RESOURCE SERIES 15
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GEOTHERMAL RESOURCE ASSESSMENT OF OURAY, COLORADO

by
Ted G. Zacharakis
Charles D. Ringrose
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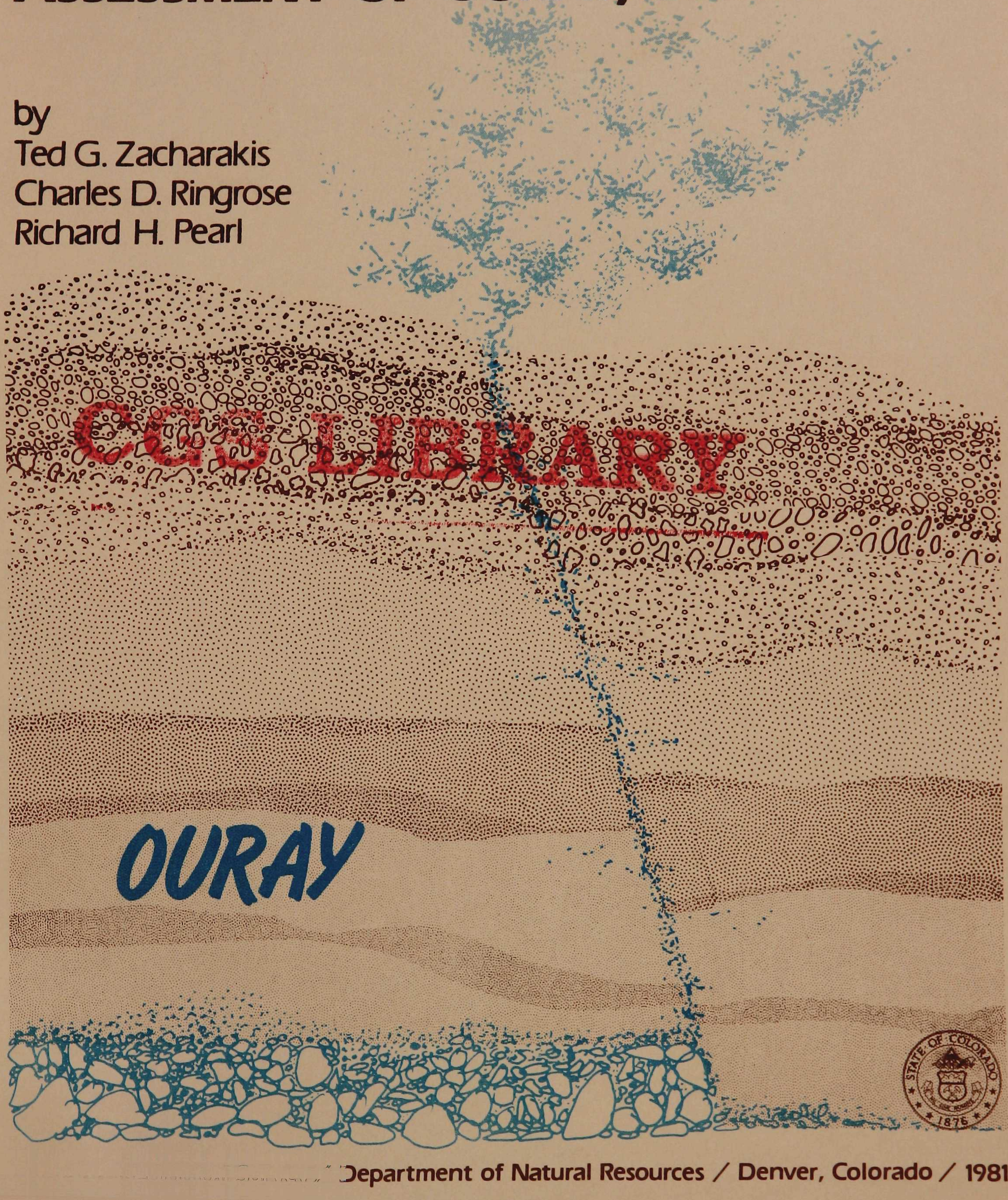

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Prepared by the
COLORADO GEOLOGICAL SURVEY
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Colorado Geological Survey
Department of Natural Resources
State of Colorado
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ABSTRACT

In 1979, the Colorado Geological Survey, in cooperation with the U.S. Department of Energy/Division of Geothermal Energy under Contract No. DE-AS07-28365, initiated a program to delineate the geological features controlling the occurrence of those geothermal resources in Colorado.

In the Ouray area, this effort consisted of geological mapping, soil mercury geochemical surveys and resistivity geophysical surveys.

The soil mercury survey obtained inconclusive results, with the Box Canyon area indicating a few anomalous values, but these values are questionable and probably are due to the hot spring activity and mineralization within the Leadville limestone rock. One isolated locality indicating anomalous values was near the Radium Springs pool and ball park, but this appears to be related to warm waters leaking from a buried pipe or from the Uncompahgre River.

The electrical resistivity survey however, indicated several areas of low resistivity zones namely above the Box Canyon area, the power station area and the Wiesbaden Motel area. From these low zones it is surmised that the springs are related to a complex fault system which serves as a conduit for the deep circulation of ground waters through the system.

INTRODUCTION

In 1979 the Colorado Geological Survey in cooperation with the U.S. Dept. of Energy/Division of Geothermal Energy under Contract No. DE-AS07-28365 initiated a program to delineate the geological features controlling the occurrence of those geothermal resources in Colorado which are believed to have a high potential for near term development. This effort consisted of a literature search, geological and hydrogeological mapping, resistivity geophysical surveys, and soil mercury geochemical surveys.

One of the thermal areas investigated was Ouray, Colorado. The community of Ouray, Colorado is located in a natural amphitheater shaped valley, here called the Ouray Valley, on the north side of the San Juan Mountains in southwestern Colorado (Fig. 1). The community, which is surrounded on all sides by nearly vertical cliffs, was the commercial center for the nearby mining districts on Red Mountain Pass to the south and the Camp Bird Mines to the west during the mining boom period 100 years ago.

The City of Ouray has been popular for many years as an area of thermal activity where tourists could enjoy the therapeutic warm mineral waters and the Alpine scenery. Thermal Springs are found in the following parts of Ouray: On the south side at the Box Canyon; the Wiesbaden Motel area on the east side of town; and the municipal pool area on the north side of town.

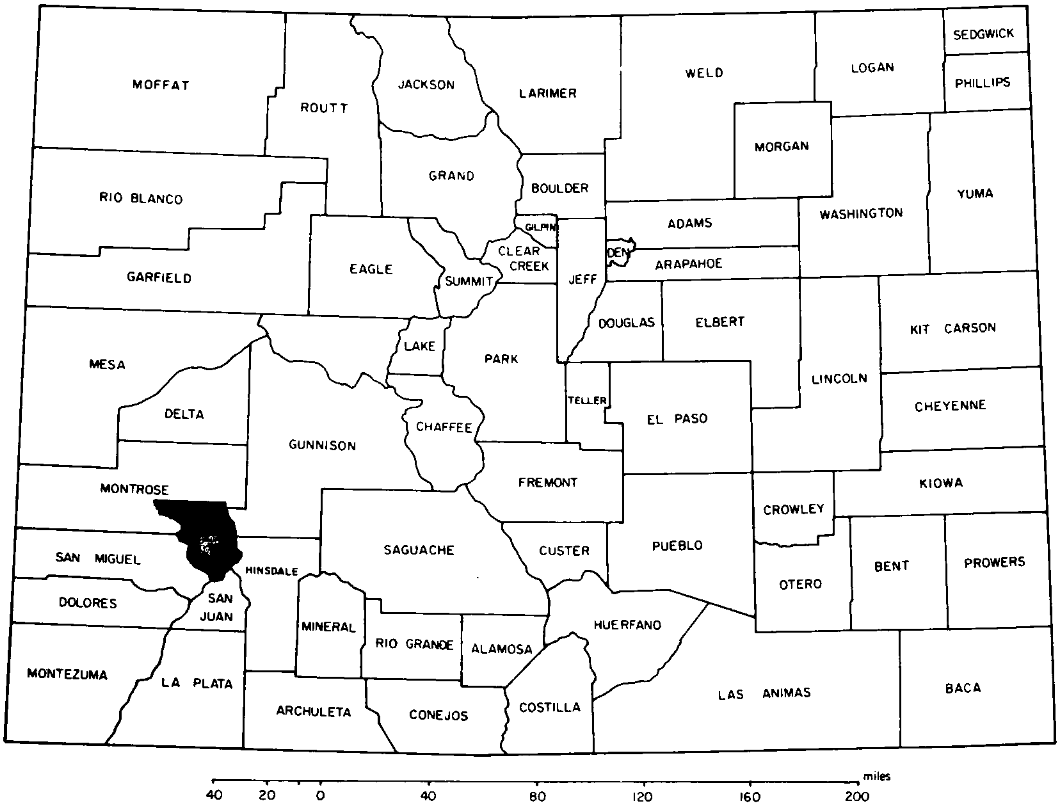


Figure 1. Ouray County, Colorado Index Map.

The thermal conditions of the Ouray area have been discussed by Barrett and Pearl (1976 and 1978); Coe (1981); George and others (1920); Lewis (1966); Mallory and Barrett (1973) and Pearl (1972 and 1979). Barrett and Pearl (1978) and Pearl (1979) attempted to estimate the subsurface temperatures of the thermal waters and to explain the origin of the springs. Based on geothermometer model analysis, Barrett and Pearl (1978) concluded that the most likely subsurface temperature that could be expected would be between 70°C and 90°C (158°F-194°F). Lacking any wells and subsurface data in the area, Pearl (1979) made several general assumptions about the size, extent and temperature of the resource. His analysis determined that the areal extent of the system could encompass approximately 2.0 sq mi and contain as much as .2 x 10^{15} B.T.U's of energy.

With these areas as the main areas for evaluation, the Colorado Geological Survey in 1980, in attempting to delineate the areal extent of these geothermal resources, ran electrical D.C. resistivity surveys and soil mercury surveys.

GEOLOGY

Introduction

The geological conditions of the Ouray area have been mapped in detail by Luedke and Burbank (1962). In addition the general geological conditions of the area have been discussed by Cross and others (1907), Barrs and See (1968), Steven and others (1967), and Weimer (1980). The following discussion of the geology and stratigraphy of the Ouray area is taken from Luedke and Burbank (1962). For a complete description of the area the reader is referred to their papers.

The Ouray thermal area is located on the northwest side of the San Juan Mountains, north of the Silverton caldera. Paleozoic and Mesozoic sedimentary age rocks are underlain by Precambrian age rocks and overlain by Tertiary age volcanics (Fig.2). These rocks dip in a northerly direction and thicken from a few thousand to 10,000 feet. Northwest and northeast trending high angle faults associated with mountain building events in the San Juan Mountains are apparent throughout the immediate area.

Tectonics and Volcanism

There were four major periods of deformation closely associated with mountain building in the Ouray area. The intensity of the deformation decreased through geologic time, whereas volcanic activity increased. In Precambrian time the rocks were deformed by strong compression and tight folding. In late Paleozoic time a domal uplift of the mountain regions with resulting monoclinal folds and faults occurred, with little or no igneous activity. In late Mesozoic and early Cenozoic time during the Laramide Orogeny, deformation was indicated by a renewal of domal uplifting with additional monoclinal folding and faulting. Approximately 22-28 million years ago, during late Tertiary time, widespread volcanic activity, intrusive action and faulting had developed. Crustal disturbances are indicated by erosional unconformities and gaps in the stratigraphic sequence.

In the Ouray area the metamorphic rocks of the Precambrian Uncompahgre formation have been compressed into a west plunging syncline with a moderate-dipping south flank, and a steep, almost vertical to locally overturned north flank. The sedimentary strata in the area are sharply folded into two prominent northerly dipping monoclinal folds. The southern monocline occupies a two mile wide zone near Ouray and involves early to Middle Paleozoic age formations. These rocks were uplifted nearly 4000 feet as a result of late Paleozoic domal uplifts.

According to Weimer (1980) one of the best examples of Paleozoic age paleotectonics has been observed on the west flank of the San Juan dome in southwestern Colorado. The three major tectonic elements, the Uncompahgre Uplift, the Sneffels Horst and the Grenadier Horst are separated by major east-west faults which form the Ouray and Silverton Grabens respectively.

Faults observed in the area commonly are normal with steep to nearly vertical dips with northwest or northeast strike. The displacement along the faults range from a few feet to several hundred feet. South of Ouray, a group of faults, including the Ouray fault were largely the result of late Paleozoic deformation, and probably follow zones of weakness developed in the underlying Precambrian basement rocks. Many of the faults along the river valley north of Ouray probably are related to the arching of strata and intrusive activity of the Laramide deformation.

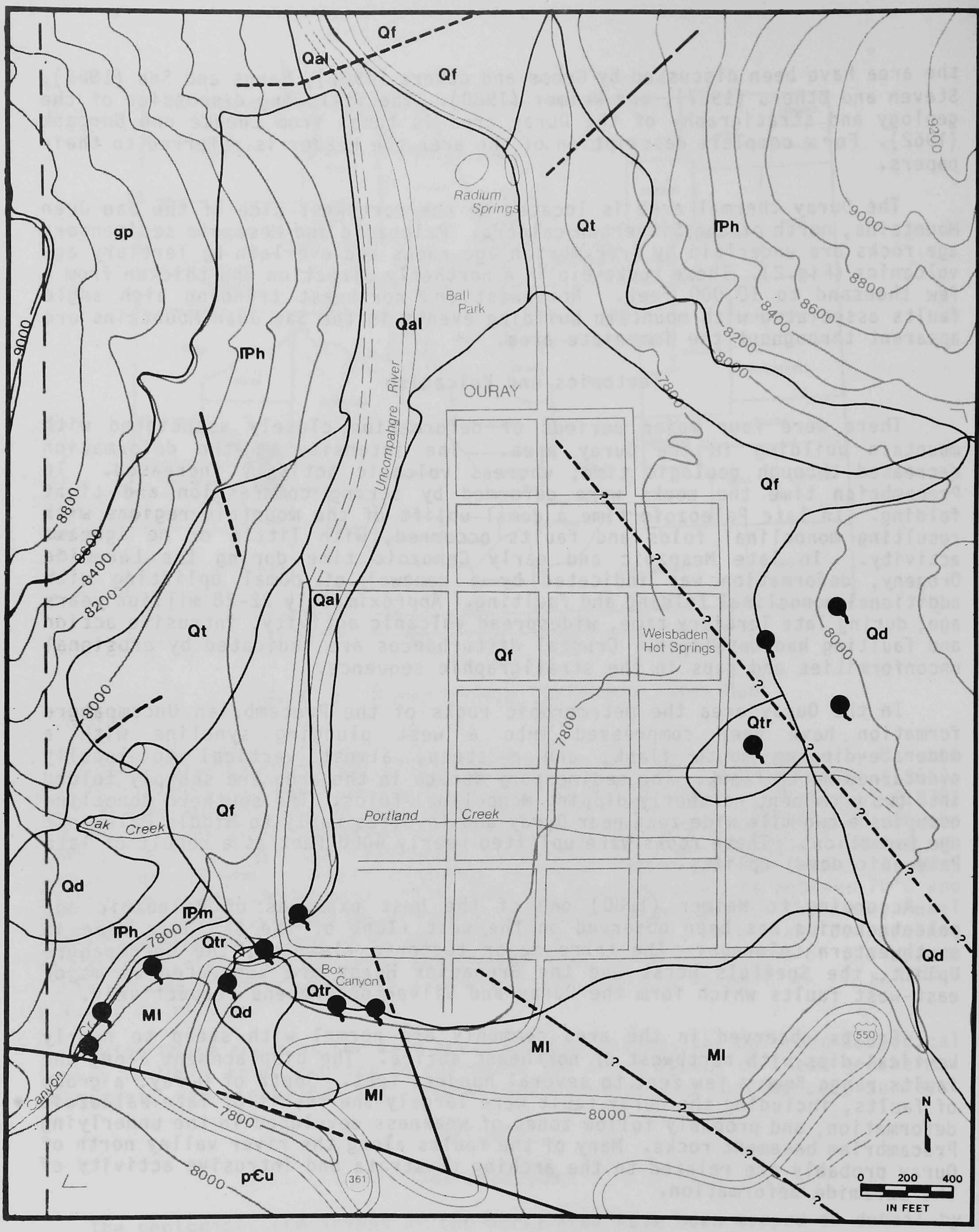


Figure 2. Ouray, Colorado Map of Geology and Thermal Springs.

EXPLANATION

Hot spring

Qal	Alluvium	Quaternary
Qf	Alluvial fan and cone deposits	
Qt	Talus	
Qtr	Travertine deposits	
Qd	Glacial drift	
gp	Granodiorite porphyry	Cretaceous
lPh	Hermosa Formation	Pennsylvanian
lPm	Molas Formation	
Ml	Leadville Limestone	Mississippian
p€u	Uncompahgre Formation	Precambrian

Contact

Fault; long dashes where approximate, short dashes where concealed, queried where probable, ball and bar on downthrown side

Joints are common throughout the area. In the San Juan Tuff formation, a set of NW trending fractures, in part mineralized, are part of the radial fracture system of the Silverton Caldera to the south and southeast.

In middle and late Tertiary time volcanic eruptions built a wide plateau of layered volcanic rocks aggregating nearly 1.5 miles in thickness in the western San Juans. The source of the volcanic materials is believed to have been a cluster of volcanoes somewhat aligned in a northwesterly direction from near Silverton to beyond Lake City. These eruptions alternated with and were accompanied by considerable volcanic-tectonic and intrusive activity. In the waning stages of these activities and afterward, but closely related to tne eruptive processes, occurred widespread and locally intense alteration of the country rocks with locally important base and precious metal mineralization.

In Pleistocene and perhaps Quaternary time volcanism was mainly restricted to local small scale basaltic eruption. During this time, erosion considerably reduced the size of the volcanic field from its original extent and carved the present rugged mountain topography of the San Juans.

Stratigraphy

The exposed stratigraphic section in the Ouray Valley presents a great variety of metasedimentary, sedimentary and layered volcanic rocks that range in age from Precambrian through Recent. Following is a brief description taken from Luedke and Burbank (1962) of the formations mapped in the Ouray area.

PRECAMBRIAN ROCKS

The Uncompahgre formation of Precambrian age, which outcrops south of Ouray is the upper unit of two formations comprising the Needle Mountain group. The formation which consists of alternating zones, each several hundred feet thick, of quartzite and slate has a thickness in excess of 3,000 ft. The quartzite with some thin partings of argillaceous material is massive to thin-bedded, strongly jointed and white to gray but locally red or black. A few beds are conglomeratic with the well-rounded quartz pebbles averaging a half inch in diameter. Crossbedding, graded bedded, and ripple marks are common. The lower contact of the quartzite zone with that of the slate zone is generally even and sharp, whereas the upper contact is gradational through several feet.

The slate zones are dark green, brown, and gray to black and consist of laminated thin to thick beds.

DEVONIAN SYSTEM

The Elbert formation unconformably overlying the Uncompahgre Formation is green, buff and gray thin-bedded calcareous shales, sandy limestone and impure sandstones. The dense sandy limestones have thin shale partings and in places are dolomitic. Casts of salt crystals are found occasionally within the shaly beds. The formation ranges in thickness from 30 to 50 feet and appears gradational with the overlying Ouray limestone.

The Ouray limestone consists predominantly of gray buff and white dense to fine-grained locally dolomitic limestone with some thin shaly partings. At a few places, the base of the Ouray limestone is marked by a sandy or conglomeratic limestone containing crinoid fragments. Where exposed the formation has a fairly uniform thickness of about 70 feet and appears to be gradational and conformable to the overlying Leadville limestone.

MISSISSIPPIAN SYSTEM

The Leadville limestone forms in most places massive cliffs with some small step-like benches caused by erosion of interbedded shaly layers. The formation ranges in thickness from 180 to 235 feet. Chert-bearing limestone, limestone breccia or calcareous sandstone are locally present at the base. Near the top of the section a few beds are composed almost entirely of fossil fragments. Some of the limestone beds near the top are siliceous and contain chert nodules and stringers. At Box Canyon the uppermost part of the Leadville formation consists of shale and ferriginous limestone. The upper contact forms an erosional unconformity with the overlying Molas formation.

PENNSYLVANIAN SYSTEM

The Molas formation is poorly exposed in most places because of its lithology and clayey cementing material. The formation is composed of thin to thick lenticular beds of reddish-brown and red shale, sandstone and conglomerate with minor amounts of green and gray shales. Throughout the area the Molas ranges in thickness from 40 to 60 feet. The difference is probably due to irregularities of the erosion surface at the base. The Molas formation is conformable and is apparently gradational with the overlying Hermosa Formation.

The Hermosa formation crops out as a series of greenish-gray and red ledges and cliffs and is composed of thin to massive beds totalling about 1,450 feet in thickness. The lower 450 feet of the Hermosa formation consists of vari-colored sandstone, siltstones and shales with interbedded limestones. The next 700 feet consists of massive reddish sandstone siltstone and shale beds. The upper 300 feet of the Hermosa formation is made up of thin to thick bedded sandstone and conglomerates with shales and limestones. The Hermosa formation is conformable and apparently gradational with the overlying Cutler formation. The contact between the two formations is placed arbitrarily about 130 feet above the uppermost fossiliferous zone and probably is not everywhere at the same horizon.

PERMIAN SYSTEM

The Cutler formation, which demonstrates varying resistance to erosion, typically forms benches and cliffs. The formation is thin to massive bedded with the beds commonly lenticular and exhibiting a marked vertical and lateral gradational change in lithology. Many of the beds are cross-stratified and show cut-and-fill deposition.

The Cutler formation ranges in thickness from zero to 2,000 feet. The lower 1,450 feet of the Cutler formation is composed of reddish and brown interbedded shale, siltstones and sandstones. The upper 550 feet consist of sandstones with several 40 foot thick conglomeratic beds and is overlain by an angular unconformity with the Dolores formation. The angular contact relationship is particularly evident on the north wall of the Amphitheater where the Dolores formation transgresses truncated beds of the Cutler formation to lie on beds of the Hermosa formation.

TRIASSIC SYSTEM

The Dolores formation generally crops out as steep rubble-covered slopes or cliffs and benches. The formation is reddish brown and even bedded in thin to massive beds, but in places exhibits irregular bedding, lenses, cut and fill structures and cross stratification. The lithology, variable both laterally and vertically, is mainly sandstones and siltstones. It ranges from 40 to 130 feet in thickness.

The contact with the overlying Entrada sandstone of Jurassic age is an erosional unconformity. Erosion preceding and following deposition of the Dolores accounts for the variance in thickness.

JURASSIC SYSTEM

The white to buff colored Entrada sandstone of Late Jurassic age crops out as a steep to rounded cliffs along the valley walls. The sandstone generally is thick to massive bedded and characterized by sweeping crossbeds.

The Entrada sandstone ranges in thickness from 45 to 80 feet. This difference in thickness primarily is due to the erosional unconformity at its base. The lower and upper contacts are sharp because of the contrasting lithologic changes between the Entrada and the underlying and overlying formations.

The Wanakah formation consists of three distinct lithologic units, a lower limestone and breccia (Pony Express) a middle sandstone (Bilk Creek) and an unnamed upper marl-mudstone. The Wanakah generally forms a cliff in the lower part and a gentle to steep slope in the upper part. The formation ranges in thickness from 85 to 125 feet.

The Wanakah formation conformably overlies the Entrada sandstone. The Pony Express basal member is composed of a lower limestone and shale portion, and an upper breccia portion. The lower part is from 0 to 20 feet thick, and the upper part up to a maximum of 70 feet thick. The middle member, the Bilk Creek sandstone, is greenish gray to a buff, salty fine grained calcareous sandstone. The sandstone ranges in thickness from 14 to 25 feet. The upper member of the Wanakah is a thin bedded reddish-brown calcareous sandstone, ranging in thickness from 40 to 75 feet.

The Morrison formation which conformably overlies the Wanakah formation is divided into two members, the lower Salt Wash sandstone, and the Upper Brushy Basin shale. The Salt Wash member consists of medium grained sandstone with interbedded mudstones. The cliff-forming sandstone is 20 to 30 feet thick. The thicker Brushy Basin shale consists of variegated mudstones with minor amounts of sandstones and limestones.

CRETACEOUS SYSTEM

North of Ouray, along the Uncompahgre River, the Dakota Sandstone forms prominent cliffs high on the valley walls of the river and its tributaries. It conformably overlies the Morrison formation, however, an erosional unconformity exists between the formations. The upper unit is similar to the middle unit and consists of massive sandstone. The formation ranges from 40 to 175 feet in thickness. The contact between the Dakota sandstone and the overlying Mancos shale is poorly exposed but is conformable and appears gradational except in the vicinity of Ouray where the Mancos seems to lie unconformably on the Dakota.

The Mancos shale consists dominantly of gray to black shale and platy mudstone with a few thin buff sandstone and gray limestone lenses in the lower part. The shale is locally sandy, concretionary, carbonaceous and calcareous. In places the shale has seams and cross cutting veinlets of coursely crystalline calcite. The thickness of the Mancos shale ranges from zero to more than 1,000 ft.

TERTIARY SYSTEM

Unlike the older sedimentary rocks, rocks of Tertiary age in the Ouray area are of volcanic origin. The dominant volcanic unit in the Ouray area is the San Juan tuff of Miocene(?) age. The San Juan Tuff which forms rounded slopes and cliffs is prominently exposed high on the valley walls east and west of the Uncompahgre River. Its thickness varies throughout the area because of the erosion surfaces above and particularly below but it attains a maximum thickness in the Ouray Valley of more than 3,000 ft. The formation is characteristically gray or greenish gray with shades of red, purple and blue locally. Although referred to as a tuff, the San Juan formation is predominantly a tuff breccia that contains intermixed sandy tuffs and tuff conglomerates in the lower part and flow breccias in the upper part. The unit consists of volcanic debris merging from microscopic size to blocks 10 foot across. The sources of the debris are not fully established, but a volcano or group volcanoes situated south of Ouray is the probable origin.

QUATERNARY SYSTEM

The Ouray area has extensive deposits of Pleistocene and Holocene ages that represent several types of material and several modes of origin. Most of the deposits consist of unsorted and unconsolidated fragmental material from the local drainage system and adjacent areas. The Pleistocene series is represented by landslide deposits outwash, glacial drift and lake beds. Deposits of Holocene age include talus at the base of many of the cliffs. Many of the valley bottoms, particularly the floodplain of the river, are covered with Holocene alluvium. The Quaternary system is basically broken down into 11 different units by Luedke and Burbank (1962), but for this study the most significant deposits are glacial drift, travertine and alluvium.

HYDROGEOLOGY OF OURAY THERMAL WATERS

As noted, there are a number of thermal springs in and adjacent to the community of Ouray (Fig. 2). Table 1 summarizes the properties of the thermal springs of the Ouray area.

TABLE 1. Thermal Springs in the Ouray Valley

Hot Spring	Discharge (gpm)	T.D.S. (mg/l)	Temp. (°C)	Spec. Cond. (Micromohs)
Pool Spring, located in Box Canyon,	60-200	1,650	69	
Uncompahgre Hot Spring, located downstream from Pool Spring	5	1,570	49	
Wiesbaden Motel Hot Springs, located in vapor caves in basement of Wiesbaden Motel				
Spring A	-	1,580	53	
Spring B	2 (est)	695	30	
Spring C	--	1,840	30-48	
*Box Canyon Motel Hot Springs, located behind the motel				
Spring 1	3		60	1600
Spring 2	8		60	1600
*Ficco Springs, located 500 ft south of the Wiesbaden Motel	8		24	300?
*Spring above and 300 ft NE of Wiesbaden Motel	3		24	310
*Well 1 mile west of Ridgway, CO	75		35	3700
*Spring at east edge of swimming pool	2		22	500?

*unpublished field data (1981)

The waters are a calcium sulfate type with high lithium (2,800 mg/l) and Boron (200 mg/l) content.

Source: Barrett and Pearl (1976)

Origin of the thermal waters

Due to lack of wells drilled into the thermal reservoir it is difficult to draw any accurate conclusions regarding the hydrogeological conditions of the Ouray thermal system. However, several tentative conclusions may be made based on the geological conditions of the area.

As shown on Fig. 2 the thermal waters emerge at the surface along faults. The bedrock formations associated with the springs are: the Precambrian Uncompahgre formation and Leadville limestone at the Pool Spring; Leadville limestone at the Uncompahgre spring; and the Leadville limestone overlain by glacial debris, at the Wiesbaden Motel Springs. It is not known if the thermal waters are directly associated with the Leadville limestone at depth. However, it is known that the Leadville limestone is a thermal water aquifer elsewhere in Colorado and therefore could be the principal aquifer for the Ouray thermal system.

Based on available evidence, several models may be developed to explain the origin of the thermal waters. The first model allows for deep circulation by normal ground-waters along faults in an areas of high heat flow. Zacharakis (1981) has shown that the heat flow in the Ouray area is 4 times normal. Recharge to the thermal system probably occurs in the high country to the south, east or west. The second model, like the first model, also allows for deep circulation of recharge of ground waters along faults. In addition this model allows for thermal waters to be moving up unmapped faults which are buried by alluvial deposits along the Uncompahgre River. The thermal waters from the buried faults then mixes with cold groundwaters in the alluvium to become part of the Uncompahgre River waters.

The third model is similar to the first two models in that it allows for recharge in the surrounding high country of normal ground-waters and deep circulation along fault zones. When the ascending thermal waters come into contact with the Leadville limestone, or other permeable subsurface formations, some of the waters flow downdip into the Leadville limestone and off to the northeast under the town of Ouray.

The fourth model differs from the other three in that it allows for recharge to occur to the thermal system along faults or other permeable zones in an area to the northeast. As the waters migrate downward they come into contact with the permeable Leadville limestone, then they flow updip toward the southwest until they reach the faults in the Ouray valley, where they emerge at the surface. During the course of their migration the waters become heated by elevated ground temperatues. Unlike the first three models, circulation of thermal waters up faults is not required in the fourth model.

One factor that the present investigation was not able to substantiate is whether or not the faults are interconnected at depth. In addition, another factor that the present investigation was not able to prove was whether or not there are any thermal waters under Ouray. From the above models it is quite possible that there are.

None of the models allow for heating of the thermal waters by a buried mass of molten igneous rocks. From available evidence regarding the geologic history of this area as compiled by previous workers there is no reason to believe that any molten rock mass exists under the San Juan Mountains. Steven and Lipman, (1976) have dated the eruptions which produced most of the volcanic rocks of the San Juan Mountains as occurring 22-25 million years ago. Theoretically the magma chamber from which the volcanic rocks of the San Juan Mountains originated should have cooled and solidified long ago. Therefore, the most logical explanation for the origin of the thermal waters calls for heating to occur by elevated geothermal gradients.

SOIL MERCURY INVESTIGATIONS

Strategy and Methodology

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 et al (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 in 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 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 relative 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 4 case studies where they used soil mercury concentrations as a 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 the six areas sampled, Glenwood Springs. Their survey indicated anomalous zones but they noted that their data would require more analysis.

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

OBJECTIVES

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 alloted 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 results of Capuano and Bamford (1978). During 1980 a slightly broader target was considered, rather than just sampling along traverses located over suspected faults, grid sampling patterns were used where possible. 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 several restrictions became apparent. One of these was soil disturbance caused by urban development. One cannot really be sure whether the surface deposits in the back streets and lawns are original or have been brought in. Another problem occurred frequently 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.

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. When using a 400 ft 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 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 rationales have been used for determining the sampling depth. The method recommended by Cupuano and Bamford (1978) is to determine the profile of mercury down to a depth of approximately 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 15 cm, with an interval of about 1 cm, was used for most of the profiles. During 1980, each sample was taken over an interval of 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 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 over night. 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 7 days later, the samples were analyzed for mercury using the Model 301 Jerome gold film mercury detector.

Background vs Anomaly

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

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.

Ouray Area Soil Mercury Surveys

As part of the resource evalution of the Ouray area three areas were sampled for contained soil mercury (Fig. 3). The first area was above and southeast of the Wiesbaden Motel, on a glacial drift type soil. This area did not yield any anomalous mercury readings above background reading of 54 parts per billion (ppb). A fault mapped in the area by Luedke and Burbank (1962) was not detected by the soil mercury survey.

The second area sampled was on the hillside south of the Box Canyon Motel and north of the Box Canyon (Fig. 3). This area did yield one cluster of anomalous values. These values may indicate the trend of an unmapped fault, but more likely they are related to mineralization from the Red Mountain area. (Mineralization can cause mercury levels in excess of 500 ppb). The third area sampled was on the north edge of the town just south of the Radium Spring swimming pool on alluvial soil (Fig. 3). Anomalous values were obtained, but the significance of these values is questioned because of warm water discharging from a buried pipe in the ball park.

Soil Description

In the Box Canyon Motel area sampling was done on the hillside below and above the million dollar highway (Fig. 3). The soil has developed on colluvium or glacial drift. Its apparent that some of the colluvium was generated during highway construction. The soil sampled on the lower part of hillside is brown and generally rocky or gravelly to sandy. On the upper part of the hillside, the soil and/or surficial deposit thins to about 6 inches, and is generally rocky with limestone float up to boulder size. At the sampling depth the material is generally fine sand, brown and noncompacted.

Along the hillside above the Wiesbaden Motel, the parent material is glacial drift which is is generally poorly sorted with clay, silts and gravels, brown and uncompacted.

The sampled material just south of Radium Springs Swimming Pool along the highway was derived from alluvium. It is questionable as to how much soil is present since the area has been leveled for a baseball field. At the sampling level (5"-7"), the material is poorly sorted, contains fines to boulder size, and is well compacted.

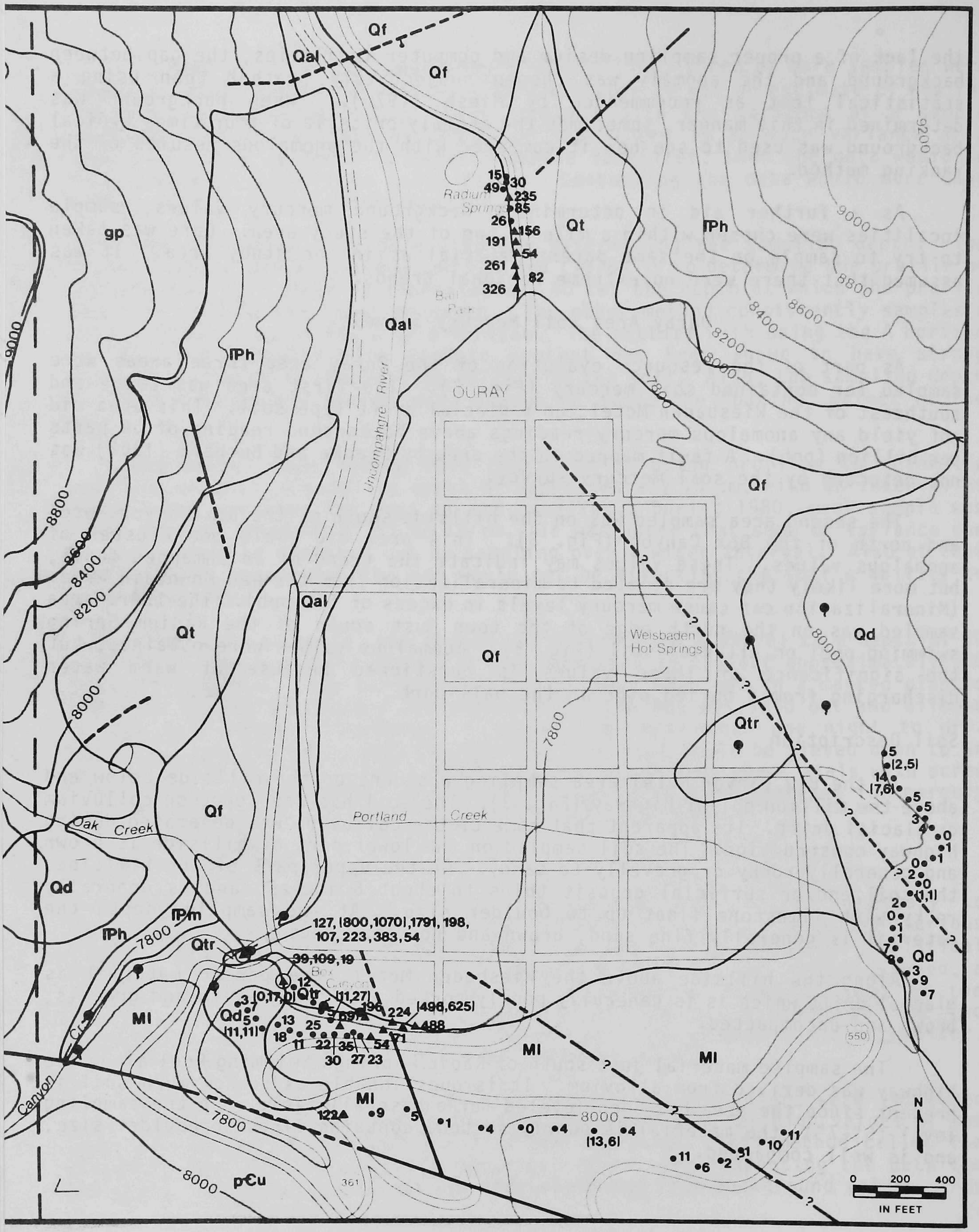


Figure 3. Ouray, Colorado geochemical-soil mercury survey.

EXPLANATION

⚲	Hot spring
●	Sampling locality
▲	Anomalous sample value at a locality
(▲)	At least one anomalous sample value at a locality with two or more samples collected approximately 20 ft apart
7,8,345, (3,9)	Each value indicates the analysis of a single sample in ppb of mercury. Values in parentheses indicate more than one analyses of a single sample.

Qal	Alluvium	Quaternary
Qf	Alluvial fan and cone deposits	
Qt	Talus	
Qtr	Travertine deposits	
Qd	Glacial drift	
gp	Granodiorite porphyry	Cretaceous
1Ph	Hermosa Formation	Pennsylvanian
1Pm	Molas Formation	
Ml	Leadville Limestone	Mississippian
p€u	Uncompahgre Formation	Precambrian
———	Contact	
—⊥— ? — — - - - -	Fault; long dashes where approximate, short dashes where concealed, queried where probable, ball and bar on downthrown side	

Mercury Anomalies

Deriving a basis for anomalous values in this area was difficult because the spatial distribution of the sampling was not uniform and the parent material, from which soil was developed, was so diverse--alluvium, glacial drift, and limestone. Thus, for this particular area, the break between background and anomalous mercury values was based on the size of gap between ranked values for each similar lithologic sampled area (Table 2) within Ouray.

For the area south of Ouray, above the Box Canyon Motel on the Leadville limestone, 50 ppb was chosen as the cut off value for background. For the data southeast of Ouray, above the Wiesbaden Motel, there did not appear to be any sufficient break in the values large enough to constitute an anomalous group. The break of the ranked data near the swimming pool appeared to be between 54 ppb and 85 ppb.

The high mercury values (Fig. 3) in the proximity of the Box Canyon Motel were expected as there were thermal springs along the hillside with associated travertine deposits. The one isolated anomalous locality situated at the west end of the upper hillside traverse above the Box Canyon Motel may indicate the trend of an unmapped fault; but it is more likely related to mineralization. Veins or mineralized faults are commonly exposed in the Leadville limestone. Judging from the mercury content of samples taken above the heavily mineralized area 3/4 miles south of Ouray) the mineralization is high in mercury, ranging at least to 500 ppb.

Anomalous values of mercury were also found in the alluvium sampled along the highway south of the Radium Hot Springs pool. The significance of these high values are also questionable. There appear to be two possible sources for the anomalous values other than migration of mercury from a subsurface reservoir. The mercury may be associated with the warm water discharging from a buried pipe. An unsuccessful effort was made to determine the origin of this pipe. It was also found that Red Mountain Creek, which drains into the Uncompahgre River above Ouray, also contains a very high mercury levels(17 ppb). This is roughly 100 to 1,000 times above the normal levels found in rivers. Mercury may be anomalous along the river in the vicinity of Ouray, as one of three samples taken in alluvium about a mile north of the swimming pool also contained anomalous amounts of mercury.

Conclusion

The anomalous results from the Soil Mercury Survey are questionable regarding their relationship with the subsurface geothermal activity. The anomalies above the Box Canyon Motel probably are due to the hot spring activity and mineralization within the host rock, the Leadville limestone. The anomalous locality in the Radium Hot Springs pool is probably related to warm water leaking from a buried pipe or from the Uncompahgre River.

Table 2. Mercury Content * (ppb) from figure 3
Arranged in Ascending Rank Order
for the Three Sample Areas

South of Ouray above Box Canyon Motel			East of Ouray above the Wiesbaden		Near Radium Swimming Pool
0**	11	488	0	3	15
0	11	496	0	4	26
1	12		0	5	30
1	13		1	5	49
1	13		1	5	54
2	18		1	7	85
3	22		1	7	156
4	23		1	7	182
4	25		2	9	191
4	27		2	14	235
5	30		2		261
5	35		3		326
5	39		3		
6	54				
7	69				
9	71				
10	71				
11	122				
11	196				
11	234				

* Represents the first value recorded at sample locality

** Zero should be interpreted as less than 1 ppb

ELECTRICAL GEOPHYSICAL RESISTIVITY SURVEYS

The electrical resistivity method was used because geothermal reservoir areas normally indicate low resistive zones. Low resistivity is normally due to water saturation, higher than normal temperatures, and high clay matrix zones caused by faults. Therefore, the mission was to determine the location of low resistive zones in the Ouray area. For a complete description of the factors which might affect electrical resistivity measurements, the reader is referred to Appendix A.

Using a Syntrex RAC-8 Electrical Resistivity system, a total of 8 resistivity survey lines were run, totalling 11,650 feet in the Box Canyon, Wiesbaden Motel and Swimming Pool areas (Fig. 4). A complete description of this system is presented in Appendix B. In the Box Canyon Motel area, 5 dipole-dipole lines were run. Relative resistive low zones were delineated in the vicinity of the hot springs (Fig. 4) where travertine deposits were also observed. Two faults were also shown on the dipole sections (Figs. 5, 6, 7, 8, 11) possessing low resistivity that corresponded with two mapped faults. These

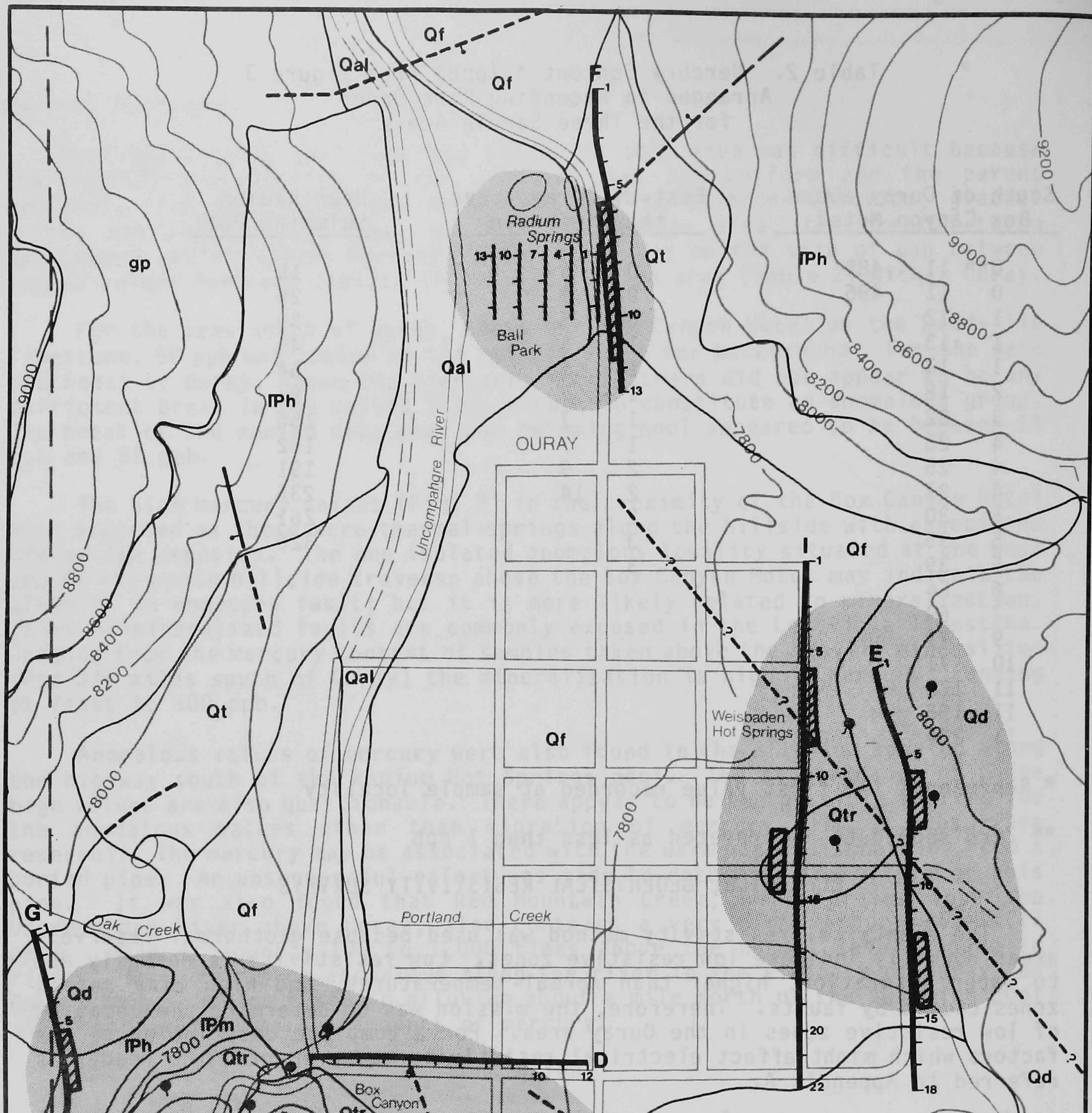
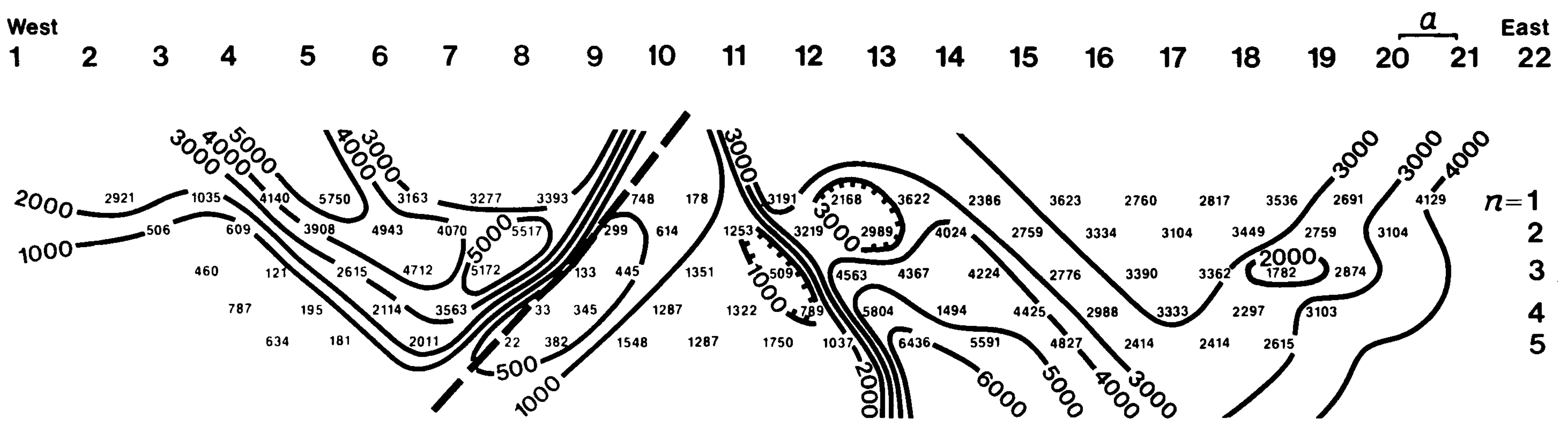


Figure 4. Ouray, Colorado geophysical resistivity survey.

EXPLANATION

●	Hot spring
┴	Dipole-dipole resistivity line and station marker and identifying letter
┠┠┠	Two dimensional Schlumberger Gradient
▨	Relative resistive low
░	Estimated areal extent of low resistivity

Qal	Alluvium	Quaternary
Qf	Alluvial fan and cone deposits	
Qt	Talus	
Qtr	Travertine deposits	
Qd	Glacial drift	
gp	Granodiorite porphyry	Cretaceous
ℙh	Hermosa Formation	Pennsylvanian
ℙm	Molas Formation	
Ml	Leadville Limestone	Mississippian
pꞒu	Uncompahgre Formation	Precambrian
—	Contact	
┴ ? — — - - -	Fault; long dashes where approximate, short dashes where concealed, queried where probable, ball and bar on downthrown side	



Dipole-Dipole Line A, located above Box Canyon Motel, is 2200 feet long (Fig. 4) and indicated extremely high resistive values. These high resistive values are probably due to the outcropping Leadville limestone which forms a ridge above the Box Canyon Hot Spring. There is a dramatic drop by a factor of ten in resistivity values between stations 7 through 11 at depths of 100' to 300'. This is probably attributed to the hot springs immediately to the north of this segment of the line. In addition, travertine deposits are also observed to the north along this low resistivity zone, which probably indicates a fault downthrown to the west, between Stations 9 and 10. This fault does not coincide with the mapped fault that intersects the line at Station 15. Table 3 (Appendix D) tabulates the resistivity calculations for line A.

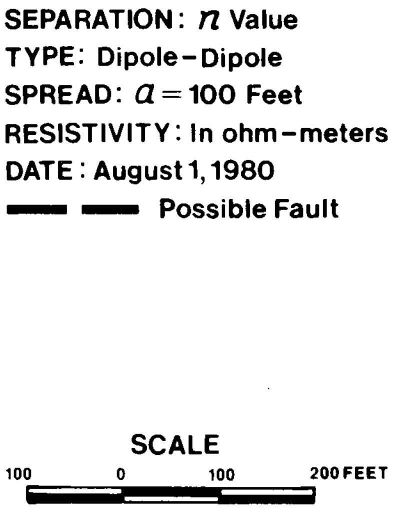
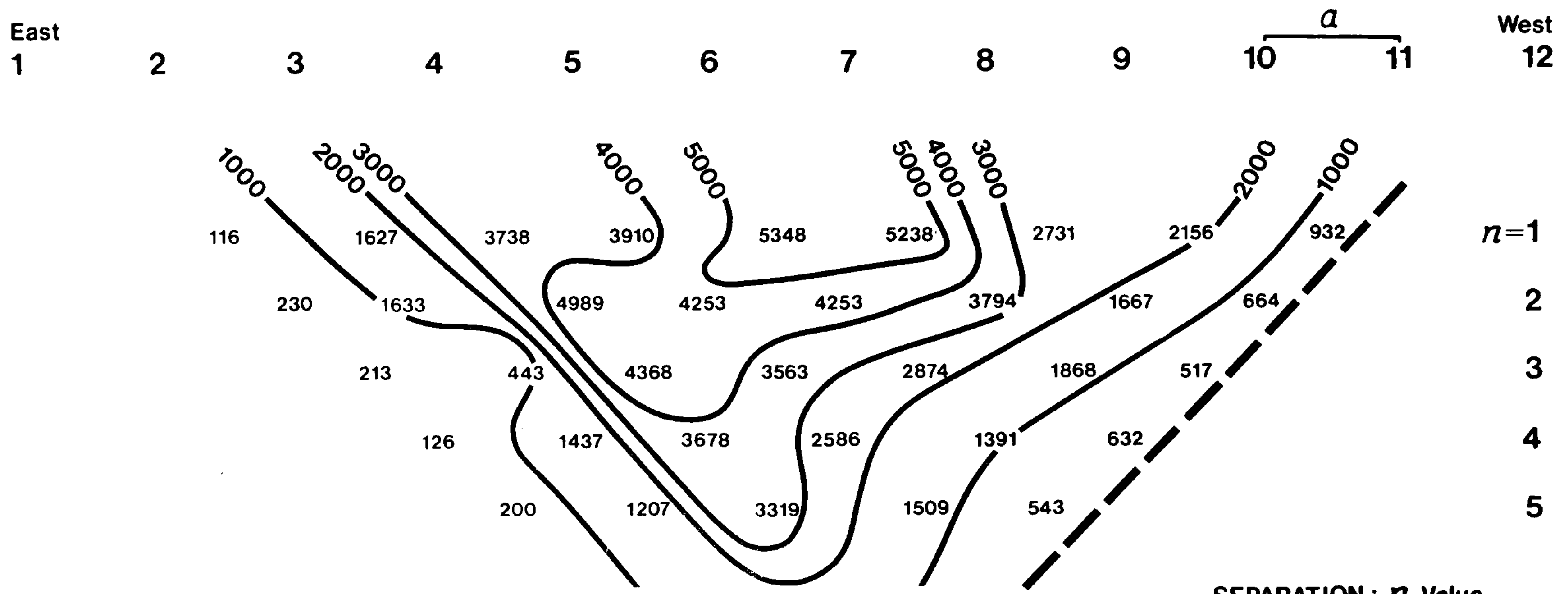
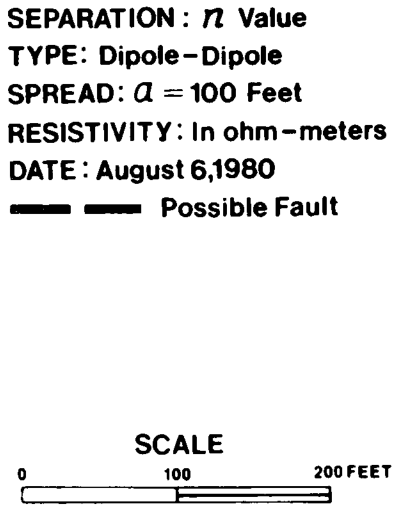


Figure 5. Line A.





Dipole-Dipole Line B, located above Box Canyon Motel in the Switchback area, is 1100 feet long (Fig. 4). The resistivity values were high along the surface with relatively low resistivity zones on each end of the line which persists for the entire depth of the dipole section. The lower resistive zones between Stations 1 through 4 appears to be attributed to the Box Canyon Hot Springs. The low resistive zone between Stations 10 through 12 may represent a fault downthrown to the east. Travertine deposits were found along these low resistive zones. Table 4 (Appendix D) tabulates the resistivity calculations for line B.

Figure 6. Line B.

Dipole-Dipole line C, directly behind the Box Canyon Motel, is a very short line with many cultural obstacles; however, this line did indicate relatively sharp resistivity differences (Fig. 4). A low resistivity zone that persists in the dipole section is evident between Station 3 and 4 and also between Station 5 and 7. Due to the urbanization, it was difficult to obtain reliable data, but the readings we did obtain were very low, especially in the area adjacent to the Box Canyon Motel Hot Springs. Table 5 (Appendix D) tabulates the resistivity calculations for line C.

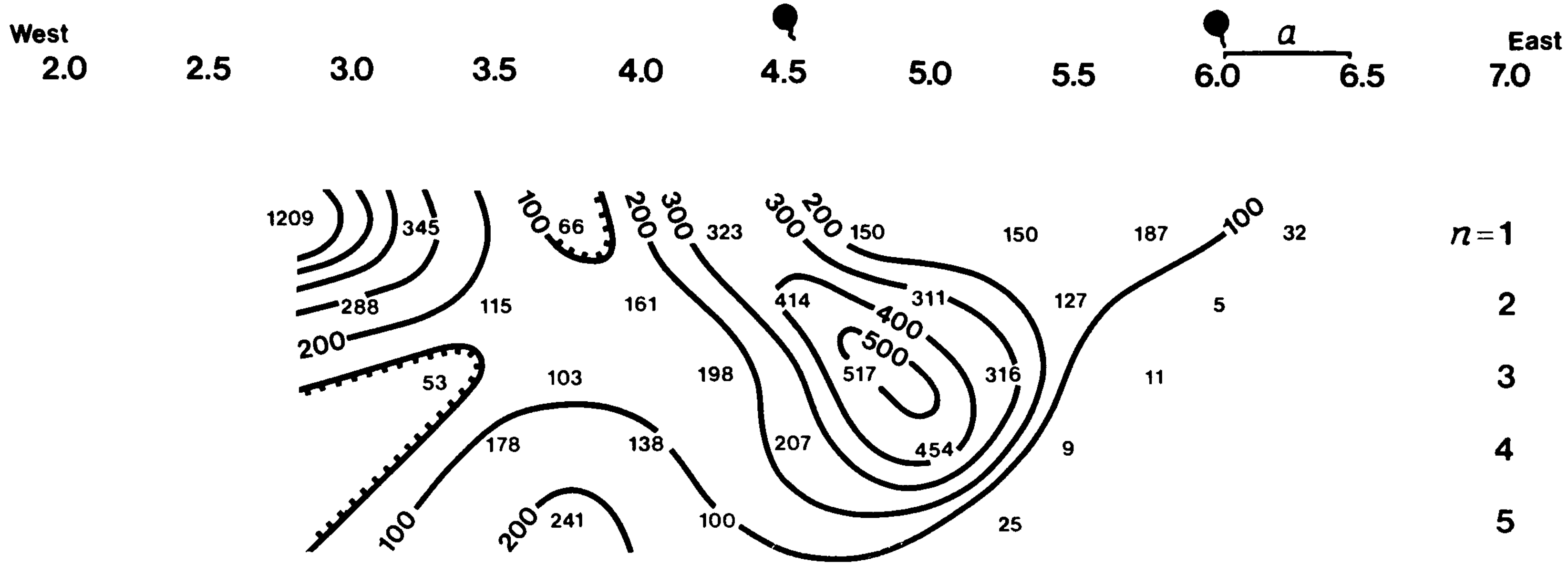
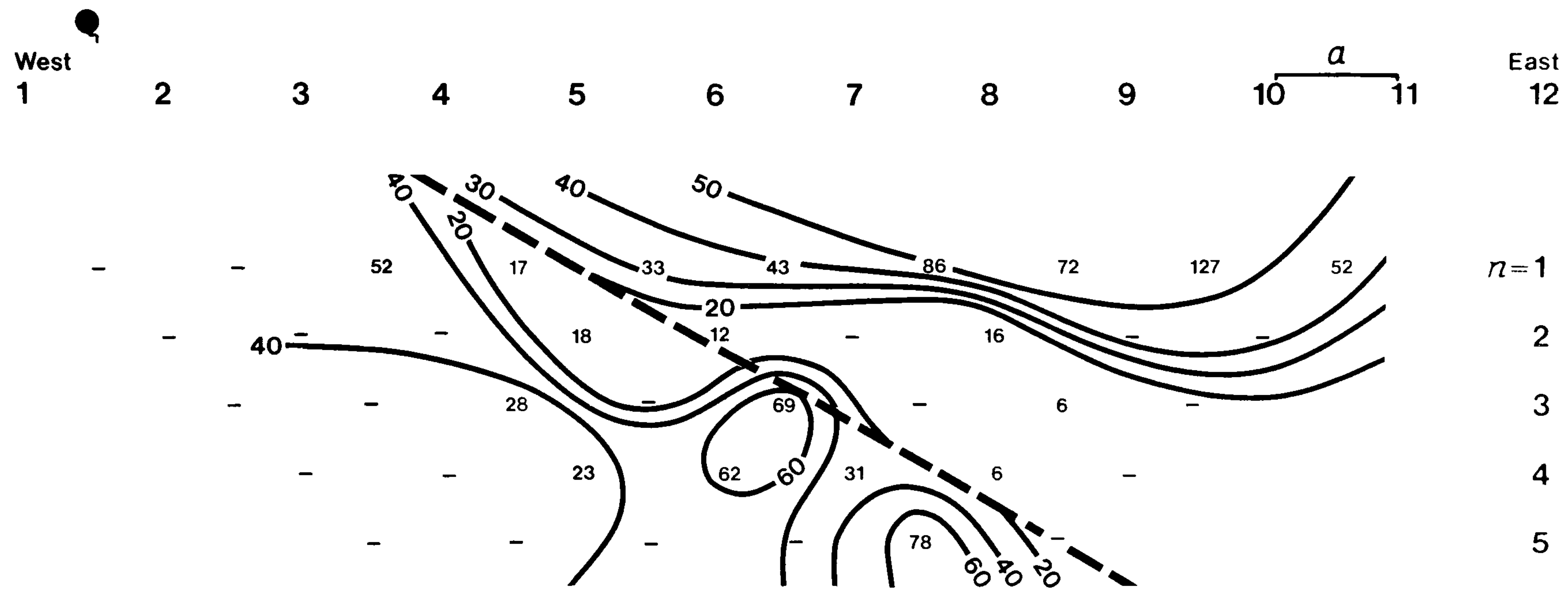


Figure 7. Line C.



Dipole-Dipole line D, on the road in front of the Box Canyon Motel (Fig. 4), is a short spread resistivity line where reliable data was obtained with great difficulty. It is believed that power lines, buried phone lines, and water mains contributed to the difficulty, however, relative resistivity differences were discerned with extremely low values to the east, in which a low angle fault downthrown to the east is illustrated on the Dipole-Dipole pseudosection. In some areas, the receiver was not able to lock on and measure any potential difference. The reason for this may be due to either of two reasons, one, urban development, or two, the resistivity is so low that the RAC-8 equipment could not resolve the data. Table 6 (Appendix D) tablulates the resistivity calculations for line D.

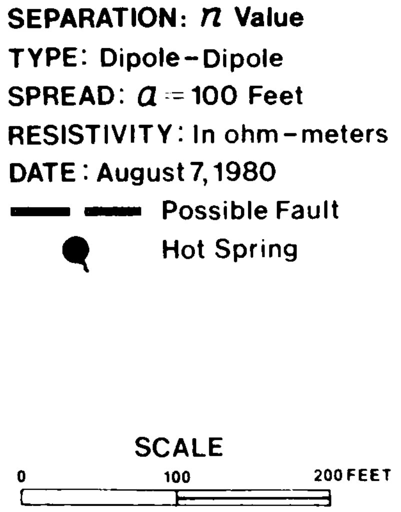
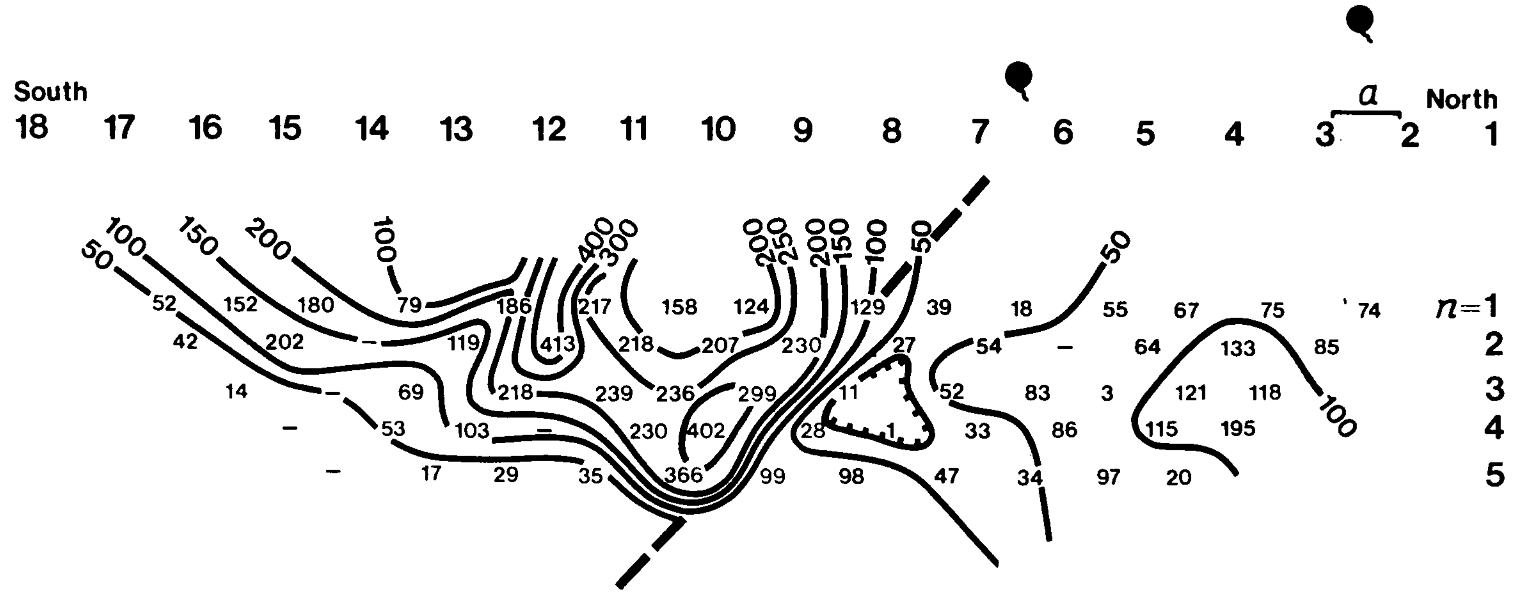


Figure 8. Line D.

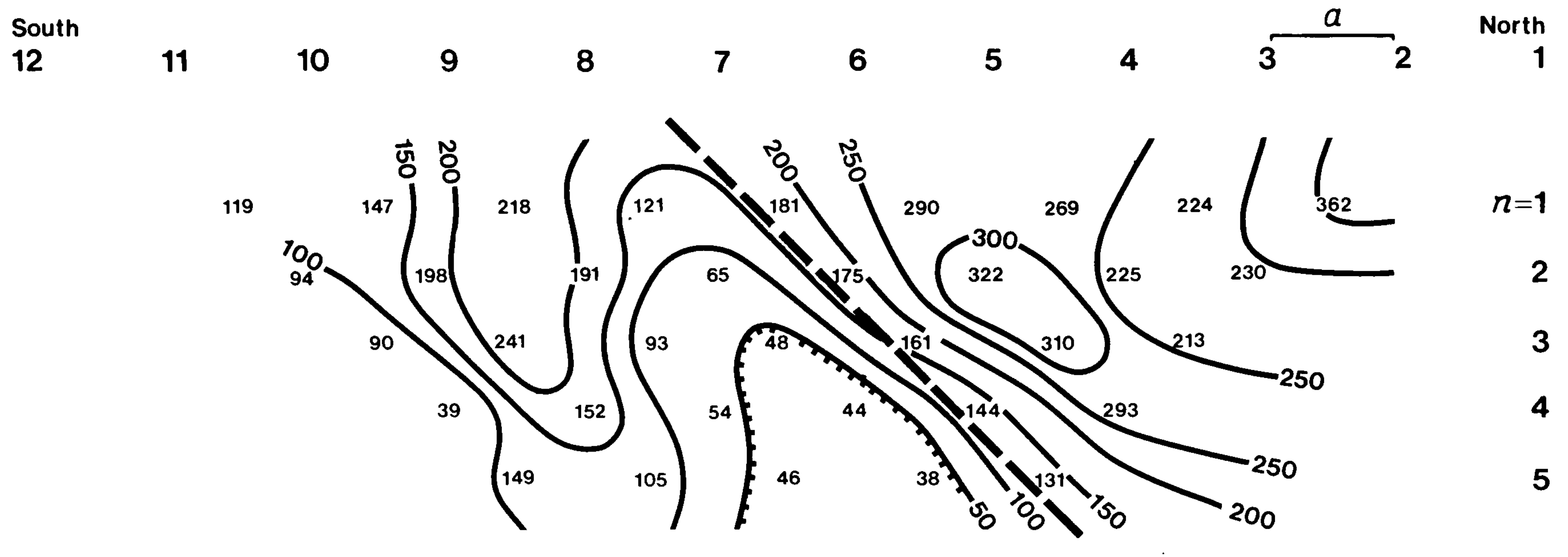


Dipole-Dipole line E is 1800 feet in length and trends north-south along a trail on a ledge above the Wiesbaden Motel (Fig. 4). Two relative resistive low areas are indicated on this section. The one to the south is by a travertine mound. The second low resistive area is observed between Station 10 to Station 7. A fault is also drawn on the Dipole-Dipole Pseudo section downthrown to the south and this fault corresponds to a questionable fault that is drawn on the geologic map of the Ouray Quadrangle. Two warm springs are found adjacent to this line. Table 7 (Appendix D) tabulates the resistivity calculations for line E.

SEPARATION: n **Value**
TYPE: Dipole-Dipole
SPREAD: $a = 100$ **Feet**
RESISTIVITY: In ohm-meters
DATE: August 8,1980
▬ ▬ Possible Fault
● Hot Spring

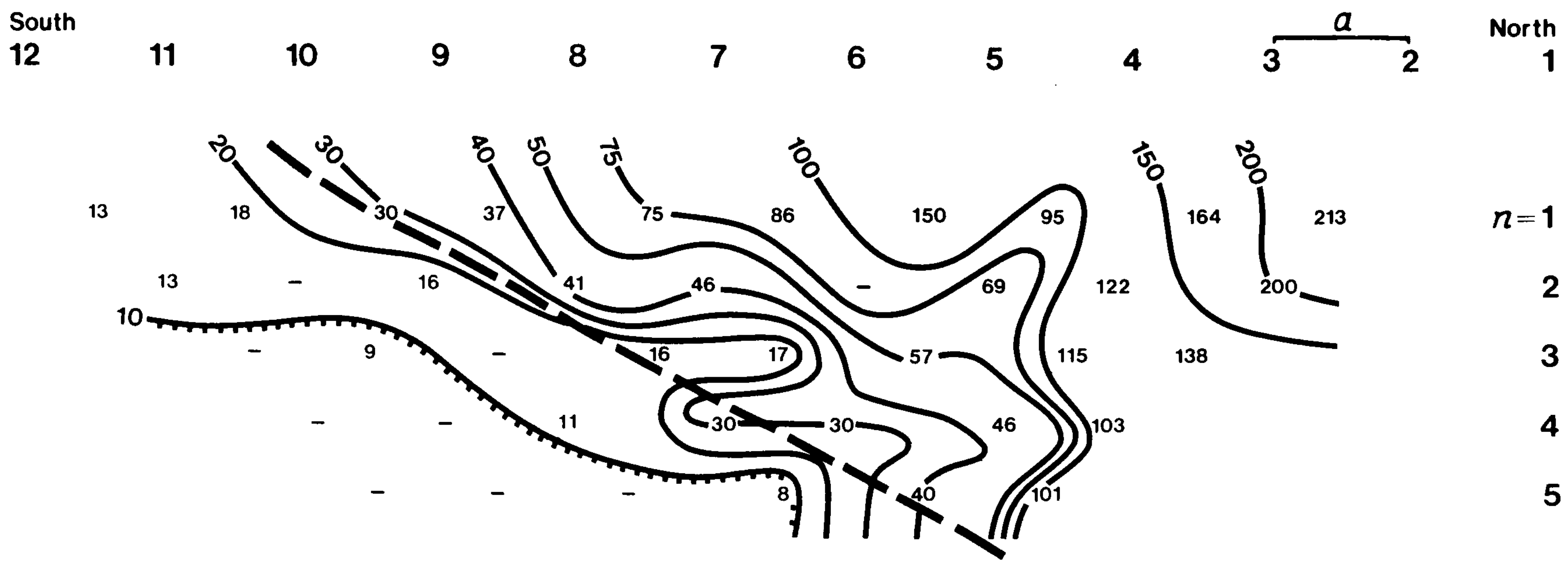
SCALE
100 0 100 200 FEET

Figure 9. Line E.



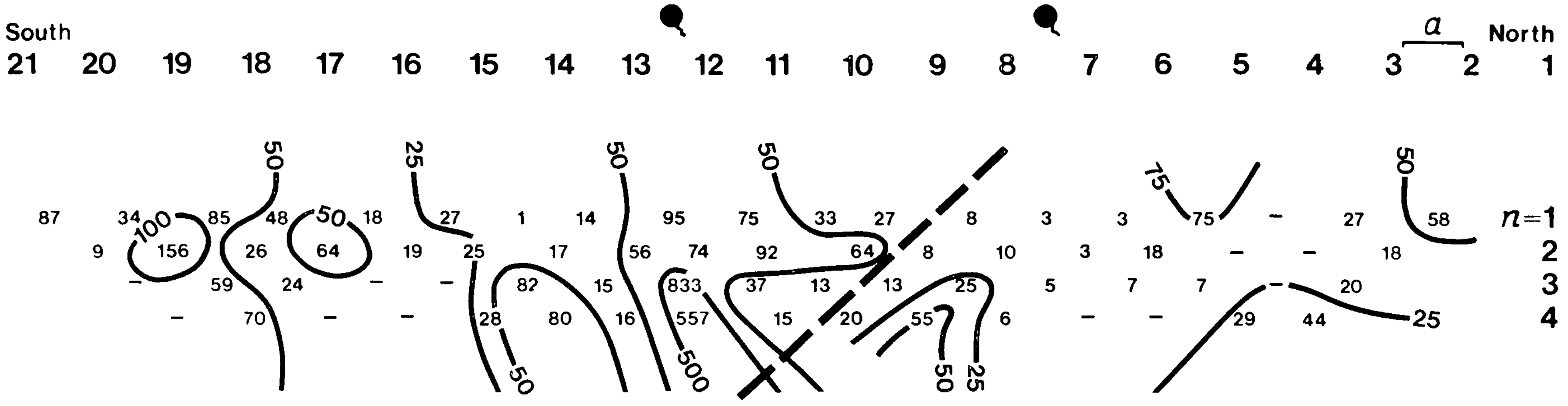
Dipole-Dipole Line F, located on the east side of the highway adjacent to the Radium Pool and Park (Fig. 4), is a 1200 ft resistivity line that shows extremely low values at the south end of the line. Due to cultural obstacles, we were not able to procure values at several locations. A high resistive cap appears on the pseudo section between Station 2 and 3. A possible low angle fault is drawn and downthrown to the north by Stations 4 and 5. Table 8 (Appendix D) tabulates the resistivity calculations for line F.

Figure 10. Line F.



Dipole-Dipole Line G, located west of the Box Canyon Motel area (Fig. 4), is a 1200 foot resistivity line that shows a deep seated low resistive zone between Stations 6 and 7. A fault which separates a high and low resistive zone is indicated between Stations 7 and 8 and is downthrown in a northerly direction. Table 9 (Appendix D) tabulates the resistivity calculations for line G.

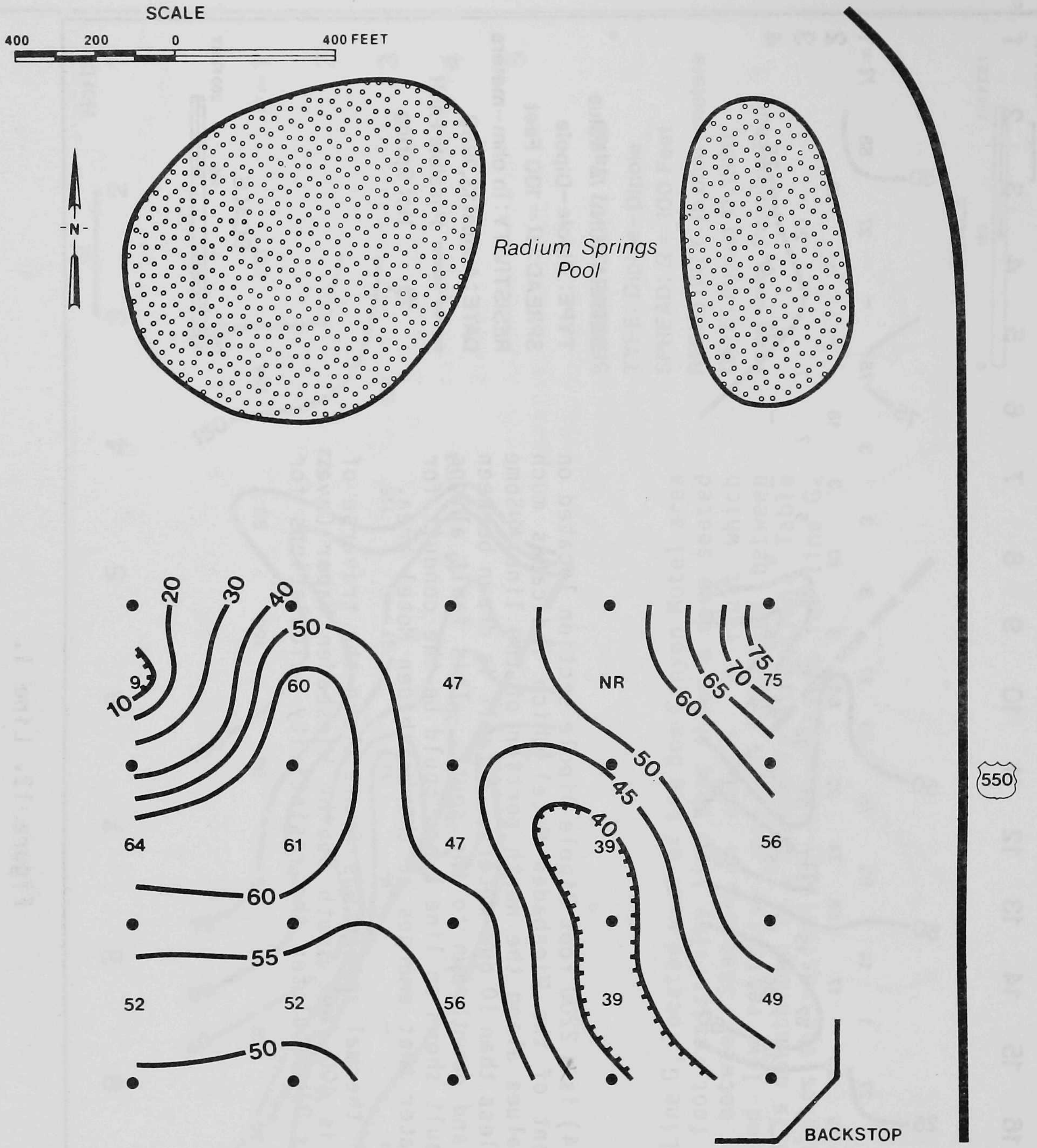
Figure 11. Line G.



Line I (Fig. 4) is a 2200 foot Dipole Dipole section located on the street in front of the Wiesbaden Motel which indicates much lower resistive values along the north portion of the line. Some of the values are less than 10 ohm-meters. A fault is drawn between Stations 8 and 9 and downthrown to the south. This fault aligns itself with the fault shown on line E and could be the conduit for the warm spring water that emerges at the Weisbaden Motel area.

An additional thermal spring was found along the traverse of this line, which is 400 feet south of the Wiesbaden Vapor Cave. Table 10 (Appendix D) tabulates the resistivity calculations for line I.

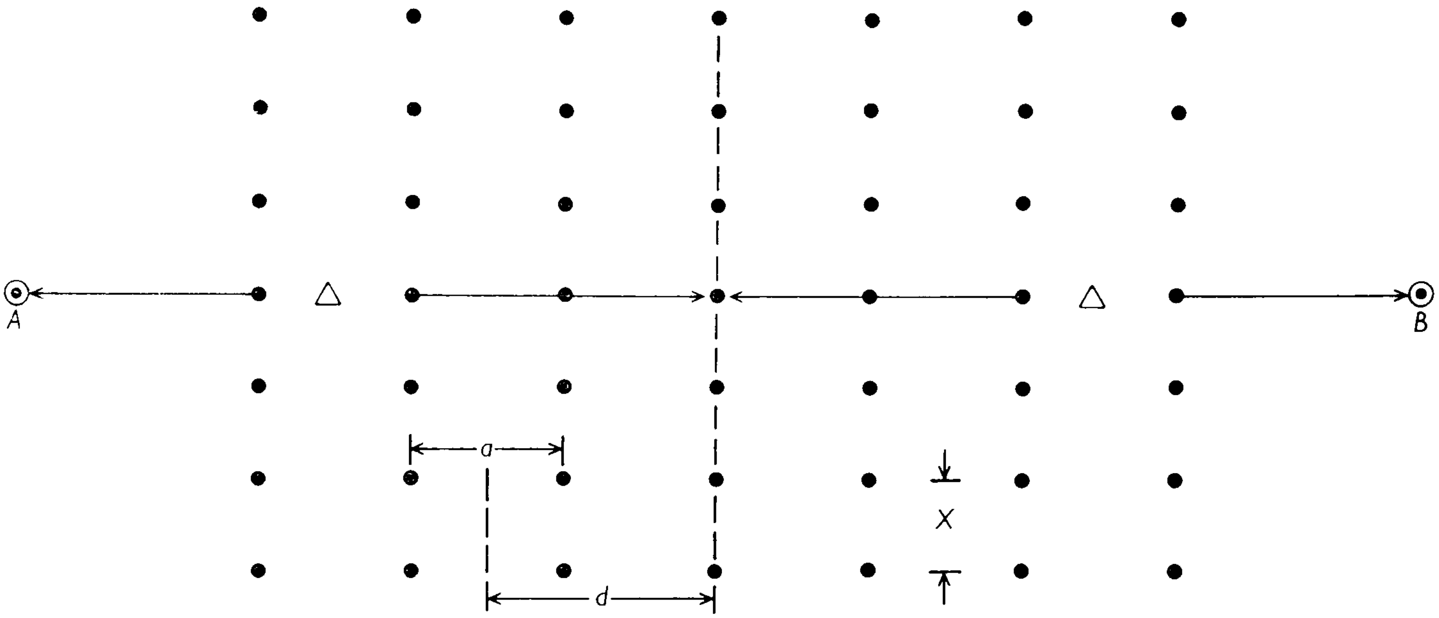
Figure 12. Line I.



A gradient array was conducted in the ball park adjacent to the public swimming pool north of the city (Fig. 4).

This gradient array did indicate two low resistive zones, one to the northwest near the power station where a value of 9 ohm-meters was obtained. Figure 14 illustrates a typical gradient array. The other area, where relatively low values were obtained, was in the vicinity of the backstop in the ball park. Table 11 (Appendix D) tabulates the resistivity values for the gradient array. The geometric factor tables in Appendix E were used to calculate the resistivity values in the Appendix D calculation tables.

Figure 13. Gradient array, baseball field.



$$\rho_a = \frac{\Delta^2}{a} K_{AB} \frac{V_p}{I_p} \qquad \begin{matrix} a = 100 \\ X = 100 \end{matrix}$$

Figure 14. Plan view of the gradient array, or AB rectangle array. The rectangular area between distant, fixed current electrodes is traversed by a pair of potential measuring electrodes. Although the array factor K_{AB} is near unity, it is a variable.

(From Principles of Induced Polarization, J. S. Sumner, 1976).

faults probably serve as a conduit for the warm water that emerges through the Leadville limestone. In the Wiesbaden Motel area two dipole-dipole resistivity lines were run (Fig. 4), one by the motel and the other on a ridge above and parallel to the line by the motel. Both lines showed a very low resistive zone, less than 10 ohm-meters, and in alignment with the travertine deposits by the motel and coinciding with a mapped fault that intersects the motel area, but does not manifest itself on the surface due to alluvium and glacial detrital deposits (Figs. 9, 12). See Appendix C for a description of field procedures pertaining to the various arrays employed.

Resistivity Computer Model Study

The University of Utah Research Institute (UURI) examined three dipole-dipole resistivity lines utilizing computer modeling techniques (Sill, 1981). It was determined that because the Ouray region has large, three-dimensional variations in lithology, and due to the scale and depth of penetration of the resistivity system used, they were limited to a two-dimensional model study (Sill, 1981). Following is a summary of the results of the computer model study.

Line A (Fig. 15) reflected a strong vertical contact at Station 16, between 500 to 4,000 ohm-meters. The study also showed a thin vertical conductive region centered at Station 10. This feature could be a fault zone, with extensive fractures causing the high conductivity. According to Sill (1981), a nominal resistivity of hundreds of ohm-meters does not necessarily reflect thermal water circulation.

Line E (Fig. 16) also demonstrates a sharp vertical contact under Stations 14 and 15 and a low resistivity zone at Station 6 and 7. This low resistive zone is also in the vicinity of a hot springs with altered travertine deposits observed on the surface. According to Sill (1981), three dimensional features affect the interpretation of the two dimensional model.

Line I (Fig. 17)

This line situated west of line E shows the lateral variations (three dimensional) that can take place in a short 500 ft distance. Several low resistive zones are indicated at Stations 5 to 7, and 14 and 16. The resistivity changes on this line are not as sharp as line E, even though warm springs emerge adjacent to the line of profile.

With the resistivity system used and the data modeled from adjacent lines, it becomes obvious that large three-dimensional variations exists. It therefore was necessary to limit the analysis to a two-dimensional computer modeling scheme (Sill, 1981).

In summary, the Dipole-Dipole pseudosections with apparent resistivity values prepared by the Colorado Geological Survey bears a very close resemblance and correlate quite well with the computer model pseudosections generated by Sill (1981). In the interpretation of any dipole-diple pseudosection, one must be cognizant of the fact that values obtained along the line of the traverse may be influenced by lateral variations of three dimensional features. This is definitely the case in the Ouray area.

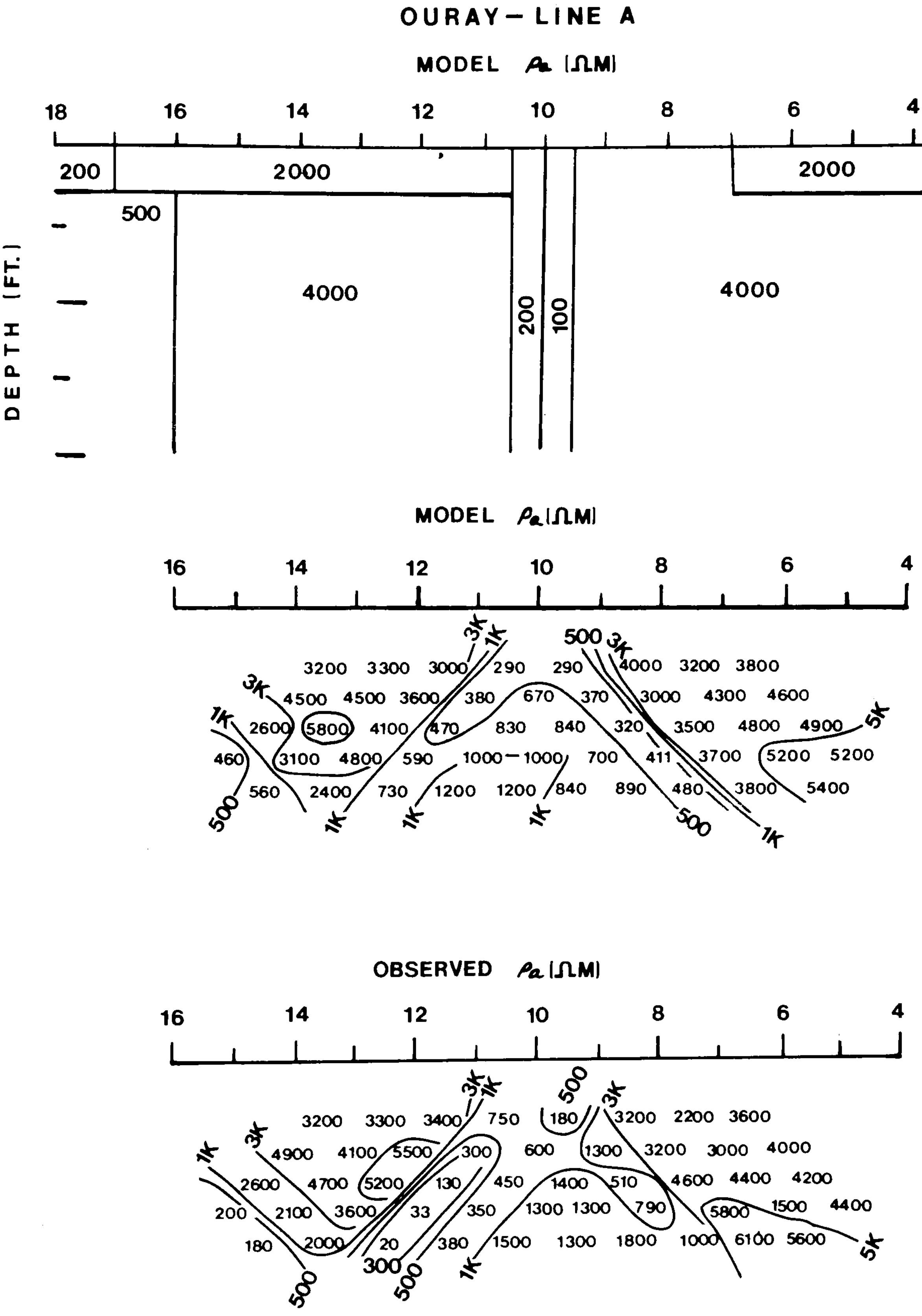


Figure 15. Ouray - Line A - Modeled (from W. Sill, 1981).

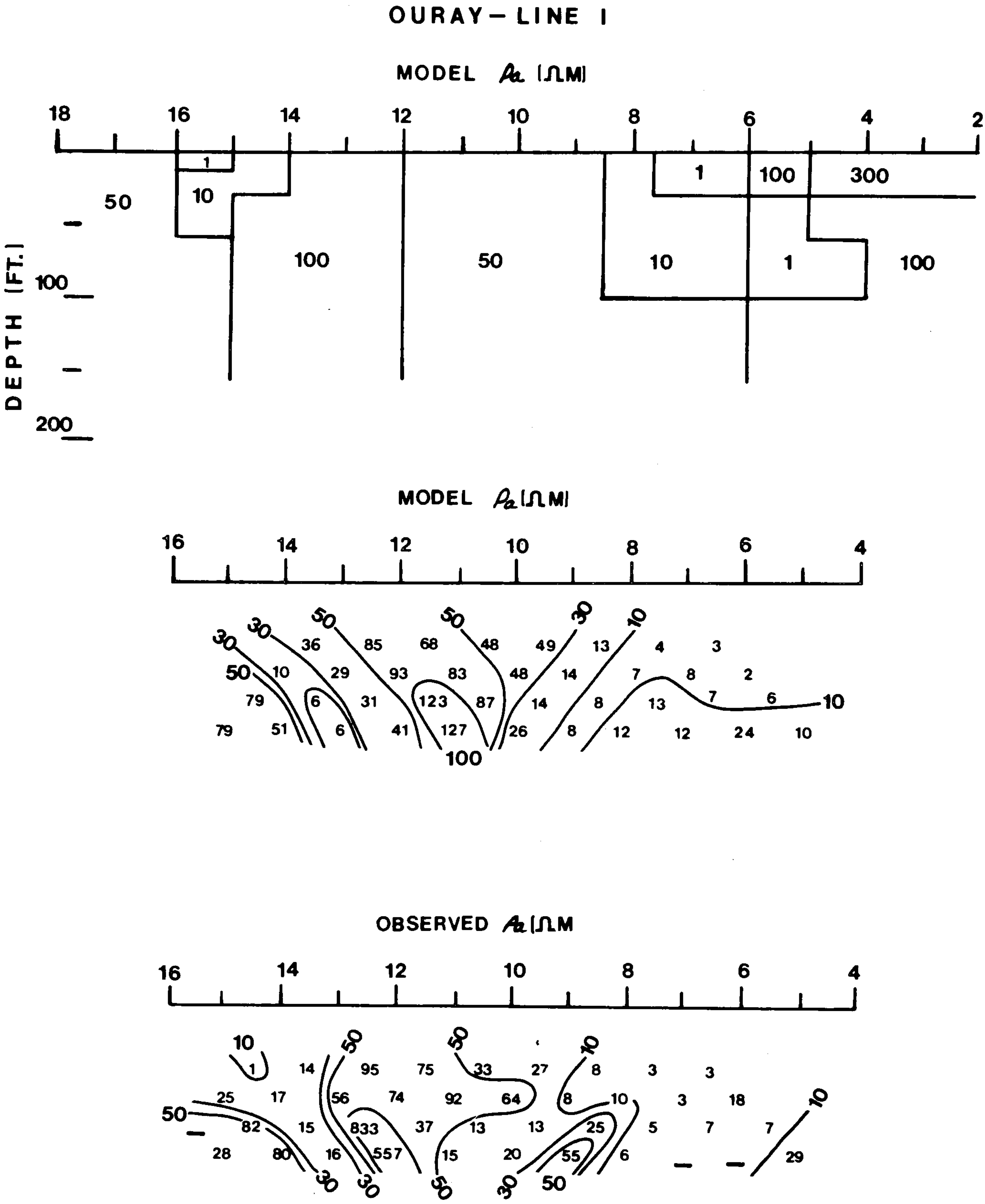
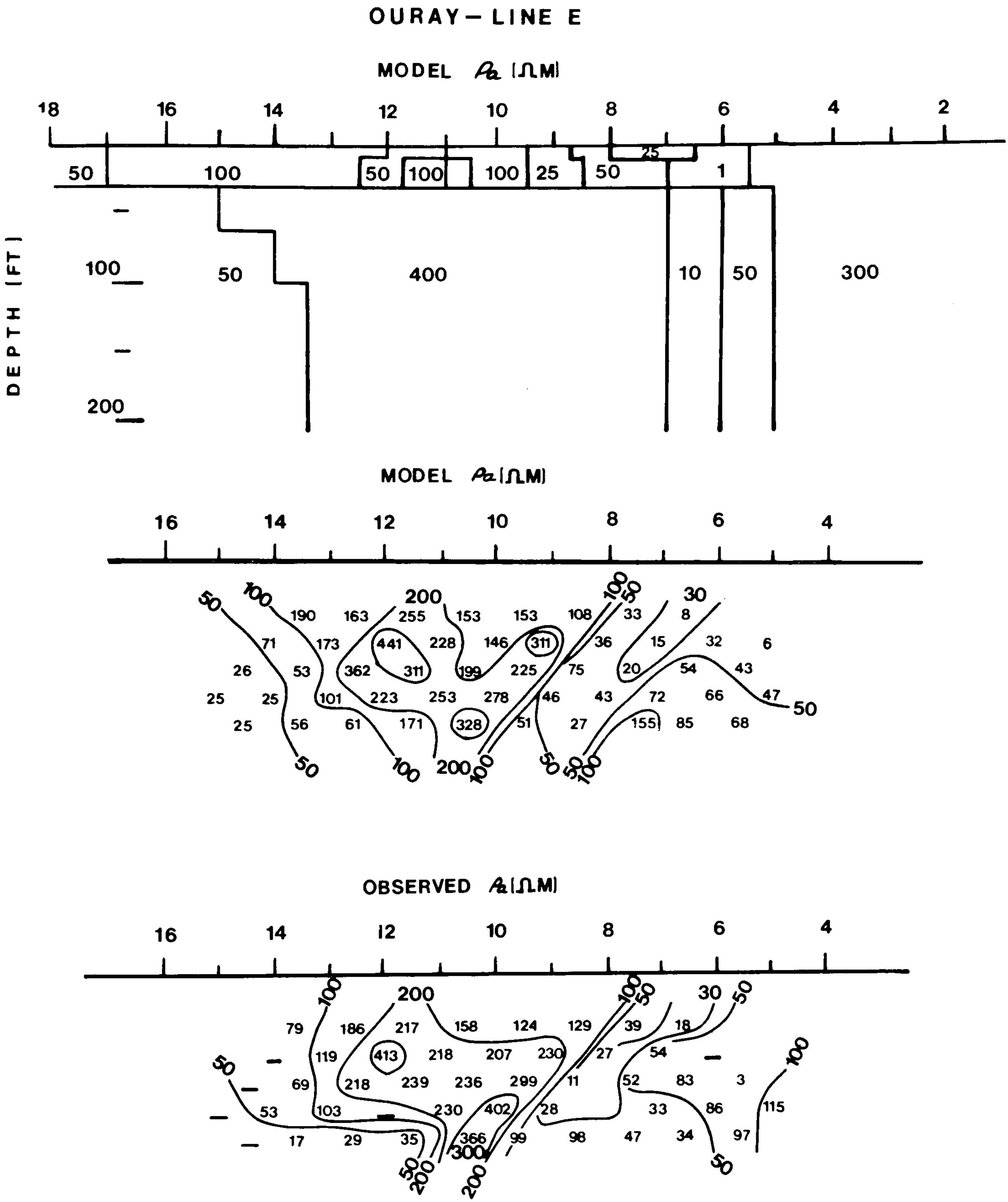


Figure 16. Ouray - Line E - Modeled (from W. Sill, 1981).


OURAY — LINE E

MODEL ρa (ΩM)

MODEL ρa (ΩM)

OBSERVED ρa (ΩM)

Figure 17. Ouray - Line I - Modeled (from W. Sill, 1981).

In the third area, by the ball park and swimming pool, a gradient array and one dipole-dipole line were run (Fig. 4). A gradient array is where there are two distant fixed current electrodes being traversed by a pair of potential measuring electrodes (Fig. 14). Two low resistive zones were observed, one to the northwest by the power station where a value of 9 ohm-meters was obtained, and the second location by the ball park backstop, where a value of 39 ohm-meters was obtained, but this value may be due to warm water leaking from buried pipes that leached the alluvium (Figs. 10, 13).

Appendix E presents the geometric factor tables used to calculate the resistivity values in Appendix D.

CONCLUSION

Due to cultural and topographic affects, the resource assessment efforts of this investigation were limited to the immediate surroundings of the various thermal springs. The resource assessment program conducted in the Ouray Valley indicated three areas worthy of consideration pertaining to a potential geothermal resource. The first area was above and adjacent to the Wiesbaden Motel, on a glacial drift type soil. The second area was in the Box Canyon Motel area and the Switchbacks immediately to the south. The third area was the municipal Ball Park and the Radium Springs swimming pool area.

During the course of this investigation, three principal studies were made, which were: first, the hydrogeological models indicate that the thermal waters could be due to a combination of deep circulation of normal groundwaters along faults in an area of high heat-flow. Recharge to the system occurs from melting snows and precipitation falling on the surrounding highlands. The actual heating of the waters is not beleived to be due to cooling of a magma chamber as the volcanic rocks were errupted over 22 million years ago and theoretically, the parent magma chamber should have cooled in that period of time.

The soil mercury surveys were, for the most part, inconclusive and most of the values considered questionable. The anomalies noted above the Box Canyon Motel probably are due to mineralization within the Leadville limestone. The isolated mercury anomaly in the Radium Pool-City Park Area is probably related to warm water leaking from buried pipes.

The geophysical resistivity program delineated three potential geothermal areas. These areas are manifested by low resistive zones and travertine deposits where warm water emerges from the bedrock. From the data presented, the resource area with greatest potential is at the confluence of the canyon and Oak Creek and the Uncompahgre River. The relative resistivity in this area is quite low compared to other areas. The Leadville limestone of Mississippian age is the bedrock and the medium through which the warm water emerges. The source rock is probably the Precambrian Uncompahgre formation. The complex fault and fracture systems in this area serve as the conduit for the deep circulation of the ground water through the system.

While the authors believe that the current work delineates the upper several hundred feet of the geothermal systems of the Ouray Valley, it is felt that before any geothermal production wells are drilled at least two geothermal gradient wells on the order of 300-450 ft deep should be completed in order to determine the gradient and the heat flow of this area. In addition, resistivity geophysical surveys should be attempted where more control is required. This may be a difficult task due cultural and terrain obstacles.

Due to the proximity of the thermal water within the City of Ouray, this area possesses great potential for harnessing this energy source, especially for space heating purposes.

REFERENCES

Barrs, D.L. and See, P.D., 1968, Pre-Pennsylvanian stratigraphy and paleotectonics of the San Juan Mountains, southwestern Colorado: Geol. Soc. America Bull. v. 79, pp. 333-350.

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

_____, 1978, An apparaisal of Colorado's geothermal resources: Colorado Geol. Survey Bull. 39, 229 p.

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

Coe, B. A., 1981, Geothermal energy opportunities at four Colorado towns: Durango, Glenwood Springs, Idaho Springs, and Ouray: U.S. Dept. of Energy DOE/ID/12018-8, Idaho Falls, Id, 60 p.

Combs, Jim, 1981, Geothermal Exploration Strategy and Techniques, 1981, Geothermal Services Inc., San Diego, CA, 41 p.

Cross and others, 1907, Description of Ouray Quadrangle USGS: Geol. Atlas Folio Series No. 153, 20 p.

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

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

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

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

Lepeltier, 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 Dept. Geography, Master Sci. Thesis 91 p.

Luedke, R.G., Burbank, W.S., 1962, Geologic map of the Ouray quadrangle, Colorado: U.S. Geol. Survey Geol. Quad. Map GQ-192.

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

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

Miesh, A.T., 1976, Sampling Designs for Geochemical Surveys - syllabus for a short course: U.S. Geol. Surv. Open-file Report 76-772.

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

_____1979, Colorado's hydrothermal resource base--An assessment: Colorado Geol. Survey Resource Series 6, 144 p.

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

Sill, William, 1981, Resistivity modeling, Ouray, Colorado: University of Utah Research Institute: Unpub. report.

Soil Test Inc., 1968, Earth Resistivity Manual: Evanston, Illinois, 52 p.

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.

Steven, T.A., Mehnert, H.H. and Obradovich, J.D., 1967, Age of volcanic activity in the San Juan Mountains, Colorado: U.S. Geol. Survey Prof. Paper P575D, pp. D47-D55.

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

Weimer, J.R., 1980, Recurrent movement on basement faults, A tectonic style for Colorado and adjacent areas: Rocky Mnt. Assoc. Geologists, pp. 301-313.

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, Preliminary heat flow map of Colorado: Colorado Geol. Survey Map Series 18, scale 1:1,000,000 (in prep).

APPENDIX A

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 B

Instrumentation

Scintrex RAC-8 Low Frequency Resistivity System

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

The Syntrex 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 C

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).

RESISTIVITY FIELD PROCEDURES

Apparent Resistivity:

$P_a = 2TTa \quad V/I$ General Formula

a = Spread length
V/I = Voltage current ratio
Pa = apparent resistivity
2II = 6.2

See Figure 18 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. 19) the electrodes are uniformly spaced in a line (Sumner, 1976).

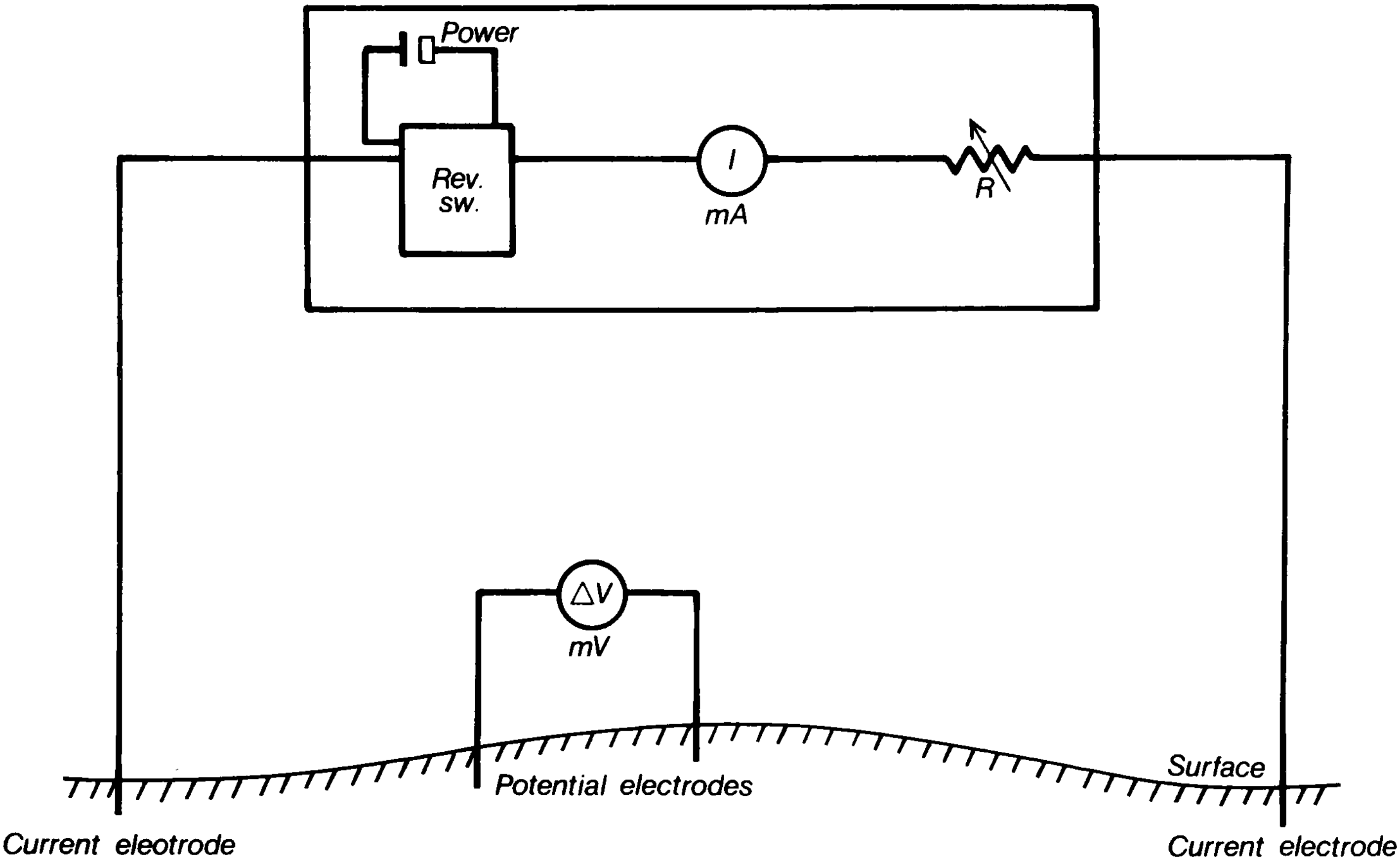
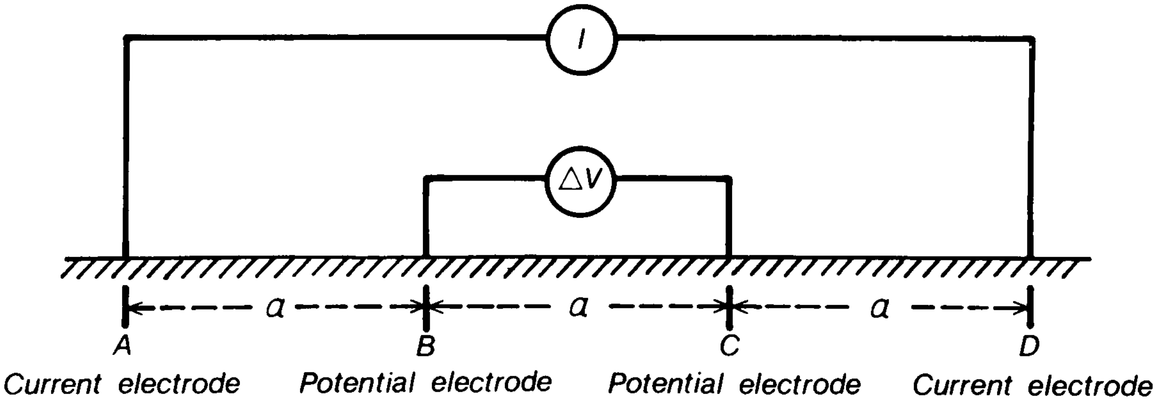


Figure 18. Schematic diagram for resistivity (from J. Combs, 1980).



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

Figure 19. Wenner array (from J. 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 Ouray 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. 20).

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

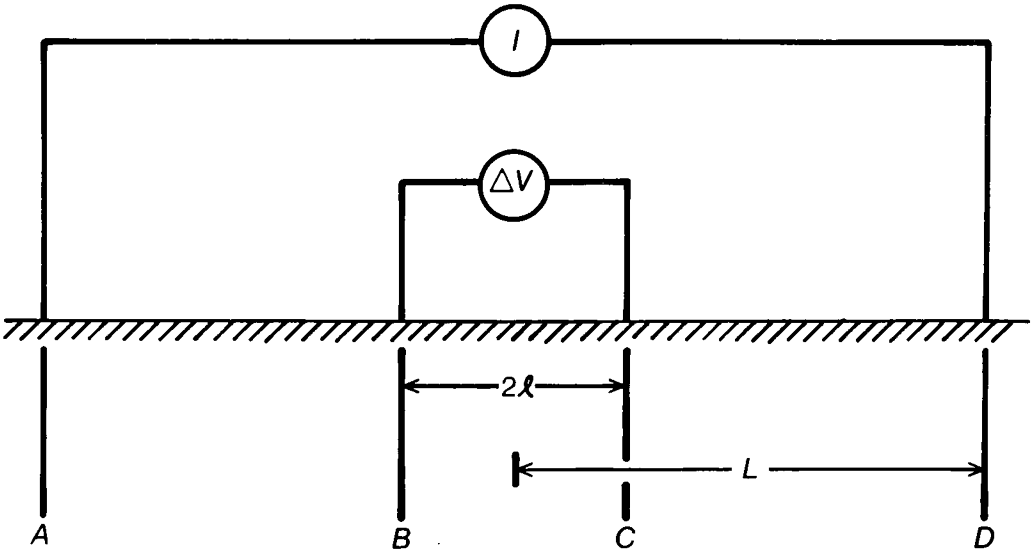
In summary, short spacing between the outer electrodes assumes shallow penetration of current flow and computed resistivity will reflect properties of shallow depth. As the electrode spacing is increased, more current penetrates to greater depth and conducted resistivity will reflect properties of each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

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_2 and P_1, usually 1 to 5 times the dipole lengths (Fig. 21).

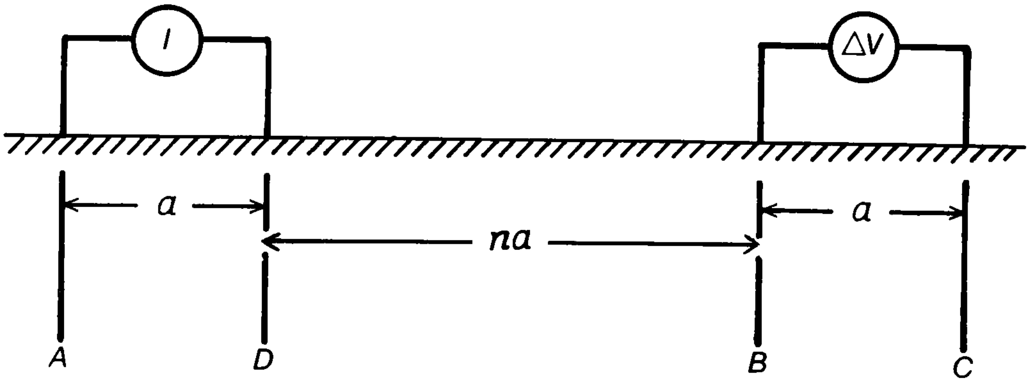
Inductive coupling between potential and current cables is reduced with this arrangement. This method was primarily used throughout all study areas because of reliability and ease of field operation. A diagram of this method is depicted in Figures 22 and Figure 23.

With reference to Figure 22 and 23, 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 20. Schlumberger array (from J. Combs, 1980).



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

Figure 21. Dipole-dipole array (from J. Combs, 1980).

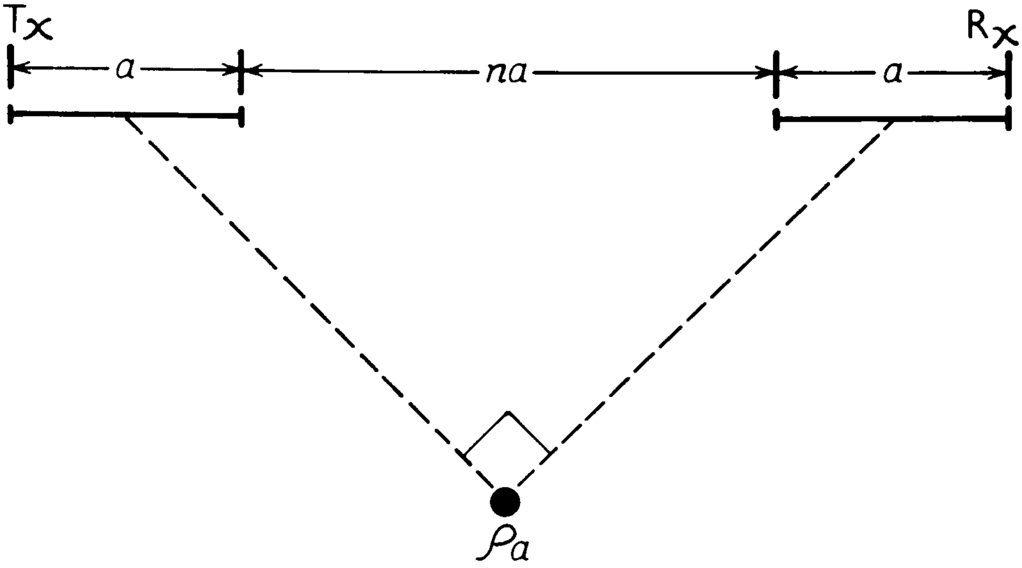


Figure 22. Data plotting scheme for dipole-dipole array (from J. Combs, 1980).

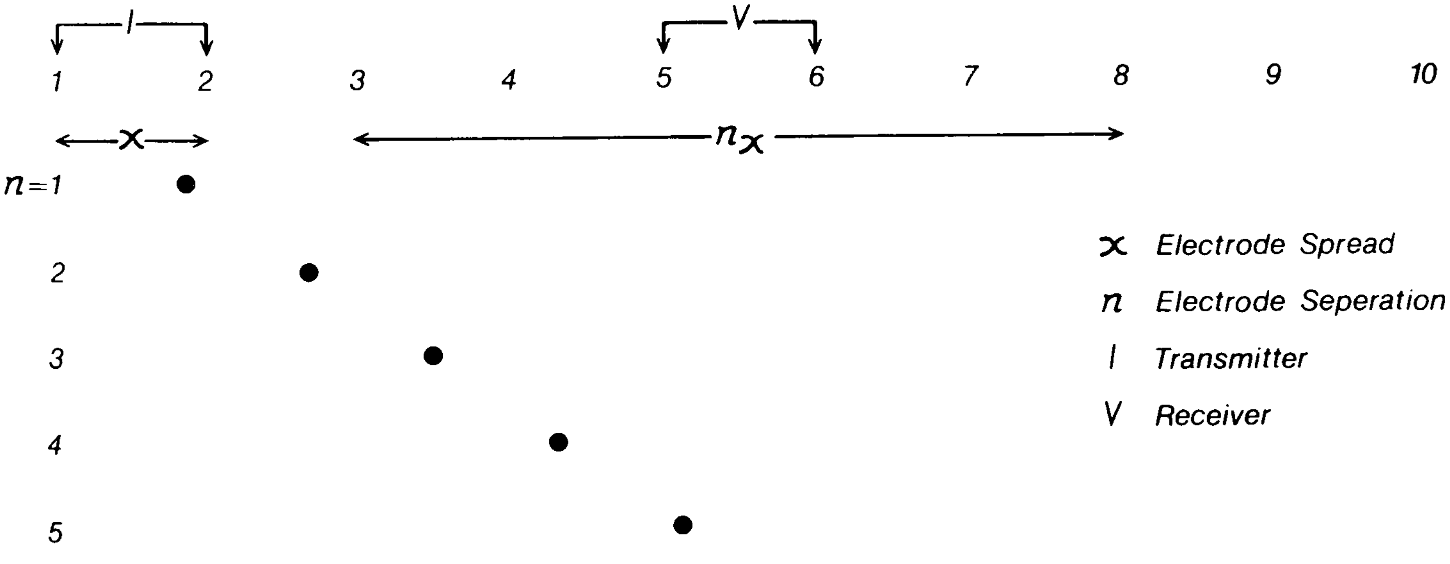


Figure 23. Typical dipole-dipole array (from J. Combs, 1980).

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 D. RESISTIVITY CALCULATIONS

TABLE 3. LINE A

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Ouray, Colo.	Line A	1 August 80
CHIEF OPERATOR	ASSISTANTS	METHOD
Jay Jones	Fargo and Treska	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage from TX	V_p	DV/I	G.F.	P_a
1-2							
3-4	1	-1	66	5.08	5.08	575	2921
4-5	1	-2	100	2.20	0.220	2289	506
5-6	1	-2	100	0.80	0.080	5747	460
6-7	1	-3	466	6.85	0.0685	11493	787
7-8	1	-3	466	3.15	0.0315	20113	634
2-3							
4-5	2	-2	133	1.80	1.80	575	1035
5-6	1	-2	133	2.65	0.265	2299	609
6-7	0	-2	133	2.10	0.0210	5747	121
7-8	0	-2	100	1.70	0.0170	11493	195
8-9	0	-2	133	0.90	0.0090	20113	181
3-4							
5-6	2	-2	100	7.20	7.20	575	4140
6-7	2	-2	100	1.70	1.70	2299	3908
7-8	1	-2	100	4.55	0.455	5747	2615
8-9	1	-2	100	1.84	0.184	11493	2114
9-10	2	-2	100	0.10	0.100	20113	2011
4-5							
6-7	3	-2	100	1.00	10.00	575	5750
7-8	2	-2	100	2.15	2.15	2299	4943
8-9	1	-2	100	8.20	0.820	5747	4712
9-10	1	-2	100	3.10	0.310	11493	3563
10-11	0	-2	100	0.10	0.0010	20113	20
5-6							
7-8	2	-2	100	5.50	5.50	575	3163
8-9	2	-2	100	1.77	1.77	2299	4070
9-10	2	-2	100	0.90	0.90	5747	5152
10-11	0	-3	366	2.80	0.0028	11493	33
11-12	1	-3	400	1.90	0.0190	20113	382
6-7							
8-9	1	-1	66	5.70	5.70	575	3277
9-10	3	-3	250	2.40	2.40	2299	5517
10-11	1	-3	250	2.30	0.023	5747	133
11-12	1	-3	250	3.00	0.030	11493	345
12-13	1	-3	250	7.70	0.0770	20113	1548

TABLE 3. LINE A (CONT.)

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Ouray, Colo.	Line A	1 August 80
CHIEF OPERATOR	ASSISTANTS	METHOD
Jay Jones	Fargo and Treska	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage from TX	V_p	DIV/I	G.F.	P_a
7-8							
9-10	2	-2	66	5.90	5.90	575	3393
10-11	1	-2	66	1.30	0.130	2299	299
11-12	1	-3	250	7.75	0.0775	5747	445
12-13	2	-3	250	1.12	0.112	11493	1287
13-14	1	-3	250	6.40	0.064	20113	1287
8-9							
10-11	2	-2	100	1.30	1.30	575	748
11-12	2	-3	275	2.67	0.267	2299	614
12-13	2	-3	275	2.35	0.235	5747	1351
13-14	2	-3	275	1.15	0.115	11483	1322
14-15	1	-3	275	8.70	0.087	20113	1750
9-10							
11-12	1	-2	66	3.10	0.310	575	178
12-13	2	-3	275	1.10	0.110	2299	253
13-14	1	-3	275	8.85	0.0885	5747	509
14-15	1	-3	275	6.85	0.0685	11493	787
15-16	1	-3	275	5.15	0.0515	20113	1037
10-11							
12-13	2	-2	66	5.55	5.55	575	3191
13-14	2	-2	66	1.40	1.40	2299	3219
14-15	2	-3	333	7.94	0.794	5747	4563
15-16	2	-3	333	5.05	0.505	11493	5804
16-17	2	-3	333	3.20	0.320	20113	6436
11-12							
13-14	2	-2	66	3.77	3.77	575	2168
14-15	2	-2	66	1.30	1.30	2299	2989
15-16	2	-3	333	7.60	0.760	5747	4368
16-17	2	-3	333	1.30	0.130	11493	1494
17-18	2	-3	333	2.78	0.278	20113	5591
12-13							
14-15	2	-2	66	6.30	6.30	575	3622
15-16	2	-2	66	1.75	1.75	2299	4024
16-17	2	-3	275	7.35	0.735	5747	4224
17-18	2	-3	275	3.85	0.385	11493	4425
18-19	2	-3	275	2.40	0.240	20113	4827

TABLE 3. LINE A (CONT.)

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Ouray, Colo.	Line A	1 August 80
CHIEF OPERATOR	ASSISTANTS	METHOD
Jay Jones	Fargo and Treska	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage from TX	V_p	DV/I	G.F.	P_a
13-14							
15-16	2	-2	66	4.15	4.15	575	2386
16-17	2	-2	66	1.20	1.20	2299	2759
17-18	2	-3	275	4.83	0.483	5747	2776
18-19	2	-3	275	2.60	0.260	11493	2988
19-20	2	-3	275	1.20	0.120	20113	2414
14-15							
16-17	2	-2	66	6.30	6.30	575	3623
17-18	2	-2	66	1.45	1.45	2299	3334
18-19	1	-2	66	5.90	0.590	5747	3390
19-20	1	-2	66	2.90	0.290	11493	3333
20-21	1	-2	66	1.20	0.120	20113	2414
15-16							
17-18	2	-2	66	4.80	4.80	575	2760
18-19	2	-2	66	1.35	1.35	2299	3104
19-20	1	-2	66	5.85	0.585	5747	3362
20-21	1	-2	66	2.00	0.200	11493	2297
21-22	1	-2	66	1.30	0.130	20113	2615
16-17							
18-19	2	-2	66	4.90	4.90	575	2817
19-20	2	-2	66	1.50	1.50	2299	3449
20-21	1	-2	66	3.10	0.310	5747	1782
21-22	1	-2	66	2.70	0.270	11493	3103
17-18							
19-20	2	-2	66	6.15	6.15	575	3536
20-21	2	-2	66	1.20	1.20	2299	2759
21-22	1	-2	66	5.00	0.50	5747	2874
18-19							
20-21	2	-2		4.68	4.68	575	2691
21-22	2	-2	66	1.35	1.35	2299	3104
19-20							
21-22	2	-2	66	7.18	7.28	575	4129

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

TABLE 4. LINE B

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Ouray, Colo.	Line B	6 August 80
CHIEF OPERATOR	ASSISTANTS	METHOD
Jay Jones	Fargo and Treska	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage from TX	V_p	DV/I	G.F.	P_a
1-2							
3-4	1	-2	100	2.02	0.202	575	116
4-5	1	-2	100	1.00	0.100	2299	230
5-6	1	-2	100	0.37	0.037	5747	213
6-7	0	-2	100	1.10	0.011	11493	126
7-8	0	-2	100	.1	.01	20113	200
2-3							
4-5	2	-2	66	2.83	2.83	5747	1627
5-6	3	-3	250	0.71	0.71	2299	1633
6-7	2	-3	250	0.77	0.077	5747	443
7-8	2	-3	250	1.25	0.125	11493	1437
8-9	2	-3	250	0.60	0.060	20113	1207
3-4							
5-6	3	-2	66	0.65	6.50	5747	3738
6-7	2	-2	66	2.17	2.17	22987	4989
7-8	2	-2	66	0.76	0.76	5747	4368
8-9	2	-3	225	3.20	0.320	11493	3678
9-10	2	-3	225	1.65	0.165	20113	3319
4-5							
6-7	3	-2	66	0.68	6.80	575	3910
7-8	3	-3	333	1.85	1.85	2299	4253
8-9	3	-3	333	0.62	0.620	5747	3563
9-10	2	-3	333	2.25	0.225	11493	2586
10-11	2	-3	333	0.75	0.075	20113	1509
5-6							
7-8	3	-2	66	0.93	9.30	575	3910
8-9	2	-2	66	1.85	1.85	2299	4253
9-10	2	-2	66	0.50	0.50	5747	2874
10-11	1	-2	66	1.21	0.121	11493	1391
11-12	1	-3	333	2.70	0.027	20113	543

TABLE 4. LINE B (CONT.)

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Ouray, Colo.	Line B	6 August 80
CHIEF OPERATOR	ASSISTANTS	METHOD
Jay Jones	Fargo and Treska	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage from TX	V_p	DV/I	G.F.	P_a
6-7							
8-9	3	-3		9.11	9.11	5747	5238
9-10	3	-3	225	1.65	1.65	2299	3794
10-11	2	-3	225	3.25	0.325	5747	1868
11-12	2	-3	225	0.55	0.055	11493	632
7-8							
9-10	3	-3	333	4.75	4.75	5747	2731
10-11	2	-3	333	7.25	0.725	2299	1667
11-12	2	-3	333	0.90	0.090	5747	517
8-9							
10-11	3	-3	250	3.75	3.75	5747	2156
11-12	2	-3	250	2.89	0.289	2299	664
9-10							
11-12	3	-3	200	1.62	1.62	5747	932

LEGEND: Range = RX Gain
MA = Dummy TXCurrent Switch
V_p = Balance Control to Null Meter
GF = Geometric Factor
P_a = Apparent Resistivity

TABLE 5. LINE C

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Ouray, Colo.	Line C	7 August 80
CHIEF OPERATOR	ASSISTANTS	METHOD
Jay Jones	Fargo and Treska	Dipole-Dipole (Nx50')

Sta.	Range	MA	Voltage from TX	V_p	DV/I	G.F.	P_a
2-2.5							
3-3.5	2	-2	100	4.20	4.20	288	1209
3-5.4	1	-2	100	2.50	0.250	1150	288
4-4.5	1	-3	366	1.85	0.0185	2873	53
4-5.5	1	-3	366	3.10	0.0310	5747	178
5-5.5	1	-3	366	2.40	0.024	10057	241
2.5-3							
3-3.5	2	-2	66	1.20	1.20	288	345
4-4.5	2	-3	250	1.00	0.100	1150	115
4-5.5	1	-3	250	3.60	0.036	2873	103
5-5.5	1	-3	250	2.40	0.024	5747	138
5-5.6	1	-3	250	<1.0	<.010	10057	<100
3-3.5							
4-4.5	1	-2	66	2.30	0.230	288	66
4-5.5	2	-3	166	1.40	0.140	1150	161
5-5.5	1	-3	166	6.90	0.069	2873	198
5-5.6	1	-3	166	3.60	0.036	5747	207
6-6.5		-3	166	N.R.	---	---	---
3.5-4							
4-5.5	3	-3	166	1.12	1.12	288	323
5-5.5	2	-3	166	3.60	0.360	1150	414
5-5.6	2	-3	166	1.80	0.180	2873	517
6-6.15	1	-3	166	7.90	0.0790	5747	454
6-5.7	0	-3	166	2.50	0.0025	10057	25
4-4.5							
5-5.5	1	-2	66	5.20	0.520	288	150
5-5.6	2	-3	200	2.70	0.270	1150	311
60-7.0	1	-3	200	0.15	0.0015	5747	9
4.5-5							
5.5-6	2	-3	133	5.20	0.520	288	150
6.6-5	2	-3	133	1.109	0.110	1150	127
6.5-7	0	-3	133	3.70	0.0037	2873	11

TABLE 5 LINE C. (CONT.)

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Ouray, Colo.	Line C	7 August 80
CHIEF OPERATOR	ASSISTANTS	METHOD
Jay Jones	Fargo and Treska	Dipole-Dipole (Nx50')

Sta.	Range	MA	Voltage from TX	V_p	DV/I	G.F.	P_a
5.0-5.5							
6-6.5	2	-3	275	6.50	0.650	288	187
6.5-7.	0	-3	275	3.90	0.0039	1150	5
5.5-6.0							
6.5-7	0	-2	166	1.10	0.011	288	32

LEGEND: Range = RX Gain
MA = Dummy TX Current Switch
V_p = Balance Control to Null Meter
GF = Geometric Factor
P_a = Balance Control to Null Meter

TABLE 6. LINE D

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION Ouray, Colo.	PROJECT Line D	DATE 7 August 80
CHIEF OPERATOR Jay Jones	ASSISTANTS Fargo and Treska	METHOD Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage from TX	V_p	DV/I	G.F.	P_a
0-1							
2-3		-3	200	N.R.			
3-4				N.R.			
4-5				N.R.			
5-6				N.R.			
6-7				N.R.			
1-2							
3-4				N.R.			
4-5				N.R.			
5-6				N.R.			
6-7				N.R.			
7-8				N.R.			
2-3							
4-5	1	-3	66	8.90	0.089	575	52
5-6	0	-3	66	N.R.		2299	
6-7	0	-3	66	4.85	0.00485	5747	28
7-8	0	.0003	166	6.60	0.00198	11493	23
3-4							
5-6	2	.0003		1.00	0.03	575	17
6-7	1	.00031		2.55	0.00765	2299	18
7-8		.0003		N.R.		5747	
8-9	2	.0003	166	0.18	0.0054	11493	62
9-10		.0003	166	N.R.			
4-5							
6-7	2	.0003	133	1.90	0.057	595	33
7-8	1	.0003	133	1.70	0.0051	2288	12
8-9	2	.0003	133	0.40	0.012	5747	69
9-10	1	.0003	133	0.90	0.0027	11493	31
10-11	1	.0003	133	1.30	0.0039	20113	78
5-6							
7-8	2	-3	66	0.75	0.075	575	43
8-9				N.R.			
9-10				N.R.			
10-11	0	-3	66	7.30	0.0073	11493	6.3
11-12		-3		N.R.			

TABLE 6. LINE D (CONT.)

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Ouray, Colo.	Line D	7 August 80
CHIEF OPERATOR	ASSISTANTS	METHOD
Jay Jones	Fargo and Treska	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage from TX	V_p	DV/I	G.F.	P_a
6-7							
8-9	2	-3	66	1.50	0.150	575	86
9-10	1	-3	66	0.70	0.007	2299	16
10-11	1	-3	66	1.00	0.001	5747	5.7
11-12		-3	66	N.R.		11493	
7-8							
9-10	2	-3	66	1.25	0.125	575	72
10-11				N.R.			
11-12				N.R.			
8-9							
10-11	2	-3	66	2.20	0.220	575	127
11-12				N.R.			
9-10							
11-12	1	-3	66	9.10	0.0910	575	52

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

TABLE 7. LINE E.

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Ouray, Colo.	Line E	8 August 80
CHIEF OPERATOR	ASSISTANTS	METHOD
Jay Jones	Fargo and Treska	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage from TX	V_p	DV/I	G.F.	P_a
1-2							
3-4	2	-3	250	1.29	0.129	575	74
4-5	1	-3	250	3.70	0.037	2299	85
5-6	1	-3	250	2.05	0.0205	5747	118
6-7	1	-3	250	1.70	0.0170	11493	195
7-8	0	-3	250	1.10	0.001	20113	[20]
2-3							
4-5	2	-3	166	1.30	0.130	575	75
5-6	2	-3	166	0.58	0.058	2299	133
6-7	1	-3	166	2.11	0.0211	5747	121
7-8	1	-3	166	N.R.	0.01?	11493	115
8-9	0	-3	166	4.82	0.00482	20113	97
3-4							
5-6	2	-3	133	1.16	0.116	575	67
6-7	1	-3	133	2.77	0.0277	2299	64
7-8	0	-3	133	0.43	0.00043	5747	2.5
8-9	1	-3	133	0.75	0.0075	11493	86
9-10	0	-3	133	1.70	0.0017	20113	34
4-5							
6-7	2	-3	166	0.95	0.095	575	55
7-8	1	-3	166	N.R.	---	2299	--
8-9	1	-3	166	1.44	0.0144	5747	83
9-10	0	-3	166	2.90	0.0029	11493	33
10-11	0	-3	166	2.35	0.00235	20113	47
5-6							
7-8	1	-3	166	3.15	0.0315	575	18
8-9	1	-3	166	2.35	0.0235	2299	54
9-10	1	-3	166	0.90	0.0090	5747	52
10-11	0	-3	166	0.10	0.00010	11493	1.15
11-12	0	-3	160	4.85	0.00485	20113	98
6-7							
8-9	2	-3	100	0.67	0.067	575	39
9-10	1	-3	100	1.17	0.0117	2299	27
10-11	0	-3	100	1.93	0.00193	5747	11
11-12	0	-3	100	2.44	0.00244	11493	28
12-13	0	-3	100	4.90	0.0049	20113	99

TABLE 7 LINE E (CONT.)

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Ouray, Colo.	Line E	8 August 80
CHIEF OPERATOR	ASSISTANTS	METHOD
Jay Jones	Fargo and Treska	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage from TX	V_p	DV/I	G.F.	P_a
7-8							
9-10	2	-3	100	2.25	0.225	573	129
10-11	2	-3	100	1.00	0.100	2299	230
11-12	2	-3	100	0.52	0.052	5747	299
12-13	1	-3	100	3.50	0.035	11493	402
13-14	1	-3	100	1.82	0.0182	20113	366
8-9							
10-11	2	-3	225	2.15	0.215	575	124
11-12	2	-3	225	0.90	0.090	2299	207
12-13	1	-3	225	4.10	0.0410	5747	236
13-14	1	-3	225	2.00	0.020	11493	230
14-15	0	-3	225	1.75	0.00175	20113	35
9-10							
11-12	2	-3	166	2.75	0.275	575	158
12-13	2	-3	166	0.95	0.095	2299	218
13-14	1	-3	166	4.15	0.0415	5747	239
14-15	0	-3	166	???	???	11493	---
10-11							
12-13	2	-3	166	3.78	0.378	575	217
13-14	2	-3	166	1.80	0.180	2299	413
14-15	1	-3	166	3.80	0.038	5747	218
15-16	1	-3	166	0.90	0.0090	11493	103
16-17	0	-3	166	(0.85)	(0.00085)	20113	17
			--electrical storm in progress--				
11-12							
13-14	2	-3	166	3.23	0.323	575	186
14-15	1	-3	200	5.20	0.052	2299	119
15-16	1	-3	200	1.20	0.012	5747	69
16-17	0	-3	200	4.60	0.0046	11493	53
17-18	---	-3	200	N.R. -- water mains in vicinity			
			--storm--				
12-13							
14-15	2	-3	133	1.38	.138	575	79
15-16	---	-3	133	---	---	2299	---
16-17	---	-3	133	NR	---	---	---
17-18	---	-3	133	NR	---	---	---
			--rain storm--				

TABLE 7 LINE E (CONT.)

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Ouray, Colo.	Line E	8 August 80
CHIEF OPERATOR	ASSISTANTS	METHOD
Jay Jones	Fargo and Treska	Depole-Dipole (Nx100')

Sta.	Range	MA	Voltage from TX	V_p	DV/I	G.F.	P_a
13-14							
15-16	2	-3	100	3.13	0.313	575	180
16-17	2	-3	100	0.88	0.088	2299	202
17-18	0	-3	100	2.45	0.00245	5747	14
14-15							
16-17	2	-3	100	2.64	0.264	575	152
17-18	1	-3	100	1.85	0.0185	2299	42
15-16							
17-18	2	-3	100	0.90	0.090	575	52

LEGEND: Range = RX Gain
MA = Dummy TX Current Switch
V_p = Balance Control to Null Meter
GF = Geometric Factor
P_a = Apparent Resistivity

TABLE 8. LINE F

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Ouray, Colo.	Line F	11 August 80
CHIEF OPERATOR	ASSISTANTS	METHOD
Jay Jones	Fargo and Treska	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage from TX	V_p	DIV/I	G.F.	P_a
1-2							
3-4	1	-2	66	3.70	0.370	575	213
4-5	0	-2	66	8.70	0.087	2299	200
5-6	1	-3	166	2.40	0.024	5747	138
6-7	0	-3	166	9.00	0.009	11493	103
7-8	0	-3	166	5.00	0.005	20115	101
2-3							
4-5	2	-3	166	2.85	0.285	---	164
5-6	1	-3	166	5.30	0.053	---	122
6-7	1	-3	166	2.0	0.020	---	115
7-8	0	-3	166	4.0	0.004	--	46
8-9				N.R	0.002		
3-4							
5-6	1	-2	66	1.65	0.165	---	95
6-7	0	-2	66	3.00	0.030	---	69
7-8	1	-3	225	1.00	0.010	---	57
8-9	0	-3	225	2.60	0.0026	---	30
9-10	0	-3	225	0.40	0.0004	---	8
4-5							
6-7	1	-2	100	2.60	0.260	575	150
7-8	0	-2	100	N.R.		2299	
8-9	0	-2	100	0.30	0.0030	5747	17
9-10	0	-2	133	N.R.	--low		
10-11	0	-2	100	0.15	0.0015	20113	30
5-6							
7-8	2	-3	500	1.50	0.150	575	86
8-9	1	-3	500	2.00	0.020	2299	46
9-10	0	-3	500	2.80	0.0028	5747	16
10-11	0	-3	500	<1.0	0.001 max	11493	11
11-12		-3	500				
6-7							
8-9	2	-3	300	1.30	.13	575	75
9-10	1	-3	300	1.80	.018	2299	41
10-11	0	-3	300	N.R.	low		
11-12	0	-3	300	N.R.	low		
12-13	0	-3	300	N.R.	low		

TABLE 8. LINE F (CONT.)

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Ouray, Colo.	Line F	11 August 80
CHIEF OPERATOR	ASSISTANTS	METHOD
Jay Jones	Fargo and Treska	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage from TX	V_p	DV/I	G.F.	P_a
7-8							
9-10	1	-3	433	6.50	0.065	575	37
10-11	0	-3	433	7.0	0.007	2299	16
11-12	0	-3	433	1.5	0.0015	5747	9
12-13				N.R.			
8-9							
10-11	1	-3	330	5.30	0.053	575	30
11-12		-3	333	N.R.	--		
12-13	0	-3	333	N.R.	--		
9-10							
11-12	1	-3	225	3.05	0.0305	575	18
12-13	0	-3	225	5.70	0.0057	2299	13
10-11							
12-13	1	-3	166	2.30	0.023	575	13

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

TABLE 9. LINE G

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Ouray, Colo.	Line G	12 August 80
CHIEF OPERATOR	ASSISTANTS	METHOD
Jay Jones	Fargo and Treska	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage from TX	V_p	DV/I	G.F.	P_a
1-2							
3-4	2	-2	66	0.63	0.630	875	362
4-5	1	-2	66	1.00	0.100	2299	230
5-6	0	-2	66	3.70	0.037	5747	213
6-7	1	-3	200	2.55	0.0255	11493	293
7 8	1	-3	200	0.65	0.0065	20113	131
2-3							
4-5	1	-2	66	3.90	0.390	575	224
5-6	1	-2	66	0.90	0.098	2299	225
6-7	2	-3	166	0.54	0.054	5747	310
7-8	1	-3	166	1.25	0.0125	11493	144
8-9	0	-3	166	1.88	0.00188	20113	38
3-4							
5-6	1	-2	66	4.67	0.467	575	269
6-7	1	-2	66	1.40	0.140	2299	322
7-8	0	-2	66	1.80	0.028	5747	161
8-9	0	-3	250	3.84	0.00384	11493	44
9-10	0	-3	250	227	0.00227	20113	46
4-5							
6-7	1	-2	66	5.04	0.504	575	290
7-8	2	-3	250	0.76	0.076	2299	175
8-9	1	-3	250	0.83	0.0083	5747	48
9-10	0	-3	250	4.67	0.00467	11493	54
10-11	1	-3	200	0.52	0.0052	20113	105
5-6							
7-8	1	-2	66	3.15	0.315	575	181
8-9	0	-2	66	2.85	0.0285	2299	65
9-10	1	-3	300	1.62	0.0162	5747	93
10-11	1	-3	300	1.32	0.0132	11493	152
11-12	1	-3	300	0.74	0.0074	20113	149
6-7							
8-9	1	-2	66	2.11	0.211	575	121
9-10	2	-3	275	0.83	0.083	2299	191
10-11	1	-3	275	4.20	0.042	5747	241
11-12	0	-3	275	3.39	0.00339	11493	39

TABLE 9. LINE G (CONT.)

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Ouray, Colo.	Line G	12 August 80
CHIEF OPERATOR	ASSISTANTS	METHOD
Jay Jones	Fargo and Treska	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage from TX	V_p	DV/I	G.F.	P_a
7-8							
9-10	1	-2	66	3.79	0.379	575	218
10-11	2	-3	133	0.86	0.086	2299	198
11-12	1	-3	133	1.56	0.0156	5747	90
8-9							
10-11	2	-3	133	2.56	0.256	575	147
11-12	1	-3	133	4.11	0.0411	2299	94
9-10							
11-12	2	-3	133	2.08	0.208	575	119

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

TABLE 10. LINE I

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Ouray, Colorado	Line I	13 August 80
Jay Jones	Fargo and Treska	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage from TX	V_p	DV/I	G.F.	P_a
1-2							
3-4	2	-3	166	1.00	.1	575	58
4-5	0	-3	166	7.80	0.0078	2299	18
5-6	0	-3	166	3.40	.0034	5747	20
6-7	0	-3	166	3.80	.0038	11493	44
7-8							
2-3							
4-5	1	-3	100	4.70	0.047	575	27
5-6		-3	100	N.R.	---		
6-7		-3	100	N.R.	---		
7-8	0	-3	100	2.50	0.0025	11493	29
8-9							
3-4							
5-6				N.R.			
6-7				N.R.			
7-8	0	-3	100	1.2	.0012	5747	7
8-9	0	-3	100	N.R.			
9-10							
4-5							
6-7	2	-3	166	1.30	0.130	575	75
7-8	1	-3	166	0.80	0.0080	2299	18
8-9	0	-3	166	1.30	0.0013	5747	7
9-10				N.R.		11493	
5-6							
8.9	0	-3	100	1.30	0.0013	2299	3
9.0	0	-3	100	0.80	0.0008	5747	5
10.11	0	-3	100	0.50	0.0005	11493	6
6-7							
8.9				N.R.			
9-10				N.R.			
10-11	0	-3	100	4.30	0.0043	5747	25
11-12	0	-3	100	4.80	0.0048	11493	55

TABLE 10. LINE I (CONT.)

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Ouray, Colo.	Line I	13 August 80
CHIEF OPERATOR	ASSISTANTS	METHOD
Jay Jones	Fargo and Treska	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage from TX	V_p	DV/I	G.F.	P_a
9-10				N.R.			
10-11	0	-3	100	4.30	0.0043	5747	25
11-12	0	-3	100	4.80	0.0048	11493	55
7-8							
9-10	1	-3	133	1.40	.014	575	8
10-11	0	-3	133	3.50	.0035	2299	8
11-12	0	-3	133	2.30	0.0023	5747	13
12-13		-3	133	1.70	.0017	11493	20
8-9							
10-11	1	-3	100	4.70	.047	575	27
11-12	1	-3	100	2.80	.028	2299	64
12-13	0	-3	100	2.30	0.0023	5747	13
13-14	0	-3	100	1.30	0.0013	11493	15
9-10							
11-12	1	-3	225	5.67	.0567	575	33
12-13	1	-3	225	4.00	.040	2299	92
12-14	0	-3		6.50	.0065	5747	37
14-15	1	-3		4.85	.0485	11493	557
10-11							
12-13	2	-3	275	1.30	0.130	579	75
13-14	1	-3	275	3.20	0.032	2299	74
14-15	2	-3	275	1.45	0.145	5747	833
15-16	0	-3	275	1.40	0.0014	11493	16
11-12							
13-14	2	-3	166	1.65	.165	5756	95
14-15	1	-3	166	1.45	.0245	2299	56
15-16	0	-3	166	2.61	.00261	5747	15
16-17	1	-3	166	.70	.0070	11493	80
12-13							
14-15	1	-3	250	2.45	.0245	575	14
15-16	1	-3	250	.75	.0075	2299	17
16-17	1	-3	250	1.42	.0142	5747	82
17 18	1	-3	250	2.40	.0024	11493	28

TABLE 10. LINE I (CONT.)

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Ouray, Colo.	Line I	13 August 80
CHIEF OPERATOR	ASSISTANTS	METHOD
Jay Jones	Fargo and Treska	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage from TX	V_p	DV/I	G.F.	P_a
13-14							
15-16	0	-2	100	.16	.0016	575	1
16-17	0	-2	100	1.01	.0107	2299	25
17-18				N.R.			
18-19				N.R.			
14-15							
16-17	0	-2	100	4.65	.0465	575	27
17-18	0	-3	366	8.05	.00805	2299	19
18-19		-3	366	N.R.	culcha, culcha & more culcha		
19-20		-3	333				
15-16							
17-18	1	-3	166	3.16	.0316	575	18
18-19	1	-3	166	2.80	.028	2299	64
19-20	0	-3	133	4.25	.00425	5747	24
20-21	0	-3	166	6.1	.0061	11493	70
16-17							
18-19	2	-3	100	.83	.083	575	48
19-20	1	-3	100	1.14	.0114	2299	26
20-21	1	-3	100	1.03	.0103	5747	59
21-22		-3	133	N.R.			
17-18							
19-20	2	-3	100	1.47	.147	575	85
20-21	2	-3	100	.68	.068	2299	156
21-22		-3	100	N.R.	too much inductance		
18-19							
20-21	2	-3	100	0.60	.060	575	34
21-22	1	-3	100	.40	.0040	2299	9
19-20							
21-22	2	-3	250	1.49	.149	575	87

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

TABLE 11. BASEBALL FIELD (SCHLUMBERGER)

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Ouray, Colo.	Baseball Field	11 August 80
CHIEF OPERATOR	ASSISTANTS	METHOD
Jay Jones	Fargo and Treska	Schlumberger Gradient Array 2-D

Sta.	Range	MA	Voltage from TX	V_p	DV/I	G.F.	P_a
1	1	-3	100	1.30	.013		75
2	0	-3	100	8.80	.0088		56
3	0	-3	100	7.70	.0077		49
4	0	-3	100	6.50	.0065		39
5	0	-3	100	7.10	.0071		39
6	0	-3	100	N.R.			
7	0	-3	100	9.10	.0091		47
8	0	-3	100	8.10	.0081		47
9	1	-3	100	.98	.0098		56
10	0	-3	100	8.60	.0086		52
11	1	-3	100	1.00	.010		61
12	1	-3	100	1.10	.011		60
13	1	-3	100	1.50	.0015		9
14	1	-3	100	1.00	.010		64
15	0	-3	100	8.20	.0082		52

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

APPENDIX E

TABLE 12
GEOMETRIC FACTOR TABLE
SCHLUMBERGER METHOD

2 (ft) L(ft)	25	50	75	100	200	300
50	95.78	47.89	31.93	23.94	11.97	7.98
75	215.5	107.75	71.83	53.87	26.94	17.96
100	383.11	191.55	127.70	95.78	47.89	31.93
200	1532.44	766.22	510.81	383.11	191.56	127.70
300	3447.99	1724	1149.33	862	431	287.33
400	6129.87	3064.89	2043.26	1532.44	766.22	510.81
500	9577.77	4788.89	3192.59	2394.44	1197.22	798.15
600	1391.99	6896	4597.33	3447.99	1724	1149.33
700	18772.43	9386.22	6257.48	4693.11	2346.55	1564.37
800	24519.1	12259.54	8173.03	6129.77	3064.89	2043.26
900	31031.99	15515.99	10344	7758	3879	2586
1000	38311.1	19155.55	12770.36	9577.77	4788.89	3192.59
1100	46356.42	23178.21	15452.14	11589.11	5794.55	3863.04
1200	55167.97	27583.99	18389.32	13791.99	6896	4597.33
1300	64745.74	32372.87	21581.91	16186.44	8093.22	5395.48
1400	75083.74	37544.87	25029.91	18772.44	9386.22	6257.48
1500	86199.96	43099.98	28733.32	21549.98	10774.99	7183.3

TABLE 13. DIPOLE-DIPOLE GEOMETRIC FACTOR TABLE

a(ft) n	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 14. WENNER GEOMETRIC FACTOR TABLE

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