GEOTHERMAL RESOURCE ASSESSMENT OF THE ANIMAS VALLEY, COLORADO

by K. P. McCarthy T. G. Zacharakis C. D. Ringrose





COLORADO GEOLOGICAL SURVEY DEPT. OF NATURAL RESOURCES DENVER, COLORADO / 1982





The first two hotels at Trimble Hot Springs.

RESOURCE SERIES 17

GEOTHERMAL RESOURCE ASSESSMENT OF THE ANIMAS VALLEY, COLORADO

bу

Kevin P. McCarthy Ted G. Zacharakis Charles D. Ringrose

DOI: https://doi.org/10.58783/cgs.rs17.mvwp8119

Prepared by the COLORADO GEOLOGICAL SURVEY in cooperation with the U.S. Dept. of Energy Under Contract No. DE-AS07-77ET28365

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

NOTICE

This report was prepared to document work sponsored by the United States Government. Neither the United States nor its agent the United States Department of Energy, nor any Federal Employees, nor any of their contractors, subcontractors or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would infringe privately owned rights.

NOTICE

Reference to a company product name does not imply approval or recommendation of the product by the Colorado Geological Survey nor the U.S. Department of Energy to the exclusion of others that may be suitable.

ACKNOWLEDGMENTS

The authors are very grateful for the assistance of the following competent individuals: Jay Jones, geophysical survey field crew chief; Bob Fargo and Chuck Treska, geophysical survey field assistants; Michael Glaze, geochemical field crew chief, Deborah Wester, and James Poss, grochemical field crew assistants; Becky Nelson and Lori Thomas, typists; and Cheryl Brchan and Etta Norwood, who patiently drafted and redrafted maps to include the new highway alteration in the valley and to accommodate the evolving geologic interpretation of the writers.

Cap Allen, P.E., of Durango, provided a great deal of information regarding characteristics and history of the thermal springs, which was essential in this analysis. This report would have been much less complete without Mr. Allen's courteous assistance. The cover, by W. H. Jackson, is used through the courtesy of the Western History Department of the Denver Public Library. Sketches of Trimble Hot Springs Hotel were generously provided by the Colorado Historical Society. The staff at both of these fine resource centers were very helpful.

PAGE	
	-

A church lodge enter	
ACROVIECUY/CRCV	1
ADSTRACT	1
Introduction	1
Geology	5
Introduction	5
Tectonics and volcanism	5
Stratigraphy	6
Hydrogeclogy of Animas Valley thermal vater	6
Grigin of thermal waters	14
Electrical Geophysical Pesistivity Survey	17
Soil Monduny Surveys	24
Introduction	21
Studtory and mathedalary	24
Strategy and methodology	20
Sampling methods	25
Analysis	20
Animas Valley soil mercury surveys	27
Conclusions	30
References	31
Appendix A. Chemistry of Animas Valley warm waters	36
Appendix B. Factors affecting resistivity	38
Appendix C. Instrumentation	39
Appendix C. Resistivity field procedures	40
Wenner arrav	40
Schlumberger array	42
Cipole-Dipole array	42
Annendix F. Resistivity calculations	46
Appendix E. Geometric factor tables	60
	00

FICURES

PAGE

F	Ι	G	U	R	E
	_		-		_

•

1.	Animas Valley, Colorado, index map	2
2.	Animas Valley, Colorado, orientation map	3
3.	Geology and thermal springs in the Animas Valley, Colorado	7
4.	Stratigraphic column of the Animas Valley, Colorado	8
5.	Trimble Hot Spring characteristics through time	13
6.	Stiff diagram of Animas Valley thermal waters	16
7.	Geology, springs, and electrical resistivity lines at Finkerton	
	Hot Springs	18
8.	Pseudosection of resistivity line A	20
9.	Pseudosection of resistivity line E	21
10.	Pseudosection of resistivity line C	22
11.	Pseudosection of resistivity line D	23
12.	Ceology, springs, and soil mercury lines at Tripp-Trimble Hot	
	Springs	28
13.	Soil mercury profiles from Tripp-Trimble Springs area	30
14.	Schematic diagram for resistivity	40
15.	Wenner array	<u>4 (</u>
16.	Schlumberger array	42
17.	Dipole-dipole array	42
18.	Data plotting scheme for dipole-dipole array	43
19.	Typical dipole-dipole array	4 ?

TABLES

1.	Animas Valley thermal spring characteristics	12
2.	Soil mercury values, Tripp-Trimble Hot Springs	29
З.	Resistivity Line A calculations	46
4.	Resistivity Line B calculations	49
5.	Resistivity Line C calculations	52
6.	Resistivity Line D calculations	-58
7.	Ceometric factor table, Schlumberger method	60
8.	Dipole-dipole geometric factor table	60
9.	Wenner geometric factor table	60

by

Kevin P. McCarthy, Ted G. Zacharakis, and Charles D. Ringrose

ABSTRACT

The Colorado Geological Survey, in cooperation with the U.S. Department of Energy, has been engaged in assessing the nature and extent of Colorado's geothermal resources since 1977. The program has included geologic and hydrogeologic reconnaissance, and geophysical and geochemical surveys.

In the Animas Valley, in southwestern Colorado, two groups of thermal springs exist: Pinkerton Springs to the north, and Tripp-Trimble-Stratten Springs about 5 miles (8.1 Km) south of Pinkerton. Temperatures range from 28 to 44° C (82 to 111° F), and discharge ranges from 1 gpm to 50 gpm (.06 to 3.15 1/s).

During the summer of 1980, the geothermal resources of the Animas Valley were studied. Due to terrain problems in the narrow valley, a soil mercury survey was conducted only at Tripp-Trimble Stratten, while an electrical D.C. resistivity survey was limited to the vincity of Pinkerton.

Although higher mercury values tended to be near a previously mapped fault, the small extent of the survey ruled out conclusive results. Consistent low resistivity zones interpreted from the geophysical data were mapped as faults near Pinkerton, and compared well with aerial photo work and spring locations.

This new information was added to reconnaissance geology and hydrogeology to provide several clues regarding the geothermal potential of the valley. (1) Hydrothermal minerals found in faults in the study area are very similar to ore mined in a very young mountain range, the La Plata Mountains, nearby. (2) Groundwater would not need to circulate very deeply along faults to attain the estimated subsurface temperatures present in the valley. (3) The water chemistry of each area is unique. (4) Although previously incompletely mapped, faulting in the area is extensive.

The geothermal resources in the Animas Valley are fault controlled. Pinkerton and Tripp-Trimble-Stratten are probably not directly connected systems, but may have the same source at distance. Recharge to the geothermal system comes from the Needle and La Plata Mountains, and the latter may also be a heat source. Movement of the thermal water is probably primarily horizontal, via the Leadville Limestone aquifer. Further shallow drilling in the valley may produce moderate temperature fluids in great quantity, but deep drilling may not be as successful.

INTRODUCTION

In July, 1977, the Colorado Geological Survey, in cooperation with the U.S. Department of Energy (contract no. DE-AS077-28365), began a geothermal resource assessment program in the state, focusing on areas with the greatest

- ! -

potential for near term development. The program has included geologic and hydrogeologic reconnaissance, and geophysical and geochemical surveys.

One of the areas chosen for study was the Animas River Valley in southwestern Colorado. Several thermal springs are located in the valley, from 9 to 14 miles (15 to 23 Km) north of Durango (Figs. 1 and 2). The springs are clustered in two groups: the Pinkerton Springs, and the Tripp-Trimble-Stratten Springs. At Pinkerton Hot Springs, the most northerly site, two springs on the western side of the valley have produced large iron-stained travertine mounds. Two nearby springs closer to the river were destroyed recently by highway construction. Two shallow wells drilled just west of the new highway have characteristics similar to the former springs.

About 5 mi. (8.1 Km) south of Pinkerton, Tripp Hot Spring has just been plugged by the owner. This spring was the hottest in the valley several years ago (44°C, 111°F). Trimble Hot Spring is about 150 ft (46 m) south of Tripp, and historically the two springs accommodated a hotel and pool before the resort was destroyed by fire. An unnamed warm spring about 1/2 mi. (.8 Km) south of Trimble (Cap Allen, 1982), has yet to be examined by the authors. Stratten Warm Spring, about one mile north of Tripp, is currently unused (Fig. 2).



Figure 1. Animas Valley, Colorado index map.



Figure 2. Animas Valley, Colorado orientation map.

The hot springs in the Animas Valley have been discussed by Barrett and Pearl (1976, 1978), Coe (1981), George and others (1920), Hawn (1874), Lakes (1906), Lewis (1966), Mallory and Barrett (1973), and Pearl (1979). Subsurface temperature estimates from various chemical geothermometers range from 45° C (113°F) to 70°C (158°F) for Tripp and Trimble Springs, and from 75°C (167°F) to 125°C (255°F) for Pinkerton Hot Springs. These estimates are of questionable reliability and should be used with caution. With very little subsurface data on the area, Pearl (1979) made several general assumptions about the size, areal extent, and total energy of the resource. Probable areal extent was determined to be one to two square miles (1.6 to 3.2 sq. Km) at Pinkerton, and one square mile (1.6 sq. Km) at Tripp and Trimble. Total heat energy available in the valley was estimated to be about 60 x 1012 Btus at an average maximum temperature of 50°C (122°F).

During the summer of 1980, the Colorado Geological Survey conducted a soil mercury survey near Tripp and Trimble springs. An electrical D.C. resistivity survey was conducted in the vicinity of the Pinkerton Hot Springs.

GEOLOGY

Introduction

As is often the case in bonanza areas, prospectors and miners were well established in southwestern Colorado before formal geologic reconnaissance occurred. The first known attempt at prospecting in the San Juans took place in the Animas Valley in 1860. Hawn (1874) made geologic notes on the Animas Valley and first described the hot springs (probably Pinkerton Hot Springs) during a Corps of Engineers expedition. Holmes (1877) reported on the area for the Hayden Territorial survey. Cross and others (1897) began accurate detailed mapping of the region, and Lakes (1896, 1902, 1906) wrote short articles on local mining activity. More detailed regional work, and unravelling of geologic history was accomplished by Atwood and Mather (1912), Baars and Knight (1957), Baars and See (1968), Barker (1969), Cross and others (1905), Eckel (1940), Kelley (1957), Kilgore (1955), Larsen and Cross (1956), Lipman and others (1970), Luedke and Burbank (1960), Steven and others (1974), Wengerd (1975), and Zapp (1949). A comprehensive view of regional volcanic history is presented by Steven and Lipman (1976). The following discussion of the geology of the valley draws heavily from the extensive work referenced above. Figure 3 shows the geology of the study area.

The study area is in a transitional zone between the Southern Rocky Mountain and Colorado Plateau physiographic provinces. The Animas River is a primary southerly drainage of the young, volcanic San Juan Mountains. The surrounding country, then, ranges from high desert to some of the most spectacular high peaks in North America.

The study area is bounded by the San Juan Basin to the south, the La Plata Mountains to the west, and the Needle Mountains to the northeast (fig. 2). The La Plata and Needle Mountains may be considered sub-structures within the larger San Juan Mountain region.

Tectonics and Volcanism

The San Juan Mountains are an eroded volcanic plateau in which at least 15 Tertiary calderas have been identified. These collapse structures were caused by recurrent large volume ash eruptions, which evacuated shallow magma chambers, leaving strato-volcanoes unsupported. Post-volcanic caldera collapse and resurgence produced ring faults and radial fractures that provided avenues for hydrothermal solutions and subsequent base metal precipitation. Gravity data suggests that a shallow, batholithic magma chamber and associated cupolas produced the eruptive materials.

Volcanic activity began in Oligocene time, peaking about 28 million years ago, and drawing to a close in the middle Pliocene. The early flows were of intermediate composition. About 25 million years ago, the character of ejected material changed abruptly to a more basaltic composition with associated high silica, alkali-rich rhyolites. This change roughly coincided with normal faulting in the adjacent Rio Grande Rift area (Steven and Lipman, 1976). By 22 million years ago, the batholith had congealed sufficiently to allow a younger magma to penetrate to shallow depth and retain its distinctive composition (Steven and Lipman, 1976). Intermittent basaltic flows persisted during the remainder of the volcanic period. The Needle Mountains, the only extensive exposure of Precambrian rocks in southwestern Colorado, were probably a topographic high during volcanism, around which the ejecta accumulated (Kelley, 1957). This positive area was the central portion of an extensive dome which stretched from Durango to the Gunnison River and encompassed the smaller Rico and La Plata domes to the west (Larsen and Cross, 1956). Uplift occurred during the Laramide Orogeny and was marked by recurrent movement along Precambrian faults. These mountains today are the most isolated high peaks in the region, and access is limited.

The La Plata Mountains are an eroded laccolithic dome encompassing only about 10 square miles (16 sq. Km). The sills, dikes, and stocks present were emplaced following the main San Juan volcanism. The intruded, altered strata range from Pennsylvanian through upper Cretaceous in age. The central, highest portion of the range is composed entirely of igneous rock. A horseshoe-shaped hinge fold nearly encircles the central portion of the mountains, and several faults of large displacement ring the outer perimeter of the dome (Eckel, 1940).

The San Juan Basin is a structural embayment between the Colorado Plateau and the southwestern edge of the Rocky Mountains. The tectonic evolution of the basin probably began in the late Paleozoic. The current morphology of the basin can be traced to late Cretaceous time (Kelley, 1950), and up to 23,000 ft (7,000 m) of sediments are present today.

In the vicinity of the hot springs, the sedimentary rocks dip gently to the south; but near Durango, the rocks plunge more steeply into the San Juan Basin. Minor faults in the area are transverse to the valley, and pass through the springs at Pinkerton and Trimble (Fig. 3).

Stratigraphy

Many-hued sedimentary rocks representing over 500 million years of geologic history may be observed between Rockwood and Bondad, Colorado (Kilgore, 1955) (Fig. 2). Figure 4 shows the stratigraphy of this area and is taken from Atwood and Mather (1912), Baars and others (1967), Baars and See (1968), Barker (1969), Brodgen and Giles (1976), Kilgore (1955), Mitchell (1957), and Steven and others (1974).

HYDROGEOLOGY OF ANIMAS VALLEY THERMAL WATER

The hot springs in the Animas Valley have undergone extensive modification recently. Tripp Spring was plugged by the owner, and no longer exists. The flow of Trimble Spring has recently been considerably reduced due to tufa buildup around the mouth of the spring. The spring orifice was drilled out in May, 1982, increasing temperature and discharge (Cap Allen, oral communication, 1982). Springs A and B at Pinkerton Hot Springs (Barrett and Pearl, 1978) have been destroyed by highway construction. Two shallow wells (probably less than 20 ft or 6 m) recently completed on the west side of the highway have characteristics similar to the former springs A and B, so will be referred to as such.

Table 1 summarizes the properties of the Animas Valley Springs. Water chemistry is shown in Appendix A.



GENERALIZED STRATIGRAPHIC COLUMN

ANIMAS VALLEY, COLORADO



Conglomerate



Figure 4.





Figure 4. Continued.



Table 1 Animas Valley thermal spring characteristics

	Discharge (GPM)	(1/s)	TCS (Mg/1)	T (°C)	(°F)
South					
Warm Spring				29 (E)	34
Trimble Hot Spring	10 (E)	•6	3340	43 (E)	110
Tripp Hot Spring (9-75)	1 (E)	.06	3240	44	111
Stratten Warm Spring	10 (E)	• 6	1300 (E)	28	82
Pinkerton Hot Springs Well B	20 (E)	1.3	3800 (E)	33	91
Well A	50 (E)	3.2	3770 (E)	32	90
Mound Spring	5 (E)	• 3	3840	29	84
Little Mound Spring	2 (E)	•1	3800 (E)	26	79

North

from Barrett and Pearl (1976) and CGS estimates

Figure 5 illustrates historical changes in water quality, discharge, and temperature at Trimble Springs prior to drilling. The spring may have been partially plugged when the resort burned down for the third time in 1963 (Barbara Coe, pers. comm., 1982). The correlative decay of water quality, discharge, and temperature probably indicates greater circulation in alluvium due to surface obstruction. This is consistent with observed tufa buildup apparently narrowing the spring orifice.

The flow of at least one of the springs in the valley has apparently decreased dramatically. Although not specific about which spring in the valley to which he refers, Fossett (1880) states: "Another flows a large stream ... This spring is violently agitated, and the escaping carbonic acid gas escapes with such force as to resemble escaping steam from an engine, and can be heard for quite a distance."

Wells A and E, completed in the alluvium at Pinkerton, have consolidated some subsurface thermal waters, and discharge is great. At Trimble, surface obstruction perhaps increased thermal water circulation in shallow alluvium. Decreases in flow of springs in the valley may be related to increased use of cold water in the alluvial aquifer for irrigation. All of the springs and wells in the valley exhibit strong seasonal fluctuations (Cap Allen, pers. comm., 1982). All of this information strengly suggests that thermal water is widely dispersed and diluted in the shallow alluvium in the valley.



Figure 5. Trimble Hot Spring characteristics through time (data from Peale, 1886: George, 1920; Waring, 1965; and Barrett and Pearl, 1978).

Origin of Thermal Waters

The highest heat flow value in the state (240 mw/m²) was recorded near Rico about 35 mi (58 Km) northwest of the study area (Decker and Bucher, 1979). Zacharakis (1981) determined that the study area may have a heat flow value of 80 mW/m².

If the thermal water is simply produced by deep groundwater circulation in this area of elevated heat flow, depth of circulation can be approximated. At Tripp-Trimble-Stratten, assuming an average subsurface temperature of $60^{\circ}C$ (140°F) (Barrett and Pearl, 1978), and a regional gradient of $35^{\circ}C/Km$ (Repplier and Fargo, 1982), groundwater would need to penetrate to about 4900 ft (1500 m) beneath the recharge area to attain the estimated subsurface temperature. Assuming an average subsurface temperature of $100^{\circ}C$ (212°F) at Pinkerton (Barrett and Pearl, 1978), groundwater circulation would need to extend to 8600 ft (2600 m).

Previous investigations have referred to faults governing the location of the thermal springs (Lakes, 1906, Kilgore, 1955), although these have not been mapped at Pinkerton, except in cross-section. The faults shown in figure 3 were inferred from Kilgore (1955), geophysical data, aerial photos, and surface observation. If this interpretation of faulting is correct, the central portion of the valley in the study area is a minor graben. If faulting extends to great depth, the faults may merge in a shattered "reservoir" of groundwater heated by normal geothermal gradients.

Lakes (1906) described an occurrence of free gold and mercury in a fault zone just west of Trimble, above the Hermosa Cliffs. A dike immediately west of the mineral site was construed to have originated from the La Plata volcanic area, further to the west. The free gold, cinnabar, and telluride minerals found were similar to ore deposits in the La Plata Mountains. The similarity of these precipitates suggests that hydrothermal fluids originate from the west. Brady (1975) mentions fluorite associated with the above minerals at the Mason Mine, about 2.5 mi. (4 Km) due west of Trimble. Significant hydrothermal fluorspar deposits elsewhere in Colorado show a genetic relationship to nearby hot springs (Brady, 1975). The thermal springs in the valley may be diluted surface expressions of a larger hydrothermal system. The undetectable mercury in the spring water is consistent with other waters that deposit mercury (Hem, 1970).

The springs at Pinkerton issue from the Leadville Limestone, an important geothermal aquifer in Colorado, or overlying alluvium. The more southerly springs emerge from the upper portion of the Honaker Trail Formation in the Hermosa Group. Figure 6 illustrates the basic chemistry of the waters by relative abundance of select ions. The Pinkerton waters are distinct from those of the other group. Correlating water chemistry to host rock, the high calcium and bicarbonate at Pinkerton are expected from limestone waters and evidenced by the large travertine aprons. On the other hand, the salt load here would be more typical of waters moving through shaly sediments. Surprisingly, Stratten, Tripp, and Trimble Springs, which issue from evaporite-bearing red-beds, are lower in salts and iron, although the abundant calcium and sulphate ions probably represent dissolution of gypsum present in the subjacent Paradox Formation. The high salt fraction at Pinkerton probably indicates: (1) that the waters migrated through the red beds before entering the limestone aquifer, moving laterally some distance; (2) that solution



Figure 6. Stiff diagram of Animas Valley thermal waters (from analysis by Barrett and Pearl, 1976). (See Appendix A)

caverns within the limestone contain collapse material from the overlying sediments; (3) solutioning has occurred at the Leadville-Molas contact, or (4) the water moved in faulted Molas and Hermosa Formations in contact with the Leadville. The chemistry and higher temperatures at Tripp-Trimble-Stratten suggest a more direct, perhaps more vertical water migration.

A likely hypothesis regarding the nature of the springs can be derived from the above information. Faults transverse to the valley convey the thermal water to near-surface but the fluid may be dispersed in the alluvium. The La Plata mountains are the closest prominent topographic high and can be considered the primary recharge area. These mountains may also be the heat source, since they are composed of very near surface intrusions which are among the youngest in the San Juan region, and hydrothermal activity associated with La Plata intrusives probably extended into the study area. The thermal waters probably are almost entirely originally meteoric, with a very minor magmatic fraction since Craig and others (1956) have shown that this is the case with nearly all thermal springs. They are hydrothermal in the sense that temperature is above normal, and mineral precipitation has occurred. The waters at Pinkerton and Tripp-Trimble-Stratten are unique, and the two systems are probably not directly connected, although the waters may come from the same source at distance, and minor mixing may occur in the valley alluvium. The water probably moves further horizontally than vertically, mostly within the Leadville Limestone aquifer.

ELECTRICAL GEOPHYSICAL RESISTIVITY SURVEY

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

Using a Scintrex RAC-8 Electrical Resistivity System a total of 4 dipole-dipole resistivity survey lines were run totalling 13,900 feet (4238 m) in the vicinity of the Pinkerton hot springs area. A complete description of this system is presented in Appendix C. Figure 7 shows survey lines, inferred faults, and springs during the survey. Wells A and B had not yet been drilled, Spring A had been diverted to a position west of the highway, and Spring B was still flowing east of the highway. Line C (Fig. 10) was run along the narrow gauge railroad and indicated three low resistive zones that showed good alignment with low resistive zones on lines B and A (Fig. 9, 8). The surface geology was primarily composed of the Pinkerton Trail Formation along line C (Fig. 10), and the Leadville/Ouray limestones near line B (Fig. 9). East of these lines, the rock type was mostly alluvial deposits of Quaternary Age. Two transverse faults are inferred on the dipole-dipole pseudosections in the low resistive zones (Figs. 8, 9, 10, 11). Due to terrain obstacles and cultural conditions, additional resistivity lines were not run that may have delineated additional faulting in the area. See Appendix D for a description of the field procedures pertaining to the various arrays employed. In the interpretation of any dipole-dipole pseudosection, one must be cognizant of the fact that values obtained along the line of traverse may be influenced by lateral variations of three dimensional features at depth. It was not discerned whether this was the case in the Pinkerton Hot Springs area. Appendix F presents the geometric factor tables used to calculate the resistivity values in Appendix E.



Figure 7. Geology, springs, and electrical resistivity lines at Pinkerton Hot Springs.

Figure 7. Continued.

EXPLANATION

۹,	Thermal springs
,,,,,	Resistivity survey lines with station numbers
<u>() </u>	Area of low resistivity
	Inferred faults
Qal	Quaternary alluvium
ΜΙο	Mississippian Leadville and Ouray limestone
IPh	Pennsylvanian Hermosa Group



LINE A - This dipole-dipole line trends NE-SW and is adjacent to the Timberline Academy (Fig. 7) A low resistive zone was measured between stations 10 through 24 in the vicinity of Spring A. It is believed that where the RAC-8 resistivity system was unable to resolve the low resistivity zone because the receiver couldn't lock on, the system probably experienced values in the single digit area. This zone manifests itself at the surface by travertine mounds that could persist with depth. Two possible faults, down-thrown to the south, are inferred by the low values. Table 3 (Appendix E) tabulates the resistivity calculations for line A.

20

LENGTH: 3,600 ft [1,090m] SEPARATION: **N** Value DATE: July 16,17, 1980 TYPE: Dipole-Dipole SPREAD: a= 200 ft RESISTIVITY: In ohm meters — POSSIBLE FAULT SCALE

0 200 feet



LINE B - This dipole-dipole line trends north-south and is adjacent to Highway 550 (Fig. 7). A deep seated low resistivity zone exists below stations 30 to 32. A poorly defined resistivity zone exists between stations 21 and 27 with the resistivity increasing to the north and south. A tufa mound by Spring B lies at Station 17 which is in the approximate area of low resistivities. A low resistive zone at Stations 6-13 reflects a strike trend from line A with the same low resistive zone. Two faults transverse to the valley are plotted that align fairly well with the faults inferred on lines A and C. Table 4 (Appendix E) tabulates the resistivity calculations for Line B.



<u>LINE C</u> - This dipole-dipole line trends north-south and is parallel and adjacent to the narrow gauge railroad (Fig. 7). Two low resistive zones exist between stations 9 and 14 by the Big and Little Mound Springs and between stations 25 and 30. Both of these low resistive zones are marked by tufa mounds. These low resistive zones may indicate possible faulting that show good strike alignment with the other two parallel lines. Table 5 (Appendix E) tabulates the resistivity calculations for line C. LENGTH: 4,500 ft [1,372m] SEPARATION: **N** Value DATE: July 21-24, 1980 TYPE: Dipole-Dipole SPREAD: a=200 ft RESISTIVITY: In ohm meters POSSIBLE FAULT SCALE

200 feet

1



LINE D - This dipole-dipole resistivity line reflects a low resistive zone in the proximity of stations 8, 9, and 10 with the resistivity increasing to the north as the bedrock changed from alluvium to limestone (Fig. 7). The similarities that exist between line D and line A are due to a low resistivity zone at their intersection. The resistive low at Station 5 is probably due to seepage near the surface. Table 6 (Appendix E) tabulates the resistivity calculations for line D. SCALE

0 100 feet

1

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 et al (1980), have used soil mercury surveys on a regional scale. On a detailed scale, Klusman and Landress (1979) and Capuano and Bamford (1978) have shown how soil mercury surveys can delineate faults or permeable zones in geothermal areas. The association of mercury with geothermal deposits has been shown by White (1967). Matlick and Buseck (1976) stated that areas with known thermal activity, such as: Geysers in California; Wairakei, New Zealand; Geyser, Iceland; Larderello, Italy; and Kamchatka in Russia contain mercury deposits.

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

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

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

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

Strategy and Methodology

The aim of the depchemical 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 200 ft or 400 ft (30 m to 61 m or 122 m). When using a 400 ft (122 m) to interval, the area in the immediate vicinity of the hot spring was considered the target rather than any particular fault. Sampling intervals of 200 ft (61 m) or less were used where attempts were made to delineate controlling faults. This spacing was used by Capuano and Bamford (1978). However, Klusman and Landress (1979) seem to think that the sample must be taken directly over the faulting for detection. Considering the empirical result of Capuano and Bamford (1978), it was believed that some anomalous mercury values should be encountered if a grid pattern encompassing the hot spring area was used. А definite structural pattern may be obvious, but if the study area is being influenced by geothermal activity, the trend should indicate that the hot springs area entirely or partially is high in mercury relative to surrounding area.

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

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

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

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

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

Analysis

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

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

- 1). Determine the number of class intervals by multiplying the logarithm of the sample by 10.
- 2). Determine the range of each class interval by dividing the maximum recorded value, determined above, by one less.
- 3). Determine logarithm of top end of each interval.
- 4). Determine class frequency by calculating the number of values in each class.

- 5). Determine relative frequency by dividing each class frequency value by total number of values.
- 6). Construct frequency distribution graph by plotting class frequency log values by cumulative frequency.
- 7). Note where break in slope of graph occurs.

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

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

ANIMAS VALLEY SOIL MERCURY SURVEYS

Due to topographic and cultural restrictions soil mercury surveys in the Animas River Valley were restricted to the immediate area surrounding the Tripp-Trimble Hot Springs. During the summer of 1979 a total of 12 soil mercury samples were collected on one hundred foot centers along two short lines (Fig 12). Interpretation of the analytical data did not provide much information regarding controlling features. As noted on Fig 13 and Table 2, the highest values were obtained at the southern end of Line A-A'. Due to topography, it was not possible to extend Line A-A' any further south. Although the higher values were recorded near an inferred fault, the extent of the survey was not great enough to be conclusive.



EXPLANATION

Thermal springs								
41 X	Soil mercury lines A and B numbers are values in ppb							
<u> </u>	Inferred faults							
Qal	Quaternary alluvium							
Pc	Permian Cutler Formation							
IPh	Pennsylvanian Hermosa Group							

Figure 12. Geology, springs, and soil mercury lines at Tripp-Trimble Hot Springs.



Figure 13. Soil mercury profiles from Tripp-Trimble Springs area.

Line B-B' Line A-A' 46 45 1. 1. 2. 28 2. 46 3. 280 * 3. 41 4. 46 4. 38 35 * Located next to old swimming pool. 5. 6. 61 7. 127* 8. 25 9. 65 10. 54 * Located on site of old hotel. Abundant charcoal present.

CONCLUSIONS

Due to culture and terrain obstacles, the resistivity survey was limited to the proximity of the thermal area of Pinkerton Hot Springs. From the low resistive zones mapped, the possible areal extent of the thermal area trends approximately 3,000 ft (915 m) in a N-S direction and 1,000 ft (305 m) in an E-W direction (Figure 13). Analysis of the dipole-dipole pseudosections revealed two possible faults, transverse to the Animas Valley.

One must keep in mind that the resistivity system employed was only able to obtain shallow depth readings of 300 to 500 ft (91 to 152 m), therefore what may be occurring at greater depths is unknown. Additional resistivity lines may be attempted where more control is required. This may be a difficult task due to cultural and terrain hindrances.

The soil mercury survey showed some correlation to springs and possible faulting at Tripp/Trimble, but was inconclusive. A much greater sampling area would more positively define the extent of thermal activity.

The mapped faults show good correlation between geophysical and geochemical survey results, aerial photo work, and previous investigations. These faults control near surface movement of thermal water in the valley.

Drilling and isotope analysis would greatly aid any further investigation. From the data gathered and analyzed by the Colorado Ceological Survey, it appears that the geothermal fluids in the Animas Valley may originate in the La Plata area. Each group of springs is separate and distinct, and the temperatures encountered by drilling will probably be low, although discharge may be great. A drilling strategy might be aimed toward intercepting faults or penetrating the Leadville Limestone geothermal aquifer on the western side of the valley.

REFERENCES.

- At wood, W. W., and Mutter, T. F., 1912, The evidence of three distinct glacial epochs in the Pleistocene history of the San Juan Mountains, Colorado: J. Geol., Vol. 20, p. 385-409.
- Baars, D. L., and Knight, P. L., 1957, Pre-Pennsylvanian stratigraphy of the San Juan Mountains and Four Corners area, in Guidebook of Southwest San Juan Mountains, Colorado, 8th Field Conference, New Mexico Ceol. Soc., p. 108-131.
- Baars, D. L., Parker, J. W., and Chronic, J., 1967, Revised stratigraphic nomenclature of Pennsylvanian System, Paradox Basin: Am. Assoc. Petroleum Geologists Bull., v. 51, no. 3, p. 393-403.
- Baars, C. L., and See, P. D., 1968, Pre-Pennsylvanian stratigraphy and paleotectonics of the San Juan Mountains, southwestern Colorado: Geol. Soc. An. Bull., Vol. 79, No. 3, p. 333-349.
- Barker, F., 1969, Precambrian geology of the Needle Mountains, southwestern Colorado: U.S. Geol. Survey Prof. Paper 644-A, p. 35.
- Barrett, J. K., and Pearl, R. H., 1976, Hydrogeologic data of thermal springs and wells in Colorado: Colorado Geol. Survey Info. Series 6, 124 p.
- _____1978, An appraisal of Colorado's geothermal resources: Colorado Geol. Survey Bull. 39, 229 p.
- Brady, B. T., 1975, Map showing flourspar deposits in Colorado: U.S. Ceol. Survey Mineral Investigations Resource Map MR-70.
- Brogden, R. E., and Ciles, T. F., 1976, Availability and chemical characteristics of ground water in central La Plata County, Colorado: U.S. Ceol. Survey Water Resource Investigations Map 76-69.
- Capuano, P.M. and Bamford, R.W., 1978, Initial Investigation of Soil Mercury Geochemistry as an Aid to Drill Site Selection in Geothermal Systems, Contract: EC-78-C-07-1701, Earth Science Laboratory, University of Utah Research Institute, Salt Lake City, Utah.
- Coe, E. A., 1981, Geothermal energy opportunities at four Colorado towns: Durango, Glenwood Springs, Idaho Springs, and Ouray: U.S. Dept. of Energy DOE/ID/12019-8, Idaho Falls, ID, 60 p.
- Combs, Jim, 1981, Geothermal Exploration Strategy and Techniques, 1981, Geothermal Services Inc., San Diego, CA, 41 p.

- Cox, M. E., and Cuff, K. G., 1980, Pn and Hg Surveys: Geothermal Exploration in N.E. Maui Hawaii, in Geothermal Energy for the Eighties, Transactions Geothermal Pesources Council Annual Meeting, Salt Lake City, UT: Geothermal Res. Council, Davis, CA, p. 451-454.
- Craig, H. G., Boato, C., and White, D. E., 1956, Isotopic geochemistry of thermal waters: National Research Council, Nuclear Science Series Report 19, p. 29-38.
- Cross, C. W., Spencer, A. C., and Purington, C. W., 1897, Descriptions of the La Plata Quadrangle: U.S. Geol. Survey Geol. Atlas Folio Series, No. 60.
- Cross, C. W., Howe, E., and Pansome, F. L., 1905, Silverton folio; Geography and general geology of the quadrangle: U.S. Geol. Survey, Geol. Atlas Folio Series, No. 120.
- Decker, E. R., Bucher, C. J., 1979, Thermal gradients and heat flow data in Colorado and Wyoming: Los Alamos Scientific Lab., LA-7993-MS, p. 1-9.
- Eckel, E. B., 1940, Geology and ore deposits of the La Plata district, Colorado: U.S. Geol. Survey Prof. Paper 219, 179 p.
- Fossett, Frank, 1880, Colorado, its gold and silver mines, farms and stock ranges, and health and pleasure resorts--Tourists guide to the Rocky Mountains, 2d ed.: New York, C.C. Crawford, 592 p.
- Ceorge, R. D., Curtis, H. A., Lester, C. C., Crook, J. K., and Yeo, J. M., 1920, Mineral Waters of Colorado: Colorado Ceol. Survey Bull. 11, 474 p.
- Hawn, F., 1874, Geological notes on the Ute Reconnaissance during examination of the Animas, in Report of the reconnaissance in the Ute country made in 1873 by Ruffner: 42nd Congr., 1st Session, House Exec. Doc. No. 193, p. 59-69.
- Hem, J. D., 1970, Study and interpretation of the chemical characteristics of natural water: U.S. Gecl. Survey Water Supply Paper 1473, 363 p.
- Holmes, W. H., 1877, Report as geologist of the San Juan division: U.S. Geol. Geogr. Survey Territ. (Hayden), Ann. Rept., No. 9, p. 237-276.
- Kelley, V. C., 1950, Regional structure of the San Juan Basin, in Guidebook of the San Juan Basin, New Mexico and Colorado, 1st Field Conf., New Mexico Geol. Soc., p. 101-108.
- 1957, General geology and tectonics of the vestern San Juan Mountains, Colorado, in Guidebook of the Southwestern San Juan Mountains, Colorado, 8th Annual Field Conference, New Mexico Ceol. Soc., p. 154-162.

- Filsond, L. W., 1965, Coolegy of the Ednargo area, La Plata County, Colorado, in Four Corners Ceological Cociety First Field Conference, p. 112-124.
- Klusman, R.W. and Landress, R.A., 1979, Dercury in Soils of the Long Valley, California. Geothermal System: Jour. Volcanology, Geothermal Res., v. 5, pp. 43-65.
- Klusman, R.W., Cowling, S., Culvey, B., Roberts, C., and Schwab, A.P., 1977, Preliminary evaluation of secondary controls on mercury in soils of geothermal districts: Geothermics, v. 6, pp. 1-8.
- Lakes, A., 1896, The San Juan region: Coll. Eng., Vor. 17, p. 206-207.
- _____1902, Geology along the Animas Piver: Mines and Minerals, Vol. 22, p. 398-399.
- 1906, A peculiar occurrence of native mercury, free gold, and telluride minerals near Trimble Springs, Durango, Colorado: Mining Peporter Vol. 54, p. 389-390.
- Larsen, E. S., and Cross, C. W., 1956, Geology and petrology of the San Juan region, southwestern Colorado: U.S. Geol. Survey Prof. Paper 258, 303 p.
- Lepeltier, Clande, 1969, A Simplified Statistical Treatment of Geochemical Data by Graphical Representation: Economic Geology, Vol. 64, pp. 538-550.
- Levinson, A.A., 1974, Introduction to Exploration Geochemistry, Applied Publishing Ltd., Calgary, pp. 561-568.
- Lewis, E.L., 1966, The thermal springs of Colorado--A resource appraisal: Univ. of Colorado Pept. Geography, Master Sci. Thesis, 91 p.
- Lipman, P. W., Steven, T. A., and Mehnert, H. H., 1970, Volcanic history of the San Juan Mountains, Colorado, as indicated by potassiumargon dating: Geol. Soc. Am. Bull., Vol. 81, No. 8, p. 2329-2351.
- Lundke, P. C., and Eurbank, W. S., 1960, Volcanism and Cauldron development in the western San Juan Mountains, Colorado, in Cenozoic volcanism in the southern Rocky Mountains: Colorado School of Mines Quarterly, Vol. 63, No. 3, p. 175-208.
- Mallory, E.C., Jr. and Barrett, P.R., 1973, Chemistry and spectrochemical analysis of selected groundwaters in Colorado: U.S. Geol. Survey open-file Report, 47 p.
- Matlick, J.S. III and Buseck, P.R., 1976, Exploration for geothermal areas using mercury - a new geochemical technique, in Proceedings Second United Nations Symposium on the Development and Use of Casthornial Poseurous San Enancisco CA : U.S. Cov. Printing Office
 - Ceethermal Resources, San Francisco, CA.: U.S. Gov. Printing Office, v. 1, pp. 785-792.

- Miesh, A.T., 1976, Sampling Designs for Geochemical Surveys syllabus for a short course: U.S. Geol. Surv. Open-file Report 76-772.
- Mitchell, J. C., 1957, No. 12, Animas River Canyon measured section, in A Symposium, Rocky Mountain Assoc. of Ceologists, p. 59-65.
- Peale, A. C., 1886, Lists and analyses of the mineral springs of the United States: U.S. Geol. Survey Bull. 32, 235 p.
- Pearl, R.H., 1972, Geothermal resources of Colorado: Colorado Geol. Survey Spec. Pub. 2, 54 p.

_____R. H., 1979, Colorado's hydrothermal resource base - An assessment: Colorado Geol. Survey Resource Series 6, 144 p.

- Repplier, F. N., and Farge, R. L., 1981, Geothermal gradient map of Colorado: Colorado Geol. Survey Map Series 20.
- Scintrex, 1971, RAC-8 low frequency A.C. resistivity system operation manual: Concord, Ontario, Canada, 22 p.
- Soil Test Inc., 1968, Earth Resistivity Manual: Evanston, Illinois, 52 p.
- Steven, T. A., Lipman, P. W., Hail, W. J., Jr., Barker, F., and Luedke, R.C., 1974, Geologic map of the Durango quadrngle, southwestern Colorado: U.S. Geol. Survey, Misc. Geol. Invest. Map I-764.
- Steven, T. A., and Lipman, P. W., 1976, Calderas of the San Juan volcanic field, southwestern Colorado: U.S. Geol. Survey Prof. Paper 958, 35 p.
- Summer, J. S., 1976, Principles of induced polarization for geophysical exploration: Elsevier Scientific Publishing Company, pp. 1-277.
- Waring, G. A., 1965, Thermal springs of the United States, and other countries of the world- -A summary, revised by R.F. Blankenship and Ray Bentall: U.S. Geol Survey Prof. Paper 492, 383 p.
- Wengerd, S. A., 1957, Permo-Pennsylvanian strata of the western San Juan Mountains, Colorado, in Guidebook of the Southwestern San Juan Mountains, Colorado, 8th Field Conference, New Mexico Geol. Soc., p. 131-138.
- White, D.E., 1967, Mercury and base-metal deposits with associated thermal and mineral waters, in Barnes, H.L., ed., Geochemistry of hydrothermal ore deposits: New York, Holt, Rinehart and Winston, pp. 575-631.
- White, D.E., Hinkle, L.G. and Barnes, I., 1970, Mercury content of natural thermal and mineral fluids: U.S. Geol. Survey Prof. Paper 713, pp. 25-28.

- Zacharakis, T.G., 1981, Pevised beat flow map of Colorado: Colorado Cool. Survey Map Series 18, scale 1:1,000,000.
- Zapp, A.D., 1949, Ceclogy and coal resourcesof the Durango area, La Plata and Montezuma Counties, Colorado: U.S Geol. Survey Oil Inv. Map No. 109, Scale 1:126,720.

-

APPENDIX A

CHEMISTRY OF ANIMAS VALLEY WARM WATERS

			Pinkerton		
	Tripp	Trimble	Spring A	Spring B	Mound Spring
Date Sampled	9/75	9/75	9/75	9/75	9/75
Arsenic (As), (UG/L):	17	17	120	160	180
Boron (B), (UG/L):	1,500	1,400	3,000	3,000	3,000
Cadmium (Cd), (UG/L):	0	0	C	0	<u>C</u>
Calcium (Ca), (MC/L):	470	510	510	530	550
Chloride (Cl), (MC/L):	220	220	1,000	990	1,000
Fluoride (F), (MG/L):	2.7	2.7	2.1	-	2.1
Iron (Fe), (UG/L):	10	50	4,400	4,400	4,100
Lithium (Li), (UG/L):	1,600	1,600	2,500	2,800	2,800
Magnesium (Mg), (MG/L):	41	42	79	71	74
Manganese (Mn), (UG/L):	08	80	470	530	500
Mercury (Hg), (UG/L):	C	0	0	0	С
Nitrogen (N), (MC/L):	0.16	80.0	0.10	-	0.06
Phosphate (PC ₄) Ortho diss.as P, (MG/L): Ortho, (MC/L):	0.05 0.15	0.02	0.05 0.15	0.01	0.01 0.03
Potassium (K), (MG/L):	47	47	120	120	120
Selenium (Se), (UG/L):	0	0	C	0	0
Silica (SiO ₂), (MG/L):	69	72	28	-	29
Sodium (Na), (MG/L):	500	510	750	720	730
Sulfate (SO ₄), (MG/L):	1,400	1,400	690	610	£20
Zinc (Zn), (UG/L):	20	10	0	20	10
Alkalinity As Calcium Carb. (MG/L): As Bicarbonate (MG/L):	810 988	894 1,090	1,340 1,630	1,350 1,640	1,340

APPENDIX A CONTIUNED

CHEMISTRY OF ANIMAS VALLEY WARM WATERS

			Pinkerton		
	Tripp	Trimble	Spring A	Spring B	Mound Spring
Hardness Noncarbonate (MG/L): Total, (MG/L):	530 1,300	550 1,400	260 1,600	280 1,600	340 1,700
Specific Conductance (Micromohs):	3,900	4,400	5,600	6,000	5,600
Total dissolved solids (TDS), (MG/L): pH, Field	3,240	3,340	3,990	-	3,940
Discharge (gpm):	-	1E	54	20	8E
Temperature (°C):	44	36	32	33	30
Remarks:					

Source of data: Barrett & Pearl, 1976.

•

APPENDIX B

FACTORS AFFECTING RESISTIVITY

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

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

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

APPENDIX C

INSTRUMENTATION

Scintrex RAC-8 Low Frequency Resistivity System

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

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

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

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

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

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

APPENDIX D

RESISTIVITY FIELD PROCEDURES

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

Apparent Resistivity:

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

See Figure 14 for a schematic diagram for resistivity.

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

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

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

Wenner Array

In the Wenner Spread (Fig. 15) the electrodes are uniformly spaced in a line (Sumner, 1976).







$$\mathcal{P}_{a=2\pi a(\triangle V/I)}$$

Figure 15. Wenner array (from Combs, 1980).

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

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

Schlumberger Array

For the Schlumberger array, the current electrodes are spaced much further apart than the potential electrodes (Fig. 16).

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

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

Dipole-Dipole Array

The potential electrodes are closely spaced and remote from the current electrodes which are close together. There is a separation between C and A, usually 1 to 5 times the dipole lengths (Fig. 17).

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 18 and Figure 19.

With reference to Figure 18 and 19, 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



Figure 16. Schlumberger array (from Combs, 1980).



 $\mathcal{P}_{a-nn(n+1)(n+2)a(\Delta V/I)}$

Figure 17. Dipole-dipole array (from Combs, 1980).



Figure 18. Data plotting scheme for dipole-dipole array (from Combs, 1980).



Figure 19. Typical dipole-dipole array (from Combs, 1980).

the other two methods (Wenner, Schlumberger). In addition, the dipole-dipole array is easier to maneuver in rugged terrain than either of the other methods. Its main disadvantage compared to the Schlumberger array is that is usually requires more current, and therefore a heavier generator for the same penetration depth. However, this advantage is not sufficient compensation for the difficulties encountered in making geologic interpretation from the resulting data (J. S. Sunner, 1976).

APPENDIX E. RESISTIVITY CALCULATIONS

TABLE 3. LINE A.

COLORADO GEOLOGICAL SURVEY Geophysical Exploration (Resistivity Survey)

LECEND:	Range	=	Gain
	MA	=	Dummy TX Current Switch
	Vp	=	Balance Control to Null Meter
	G.F.	=	Geometric Factor
	_		

Pa = Apparent Resistivity

LOCATION Pinkerton CHIEF OPERATOR Jay Jones			PROJECTDATELine A15 July 1980ASSISTANTSMETHODFargo and TreskaDipole-Dipole (Nx200)				980 Nx200')
Sta.	Range	MA	Voltage	۷ _P	DV/I	G.F.	P _a
1-3 5-7 7-9 9-11 11-13 13-15	1 1 1 1	-3 -3 -3 -3 -3	250 250 250 250 250	9.20 5.58 4.38 2.10 1.50	0.0920 0.0558 0.0438 0.0210 0.0150	1149 4597 11493 22987 40226	106 256 505 483 603
3-5 7-9 9-11 11-13 13-15 15-17	1 1 1 0	- 3 - 3 - 3 - 3 - 3	433 433 433 433 433	8.10 5.60 2.30 1.25 5.9	0.081 0.0560 0.0230 0.0125 C.0059	1149 4597 11493 22987 40226	93 257 264 287 237
5-7 9-11 11-13 13-15 15-17 17-19	1 1 0/0 0 0	-2 -2 -2/-3 -3 -3	133 133 100/250 225 225	0.61 0.18 0.20/7.80 3.50 1.20	0.061 0.018 0.0078 0.0035 0.0012	1149 4597 11493 22987 40226	70 83 90 8 48
7-9 11-13 13-15 15-17 17-19 19-21	1 1 1 0	- 3 - 3 - 3 - 3 - 3	166 166 166 166 166	6.50 1.90 1.00 1.30 2.00	0.065 0.019 0.010 0.0013 0.0020	1149 4597 11493 22987 40226	75 87 115 30 80
9-11 13-15 15-17 17-19 19-21 21-23	1 1 1 0	-3 -3 -3 -3	225 285 250/225 225 N.R	5.60 1.55 0.68 4.95 wouldn't	0.056 0.0155 0.0068 0.00495 stabilize	1149 4597 11493 22987	64 72 78 114

TABLE 1. LINE A (CONT.)

<u> </u> P CHIE J	<u>OCATION</u> inkerton F OPERATO ay Jones	R	PRCJ Line ASSIST Fargo ard	ECT A ANTS Treska	DATE 16 July 1980 <u>METHOD</u> Dipole-Dipole (Nx200'		
Sta.	Range	î1A	Voltage	V _P	DV/I	G.F.	Pa
11-13 15-17 17-19 19-21 21-23 23-25	1	-3 -3 -3 -3	400 400 366 433	3.95 N.R. N.R. N.R. N.R.	0.0395	1149 4597 11493 22987 40226	45
13-15 17-19 19-21 21-23 23-25 25-27	2 1 1	- 3 - 3 - 3	400 400 400 no	0.69 1.64 0.60 t read t read	0.069 0.0164 0.006	1149 4597 11493	79.3 75.4 69.0
15-17 19-21 21-23 23-25 25-27	2 1 0 0	-3 -3 -3 -3	133 133 133 133	0.96 2.24 5.98 2.97	0.096 0.0224 0.00598 0.00297	1149 4597 11493 22987	110.3 103.0 68.7 68.3
17-19 21-23 23-25 25-27 27-29	2 1 0 0	-3 -3 -3	250 250 250 250	1.13 2.05 7.25 4.09	0.113 0.0205 0.00725 0.00409	1149 4597 11493 22987	129 94.2 83.3 94
19-21 23-25 25-27 27-29 29-31	2 1 1 1	- 3 - 3 - 3 - 3	275 275 275 275 275	0.71 2.04 0.98 1.15	0.071 0.0204 0.0098 0.0115	1149 4597 11493 22987	81.6 93.8 112.6 264.3

TABLE 3. LINE A (CONT.)

<u>L</u> P CHIE J	LOCATION Pinkerton CHIEF CPERATOR Jay Jones			PROJECT Line A ASSISTANTS Fargo and Treska		DATE 16 July 1980 <u>METHOD</u> Dipcle-Dipole (Nx200')		
Sta.	Range	MA	Voltage	V _P	DV/I	G.F.	Pa	
21-23 25-27 27-29 29-31 31-33 33-35	1 1 1 1 0	-3 -3 -3 -3 -3	200 200 200 200 200 200	6.52 2.62 2.60 1.54 6.62	0.0652 0.0262 0.0260 0.0154 .00662	1149 4597 11493 22987 40226	75 120.4 298.8 354 266.3	
23-25 27-29 29-31 31-33 33-35	1 1 1 1	-3 -3 -3 -3	133 133 133 133 133	3.90 3.37 1.83 0.64	0.0390 0.0337 0.0183 0.0064	1149 4597 11493 22987	44.8 154.9 210.3 147	
25-27 29-31 31-33 33-35	2 1 1	-3 -3 -3	133 133 133	0.69 2.93 1.17	0.069 0.0293 0.0117	1149 4597 11493	79.3 134.7 134.5	
27-29 31-33 33-35	2 1	-3 -3	133 133	0.83 2.60	.083 .0260	1149 4597	95.4 119.5	
29-31 33-35	2	-3	133	0.58	0.058	1149	666	

APPENDIX F. PESISTIVITY CALCULATIONS

TABLE 4. LINE B.

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

 <u>L(</u> P· CHIEI J.	<u>CCATION</u> inkerton F OPERATO ay Jones	IR	PROL Line ASSIS Fargo and	JECT 2 B TANTS 3 Treska	DATE 16 July 1980 <u>METHOD</u> Dipole-Dipole (Nx300		
Sta.	Pange	MA	Voltage	V _P	DV/I	G.F.	Pa
1-4 7-10 10-13 13-16 16-19 19-22	1 1 1 1 1	-3 -3 -3 -3 -3	250 225 225 225 225 225	10.0 4.50 1.80 0.45 0.50	0.100 0.045 0.018 0.0045 0.0050	1724 6896 17240 34480 60340	172.4 310.3 310.3 155.16 301.7
4-7 10-13 13-16 16-19 19-22 22-25	2 1 0 0	-3 -3 -3 -3	133 133 133 133 133	0.98 2.20 5.50 5.00 1.65	0.098 0.0220 0.0055 0.0050 0.00165	1724 6896 17240 34480 60340	168.9 151.7 94.8 172.4 99.6
7-10 13-16 16-19 19-22 22-25 25-28	2 1 1 0 0	- 3 - 3 - 3 - 3 - 3	250 250 250 250 250	1.00 2.28 1.18 4.20 2.15	0.100 0.0228 0.0118 .0042 .00215	1724 6896 17240 34480 60340	172.4 157.2 203.4 144.8 129.7
10-13 16-19 19-22 22-25 25-28 28-31	1 0 0 0	- 3 - 3 - 3 - 3 - 3	200 200 200 200 200 200	8.00 2.27 6.80 3.70 2.90	0.080 0.0227 0.0068 0.0037 0.0029	1724 6896 17240 34480 60340	137.9 156.5 117.2 127.58 174.99

TABLE 4. LINE B. (CONT.)

		CATION		PROJ	ECT		0.0	
	CHIEF	OPERATO	R	Line ASSIST	ANTS	1	80	
	Ja	y Jones		Fargo and	Treska	Dipole	Nx300')	
S.	ta.	Range	MA	Voltage	V _P	DV / I	G.F.	P _a
13	-16 19-22 22-25 25-28 28-31 31-34	1 1 0 0 0	-3 -3 -3 -3 -3	66 66 66 66 66	8.40 1.91 7.20 4.30 2.30	0.084 0.0191 0.0072 0.0043 0.0023	1724 6896 17240 34480 60340	144.8 131.7 124.1 148.26 138.8
16	-19 22-25 25-28 28-31 31-34 34-37	2 1 1 0 0	-3 -3 -3 -3 -3	66 66 66 66 66	0.98 2.30 1.15 3.50 2.35	0.098 0.023 0.0115 0.0035 0.00235	1724 6896 17240 34480 60340	168.9 158.6 198.3 120.68 141.8
19	-22 25-28 28-31 31-34 34-37 37-40	1 1 1 0 0	-3 -3 -3 -3 -3	166 166 166 166 166	7.00 2.35 1.00 6.00 2.55	0.070 0.0235 0.010 0.0060 0.00255	1724 6896 17240 34480 60340	120.7 162.1 172.4 206.9 153.9
22	-25 28-31 31-34 34-37 37-40 40-43	1 1 1 0 0	-3 -3 -3 -3 -3	225 225 225 225 225 225	7.60 2.10 0.95 2.60 1.20	0.076 0.0210 0.0095 0.0026 0.0012	1724 6896 17240 34480 60340	131.0 144.8 163.8 89.7 72.4
25	31-34 34-37 37-40 40-43	2 1 1 0	-3 -3 -3 -2	250 250 250 66	1.50 3.90 1.5 0.45	0.150 0.039 0.015 .0045	1724 6896 17240 34480	258.6 269 258.6 155.2

TABLE 4. LINE B. (CONT.)

State CEOLCOICAL SURVEY Seophysical Exploration (Resistivity Survey)

<u> </u> Р СН I Е Ј	<u>OCATION</u> inkertor F OPERATU ay Jones	<u>29</u>	PROJ Line ASSIST Fargo and	ECT 2 ANTS Treska	Dipol	080 Nx300')	
Sta.	Range	MA	Voltage	V _P	CV/I	G.F.	Pa
28-31 34-37 37-40 40-43	1 0 1	-2 -2 -3	66 66 250	2.10 2.50 1.50	0.210 0.025 0.015	1724 6896 17240	362.0 172.4 258.6
31 - 34 37 - 40 40 - 43 34 - 37	1 0 1	-2 -2 -3	66 66 225	3.98 2.70 0.95	0.298 0.027 C.0095	1724 6896 17240	513.8 186.2 163.8
34-37 40-43	1	-2	66	3.41	0.341	1724	587.8

APPENDIX E. RESISTIVITY CALCULATIONS

TABLE 5. LINE C.

COLORADO GEOLOGICAL SURVEY Geophysical Exploration (Resistivity Survey)

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

L(Pin CHIEF	DCATION hkerton = OPERATO	R	PROJ Line ASSIST	ECT C ANTS	24 July 1980 METHOD			
 Sta.	Range	MA	Voltage	V _D		G.F.	P.	
				F			d 	
1-3 5-7 7-9 9-11 11-13 13-15	1 1 0 0 0	- 3 - 3 - 3 - 3 - 3	300 300 300 300 300 300	5.60 1.98 5.20 3.10 2.00	0.0560 0.0198 0.0052 .0031 .0020	1149 4597 11493 22987 40226	64 91 60 71 80	
3-5 7-9 9-11 11-13 13-15 15-17	1 0 0 0	-3 -3 -3 -3	225 225 225 225 225 225	5.05 1.15 4.90 2.60 3.00	0.0505 0.0115 0.0049 0.0026 0.0030	1149 4597 11493 22987 40226	58 53 56 60 12	
5-7 9-11 11-13 13-15 15-17 17-19	1 1 0 0 0	-3 -3 -3 -3 -3	166 166 166 166 166	5.06 1.82 7.50 8.65 5.10	0.0506 0.0182 0.0075 0.00865 0.0051	1149 4597 11493 22987 40226	58 84 86 199 205	

λ**i**

TABLE 5. LINE I (COPT.)

CCLORAPO CECLECIC/L SUPVEY Geophysical Ex;lonation (Resistivity Survey)

L(Pi CHIEI J	<u>DCATION</u> nkerton F CPERATC ay Jones	۱P.	PROJ Line ASSIST Fargo and	ECT C ANTS Troska	2 Dipole	80 Nx200')	
Sta.	Range	11A	Voltage	Vp	DV/I	G.F.	Pa
7-9							
11-13	0	-2	66	3.30	0.0330	1149	38
13-15	0	-2	66	0.80	0.0080	4597	37
15-17	1	-3	166	1.10	0.0110	11493	126
17-19	C	-3	166	4.20	0.0042	22986	96
19-21	0	-3	166	4.00	0.0040	40226	161
9-11							
13-15	1	-3	166	3.40	0.034	1149	39
15-17	1	-3	166	1.60	0.0160	4597	74
17-19	1	-3	166	0.80	0.0080	11493	92
19-21	0	- 3	166	4.50	0.00450	22986	103
21-23			N.R	lightnin	g		
11-13							
15-17	1	- 3	100	4.10	0.041	1149	47
17-19	1	- 3	100	1.85	0.0185	4597	85
19-21	С	- 3	100	5.00	0.0050	11493	57
21-23	0	-3	100	2.00	0.0020	22986	46
23-25			N.P	lightning	3		

TABLE 5. LINE C (CONT.)

L P CHIE J	<u>OCATION</u> inkerton F OPERATO ay Jones	R	PROJ Line ASSIST Fargo and	ECT C ANTS Treska	Dipole	<u>DATE</u> 23 July 19 <u>METHOD</u> e-Dipole (
Sta.	Range	MA	Voltage	V _P	DV/I	G.F.	Pa	
19-21 21-23 23-25 25-27 27-29 29-31	1 1 1 1	-2 -3 -3 -3 -3	66 133 133 133 133 133	2.29 4.59 1.71 0.65 N.R.	0.229 0.0459 0.0171 0.0065	1149 4597 11493 22986 40226	263 211 196 149	
21-23 23-25 25-27 27-29 29-31 31-33	2 1 0 0	-3 -3 -3 -3 -3	133 133 133 133 133 133	1.53 4.30 1.50 N.R. N.R.	0.153 0.0430 0.0150 	1149 4597 11493 22986	88 198 172	
23-25 25-27 27-29 29-31 31-33 33-35	2 1 0 0 0	-3 -3	100 100	0.90 2.09 N.R. N.R. N.R.	0.090 0.0209	1149 4597	103 96	

TABLE 5. LINE C (CURT.)

<u> </u> P CHIE J	<u>OCATION</u> inkerton F OPERATO ay Jones	IR	PPOJ Line ASSIST Fargo and	ECT C ANTS Treska	2 Dipole	80 Nx2 <u>00')</u>	
Sta.	Range	11A	Voltage	V _P	DV/I	G.F.	P a
25 - 27 27 - 29 29 - 31 31 - 32 33 - 35 35 - 37	1 1 0	- 3 - 3 - 3 - 3	100 100 100 100	5.00 1.24 C.80 N.R. N.R.	0.050 0.0124 0.0080	1149 4597 11493 22986 40226	57 57 92
27-29 29-31 31-33 33-35 35-37 37-39	1 1 0 0	-3 -3 -3 -3 -3	133 133 100 100 100	4.31 1.49 0.94 5.33 2.75	0.0431 0.0149 0.0049 0.00533 0.00275	1149 4597 11493 22986 40226	50 68 56 122 111
29-31 31-33 33-35 35-37 37-39 39-41	2 1 1 0 0	-3 -3 -3 -3 -3	475 475 475 475 475 475	0.88 3.91 1.78 8.25 4.85	0.088 0.0391 0.0178 0.00825 0.00485	1149 4597 11493 22986 40226	101 180 205 173 195

TABLE 5. LINE C (CONT.)

	OCATION inkerton		PROJ Line	ECT	2	080	
J	ay Jones	JR 	Fargo and	<u>Treska</u>	Dipole	Nx200')	
Sta.	Range	MA	Voltage	۷ _P	DV/I	G.F.	Pa
13-15							
15-17	2	-3	166	0.97	0.097	1149	111
17-19	1	-3	166	2.88	0.0288	4597	132
19-21	1	-3	166	1.92	0.0192	11493	221
21-23	0	-3	166	8.15	0.00815	22986	187
23-25	-	-3	166 N.R	elect	rical storm	40226	
15-17							
17-19	2	-3	250	1.86	0.186	1149	214
19-21	2	-3	250	0.92	0.092	4597	423
21-23	1	-3	250	2.78	0.0278	11493	320
23-25	1	-3	275	0.97	0.0097	22986	223
25-27	-	-3	250	Ν.R.			
17-19							
19-21	2	-3	225	2.75	0.275	1149	316
21-23	2	-3	225	0.50	0.050	4597	230
23-25	1	-3	225	1.40	0.0140	11493	161
25-27	$\overline{1}$	-3	225	0.75	0.0075	22986	172
27-29	_	-		N . R .		22300	1 / L

TABLE 5. LINE C.

CH	LOCATION Pinkontor HEF OPERAT Jay Jones	(°P.	PROJ Line <u>ASSIST</u> Fargo and	ECT C ANTS Treska	2 Dipole	80 Nx200')	
Sta.	Range	11A	Voltage	V _P	DV/I	G.F.	Pa
31-33 33-3 35-3 37-3 39-4 41-4	$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	-3 -3 -3 -3 -3	466 466 433 433 433	0.75 2.10 0.91 5.42 N.R.	0.075 0.021 0.0091 0.00542	1149 4597 11493 22986	86 96 105 114
33-35 35-3 37-3 39-4 41-4	87 2 89 1 1 0 -3 0	- 3 - 3 - 3 - 3	133 133 133 133 132	0.65 1.79 8.25 4.75	0.065 0.0179 0.00825 0.00475	1149 4597 11493 22986	75 82 95 100
35-37 37-3 39-4 41-4	39 1 41 1 43 1	- 3 - 3 - 3	133 133 133	5.50 1.57 0.75	0.055 0.0157 0.0075	1149 4597 11493	32 72 86
37-39 39-4 41-4	41 +1 42 1	-3 -3	137 133	4.73 1.25	0.0473 0.0125	1149 4597	54 57
39-41 41-4	13 2	-3	300	0.54	0.054	1149	62

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

LOCATION Pinkerton CHIEF OPERATOR Jay Jones			PROJECT Line D ASSISTANTS Fargo and Treska		DATE 29 July 1980 <u>METHOD</u> Dipole-Dipole (Nx100')		
Sta.	Range	MA	Voltage	V _P	DV/I	G.F.	Pa
3-4	<u></u>		· <u> </u>				
5-6	1	-2	66	1.15	0.115	574	66
6 – 7	0	-2	66	3.80	0.038	2298	87
7-8	1	-3	166	1.90	0.019	5746	109
8 - 9	1	-3	166	1.00	0.010	11493	115
9-10	0	-3	166	4.00	0.004	20113	80
4 - 5							
6-7	1	-3	100	7.50	0.0750	574	43
7-8	1	-3	100	2.45	0.0245	2298	5 E
8-9	1	-3	100	1.00	0.010	5746	57
9-10	0	-3	100	4.10	0.0041	11493	47
10-11	0	-3	100	2.65	0.00265	20113	43
5-6							
7-8	1	-2	66	1.30	0.130	574	75
2- 9	С	-2	66	2.20	0.0220	2298	29
9-10	1	-3	166	1.20	0.0120	5746	69
10-11	0	-3	166	6.50	0.0065	11493	65
11-12	0	-3	166	3.45	0.00345	20113	69
6-7							
8-9	1	-3	225	7.96	0.0796	575	46
9-10	1	-3	225	2.20	0.0220	2299	51
10-11	1	- 3	225	0.91	0.0091	5747	52
11-12	0	-3	225	4.40	0.0044	11493	51
12-13	0	-3	225	2.05	0.00205	20113	41

TABLE 6. LINE D. (CONT.)

LOCATION Pinkerton CHIEF OPERATOR Jay Jones		PPOJECT Line D ASSISTANTS Fargo and Treska		DATE 29 July 1980 <u>METHOD</u> Dipole-Dipole (Nx100')				
Sta.	Range	MA	Voltage	Vp	DV/I	C.F.	Pa	
7-8 9-10 10-11 11-12 12-13 13-14	0 1 0 0 0	-2 -3 -3 -3 -3	66 250 250 250 250 250	3.90 1.70 8.10 3.20 1.70	0.0390 0.0170 0.0081 0.0032 .00170	575 2299 5747 11493 20113	22 39 47 37 34	
3-9 10-11 11-12 12-13 13-14 14-15	1 1 0 0	-3 -3 -3 -3	300 300 300 300 300	5.20 2.30 7.80 4.50 N.R	0.052 0.023 0.0078 0.0045 power li	575 2299 5747 11493 ne interf	30 53 45 52 erence	
9-10 11-12 12-13 13-14 14-15	1 1 0 0	- 3 - 3 - 3 - 3	200 200 200 200	4.90 1.50 6.50 3.80	0.049 0.0150 0.0065 0.0038	575 2299 5747 11493	28 34 37 44	
10-11 12-13 13-14 14-15	1 1 1	-3 -3 -3	166 166 166	9.70 2.15 1.00	0.097 0.0215 0.010	575 2299 5747	56 49 57	
11-12 13-14 14-15	1 1	-3 -3	200 200	6.55 2.10	0.0655 .0210	575 2299	38 48	
12-13 14-15	0	-2	66	7.00	0.070	575	40	

APPENDIX F

TABLE 7 GEOMETRIC FACTOR TABLE SCHLUMBERGER METHOD

21						
(ft)					
L(ft)	25	50	75	100	200	300
					11 07	7 00
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	25 86
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 8. DIPOLE-DIPOLE GEOMETRIC FACTOR TABLE

<u>n</u> a(ft)	25	50	100	150	200	300
1	143.67	287.33	574.67	862	1149.33	1724
2	574.67	1149.32	2298.67	3448	4597.32	6896
3	1436.7	2873.3	5746.7	8620	11493.3	17240
4	2873.4	5746.6	11493.4	17240	22986.6	3480
5	5028.45	1056.55	20113.45	30170	40226.55	60340
6	8045.52	16090.48	32181.52	422 72	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 9. WENNER CEOMETRIC FACTOR TABLE

<u>2P</u> Ia(ft)	25	50	100	200	300	400	500
6.2	157	314.16	628.32	1256.64	1884.64	2513.27	3141.6

GEOTHERMAL ENERGY PUBLICATIONS --

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

- Bull. 11, MINERAL WATERS OF COLORADO, by R.D. George and others, 1920, 474 p., out of print.
- Bull. 35, SUMMARY OF GEOLOGY OF COLORADO RELATED TO GEOTHERMAL ENERGY POTENTIAL, PROCEEDINGS OF A SYMPOSIUM ON GEOTHERMAL ENERGY AND COLORADO, ed. by R.H. Pearl, 1974, \$3.00
- Bull. 39, AN APPRAISAL OF COLORADO'S GEOTHERMAL RESOURCES, by J.K. Barrett and R.H. Pearl, 1978, 224 p., \$7.00
- Bull. 44, BIBLIOGRAPHY OF GEOTHERMAL REPORTS IN COLORADO, by R.H. Pearl, T.G. Zacharakis, F.N. Repplier and K.P. McCarthy, 1981, 24 p., \$2.00.
- Resource Ser. 6, COLORADO'S HYDROTHERMAL RESOURCE BASE--AN ASSESSMENT, by R.H. Pearl, 1979, 144 p., \$2.00.
- Resource Ser. 14, AN APPRAISAL FOR THE USE OF GEOTHERMAL ENERGY IN STATE OWNED BUILDINGS IN COLORADO, by R.T. Meyer, B.A. Coe and J.D. Dick, 1981, 63 p., \$5.00.
- Resource Ser. 15, GEOTHERMAL RESOURCE ASSESSMENT OF OURAY, COLORADO, by T.G. Zacharakis, C.D. Ringrose and R.H. Pearl, 1981, 70 p., Free over the counter.
- Resource Ser. 16. GEOTHERMAL RESOURCE ASSESSMENT OF IDAHO SPRINGS, COLORADO, by. F.N. Repplier, T.G. Zacharakis, and C.D. Ringrose, 1982, Free over the counter.
- Resource Ser. 17, GEOTHERMAL RESOURCE ASSESSMENT OF THE ANIMAS VALLEY, COLORADO, by. K.P. McCarthy, T.G. Zacharakis, and R.H. Pearl, In prep. 1982, Free over the counter.
- Resource Ser. 18, GEOTHERMAL RESOURCE ASSESSMENT OF HARTSEL, COLORADO, by K.P. McCarthy, T.G. Zacharakis and R.H. Pearl, In prep. 1982, Free over the counter.
- Resource Ser. 19, GEOTHERMAL RESOURCE ASSESSMENT OF WESTERN SAN LUIS VALLEY, by T.G. Zacharakis and C.D. Ringrose, In prep. 1982, Free over the counter.
- Resource Ser. 20, GEOTHERMAL RESOURCE ASSESSMENT OF CANON CITY AREA, COLORADO, BY T.G. Zacharakis, C.D. Ringrose and R.H. Pearl, In prep. 1982, Free over the counter.
- Resource Ser. 22, GEOTHERMAL RESOURCE ASSESSMENT OF STEAMBOAT SPRINGS AREA, COLORADO, by K.P. McCarthy, T.G. Zacharakis and R.H. Pearl, In prep. 1982, Free over the counter.
- Resource Ser. 23, GEOTHERMAL RESOURCE ASSESSMENT OF HOT SULPHUR SPRING, COLORADO, by T.G. Zacharakis, K.P.McCarthy and C.D. Ringrose, In prep. 1982, Free over the counter.
- Resource Ser. 24, GEOTHERMAL RESOURCE ASSESSMENT OF RANGER HOT SPRINGS, COLORADO, by T.G. Zacharakis and R.H. Pearl, In prep. 1982, Free over the counter.
- Special Pub. 2, GEOTHERMAL RESOURCES OF COLORADO, by R.H. Pearl, 1972, 54 p.
 \$2.00.

- Special Pub. 10, HYDROGEOLOGICAL AND GEOTHERMAL INVESTIGATIONS OF PAGOSA SPRINGS, COLORADO, by M.A. Galloway <u>WITH A SECTION ON</u> MINERALOGICAL AND PETROGRAPHIC INVESTIGATIONS OF SAMPLES FROM GEOTHERMAL WELLS 0-1 AND P-1, PAGOSA SPRINGS, COLORADO, by W.W. Atkinson, 1980, 95 p. \$10.00
- Special Pub. 16, GEOTHERMAL RESOURCE ASSESSMENT OF WAUNITA HOT SPRINGS, COLORADO, ed. by T. G. Zacharakis, 1981, 69 p., Free over the counter.
- Special Pub. 18, GROUNDWATER HEAT PUMPS IN COLORADO, AN EFFICIENT AND COST EFFECTIVE WAY TO HEAT AND COOL YOUR HOME, by K.L. Garing and F.R. Connor, 1981, 32 p., Free over the counter.
- Special Pub. 20, INDUSTRIAL MARKET OPPORTUNITIES FOR GEOTHERMAL ENERGY IN COLORADO, by B.A. Coe, 1982, Free over the counter.
- Map Series 14, GEOTHERMAL RESOURCES OF COLORADO, by R.H. Pearl, Scale 1:500,000, Free over the counter.
- Map Series 18, REVISED HEAT FLOW MAP OF COLORADO, by T.G. Zacharakis, Scale 1:1,000,000, Free over the counter.
- Map Series 20, GEOTHERMAL GRADIENT MAP OF COLORADO, by F.N. Repplier and R.L. Fargo, 1981, Scale 1: 1,000,000, Free over the counter.
- Info. Series 4, MAP SHOWING THERMAL SPRINGS, WELLS, AND HEAT FLOW CONTOURS IN COLORADO, by J.K. Barrett, R.H. Pearl and A.J. Pennington, 1976, Scale 1:1,000,000, out of print.
- Info. Series 6, HYDROGEOLOGICAL DATA OF THERMAL SPRINGS AND WELLS IN COLORADO, by J.K. Barrett and R.H. Pearl, 1976, 124 p. \$4.00
- Info. Series 9, GEOTHERMAL ENERGY DEVELOPMENT IN COLORADO, PROCESSES, PROMISES AND PROBLEMS, by B.A. Coe, 1978, 51 p., \$3.00
- Info. Series 15, REGULATION OF GEOTHERMAL ENERGY DEVELOPMENT IN COLORADO, by B.A. Coe and N.A. Forman, 1980, Free over the counter.
- Open-File Report 80-10, GEOTHERMAL POTENTIAL IN CHAFFEE COUNTY, COLORADO, by. F.C. Healy, 47 p., Free over the counter.
- Open-File Report 80-11, COMMUNITY DEVELOPMENT OF GEOTHERMAL ENERGY IN PAGOSA SPRINGS, COLORADO, by B.A. Coe, 1980, Free over the counter.
- Open-File Report 80-12, TEMPERATURE-DEPTH PROFILES IN THE SAN LUIS VALLEY AND CANON CITY AREA, COLORADO, by C.D. Ringrose, Free over the counter.
- Open-File Report 80-13, GEOTHERMAL ENERGY POTENTIAL IN THE SAN LUIS VALLEY, COLORADO, by B.A. Coe, 1980, 44 p., Free over the counter.
- Open-File Report 81-1, GEOTHERMAL ENERGY OPPORTUNITIES AT FOUR COLORADO TOWNS, by B.A. Coe and Judy Zimmerman, 1981, Free over the counter.
- Open-File Report 81-3, APPENDICES OF AN APPRAISAL FOR THE USE OF GEOTHERMAL ENERGY IN STATE-OWNED BUILDINGS IN COLORADO: SECTION A, Alamosa; SECTION B, BUENA VISTA; SECTION C, BURLINGTON: SECTION D, DURANGO; SECTION E, GLENWOOD SPRINGS; SECTION F, STEAMBOAT SPRINGS, 1981, \$1.50 each or \$8.00 for the set.
- Pamphlet, GEOTHERMAL ENERGY-COLORADO'S UNTAPPED RESOURCE, Free over the counter.

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