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GEOTHERMAL RESOURCE ASSESSMENT OF THE ANIMAS VALLEY, COLORADO

by K. P. McCarthy
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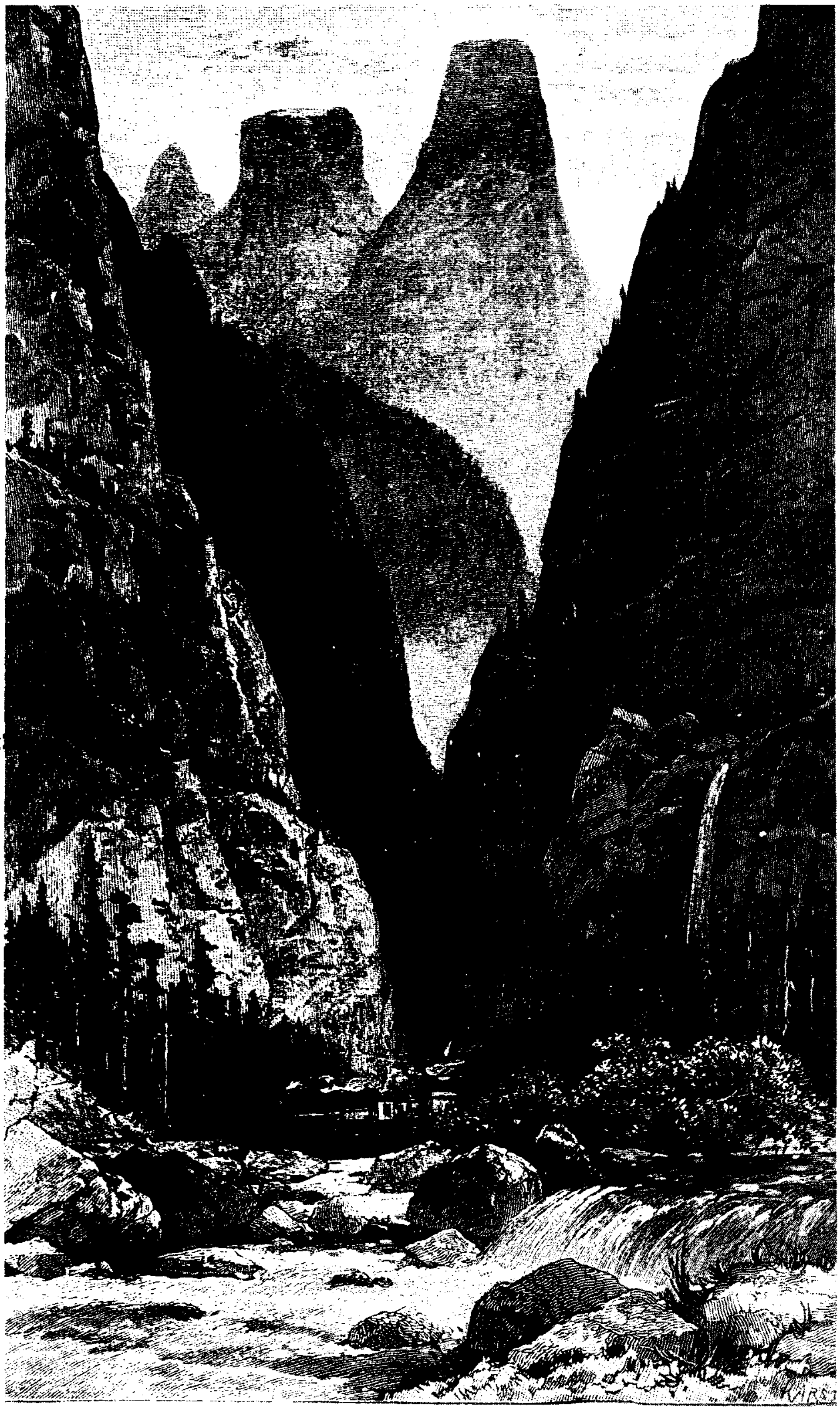

COLORADO GEOLOGICAL SURVEY
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RESOURCE SERIES 17

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by

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1982

NOTICE

NOTICE

ACKNOWLEDGMENTS

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CONTENTS

FIGURES

TABLES

GEOTHERMAL RESOURCE ASSESSMENT OF THE ANIMAS VALLEY, COLORADO

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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 l/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).

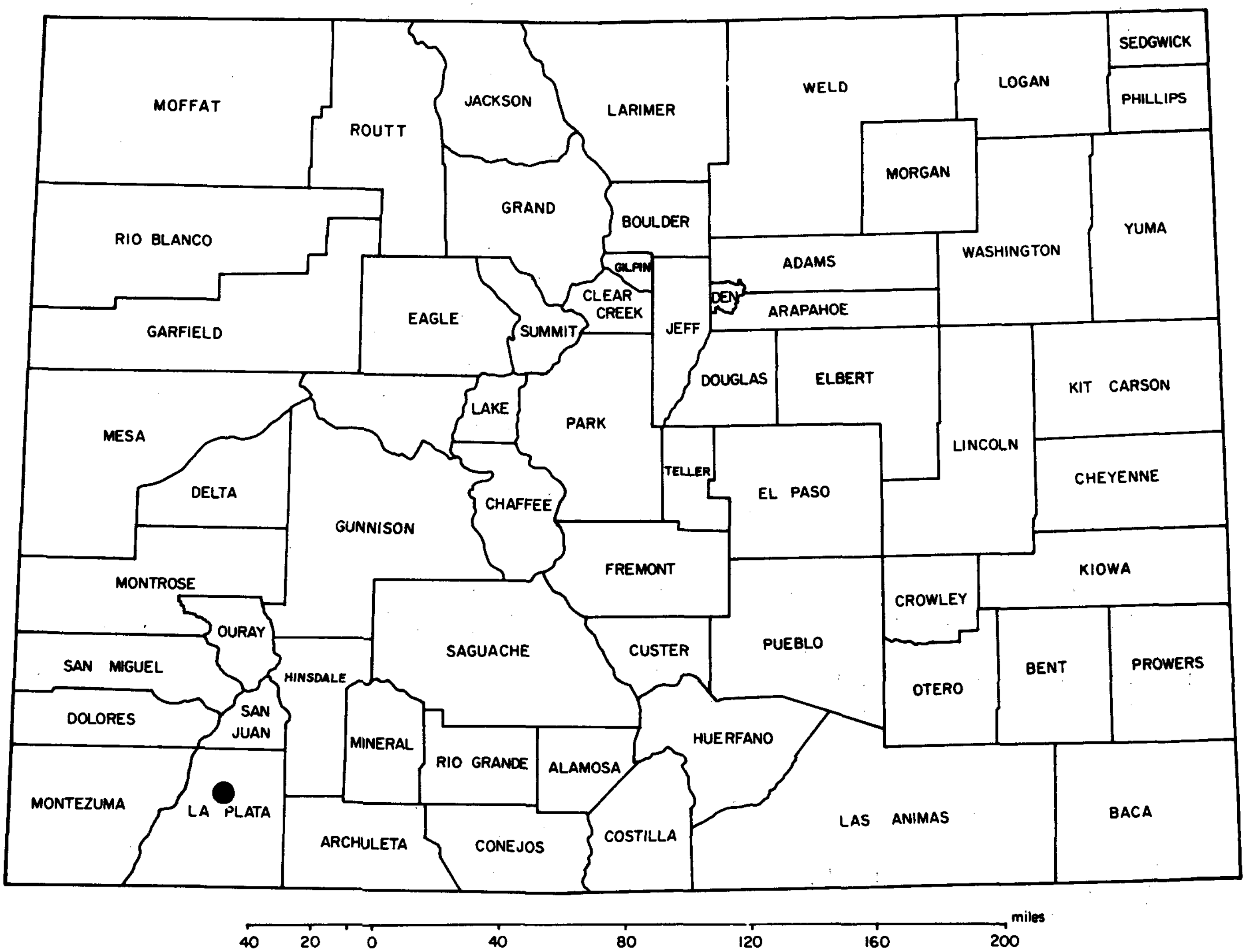


Figure 1. Animas Valley, Colorado index map.

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.

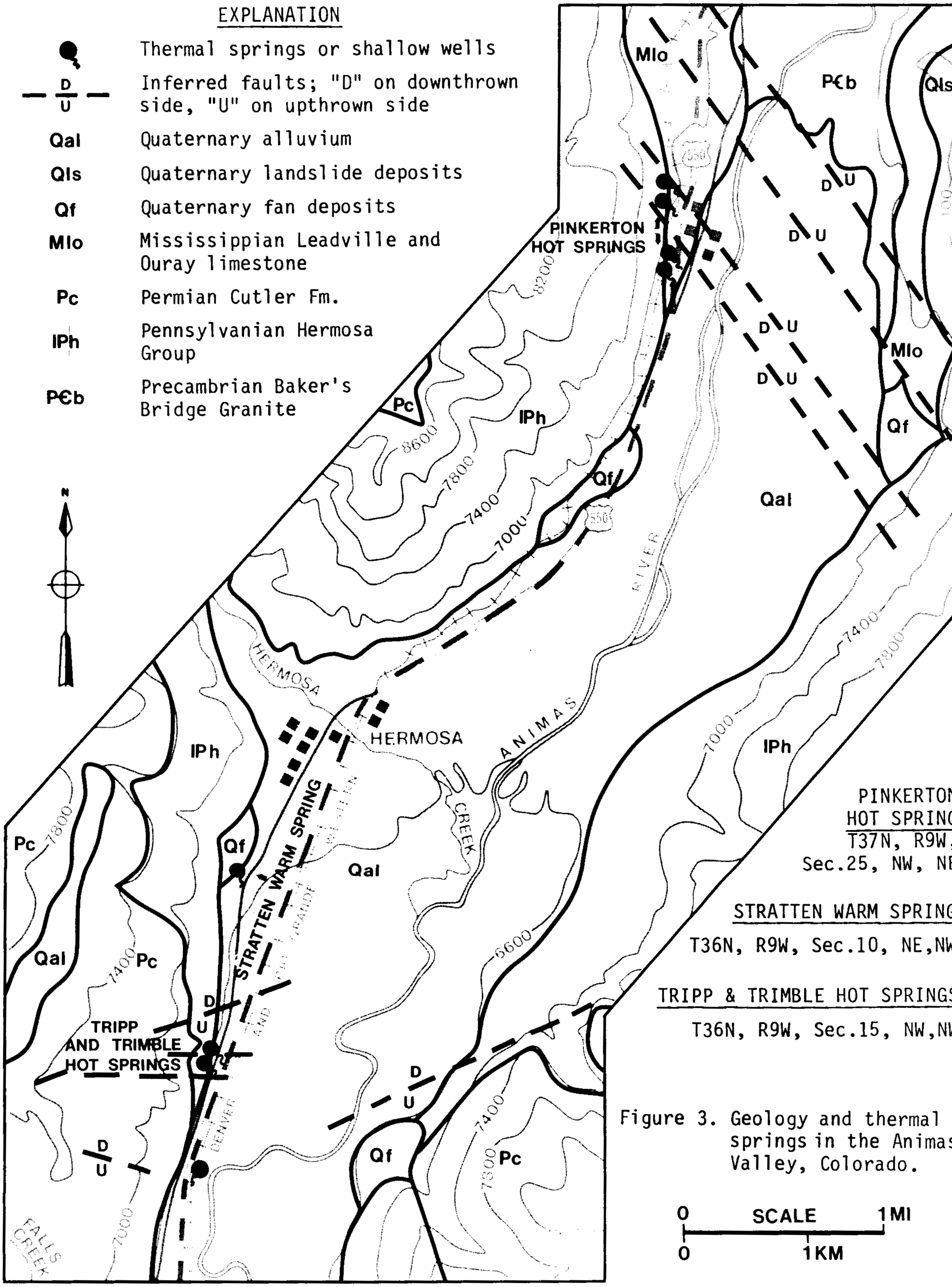


Figure 3. Geology and thermal springs in the Animas Valley, Colorado.

GENERALIZED STRATIGRAPHIC COLUMN

ANIMAS VALLEY, COLORADO

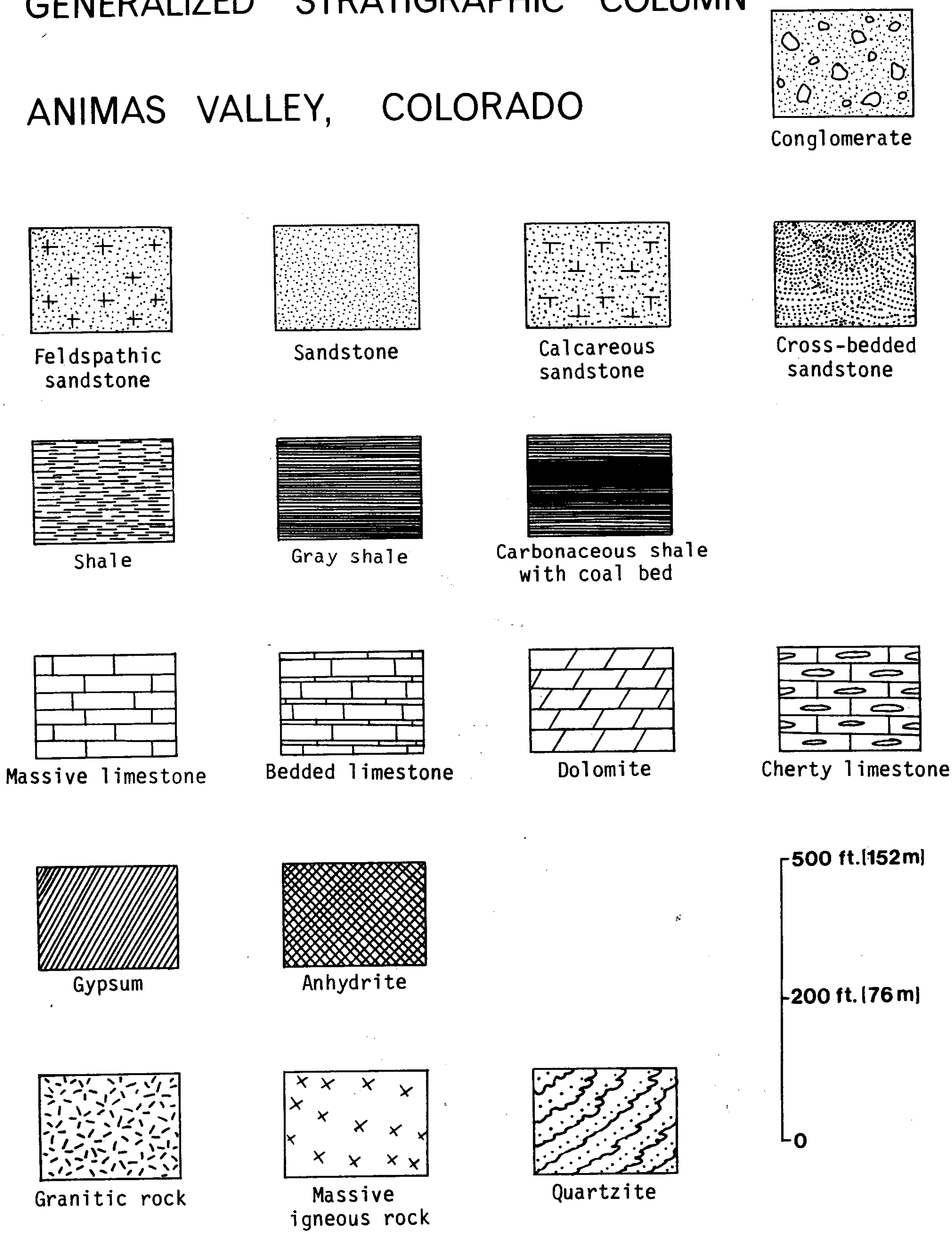
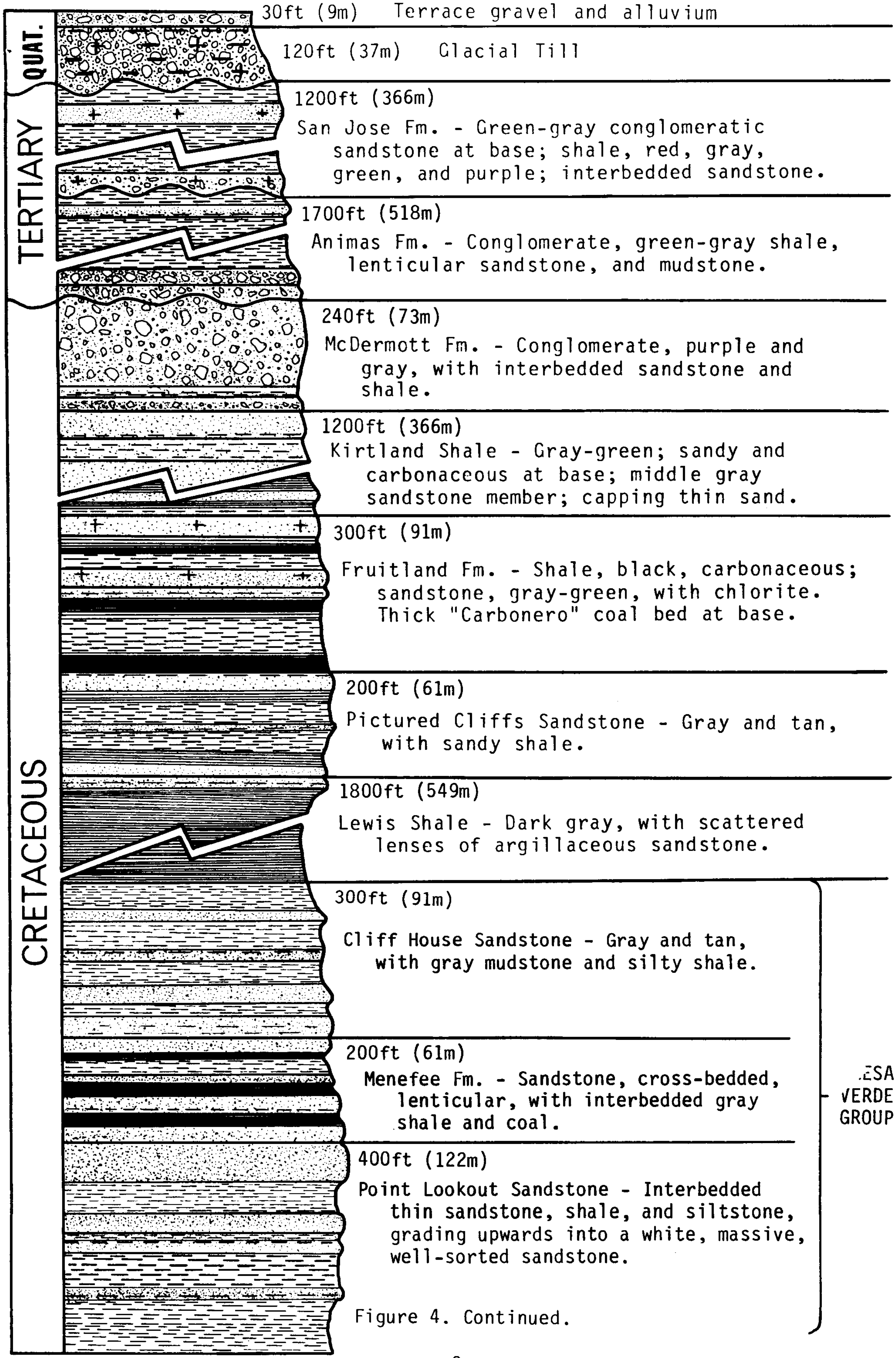


Figure 4.



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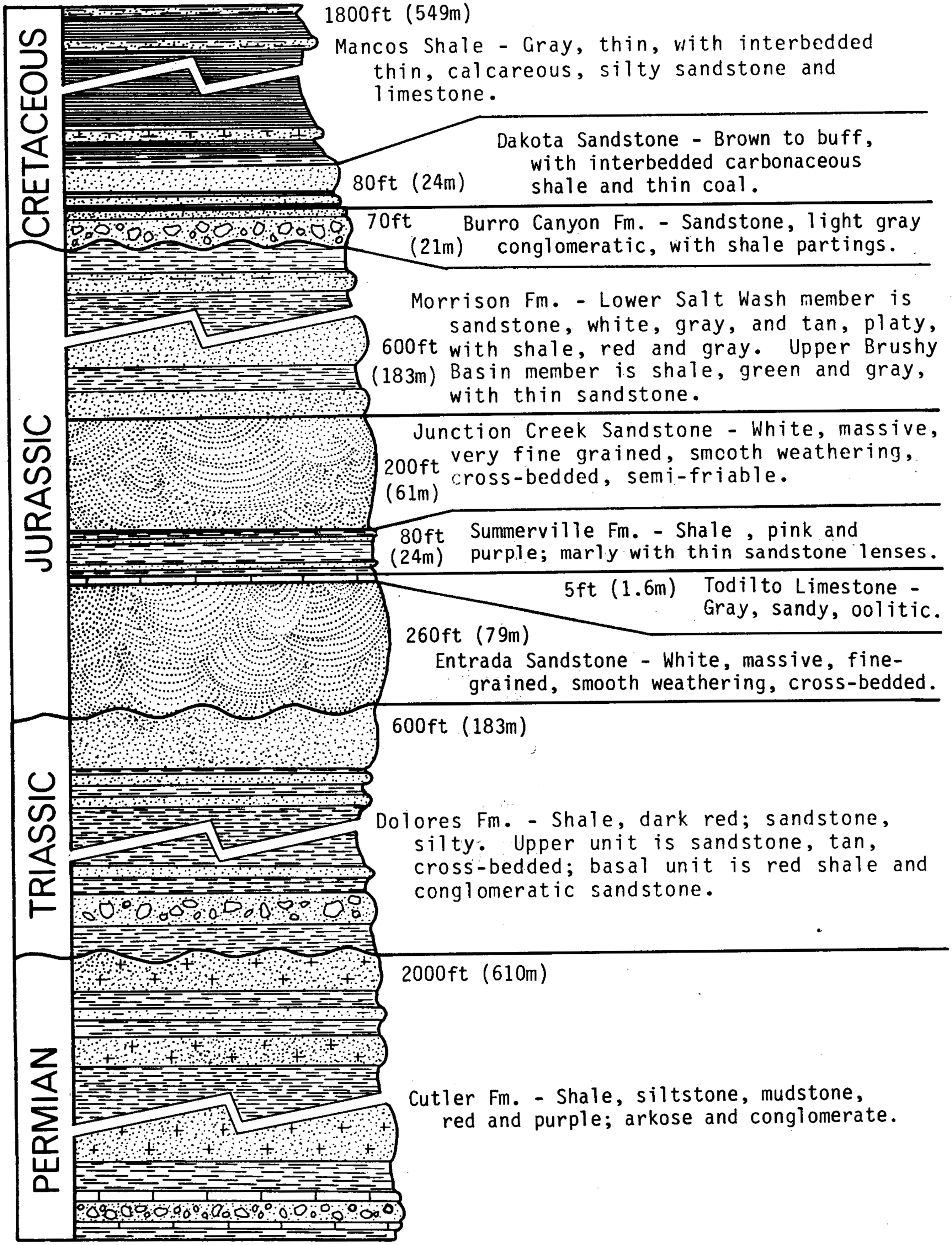

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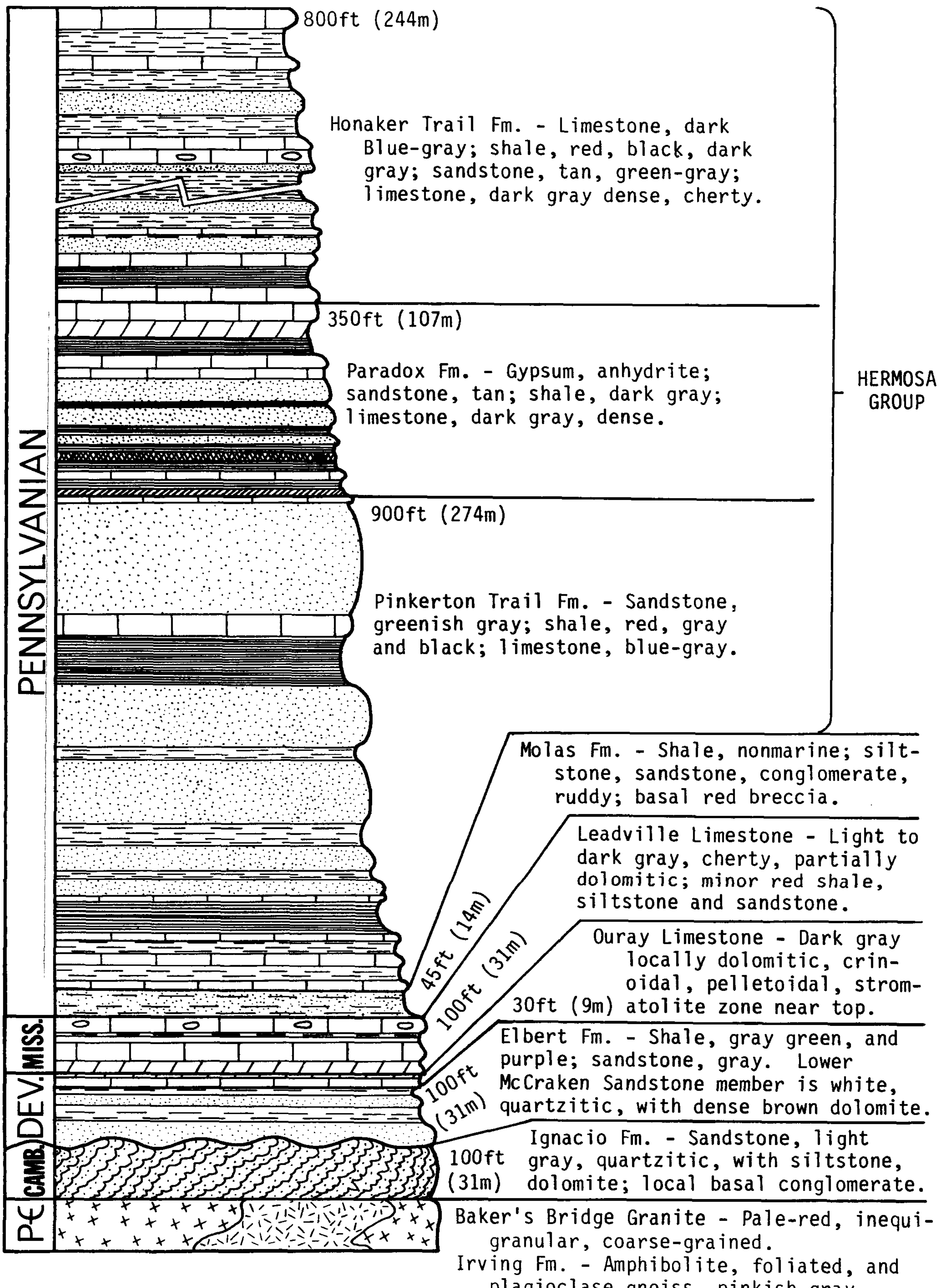


Figure 4. Continued.

Table 1
Animas Valley thermal spring characteristics

	Discharge (GPM)	(l/s)	TDS (Mg/l)	T (°C)	(°F)
South					
Warm Spring	--	--	--	29 (E)	84
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 B, 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 strongly suggests that thermal water is widely dispersed and diluted in the shallow alluvium in the valley.

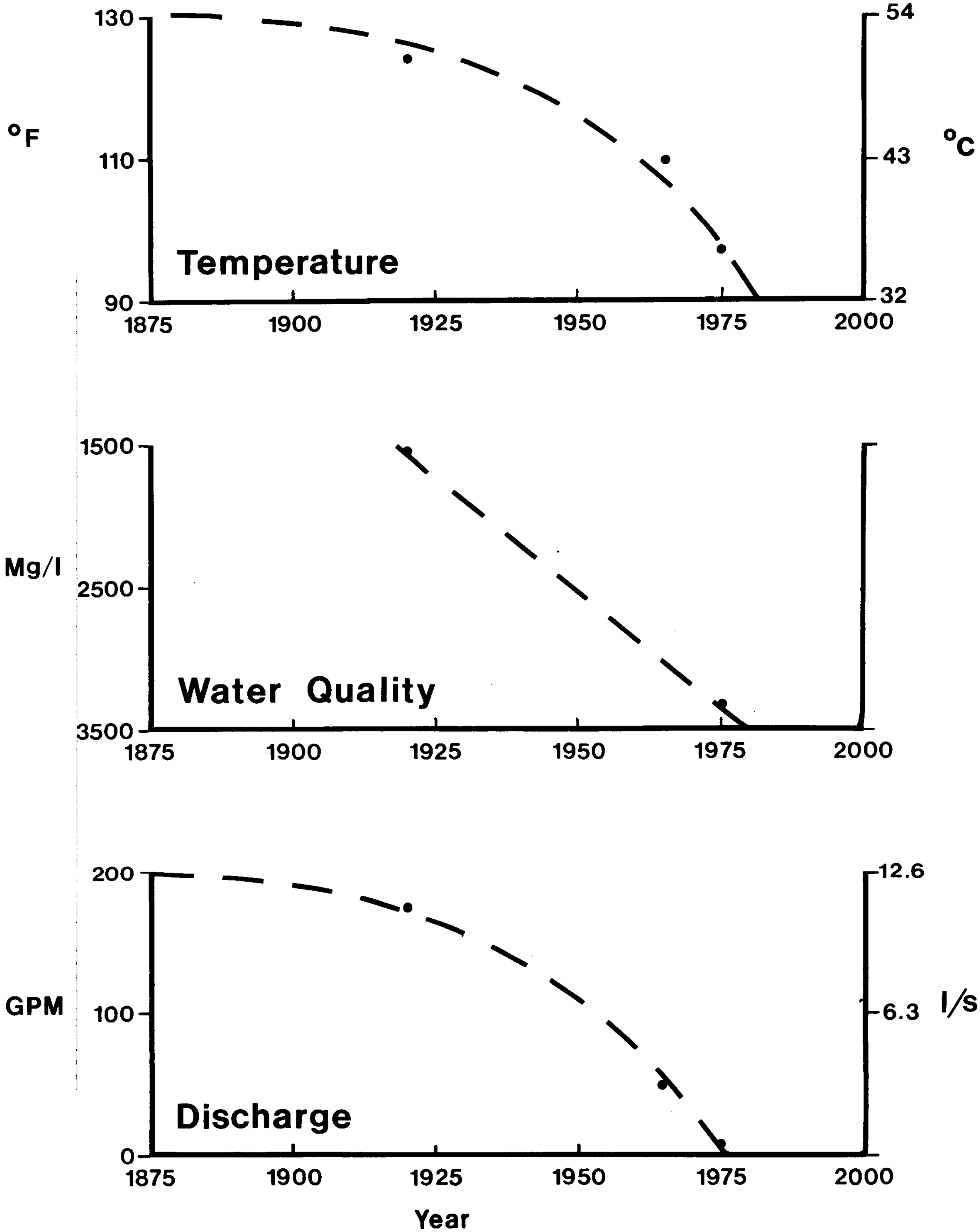


Figure 5. Trimble Hot Spring characteristics through time (data from Peale, 1886; George, 1920; Waring, 1965; and Barrett and Pearl, 1978).

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/m^2.

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°C (140°F) (Barrett and Pearl, 1978), and a regional gradient of 35°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°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

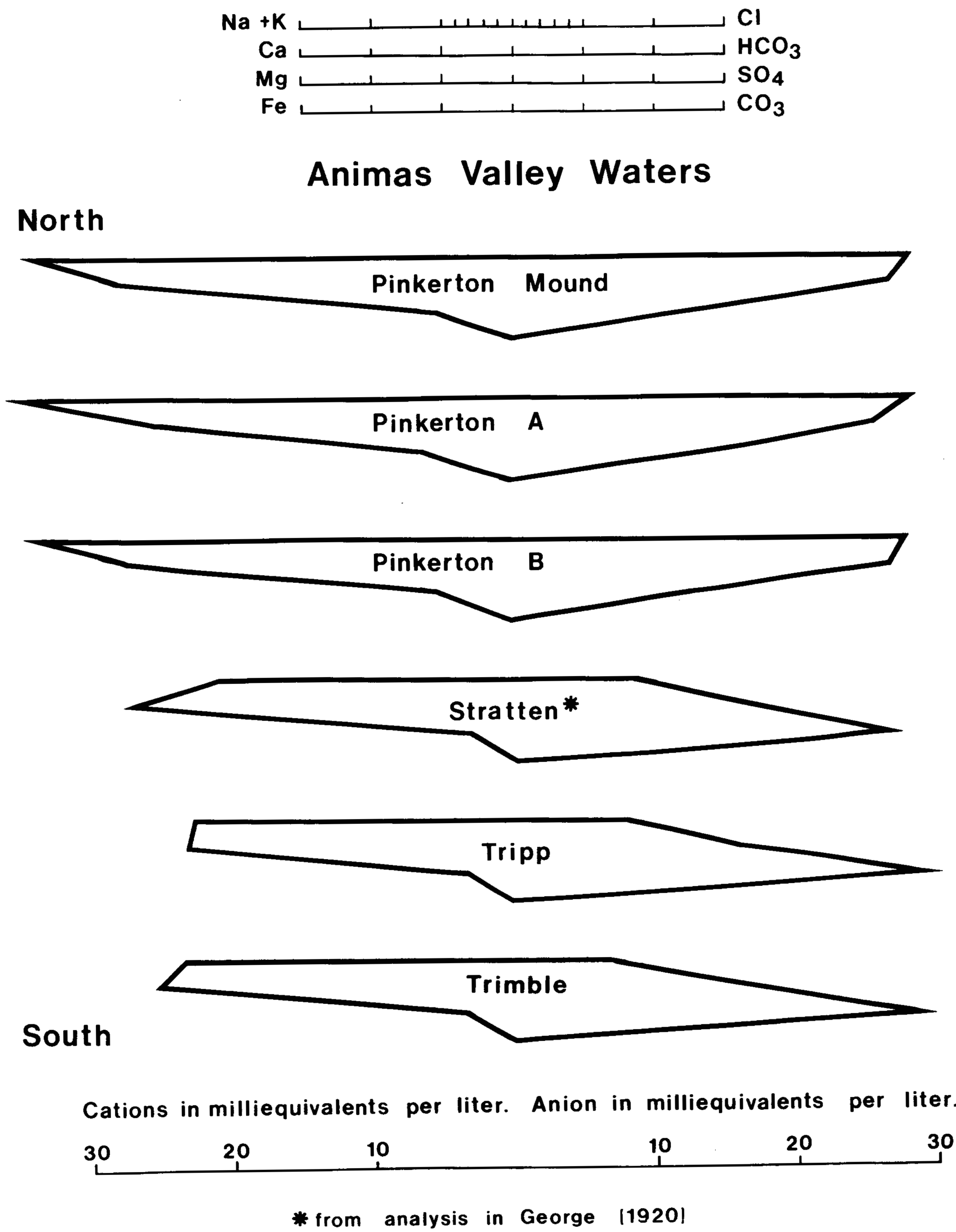


Figure 6. Stiff diagram of Animas Valley thermal waters (from analysis by Barrett and Pearl, 1976). (See Appendix A)

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.

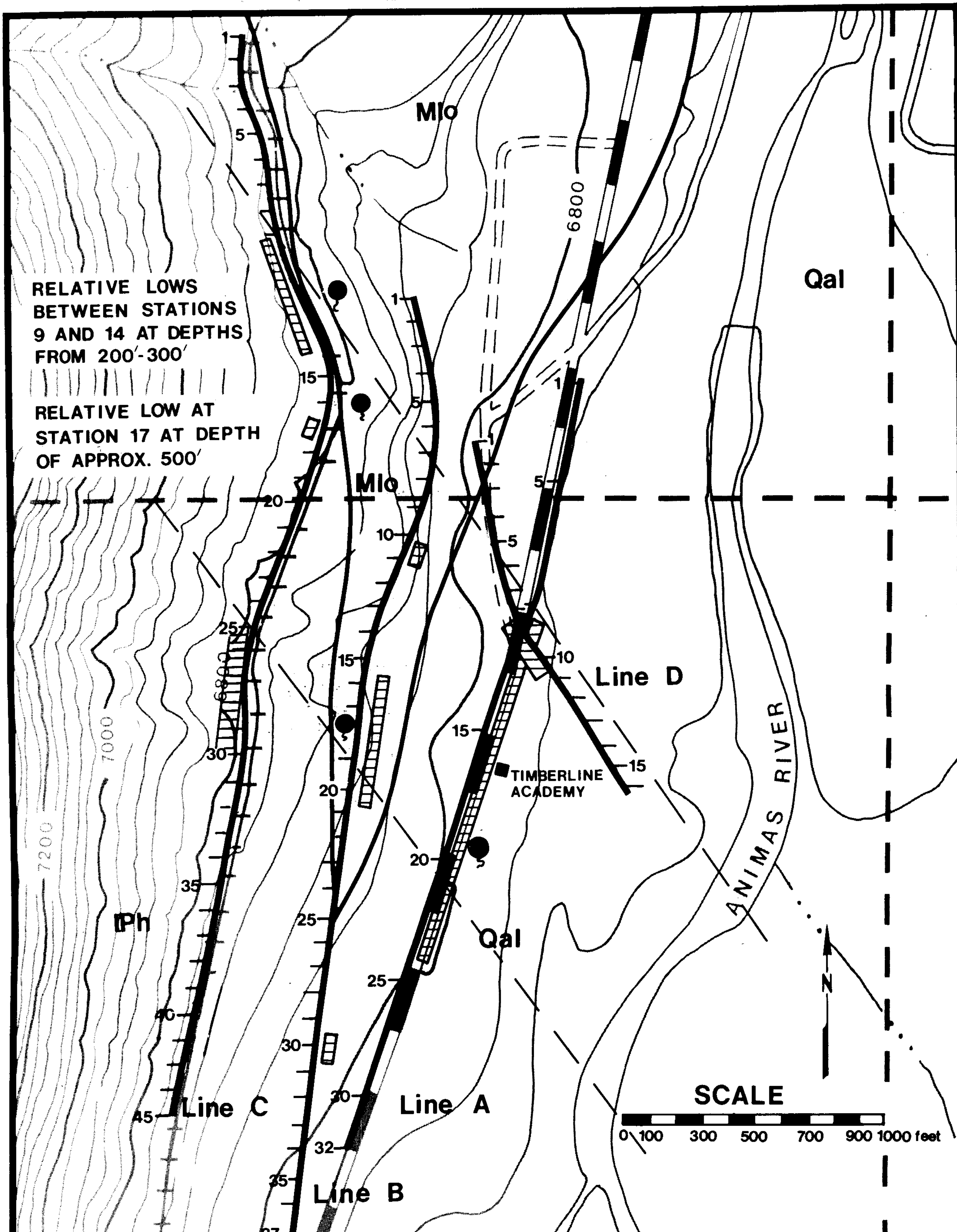
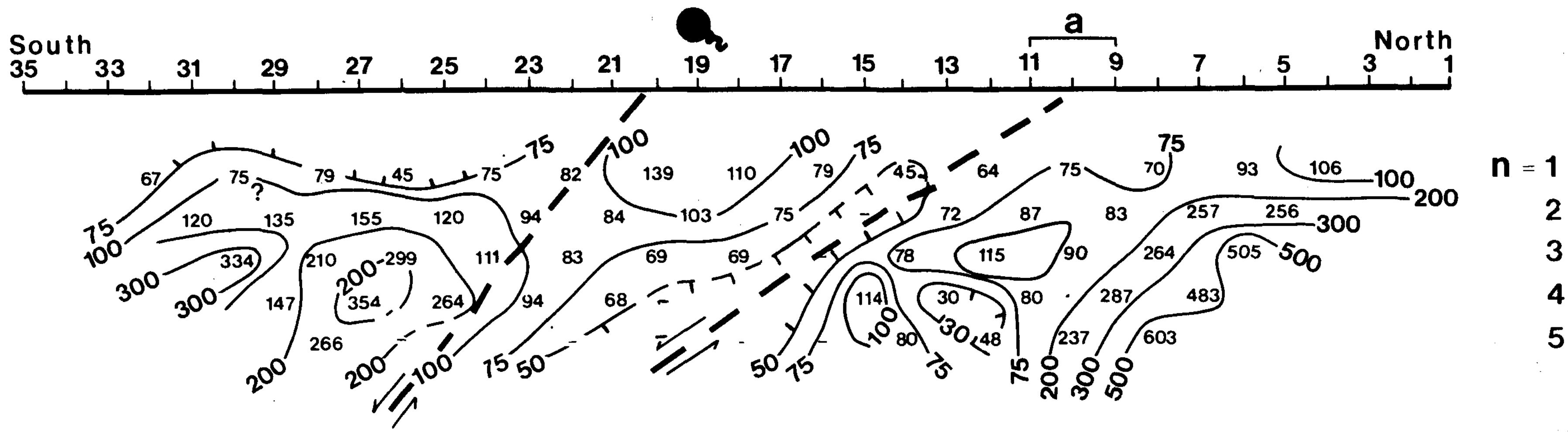


Figure 7. Geology, springs, and electrical resistivity lines at Pinkerton Hot Springs.

Figure 7. Continued.

EXPLANATION

	Thermal springs
26	Resistivity survey lines with station numbers
	Area of low resistivity
	Inferred faults
Qal	Quaternary alluvium
Mlo	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.

LENGTH: 3,600 ft (1,090m)

SEPARATION: n Value

DATE: July 16,17, 1980

TYPE: Dipole-Dipole

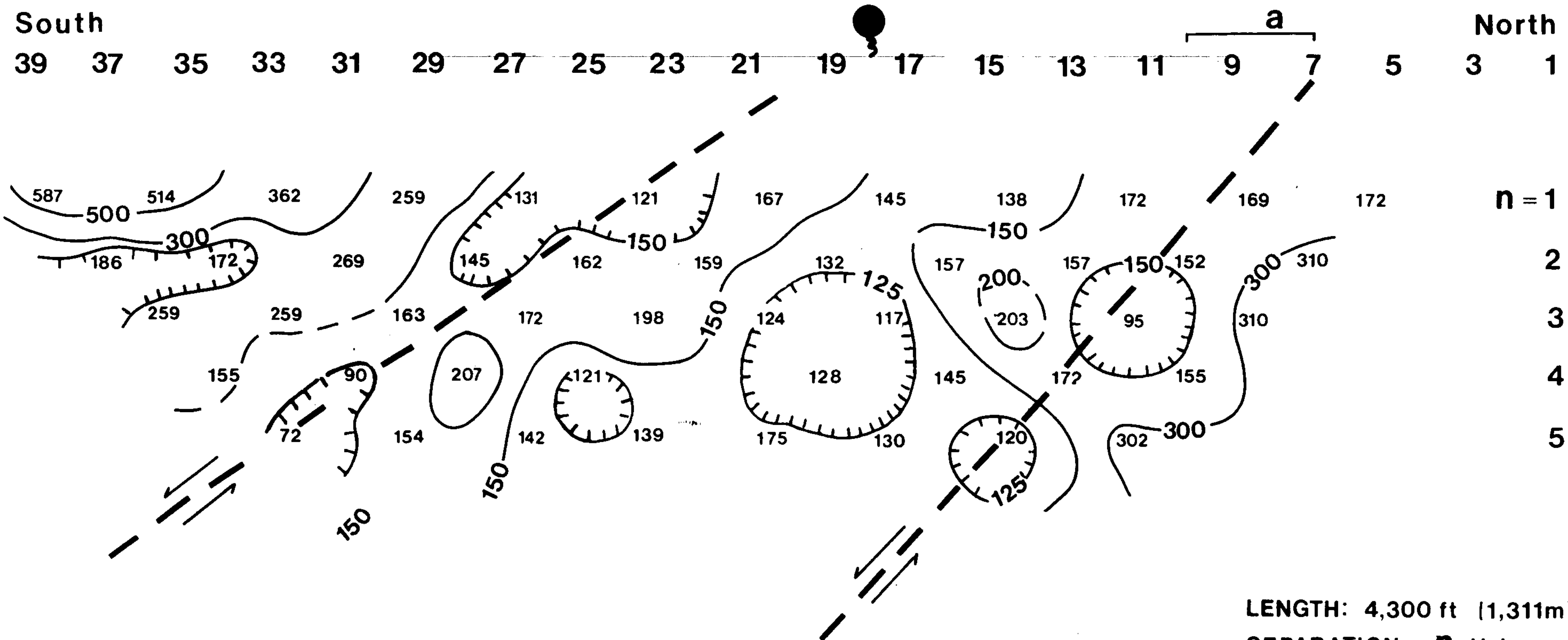
SPREAD: a=200 ft

RESISTIVITY: In ohm meters

— — POSSIBLE FAULT

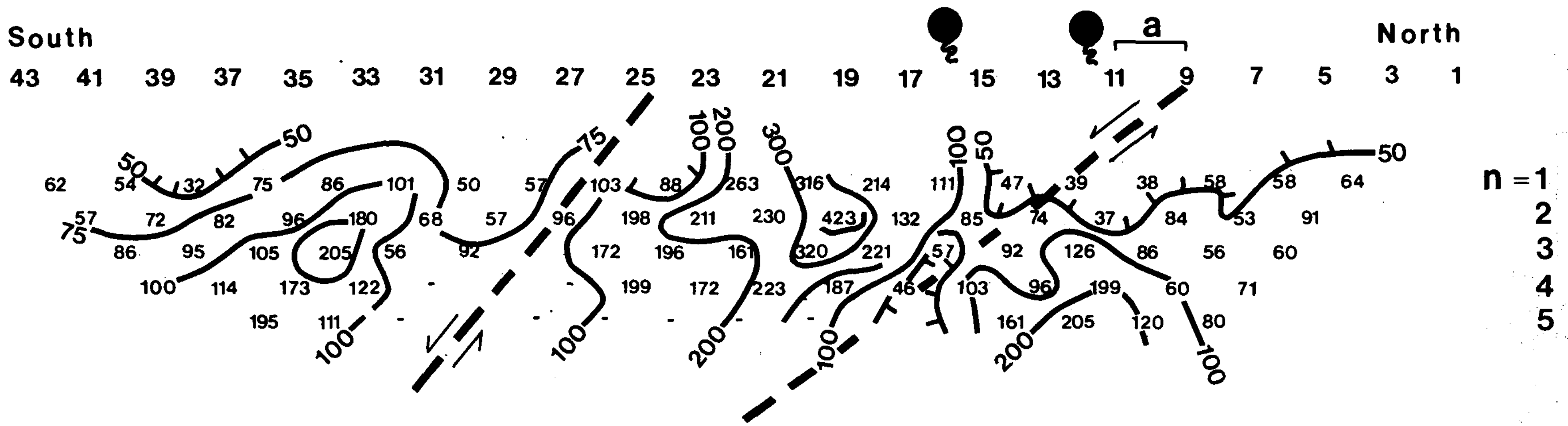
SCALE
0 200 feet

Figure 8. Pseudosection of resistivity line A.



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.

Figure 9. Pseudosection of resistivity line B.



LINE C - 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 (1,372 m)

SEPARATION: n Value

DATE: July 21-24, 1980

TYPE: Dipole-Dipole

SPREAD: a = 200 ft

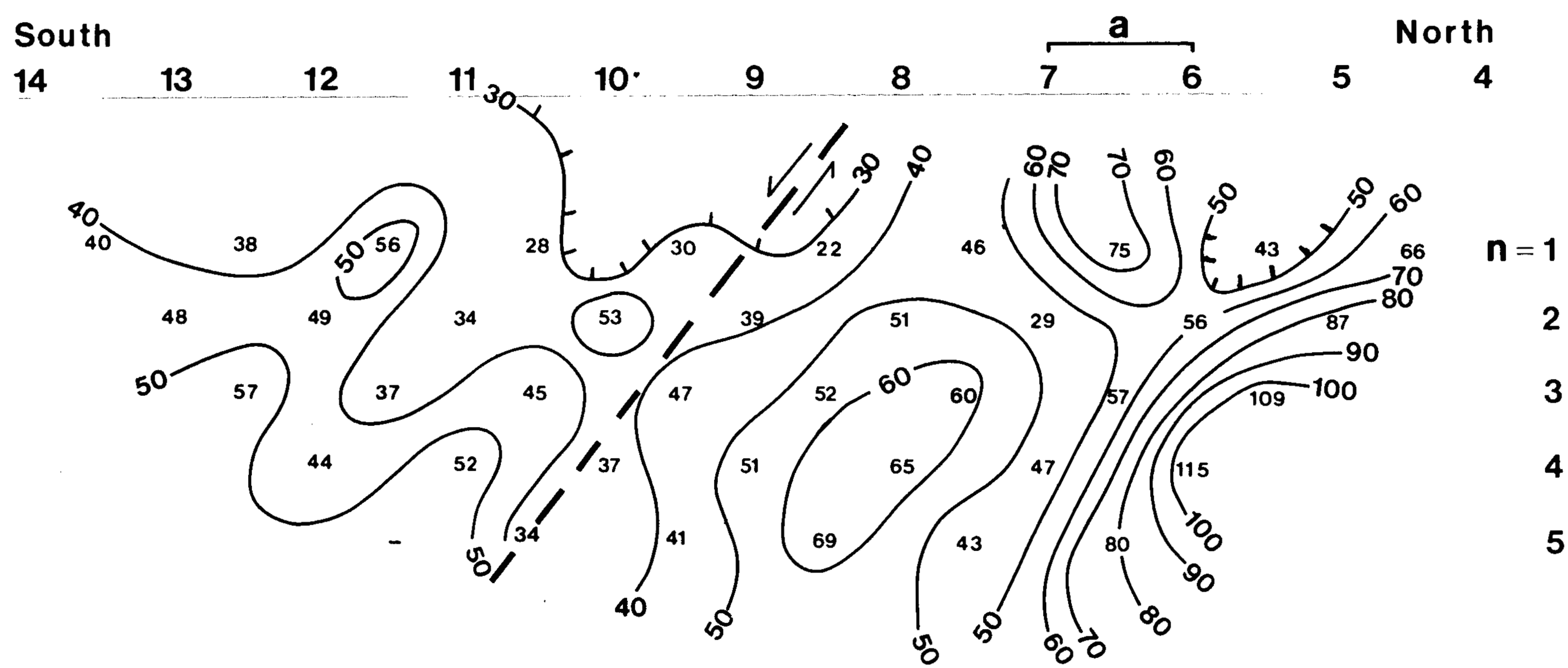
RESISTIVITY: In ohm meters

▬ ▬ POSSIBLE FAULT

SCALE

0 200 feet

Figure 10. Pseudosection of resistivity line C.



LENGTH: 1,400 ft (426m)

SEPARATION: n Value

DATE: July 28, 1980

TYPE: Dipole-Dipole

SPREAD: a= 100 ft

RESISTIVITY: In ohm meters

— — POSSIBLE FAULT

SCALE

0 100 feet

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.

Figure 11. Pseudosection of resistivity line D.

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

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

Sampling Methods

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

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

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

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

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

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

Analysis

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

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

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

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

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

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

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

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

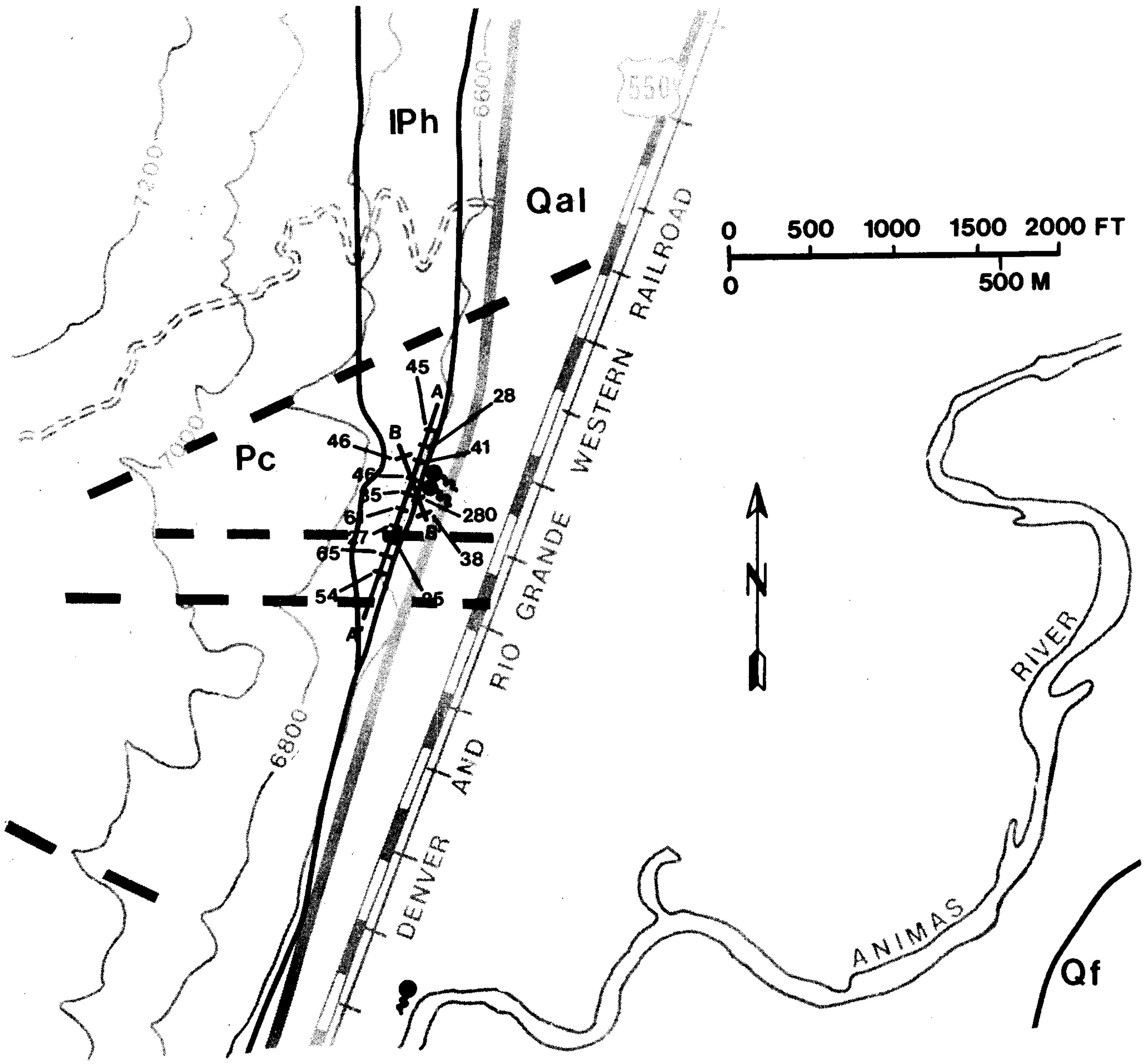
7). Note where break in slope of graph occurs.

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

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

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.



<u>EXPLANATION</u>

Thermal springs

41 Soil mercury lines A and B numbers are values in ppb

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.

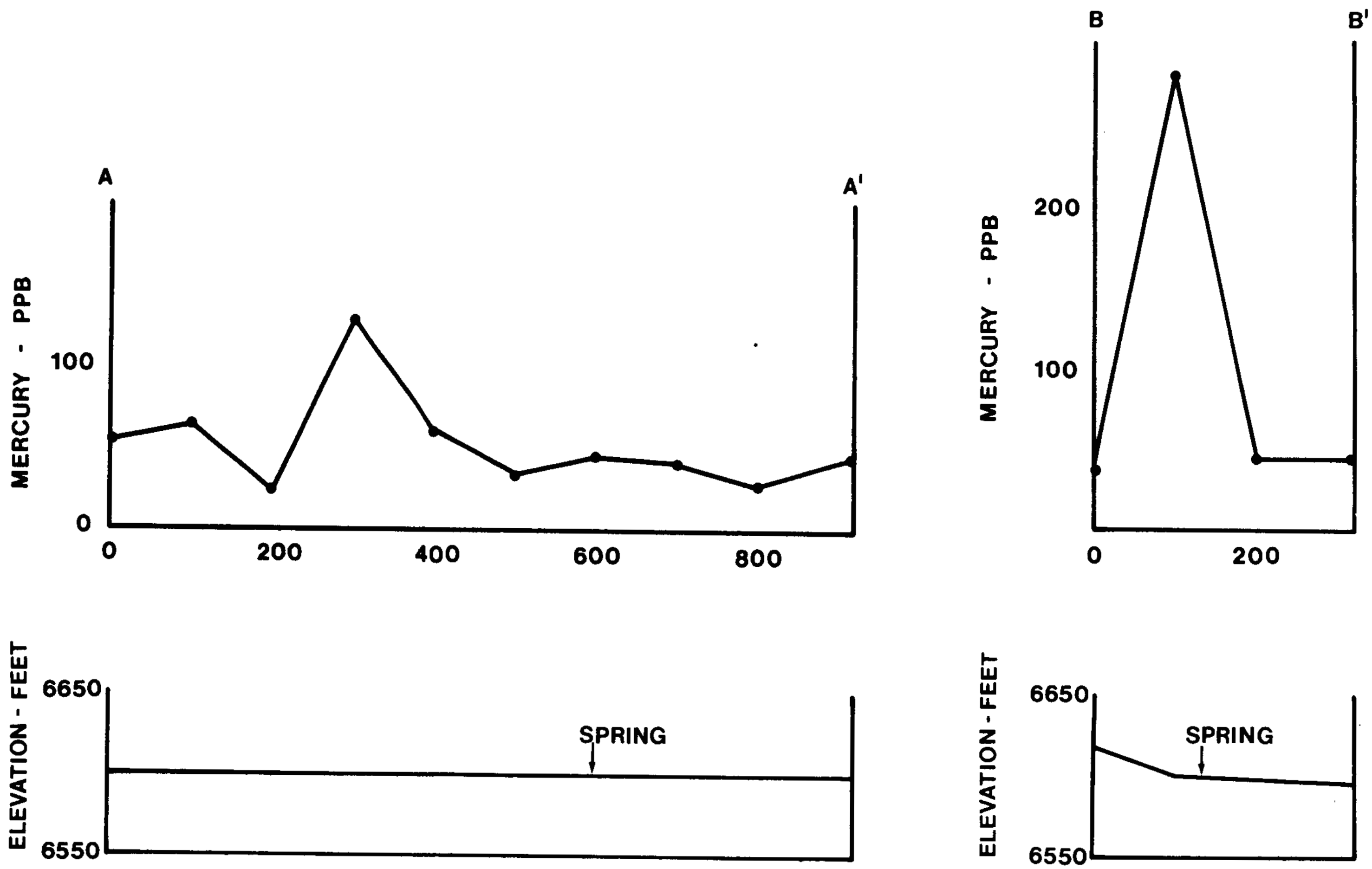


Figure 13. Soil mercury profiles from Tripp-Trimble Springs area.

Table 2. Soil mercury values, Tripp-Trimble Hot Springs (ppb)

Line A-A'		Line B-B'	
1.	45	1.	46
2.	28	2.	46
3.	41	3.	280 *
4.	46	4.	38
5.	35		
6.	61		
7.	127*		
8.	25		
9.	65		
10.	54		

Line A-A': * Located on site of old hotel. Abundant charcoal present.

Line B-B': * Located next to old swimming pool.

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 Geological 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.

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APPENDIX A

CHEMISTRY OF ANIMAS VALLEY WARM WATERS

	Tripp	Trimble	Pinkerton Spring A	Pinkerton Spring B	Pinkerton 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	0	0	0
Calcium (Ca), (MG/L):	470	510	510	530	550
Chloride (Cl), (MG/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):	80	80	470	530	500
Mercury (Hg), (UG/L):	0	0	0	0	0
Nitrogen (N), (MG/L):	0.16	0.08	0.10	-	0.06
Phosphate (PO_4)					
Ortho diss. as P, (MG/L):	0.05	0.02	0.05	0.01	0.01
Ortho, (MG/L):	0.15	0.06	0.15	0.04	0.03
Potassium (K), (MG/L):	47	47	120	120	120
Selenium (Se), (UG/L):	0	0	0	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	620
Zinc (Zn), (UG/L):	20	10	0	20	10
Alkalinity					
As Calcium Carb. (MG/L):	810	894	1,340	1,350	1,340
As Bicarbonate (MG/L):	988	1,090	1,630	1,640	1,630

APPENDIX A CONTIUNED

CHEMISTRY OF ANIMAS VALLEY WARM WATERS

			Pinkerton		
	Tripp	Trimble	Spring A	Spring B	Mound Spring
Hardness					
Noncarbonate (MG/L):	530	550	260	280	340
Total, (MG/L):	1,300	1,400	1,600	1,600	1,700
Specific Conductance (Micromohs):	3,900	4,400	5,600	6,000	5,600
Total dissolved solids (TDS), (MG/L):	3,240	3,340	3,990	-	3,940
pH, Field	-	-	-	-	-
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:

$$P_a = 2PIa \quad V/I \qquad \text{General Formula}$$

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).

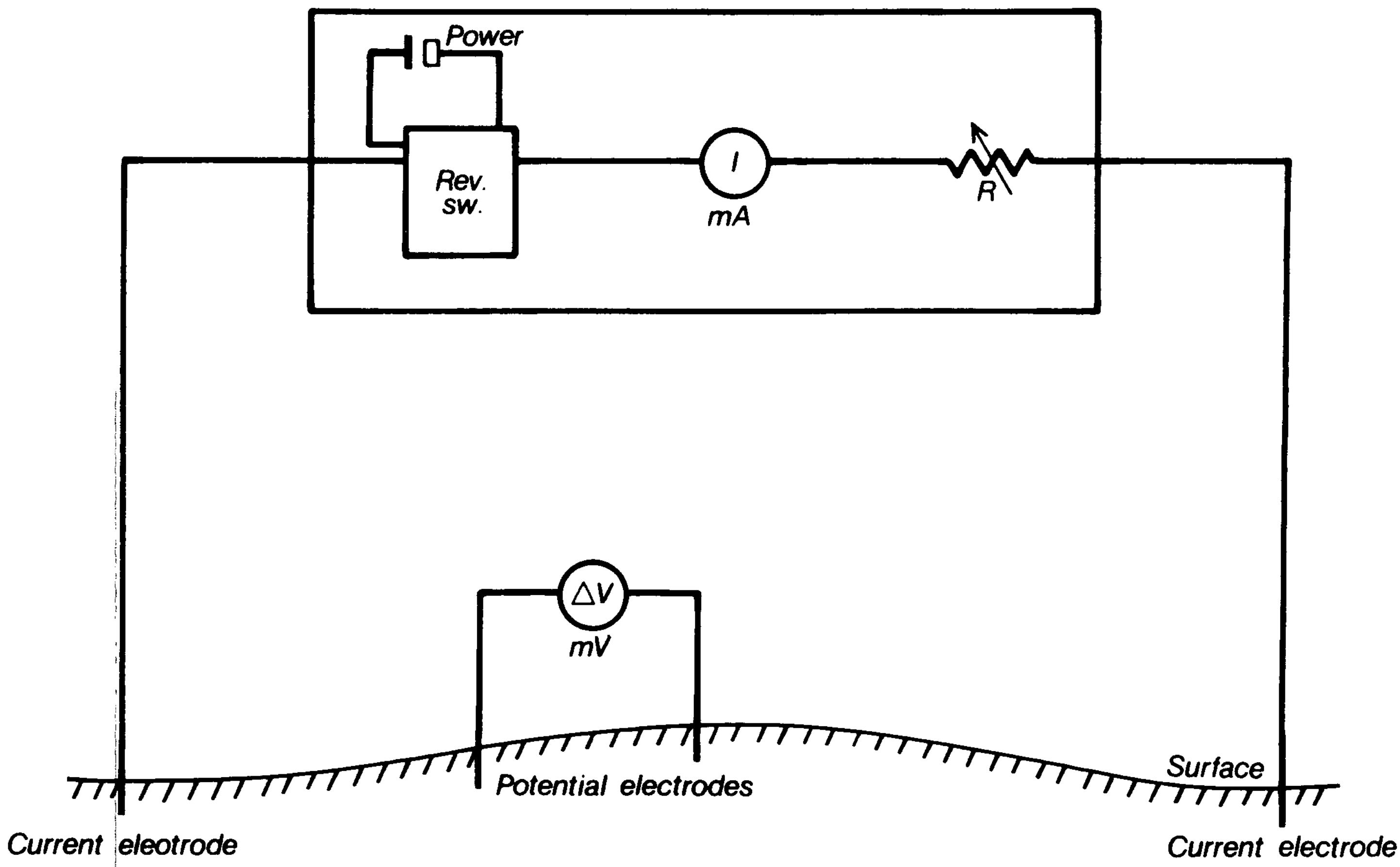
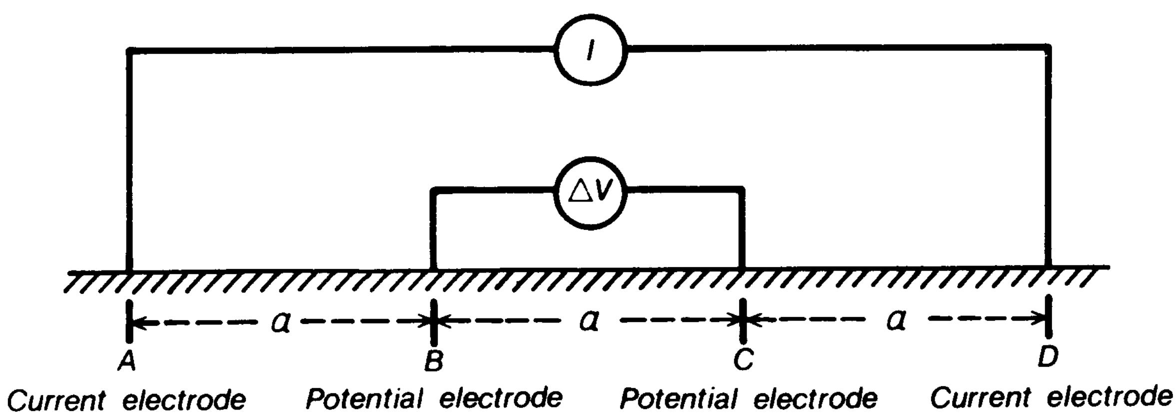


Figure 14. Schematic diagram for resistivity.



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

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).

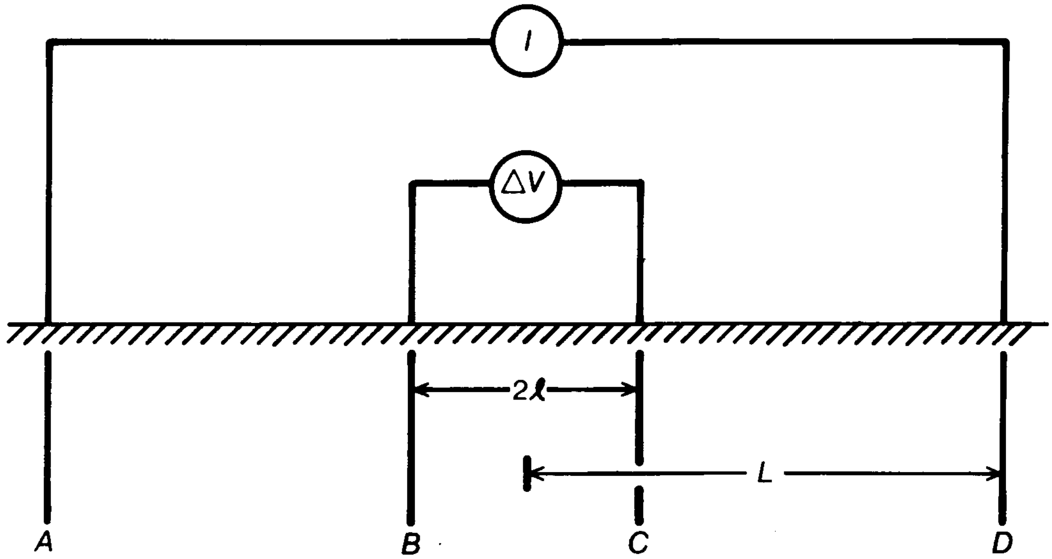
In summary, short spacing between the outer electrodes assumes shallow penetration of current flow and computed resistivity will reflect properties of shallow depth. As the electrode spacing is increased, more current penetrates to greater depth and conducted resistivity will reflect properties of each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

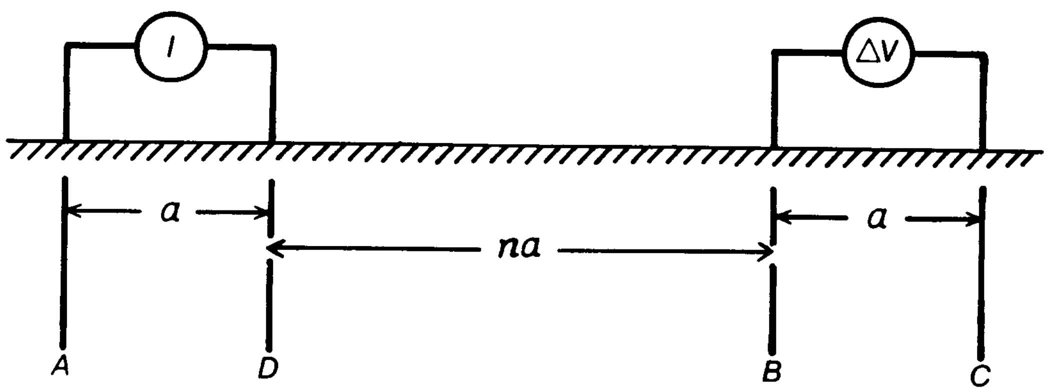
Inductive coupling between potential and current cables is reduced with this arrangement. This method was primarily used throughout all study areas because of reliability and ease of field operation. A diagram of this method is depicted in Figures 18 and Figure 19.

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



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

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



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

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

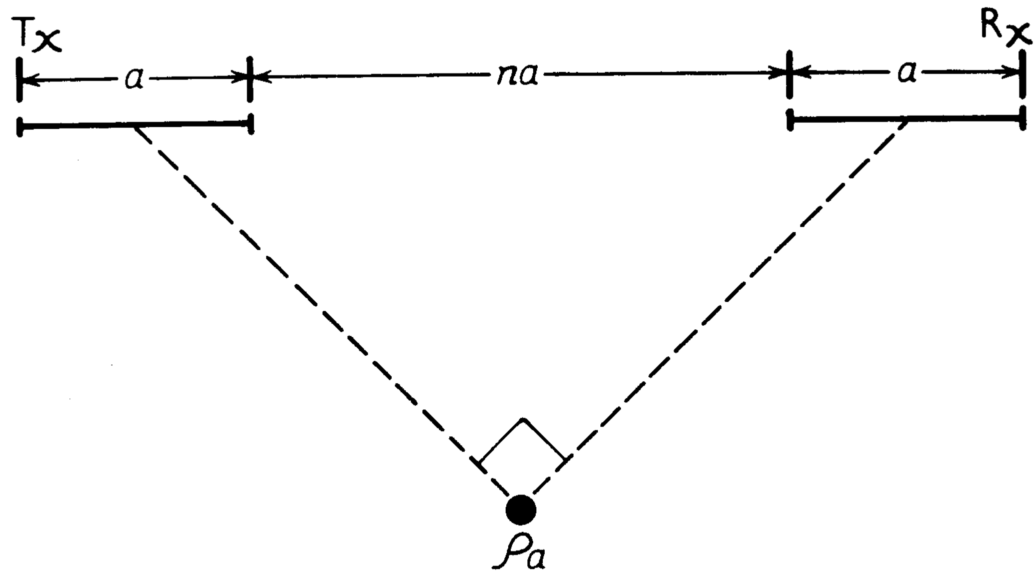


Figure 18. Data plotting scheme for dipole-dipole array (from Combs, 1980).

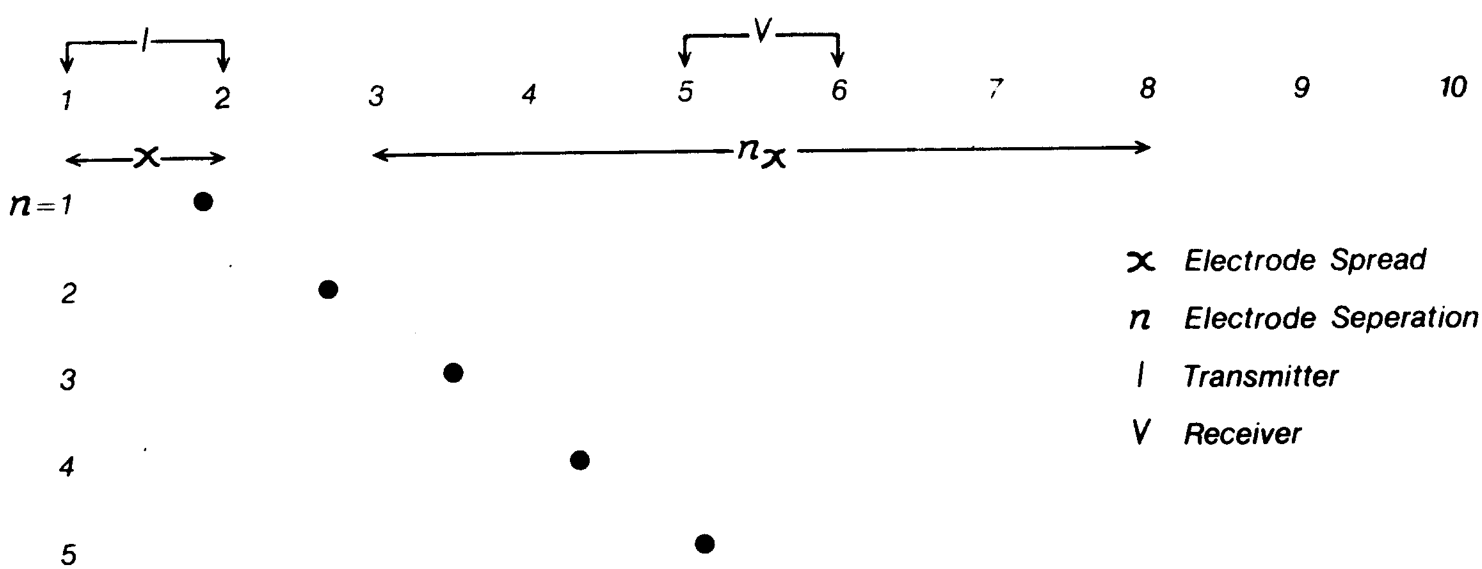


Figure 19. Typical dipole-dipole array (from Combs, 1980).

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. Sumner, 1976).

APPENDIX E. RESISTIVITY CALCULATIONS

TABLE 3. LINE A.

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

LOCATION	PROJECT	DATE
Pinkerton	Line A	15 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	-3	250	9.20	0.0920	1149	106
7-9	1	-3	250	5.58	0.0558	4597	256
9-11	1	-3	250	4.38	0.0438	11493	505
11-13	1	-3	250	2.10	0.0210	22987	483
13-15	1	-3	250	1.50	0.0150	40226	603
3-5							
7-9	1	-3	433	8.10	0.081	1149	93
9-11	1	-3	433	5.60	0.0560	4597	257
11-13	1	-3	433	2.30	0.0230	11493	264
13-15	1	-3	433	1.25	0.0125	22987	287
15-17	0	-3	433	5.9	0.0059	40226	237
5-7							
9-11	1	-2	133	0.61	0.061	1149	70
11-13	1	-2	133	0.18	0.018	4597	83
13-15	0/0	-2/-3	100/250	0.20/7.80	0.0078	11493	90
15-17	0	-3	225	3.50	0.0035	22987	8
17-19	0	-3	225	1.20	0.0012	40226	48
7-9							
11-13	1	-3	166	6.50	0.065	1149	75
13-15	1	-3	166	1.90	0.019	4597	87
15-17	1	-3	166	1.00	0.010	11493	115
17-19	1	-3	166	1.30	0.0013	22987	30
19-21	0	-3	166	2.00	0.0020	40226	80
9-11							
13-15	1	-3	225	5.60	0.056	1149	64
15-17	1	-3	285	1.55	0.0155	4597	72
17-19	1	-3	250/225	0.68	0.0068	11493	78
19-21	0	-3	225	4.95	0.00495	22987	114
21-23			N.R. -- wouldn't stabilize				

TABLE 3. LINE A (CONT.)

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Pinkerton	Line A	16 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
11-13							
15-17	1	-3	400	3.95	0.0395	1149	45
17-19		-3	400	N.R.		4597	--
19-21		-3	366	N.R.		11493	--
21-23		-3	433	N.R.		22987	--
23-25				N.R.		40226	--
13-15							
17-19	2	-3	400	0.69	0.069	1149	79.3
19-21	1	-3	400	1.64	0.0164	4597	75.4
21-23	1	-3	400	0.60	0.006	11493	69.0
23-25			not	read			
25-27			not	read			
15-17							
19-21	2	-3	133	0.96	0.096	1149	110.3
21-23	1	-3	133	2.24	0.0224	4597	103.0
23-25	0	-3	133	5.98	0.00598	11493	68.7
25-27	0	-3	133	2.97	0.00297	22987	68.3
17-19							
21-23	2	-3	250	1.13	0.113	1149	129
23-25	1	-3	250	2.05	0.0205	4597	94.2
25-27	0	-3	250	7.25	0.00725	11493	83.3
27-29	0	-3	250	4.09	0.00409	22987	94
19-21							
23-25	2	-3	275	0.71	0.071	1149	81.6
25-27	1	-3	275	2.04	0.0204	4597	93.8
27-29	1	-3	275	0.98	0.0098	11493	112.6
29-31	1	-3	275	1.15	0.0115	22987	264.3

TABLE 3. LINE A (CONT.)

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Pinkerton	Line A	16 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
21-23							
25-27	1	-3	200	6.52	0.0652	1149	75
27-29	1	-3	200	2.62	0.0262	4597	120.4
29-31	1	-3	200	2.60	0.0260	11493	298.8
31-33	1	-3	200	1.54	0.0154	22987	354
33-35	0	-3	200	6.62	.00662	40226	266.3
23-25							
27-29	1	-3	133	3.90	0.0390	1149	44.8
29-31	1	-3	133	3.37	0.0337	4597	154.9
31-33	1	-3	133	1.83	0.0183	11493	210.3
33-35	1	-3	133	0.64	0.0064	22987	147
25-27							
29-31	2	-3	133	0.69	0.069	1149	79.3
31-33	1	-3	133	2.93	0.0293	4597	134.7
33-35	1	-3	133	1.17	0.0117	11493	134.5
27-29							
31-33	2	-3	133	0.83	.083	1149	95.4
33-35	1	-3	133	2.60	.0260	4597	119.5
29-31							
33-35	2	-3	133	0.58	0.058	1149	666

APPENDIX E. RESISTIVITY CALCULATIONS

TABLE 4. LINE B.

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

LOCATION	PROJECT	DATE
Pinkerton	Line B	16 July 1980
CHIEF OPERATOR	ASSISTANTS	METHOD
Jay Jones	Fargo and Treska	Dipole-Dipole (Nx300')

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
1-4							
7-10	1	-3	250	10.0	0.100	1724	172.4
10-13	1	-3	225	4.50	0.045	6896	310.3
13-16	1	-3	225	1.80	0.018	17240	310.3
16-19	1	-3	225	0.45	0.0045	34480	155.16
19-22	1	-3	225	0.50	0.0050	60340	301.7
4-7							
10-13	2	-3	133	0.98	0.098	1724	168.9
13-16	1	-3	133	2.20	0.0220	6896	151.7
16-19	0	-3	133	5.50	0.0055	17240	94.8
19-22	0	-3	133	5.00	0.0050	34480	172.4
22-25	0	-3	133	1.65	0.00165	60340	99.6
7-10							
13-16	2	-3	250	1.00	0.100	1724	172.4
16-19	1	-3	250	2.28	0.0228	6896	157.2
19-22	1	-3	250	1.18	0.0118	17240	203.4
22-25	0	-3	250	4.20	.0042	34480	144.8
25-28	0	-3	250	2.15	.00215	60340	129.7
10-13							
16-19	1	-3	200	8.00	0.080	1724	137.9
19-22	1	-3	200	2.27	0.0227	6896	156.5
22-25	0	-3	200	6.80	0.0068	17240	117.2
25-28	0	-3	200	3.70	0.0037	34480	127.58
28-31	0	-3	200	2.90	0.0029	60340	174.99

TABLE 4. LINE B. (CONT.)

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Pinkerton	Line B	17 July 1980
CHIEF OPERATOR	ASSISTANTS	METHOD
Jay Jones	Fargo and Treska	Dipole-Dipole (Nx300')

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
13-16							
19-22	1	-3	66	8.40	0.084	1724	144.8
22-25	1	-3	66	1.91	0.0191	6896	131.7
25-28	0	-3	66	7.20	0.0072	17240	124.1
28-31	0	-3	66	4.30	0.0043	34480	148.26
31-34	0	-3	66	2.30	0.0023	60340	138.8
16-19							
22-25	2	-3	66	0.98	0.098	1724	168.9
25-28	1	-3	66	2.30	0.023	6896	158.6
28-31	1	-3	66	1.15	0.0115	17240	198.3
31-34	0	-3	66	3.50	0.0035	34480	120.68
34-37	0	-3	66	2.35	0.00235	60340	141.8
19-22							
25-28	1	-3	166	7.00	0.070	1724	120.7
28-31	1	-3	166	2.35	0.0235	6896	162.1
31-34	1	-3	166	1.00	0.010	17240	172.4
34-37	0	-3	166	6.00	0.0060	34480	206.9
37-40	0	-3	166	2.55	0.00255	60340	153.9
22-25							
28-31	1	-3	225	7.60	0.076	1724	131.0
31-34	1	-3	225	2.10	0.0210	6896	144.8
34-37	1	-3	225	0.95	0.0095	17240	163.8
37-40	0	-3	225	2.60	0.0026	34480	89.7
40-43	0	-3	225	1.20	0.0012	60340	72.4
25-28							
31-34	2	-3	250	1.50	0.150	1724	258.6
34-37	1	-3	250	3.90	0.039	6896	269
37-40	1	-3	250	1.5	0.015	17240	258.6
40-43	0	-2	66	0.45	.0045	34480	155.2

TABLE 4. LINE B. (CONT.)

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Pinkerton	Line B	17 July 1980
CHIEF OPERATOR	ASSISTANTS	METHOD
Jay Jones	Fargo and Treska	Dipole-Dipole (Nx300')

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
28-31							
34-37	1	-2	66	2.10	0.210	1724	362.0
37-40	0	-2	66	2.50	0.025	6896	172.4
40-43	1	-3	250	1.50	0.015	17240	258.6
31-34							
37-40	1	-2	66	3.98	0.298	1724	513.8
40-43	0	-2	66	2.70	0.027	6896	186.2
34-37	1	-3	225	0.95	0.0095	17240	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

LOCATION	PROJECT	DATE
Pinkerton	Line C	24 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	-3	300	5.60	0.0560	1149	64
7-9	1	-3	300	1.98	0.0198	4597	91
9-11	0	-3	300	5.20	0.0052	11493	60
11-13	0	-3	300	3.10	.0031	22987	71
13-15	0	-3	300	2.00	.0020	40226	80
3-5							
7-9	1	-3	225	5.05	0.0505	1149	58
9-11	1	-3	225	1.15	0.0115	4597	53
11-13	0	-3	225	4.90	0.0049	11493	56
13-15	0	-3	225	2.60	0.0026	22987	60
15-17	0	-3	225	3.00	0.0030	40226	12
5-7							
9-11	1	-3	166	5.06	0.0506	1149	58
11-13	1	-3	166	1.82	0.0182	4597	84
13-15	0	-3	166	7.50	0.0075	11493	86
15-17	0	-3	166	8.65	0.00865	22987	199
17-19	0	-3	166	5.10	0.0051	40226	205

TABLE 5. LINE C (CONT.)

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Pinkerton	Line C	24 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
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	0	-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. -- lightning				
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	0	-3	100	5.00	0.0050	11493	57
21-23	0	-3	100	2.00	0.0020	22986	46
23-25			N.R. -- lightning				

TABLE 5. LINE C (CONT.)

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Pinkerton	Line C	23 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
19-21							
21-23	1	-2	66	2.29	0.229	1149	263
23-25	1	-3	133	4.59	0.0459	4597	211
25-27	1	-3	133	1.71	0.0171	11493	196
27-29	1	-3	133	0.65	0.0065	22986	149
29-31		-3	133	N.R.	--	40226	
21-23							
23-25	2	-3	133	1.53	0.153	1149	88
25-27	1	-3	133	4.30	0.0430	4597	198
27-29	1	-3	133	1.50	0.0150	11493	172
29-31	0	-3	133	N.R.	--	22986	
31-33	0	-3	133	N.R.	--		
23-25							
25-27	2	-3	100	0.90	0.090	1149	103
27-29	1	-3	100	2.09	0.0209	4597	96
29-31	0			N.R.			
31-33	0			N.R.			
33-35	0			N.R.			

TABLE 5. LINE C (CONT.)

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Pinkerton	Line C	23 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
25-27							
27-29	1	-3	100	5.00	0.050	1149	57
29-31	1	-3	100	1.24	0.0124	4597	57
31-33	1	-3	100	0.80	0.0080	11493	92
33-35	0	-3	100	N.R.		22986	
35-37				N.R.		40226	
27-29							
29-31	1	-3	133	4.31	0.0431	1149	50
31-33	1	-3	133	1.49	0.0149	4597	68
33-35	1	-3	100	0.94	0.0049	11493	56
35-37	0	-3	100	5.33	0.00533	22986	122
37-39	0	-3	100	2.75	0.00275	40226	111
29-31							
31-33	2	-3	475	0.88	0.088	1149	101
33-35	1	-3	475	3.91	0.0391	4597	180
35-37	1	-3	475	1.78	0.0178	11493	205
37-39	0	-3	475	8.25	0.00825	22986	173
39-41	0	-3	475	4.85	0.00485	40226	195

TABLE 5. LINE C (CONT.)

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Pinkerton	Line C	21 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
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.--electrical 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	N.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	1	-3	225	0.75	0.0075	22986	172
27-29				N.R.			

TABLE 5. LINE C.

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Pinkerton	Line C	23 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
31-33							
33-35	2	-3	466	0.75	0.075	1149	86
35-37	1	-3	466	2.10	0.021	4597	96
37-39	1	-3	433	0.91	0.0091	11493	105
39-41	0	-3	433	5.42	0.00542	22986	114
41-43	0	-3	433	N.R.			
33-35							
35-37	2	-3	133	0.65	0.065	1149	75
37-39	1	-3	133	1.79	0.0179	4597	82
39-41	0	-3	133	8.25	0.00825	11493	95
41-43	0	-3	133	4.75	0.00475	22986	100
35-37							
37-39	1	-3	133	5.50	0.055	1149	32
39-41	1	-3	133	1.57	0.0157	4597	72
41-43	1	-3	133	0.75	0.0075	11493	86
37-39							
39-41	+1	-3	137	4.73	0.0473	1149	54
41-43	1	-3	133	1.25	0.0125	4597	57
39-41							
41-43	2	-3	300	0.54	0.054	1149	62

TABLE 6. LINE D.

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

LOCATION	PROJECT	DATE
Pinkerton	Line D	29 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
3-4							
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	56
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
8-9	0	-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.)

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Pinkerton	Line D	29 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
7-8							
9-10	0	-2	66	3.90	0.0390	575	22
10-11	1	-3	250	1.70	0.0170	2299	39
11-12	0	-3	250	8.10	0.0081	5747	47
12-13	0	-3	250	3.20	0.0032	11493	37
13-14	0	-3	250	1.70	.00170	20113	34
8-9							
10-11	1	-3	300	5.20	0.052	575	30
11-12	1	-3	300	2.30	0.023	2299	53
12-13	0	-3	300	7.80	0.0078	5747	45
13-14	0	-3	300	4.50	0.0045	11493	52
14-15	-	-3	300	N.R.--power line interference			
9-10							
11-12	1	-3	200	4.90	0.049	575	28
12-13	1	-3	200	1.50	0.0150	2299	34
13-14	0	-3	200	6.50	0.0065	5747	37
14-15	0	-3	200	3.80	0.0038	11493	44
10-11							
12-13	1	-3	166	9.70	0.097	575	56
13-14	1	-3	166	2.15	0.0215	2299	49
14-15	1	-3	166	1.00	0.010	5747	57
11-12							
13-14	1	-3	200	6.55	0.0655	575	38
14-15	1	-3	200	2.10	.0210	2299	48
12-13							
14-15	0	-2	66	7.00	0.070	575	40

APPENDIX F

TABLE 7
GEOMETRIC FACTOR TABLE
SCHLUMBERGER METHOD

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

TABLE 8. DIPOLE-DIPOLE GEOMETRIC FACTOR TABLE

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

TABLE 9. WENNER GEOMETRIC FACTOR TABLE

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

GEOTHERMAL ENERGY PUBLICATIONS--

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

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

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

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

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

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

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

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

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

Resource Ser. 17, GEOTHERMAL RESOURCE ASSESSMENT OF THE ANIMAS VALLEY, COLORADO, by. K.P. McCarthy, T.G. Zacharakis, and R.H. Pearl, 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 WITH A SECTION ON MINERALOGICAL AND PETROGRAPHIC INVESTIGATIONS OF SAMPLES FROM GEOTHERMAL WELLS 0-1 AND P-1, PAGOSA SPRINGS, COLORADO, by W.W. Atkinson, 1980, 95 p. $10.00

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Open-File Report 81-1, 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.

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