., and Barnes, I., 1970, Mercury content of natural thermal and mineral fluids: U.S. Geol. Survey Prof. Paper 713, pp. 25-28.

Zacharakis, T. G., 1981, Revised heat flow map of Colorado: Colorado Geol. Survey Map Series 18, scale 1:1,000,000.

APPENDIX A

Table 5. Physical properties and chemical analysis of Hartsel thermal waters (from Barrett and Pearl, 1976)

	Spg. A (West)	Spg. B (East)
Arsenic, (UG/L)	2	2
Boron, (UG/L)	560	550
Cadium, (UG/L)	1	1
Calcium, (MG/L)	120	120
Chloride, (MG/L)	820	780
Fluoride, (MG/L)	2.1	2
Iron, (UG/L)	170	520
Lithium, (UG/L)	1,000	1,000
Magnesium, (MG/L)	20	20
Manganese, (UG/L)	150	180
Mercury, (UG/L)	0	0.1
Nitrogen, (MG/L)	0.22	0.03
Phosphate		
Ortho diss. as P, (MG/L)	0.04	0.03
Ortho, (MG/L)	0.12	0 0.09
Potassium, (MG/L)	33	32
Selenium, (UG/L)	0	0
Silica, (MG/L)	40	38
Sodium, (MG/L)	680	650
Sul ate, (MG/L)	320	260
Zinc, (UG/L)	10	10
Alkalinity		
As Calcium Carb., (MG/L)	393	397
As Bicarbonate, (MG/L)	479	484
Hardness		
Noncarbonate, (MG/L)	0	0
Total, (MG/L)	380	380
Specific Conductance (Micromohs)	3,780	3,850
Total Dissolved Solids (TDS), (MG/L)	2,280	2,140
ph, Field	-	-
Discharge (gpm)	-	48
Temperature (°C)	52	52
Date Sampled	6/75	6/75
Location	T.12S., R.75W. NESE Sec 8	T.12S., R. 75W. NESE Sec. 8

Table 6. Spectrographic analyses of Hartsel thermal waters (UG/L) (from Barrett and Pearl, 1976).

Aluminum	100	Copper	<3	Strontium	200
Barium	90	Gallium	<6	Tin	<13
Beryllium	<3	Germanium	<13	Titanium	<6
Bismuth	<13	Lead	<13	Vanadium	<13
Chromium	<13	Nickel	<13	Zirconium	<20
Cobalt	<13	Silver	<2		

APPENDIX B

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 them 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 C

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 D

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. 22). 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. 23) 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.

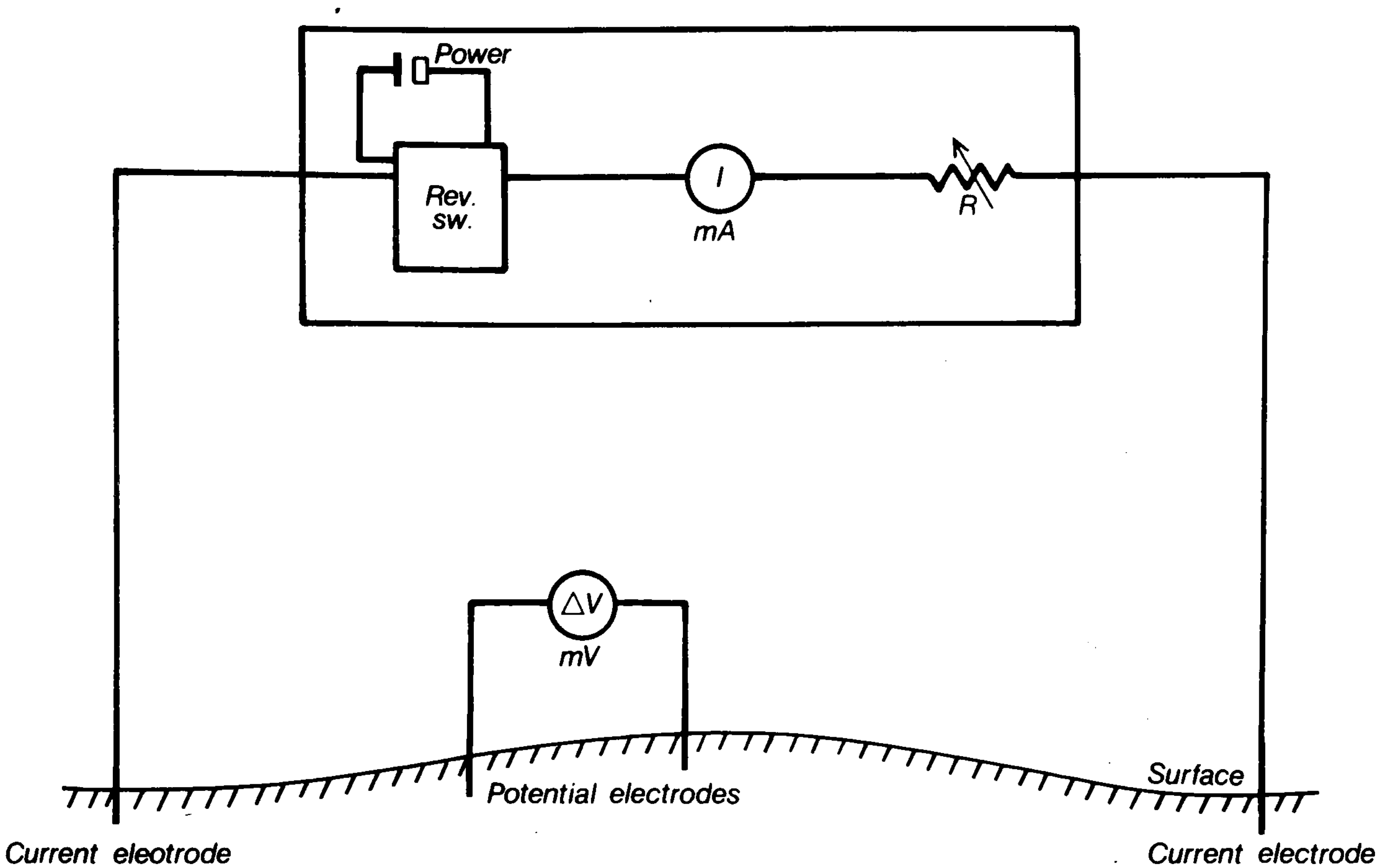
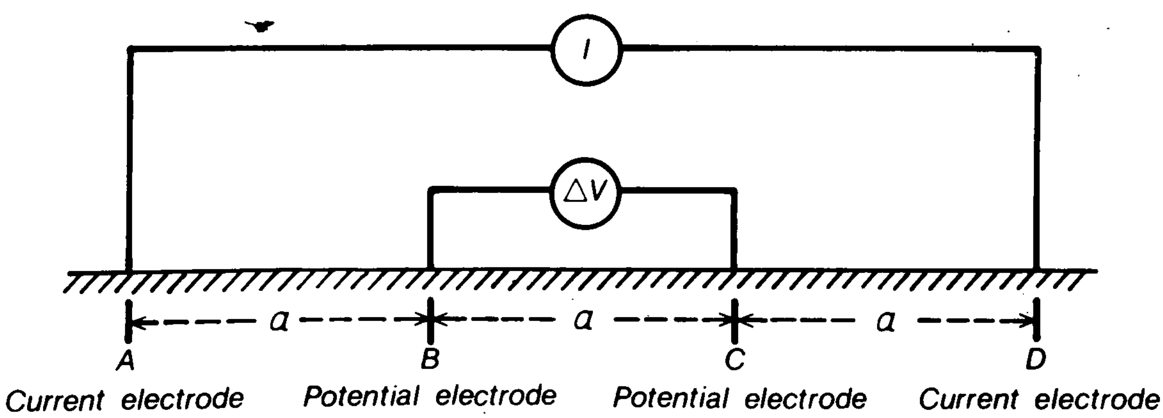


Figure 25. Schematic diagram for resistivity (from J. Combs, 1980).



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

Figure 26. Wenner array (from J. Combs, 1980).

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

Schlumberger Array

For the Schlumberger array, the current electrodes are spaced much further apart than the potential electrodes (Fig. 24).

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

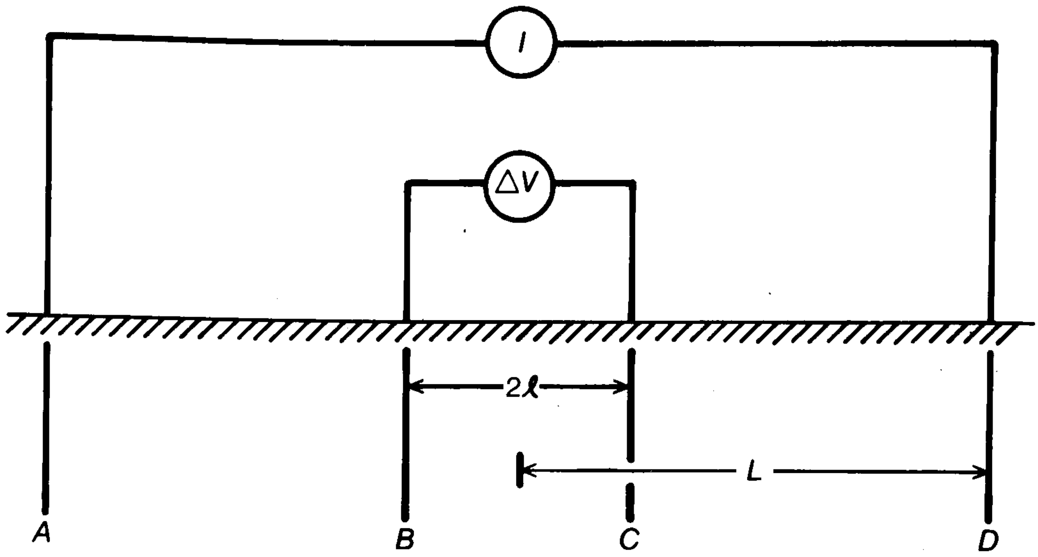
In summary, short spacing between the outer electrodes assumes shallow penetration of current flow and computed resistivity will reflect properties of shallow depth. As the electrode spacing is increased, more current penetrates to greater depth and conducted resistivity will reflect properties of each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

Dipole-Dipole Array

The potential electrodes are closely spaced and remote from the current electrodes which are close together. There is a separation between C and P , usually 1 to 5 times the dipole lengths (Fig. 25).

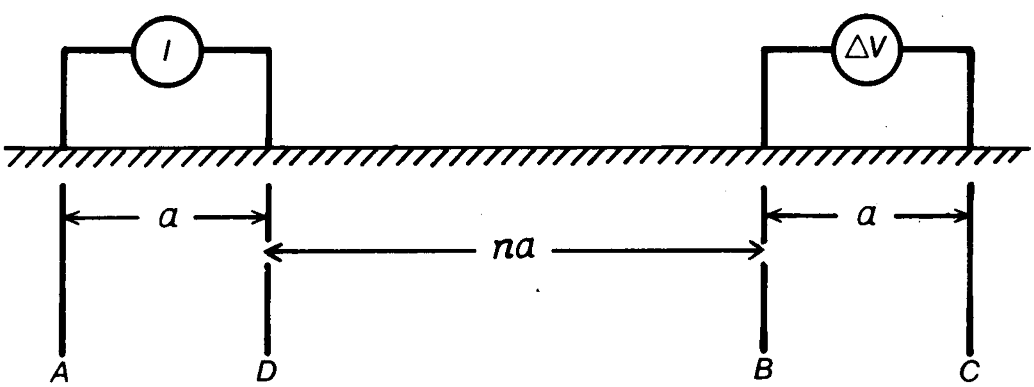
Inductive coupling between potential and current cables is reduced with this arrangement. This method was primarily used throughout all study areas because of reliability and ease of field operation. A diagram of this method is depicted in Figures 26 and Figure 27.

With reference to Figure 26 and 27, 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).



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

Figure 27. Schlumberger array (from J. Combs, 1980).



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

Figure 28. Dipole-dipole array (from J. Combs, 1980).

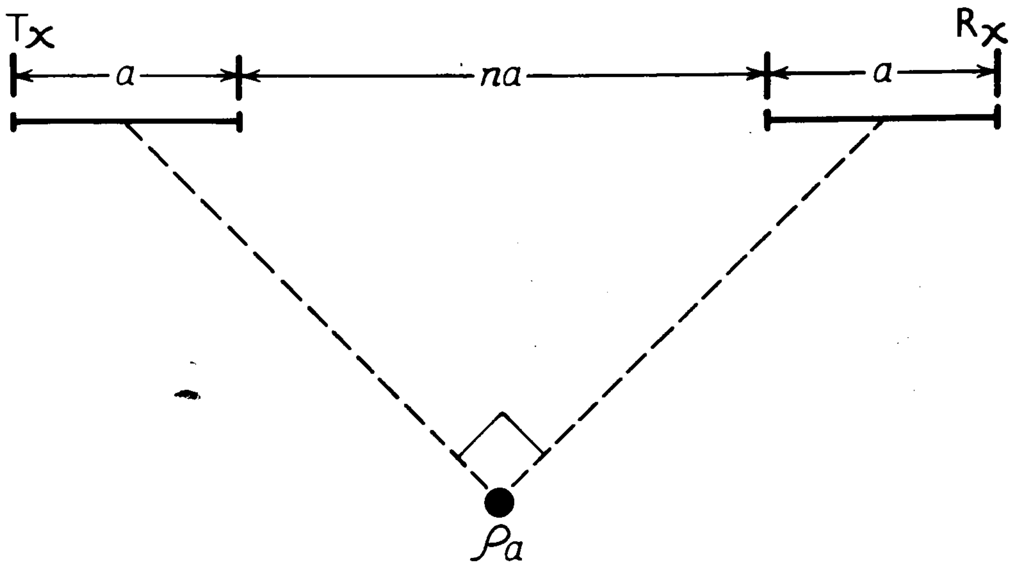


Figure 29. Data plotting scheme for dipole-dipole array (from J. Combs, 1980).

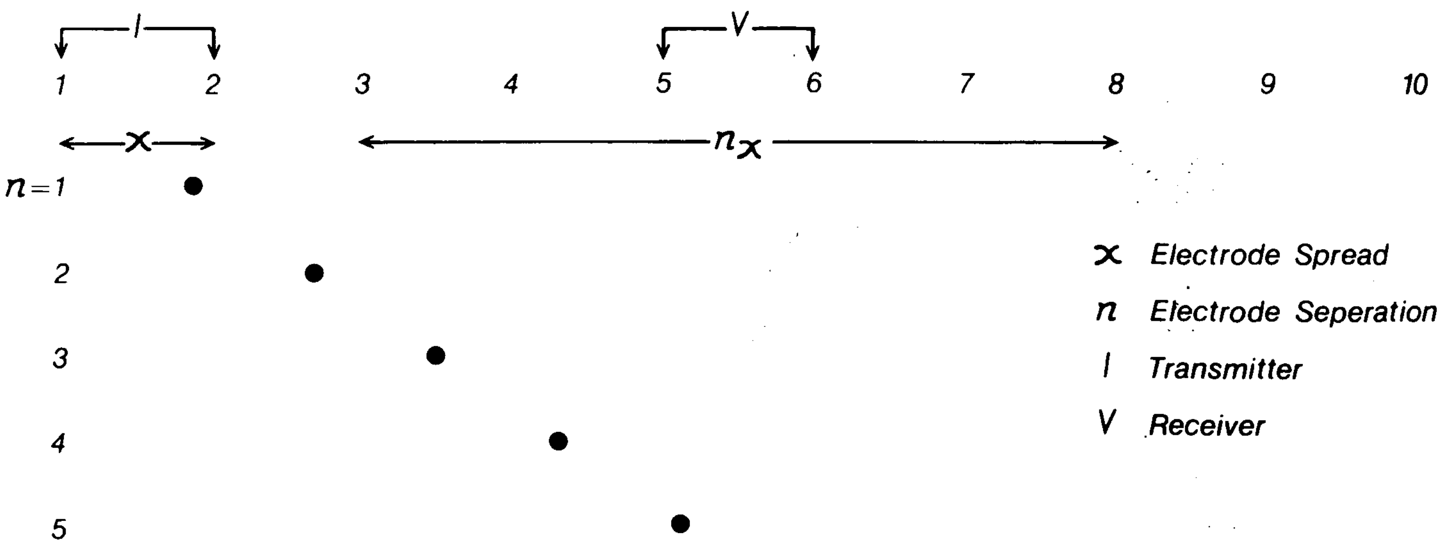


Figure 30. Typical dipole-dipole array (from J. Combs, 1980).

APPENDIX E. RESISTIVITY CALCULATIONS

TABLE 8. LINE A.

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Hartsel, Colo.	Line A	20 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
4-5							
6-7	10	.01	66	4.29	0.429	574	246.7
7-8	10	.01	66	0.84	0.084	2298	193.1
8-9	1	.01	66	2.28	0.0228	5745	131.0
9-10	1	.01	66	0.81	0.0081	11490	93.0
10-11	1	.01	66	0.38	0.00380	20108	76
11-12	1	.001	225	1.83	0.00183	32173	59
5-6							
7-8	10	.01	133	3.66	0.366	574	210.5
8-9	1	.01	133	6.10	0.061	2298	140.2
9-10	1	.01	66	1.45	0.0145	5745	83.3
10-11	1	.01	66	0.48	0.0048	11490	55
11-12	1	.01	66	0.23	0.0023	20108	46
12-13	1	.01	66		-- N.R. --		
6-7							
8-9	10	.01	66	3.73	0.373	574	214.5
9-10	1	.01	100	5.28		2298	121.3
10-11	1	.01	100	1.16		5745	66.6
11-12	1	.01	100	0.30		11490	34
12-13		.01	100				22.1
13-14	1	.01		0.05			16.0
7-8							
9-10	10	.01	66	3.03	0.303	574	174.2
10-11	1	.01	66	3.35	0.0335	2298	77
11-12	1	.001	133	6.30	0.0063	5745	36
12-13	1	.001	133	3.00	0.0030	11490	34
13-14	1	.001	133	1.56	0.00156	20108	31
14-15	1	.001	133	1.06	0.00106	32173	34

TABLE 8: LINE A (CONT.)

Sta.	Range	MA	Voltage	V_P	DV/I	G.F.	P_a
8-9							
10-11	10	.01	66	4.25	0.425	574	244.4
11-12	1	.01	66	2.67	.0267	2298	61.4
12-13	10	.001	133	1.00	.001	5745	60
13-14	1	.001	133	3.41	.00341	11490	39
14-15	1	.001	133	1.84	.00184	20108	37
15-16	1	.001	133	1.41	.00141	32173	45
9-10							
11-12	10	.01	66	2.04	.204	574	117.3
12-13	1	.01	66	3.56	.0356	2298	868
13-14	1	.001	200	7.54	.00754	5745	43
14-15	1	.001	200	3.45	.00345	11490	40
15-16	1	.001	200	2.43	.00243	20108	49
16-17	1	.001	200	0.90	.00090	32173	29
10-11							
13-14	1	.01	66	2.13	0.0213	574	12.2
14-15	1	.01	66	0.76	0.0076	2298	17.5
15-16	1	.001	200	4.46	0.00446	5745	25.6
16-17	1	.001	200	1.63	0.00163	11490	19
17-18	1	.001	200	1.84	0.00184	20108	37
18-19	1	.001	200	1.32	0.00132	32173	43
11-12							
13-14	10	.001	133	1.28	.0128	574	7.4
14-15	1	.001	133	2.74	0.00274	2298	6.3
15-16	1	.001	133	1.71	0.00171	5745	9.8
16-17	1	.001	133	0.80	0.00080	11490	9.2
17-18	1	.001	133	1.05	0.00105	20108	21
18-19	1	.001	133	0.94	0.00094	32173	30
12-13							
14-15	10	.01	66	1.15	0.115	574	66.1
15-16	1	.01	66	4.21	0.0421	2298	96.8
16-17	1	.01	66	1.09	0.0109	5745	62.6
17-18	1	.01	66	1.09	0.0109	11490	125
18-19	1	.01	66	0.58	0.00609	20108	122
19-20	10	.001	200	0.41	0.0041	32173	132
13-14							
15-16	10	.01	66	1.40	0.140	574	80.5
16-17	1	.01	66	2.19	0.0219	2298	50.3
17-18	1	.01	66	1.20	0.0120	5745	68.9
18-19	1	.01	66	1.00	0.010	11490	115
19-20	10	.001	433	0.65	0.0065	20108	131
20-21	10	.001	433	0.33	0.0033	32173	106

TABLE 8. LINE A (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
14-15							
16-17	10	.01	66	1.03	0.103	574	59.2
17-18	1	.01	66	5.18	0.0518	2298	119.1
18-19	1	.01	66	1.80	0.018	5745	103.5
19-20	10	.001	400	1.34	0.0134	11490	154
20-21	1	.001	400	6.50	0.0065	20108	131
21-22	1	.001	366	3.05	0.00305	32173	98
15-16							
17-18	10	.01	66	2.08	0.208	574	119.6
18-19	1	.01	66	6.00	0.060	2298	137.9
19-20	10	.01	66	0.32	0.0320	5745	183.9
20-21	10	.001	225	1.25	0.0125	11490	144
21-22	1	.001	250	5.38	0.00538	20108	108
22-23	1	.001	225	4.30	0.00430	32173	138
16-17							
18-19	10	.01	66	1.76	0.176	574	101.2
19-20	1	.01	66	5.90	0.0590	2298	135.6
20-21	1	.01	66	1.80	0.0180	5745	103.5
21-22	10	.001	166	0.67	0.0067	11490	77
22-23	10	.001	166	0.40	0.0040	20108	80
23-24	1	.001	166	2.05	0.00205	32173	66
17-18							
19-20	10	.01	66	5.70	0.570	574	327.8
20-21	10	.01	66	1.08	0.108	2298	248.3
21-22	1	.01	66	2.85	0.0285	5745	163.8
22-23	10	.001	133	1.42	0.0142	11490	163
23-24	10	.001	133	0.61	0.0061	20108	123
24-25	10	.001	133	0.45	0.0045	32173	145
18-19							
20-21	10	.01	66	7.40	0.740	574	425.5
21-22	10	.01	66	1.20	0.120	2298	275.9
23-22	10	.01	66	0.40	0.040	5745	229.9
24-23	10	.001	250	1.50	0.0150	11490	173
25-24	10	.001	250	0.95	0.0095	20108	191
26-25	10	.001	250	0.75	0.0075	32173	241
19-20							
21-22	10	.01	66	9.60	.960	574	552
22-23	10	.01	66	2.03	0.203	2298	466.7
23-24	1	.01	66	5.25	0.0525	5745	301.7
24-25	10	.001	2.50	3.00	0.030	11490	345
25-26	10	.001	250	1.94	0.0194	20108	390
26-27	1	.001	25	6.50	0.0065	32173	209

TABLE 8. LINE A (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
20-21							
22-23	10	.01	66	9.58	0.9586	574	550.8
23-24	10	.01	66	1.85	0.185	2298	425.3
24-25	10	.01	66	0.81	0.081	5745	465.6
25-26	10	.001	166	4.65	0.0465	11490	534
26-27	10	.001	166.	1.49	0.0149	20108	300
27-28	1	.001	166	7.71	0.00771	32173	248
21-22							
23-24	10	.01	66	5.50	.550	574	316.3
24-25	10	.01	66	1.85	0.185	2298	425.3
25-26	1	.01	66	8.10	0.081	5745	104.0
26-27	10	.001	166	2.51	0.0251	11490	288
27-28	10	.001	166	1.21	0.0121	20108	244
28-29	1	.001	166	8.60	0.0086	32173	277
22-23							
24-25	10	.01	66	8.70	0.870	574	500.3
25-26	10	.01	66	2.44	0.244	2298	560.9
26-27	1	.01	66	6.20	0.0620	5745	356.3
27-28	10	.001	275	2.92	0.0292	11490	336
28-29	10	.001	275	1.86	0.0186	20108	374
29-30	1	.001	275	8.20	0.0082	32173	264
23-24							
25-26	10	.01	6	9.50	0.950	574	546.3
26-27	10	.01	6	1.58	0.1584	2298	363.2
27-28	1	.01	6	6.58	0.0658	5745	378.2
28-29	10	.001	333	4.98	0.0498	11490	322
29-30	10	.001	333	1.60	0.0160	20108	322
30-31	1	.001	333	7.50	0.0075	32173	241
24-25							
26-27	10	.01	6	5.35	0.535	574	307.6
27-28	10	.01	6	1.75	0.175	2298	402.3
28-29	1	.01	6	8.64	0.0864	5745	496.5
29-30	10	.001	225	3.52	0.0352	11490	405
30-31	10	.001	225	1.54	0.0154	20108	310
31-32	10	.001	225	1.46	0.0146	32173	470
25-26							
27-28	10	.01	100	8.02	0.802	574	461.2
28-29	10	.01	100	2.90	0.290	2298	666.7
29-30	10	.01	100	1.03	0.103	5745	592.0
30-31	10	.001	366	4.10	0.0410	11490	471
31-32	10	.001	366	3.56	0.03568	20108	716
32-33	10	.001	366	2.48	0.0248	32173	798

TABLE 8. LINE A (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
26-27							
28-29	10	.01	100	7.88	0.788	574	453.1
29-30	10	.01	100	1.91	0.191	2298	439.1
30-31	1	.01	100	6.61	0.0661	5745	379.9
31-32	1	.01	100	4.92	0.0492	11490	565
32-33	10	.001	466	3.33	0.0333	20108	670
33-34		.01	66		-- N.R. --		
27-28							
29-30	10	.01	66	5.82	0.582	574	334.7
30-31	10	.01	66	1.53	0.153	2298	351.7
31-32	10	.01	66	0.94	0.094	5745	540.2
32-33	1	.01	6	5.45	0.0545	11490	626
33-34	10	.001	225	1.91	0.0191	20108	384
34-35	10	.001	225	2.65	0.0265	32173	853
28-29							
30-31	10	.01	66	5.16	0.516	574	296.7
31-32	10	.01	66	2.34	0.234	2298	537.9
32-33	10	.01	66	1.23	0.123	5745	706
33-34	1	.01	66	3.84	0.0384	11490	441
34-35	1	.01	6	4.63	0.0463	20108	931
29-30							
31-32	10	.01	66	4.42	0.442	574	254.2
32-33	10	.01	66	1.83	0.183	2298	420.7
33-34	1	.01	66	5.28	0.0528	5745	303.4
34-35	1	.01	66	5.10	0.0510	11490	586
30-31							
32-33	10	.01	66	4.49	0.449	574	258.2
33-34	10	.01	66	0.95	0.095	2298	218.4
34-35	10	.01	66	0.68	.068	5745	390.8
31-32							
33-34	10	.01	66	6.82	0.682	574	392.2
34-35	10	.01	66	2.31	0.231	2298	531.1
32-33							
34-35	10	.01	66	4.42	0.442	574	254.2

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

TABLE 9. LINE B

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Hartsel, Colo.	Line B	24 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
8-7							
6-5	10	.01	66	1.14	0.114	574	65.5
5-4	1	.01	66	2.75	.0275	2298	63
4-3	1	.01	66	0.70	.0070	5745	40
3-2	1	.001	250	3.70	.00370	11490	42.5
2-1	1	.001	250	1.68	.00168	20108	33.8
7-6							
5-4	10	.01	66	1.14	.114	574	65.6
4-3	1	.01	66	2.53	.0253	2298	58.2
3-2	10	.01	133	6.10	0.061	5745	140.2
2-1	1	.001	166	3.80		11490	43.7
6-5							
4-3	1	.01	66	8.65	.0865	574	49.7
3-2	1	.01	66	2.18	.0218	2298	50.8
2-1	1	.01	66	0.82	.0082	5745	47.1
5-4							
3-2	10	.01	66	0.93	.093	574	53.5
2-1	1	.01	66	2.18	.0218	2298	50.1
4-3							
2-1	10	.01	66	0.92	.098	574	53
11-10							
9-8	1	.01	66	0.82	0.082	574	47.2
8-7	1	.01	66	1.75	.0175	2298	40.2
7-6	1	.001	166	6.81	.00681	5745	39.1
6-5	1	.001	166	2.60	0.0026	11490	29.8
5-4	1	.001	166	1.55	0.00155	20108	31.2

TABLE 9. LINE B (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
10-9							
8-7	1	.01	66	9.50	0.095	574	54.6
7-6	1	.01	66	2.29	.0229	2298	52.6
6-5	1	.01	66	0.78	.0078	5745	44.8
5-4	1	.001	133	3.38		11490	38.8
4-3	1	.001	133	1.54		20108	31
9-8							
7-6	10	.01	66	1.25	.125	574	71.9
6-5	1	.01	66	2.60	.0260	2298	59.7
5-4	10	.001	200	1.00	0.010	5745	57.5
4-3	1	.001	200	4.00		11490	45.9
3-2	1	.001	200	1.86		20108	37.4
13-14							
12-11	1	.01	66	1.30	0.013	574	7
11-10	1	.001	66	0.29	0.00327	2298	8
10-9	1	.001	66	1.36	0.00136	5745	7.8
9-8	1	.001	66	0.91	0.00091	11490	10.5
8-7	1	.001	66	0.68		20108	14
13-12							
11-10	1	.01	66	2.81	.0281	574	16.2
10-9	1	.01	66	0.55	0.0055	2298	13
9-8	1	.01	133	2.80	0.0028	5745	16.1
8-7	10	.001	133	0.13		11490	14.9
7-6	1	.001	133	0.78		20108	15.7
12-11							
10-9	1	.01	66	4.77	.0477	574	27.4
9-8	1	.01	66	1.18	0.0118	2298	27
8-7	1	.001	250	4.36	0.00436	5745	25
7-6	1	.001	250	1.90		11490	21.8
6-5	1	.001	250	0.91		20108	10.5

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

TABLE 10. LINE C

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Hartsel, Colo.	Line C	25 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
2-3							
4-5	10	.01	66	4.88	0.488	574	280.6
5-6	10	.01	66	2.29	0.229	2298	526.5
6-7	10	.01	66	1.75	0.175	5745	1005.7
7-8	10	.01	66	1.05	0.105	11490	1207
8-9	1	.01	66	4.18	0.0418	20108	840
9-10	1	.01	66	3.38		32173	1088
3-4							
5-6	10	.01	66	4.95	0.495	574	284.6
6-7	10	.01	66	2.32	0.232	2298	533.4
7-8	10	.01	6	1.43	0.143	5745	821.8
8-9	1	.01	66	5.18	0.0518	11490	595
9-10	1	.01	66	3.88	0.0388	20108	780
10-11	1	.01	66	4.11	0.0411	32173	1322
4-5							
6-7	10	.01	66	3.97	0.397	574	228.3
7-8	10	.01	66	2.04	0.204	2298	469.0
8-9	1	.01	66	5.68	0.0568	5745	326.4
9-10	1	.01	66	3.80	0.0380	11490	437
10-11	10	.001	66	3.92	0.0392	20108	788
11-12	1	.001	66	6.10	0.00610	32173	196
5-6							
7-8	100	.01	66	0.68	0.680	574	391
8-9	10	.01	66	1.13	0.113	2298	259.8
9-10	1	.01	66	6.06	0.0606	5745	348.3
10-11	10	.001	66	5.84	0.0584	11490	671
11-12	1	.001	6	9.62	0.00962	20108	193
12-13	10	.001	6	0.73	0.0073	32173	235

TABLE 10. LINE C (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
6-7							
8-9	10	.01	66	2.96	0.296	574	170.2
9-10	10	.01	66	1.07	0.107	2298	246.0
10-11	10	.01	66	0.93	0.093	5745	534.5
11-12	10	.001	66	3.47	0.0347	11490	399
12-13	10	.001	66	1.12	0.0112	20108	225
13-14	1	.001	66	5.50	0.0055	32173	177
7-8							
9-10	10	.01	66	2.74	.274	574	157.5
10-11	100	.001	66	1.55	.155	2298	356.3
11-12	10	.001	66	3.62	.0362	5745	208.0
12-13	10	.001	66	1.56	.0156	11490	179
13-14	10	.001	66	0.73	.0073	20108	147
8-9							
10-11	10	.01	66	3.16	0.316	574	181.7
11-12	10	.01	66	0.87	0.087	2298	200
12-13	1	.01	66	1.78	0.0178	5745	102.3
13-14	1	.01	66	0.72	0.0072	11490	83
9-10							
11-12	10	.01	6	1.84	.184	574	105.8
12-13	1	.01	66	4.48	.0448	2298	103.0
13-14	1	.01	66	1.45	.0145	5745	83.3
10-11							
12-13	10	.01	66	1.73	0.173	574	99.5
13-14	10	.001	225	2.90	0.0290	2298	66.7
11-12							
13-14	10	.01	66	0.65	0.065	574	37.4

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

TABLE 11. LINE D

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Hartsel, Colo.	Line D	24 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							
3-4	100	.01	66	1.61	1.61	574	925.8
4-5	10	.01	66	3.60	0.360	2298	827.6
5-6	1	.01	66	1.32	0.0132	5745	75.9
6-7	10	.001	400	2.10	0.0210	11490	241
7-8	10	.001	400	0.85	0.0085	20108	171
8-9	1	.001	400	4.90	0.0049	32173	158
2-3							
4-5	100	.01	66	1.82	1.82	574	1046.5
5-6	1	.01	66	0.30	0.0030	2298	6.9
6-7	10	.001	333	5.82	0.0582	5745	334.5
7-8	10	.001	333	2.09	0.0209	11490	240
8-9	10	.001	333	1.12	0.0112	20108	225
9-10	1	.001	333	5.88	0.00588	32173	189
3-4							
5-6	1	.01	66	4.52	0.0452	574	26.0
6-7	10	.01	66	2.09	0.209	2298	480.5
7-8	1	.01	66	5.50	0.0550	5745	316.1
8-9	1	.01	66	2.91	0.0291	11490	334
9-10	10	.001	300	1.31	0.0131	20108	263
10-11			-- N.R. --				
4-5							
6-7	10	.01	66	2.76	0.276	574	158.7
7-8	10	.01	66	1.77	0.177	2298	406.9
8-9	10	.01	66	0.62	0.062	5745	356.3
9-10	10	.001	200	1.84	0.0184	11490	211
10-11	1	.001	200	6.62	0.00662	20108	133
11-12		.001	200		-- N.R. --	32173	
5-6							
7-8	100	.01	66	1.33	1.33	574	764.8
8-9	10	.01	66	3.65	0.365	2298	839.1
9-10	10	.01	66	1.12	0.112	5745	643.7
10-11	10	.001	100	1.88	0.0188	11490	216
11-12	10	.001	100	1.08	0.0108	20108	217
12-13	10	.001	100	0.43	0.0043	32173	138

TABLE 11. LINE D (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
6-7							
8-9	100	.01	66	1.58	1.58	574	908.5
9-10	10	.01	66	3.72	0.372	2298	855.2
10-11	1	.01	66	3.21	0.0321	5745	184.5
11-12	10	.001	250	1.66	0.0166	11490	191
12-13	1	.001	250	6.15	0.00615	20108	124
13-14	1	.001	250	2.25	0.00225	32173	72.4
7-8							
9-10	100	.01	66	2.21	2.21	574	1270.8
10-11	10	.01	66	1.40	0.140	2298	321.9
11-12	10	.001	250	4.38	0.0438	5745	251.7
12-13	10	.001	250	1.44	0.0144	11490	166
13-14	1	.001	250	5.50	0.0055	20108	110
8-9							
10-11	10	.01	66	8.60	.0860	574	494.5
11-12	10	.01	66	2.16	0.216	2298	496.6
12-13	10	.001	400	6.30	0.0630	5745	362.1
13-14	10	.001	400	2.00	0.0200	11490	230
9-10							
11-12	100	.01	66	1.15	1.15	574	661.3
12-13	10	.01	66	2.08	0.208	2298	478.2
13-14	1	.01	66	5.73	.0573	5745	329.3
10-11							
12-13	100	.01	66	1.31	1.31	574	753.3
13-14	10	.01	66	2.21	0.221	2298	508.1
11-12							
13-14	100	.01	66	1.95	1.95	574	1121.3
C1-2							
3-4	100	.01	66	2.89	2.89	574.67	1660.8
4-5	100	.01		.67	.67	2298.67	1540.11
5-6	10	.01		1.88	.188	5746.7	1080.38
6-7	100	.001	500	.52	.052	11493.4	597.66
7-8	10	.001	466	1.72	.0172	20113.45	345.95
8-9	10	.001		.77	.0077	32181.52	247.80
C2-3							
4-5	1000	.01	66	.45	4.50	574.67	2586.02
5-6	100	.01		.85	.85	2298.67	1953.87
6-7	10	.01		1.69	.169	5746.7	971.19
7-8	100	.001	400	.52	.052	11493.4	597.66
8-9	10	.001	400	1.88	.0188	20113.45	378.13
9-10	10	.001		.54	.0054	32181.52	173.78

TABLE 11. LINE D. EXTENSION (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C3-4							
5-6	1000	.01	66	.51	5.10	574.67	2930.82
6-7	100	.01		.67	.67	2298.67	1540.11
7-8	10	.01		1.53	.153	5746.7	879.25
8-9	100	.001	275	.53	.053	11493.4	609.15
9-10	10	.001		1.25	.0125	20113.45	251.42
10-11	10	.001		.69	.0069	32181.52	222.05
C4-5							
6-7	100	.01	66	3.83	3.83	574.67	2200.99
7-8	100	.01	66	.60	.60	2298.67	1379.20
8-9	100	.001	300	1.57	.157	5746.7	902.23
9-10	10	.001	300	3.38	.0338	11493.4	388.48
10-11	10	.001	300	1.54	.0154	20113.45	309.75
11-12	10	.001		.65	.0065	32181.52	209.18
C5-6							
7-8	1000	.01	66	.39	3.90	574.67	2241.21
8-9	100	.01		.67	.67	2298.67	1540.11
9-10	10	.01		1.19	.119	5746.7	683.86
10-11	100	.001	250	.51	.051	11493.4	586.16
11-12	10	.001		1.88	.0188	20113.45	378.13
12-13	10	.001		1.03	.0103	32181.52	331.47
C6-7							
8-9	1000	.01	66	.46	4.60	574.67	2643.48
9-10	100	.01		.58	.58	2298.67	1333.23
10-11	100	.001	250	1.91	.191	5746.7	1097.62
11-12	100	.001	250	.63	.063	11493.4	724.08
12-13	10	.001	250	3.11	.0311	20113.45	625.53
13-14	10	.001		1.66	.0166	32181.52	534.21
C7-8							
9-10	100	.01	66	2.95	2.95	574.67	1695.28
10-11	100	.01		.68	.68	2298.67	1563.10
11-12	10	.01		1.80	.180	5746.7	1034.41
12-13	100	.001	300	.85	.085	11493.4	976.94
13-14	100	.001		.44	.044	20113.45	884.99
14-15	10	.001		1.65	.0165	32181.52	531.00
C8-9							
10-11	1000	.01	66	.45	4.50	574.67	2586.02
11-12	100	.01		.74	.74	2298.67	1701.02
12-13	10	.01	66	2.72	.272	5746.7	1563.10
13-14	100	.001	333	1.19	.119	11493.4	1367.71
14-15	100	.001	333	.44	.044	20113.45	884.99
15-16	10	.001		1.85	.0185	32181.52	595.36

TABLE 11. LINE D EXTENSION (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C9-10							
11-12	1000	.01	66	.50	5.0	574.67	2873.35
12-13	100	.01		1.00	1.00	2298.67	2298.67
13-14	10	.01		3.07	.307	5746.7	1764.24
14-15	10	.01		.94	.094	11493.4	1080.38
15-16	10	.001	333	3.60	.036	20113.45	724.08
16-17	10	.001		1.37	.0137	32181.52	440.89
C10-11							
12-13	100	.1	33	1.00	10.00	574.67	5746.7
13-14	100	.01	66	1.73	1.73	2298.67	3976.70
14-15	100	.01		.43	.430	5746.7	2471.08
15-16	100	.001	400	1.24	.124	11493.4	1425.18
16-17	100	.001	400	.42	.042	20113.45	844.76
17-18	10	.001		1.24	.0124	32181.52	399.05
C11-12							
13-14	100	.1	33	.99	9.9	574.67	5689.23
14-15	10	.1		1.57	1.57	2298.67	3608.91
15-16	100	.01	66	.40	.40	5746.7	2298.68
16-17	100	.001	300	1.07	.107	11493.4	1229.79
17-18	10	.001		2.83	.0283	20113.45	569.21
18-19	10	.001		1.35	.0135	32181.52	434.45
C12-13							
14-15	1000	.01	66	.87	8.7	574.53	4998.45
15-16	100	.01		1.40	1.40	2298.14	3217.39
16-17	10	.01		3.11	.311	5745.34	1796.80
17-18	10	.01		.67	.067	11490.69	769.88
18-19	10	.001	300	3.06	.0306	20108.71	615.33
19-20	10	.001	300	1.23	.0123	32173.93	395.74
C13-14							
15-16	1000	.01	66	.83	8.30	574.53	4768.64
16-17	100	.01		1.39	1.39	2298.14	4194.41
17-18	10	.01	100	2.43	.243	5745.34	1396.12
18-19	10	.01	100	.96	.096	11490.69	1103.11
19-20	10	.001	500	3.55	.03558	20108.71	713.86
20-21	10	.001		1.73	.0173	32173.93	556.61
C14-15							
16-17	1000	.01	66	.68	6.80	574.53	3906.83
17-18	100	.01	66	.85	.85	2298.14	1953.42
18-19	10	.01		2.91	.291	5745.34	1671.90
19-20	10	.01	100	.89	.089	11490.69	1022.67
20-21	10	.01		.37	.037	20108.71	744.02
21-22	10	.001	366	1.33	.0133	32173.93	427.91

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C15-16							
17-18	1000	.01	66	.43	4.3	574.53	2470.50
18-19	100	.01		1.21	1.21	2298.14	2780.75
19-20	10	.01		3.20	.320	5745.34	1838.51
20-21	100	.001	250	1.13	.113	11490.69	701.79
21-22	10	.001	250	3.49	.0349	20108.71	701.79
22-23	10	.001		1.33	.0133	32173.93	427.91
C16-17							
18-19	1000	.01	66	.39	3.90	574.53	2240.68
19-20	100	.01		.85	.85	2298.14	1953.42
20-21	10	.01		2.63	.263	5745.34	1511.03
21-22	10	.01		.69	.069	11490.69	792.86
22-23	10	.001	333	2.32	.0232	20108.71	466.52
23-24	10	.001		1.10	.0110	32173.93	353.91
C17-18							
19-20	1000	.01	66	.42	4.20	574.53	2413.04
20-21	100	.01		1.06	1.06	2298.14	2436.03
21-22	10	.01	100	2.58	.258	5745.34	1482.30
22-23	10	.01	100	.73	.073	11490.69	838.82
23-24	10	.001	433	3.01	.0301	20108.71	605.27
24-25	10	.001		1.35	.0135	32173.93	434.35
C18-19							
20-21	1000	.01	66	.39	3.90	574.53	2240.68
21-22	100	.01		.78	.78	2298.14	1792.55
22-23	10	.01	66	2.00	.200	5745.34	1149.07
23-24	10	.01		.73	.073	11490.69	838.82
24-25	10	.001	366	2.93	.0293	20108.71	589.19
C19-20							
21-22	100	.01	66	3.62	3.62	574.53	2079.81
22-23	100	.01		.73	.73	2298.14	1677.64
23-24	10	.01		2.31	.231	5745.34	1327.17
24-25	100	.001	366	.81	.081	11490.69	930.75
C20-21							
22-23	100	.01	66	2.60	2.60	574.53	1493.73
23-24	100	.01		.68	.68	2298.14	1562.73
24-25	10	.01		2.17	.217	5745.34	1246.74
C21-22							
23-24	100	.01	66	2.44	2.44	574.53	1401.86
24-25	100	.01		.61	.61	2298.14	1401.86
C22-23							
24-25	100	.01	66	2.34	2.34	574.53	1344.41

LEGEND:

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

TABLE 12. LINE E.

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Hartsel, Colo.	Line E	25 June 1981
CHIEF OPERATOR	ASSISTANTS	METHOD
Robert Fargo	Memmi and Strong	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
10-11							
12-13	10	.01	66	1.25	0.125	574	71.9
13-14	1	.01	66	0.85	0.0085	2298	19.5
14-15	1	.01	66	0.59	0.0059	5746	34.0
15-16	1	.01	66	0.19	0.0019	11493	22
11-12							
13-14	10	.01	66	0.83	0.083	574	47.7
14-15	1	.01	66	1.40	0.0140	2298	32.2
15-16	1	.001	66	6.50	0.0065	5746	37.4
16-17	1	.001	66	2.81	0.00281	11493	32.3
12-13							
14-15	1	.01	66	7.89	0.0789	574	45.4
15-16	1	.01	66	1.63	0.0163	2298	37.5
16-17	1	.001	66	6.48	0.00648	5746	37.3
17-18	1	.001	66	2.25	0.00225	11493	25.8
13-14							
15-16	1	.01	66	4.18	.0418	574	24.0
16-17	10	.001	66	1.12	0.0112	2298	25.7
17-18	1	.001	66	3.03	0.00303	5746	17.4
18-19	1	.001	66	1.58	0.00158	11493	18.2
14-15							
16-17	1	.01	66	3.04	0.0304	574	17.5
17-18	1	.001	66	6.60	0.0066	2298	15.2
18-19	1	.001	66	2.77	0.00277	5745	15.9
19-20	1	.001	66	1.04	0.00104	11490	11.9
15-16							
17-18	10	.001	66	0.66	.0066	574	3.8
18-19	10	.001	66	1.94	0.0194	2298	44.6
19-20	1	.001	66	6.55	0.00655	5745	37.6
20-21	1	.001	66	3.85	0.00385	11490	44.2

TABLE 12. LINE E (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
16-17							
18-19	10	.01	66	0.75	0.075	574	43.1
19-20	1	.01	66	1.41	0.0141	2298	32.4
20-21	1	.001	66	5.70	0.00570	5745	32.8
21-22	1	.001	66	3.82	0.00382	11490	43.9
17-18							
19-20	10	.001	66	5.83	.05	574	28.8
20-21	10	.001	66	1.12	0.0112	2298	25.7
21-22	1	.001	66	5.34	0.00534	5745	30.7
18-19							
20-21	1	.01	66	5.52	.0552	574	31.7
21-22	1	.01	66	1.38	.0138	2298	31.7
19-20							
21-22	100	.001	66	0.63	.063	574	362.2

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

TABLE 13. LINE F.

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Hartsel, Colo.	Line F	25 June 1980
CHIEF OPERATOR	ASSISTANTS	METHOD
Robert Fargo	Memmi and Strong	Dipole-Dipole (Nx150')

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
0-1							
2-3	10	.01	66	6.09	0.609	862	524.9
3-4	10	.01	66	1.56	0.156	3448	537.9
4-5	1	.01	66	6.52	0.0652	8620	562.0
5-6	1	.01	66	3.78	0.0378	17240	652
6-7	10	.001	333	2.80	0.0280	30170	845
1-2							
3-4	10	.01	100	8.20	0.820	862	706.8
4-5	10	.01	100	2.41	0.241	3448	830.9
5-6	10	.01	100	1.18	0.118	8620	1017
6-7	1	.01	100	7.50	0.07	17240	1293
7-8	1	.01	100	1.67	0.0167	30170	504
2-3							
4-5	10	.01	100	7.08	0.708	862	610.3
5-6	10	.01	100	2.28	0.228	3448	786.1
6-7	10	.01	100	1.15	0.115	8620	991.3
7-8	1	.01	1 0	2.21	0.0221	17240	381
8-9	1	.01	100	1.20		30170	362
3-4							
5-6	1	.01	66	1.40	0.140	574	80.5
6-7	10	.01	66	3.01	0.301	3448	1037.8
7-8	10	.001	166	5.45	0.0545	8620	469.8
8-9	1	.01	66	2.99	0.0299	17240	515
9-10	10	.001	166	2.15	0.0215	30170	648
4-5							
6-7	100	.01	66	1.00	1.00	862	862
7-8	10	.01	66	1.30	0.130	3448	448.3
8-9	1	.01	66	6.10	0.0610	8620	525.8
9-10	10	.001	100	3.98	0.0398	17240	686
10-11	10	.001	1 0	2.11	0.0211	30170	637

TABLE 13. LINE F (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
5-6							
7-8	10	.01	100	6.40	.640	862	551.7
8-9	10	.01	100	2.40	.240	3448	827.5
9-10	100	.001	400	1.34	.134	8620	1155.1
10-11	10	.001	400	6.86	0.0686	17240	1182
11-12	10	.001	400	2.90	0.0290	30170	875
6-7							
8-9	100	.01	100	1.05	1.05	862	905.1
9-10	10	.01	100	4.58	0.458	3448	1579.2
10-11	10	.01	100	2.00	0.200	8620	1724
11-12	1	.01	100	7.80	0.078	17240	1344
7-8							
9-10	10	.01	100	9.00	.900	862	775.8
10-11	10	.01	100	3.09	0.309	3448	1065.4
11-12	10	.01	100	1.16	0.116	8620	999.9
8-9							
10-11	100	.01	66	1.52	1.52	862	1310.2
11-12	10	.01	66	4.18	0.418	3448	1441.3
9-10							
11-12	100	.01	66	2.73	2.73	862	2353.3

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

TABLE 14. LINE G

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Hartsel, Colo.	Line G	6 June 1981
CHIEF OPERATOR	ASSISTANTS	METHOD
Robert Fargo	Memmi and Strong	Dipole-Dipole (Nx200')

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C1-3							
5-7	100	1000	100	1.02	.102	1149.07	117.21
7-9	10	1000		2.26	.0226	4596.28	103.88
9-11	10	1000		1.02	.0102	11490.69	117.21
11-13	10	.00031	200	1.24	.00384	22981.38	88.25
13-15	10	.00031		.77	.00254	40217.41	102.15
C3-5							
7-9	100	.00031	100	1.94	.0611	1149.07	70.21
9-11	100	.00031	100	.65	.0202	4596.28	92.84
11-13	10	.00031	100	2.06	.0064	11490.69	73.54
13-15	10	.00031	100	1.27	.00394	22981.38	90.55
15-17	10	.00031	133	.94	.0029	40217.41	116.63
C5-7							
9-11	100	.001	66	.47	.047	1149.07	54.01
11-13	10	.001		1.02	.0102	4596.28	46.88
13-15	10	.00031	133	1.81	.00561	11490.69	64.46
15-17	10	.00031		1.34	.00415	22981.38	95.37
17-19	10	.00031		.77	.00239	40217.41	96.12
C7-9							
11-13	100	.001	66	.40	.040	1149.07	45.96
13-15	100	.00031	166	.44	.0136	4596.28	62.51
15-17	10	.00031	166	2.30	.00713	11490.69	81.93
17-19	10	.00031	166	1.21	.00375	22981.38	86.18
19-21	10	.00031	166	.69	.00214	40217.41	86.07
C9-11							
13-15	100	.001	66	.44	.044	1149.07	50.56
15-17	10	.001	100	1.63	.0163	4596.28	74.92
17-19	10	.00031	200	2.18	.00676	11490.69	77.68
19-21	10	.00031	200	1.18	.00366	22981.38	84.11
21-23	10	.00031	200	.43	.00133	40217.41	53.49

TABLE 14. LINE G (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C11-13							
15-17	100	.00031	100	.46	.046	1149.07	52.86
17-19	10	.00031	100	1.25	.0125	4596.28	57.45
19-21	10	.00031	166	1.74	.00538	11490.69	61.82
21-23	10	.00031	200	.57	.00177	22981.38	40.68
23-25	10	.00031	200	.34	.00105	40217.41	42.23
C13-15							
17-19	10	.01	66	.70	.070	1149.07	80.43
19-21	10	.001	66	1.90	.0190	4596.28	87.33
21-23	10	.001	66	.50	.0050	11490.69	57.45
23-25	10	.001	66	.25	.0025	22981.38	57.45
25-27		.00031	166	-- N.R. --			
C15-17							
19-21	100	.001	66	.80	.080	1149.07	91.93
21-23	10	.001	66	1.40	.0140	4596.28	64.35
2 -25	10	.001	66	.65	.0065	11490.69	74.69
25-27	10	.00031	166	.95	.00295	22981.38	67.80
27-29	1	.00031	166	5.13	.001590	40217.41	63.95
C17-19							
21-23	100	.00031	66	.44	.044	1149.07	50.56
23-25	10	.00031		1.33	.0133	4596.28	61.13
25-27	10	.00031		.48	.0048	11490.69	55.16
27-29	10	.00031	133	.80	.00248	22981.38	56.99
29-31	10	.00031		.36	.00112	40217.41	45.04
C19-21							
23-25	100	.001	6	.45	.045	1149.07	51.71
25-27	10	.001		1.10	.0110	4596.28	50.56
27-29	10	.00031	100	1.53	.00474	11490.69	54.47
29-31	10	.00031	100	.65	.00202	22981.38	46.42
31-33	1	.00031	100	3.76	.001165	40217.41	46.85
C21-23							
25-27	10	.001	66	2.98	.0298	1149.07	32.24
27-29	10	.001		.75	.0075	4596.28	34.47
29-31	10	.001	100	.25	.0025	11490.69	28.73
31-33	10	.00031		.40		-- N.R. --	
33-35						-- N.R. --	

TABLE 14. LINE G (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C23-25							
27-29	10	.001	100	3.04	.0304	1149.07	34.93
29-31	10	.001	100	.62	.0062	4596.28	28.50
31-33		.001	100			-- N.R. --	
C25-27							
29-31	10	.001	100	2.32	.0232	1149.07	26.66
31-33	10	.001	100	.50	.0050	4596.28	22.98
33-35	10	.001	100	.19	.0019*	11490.69	21.83
C27-29							
31-33	10	.001	100	2.33	.0233	1149.07	26.77
33-35	10	.001	100	.45	.0045	4596.28	20.68
C29-31							
33-35	10	.001	100	1.98	.0198	1149.07	22.75

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

TABLE 15. LINE H

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Hartsel, Colo.	Line H	1 July 1981
CHIEF OPERATOR	ASSISTANTS	METHOD
Robert Fargo	Memmí and Strong	Dipole-Dipole (Nx200')

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C1-3							
5-7	10	.01	66	2.29	.229	1149.33	256.33
7-9	10	.01		.32	.032	4597.32	147.11
9-11	10	.001	166	1.24	.0124	11493.3	142.52
11-13	1	.001		3.58	.00358	22986.6	82.29
13-15	1	.001		3.22	.00322	40226.55	129.52
C3-5							
7-9	10	.01	66	1.40	.140	1149.33	160.91
9-11	10	.001	166	3.98	.0398	4597.32	182.97
11-13	10	.001	166	1.48	.0148	11493.3	170.10
13-15	10	.001	166	.89	.0089	22986.6	204.58
15-17	10	.001		.57	.0057	40226.55	229.29
C5-7							
9-11	1	.001	133	1.12	.00112*	1149.33	1.3*
11-13	10	.001		1.71	.0171	4597.32	78.61
13-15	10	.001		.81	.0081	11493.3	93.09
15-17	10	.001		.57	.0051	22986.6	117.23
17-19			-- N.R. --				
C7-9							
11-13	10	.001	100	3.58	.0358	1149.33	41.15
1 -15	10	.001	100	1.34	.0134	4597.32	61.60
15-17	10	.001	100	.60	.0060	11493.3	68.96
17-19		.001	100			22986.6	-N.R.-
19-21		.001	100			40226.55	-N.R.-
C9-11							
13-15	10	.001	100	5.95	.0595	1149.33	68.39
15-17	10	.001	100	1.65	.0165	4597.32	75.86
17-19	10	.00031	200	2.21	.00663	11493.3	76.20
19-21	10	.00031	200	1.24	.00372	22986.6	85.51
21-23	10	.00031	200	0.68	.00204	40226.55	102.46

TABLE 15. LINE H (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C11-13							
15-17	10	.001	100	4.14	.0414	1149.33	47.58
17-19	10	.001	100	.63	.0063	4597.32	28.96
19-21	1	.001	100	4.85	.00485	11493.3	55.74
21-23	1	.001	100	2.61	.00261	22986.6	59.99
23-25		.001	100			40226.55	-N.R.-
C13-15							
17-19	10	.001	100	2.16	.0216	1149.33	24.83
19-21	10	.001	100	1.11	.0111	4597.32	51.03
21-23	10	.001	100	1.51	.0051	11493.3	58.62
23-25	10	.00031	200	.47	.00141	22986.6	32.41
C15-17							
19-21	100	.00031	200	1.42	.0426	1149.33	48.96
21-23	10	.00031	200	4.70	.0141	4597.32	64.82
23-25	10	.00031	200	1.05	.00315	11493.3	36.20
C17-19							
21-23	100	.00031	200	2.74	.0822	1149.33	94.48
23-25	10	.00031	200	4.55	.01365	4597.32	62.75
C19-21							
23-25	100	.00031	200	1.31	.0393	1149.33	45.17

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

TABLE 16. LINE I.

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Hartsel, Colo.	Line I	1 July 1981
CHIEF OPERATOR	ASSISTANTS	METHOD
Robert Fargo	Memmi and Strong	Dipole-Dipole (Nx200')

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C1-3							
5-7	10	.01	66	1.49	.149	1149.07	171.21
7-9	10	.001	166	1.19	.0119	4596.28	54.70
9-11	10	.001		1.29	.0129	11490.69	148.23
11-13	10	.001		.69	.0069	22981.38	158.57
13-15	10	.001	200	.46	.0046	40217.41	185.00
C3-5							
7-9	100	.001	133	.81	.081	1149.07	93.07
9-11	10	.001	133	2.52	.0252	4596.28	115.83
11-13	10	.001	133	1.20	.0120	11490.69	137.89
13-15		.001	133				-N.R.-
15-17							-N.R.-
C5-7							
9-11	10	.001	133	3.44	.0344	1149.07	39.53
11-13	10	.001		1.00	.0100	4596.28	45.96
13-15	10	.001		.46	.0046	11490.69	52.86
15-17							-N.R.-
17-19							-N.R.-
C7-9							
11-13	100	.001	100	.48	.048	1149.07	55.16
13-15	100	.00031	200	.47	.0146	4596.28	67.11
15-17	10	.00031	200	1.40	.00434	11490.69	49.87
17-19	10	.00031	200	.99	.00307	22981.38	70.55
19-21		.00031	200				-N.R.-
C9-11							
13-15	100	.001	100	.77	.077	1149.07	88.48
15-17	10	.001		1.29	.0129	4596.28	59.29
17-19	10	.00031	200	2.19	.00679	11490.69	78.02
19-21	10	.00031		.94	.00291	22981.38	66.88
21-23		.00031	200				-N.R.-
C11-13							
15-17	100	.001	133	.48	.048	1149.07	55.16
17-19	10	.001	133	1.87	.0187	4596.28	85.95
19-21		.001	133				-N.R.-
21-23		.001	133				-N.R.-
23-25							-N.R.-

TABLE 16. LINE I (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C13-15							
17-19	100	.001	100	.95	.095	1149.07	109.16
19-21	10	.001	100	1.97	.0197	4596.28	90.55
21-23	10	.001	100	.54	.0054	11490.69	62.05
23-25	1	.001	100	2.67	.00267	22981.38	61.36
25-27	1	.001	133	1.14	.00114*	40217.41	45.85
C15-17							
19-21	100	.001	100	.55	.055	1149.07	63.20
21-23	10	.001	100	1.30	.0130	4595.28	59.75
23-25	10	.001	100	.51	.0051	11490.69	58.60
25-27	1	.001	100	2.00	.002*	22981.38	45.96
27-29	1	.001	100	1.10	.0011*	40217.41	44.24
C17-19							
21-23	100	.001	100	.57	.057	1149.07	65.50
23-25	10	.001	100	1.62	.0162	4596.28	74.46
25-27	10	.001	133	.52	.0052	11490.69	59.75
27-29	1	.001	133	2.57	.00251	22981.38	57.68
29-31		.001	133				-N.R.-
C19-21							
23-25	10	.001	100	3.95	.0395	1149.07	45.39
25-27	10	.001		.89	.0089	4596.28	40.91
27-29	10	.00031	200	1.21	.00375	11490.69	43.09
29-31	10			.53	.00164	22981.38	37.6
31-33	1			2.39	.000740	40217.41	29.76
C21-23							
25-27	10	.001	100	1.94	.0194	1149.07	22.29
27-29	10	.00031	200	1.54	.00477	4596.28	21.92
29-31	10	.00031	200	.54	.00167	11490.69	19.19
31-33	1	.00031	200	2.20	.00682	22981.38	15.67
C23-25							
27-29	10	.001	100	1.90	.0190	1149.07	21.83
29-31	10	.00031	166	1.16	.00360	4596.28	16.55
31-33	10	.00031		.34	.00105	11490.69	12.07
C25-27							
29-31	10	.00031	133	4.24	.01315	1149.07	15.11
31-33	10	.00031	133	.75	.00233	4596.28	10.71
C27-29							
31-33	10	.001	66	.97	.0097	1149.07	11.15

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

TABLE 17. LINE: Gradient Array

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Hartsel, Colo.	Gradient Array	7 July 1981
CHIEF OPERATOR	ASSISTANTS	METHOD
Robert Fargo	Memmi and Strong	a = 100' Delta = 1500'

Sta.	Range	MA	Voltage	V_p	DV/I	x/delta d/delta			P_a
NE 1	10	.00031	133	.74	.00229	.07	.30	.75	11.78
2	10	.00031	133	.72	.00223	.07	.23	.83	12.69
3	10	.00031	133	.70	.00218	.07	.17	.88	13.16
4	10	.00031	133	.77	.00239	.07	.1	.93	15.24
5	10	.00031	133	.60	.00186	.07	.03	.96	12.25
6	10	.00031	133	.72	.00223	.07	.03	.96	14.68
7	10	.00031	133	.67	.00208	.07	.1	.93	13.27
8	10	.00031	133	.83	.00257	.07	.17	.88	15.51
9	10	.00031	133	.84	.00260	.07	.23	.83	14.80
10	10	.00031	133	1.04	.00322	.07	.30	.75	16.56
11	10	.00031	133	1.34	.00415	.07	.30	.75	21.35
12	10	.00031	133	.94	.00291	.07	.23	.83	16.56
13	10	.00031	133	1.14	.00353	.07	.17	.88	21.30
14	10	.00031	133	.84	.00260	.07	.1	.93	16.58
15	10	.00031	133	1.00	.00310	.07	.03	.96	20.41
16	10	.00031	133	.87	.00270	.07	.03	.96	17.78
17	10	.00031	133	.84	.00260	.07	.1	.93	16.58
18	10	.00031	133	.83	.00257	.07	.17	.88	15.51
19	10	.00031	133	.90	.00279	.07	.23	.83	15.88
20	10	.00031	133	.90	.00279	.07	.30	.75	14.35
21	1	.001	100	3.31	.00331	.07	.30	.75	17.02
22	1	.001	100	2.73	.00273	.07	.23	.83	15.54
23	1	.001	100	3.20	.00320	.02	.17	.88	19.31
24	1	.001	100	2.61	.00261	.07	.1	.93	16.65
25	1	.001	100	3.18	.00318	.07	.03	.96	20.94
26	1	.001	100	3.44	.00344	.07	.03	.96	22.65
27	10	.00031	133	1.02	.00316	.07	.1	.93	20.15
28	10	.00031	166	1.16	.00360	.07	.17	.88	21.73
29	10	.00031	166	1.11	.00344	.07	.23	.83	19.58
30	10	.00031	166	1.36	.00421	.07	.30	.75	21.65
31	1	.001	100	4.38	.00438	.07	.30	.75	22.53
32	10	.00031	166	1.61	.00499	.07	.23	.83	28.40
33	10	.00031		1.57	.00468	.07	.17	.88	28.24
34	10	.00031		1.33	.00412	.07	.1	.93	26.28
35	10	.00031		1.22	.00372	.07	.03	.96	24.49
36	10	.00031		1.27	.00394	.07	.03	.96	25.94
37	10	.00031		.98	.00304	.07	.1	.93	19.39
38	10	.00031		1.28	.00396	.07	.17	.88	23.90

TABLE 17. LINE: Gradient Array (Cont.)

Sta.	Range	MA	Voltage	V_p	DV/I	x/delta d/delta			P_a
38	10	.00031		1.44	.00446	.07	.23	.83	25.39
40	10	.00031		1.80	.00558	.07	.30	.75	28.70
41	10	.00031		1.92	.00595	.07	.30	.75	30.60
42	10	.001	100	.47	.00470	.07	.23	.83	26.75
43	10	.00031	166	1.57	.00468	.07	.17	.88	28.24
44	10	.00031		1.22	.00378	.07	.1	.93	23.60
45		.00031							
46									

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

APPENDIX F

TABLE 18
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 19. 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 20. WENNER GEOMETRIC FACTOR TABLE

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

GEOTHERMAL ENERGY PUBLICATIONS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

(CONTINUED ON INSIDE OF BACK COVER)

Special Pub. 10, HYDROGEOLOGICAL AND GEOTHERMAL INVESTIGATIONS OF PAGOSA SPRINGS, COLORADO, by M.A. Galloway WITH A SECTION ON MINERALOGICAL AND PETROGRAPHIC INVESTIGATIONS OF SAMPLES FROM GEOTHERMAL WELLS 0-1 AND P-1, PAGOSA SPRINGS, COLORADO, by W.W. Atkinson, 1980, 95 p. $10.00

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

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

Special Pub. 20, INDUSTRIAL MARKET OPPORTUNITIES FOR GEOTHERMAL ENERGY IN COLORADO, by B.A. Coe, 1982, Free over the counter.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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