RESOURCE SERIES 19

DOE/ET/28365-25

# Geothermal Resource Assessment of Western San Luis Valley, Colorado

by

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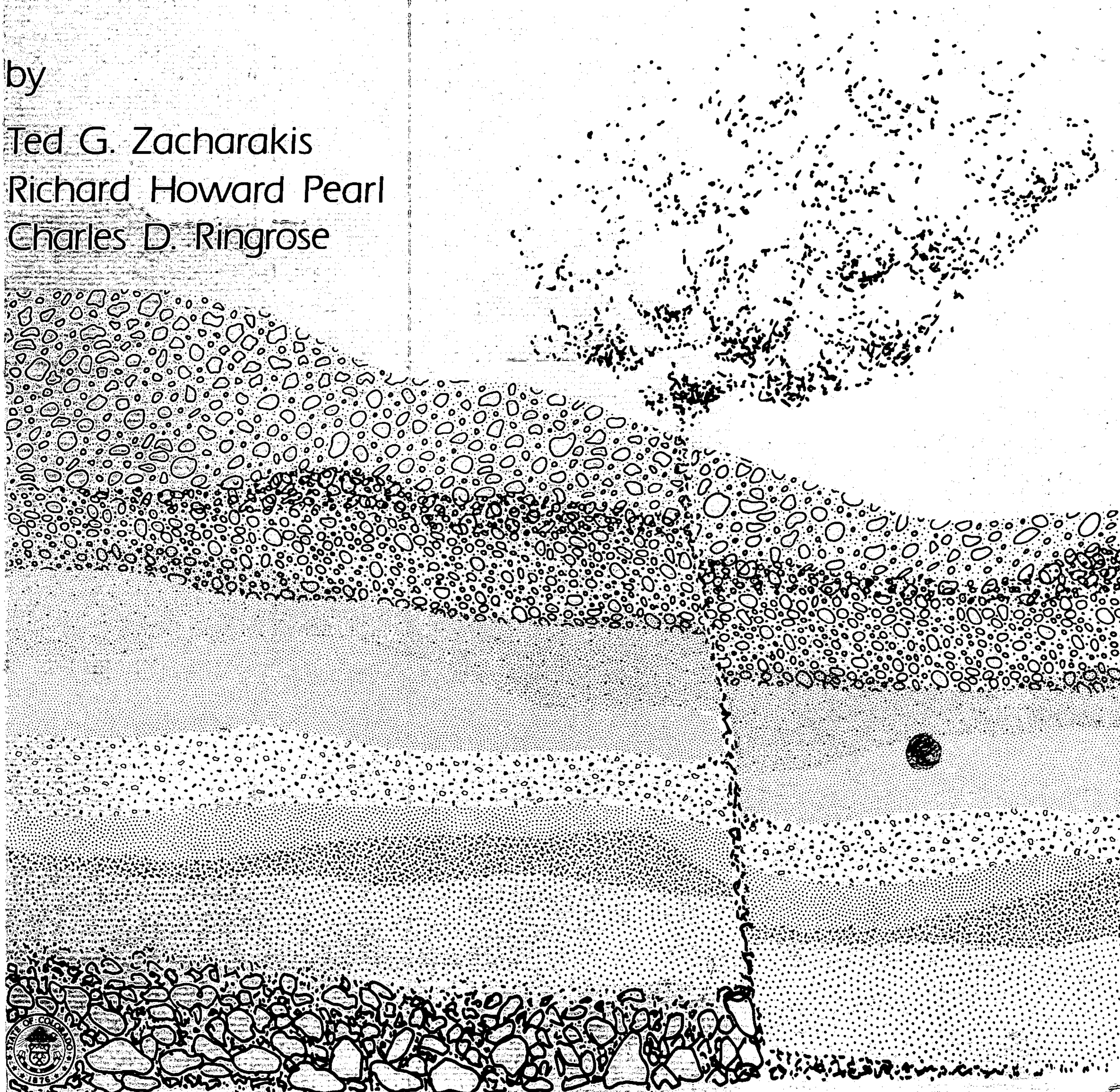

Colorado Geological Survey / Department of Natural Resources / Denver, Colorado / 1983

## DISCLAIMER

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# GEOTHERMAL RESOURCE ASSESSMENT OF WESTERN SAN LUIS VALLEY, COLORADO

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

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COLORADO GEOLOGICAL SURVEY
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Colorado Geological Survey
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State of Colorado
Denver, Colorado
1983

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## ABSTRACT

The Colorado Geological Survey initiated and carried out a fully integrated assessment program of the geothermal resource potential of the western San Luis Valley during 1979 and 1980. The San Luis Valley is a large intermontane basin located in southcentral Colorado. While thermal springs and wells are found throughout the Valley, the only thermal waters found along the western part of the Valley are found at Shaw Warm Springs which is a relatively unused spring located approximately 6 miles (9.66 km) north of Del Norte, Colorado. The waters at Shaws Warm Spring have a temperature of 86°F (30°C), a discharge of 40 gallons per minute and contain approximately 408 mg/l of total dissolved solids.

The assessment program carried out in the western San Luis Valley consisted of: soil mercury geochemical surveys; geothermal gradient drilling; and dipole-dipole electrical resistivity traverses, Schlumberger soundings, Audio-magnetotelluric surveys, telluric surveys, and time-domain electromagnetic soundings and seismic surveys.

Shaw Warm Springs appears to be the only source of thermal waters along the western side of the Valley. From the various investigations conducted the springs appear to be fault controlled and is very limited in extent.

Based on best evidence presently available estimates are presented on the size and extent of Shaw Warm Springs thermal system.. It is estimated that this could have an areal extent of 0.63 sq. miles (1.62 sq. km) and contain 0.0148 Q's of heat energy.

## INTRODUCTION

In 1979, the Colorado Geological Survey, in cooperation with the U.S. Department of Energy, Division of Geothermal Energy, under Contract No. DE-AS07-77ET28365, initiated a program designed to determine the nature and extent of Colorado's geothermal resources. Priority was given to those areas with the greatest potential for near term development. The areas evaluated under this program were The Animas Valley north of Durango, Canon City Area, Hartsel Hot Springs, Hot Sulphur Springs, Idaho Springs, Ouray, Ranger Hot Springs, the Steamboat Springs-Routt Hot Springs area, and the western San Luis Valley in the vicinity of Shaw Warm Springs. This publication reports the findings of the resource assessment program carried out in the area surrounding Shaw Warm Springs in the western San Luis Valley (Fig. 1). As the geological conditions controlling the occurrence of Shaws Warm Spring were not apparent, a multi-faceted exploration program was conducted. The program consisted of literature search, reconnaisance geologic and hydrogeological mapping, geophysical surveys, soil mercury geochemical surveys, and determination of the geothermal gradient of the area.

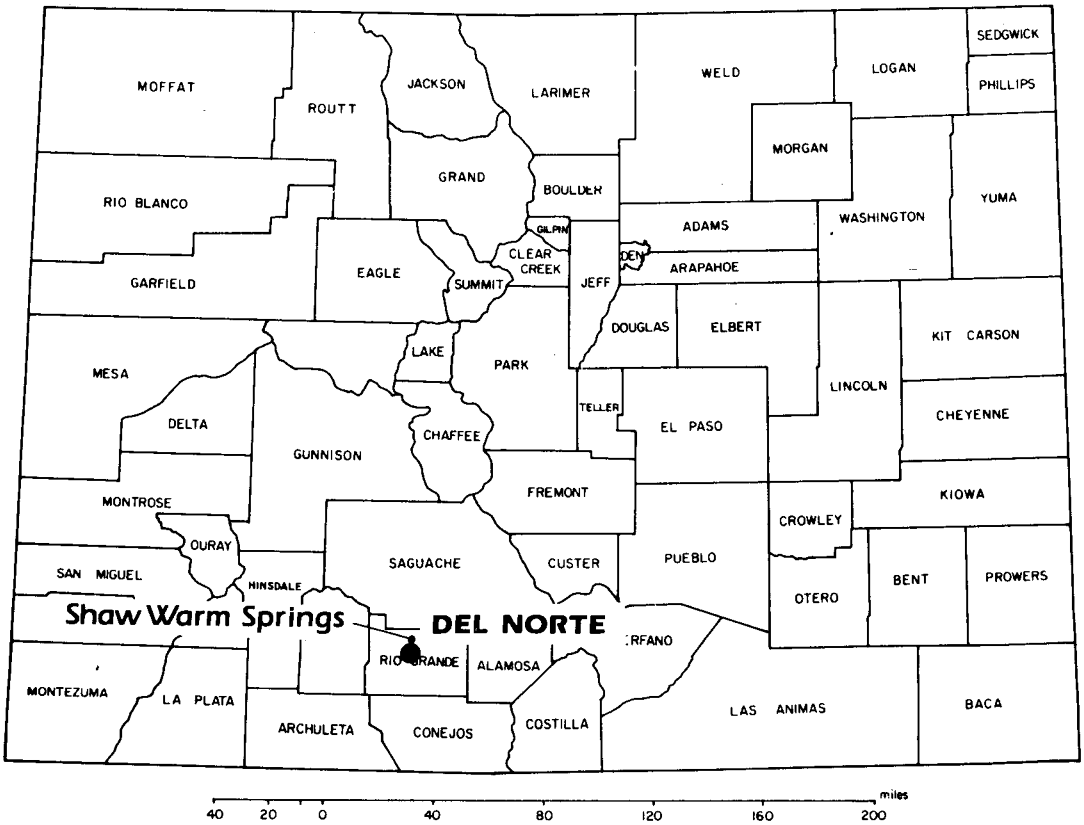



Figure 1. Index map.

The San Luis Valley of southcentral Colorado is a large intermontane basin having an average altitude of approximately 7,600 ft (2.32 km) above sea level. Principal industries of the Valley are agriculture, agricultural product processing and mining (Coe, 1980). The San Luis Valley is an energy poor region with 45% of its electrical energy and 100% of its petroleum products being imported (Coe, 1980). In her in-depth assessment of the energy needs and consumption in the San Luis Valley, Coe (1980) noted that due to a moratorium on new gas taps, many of the residents of the Valley were forced to turn to expensive electricity or propane for heat in the 1970s. She pointed out that a possible source of energy that could be used to help alleviate the growing energy needs of the Valley is geothermal energy. According to Coe's (1980) calculations, the geothermal resources of the Valley have the potential for supplying annually more than 2 times the amount of natural gas consumed throughout the Valley in 1977. Mainfestations of geothermal energy in the form of hot water (hydrothermal) springs are found throughout the Valley. From north to south, these hydrothermal areas are: Mineral Hot Springs; Valley View Warm Springs; Sand Dunes Swimming Pool Hot Water Well; Shaw Warm Springs; the Alamosa area; and Dexter and McIntyre Warm Springs. Temperatures of the thermal waters found in the Valley range from a low of 68°F (20°C) to a high of 140°F (60°C).

During the last 10 years various aspects of the geothermal resources of the San Luis Valley have been discussed by numerous authors. Some of these papers were authored by: Barrett and Pearl (1976 and 1978); Burroughs (1981); Coe (1980); Coury and Vorum (1978); Goering and Connor (1980); Goering and others (1979a, 1979b, and 1980); Harder and others (1980); Jordan (1974); Meyer and Roberts (1979); Pearl (1972 and 1979); Pearl and Barrett (1976); Romero and Fawcett (1978); and Vorum and others (1978).

Geothermal energy, the natural heat of the earth, is a source of energy that can, under favorable conditions, be put to a wide range of uses. Under normal conditions geothermal energy is either too diffuse or found at depths too great to be of practical value. In those instances where geothermal energy occurs close to the surface it can be developed and put to practical use. Techniques and equipment for developing and using geothermal energy are readily available today. A brief description of geothermal energy and some of its possible uses are presented in Appendix A.

# THERMAL CONDITIONS OF THE WESTERN SAN LUIS VALLEY AREA

## Thermal Waters

A number of thermal springs and wells whose water temperatures are in excess of 68°F (20°C) are located in the San Luis Valley. However, the only thermal waters in the western part of the San Luis Valley are found at Shaw Warm Springs. This are small relatively unused thermal springs located approximately 6 mi (9.66 km) north of Del Norte, Colorado and 5 mi (8.05 km) southeast of the Summer Coon volcanic area on the eastern slope of the San Juan Mountains (Fig. 2). The waters of Shaw Warm Springs have a temperature of 86°F (30°C), an annual average discharge of 40 gallons per minute (gpm) and contain approximately 408 mg/l of total dissolved solids. Historically the thermal waters have only been used by the owner for recreational purposes (Barrett and Pearl, 1978). Chemical analysis of the Shaw Warm Springs waters is presented in Appendix B.

## Geothermal Gradients and Heat Flow

Only one true heat-flow hole has been drilled along the western side of the San Luis Valley. Calculations from measurements made in this well, located approximately 3 miles (4.8 Km) north of Shaw Warm Springs, determined that the corrected heat flow for the area is 113 mW/m2 (Decker and Bucher, 1979). Based on regional data, Zacharakis (1981) has shown that the heat flow of the Western San Luis Valley ranges from less than 100 mW/m2 to over 120 mW/M2 (Fig. 3).

During the winter of 1979-80, 16 temperature gradient holes were drilled throughout the central part of the San Luis Valley (Fig. 4). The depth of these holes ranged up to 300 ft (91.4 m) (Ringrose, 1980). In order that a complete and representive measurement of the geothermal gradients be made, unperforated, two-inch diameter, black iron pipe was installed in the holes to total depth. The annular space was backfilled with drill cuttings to within 3-4 ft (1-1.2 m) of the surface on which a cement grout seal extending to the surface was placed. The pipe was filled with water and allowed a minimum of two weeks to reach equilibrium temperature conditions before temperature measurements were made (Ringrose, 1980). As shown in Figure 4, gradients measured in these holes ranged from 1.62°F/100 ft (29.6°C/km) to a high of 4.1°F/100 ft (74.7°C/km). The average geothermal gradient for these 16 holes was 3.17°F/100 ft (57.8°C/km). A Fluid Dynamics temperature probe calibrated to an accuracy of ± 0.1°C with a resolution of at least .01°C was used to measure the temperatures in the holes (Ringrose, 1980).

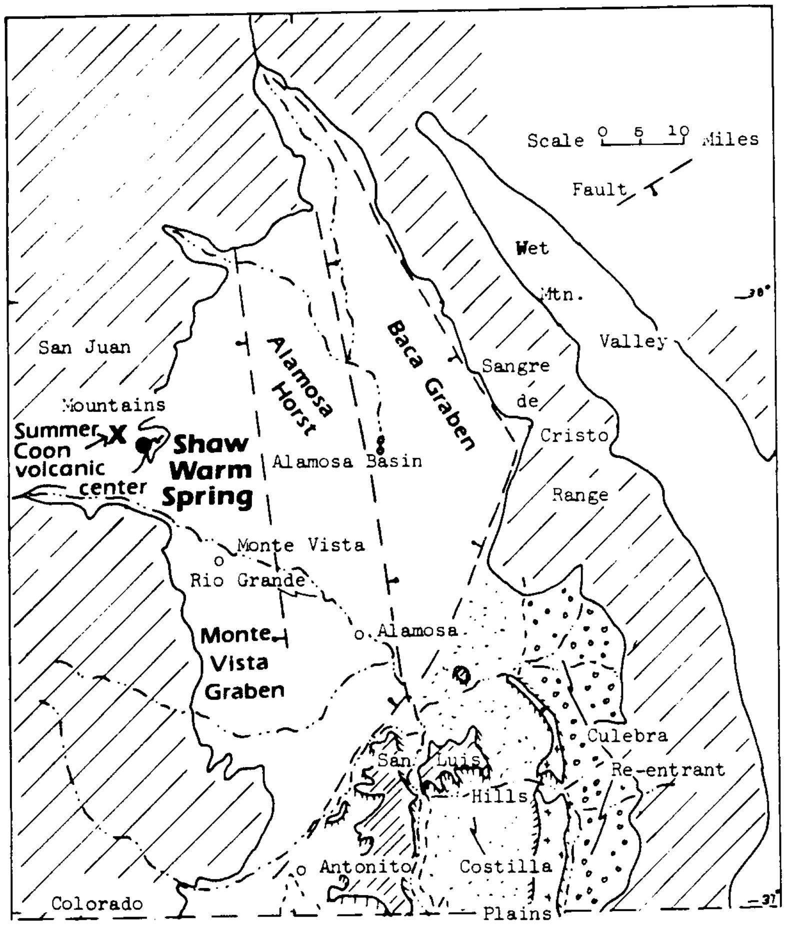



Figure 2. Physiographic subdivisions, San Luis Valley (modified from Burroughs, 1981).

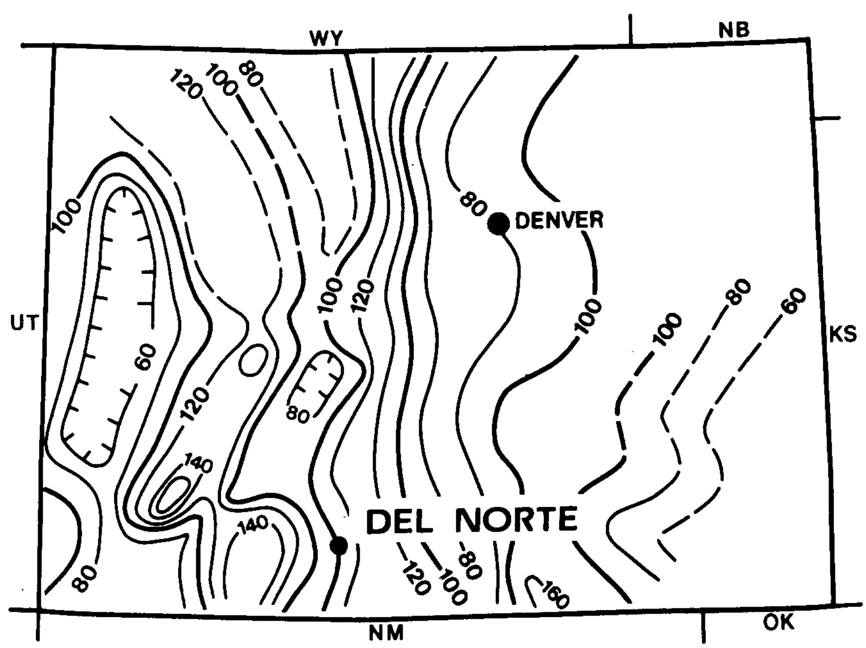
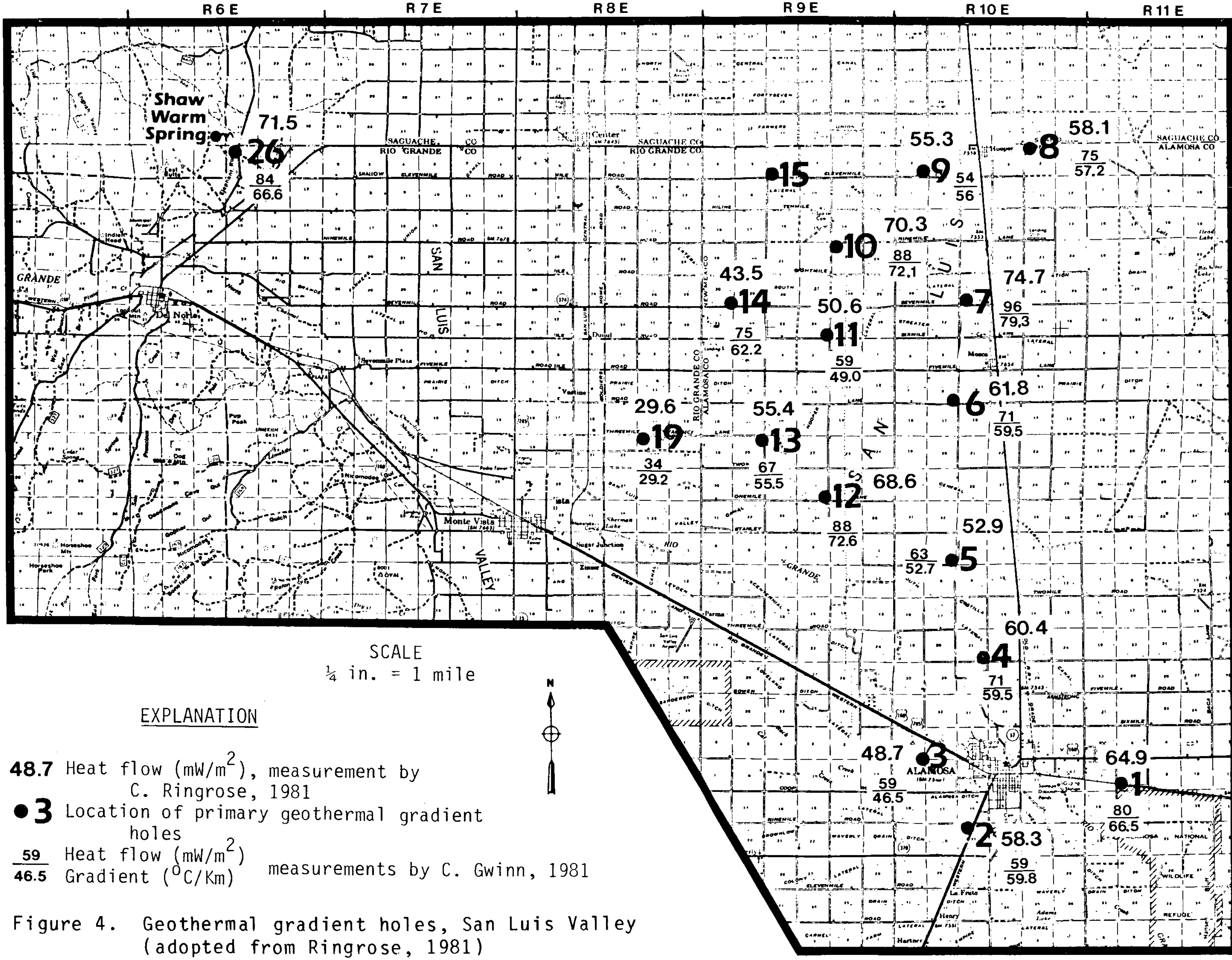



Figure 3. Heat flow map of Colorado (from Zacharakis, 1981).




EXPLANATION

**48.7** Heat flow ($mW/m^2$), measurement by C. Ringrose, 1981

**● 3** Location of primary geothermal gradient holes

$\frac{59}{46.5}$ Heat flow ($mW/m^2$) / Gradient ($^oC/Km$) measurements by C. Gwinn, 1981

Figure 4. Geothermal gradient holes, San Luis Valley (adopted from Ringrose, 1981)

During the summer of 1981, Ms. Cindy Gwinn (Southern Methodist University), remeasured the temperatues in these holes and calculated both the geothermal gradient and heat flow. Her measurments showed that the gradients ranged from 1.24°F/100 ft (22.6C/km) to 4.35°F/100 ft (79.3°C/km) with an average gradient of 3.34°F/100 ft (59.0°C/km) (Fig. 4) (Gwinn, 1981).

Using bottom hole temperature measurements from oil wells, plus other data, Repplier and Fargo (1981) have shown that the regional gradient in the western San Luis Valley is approximately 2.2°F/100 ft (40°C/km).

Gwinn (1981), determined that the heat-flow in the gradient holes she remeasured ranged from 34 mW/m2 to 96 mW/m2 (Fig. 4), with an average heat flow of 70.5 mW/m2. Due to the large number of variables including shallow depth of holes, ground-water movement, and assumed conductivity of sediments which could be influencing the temperature measurements, her results are in fairly close agreement with other published data.

# GEOLOGY

## Introduction

The following discussion is taken from Burroughs (1981), Chapin, (1979) and Tweto (1975 and 1979) although Cordell, 1978; James, 1971; and Riecker, 1979 have also published on various aspects of the geological conditions of the Valley and its immediate surroundings.

The San Luis Valley is part of the larger Rio Grande Rift Zone, which extends from southern New Mexico northward through the San Luis and upper Arkansas Valleys, and terminates about 12 miles (19 km) north of Leadville, Colorado. The Valley, which opens southward into New Mexico, is bounded on three sides by mountain ranges: The Sangre de Cristo Range on the east and north; and the San Juan Mountains on the west and northwest (Fig. 2).

Along the east side of the valley block faulting has brought Precambrian age rocks of the Sangre de Cristo Mountains up into contact with the Tertiary age rocks of the Valley. On the west side of the valley Oligocene age volcanic rocks of the San Juan Mountains dip into the Valley where they become interbedded with the valley fill deposits. In the subsurface the Valley is broken by two horst blocks. At the southern end of the Valley, near the New Mexico border, as a result of block faulting Oligocene volcanic rocks have been brought to the surface, forming the San Luis Hills (Fig. 2). Extending north form this structure is a easterly tilted, deeply buried horst, named the Alamosa Horst, which is composed of Precambrian age rocks (Tweto, oral communication, 1982; Zeisloft and Mackelprang, in prep.) (Fig. 2). A geothermal well drilled in the City of Alamosa in late 1981 encountered the Alamosa Horst at a depth in excess of 5,000 ft (1.52 Km) (Zeisloft and Mackelprang, in prep.). On either side of the Alamosa Horst are two deep basins, the Baca Graben on the east and the Monte Vista Graben on the west (Fig. 2). It is estimated that the Baca Graben is approx. 19,000 ft (5.8 km) deep and the Monte Vista Graben over 10,000 ft (3.05 km) deep.

Overlying the Precambrian basement rocks is a thick sequence of Tertiary age valley fill sediments and volcanic rocks. The absence of Paleozoic and Mesozoic age sediments reflects the fact that throughout much of geologic time most of the San Luis Valley area was a positive feature.

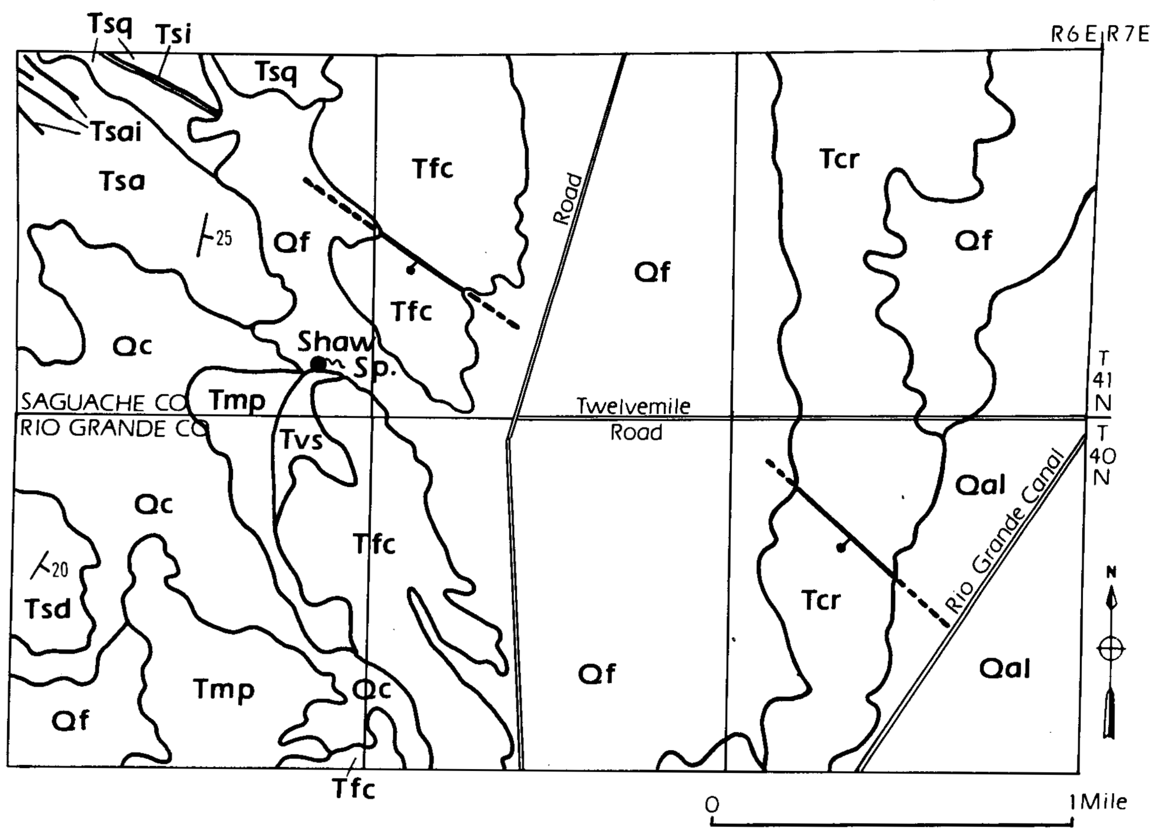
While the Rio Grande Rift as a whole started developing between 32 and 27 m.y. ago (Late Oligocene), the Colorado segment started developing about 26-27 m.y. ago (Early Miocene). At this same time igneous activity associated with the rifting occurred. Igneous rocks contemporaneous with the rifting occur as far northward as the Wyoming border. During the rifting phase, and continuing up to the present the crust sagged allowing broad shallow basins to form in which mafic flows and volcanic ash beds were interbedded with alluvial deposits which were later broken by faulting. It is beyond the scope of this paper to present a description of all the various rock units found in the western San Luis Valley. Table 1 is a summary description of the various rock units. For a more complete description the reader is refered to papers by Burroughs (1981), Lipman (1968 and 1978), Lipman and Mehnert (1975), and Mertzman (1971).

TABLE 1. STRATIGRAPHIC SECTION, WESTERN SAN LUIS VALLEY
(From Lipman, 1976)

| SYSTEM | SERIES | FORMATION | THICKNESS ft (m) | DESCRIPTION |
|---|---|---|---|---|
| | | Surficial | | Deposits |
| Quaternary | Holocene | Alluvium | variable | Silt, sand, gravel, peat in valley bottoms. |
| | Holocene | Colluvium | " | Poorly sorted slope material. |
| | | Talus dep. | " | Angular rock fragments poorly sorted. |
| | Pleistocene | Landslide dep. | " | Poor sorted rock debris. |
| | | Glacial outwash | " | Well sorted sand and gravel,rounded boulders. |
| | | Alluvial fan | " | Poorly sorted silt and boulder. |
| | REGIONAL LAVAS AND RELATED ROCKS | | | |
| Tertiary | Pliocene Miocene | Hinsdale Formation | 0-164 ft. (0-50m) | Fine grained lava flow material. Silicic alkaliolivine basalt and basaltic andesite. |
| | Pliocene Oligocene | Los Pinos Formation | 0-131 ft. (0-40m) | Conglomerate, sandstone and mudflow breccia. Contains clasts derived from volcanoes to south west. |
| | Oligocene | Volcanic Sandstone | 0-82 ft. (0-25m) | Eroded sandy debris from Summer Coon Volcano. |
| | | ASH-FLOW SHEETS | | |
| | Oligocene | Carpenter Ridge Tuff | 0-246 ft. (0-75 m) | Non-welded light gray to densely welded red-brown rhyolitic ash-flow. |
| | Oligocene | Fish Canyon Tuff | 0-328 ft. (0-100 m) | Non-welded lt-gray to moderately welded tan quartz latitic ash flow |
| | Oligocene | Masonic Park Tuff | 0-164 ft. (0-50 m) | Non-welded gray to partly welded yellow-brown quartz latitic ash-flow sheet. |
| | Oligocene | Treasure Mtn. Tuff | 0-640 ft. (0-195 m) | Pyroclastic sequence of two widespread quartz latitic ash-flow sheets interlayered with rhyolitic ash-flow and ash-fall deposits. Found primarily south of Rio Grande River. |
| | EARLY INTERMEDIATE COMPOSITION ROCK | | | |
| | Oligocene | Conejos Formation | 0-1.01 mi) (0-1.64 km) | Lava flows and flow breccias of andesite, rhyodacite, and quartz latite. Beded. conglomerate, sandstone and mudflows. |
| | Oligocene | Flows and dikes | 0-1.11 mi (0-1.8 km) | Rhyodacite, Quartz latite, Porphyritic rhyolite, rhyolite, and andesite. |

## Stratigraphy

Shaw Warm Springs are located approximately 5 mi (8.05 Km) southeast of, and well down on the southeast flank of the Summer Coon volcanic center (Lipman, 1976). Bedrock of the region consists of rocks ejected from the Summer Coon Volcano and other volcanoes located to the west (Fig. 5). Most of these extrusive rocks are predominantly ash flow sheets of Early Oligocene age called the Masonic Park Tuff, Fish Canyon Tuff and the Carpenter Ridge Tuff (Fig. 5). These units dip eastward into the Valley where they become interbedded with the thick sequence of relatively unconsolidated valley fill material. Intruding these and other rock units are a large number of dikes of varying composition that expand radially from the volcanic complex. Overlying the volcanic rocks are poorly sorted surficial and alluvial deposits ranging from silts to boulders, of Pleistocene and Holocene age.




EXPLANATION

| | | | |
|---|---|---|---|
| **Qal** | Quaternary alluvium | **Tsa** | Tertiary andesite |
| **Qc** | Quaternary colluvium | **Tsd** | Tertiary rhyodacite |
| **Qf** | Quaternary alluvial-fan deposits | **Tsi** | Tertiary intermediate composition dike |
| **Tvs** | Tertiary volcanic sandstone | **Tsai** | Tertiary andesite dike |
| **Tfc** | Tertiary Fish Canyon Tuff | (line) | Geologic contact |
| **Tmp** | Tertiary Masonic Park | (line with ball) | Fault; dashed where inferred, ball on downthrown side |
| **Tsq** | Tertiary quartz latite | 25 | Strike and dip of bed |

Figure 5. Regional geologic map (adopted from Lipman, 1976)

## HYDROGEOLOGY OF THE WESTERN SAN LUIS VALLEY

Due to its geologic character the San Luis Valley contains large quantities of non-thermal ground waters at relatively shallow depths. Over the years a successful agricultural industry has developed based on the use of these ground-water supplies. The hydrogeological investigations conducted in the Valley by Emery and others (1971 and 1973), Huntley (1975), and Powell (1958) dealt primarily with the nonthermal water of the valley, which are used for irrigation purposes, and not the thermal resources. For the most part these waters have no relationship to the thermal waters and therefore will not be discussed in any detail here.

Emery and others (1972) reported the existence of thermal water wells north and east of Shaws Warm Spring in the more central parts of the Valley. These waters were coming from wells having reported depths ranging from 354 ft (108 m) to 4,200 ft (1.28 km). From an examination of the literature plus field investigations, it appears that the only hydrothermal area along the western side of the San Luis Valley the Shaw Warm Springs area. While no in-depth papers have been published on the hydrothermal conditions of the western San Luis Valley, a number of papers have been published pertaining to the thermal conditions of the Shaw Warm Springs area. These papers have been authored by: Barrett and Pearl (1976 and 1978), Berry and others (1980); George and others (1920); Lewis, (1966); Mallory and Barnett (1973); Pearl (1972 and 1979); and Waring (1965).

George and others (1920) made the first comprehensive appraisal of the thermal waters of Colorado and the medicinal values associated with them. Those interested in the historic treatment of this subject will find this report of immense value. In addition to reporting the chemical composition of the thermal waters, George and others (1920) listed such physical parameters as temperature, location, radioactivity, and location of the spring. In 1978 Barrett and Pearl, following up on the work of George and others (1920), reevaluated the thermal waters of of Colorado. They (Barrett and Pearl, 1978) relocated the thermal water sources, measured their temperature, pH, and other field parameters, and had a complete modern chemical analysis of the waters made. In addition they tried through the use of geochemical geothermometer models to estimate the subsurface reservoir temperatures. In 1979 Pearl carried this analysis one step futher and presented estimates of the size and extent of the thermal area (Table 2).

Barrett and Pearl (1978) and Pearl (1979) stated that they believed recharge for Shaw Warm Springs was probably occurring in the higher ground to the west. They felt that as the ground waters moved downdip through permeable interflow units the waters became heated due to residual heat from the Tertiary volcanic activity of the area.

Table 2. Resource analysis of Shaw Warm Springs (From Barrett and Pearl, 1978 and Pearl, 1979).

| | |
|---|---|
| Geothermometer temperature estimates: | |
| Mixing Model (amorphous silica)......... | 81°F (27°C) |
| Na-K.................................. | 212°F (100°C) |
| Na-K-Ca............................... | 217°F (103°C) |
| Most likely Temp........................ | 86-140°F (30-60°C) |
| Areal extent:........................... | 0.63 sq mi |
| Heat energy:............................ | 0.0148 Q's |

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

Barrett and Pearl (1978) noted that the above reservoir temperature estimates should be used with caution because most the assumptions inherent in their use are violated. Therefore after a review of all the data they stated that the most likely reservoir temperature for this area is between 86 and 140°F (30 and 60°C).

# GEOPHYSICAL INVESTIGATIONS

## Introduction

During the course of this investigation, in an attempt to map the subsurface geological conditions of the western San Luis Valley, the following geophysical surveys were carried out: seismic; electrical resistivity; telluric; Audio-magnetotelluric (AMT); and time-domain electromagnetic soundings by either the Colorado Geological Survey, U.S. Geological Survey, the Colorado School of Mines summer field camp, or by private companies. Most of these investigations were primarily designed to map the geological conditions controlling Shaw Warm Springs, and to that end they were partially successful.

## Electrical Resistivity Surveys

### Dipole-Dipole Resistivity Surveys:

In the immediate vicinity of Shaw Warm Springs the Colorado Geological Survey ran 6 dipole-dipole electrical resistivity traverses totalling 20,100 ft (6.1 km) (Fig. 6) to determine the boundaries of low resistivity zones. These zones are one of the primary indicators of geothermal systems. A complete description of all the various factors which might affect electrical resistivity measurements are presented in Appendix C. A complete description of the equipment used in these surveys is presented in Appendix D.

One of the more common methods of portraying and interperating electrical resistivity data is through the use of pseudosections. These essentially are cross sections drawn for each traverse line showing the measured resistivity values. In the interperation of these sections one must be aware that lateral variations in the subsurface geological conditions may influence the resistivity measurements. Figures 7 to 12 are pseudosections for the various dipole-dipole resistivity traverses. Due to geological conditions and equipment limitations it was only possible to acquire information on the subsurface conditions to a depth of 300 to 400 ft (91.4 to 122 m). Another method, which was not used, to interperate electrical resistivity geophysical data are detailed computer models. These models would give a more accurate description of the individual faults.

These surveys were successful in helping to delineate the geological controls of Shaw Warm Springs. A northwest trending fault passing through Shaws Warm Spring was delineated. Unfortunately no data were acquired along the traverse line bisecting the mapped fault approximately 0.5 mi (0.8 km) to the north.

### Schlumberger Depth Soundings:

In addition to the dipole-dipole surveys, three Schlumberger depth sounding surveys were made. Data from 300, 500, and 900 ft (91, 152, and 274 m) depths were used to prepare subsurface contour maps of the Shaw Warm Springs area delineating the areal extent of the thermal reservoir (Figs 13,14,15). As is noted, the reservoir appears to be located north of Shaw Warm Springs and is bounded by the mapped fault located approx. 0.5 mi (805 m) north of Shaw Warm Springs, in the next valley.

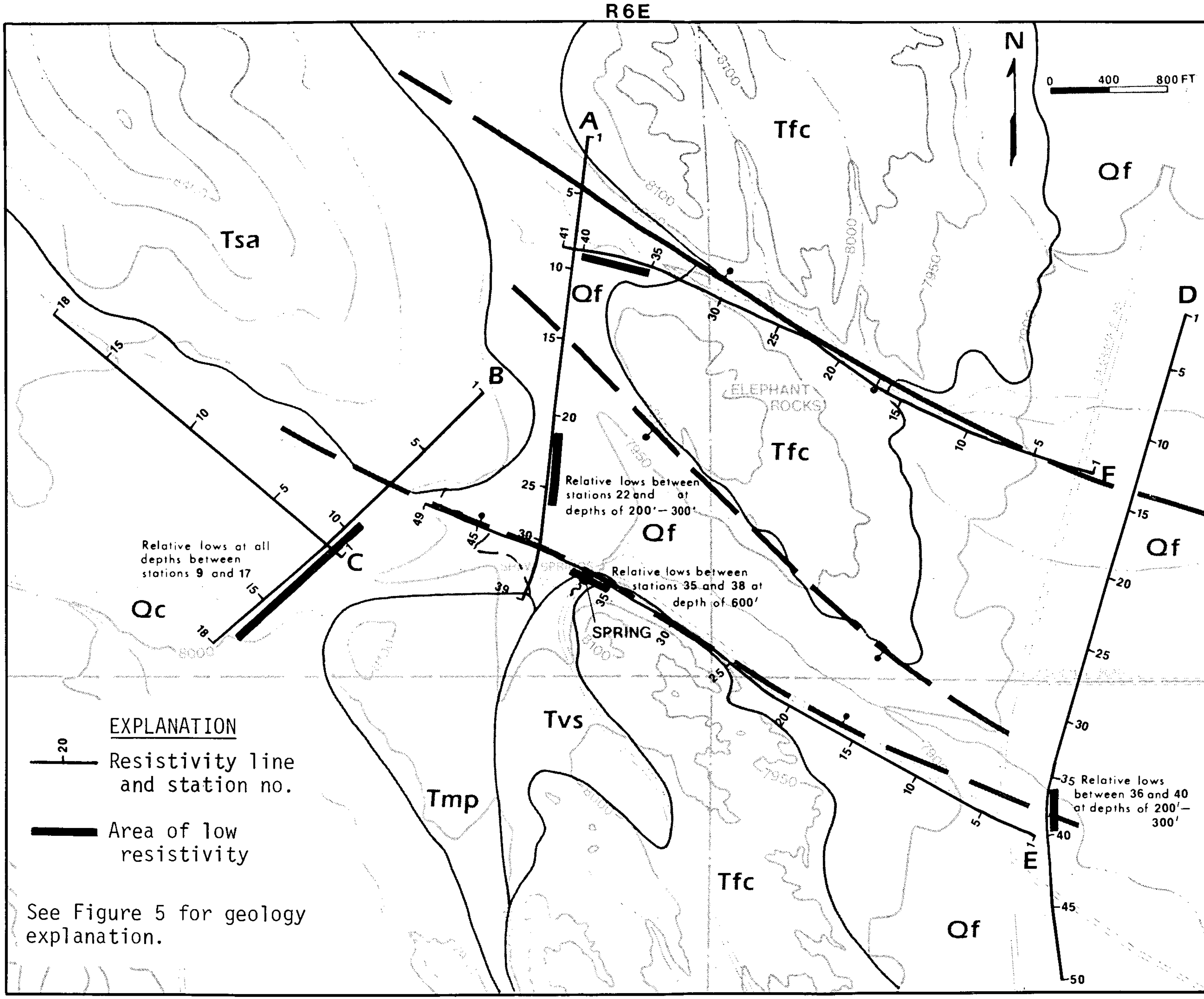
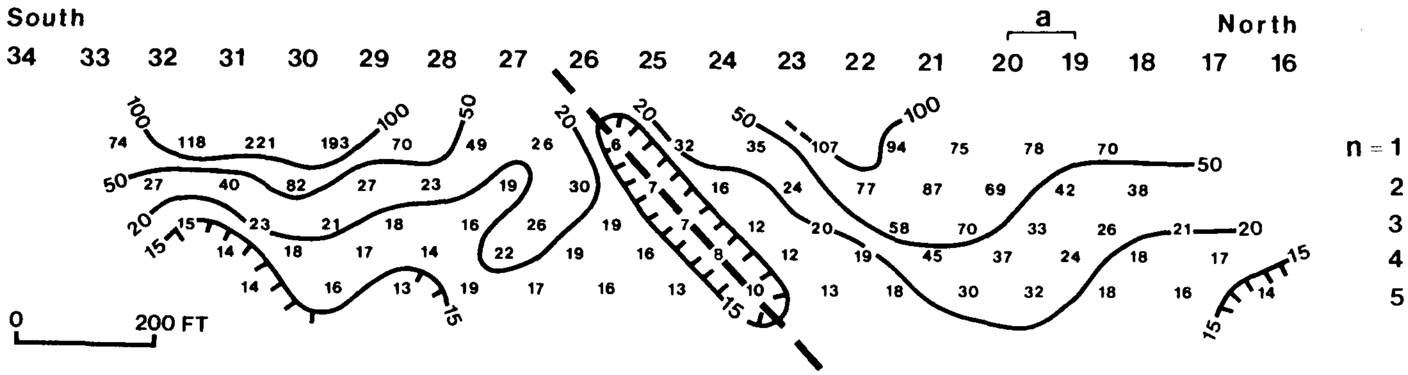


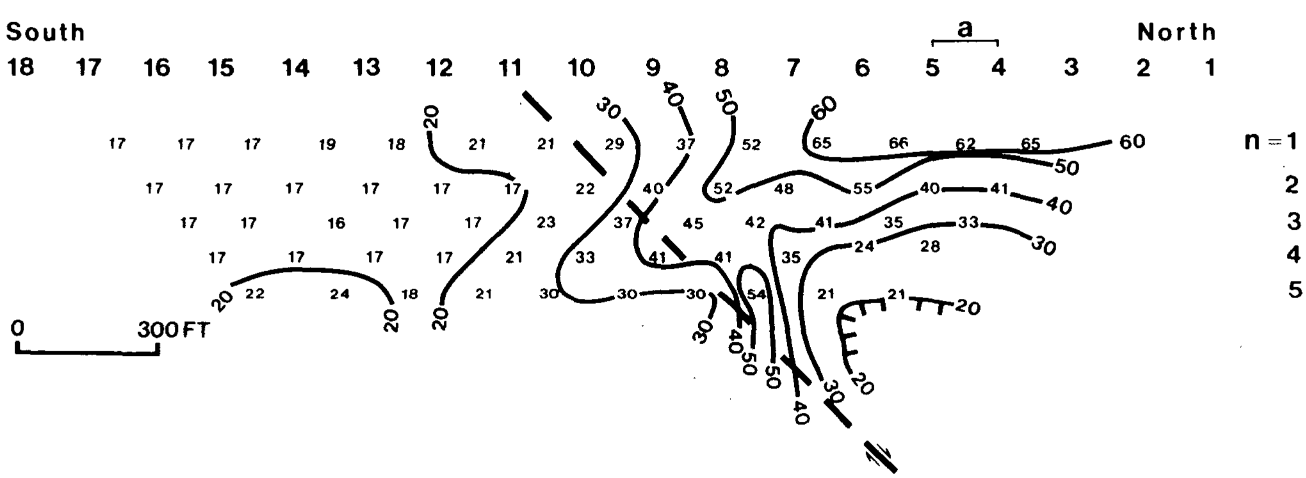

Figure 6. Location of dipole-dipole resistvity survey, western San Luis Valley, Colorado.




A low resistivity zone was mapped between stations 23 to 27 approximately 400 ft northwest of the warm springs area. The resistivity values increase north and south of this area. At the surface to the south, the values increase to 221 ohm-meters, however, at depth (n = 5) the values decrease to approximately 15 ohm-meters. These low values may be attributed to either water saturated alluvium or possibly a fault downthrown to the north. Generally, the values along this line demonstrate a higher resistive surface rock which may be due to a buried stream channel or faulting (data from Stations 1-16 were not obtained).

LENGTH: 1800 ft ( 549 m)
SEPARATION: n Value
DATE: 6/30/80
TYPE: Dipole - Dipole
SPREAD: a = 100 ft
RESISTIVITY: In ohm meters
POSSIBLE FAULT: ▬ ▬

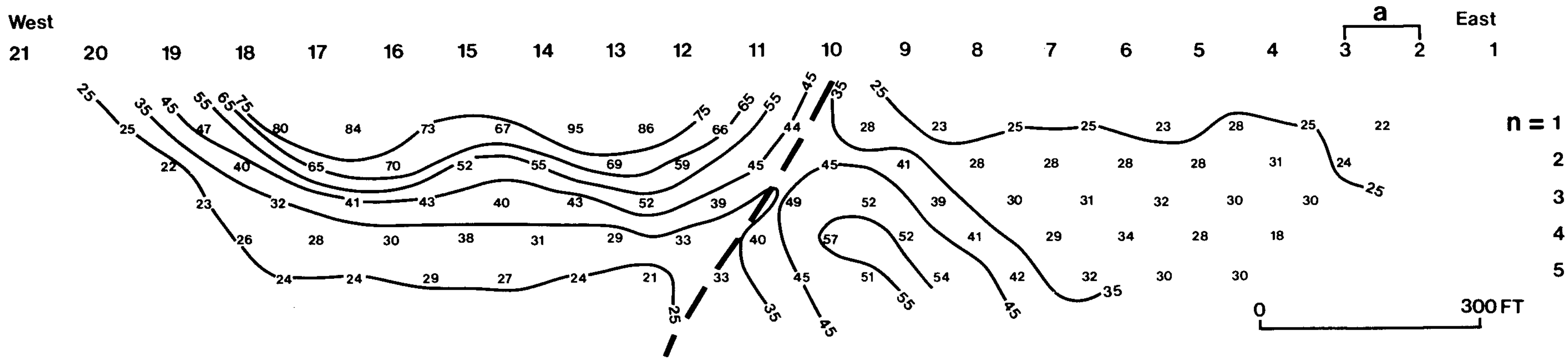
Figure 7. Dipole-dipole pseudosection line A.




LENGTH: 1800 ft ( 549 m)
SEPARATION: n Value
DATE: 6/30/80
TYPE: Dipole - Dipole
SPREAD: a = 100 ft
RESISTIVITY: In ohm meters
POSSIBLE FAULT: ▬ ▬

A low resistivity zone was mapped between stations 9 to 18. This zone which may be a fault zone correlates with the low resistivity fault zone mapped on line A. An additional deep-seated low was mapped between stations 4 and 6.

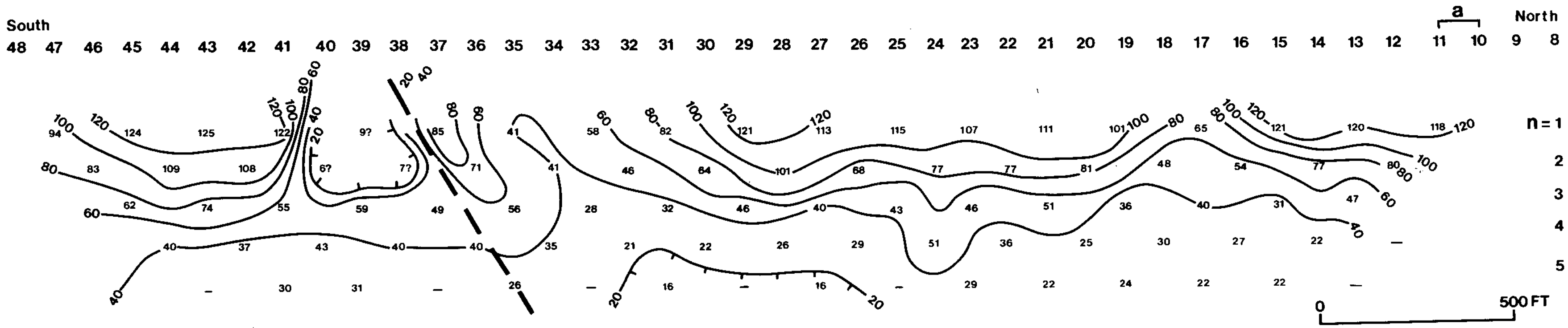
Figure 8. Dipole-dipole pseudosection line B.




This northwest-southeast trending line is approximately 2,100 ft (640 m) in length. No clear structural trends were evident along this traverse. A possible fault may be conjectured in the vicinity of Station 10 downthrown to the northwest. A surface low occurs between stations 2 - 5, but is not indicative of any features of significance. Generally the resistivity layers on this line appear to decrease with depth, which could be attributed to a buried channel bed.

LENGTH: 2100 ft ( 640 m)
SEPARATION: n Value
DATE: 7/2/80
TYPE: Dipole - Dipole
SPREAD: a = 100 ft
RESISTIVITY: In ohm meters
POSSIBLE FAULT: ▬ ▬

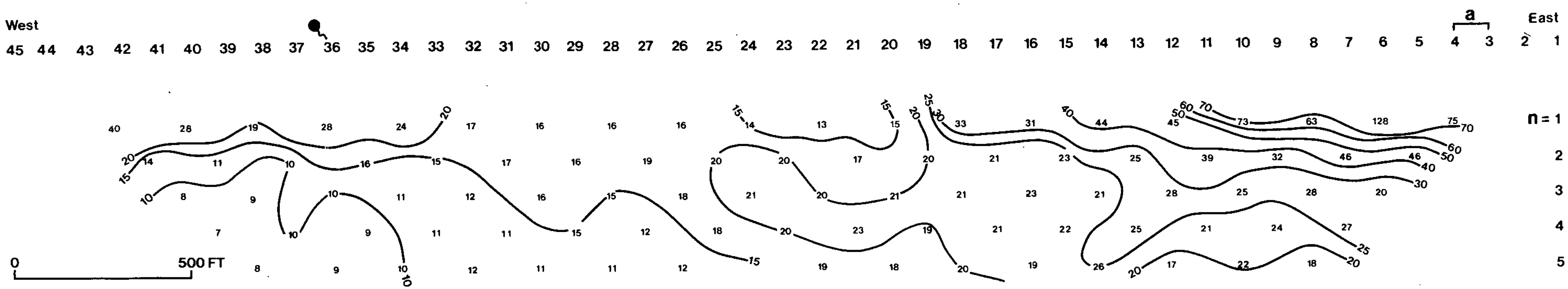
Figure 9. Dipole-dipole pseudosection line C.




This line, parallel to the north - south county road, was the longest traverse conducted (5,000 ft (1.52 km)) during the course of this investigation. A very pronounced low resistivity zone was mapped in the vicinity of stations 37 through 40 with values as low as 5 ohm-meters. This low zone, however, does not persist with depth, and the fault depicted is very questionable. The unnamed creek that flows by Shaw Warm Springs could be controlled by this fault. The surface layers reflect higher resistivity values than the deeper layers.

LENGTH: 5000 ft (1524 m)
SEPARATION: n Value
DATE: 7/8/80
TYPE: Dipole - Dipole
SPREAD: a = 100 ft
RESISTIVITY: In ohm meters
POSSIBLE FAULT: ▬ ▬

Figure 10. Dipole-dipole pseudosection line D.

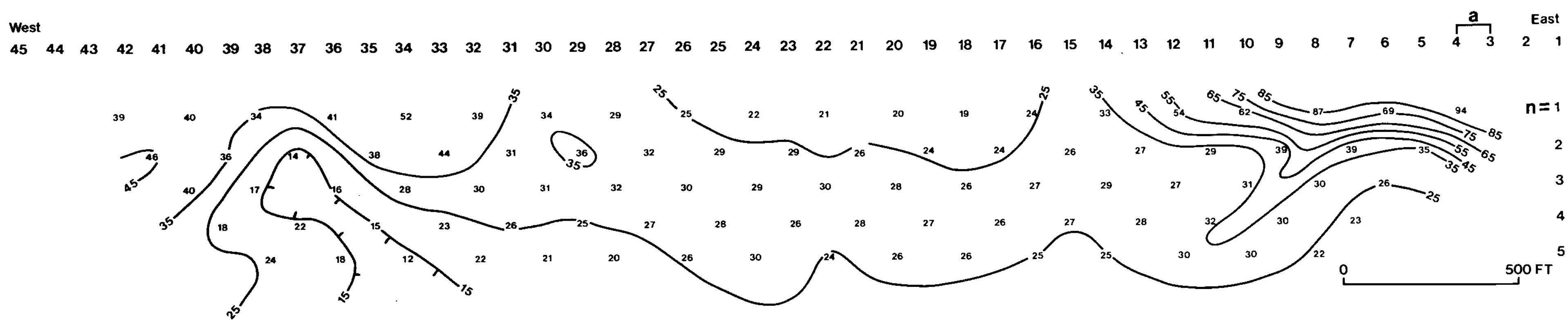



This traverse parallels the buried east-west fault, defined by traverses A and D, which passes through the spring. A low resistivity zone at the intersection of line A and this traverse (station 40) correlates with the low resistivity zone mapped on line A at station 31. Due to access problems no data was collected from stations 43 to 49.

**LENGTH:** 4100 ft (1250 m)
**SEPARATION:** n Value
**DATE:** 7/9/80
**TYPE:** Dipole-Dipole
**SPREAD:** a = 100 ft
**RESISTIVITY:** In ohm meters
**HOT SPRING:** ●

Figure 11. Dipole-dipole pseudosection line E.






This line is approx. 0.5 mi (0.8 km) north of Shaw Warm Springs parallels the northwest trending mapped fault. A low resistivity zone was mapped at depth between stations 35 to 40, with the deeper layers showing the lower resistivity values. From an examination of the data the mapped fault is not apparent. However since the trend of this line parallels the strike of the fault, the fault would not be too apparent.

**LENGTH:** 4000 ft (1219 m)
**SEPARATION:** n Value
**DATE:** 7/10/80
**TYPE:** Dipole-Dipole
**SPREAD:** a = 100 ft
**RESISTIVITY:** In ohm meters

Figure 12. Dipole-dipole pseudosection line F.

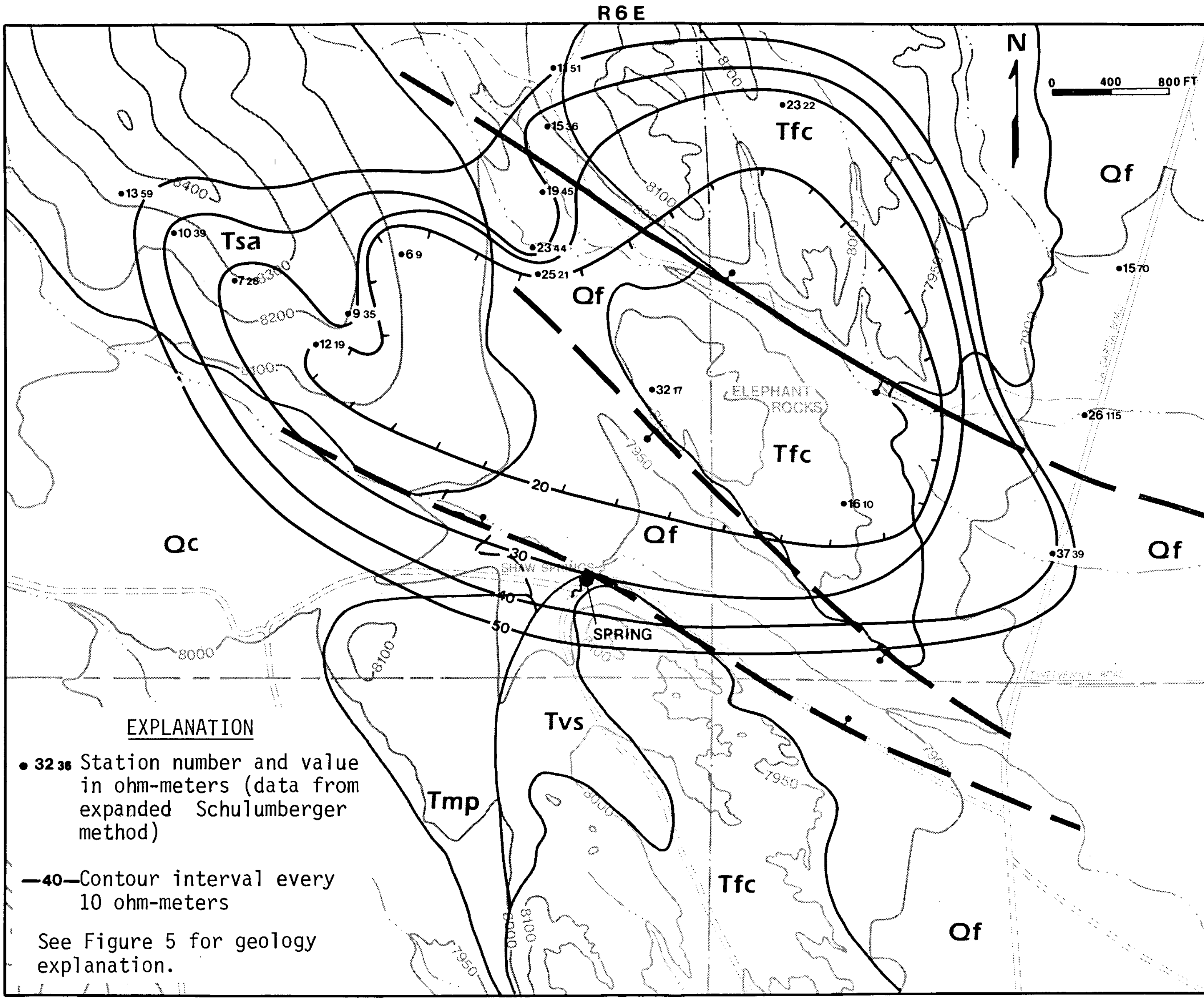



Figure 13. Schlumberger depth sounding, 300 ft. depth

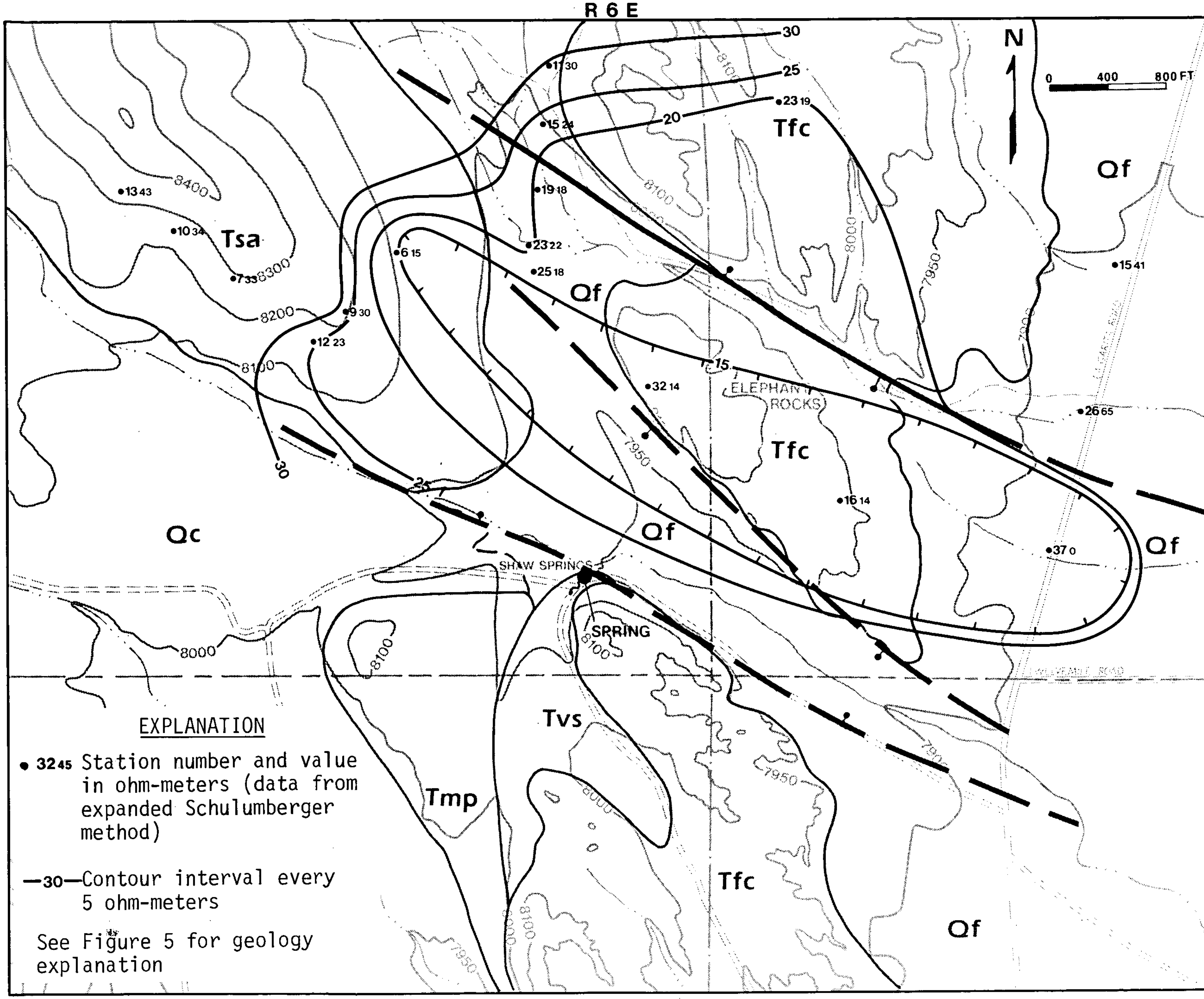



Figure 14. Schlumberger depth sounding, 500 ft. depth

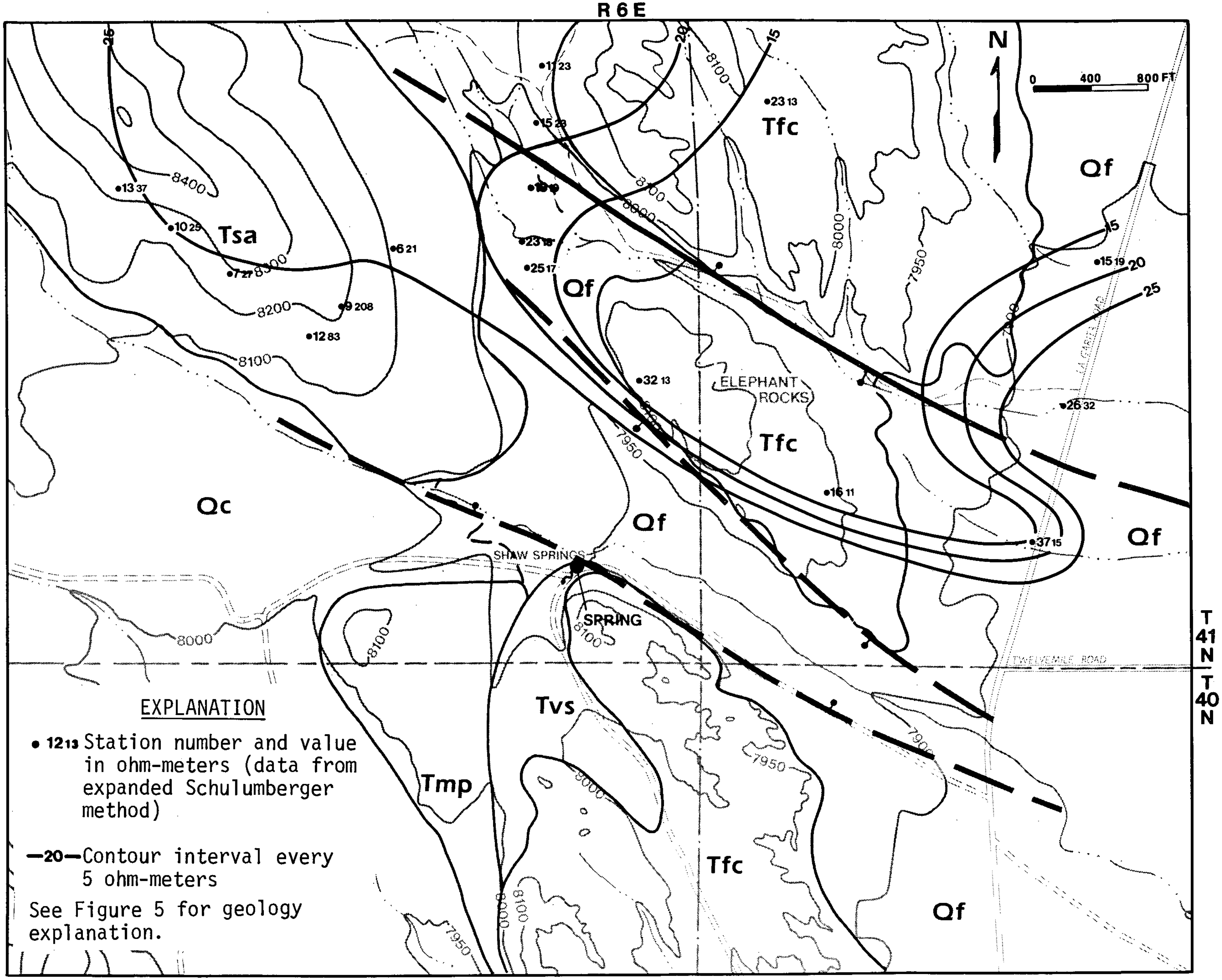



Figure 15. Schlumberger depth sounding, 900 ft. depth.

## Audio-magnetotelluric and Telluric Surveys

During the summer of 1980 personnel from the U.S. Geological Survey ran Audio-magnetotellurics (AMT) and telluric surveys in the Shaw Warm Springs region (Christopherson and others, 1981). The following is a summary of their findings and conclusions.

Two northeast trending telluric profiles were made in the Shaw Warm Springs area using 250 meter dipoles (Fig. 16). These profiles delineated three faults in the region, one of which was known and two previously unmapped faults. Evidence was gathered to extend the fault that Lipman (1976) had mapped approximately .5 mi (.8 km) north of Shaw Warm Springs to the west and east. The two previously unmapped faults were in the Shaw Warm Springs valley south of the Elephant Rocks. One of these faults is just south of the Elephant Rocks and the other is in the vicinity of the warm springs that follows the drainage of Shaw Warm Springs.

The AMT surveys showed that there is a lack of warm waters to at least a depth of 1640 ft (500 m) although there may be some leakage into the valley fill material east of Shaw Warm Springs. The concluded that no significant reservoir is apparent, other that what may be present in the valley fill.

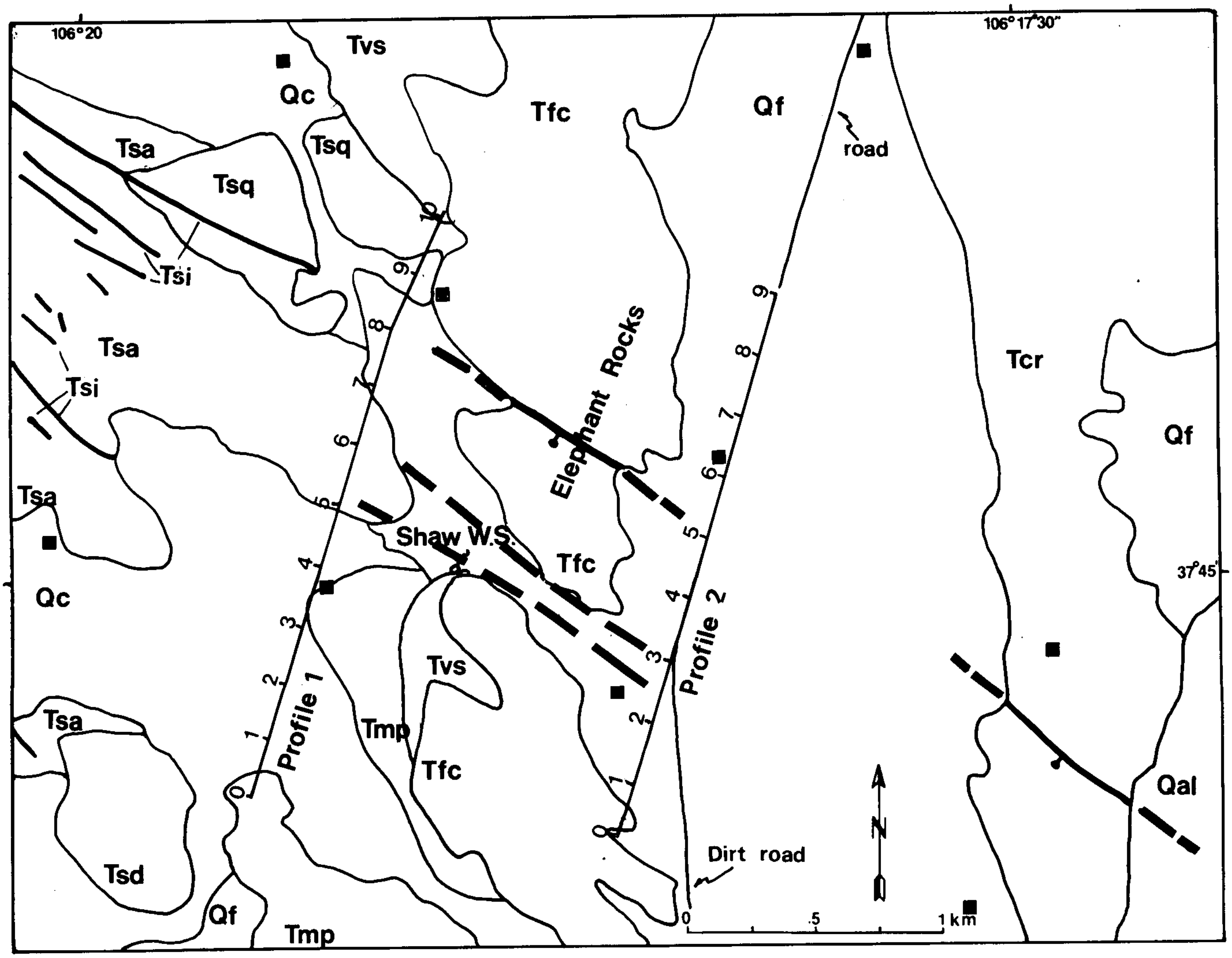
## Geophysical Surveys Conducted by the Colorado School of Mines

During the summer of 1980 the Colorado School of Mines (C.S.M.), Department of Geophysics, conducted seismic reflection and refraction and time-domain electromagnetic sounding as part of its summer field camp in the western San Luis Valley. Bond (1981) evaluated all of the geophysical surveys conducted by C.S.M. and others in the western San Luis Valley area. Bond's studies showed that a low resistivity zone is present in the immediate vicinity north of Shaw Warm Springs, which may be related to the thermal water emerging from the mapped faults in the area.

### Seismic Reflection Surveys:

Geophysics Fund Inc., under contract to the Colorado Geological Survey, attempted seismic reflection surveys along the western side of the San Luis Valley. Due to unfavorable geological conditions, namely volcanic flows, the reflective data acquired was poor. James K. Applegate (1981), project leader, noted that it is possible to analyze this problem by looking at seismic data acquired in other portions of the San Luis Valley and from other studies in similar geological provinces and contrasting them to the Shaw Warm Springs data.

Applegate (1981), noted that much better quality seismic data has been acquired on the east side of the San Luis Valley where there is a thicker section of sediments. He postulated that on the west side the thicker volcanic rock sequence, which occurs closer to the surface than on the east side, may act as a scatterer and reflector of the seismic energy. To over come this problem Applegate suggested that maybe a different set of seismic parameters than those used might give useful seismic data on the western side of the Valley.




EXPLANATION

| | | | |
|---|---|---|---|
| **Qf** | Quaternary alluvial fan deposits | **Tsd** | Tertiary rhyodactite |
| **Qal** | Quaternary alluvium | **Tsq** | Tertiary quartz latite |
| **Qc** | Quaternary colluvium | **Tsa** | Tertiary andesite |
| **Tvs** | Tertiary volcanic sandstone and conglomerate | **Tsi** | Tertiary dikes |
| **Tcr** **Tfc** **Tmp** | Tertiary tuff | ■ | AMT stations |
| | | (fault symbol) | Fault; dashed where inferred, ball on downthrown side |

Figure 16. Telluric profile location map and generalized geology of Shaw Springs, Colorado (adopted from Christopherson and others, 1981).

Applegate (1981), noted that successful seismic surveys have been conducted in other interlayered volcanic rock areas, such as the Snake and Raft River Plains of Idaho and the Nevada Test Site. These surveys were conducted utilizing high resolution seismic methods with very close geophone spacings using "Vibroseis" equipment ("Vibroseis" is a registered trademark of Continental Oil Company).

In summary, Applegate (1981) stated that in light of the geological conditions of the area and equipment limitations, it would appear, that no matter what methods are used, that it would be difficult to acquire quality seismic data on the western flank of the San Luis Valley. It is possible that there are "windows" where one could see through the shallow volcanics. However, it is also quite possible that these windows are very limited in extent and that it would be very expensive and difficult to locate them.

Applegate (1981) stated that it appears unlikely that, without extensive work, it will be impossible to acquire quality seismic data on the western flank of the valley and, in particular, in the Shaw Warm Springs area. How far one has to go to the east before the data quality improves significantly is an unknown factor which can be determined only by expanded field effort.

## Time-Domain Electromagnetic Sounding Surveys:

Students at the Colo. School of Mines geophysical summer camp ran two time-domain electromagnetic sounding (TDEM) surveys north and east of Shaws Warm Springs (Fig. 17). TDEM is an electrical prospecting technique that provides information about the electrical properties of rocks to a depth of several kilometers. Bond (1981) presents a complete description of the theory and the field techniques employed by this method.

Based on TDEM soundings conducted in the Shaw Warm Springs area Bond (1981), drew an east-west and a north-south section (Figs 18 and 19). According to Bond (1981) these two sections, which represent a complete coverage of the Shaw Warm Springs area, show a zone to a depth of at least 3,281 ft (1000 m) of saturated volcanic flows, tuffs and alterations.

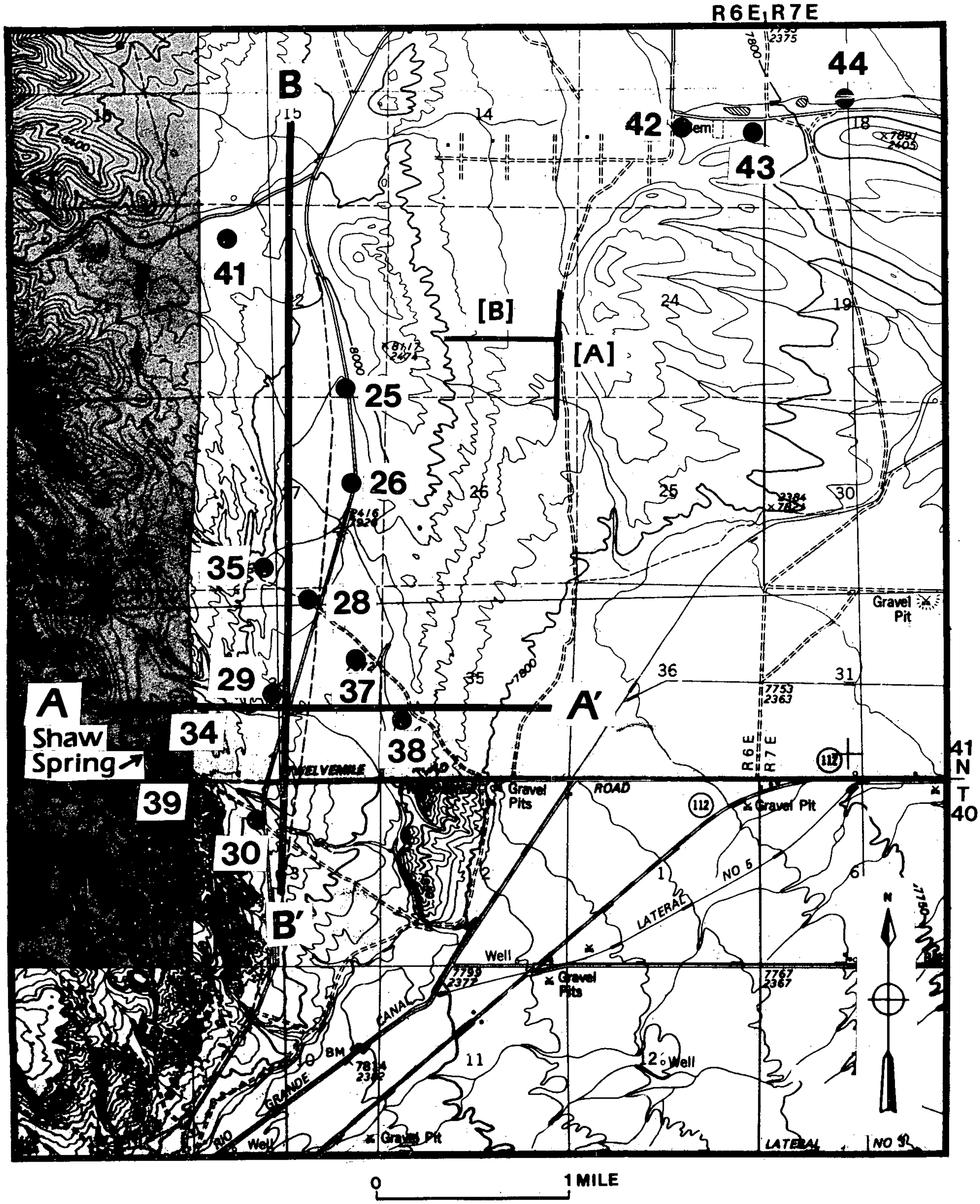



Figure 17. TDEM receiver and profile locations map. Sources (A) and (B). (Adopted from Bond, 1981.)

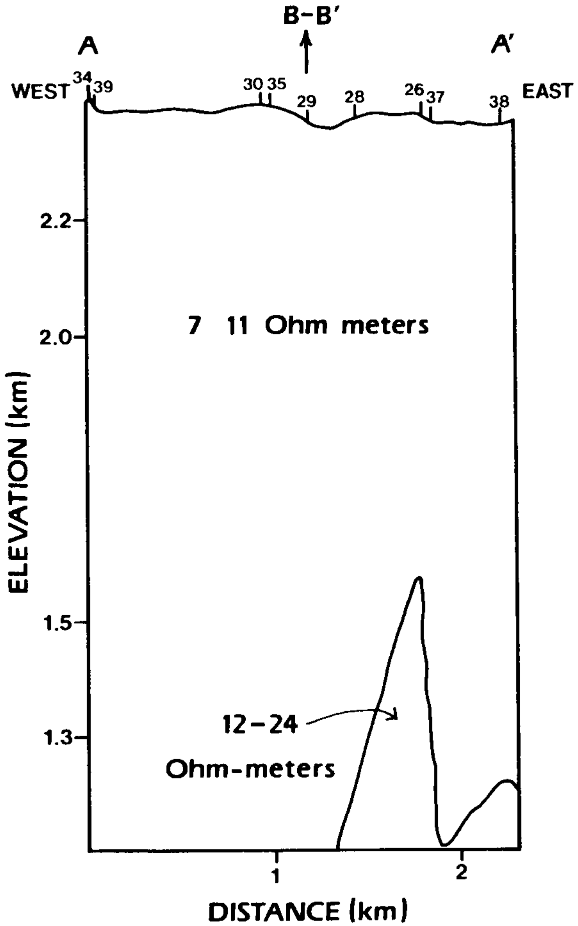



Figure 18. East-west time-domain electro-magnetic sounding cross-section (adopted from Bond, 1981).

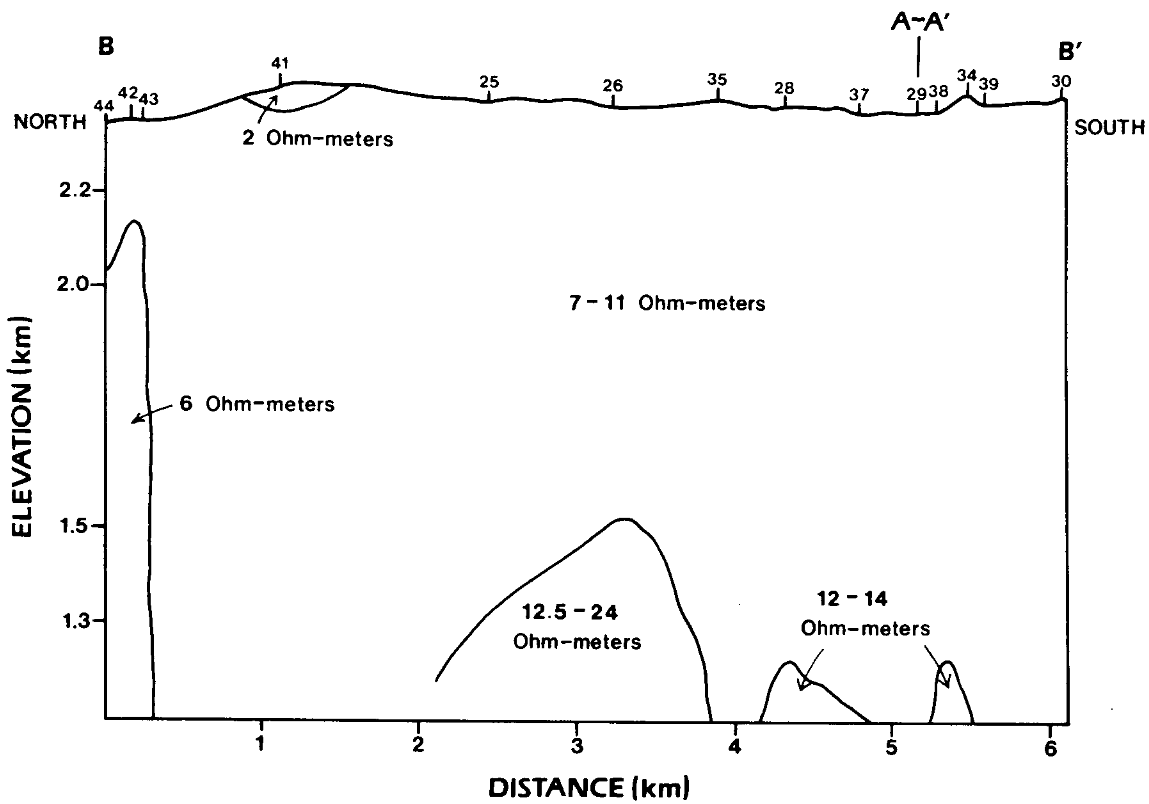



Figure 19. North-south time-domain electromagnetic sounding cross-section (adopted from Bond, 1981).

## SOIL MERCURY SURVEYS

### Introduction

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

Matlick and Buseck (1976), in presenting the geochemical theory behind the associations of mercury with geothermal deposits, noted that mercury has great volatility, and that the elevated temperatures of most geothermal systems tends to cause the element to migrate upward and away from the geothermal reservoir. In addition, they noted the work of White (1967) and White and others (1970), showed that relatively high concentrations of mercury are found in thermal waters. Matlick and Buseck (1976) 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 in the Glenwood Springs geothermal area. 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. Their survey indicated anomalous zones at Glenwood Springs.

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

## SOIL MERCURY SURVEY IN THE SHAW WARM SPRINGS AREA

Employing sampling methods set forth by Capuano and Bamford (1978), 143 soil samples were collected during the summer of 1979 at 100 ft (30.48 m) intervals in the Shaw Warm Springs area (Fig. 20). The lines were located to cross any

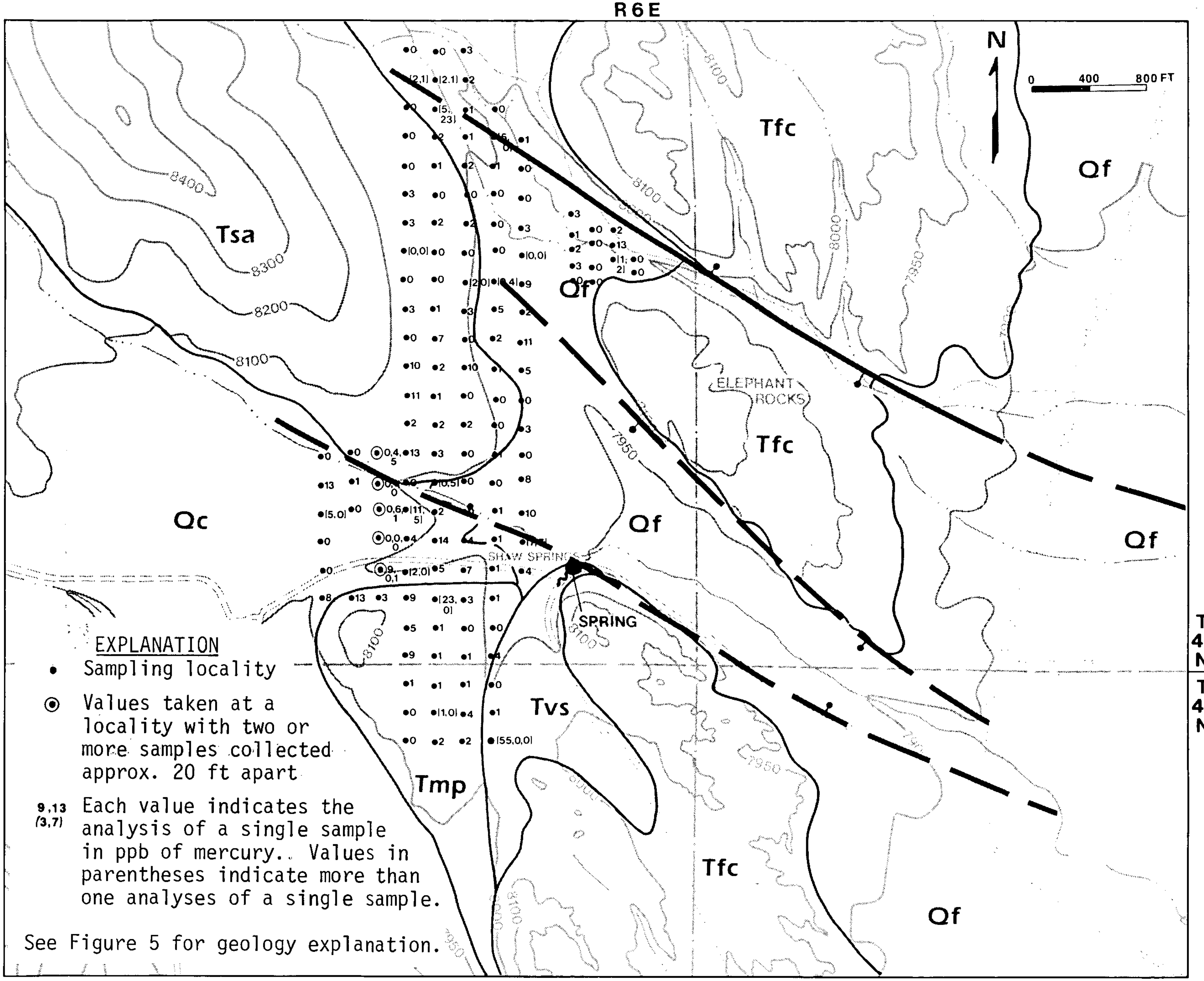



Figure 20. Location, soil mercury lines, Shaw Warm Springs.

possible controlling faults. Analytical results ranged from a low of 0 ppb to a high of 55 ppb. A complete description of the equipment and methodology employed by the Colorado Geological Survey for this program at Shaw Warm Springs are presented in Appendix F.

## Soil Description

Soil development along the three lines is very thin or nonexistent. For the sample localities located on the Tertiary andesite bedrock, samples were collected just above the bedrock usually at a depth of less than 7 in (17.78 cm). For those samples collected in the Quaternary deposits and in the Tertiary tuffs, sands and gravels were consistently found at sampling depth which varied from 4 - 7 in (10.16 - 17.78 cm).

## Mercury Anomalies

Sixteen samples were collected about one mile south of Shaw Warm Springs to determine the soil mercury background values. Analysis determined that the mercury contained in these samples ranges from less than 1 ppb to 8 ppb. These samples were all taken from Quaternary alluvial fan deposits, and thus are not completely representive of the study area. Analysis of the mercury values in the study areas was not so straightforward because there were so many values less than 1 ppb.

To aid in determination of background vs anomalous concentration levels the analytical data was graphically plotted and analyzed (Fig. 21). Based on a subjective interperation of the histogram plot of the analytical data, it was decided that all values above 6 ppb should be considered anomalous.

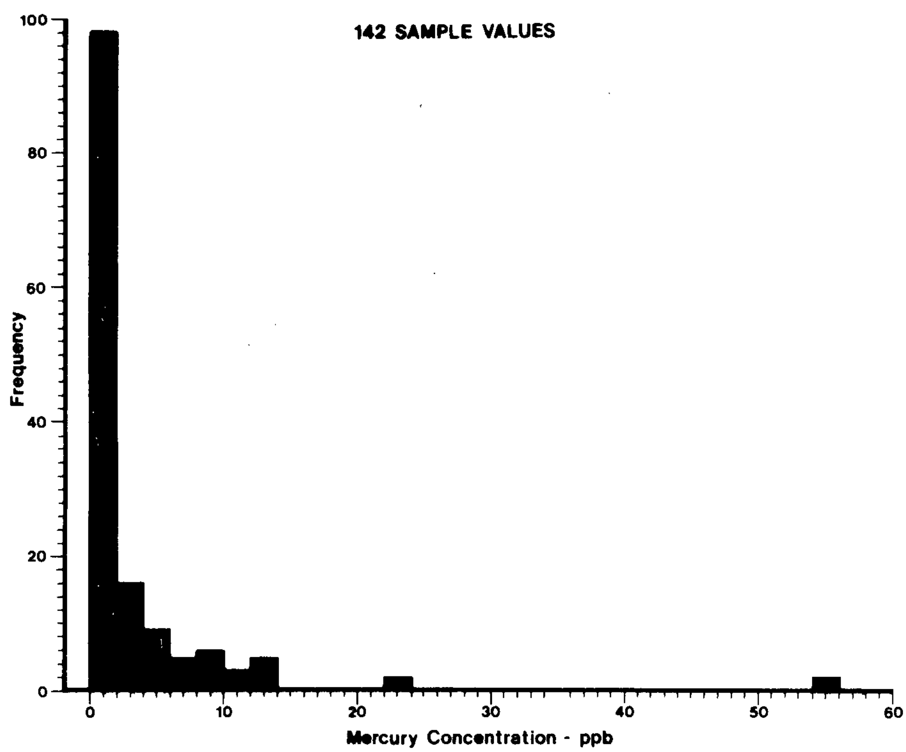



Figure 21. Shaw Warm Springs, Colorado soil mercury histogram

At numerous sample sites mercury concentrations were measured above the expected background limits (Fig. 20). Upon reanalysis many of these values were determined not to be significant. Cursory observation suggests that variation due to laboratory analysis is contributing a high percentage of the variance between sample localties.

Even though some of the anomalous values upon reanalysis proved to be lower, the presence of several faults is indicated (Fig 20). Prior to the commencement of this study one of these faults was unknown. This fault, which trends in a northwest direction, is located just adjacent to Shaw Warm Springs and is indicated by several high analytical values. Another fault, which had been previously mapped, located in the first valley north of Shaw Warm Springs, is indicated by high analytical values.

One of the problems why more definitive values were not recorded may have been the unfavorable soil media (sand and gravel material) for adsorbing mercury.

Table 3 Analytical mercury values, Shaw Warm Springs area.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0* | 0 | 0 | 0 | 1 | 1 | 2 | 3 | 5 | 11 |
| 0** | 0 | 0 | 0 | 1 | 1 | 2 | 3 | 5 | 13 |
| 0 | 0 | 0 | 0 | 1 | 1 | 2 | 3 | 7 | 13 |
| 0 | 0 | 0 | 0 | 1 | 1 | 2 | 3 | 7 | 13 |
| 0 | 0 | 0 | 0 | 1 | 2 | 2 | 3 | 7 | 13 |
| 0 | 0 | 0 | 0 | 1 | 2 | 2 | 3 | 8 | 14 |
| 0 | 0 | 0 | 0 | 1 | 2 | 2 | 4 | 8 | 23 |
| 0 | 0 | 0 | 0 | 1 | 2 | 2 | 4 | 9 | 55 |
| 0 | 0 | 0 | 0 | 1 | 2 | 2 | 4 | 9 | |
| 0 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 9 | |
| 0 | 0 | 0 | 0 | 1 | 2 | 3 | 5 | 10 | |
| 0 | 0 | 0 | 0 | 1 | 2 | 3 | 5 | 10 | |
| 0 | 0 | 0 | 1 | 1 | 2 | 3 | 5 | 10 | |
| 0 | 0 | 0 | 1 | 1 | 2 | 3 | 5 | 11 | |
| 0 | 0 | 0 | 1 | 1 | 2 | 3 | 5 | 11 | |

* Represents first value recorded and no replicated values.
** Zero should be interpreted as less than 1 ppb.

## ORIGIN OF THE SHAW WARM SPRINGS THERMAL WATERS

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

Thermal waters are of either magmatic or meteoric origin. Magmatic waters are waters driven off from a cooling igneous rock body. Meteoric waters are those waters which have fallen on the surface of the earth in the form of precipitation, then due to natural processes have become part of the ground-water system. Craig (1961) and Craig and others (1956) have demonstrated that most thermal waters are of meteoric origin. To definitely prove that the thermal waters of the study area are of meteoric origin would necessitate sampling and analyzing the waters for various oxygen isotopes, which was not done. There is a remote possibility that the thermal waters of Shaw Warm Springs could be of magmatic origin, however on a world wide basis waters of this origin are very rare and until proven otherwise it will be assumed that the thermal waters of the study area are of meteoric origin.

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

One of the problems left unanswered by this investigation is the mechanism by which the ground waters are heated. The several possible means by which the waters could become heated are volcanic rocks, high heat flow, and decay of radioactive minerals. While the San Juan volcanic field is composed of Tertiary age volcanic rocks (Table 2) theoretically these rocks are too old (>20 million years) to be the source of the heat. Another mechanism by which the waters could become heated is by the regional heat-flow of the area. Heat-flow calculations have shown that the San Luis Valley has above normal heat-flow (Edwards and others, 1978, Reiter and others, 1975, and Zacharakis, 1981). The regional heat-flow of the western San Luis Valley ranges from less than 100 $mW/m^2$ to over 120 $mW/m^2$. This is above the state wide average of approximately 100 $mW/m^2$ (Fig. 3). Cordell (1978), in his geophysical assessment of the Rio Grande Rift, stated that the high heat-flow along the Rift is probably of magmatic and subcrustal origin rather than radiogenic. He (Cordell, 1978) believed that the high heat-flow is probably associated with a Pliocene age high-temperature anomaly at depth. Therefore, until proven other wise, it is assumed by the authors that the thermal waters of Shaws Warm Spring are of meteoric origin and are being heated by deep circulation in an area having above normal geothermal gradients.

An estimate to what depth these thermal waters might have circulated too can be made based on the geothermal gradient of the area plus the estimated reservoir temperature. It has been estimated that Shaw Warm Springs thermal system has a maximum subsurface reservoir temperature of 140°F (Barrett and Pearl, 1978).

As noted earlier the geothermal gradient for this area is 1.9°F/100 ft (35°C/km). Therefore to reach these temperatures, it can be calculated that the waters would need to circulate to a depth of approximately 5,526 ft. (1.7 km) below the recharge area.

In summary it can be concluded that the thermal waters of Shaw Warm Springs most likely are of meteoric origin. Some of the precipitation that fell on the surface of the land became part of the ground waters of the area which migrated to depth along faults or other permeable channels in an area of above normal gradients. In so doing the waters became heated, then returned to the surface via fault zones or other permeable zones.

## SUMMARY AND CONCLUSIONS

An extensive geothermal energy resource assessment program was carried out in the vicinity of Shaws Warm Spring. Shaw Warm Springs, is located about 6 mi (9.66 km) north of Del Norte along the western side of the San Luis Valley in southcentral Colorado. While thermal waters have been produced from water wells east of Del Norte, in the central part of the Valley, other than Shaw Warm Springs, no thermal waters have been reported along the west side of the Valley.

With the exception of the seismic geophysical survey, all the other surveys conducted in the vicinity of Shaw Warm Springs were successful, to one degree or another, in delineating the geological conditions controlling its occurrence. Shaws Warm Spring appear to be coming up from depth along a buried fault having no surface expression. Two of the electrical geophysical surveys gave contradictory interpretations of the geothermal conditions. The Schlumberger depth soundings demonstrated a shallow (<900 ft (274 m)) fault bounded reservoir located north of Shaw Warm Springs. On the other hand the deeper reading (1,640 ft (500 m)) AMT survey did not locate any reservoir. As this contradiction was not apparent until after all field work had been completed no other measurements were made which might have resolved the problem.

From the best evidence available it appears that the thermal waters of Shaw Warm Springs are of meteoric origin, and became heated due to deep circulation (< 5,526 ft, 1.7 km) in an area having above normal geothermal gradients. The reservoir is probably small and limited in extent. Earlier estimates suggested that this thermal area might encompass no more than 0.63 sq mi (1.62 sq km) and contain approx. 0.0148 Q's of heat energy at a temperature of 113° F (45° C). In light of the findings of this present study it is believed that those estimates are probably correct. Figure 22 summarizes findings of all the surveys conducted.

From all evidence gathered during the course of this investigation it appears that the only thermal waters along the western side of the San Luis Valley are those at Shaw Warm Springs. While this investigation centered on Shaw Warm Springs and the immediate adjacent area, no evidence was obtained to suggest that other thermal waters would be found at relatively shallow depths along the west side of the San Luis Valley. It was beyond the scope of this project to investigate the geothermal resources of the deep Monte Vista Graben, east of Shaw Warm Springs. From a cursory examination of the geological conditions of the Monte Vista Graben it appears that one could expect to find geothermal fluids in it at depth.

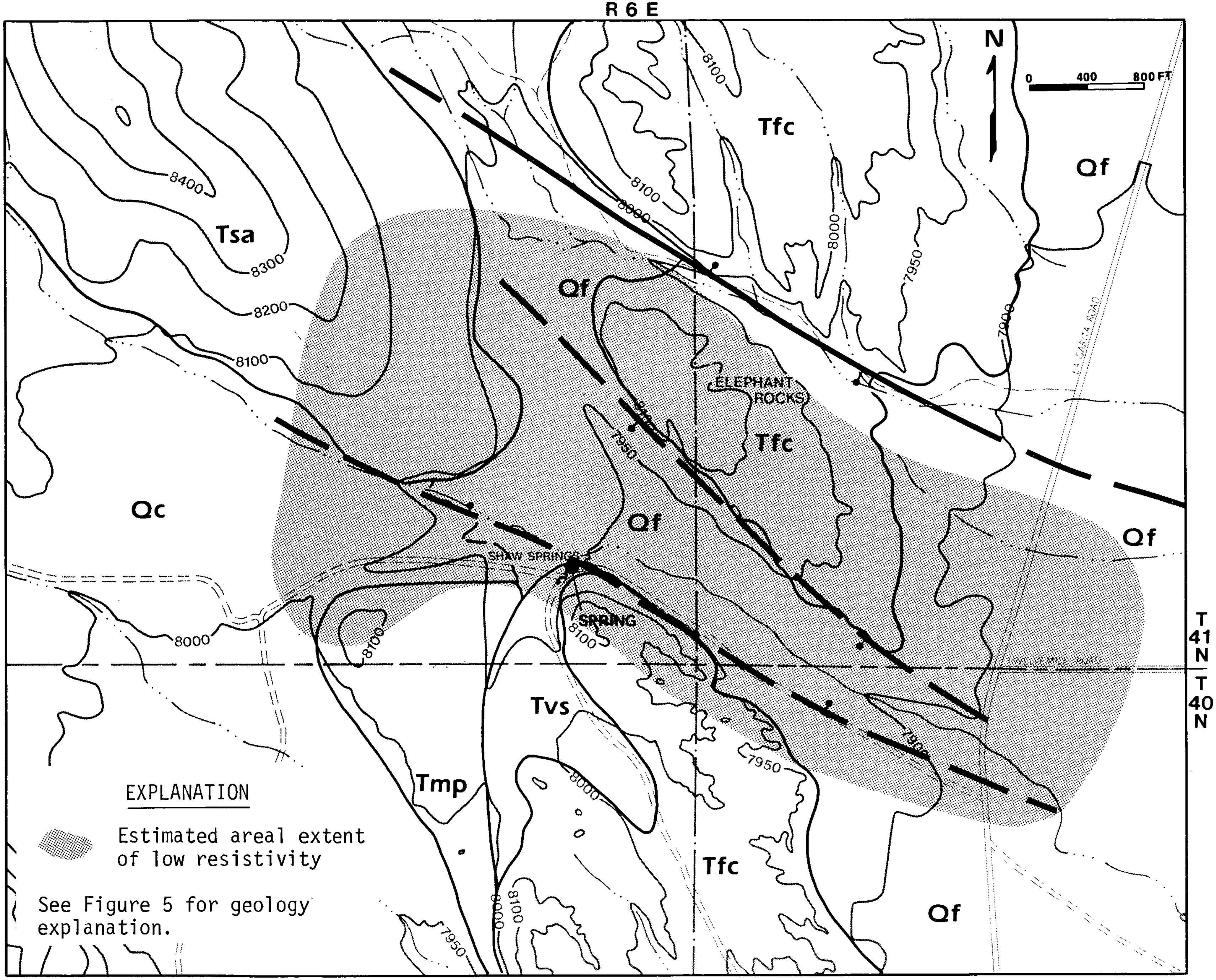



Figure 22. Shaw Springs, Colorado geothermal resource area map.

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## APPENDIX A

## GEOTHERMAL ENERGY AND ITS POSSIBLE USES

Geothermal energy, the heat generated by natural processes beneath the earth's surface normally occurs at great depths. In some places, however it can be found close to or at the surface in the form of volcanoes, geysers or hot springs. Where it occurs near the surface it can be developed and put to beneficial use. Geothermal energy in the form of hot springs has been used by mankind for medicinal and cooking purposes since the earliest days of recorded history. In the last 100 years development of this energy source for other uses has occurred, and it is now used for such purposes as: Generation of electricity; heating and cooling of buildings; processing of food and other goods; heating cattle barns, greenhouses and fish ponds; milk pasteurization; and recreation and medicinal purposes. Due to declining petroleum reserves It is anticipated that in years to come development of this energy source will increase. Figure 23 lists some of the uses geothermal energy could be put to and the temperatures required.

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

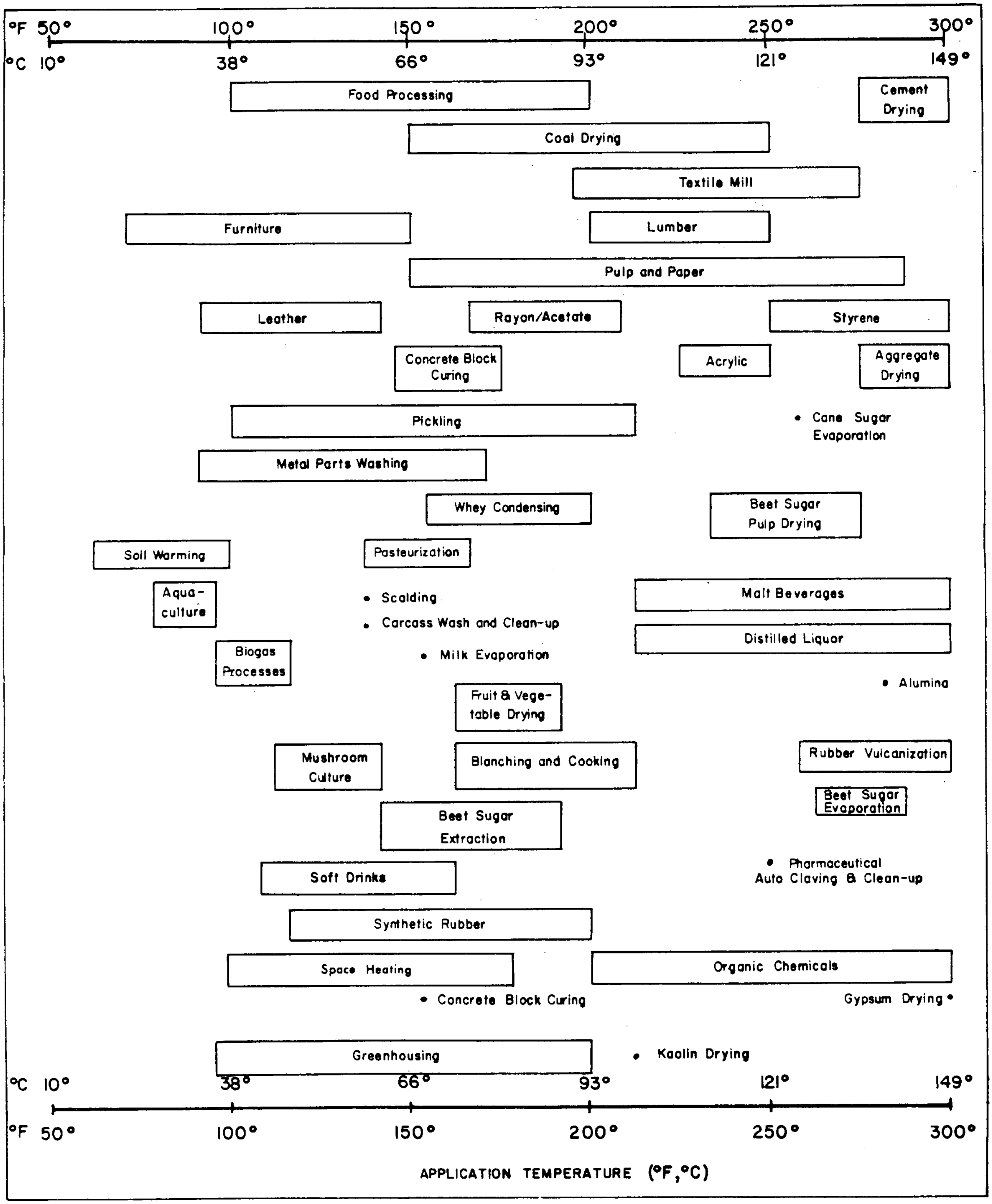



Figure 23. Temperature range for some direct uses of geothermal energy. (Adopted from Anderson and Lund, 1979).

## APPENDIX B. SHAW WARM SPRINGS THERMAL WATERS

Table 4. Physical properties and chemical analysis of Shaw Warm Springs.

| | Date Sampled | | | |
|---|---|---|---|---|
| | 8/75 | 10/75 | 1/76 | 4/76 |
| Arsenic, (UG/L) | 0 | 0 | - | - |
| Boron, (UG/L) | 130 | 140 | 120 | 270 |
| Cadium, (UG/L) | 0 | 0 | - | - |
| Calcium, (MG/L) | 0.9 | 0.5 | 2.7 | 0.9 |
| Chloride, (MG/L) | 7.5 | 7.2 | 7.3 | 7.0 |
| Fluoride, (MG/L) | 3.1 | 2.9 | 3.0 | 4.2 |
| Iron, (UG/L) | 40 | 20 | 10 | 0 |
| Lithium, (UG/L) | 10 | 10 | - | - |
| Magnesium, (MG/L) | 0.6 | 0.3 | 0.7 | 0.1 |
| Manganese, (UG/L) | 0 | 0 | 0 | 10 |
| Mercury, (UG/L) | 0 | 0 | - | - |
| Nitrogen, (MG/L) | 0.01 | 0.02 | 0.02 | 0.01 |
| Phosphate | | | | |
| Ortho diss. as P, (MG/L) | 0.04 | 0.03 | 0.05 | 0.04 |
| Ortho, (MG/L) | 0.12 | 0.09 | 0.15 | 0.12 |
| Potassium, (MG/L) | 1.5 | 1.4 | 1.5 | 1.5 |
| Selenium, (UG/L) | 0 | 0 | - | -0 |
| Silica, (MG/L) | 83 | 73 | 100 | 76 |
| Sodium, (MG/L) | 130 | 130 | 130 | 130 |
| Sulfate, (MG/L) | 50 | 53 | 46 | 46 |
| Zinc, (UG/L) | 0 | 0 | - | - |
| Alkalinity | | | | |
| As Calcium Carb., (MG/L) | 214 | 222 | 221 | 219 |
| As Bicarbonate, (MG/L) | 121 | 114 | 154 | 127 |
| Hardness | | | | |
| Noncarbonate, (MG/L) | 0 | 0 | 0 | 0 |
| Total, (MG/L) | 5 | 2 | 10 | 3 |
| Specific Conductance (Micromohs) | 550 | 540 | 569 | 556 |
| Total Dissolved Solids (MG/L) | 406 | 402 | 424 | 398 |
| ph, Field | 9.3 | 9.3 | 9.0 | 8.9 |
| Discharge (gpm) | 34 | 34 | 52 | 40 |
| Temperature (°C) | 30 | 30 | 30 | 30 |

Location: SE, SE, Sec. 33, T. 41 N., R. 6 E., New Mexico Principal Meridan.

Remarks: Carbonate content: 69; 77; 57; and 69 mg/l respectively.
Source of data: Barrett and Pearl (1976)

# APPENDIX C

## FACTORS AFFECTING RESISTIVITY

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

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

During the course of its investigations The Colorado Geological Survey, employed the method of man induced electrical currents. A complete description of the equipment and field procedures used are presented in Appendecies D and E.

## APPENDIX D

### SCINTREX RAC-8 LOW FREQUENCY RESISTIVITY SYSTEM

The following description of the Scintrex RAC-8 electrical resistivity equipment used by the Colorado Geological Survey is taken from the Scintrex Manual (1971). The Scintrex RAC-8 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 differences in resistivity. In some areas where the lithology reflected small differences in resistivity, the RAC-8 system appeared to average the penetrated lithologic sequences rather than picking up distinct breaks. Considering cost and time constraints, the system performed as indicated and performed best in areas of high resistivity.

APPENDIX E

# RESISTIVITY FIELD PROCEDURES

## Introduction

One of the most widely used electrical 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. 24). 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. 25) 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.

## Schlumberger Array

For the Schlumberger array, the current electrodes are spaced much further apart than the potential electrodes (Fig. 26).

In depth probing the potential electrode remains fixed while the current electrode spacing is expanded symmetrically about the center of the spread. For large values of L it may be necessary to increase 2 x 1 also in order to maintain a measurable potential. This procedure is more convenient than the Wenner expanding spread because only two electrodes need move. In addition, the effect of shallow resistivity variations is constant with fixed potential spread (Sumner, 1976).

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

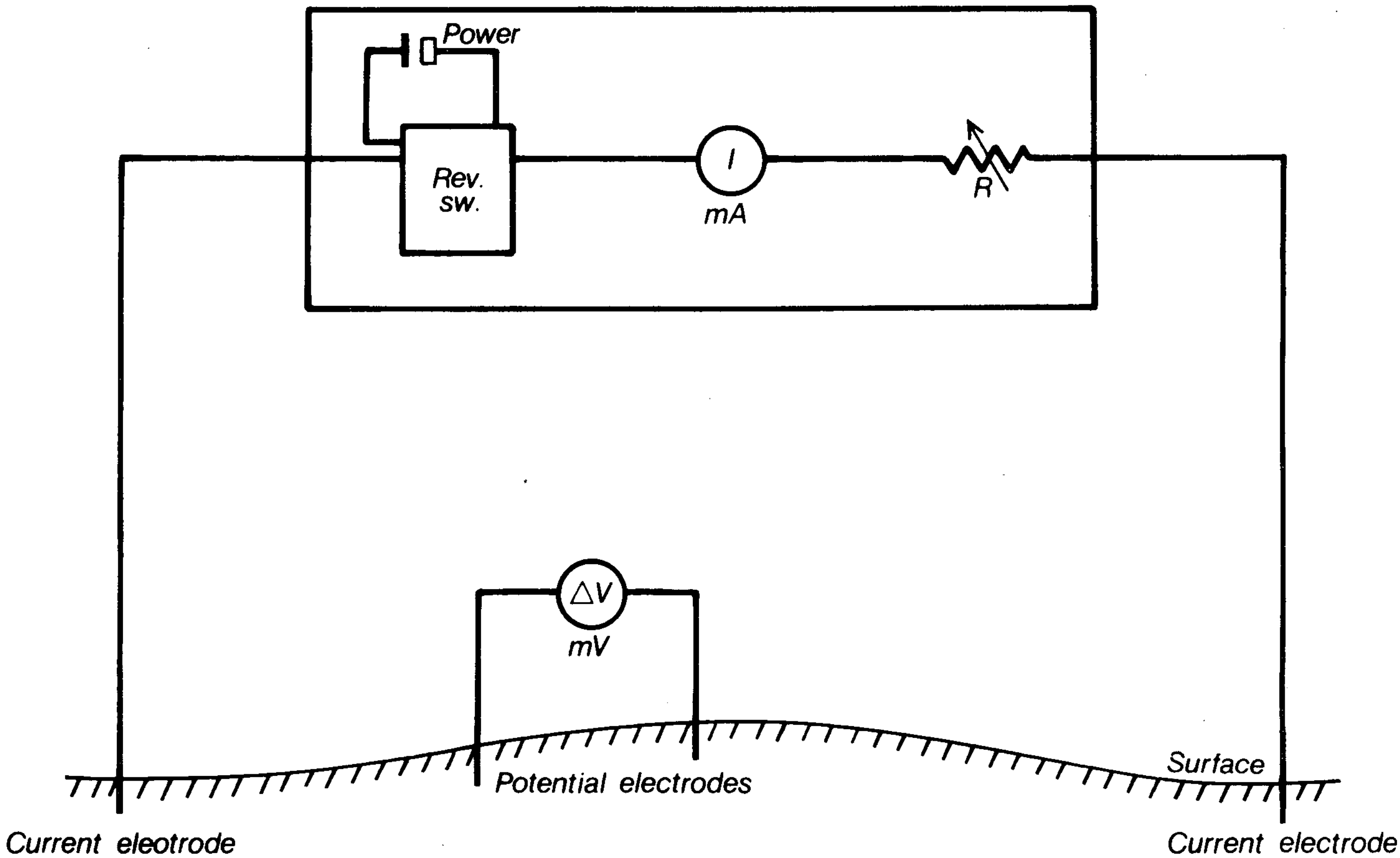
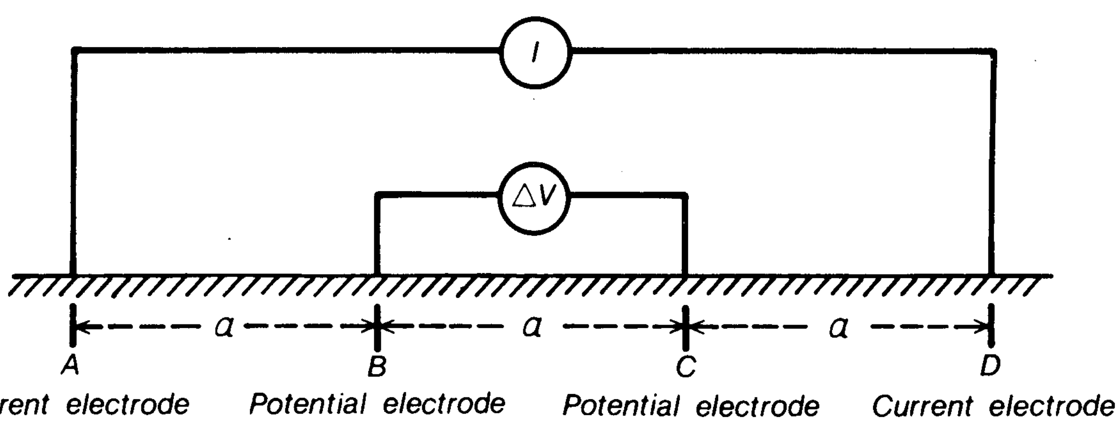



Figure 24. Schematic diagram for resistivity (from Combs, 1980).




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

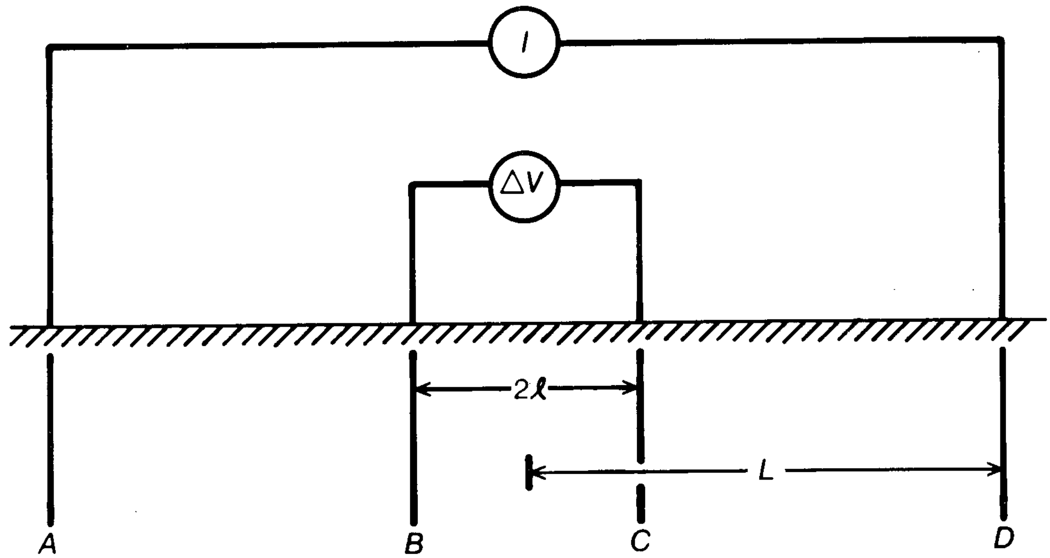
Figure 25. Wenner array (from Combs, 1980).

## Dipole-dipole Array

The potential electrodes are closely spaced and remote from the current electrodes which are close together. There is a separation between C and P , usually 1 to 5 times the dipole lengths (Fig. 27).

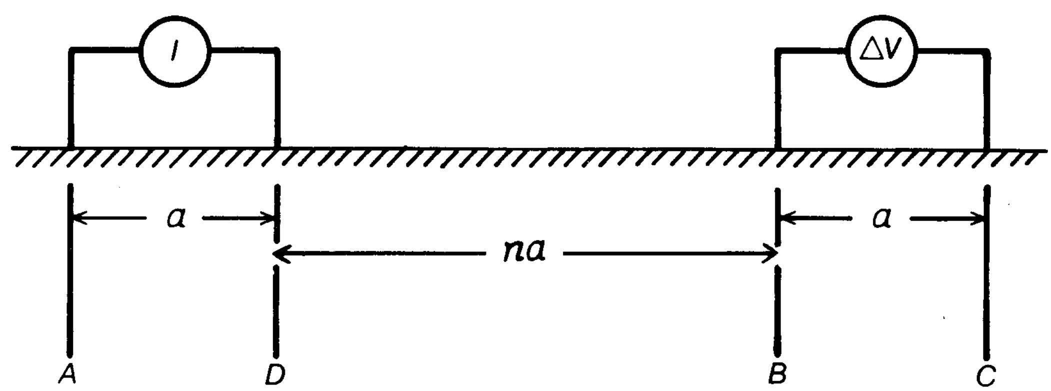
Inductive coupling between potential and current cables is reduced with this arrangement. This method was primarily used throughout all study areas because of reliability and ease of field operation. A diagram of this method is depicted in Figures 28 and 29.

With reference to Figures 28 and 29, an in-line 100 foot dipole-dipole electrode geometry was used. Measurements were made at dipole separations of n = 1, 2, 3, 4, 5. The apparent resistivities have been plotted as pseudosections, with each data point being plotted at the intersections of two lines drawn at 45° from the center of the transmitting and receiving dipoles. This type of survey provides both resolution of vertical and horizontal resistivity contrasts since the field procedures generate both vertical sounding and horizontal profile measurements. The principal advantage of this technique is that it produces better geologically interpretable results than the other two methods (Wenner, Schlumberger). In addition, the dipole-dipole array is easier to maneuver in rugged terrain than either of the other methods. Its main disadvantage compared to the Schlumberger array is that is usually requires more current, and therefore a heavier generator for the same penetration depth. Another disadvantage of this method is that it is very difficult to make an accurate interperation from the data collected (Sumner, 1976).




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

Figure 26. Schlumberger array (from Combs, 1980).




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

Figure 27. Dipole-dipole array (from Combs, 1980).

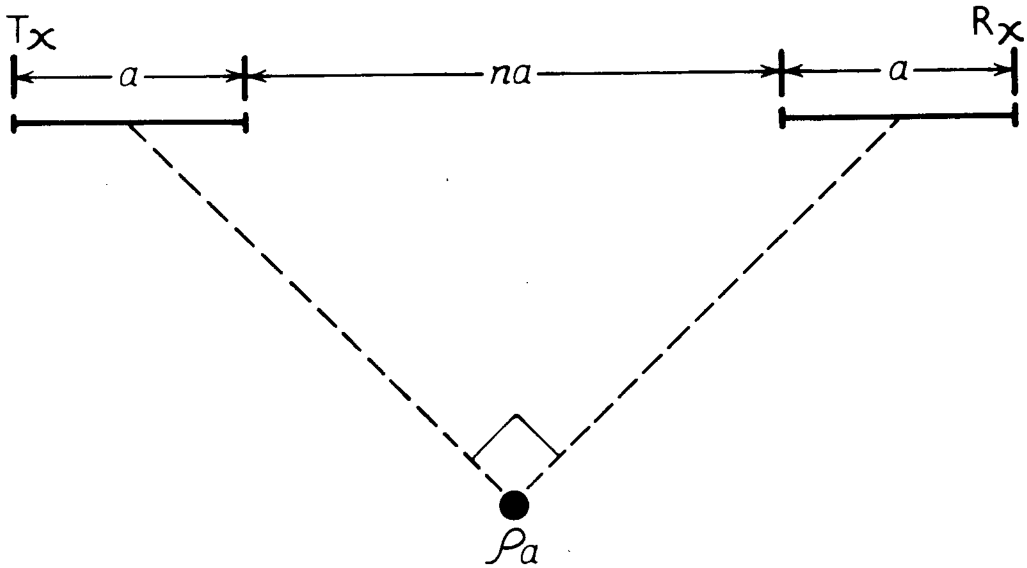



Figure 28. Data plotting scheme for dipole-dipole array (from Combs, 1980).

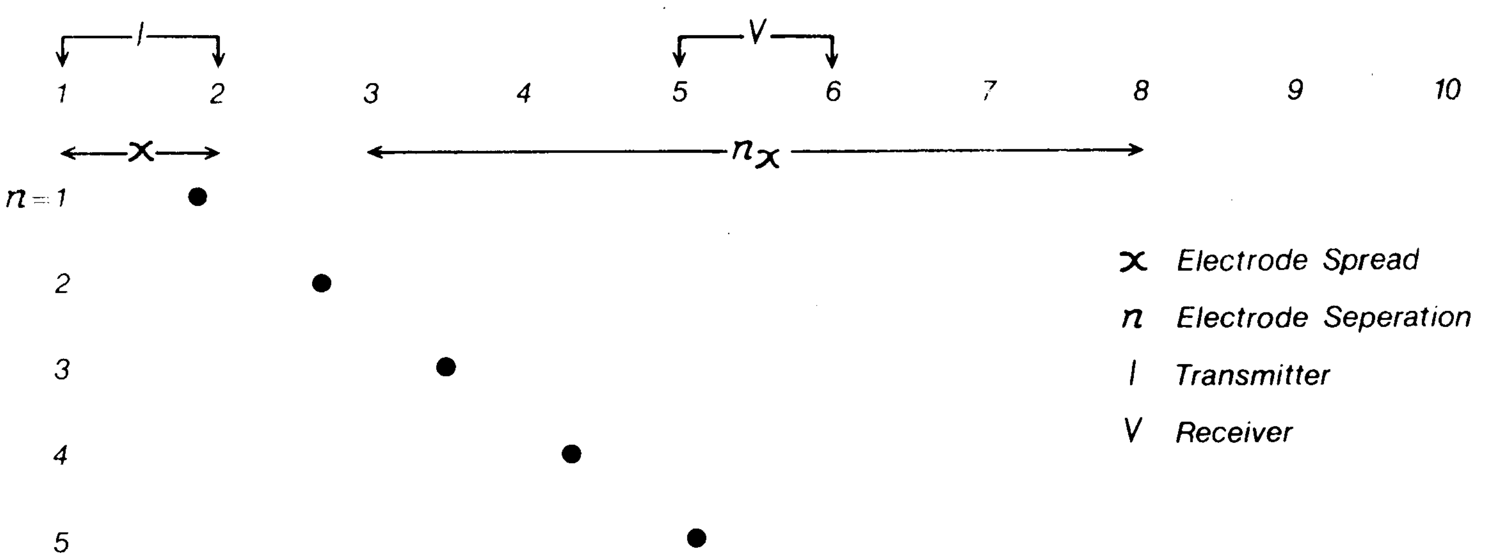



Figure 29. Typical dipole-dipole array (from Combs, 1980).

## APPENDIX F

## SOIL MERCURY SURVEYS

### Strategy and Methodology

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

During the course of the investigations the following restrictions became apparent: urban development; alluvial and colluvial deposits; and mining areas. In urban developments one cannot really be sure whether the surface deposits in the back streets and lawns are original or have been brought in. In sampling alluvial and colluvial surficial deposits such deposits because of their origin, age and mineral content tend to mask, dilute, and/or distort any anomalies. In old mining area the problem becomes whether the mercury concentrations found are caused by mineralization or by geothermal actitivty.

### Sampling Methods

At selected sample sites, one to eight samples were taken at points within 15 to 20 ft of each other. The notation of sampling locality is explained in Miesch (1976). The interval between sampling sites depends on the target being considered. For areas investigated, the sample site interval was either 100 ft to 200 ft or 400 ft (30 m to 61 m or 122 m). When using a 400 ft (122 m) interval, the area in the immediate vincinity of the hot spring was considered the target rather than any particular fault. Sampling intervals of 200 ft (61 m) or less were used where attempts were made to delineate controlling faults. This spacing was used by Capuano and Bamford (1978). However, Klusman and Landress (1979) seem to think that the sample must be taken directly over the faulting for detection. Considering the empirical result of Capuano and Bamford (1978), it was believed that some anomalous mercury values should be encountered if a grid pattern encompassing the hot spring area was used. A definite structural pattern may be obvious, but if the study area is being influenced by geothermal activity, the trend should indicate that the hot sprins area entirely or partially is high in mercury relative to surrounding area.

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

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

Two rationales have been used for determining the sampling depth. The method recommended by Capuano and Bamford (1978) is to determine the profile of mercury down to a depth of approximately 16 in (40 cm), the depth at which the profile peaks determines the sampling depth. The other method consistently samples a soil horizon, such as the A or B horizon. The problem with using the A horizon is that its normally high organic content has been shown to have strong secondary effects in controlling mercury in the soil. Also, the sampling depth in the A horizon may not be deep enough to avoid the "baking" effect of the sun.

The method used during 1979 consisted of using profiles to determine sampling depths. A sampling depth of approximately 6 in (15 cm), with an interval of about 0.4 in (1 cm), was used for most of the profiles. During 1980 each sample was taken over an interval of 5 to 7 in (13 to 18 cm). It was hoped that some of variance due to depth would be smoothed out by sampling over a wider interval. Also, at that depth it was hoped that the sun would not be affecting the soil's ability to retain mercury.

To collect a sample, the ground was broken with a shovel to a depth of 9 to 10 in (20 to 25 cm). Then a spatula and metal cup were used to collect approximately 100 grams of material. The contents of the cup were then put in a marked plastic bag. At the end of the day the material in each bag was laid out and allowed to dry overnight. Sometimes it would take more than one night to dry. Normally, the following morning the dried material would be sieved down to an 80 mesh size outside in a shaded area and stored in 4 ml glass vials with screw caps. Within a period of seven days later, the samples were analyzed for mercury using the Model 301 Jerome gold film mercury detector.

## Analysis

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

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

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

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

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

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

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

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

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

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

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

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

APPENDIX G. RESISTIVITY CALCULATIONS

Table 5. LINE A

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

| LOCATION | PROJECT | DATE |
|---|---|---|
| Shaw Springs | Line A | 11 June 1980 |
| CHIEF OPERATOR | ASSISTANTS | METHOD |
| Jay Jones | Fargo and Treska | Dipole-Dipole (Nx100') |

| Sta. | Range | MA | Voltage | $V_p$ | DV/I | G.F. | $P_a$ |
|---|---|---|---|---|---|---|---|
| 34-33 | | | | | | | |
| 32-31 | 10 | .01 | 66 | 1.29 | .129 | 575 | 74.2 |
| 31-30 | 1 | .01 | 66 | 1.18 | .0118 | 2299 | 27.1 |
| 30-29 | 1 | .01 | 66 | 0.28 | .00258 | 5747 | 15 |
| 29-28 | 1 | .001 | 66 | 1.25 | .00125 | 11493 | 14 |
| 28-27 | 1 | .001 | 66 | 0.71 | .00071 | 20112 | 14 |
| 33-32 | | | | | | | |
| 31-30 | 100 | .001 | 66 | 2.06 | .206 | 575 | 118 |
| 30-29 | 10 | .001 | 66 | 1.73 | .0173 | 2299 | 40 |
| 29-28 | 1 | .001 | 66 | 3.95 | .00395 | 5747 | 23 |
| 28-27 | 1 | .001 | 66 | 1.53 | .00153 | 11493 | 18 |
| 27-26 | 1 | .001 | 66 | 0.78 | .00078 | 20112 | 16 |
| 32-31 | | | | | | | |
| 30-29 | 100 | .001 | 66 | 3.85 | .385 | 575 | 221 |
| 29-28 | 10 | .001 | 66 | 3.58 | .0358 | 2299 | 82 |
| 28-27 | 1 | .001 | 66 | 3.73 | .00373 | 5747 | 21 |
| 27-26 | 1 | .001 | 66 | 1.46 | .00146 | 11493 | 17 |
| 26-25 | 1 | .001 | | 0.65 | .00065 | 20112 | 13 |
| 25-24 | 1 | .001 | | .55 | | | 18 |
| 31-30 | | | | | | | |
| 29-28 | 100 | .001 | 66 | 3.35 | .335 | 575 | 193 |
| 28-27 | 10 | .001 | 66 | 1.16 | .0116 | 2299 | 27 |
| 27-26 | 1 | .001 | 66 | 3.14 | .00314 | 5747 | 18 |
| 26-25 | 1 | .001 | 66 | 1.22 | .00122 | 11493 | 14 |
| 25-24 | 1 | .001 | 66 | 0.93 | .00093 | 20113 | 19 |
| 30-29 | | | | | | | |
| 28-27 | 100 | .001 | 66 | 1.21 | .121 | 575 | 70 |
| 27-26 | 10 | .001 | 66 | 1.00 | .01 | 2299 | 23 |
| 26-25 | 1 | .001 | 66 | 2.81 | .00281 | 5747 | 16 |
| 25-24 | 1 | .001 | 66 | 1.88 | .00188 | 11493 | 22 |
| 24-23 | 1 | .001 | 66 | .8430 | .000843 | 20113 | 17 |

TABLE 5. LINE A (CONT.)

| Sta. | Range | MA | Voltage | $V_p$ | DV/I | G.F. | $P_a$ |
|---|---|---|---|---|---|---|---|
| 29-28 | | | | | | | |
| 27-26 | 100 | .001 | 100 | .85 | .085 | 575 | 59 |
| 26-25 | 10 | .001 | 100 | .84 | .0084 | 2299 | 19 |
| 25-24 | 10 | .001 | 100 | .45 | .0045 | 5747 | 26 |
| 24-23 | 1 | .001 | 100 | 1.61 | .00161 | 11493 | 19 |
| 23-22 | 1 | .001 | 66 | .78 | .0078 | 20113 | 16 |
| 28-27 | | | | | | | |
| 26-25 | 100 | .001 | 100 | .46 | .046 | 575 | 26 |
| 25-24 | 10 | .001 | 100 | 1.32 | .0132 | 2299 | 30 |
| 24-23 | 1 | .001 | 100 | 3.29 | .00329 | 5747 | 19 |
| 23-22 | 1 | .001 | 100 | 1.35 | .00135 | 11493 | 16 |
| 22-21 | 1 | .001 | 100 | .67 | .00067 | 20113 | 13 |
| 27-26 | | | | | | | |
| 24-25 | 100 | .001 | 66 | 1.60 | | | |
| 25-24 | 10 | .001 | 66 | 1.09 | .0109 | 575 | 6 |
| 23-22 | 1 | .001 | 66 | 3.06 | .00306 | 2299 | 7 |
| 22-21 | 1 | .001 | 66 | 1.26 | .00126 | 5747 | 7 |
| 21-20 | 1 | .001 | 66 | .72 | .00072 | 11493 | 8 |
| 20-19 | 1 | .001 | 66 | .51 | .00051 | 20113 | 10 |
| 26-25 | | | | | | | |
| 24-22 | 100 | .001 | 66 | .56 | .056 | 575 | 32 |
| 23-22 | 10 | .001 | 66 | .69 | .0069 | 2299 | 16 |
| 22-21 | 1 | .001 | 66 | 2.08 | .00208 | 5747 | 12 |
| 21-20 | 1 | .001 | 66 | 1.02 | .00102 | 11493 | 12 |
| 20-19 | 1 | .001 | 66 | .64 | .00064 | 20113 | 13 |
| 25-24 | | | | | | | |
| 23-22 | 10 | .001 | | 6.45 | .0645 | | (37) |
| 22-21 | 10 | .001 | 66 | 1.05 | .0105 | | 12 |
| 21-20 | 1 | .001 | 66 | 3.48 | .00348 | | 20 |
| 20-19 | 1 | .001 | 66 | 1.69 | .00169 | 11493 | 19 |
| 19-18 | 1 | .001 | 66 | 1.40 | .0014 | | 28 |
| 24-23 | | | | | | | |
| 22-21 | 100 | .001 | 66 | 1.82 | .182 | 575 | 105 |
| 21-20 | 10 | .001 | 66 | 3.36 | .0336 | 2299 | 77 |
| 20-19 | 10 | .001 | 66 | 1.00 | .010 | 5747 | 575 |
| 19-18 | 1 | .001 | 66 | 3.88 | .00388 | 11493 | 45 |
| 18-17 | 1 | .001 | 66 | 1.50 | .0015 | 20113 | 30 |

TABLE 5. LINE A (CONT.)

| Sta. | Range | MA | Voltage | $V_P$ | DV/I | G.F. | $P_a$ |
|---|---|---|---|---|---|---|---|
| 23-22 | | | | | | | |
| 21-20 | 100 | .001 | 66 | 1.63 | | | 94 |
| 20-19 | 10 | .001 | 66 | 3.80 | .038 | 2299 | 87 |
| 19-18 | 10 | .001 | 66 | 1.22 | .0122 | | 70 |
| 18-17 | 1 | .001 | 66 | 3.20 | .00320 | | 37 |
| 17-16 | 1 | .001 | 66 | 1.56 | .00156 | | 32 |
| 22-21 | | | | | | | |
| 20-19 | 100 | .001 | 66 | 1.13 | .113 | 575 | 75 |
| 19-18 | 10 | .001 | 66 | 2.92 | .0292 | 2299 | 67 |
| 18-17 | 1 | .001 | | 5.66 | .00566 | 5747 | 33 |
| 17-16 | 1 | .001 | | 2.12 | .00212 | 11493 | 24 |
| 16-15 | 1 | .001 | | 0.88 | .00088 | 20113 | 18 |
| 21-20 | | | | | | | |
| 19-18 | 100 | .001 | 66 | 1.35 | | 575 | 78 |
| 18-17 | 10 | .001 | 66 | 1.84 | 0.184 | 2299 | 42 |
| 17-16 | 1 | .001 | 66 | 4.5 | .0045 | 5747 | 26 |
| 16-15 | 1 | .001 | 66 | 1.56 | 00.156 | | 18 |
| 15-14 | 1 | .001 | 66 | 0.78 | | | 16 |
| 20-19 | | | | | | | |
| 18-17 | 100 | .001 | 66 | 1.21 | .121 | | 70 |
| 17-16 | 10 | .001 | 66 | 1.67 | .0167 | | 38 |
| 16-15 | 1 | .001 | 66 | 3.64 | .00364 | | 21 |
| 15-14 | 1 | .001 | 66 | 1.51 | .00151 | | 17 |
| 14-13 | 1 | .001 | 66 | 0.68 | .00068 | | 14 |

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

TABLE 6. LINE B.

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

| LOCATION | PROJECT | DATE |
|---|---|---|
| Shaw Springs | Line B | 1 July 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 | 1 | .01 | 100 | 7.50 | .075 | 862 | 65 |
| 5-6 | 1 | .01 | 100 | 1.15 | .0115 | 3448 | 41 |
| 6-7 | 1 | .01 | 100 | .38 | .0038 | 8620 | 33 |
| 7-8 | 1 | .001 | 500 | 1.63 | .00163 | 17240 | 28 |
| 8-9 | 1 | .001 | 500 | .69 | .00069 | 30170 | 21 |
| 3-4 | | | | | | | |
| 5-6 | 1 | .01 | 66 | 7.20 | .072 | 862 | 62 |
| 6-7 | 1 | .01 | 66 | 1.16 | .0116 | 3448 | 40 |
| 7-8 | 1 | .01 | 66 | .40 | .0040 | 8620 | 35 |
| 7-8 | 1 | .001 | 366 | 1.41 | .00141 | 17240 | 24 |
| 9-10 | 1 | .001 | 366 | .70 | .0007 | 30170 | 21 |
| 4-5 | | | | | | | |
| 6-7 | 1 | .01 | 66 | 7.70 | .077 | 862 | 66 |
| 7-8 | 1 | .01 | 66 | 1.62 | .0162 | 3448 | 55 |
| 8-9 | 1 | .01 | 66 | .47 | .0047 | 8620 | 41 |
| 9-10 | 1 | .001 | 166 | 2.09 | .00209 | 17240 | 35 |
| 10-11 | 1 | .001 | 166 | 1.18 | .0018 | 30170 | 54 |
| 5-6 | | | | | | | |
| 7-8 | 1 | .01 | 66 | 7.54 | 0.0754 | 862 | 65 |
| 8-9 | 1 | .01 | 66 | 1.37 | .0137 | 3448 | 48 |
| 9-10 | 1 | .01 | 66 | 0.49 | .0049 | 8620 | 42 |
| 10-11 | 1 | .001 | 275 | 2.41 | .00241 | 17240 | 41 |
| 11-12 | 1 | .001 | 275 | 1.12 | .00112 | 30170 | 30 |
| 6-7 | | | | | | | |
| 8-9 | 1 | .01 | 66 | 6.00 | .060 | 862 | 52 |
| 9-10 | 1 | .01 | 66 | 1.48 | .0148 | 3448 | 52 |
| 10-11 | 1 | .01 | 66 | .59 | .0059 | 8620 | 45 |
| 11-12 | 1 | .001 | 300 | 2.44 | .00244 | 17240 | 41 |
| 12-13 | 1 | .001 | 300 | 1.20 | .00120 | 30170 | 30 |

TABLE 6. LINE B (CONT.)

| Sta. | Range | MA | Voltage | $V_p$ | DV/I | G.F. | $P_a$ |
|---|---|---|---|---|---|---|---|
| 7-8 | | | | | | | |
| 9-10 | 1 | .01 | 66 | 4.34 | .0434 | 862 | 37 |
| 10-11 | 1 | .01 | 66 | 1.15 | .0115 | 3448 | 40 |
| 11-12 | 1 | .001 | 166 | 4.33 | .00433 | 8620 | 37 |
| 12-13 | 1 | .001 | 166 | 1.92 | .00192 | 17240 | 33 |
| 13-14 | 1 | .001 | 166 | 1.03 | .001 | 30170 | 30 |
| 8-9 | | | | | | | |
| 10-11 | 1 | .01 | 66 | 3.40 | 0.034 | 862 | 29 |
| 11-12 | 1 | .01 | 66 | 0.65 | 0.0065 | 3448 | 22 |
| 12-13 | 1 | .01 | 66 | 0.27 | 0.0027 | 8620 | 23 |
| 13-14 | 1 | .001 | 133 | 1.20 | 0.00120 | 17240 | 21 |
| 14-15 | 1 | .001 | 133 | 0.72 | 0.00072 | 30170 | 21 |
| 9-10 | | | | | | | |
| 11-12 | 1 | .01 | 66 | 2.39 | 0.0239 | 862 | 21 |
| 12-13 | 1 | .001 | 133 | 4.90 | 0.0049 | 3448 | 17 |
| 13-14 | 1 | .001 | 133 | 1.95 | 0.00195 | 8620 | 17 |
| 14-15 | 1 | .001 | 133 | 1.05 | 0.00105 | 17240 | 17 |
| 15-16 | 1 | .001 | 133 | 0.61 | 0.00061 | 30170 | 18 |
| 10-11 | | | | | | | |
| 12-13 | 1 | .01 | 66 | 2.45 | 0.0245 | 862 | 21 |
| 13-14 | 1 | .01 | 66 | 0.55 | 0.0055 | 3448 | 17 |
| 14-15 | 1 | .001 | 133 | 2.15 | 0.00215 | 8620 | 17 |
| 15-16 | 1 | .001 | 133 | 1.10 | 0.00110 | 17240 | 17 |
| 16-17 | 1 | .001 | 133 | 0.80 | 0.00080 | 30170 | 24 |
| 8-9 | | | | | | | |
| 10-11 | 1 | .01 | 66 | 3.40 | 0.034 | 862 | 29 |
| 11-12 | 1 | .01 | 66 | 0.65 | 0.0065 | 3448 | 22 |
| 12-13 | 1 | .01 | 66 | 0.27 | 0.0027 | 8620 | 23 |
| 13-14 | 1 | .001 | 133 | 1.20 | 0.00120 | 17240 | 21 |
| 14-15 | 1 | .001 | 133 | 0.72 | 0.00072 | 30170 | 21 |
| 9-10 | | | | | | | |
| 11-12 | 1 | .01 | 66 | 2.39 | 0.0239 | 862 | 21 |
| 12-13 | 1 | .001 | 133 | 4.90 | 0.0049 | 3448 | 17 |
| 13-14 | 1 | .001 | 133 | 1.95 | 0.00195 | 8620 | 17 |
| 14-15 | 1 | .001 | 133 | 1.05 | 0.00105 | 17240 | 17 |
| 15-16 | 1 | .001 | 133 | 0.61 | 0.00061 | 30170 | 18 |
| 10-11 | | | | | | | |
| 12-13 | 1 | .01 | 66 | 2.45 | 0.0245 | 862 | 21 |
| 13-14 | 1 | .01 | 66 | 0.55 | 0.0055 | 3448 | 17 |
| 14-15 | 1 | .001 | 133 | 2.15 | 0.00215 | 8620 | 19 |
| 15-16 | 1 | .001 | 133 | 1.10 | 0.00110 | 17240 | 17 |
| 16-17 | 1 | .001 | 133 | 0.80 | 0.00080 | 30170 | 24 |

TABLE 6. LINE B (CONT.)

| Sta. | Range | MA | Voltage | $V_p$ | DV/I | G.F. | $P_a$ |
|---|---|---|---|---|---|---|---|
| 11-12 | | | | | | | |
| 13-14 | 1 | .01 | 66 | 2.11 | 0.0211 | 862 | 18 |
| 14-15 | 1 | .001 | 133 | 4.85 | 0.00485 | 3448 | 17 |
| 15-16 | 1 | .001 | 133 | 1.85 | 0.00185 | 8620 | 16 |
| 16-17 | 1 | .001 | 133 | 1.10 | 0.00110 | 17240 | 17 |
| 17-18 | 1 | .001 | 133 | 0.75 | 0.00075 | 30170 | 22 |
| 12-13 | | | | | | | |
| 14-15 | 1 | .01 | 66 | 2.25 | 0.0225 | 862 | 19 |
| 15-16 | 1 | .01 | 66 | 0.47 | 0.0047 | 3448 | 17 |
| 16-17 | 1 | .001 | 100 | 2.09 | 0.00209 | 8620 | 17 |
| 17-18 | 1 | .001 | 100 | 1.20 | 0.00120 | 17240 | 17 |
| 13-14 | | | | | | | |
| 15-16 | 1 | .01 | 66 | 1.92 | 0.0192 | 862 | 17 |
| 16-17 | 1 | .001 | 100 | 4.73 | 0.00473 | 3448 | 17 |
| 17-18 | 1 | .001 | 100 | 2.10 | 0.00210 | 8620 | 17 |
| 14-15 | | | | | | | |
| 16-17 | 1 | .01 | 6 | 2.00 | 0.02 | 862 | 17 |
| 17-18 | 1 | .01 | 66 | 0.54 | 0.0054 | 3448 | 17 |
| 15-16 | | | | | | | |
| 17-18 | 1 | .01 | 66 | 2.07 | 0.0207 | 862 | 17 |

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

TABLE 7. LINE C.

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

| LOCATION | PROJECT | DATE |
|---|---|---|
| Shaw Springs | Line C | 1 July 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 | 1 | .01 | 66 | 2.55 | 0.0255 | 862 | 22 |
| 4-5 | 1 | .01 | 66 | 0.70 | 0.0070 | 3448 | 24 |
| 5-6 | 1 | .001 | 100 | 3.46 | 0.00346 | 8620 | 30 |
| 6-7 | 1 | .001 | 100 | 1.58 | 0.00158 | 17240 | 18 |
| 7-8 | 1 | .001 | 100 | 1.05 | .00105 | 30170 | 30 |
| 2-3 | | | | | | | |
| 4-5 | 1 | .01 | 66 | 2.90 | 0.0290 | 862 | 25 |
| 5-6 | 1 | .01 | 66 | 0.92 | 0.0092 | 3448 | 31 |
| 6-7 | 1 | .001 | 166 | 3.43 | 0.00343 | 8620 | 30 |
| 7-8 | 1 | .001 | 166 | 1.95 | 0.00195 | 17240 | 28 |
| 8-9 | 1 | .001 | 166 | 1.16 | 0.00116 | 30170 | 30 |
| 3-4 | | | | | | | |
| 5-6 | 1 | .01 | 66 | 3.33 | 0.0333 | 862 | 28 |
| 6-7 | 1 | .01 | 66 | 0.83 | 0.0083 | 3448 | 28 |
| 7-8 | 1 | .001 | 66 | 3.77 | 0.00377 | 8620 | 32 |
| 8-9 | 1 | .001 | 100 | 2.04 | 0.00204 | 17240 | 34 |
| 9-10 | 1 | .001 | 100 | 1.06 | .00106 | 30170 | 38 |
| 4-5 | | | | | | | |
| 6-7 | 1 | .01 | 66 | 2.77 | 0.0277 | 862 | 23 |
| 7-8 | 1 | .001 | 100 | 7.92 | 0.00792 | 3448 | 28 |
| 8-9 | 1 | .001 | 100 | 3.62 | 0.00362 | 8620 | 31 |
| 9-10 | 1 | .001 | 100 | 1.70 | 0.00170 | 17240 | 29 |
| 10-11 | 1 | .001 | 100 | 1.39 | 0.00139 | 30170 | 42 |
| 5-6 | | | | | | | |
| 7-8 | 1 | .01 | 66 | 2.88 | 0.0288 | 862 | 25 |
| 8-9 | 1 | .01 | 66 | 0.83 | 0.0083 | 3448 | 28 |
| 9-10 | 1 | .001 | 100 | 3.29 | 0.00329 | 8620 | 30 |
| 10-11 | 1 | .001 | 100 | 2.42 | 0.00242 | 17240 | 41 |
| 11-12 | 1 | .001 | 100 | 1.80 | 0.00180 | 30170 | 54 |

TABLE 7. LINE C (CONT.)

| Sta. | Range | MA | Voltage | $V_p$ | DV/I | G.F. | $P_a$ |
|---|---|---|---|---|---|---|---|
| 6-7 | | | | | | | |
| 8-9 | 10 | .001 | 100 | 2.93 | .0293 | 862 | 25 |
| 9-10 | 10 | .001 | 100 | 0.76 | 0.0076 | 3448 | 28 |
| 10-11 | 1 | .001 | 100 | 4.52 | 0.00452 | 8620 | 39 |
| 11-12 | 1 | .001 | 100 | 3.04 | 0.00304 | 17240 | 52 |
| 12-13 | 1 | .001 | 100 | 1.70 | 0.00170 | 30170 | 51 |
| 8-7 | | | | | | | |
| 9-10 | 1 | .01 | 66 | 2.73 | 0.0273 | 862 | 23 |
| 10-11 | 1 | .01 | 66 | 1.18 | 0.0118 | 3448 | 41 |
| 11-12 | 1 | .01 | 66 | 0.70 | 0.0070 | 8620 | 52 |
| 12-13 | 1 | .001 | 133 | 3.30 | 0.00330 | 17240 | 57 |
| 13-14 | 1 | .001 | 133 | 1.50 | 0.0015 | 30170 | 45 |
| 9-8 | | | | | | | |
| 10-11 | 1 | .01 | 66 | 3.27 | 0.0327 | 862 | 28 |
| 11-12 | 10 | .001 | 133 | 1.31 | 0.0131 | 3448 | 45 |
| 12-13 | 1 | .001 | 133 | 5.59 | 0.00559 | 8620 | 49 |
| 13-14 | 1 | .001 | 133 | 2.26 | 0.00226 | 17240 | 40 |
| 14-15 | 1 | .001 | 133 | 1.12 | 0.00112 | 30170 | 33 |
| 10-9 | | | | | | | |
| 11-12 | 1 | .01 | 66 | 5.13 | 0.0513 | 862 | 44 |
| 12-13 | 1 | .01 | 66 | 1.35 | 0.0135 | 3448 | 45 |
| 13-14 | 1 | .001 | 100 | 4.51 | 0.00451 | 8620 | 39 |
| 14-15 | 1 | .001 | 100 | 1.94 | 0.00194 | 17240 | 33 |
| 15-16 | 1 | .001 | 100 | 0.69 | .00069 | 30170 | 21 |
| 10-11 | | | | | | | |
| 12-13 | 10 | .01 | 100 | 7.70 | 0.770 | 862 | 663 |
| 13-14 | 10 | .01 | 100 | 1.71 | 0.171 | 3448 | 59 |
| 14-15 | 1 | .001 | 133 | 6.10 | 0.0061 | 8620 | 52 |
| 15-16 | 1 | .001 | 133 | 1.76 | 0.00176 | 17240 | 29 |
| 16-17 | 1 | .001 | 133 | 0.81 | 0.00081 | 30170 | 24 |
| 11-12 | | | | | | | |
| 13-14 | 10 | .01 | 66 | 1.00 | 0.1000 | 862 | 86 |
| 14-15 | 1 | .01 | 66 | 2.40 | 0.0240 | 3448 | 69 |
| 15-16 | 1 | .01 | 6 | 0.50 | 0.0050 | 8620 | 43 |
| 16-17 | 1 | .001 | 200 | 1.85 | 0.00185 | 17240 | 31 |
| 17-18 | 1 | .001 | 200 | 0.90 | 0.00090 | 30170 | 27 |
| 12-13 | | | | | | | |
| 14-15 | 10 | .01 | 66 | 1.11 | 0.111 | 862 | 95 |
| 15-16 | 1 | .01 | 66 | 1.62 | 0.0162 | 3448 | 55 |
| 16-17 | 1 | .001 | 133 | 4.78 | 0.00478 | 8620 | 40 |
| 17-18 | 1 | .001 | 133 | 1.90 | 0.00190 | 17240 | 33 |
| 18-19 | 1 | .001 | 133 | 1.01 | 0.00101 | 30170 | 29 |

TABLE 7. LINE C (CONT.)

| Sta. | Range | MA | Voltage | $V_p$ | DV/I | G.F. | $P_a$ |
|---|---|---|---|---|---|---|---|
| 13-14 | | | | | | | |
| 15-16 | 1 | .01 | 66 | 7.75 | 0.0775 | 862 | 67 |
| 16-17 | 1 | .01 | 66 | 1.55 | 0.0155 | 3448 | 52 |
| 17-18 | 1 | .001 | 166 | 5.00 | 0.0050 | 8620 | 43 |
| 18-19 | 1 | .001 | 166 | 1.80 | 0.00180 | 17240 | 30 |
| 19-20 | 1 | .001 | 166 | 0.80 | 0.00080 | 30170 | 24 |
| 14-15 | | | | | | | |
| 16-17 | 1 | .01 | 66 | 8.50 | .0850 | 862 | 73 |
| 17-18 | 1 | .001 | 200 | 1.90 | 0.00190 | 3448 | 70 |
| 18-19 | 1 | .001 | 200 | 5.38 | 0.00538 | 8620 | 41 |
| 19-20 | 1 | .001 | 200 | 1.70 | 0.00170 | 17240 | 28 |
| 20-21 | 1 | .001 | 225 | 0.80 | 0.00080 | 30170 | 24 |
| 15-16 | | | | | | | |
| 17-18 | 1 | .01 | 66 | 9.68 | .0968 | 862 | 84 |
| 18-19 | 1 | .01 | 66 | 1.89 | .0189 | 3448 | 65 |
| 19-20 | 1 | .001 | 100 | 3.68 | .00368 | 8620 | 32 |
| 20-21 | 1 | .001 | 100 | 1.50 | .00150 | 17240 | 26 |
| 16-17 | | | | | | | |
| 18-19 | 10 | .01 | 66 | 0.93 | 0.093 | 862 | 80 |
| 19-20 | 10 | .001 | 100 | 1.10 | 0.0011 | 3448 | 40 |
| 20-21 | 1 | .001 | 100 | 2.64 | 0.00264 | 8620 | 23 |
| 17-18 | | | | | | | |
| 19-20 | 1 | .01 | 100 | 5.50 | 0.055 | 862 | 47 |
| 20-21 | 1 | .01 | 100 | 0.63 | 0.0063 | 3448 | 22 |
| 18-19 | | | | | | | |
| 20-21 | 1 | .01 | 66 | 2.90 | 0.029 | 862 | 25 |

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

TABLE 8. LINE D.

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

| LOCATION | PROJECT | DATE |
|---|---|---|
| Shaw Springs | Line D | 8 July 1980 |
| CHIEF OPERATOR | ASSISTANTS | METHOD |
| Jay Jones | Fargo and Treska | Dipole-Dipole (Nx200') |

| Sta. | Range | MA | Voltage | $V_p$ | DV/I | G.F. | $P_a$ |
|---|---|---|---|---|---|---|---|
| 44-42 | | | | | | | |
| 38-40 | 100 | .001 | 133 | 1.06 | 0.106 | 1149 | 121.8 |
| 38-36 | 1 | .001 | 133 | 1.26 | 0.00126 | 4597 | 5.8 |
| 36-34 | 1 | .001 | 133 | 5.20 | 0.0052 | 11493 | 59 |
| 34-32 | 1 | .001 | 133 | 1.75 | 0.00175 | 22987 | 40.2 |
| 32-30 | - | .001 | 133 | N.R.--lost signal | | 40227 | |
| 42-40 | | | | | | | |
| 38-36 | 10 | .001 | 133 | 7.91 | 0.00791 | 1149 | 91 |
| 36-34 | 10 | .001 | 133 | 1.59 | 0.00159 | 4597 | 73 |
| 34-32 | 1 | .001 | 133 | 4.30 | 0.00430 | 11493 | 49.4 |
| 32-30 | 1 | .001 | 133 | 1.72 | 0.00172 | 22987 | 39.5 |
| 30-28 | 1 | .001 | 133 | 0.65 | 0.00065 | 40227 | 26.15 |
| 40-38 | | | | | | | |
| 36-34 | 10 | .001 | 133 | 7.40 | 0.0074 | 1149 | 85.1 |
| 34-32 | 10 | .001 | 133 | 1.54 | 0.0154 | 4597 | 70.8 |
| 32-30 | 1 | .001 | 133 | 4.90 | 0.00490 | 11493 | 56.3 |
| 30-28 | 1 | .001 | 133 | 1.50 | 0.00150 | 22987 | 34.5 |
| 28-26 | - | .001 | 133 | N.R.--lost signal-- | | 20112 | |
| 38-36 | | | | | | | |
| 34-32 | 10 | .001 | 225 | 3.53 | 0.0353 | 11492 | 40.6 |
| 32-30 | 1 | .001 | 225 | 8.90 | 0.0089 | 4597 | 41.0 |
| 30-28 | 1 | .001 | 166 | 2.45 | 0.00245 | 11493 | 28.1 |
| 28-26 | 1 | .001 | 166 | 0.91 | 0.00091 | 22987 | 21.0 |
| 26-24 | 1 | .001 | 166 | 0.39 | 0.00039 | 40227 | 15.7 |
| 36-34 | | | | | | | |
| 32-30 | 10 | .001 | 166 | 5.02 | 0.0502 | 11492 | 57.7 |
| 28-30 | 10 | .001 | 166 | 1.00 | 0.010 | 4597 | 46.0 |
| 28-26 | 1 | .001 | 166 | 2.80 | 0.0280 | 11493 | 321.8 |
| 26-24 | 1 | .001 | 166 | 0.94 | 0.00094 | 22987 | 21.6 |
| 24-22 | - | .001 | 166 | N.R.--lost signal-- | | 40227 | |

TABLE 8. LINE D (CONT.)

| Sta. | Range | MA | Voltage | $V_p$ | DV/I | G.F. | $P_a$ |
|---|---|---|---|---|---|---|---|
| 34-32 | | | | | | | |
| 30-28 | 10 | .001 | 100 | 7.10 | 0.0710 | 11492 | 81.6 |
| 28-26 | 10 | .001 | 100 | 1.40 | 0.0140 | 4597 | 64.4 |
| 26-24 | 10 | .001 | 100 | 0.40 | 0.0040 | 11493 | 45.9 |
| 24-22 | 1 | .001 | 100 | 1.14 | 0.00114 | 22987 | 26.2 |
| 22-20 | 1 | .001 | 100 | 0.40 | 0.00040 | 40227 | 16.1 |
| 32-30 | | | | | | | |
| 28-26 | 100 | .001 | 100 | 1.05 | 0.105 | 11497 | 120.7 |
| 26-24 | 10 | .001 | 100 | 2.20 | 0.022 | 4597 | 101.1 |
| 24-22 | 10 | .001 | 100 | 0.35 | 0.0035 | 11493 | 40.2 |
| 22-20 | 1 | .001 | 100 | N.R.--Lost | Signal-- | 22987 | |
| 28-30 | | | | | | | |
| 26-24 | 100 | .001 | 100 | 0.98 | 0.098 | 11497 | 112.6 |
| 24-22 | 10 | .001 | 100 | 1.49 | 0.0149 | 4597 | 68.5 |
| 22-20 | 1 | .001 | 100 | 3.77 | 0.00377 | 11493 | 43.3 |
| 20-18 | 1 | .001 | 100 | 1.26 | 0.00126 | 22987 | 51.0 |
| 18-16 | 1 | .001 | 100 | 0.71 | 0.00071 | 40227 | 28.6 |
| 26-28 | | | | | | | |
| 24-22 | 10 | .01 | 66 | 1.00 | 0.100 | 11497 | 1114.9 |
| 22-20 | 1 | .01 | 66 | 1.67 | 0.0167 | 4597 | 76.77 |
| 20-18 | 1 | .001 | 166 | 4.05 | 0.00405 | 11493 | 46.5 |
| 18-16 | 1 | .001 | 166 | 1.55 | 0.00155 | 22987 | 35.6 |
| 16-14 | 1 | .001 | 166 | 0.54 | 0.00054 | 40227 | 21.7 |
| 24-26 | | | | | | | |
| 20-22 | 10 | .01 | 66 | 0.93 | 0.093 | 11492 | 106.9 |
| 8-20 | 10 | .001 | 166 | 1.67 | 0.0167 | 4597 | 76.7 |
| 16-18 | 1 | .001 | 166 | 4.42 | 0.00442 | 11493 | 50.8 |
| 14-16 | 1 | .001 | 166 | 1.09 | 0.00109 | 22987 | 25.1 |
| 12-14 | 1 | .001 | 166 | 0.60 | 0.0006 | 40227 | 24.1 |
| 24-22 | | | | | | | |
| 20-18 | 10 | .01 | 66 | 0.97 | 0.097 | 11492 | 111.4 |
| 18-16 | 10 | .001 | 166 | 1.76 | 0.0176 | 4597 | 80.9 |
| 16-14 | 1 | .001 | 166 | 3.11 | 0.00311 | 11493 | 36.0 |
| 14-12 | 1 | .001 | 166 | 1.30 | 0.00130 | 22987 | 29.9 |
| 12-10 | 1 | .001 | 166 | 0.55 | 0.00055 | 40227 | 22.1 |
| 22-20 | | | | | | | |
| 18-16 | 10 | .01 | 66 | 0.88 | 0.088 | 11492 | 101.1 |
| 16-14 | 10 | .001 | 200 | 1.04 | 0.0104 | 4597 | 47.8 |
| 14-12 | 1 | .001 | 200 | 3.45 | 0.00345 | 11493 | 39.6 |
| 12-10 | 1 | .001 | 166 | 1.17 | 0.00117 | 22987 | 26.9 |
| 10-8 | 1 | .001 | 166 | 0.54 | .00054 | 40227 | 21.7 |

TABLE 8. LINE D (CONT.)

| Sta. | Range | MA | Voltage | $V_P$ | DV/I | G.F. | $P_a$ |
|---|---|---|---|---|---|---|---|
| 20-18 | | | | | | | |
| 16-14 | 1 | .01 | 66 | 5.68 | 0.0568 | 11492 | 65.3 |
| 14-12 | 10 | .001 | 166 | 1.18 | 0.0118 | 4597 | 54.2 |
| 12-10 | 1 | .001 | 166 | 2.70 | 0.0027 | 11493 | 31.0 |
| 10-8 | 1 | .001 | 166 | 0.96 | 0.00096 | 22987 | 22.1 |
| 18-16 | | | | | | | |
| 14-12 | 10 | .01 | 66 | 1.05 | 0.105 | 11492 | 120.7 |
| 12-10 | 10 | .001 | 133 | 1.67 | 0.0167 | 4597 | 76.7 |
| 10-8 | 1 | .001 | 133 | 4.06 | 0.00406 | 11493 | 46.6 |
| 16-14 | | | | | | | |
| 12-10 | 100 | .001 | 133 | 1.05 | 0.105 | 11492 | 120.6 |
| 10-8 | 10 | .001 | 133 | 1.75 | 0.0175 | 4597 | 80.45 |
| 14-12 | | | | | | | |
| 10-8 | 100 | .001 | 133 | 1.03 | 0.103 | 11492 | 118.4 |
| 50-48 | | | | | | | |
| 46-44 | 10 | .001 | 133 | 8.15 | 0.00815 | 11492 | 93.7 |
| 44-42 | 10 | .001 | 133 | 1.81 | 0.0181 | 4597 | 83.2 |
| 42-40 | 1 | .001 | 133 | 5.38 | 0.00538 | 11493 | 61.8 |
| 40-38 | 1 | .001 | 133 | 1.74 | 0.00174 | 22987 | 39.9 |
| 38-36 | | .001 | 133 | -- N.R. -- | | 40227 | |
| 48-46 | | | | | | | |
| 44-42 | 100 | .001 | 200 | 1.08 | 0.108 | 11492 | 124.1 |
| 42-40 | 10 | .001 | 200 | 2.38 | 0.0128 | 4597 | 109.4 |
| 40-38 | 1 | .001 | 200 | 6.40 | 0.0064 | 11493 | 73.5 |
| 38-36 | 1 | .001 | 200 | 1.60 | 0.00160 | 22987 | 36.7 |
| 36-34 | 1 | .001 | 200 | 0.75 | 0.00075 | 40227 | 30.17 |
| 46-44 | | | | | | | |
| 42-40 | 100 | .001 | 200 | 1.09 | 0.109 | 11492 | 125.3 |
| 40-38 | 10 | .001 | 200 | 2.35 | 0.00235 | 4597 | 108.0 |
| 38-36 | 1 | .001 | 200 | 4.80 | 0.0048 | 11493 | 55.1 |
| 36-34 | 1 | .001 | 200 | 1.85 | 0.00185 | 22987 | 42.5 |
| 34-32 | 1 | .001 | 200 | 0.78 | 0.00078 | 40227 | 31.4 |

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

TABLE 9. LINE E

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

| LOCATION | PROJECT | DATE |
|---|---|---|
| Shaw Springs | Line E | 9 July 1980 |
| CHIEF OPERATOR | ASSISTANTS | METHOD |
| Jay Jones | Fargo and Treska | Dipole-Dipole (Nx200') |

| Sta. | Range | MA | Voltage | $V_p$ | DV/I | G.F. | $P_a$ |
|---|---|---|---|---|---|---|---|
| 1-3 | | | | | | | |
| 5-7 | 1 | .01 | 66 | 6.50 | 0.0650 | 1149 | 74.7 |
| 7-9 | 1 | .01 | 66 | 1.00 | 0.010 | 4597 | 46.0 |
| 9-11 | 1 | .001 | 133 | 1.76 | 0.00176 | 11493 | 20.2 |
| 11-13 | 1 | .001 | 133 | 1.18 | 0.00118 | 22987 | 27.13 |
| 13-15 | 1 | .001 | 133 | 0.45 | 0.00045 | 40227 | 18.1 |
| 3-5 | | | | | | | |
| 7-9 | 100 | .001 | 66 | 1.11 | 0.111 | 1149 | 127.5 |
| 9-11 | 10 | .001 | 66 | 1.00 | 0.010 | 4597 | 46.0 |
| 11-13 | 1 | .001 | 66 | 2.45 | 0.00245 | 11493 | 28.1 |
| 13-15 | 1 | .001 | 66 | 1.04 | 0.00104 | 22987 | 24.0 |
| 15-17 | 1 | .001 | 66 | 0.55 | 0.00055 | 40227 | 22.12 |
| 5-7 | | | | | | | |
| 9-11 | 1 | .01 | 66 | 5.50 | 0.055 | 1149 | 63.2 |
| 11-13 | 1 | .01 | 66 | 0.70 | 0.0070 | 4597 | 32.18 |
| 13-15 | 1 | .001 | 66 | 2.17 | 0.00217 | 11493 | 25.0 |
| 15-17 | 1 | .001 | 66 | 0.91 | 0.00091 | 22987 | 20.9 |
| 17-19 | 1 | .001 | 66 | 0.40 | 0.00041 | 40227 | 16.5 |
| 7-9 | | | | | | | |
| 11-13 | 1 | .01 | 66 | 6.30 | 0.0630 | 11493 | 72.4 |
| 13-15 | 1 | .001 | 133 | 8.50 | 0.00850 | 4597 | 39.0 |
| 15-17 | 1 | .001 | 133 | 2.40 | 0.00240 | 11493 | 27.6 |
| 17-19 | 1 | .001 | 133 | 1.08 | 0.00108 | 22987 | 24.8 |
| 19-21 | 1 | .001 | 133 | 0.64 | 0.00064 | 40227 | 25.7 |
| 9-11 | | | | | | | |
| 13-15 | 1 | .01 | 66 | 3.90 | 0.0390 | 11493 | 44.8 |
| 15-17 | 1 | .001 | 133 | 5.40 | 0.00540 | 4597 | 24.8 |
| 17-19 | 1 | .001 | 133 | 1.84 | 0.00184 | 11493 | 21.15 |
| 19-21 | 1 | .001 | 133 | 0.95 | 0.00095 | 22987 | 21.84 |
| 21-23 | 1 | .001 | 133 | 0.48 | 0.00048 | 40227 | 19.3 |

TABLE 9 LINE E (CONT.)

| Sta. | Range | MA | Voltage | $V_p$ | DV/I | G.F. | $P_a$ |
|---|---|---|---|---|---|---|---|
| 11-13 | | | | | | | |
| 15-17 | 1 | .01 | 66 | 3.08 | .0308 | 11493 | 43.7 |
| 17-19 | 1 | .001 | 133 | 5.08 | 0.00508 | 4597 | 23.4 |
| 19-21 | 1 | .001 | 133 | 2.00 | 0.0020 | 11493 | 23.0 |
| 21-23 | 1 | .001 | 133 | 0.91 | 0.00091 | 22987 | 20.9 |
| 23-25 | 1 | .001 | 133 | 0.50 | 0.00050 | 40227 | 20.1 |
| 13-15 | | | | | | | |
| 17-19 | 1 | .01 | 66 | 2.68 | 0.0268 | 1149 | 31.0 |
| 19-21 | 1 | .001 | 133 | 4.56 | 0.00456 | 4597 | 21.0 |
| 21-23 | 1 | .001 | 133 | 1.78 | 0.00178 | 11493 | 20.5 |
| 23-25 | 1 | .001 | 133 | 0.81 | 0.00081 | 22987 | 18.6 |
| 25-27 | 1 | .001 | 133 | 0.45 | 0.00045 | 40227 | 18.10 |
| 15-17 | | | | | | | |
| 19-21 | 10 | .001 | 133 | 2.90 | 0.0240 | 1149 | 33.3 |
| 21-23 | 1 | .001 | 133 | 4.30 | 0.00430 | 4597 | 19.7 |
| 23-25 | 1 | .001 | 133 | 1.82 | 0.00182 | 11493 | 20.9 |
| 25-27 | 1 | .001 | 133 | 1.00 | 0.0010 | 22987 | 22.9 |
| 27-29 | 1 | .001 | 133 | 0.48 | 0.00048 | 40227 | 19.3 |
| 17-19 | | | | | | | |
| 21-23 | 1 | .01 | 66 | 1.31 | 0.0131 | 1149 | 15.2 |
| 23-25 | 1 | .001 | 133 | 3.67 | 0.00367 | 4597 | 16.8 |
| 25-27 | 1 | .001 | 133 | 1.78 | 0.00178 | 11493 | 20.45 |
| 27-29 | 1 | .001 | 133 | 0.85 | 0.00085 | 22987 | 19.5 |
| 29-31 | 1 | .001 | 133 | 0.36 | 0.00036 | 40227 | 14.48 |
| 19-21 | | | | | | | |
| 25-23 | 1 | .01 | 66 | 1.15 | 0.0115 | 1149 | 13.2 |
| 27-25 | 1 | .001 | 166 | 4.32 | 0.00432 | 4597 | 19.8 |
| 29-27 | 1 | .001 | 166 | 1.86 | 0.00186 | 11493 | 21.4 |
| 31-29 | 1 | .001 | 166 | 0.76 | 0.00076 | 22987 | 17.5 |
| 33-31 | 1 | .001 | 166 | 0.30 | 0.00030 | 40227 | 12.06 |
| 21-23 | | | | | | | |
| 25-27 | 1 | .01 | 66 | 1.22 | 0.0122 | 1149 | 14.0 |
| 27-29 | 1 | .001 | 250 | 4.40 | 0.00440 | 4597 | 20.2 |
| 29-31 | 1 | .001 | 250 | 1.53 | 0.00153 | 11493 | 17.5 |
| 31-33 | 1 | .001 | 250 | 0.54 | 0.00054 | 22987 | 12.4 |
| 33-35 | 1 | .001 | 250 | 0.27 | 0.00027 | 40227 | 10.87 |
| 23-25 | | | | | | | |
| 27-29 | 1 | .01 | 66 | 1.43 | 0.0143 | 1149 | 16.4 |
| 29-31 | 1 | .001 | 166 | 4.04 | 0.00404 | 4597 | 18.5 |
| 31-33 | 1 | .001 | 166 | 1.31 | 0.00131 | 11493 | 15.1 |
| 33-35 | 1 | .001 | 166 | 0.65 | 0.00065 | 22987 | 14.94 |
| 35-37 | 1 | .001 | 166 | 0.28 | 0.00028 | 40227 | 11.3 |

TABLE 9. LINE E (CONT.)

| Sta. | Range | MA | Voltage | $V_p$ | DV/I | G.F. | $P_a$ |
|---|---|---|---|---|---|---|---|
| 25-27 | | | | | | | |
| 29-31 | 1 | .01 | 66 | 1.36 | 0.0136 | 1149 | 15.6 |
| 31-33 | 1 | .001 | 066 | 3.52 | 0.00352 | 4597 | 16.2 |
| 33-35 | 1 | .001 | 066 | 1.39 | 0.00139 | 11493 | 16.0 |
| 35-37 | 1 | .001 | 066 | 0.48 | 0.00048 | 22987 | 11.0 |
| 37-39 | 1 | .001 | 66 | 0.27 | .00027 | 40227 | 10.9 |
| 27-29 | | | | | | | |
| 31-33 | 1 | .01 | 66 | 1.39 | 0.0139 | 1149 | 16.0 |
| 33-35 | 1 | .001 | 66 | 3.58 | 0.00358 | 4597 | 16.5 |
| 35-37 | 1 | .001 | 66 | 1.04 | 0.00104 | 11493 | 11.95 |
| 37-39 | 1 | .001 | 66 | 0.48 | 0.00048 | 22987 | 11.0 |
| 39-41 | 1 | .001 | 66 | 0.24 | 0.00024 | 40227 | 9.6 |
| 29-31 | | | | | | | |
| 33-35 | 1 | .01 | 66 | 1.49 | 0.0149 | 1149 | 17.1 |
| 35-37 | 1 | .001 | 100 | 3.21 | 0.00321 | 4597 | 14.8 |
| 37-39 | 1 | .001 | 100 | 0.95 | 0.00095 | 11493 | 11.0 |
| 39-41 | 1 | .001 | 100 | 0.38 | .00038 | 22987 | 8.7 |
| 41-43 | 1 | .001 | 100 | 0.22 | .00022 | 40227 | 8.85 |
| 31-33 | | | | | | | |
| 35-37 | 1 | .01 | 66 | 2.11 | 0.0211 | 1149 | 24.3 |
| 37-39 | 1 | .001 | 133 | 3.41 | 0.00341 | 4597 | 15.7 |
| 39-41 | 1 | .001 | 133 | 0.84 | 0.00084 | 11493 | 9.7 |
| 41-43 | 1 | .001 | 133 | 0.44 | 0.00044 | 22987 | 10.1 |
| 43-45 | 1 | .001 | 133 | 0.20 | 0.00020 | 40227 | 8.0 |
| 33-35 | | | | | | | |
| 37-39 | 1 | .01 | 66 | 2.46 | 0.0246 | 1149 | 28.3 |
| 39-41 | 1 | .001 | 66 | 2.07 | 0.00207 | 4597 | 9.5 |
| 41-43 | 1 | .001 | 66 | 0.77 | 0.00077 | 11493 | 8.8 |
| 43-45 | 1 | .001 | 66 | 0.32 | 0.00032 | 22987 | 7.35 |
| 35-37 | | | | | | | |
| 39-41 | 1 | .01 | 66 | 1.63 | 0.0163 | 1149 | 18.7 |
| 41-43 | 1 | .001 | 133 | 2.39 | 0.00239 | 4597 | 10.9 |
| 43-45 | 1 | .001 | 133 | 0.72 | 0.00072 | 11493 | 8.3 |
| 37-39 | | | | | | | |
| 41-43 | 1 | .01 | 66 | 2.41 | 0.0241 | 1149 | 27.7 |
| 43-45 | 1 | .001 | 166 | 3.09 | 0.00309 | 4597 | 14.2 |
| 39-41 | | | | | | | |
| 43-45 | 1 | .01 | 66 | 3.50 | 0.0350 | 1149 | 40.2 |

LEGEND: Range = Gain; MA = Dummary TX Current Switch
G.G. = Geometric Factor; Vp = Ballance control to null meter
Pa = Apparent Resistivity

TABLE 10. LINE F.

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

| LOCATION | PROJECT | DATE |
|---|---|---|
| Shaw Springs | Line F | 10 July 1980 |
| CHIEF OPERATOR | ASSISTANTS | METHOD |
| Jay Jones | Fargo and Treska | Dipole-Dipole (Nx200') |

| Sta. | Range | MA | Voltage | $V_p$ | DV/I | G.F. | $P_a$ |
|---|---|---|---|---|---|---|---|
| 1-3 | | | | | | | |
| 5-7 | 1 | .01 | 66 | 8.20 | 0.0820 | 1149 | 94 |
| 7-9 | 1 | .01 | 66 | 0.75 | 0.0075 | 4597 | 35 |
| 9-11 | 1 | .001 | 466 | 2.25 | 0.00225 | 11493 | 26 |
| 11-13 | 1 | .001 | 466 | 0.98 | 0.00098 | 22987 | 23 |
| 13-15 | 1 | .001 | 466 | 0.55 | 0.00055 | 40227 | 22 |
| 3-5 | | | | | | | |
| 7-9 | 1 | .01 | 66 | 6.00 | 0.060 | 1149 | 69 |
| 9-11 | 1 | .001 | 100 | 8.50 | 0.00850 | 4597 | 39 |
| 11-13 | | .001 | 100 | 2.64 | 0.00264 | 11493 | 30 |
| 13-15 | 1 | .001 | 100 | 1.29 | 0.00129 | 22987 | 30 |
| 15-17 | 1 | .001 | 100 | 0.74 | 0.00074 | 40227 | 30 |
| 5-7 | | | | | | | |
| 9-11 | 1 | .01 | 66 | 7.55 | 0.0755 | 1149 | 87 |
| 11-13 | 1 | .01 | 66 | 0.85 | 0.0085 | 4597 | 39 |
| 13-15 | 1 | .001 | 100 | 2.68 | 0.00268 | 11493 | 31 |
| 15-17 | 1 | .001 | 100 | 1.39 | 0.00139 | 22987 | 32 |
| 17-19 | 1 | .001 | 133 | 0.75 | 0.00075 | 40227 | 30 |
| 7-9 | | | | | | | |
| 11-13 | 1 | .01 | 66 | 5.35 | 0.0535 | 1149 | 62 |
| 13-15 | 1 | .001 | 200 | 6.21 | 0.00621 | 4597 | 29 |
| 15-17 | 1 | .001 | 200 | 2.35 | 0.00235 | 11493 | 27 |
| 17-19 | 1 | .001 | 200 | 1.22 | 0.00122 | 22987 | 28 |
| 19-21 | 1 | .001 | 200 | 0.61 | 0.00061 | 40227 | 25 |
| 9-11 | | | | | | | |
| 13-15 | 1 | .01 | 66 | 4.72 | 0.0472 | 1149 | 54 |
| 15-17 | 1 | .001 | 200 | 5.91 | 0.00591 | 4597 | 27 |
| 17-19 | 1 | .001 | 200 | 2.52 | 0.00252 | 11493 | 29 |
| 19-21 | 1 | .001 | 200 | 1.19 | 0.00119 | 22987 | 27 |
| 21-23 | 1 | .001 | 200 | 0.63 | 0.00063 | 40227 | 25 |

TABLE 10. LINE F (CONT.)

| Sta. | Range | MA | Voltage | $V_p$ | DV/I | G.F. | $P_a$ |
|---|---|---|---|---|---|---|---|
| 11-13 | | | | | | | |
| 15-17 | 1 | .01 | 66 | 2.90 | 0.0290 | 1149 | 33 |
| 17-19 | 1 | .001 | 133 | 5.70 | 0.00570 | 4597 | 26 |
| 19-21 | 1 | .001 | 133 | 2.31 | 0.00231 | 11493 | 27 |
| 21-23 | 1 | .001 | 133 | 1.13 | 0.00113 | 22987 | 26 |
| 23-25 | 1 | .001 | 133 | 0.65 | 0.00065 | 40227 | 26 |
| 13-15 | | | | | | | |
| 17-19 | 1 | .01 | 66 | 2.06 | 0.0206 | 1149 | 24 |
| 19-21 | 1 | .001 | 100 | 5.14 | 0.00514 | 4597 | 24 |
| 21-23 | 1 | .001 | 100 | 2.25 | 0.00225 | 11493 | 26 |
| 23-25 | 1 | .001 | 100 | 1.16 | 0.00116 | 22987 | 27 |
| 25-27 | 1 | .001 | 100 | 0.65 | .00065 | 40227 | 26 |
| 15-17 | | | | | | | |
| 19-21 | 1 | .01 | 66 | 1.64 | 0.0164 | 1149 | 19 |
| 21-23 | 1 | .001 | 100 | 5.28 | 0.00528 | 4597 | 24 |
| 23-25 | 1 | .001 | 100 | 2.40 | 0.00240 | 11493 | 28 |
| 25-27 | 1 | .001 | 100 | 1.24 | 0.00124 | 22987 | 28 |
| 27-29 | 1 | .001 | 100 | 0.60 | 0.00060 | 40227 | 29 |
| 17-19 | | | | | | | |
| 21-23 | 1 | .01 | 66 | 1.73 | 0.0173 | 1149 | 20 |
| 23-25 | 1 | .001 | 100 | 5.75 | 0.00575 | 4597 | 26 |
| 25-27 | 1 | .001 | 100 | 2.58 | 0.00258 | 11493 | 30 |
| 27-29 | 1 | .001 | 100 | 1.15 | 0.00115 | 22987 | 26 |
| 29-31 | 1 | .001 | 100 | 0.75 | 0.00075 | 40227 | 30 |
| 19-21 | | | | | | | |
| 23-25 | 1 | .01 | 66 | 1.84 | 0.0184 | 1149 | 21 |
| 25-27 | 1 | .001 | 133 | 6.21 | 0.00621 | 4597 | 29 |
| 27-29 | 1 | .001 | 133 | 2.50 | 0.00250 | 11493 | 29 |
| 29-31 | 1 | .001 | 133 | 1.20 | 0.00120 | 22987 | 28 |
| 31-33 | 1 | .001 | 133 | 0.65 | 0.00065 | 40227 | 26 |
| 21-23 | | | | | | | |
| 25-27 | 1 | .01 | 66 | 1.95 | 0.0195 | 1149 | 22 |
| 27-29 | 1 | .001 | 200 | 6.24 | 0.00624 | 4597 | 29 |
| 29-31 | 1 | .001 | 200 | 2.63 | 0.00263 | 11493 | 30 |
| 31-33 | 1 | .001 | 200 | 1.18 | 0.00118 | 22987 | 27 |
| 33-35 | 1 | .001 | 200 | 0.51 | 0.00051 | 40227 | 20 |
| 23-25 | | | | | | | |
| 27-29 | 1 | .01 | 66 | 2.16 | .0216 | 1149 | 25 |
| 29-31 | 1 | .001 | 200 | 7.05 | 0.00705 | 4597 | 32 |
| 31-33 | 1 | .001 | 200 | 2.78 | 0.00278 | 11493 | 32 |
| 33-35 | 1 | .001 | 200 | 1.10 | 0.00110 | 22987 | 25 |
| 35-37 | 1 | .001 | 200 | 0.52 | 0.00052 | 40227 | 21 |

TABLE 10. LINE F (CONT.)

| Sta. | Range | MA | Voltage | $V_p$ | DV/I | G.F. | $P_a$ |
|---|---|---|---|---|---|---|---|
| 25-27 | | | | | | | |
| 29-31 | 1 | .01 | 66 | 2.55 | 0.0255 | 1149 | 29 |
| 31-33 | 1 | .001 | 133 | 7.90 | 0.00790 | 4597 | 36 |
| 33-35 | 1 | .001 | 133 | 2.68 | 0.00268 | 11493 | 31 |
| 35-37 | 1 | .001 | 133 | 1.15 | 0.00115 | 22987 | 26 |
| 37-39 | 1 | .001 | 133 | 0.55 | 0.00055 | 40227 | 22 |
| 27-29 | | | | | | | |
| 31-33 | 1 | .01 | 66 | 3.00 | 0.030 | 1149 | 34 |
| 33-35 | 1 | .001 | 166 | 6.80 | 0.0068 | 4597 | 31 |
| 35-37 | 1 | .001 | 166 | 2.60 | 0.00260 | 11493 | 30 |
| 37-39 | 1 | .001 | 166 | 1.00 | 0.0010 | 22987 | 23 |
| 39-41 | 1 | .001 | 166 | 0.30 | 0.00030 | 40227 | 12 |
| 33-35 | 1 | .01 | 66 | 3.4 | 0.0340 | 1149 | 39 |
| 35-37 | 10 | .001 | 200 | 0.95 | 0.0095 | 4597 | 44 |
| 37-39 | 1 | .001 | 200 | 2.40 | 0.0024 | 11493 | 28 |
| 39-41 | 1 | .001 | 200 | 0.65 | 0.00065 | 22987 | 15 |
| 41-43 | 1 | .001 | 200 | 0.45 | 0.00045 | 40227 | 18 |
| 31-33 | | | | | | | |
| 35-37 | 1 | .01 | 66 | 4.50 | 0.0450 | 1149 | 52 |
| 37-39 | 1 | .001 | 200 | 8.20 | 0.00820 | 4597 | 38 |
| 39-41 | 1 | .001 | 200 | 1.40 | 0.00140 | 11493 | 16 |
| 41-43 | 1 | .001 | 200 | 0.95 | 0.00095 | 22987 | 22 |
| 43-45 | 1 | .001 | 200 | 0.60 | 0.00060 | 40227 | 24 |
| 33-35 | | | | | | | |
| 37-39 | 1 | .01 | 66 | 3.60 | 0.0360 | 1149 | 41 |
| 39-41 | 1 | .001 | 100 | 3.00 | 0.0030 | 4597 | 14 |
| 41-43 | 1 | .001 | 100 | 1.52 | 0.00152 | 11493 | 17 |
| 43-45 | 1 | .001 | 100 | 0.80 | 0.00080 | 22987 | 18 |
| 35-37 | | | | | | | |
| 39-41 | 1 | .01 | 66 | 3.00 | 0.030 | 1149 | 34 |
| 41-43 | 1 | .001 | 166 | 7.80 | 0.0078 | 4597 | 36 |
| 43-45 | 1 | .001 | 166 | 3.48 | 0.00348 | 11493 | 40 |
| 37-39 | | | | | | | |
| 41-43 | 1 | .01 | 66 | 3.50 | 0.0350 | 1149 | 40 |
| 43-45 | 1 | .01 | 66 | 1.00 | 0.010 | 4597 | 46 |
| 39-41 | | | | | | | |
| 43-45 | 1 | .01 | 66 | 3.40 | .034 | 1149 | 39 |

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

APPENDIX H

TABLE 11
GEOMETRIC FACTOR TABLE
SCHLUMBERGER METHOD

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

TABLE 12. DIPOLE-DIPOLE GEOMETRIC FACTOR TABLE

| na(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 13. WENNER GEOMETRIC FACTOR TABLE

| 2IIa(ft) | 25 | 50 | 100 | 200 | 300 | 400 | 500 |
|---|---|---|---|---|---|---|---|
| 6.2 | 157 | 314.16 | 628.32 | 1256.64 | 1884.64 | 2513.27 | 3141.6 |

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

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

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

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

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

## GEOTHERMAL ENERGY PUBLICATIONS

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

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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.

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

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