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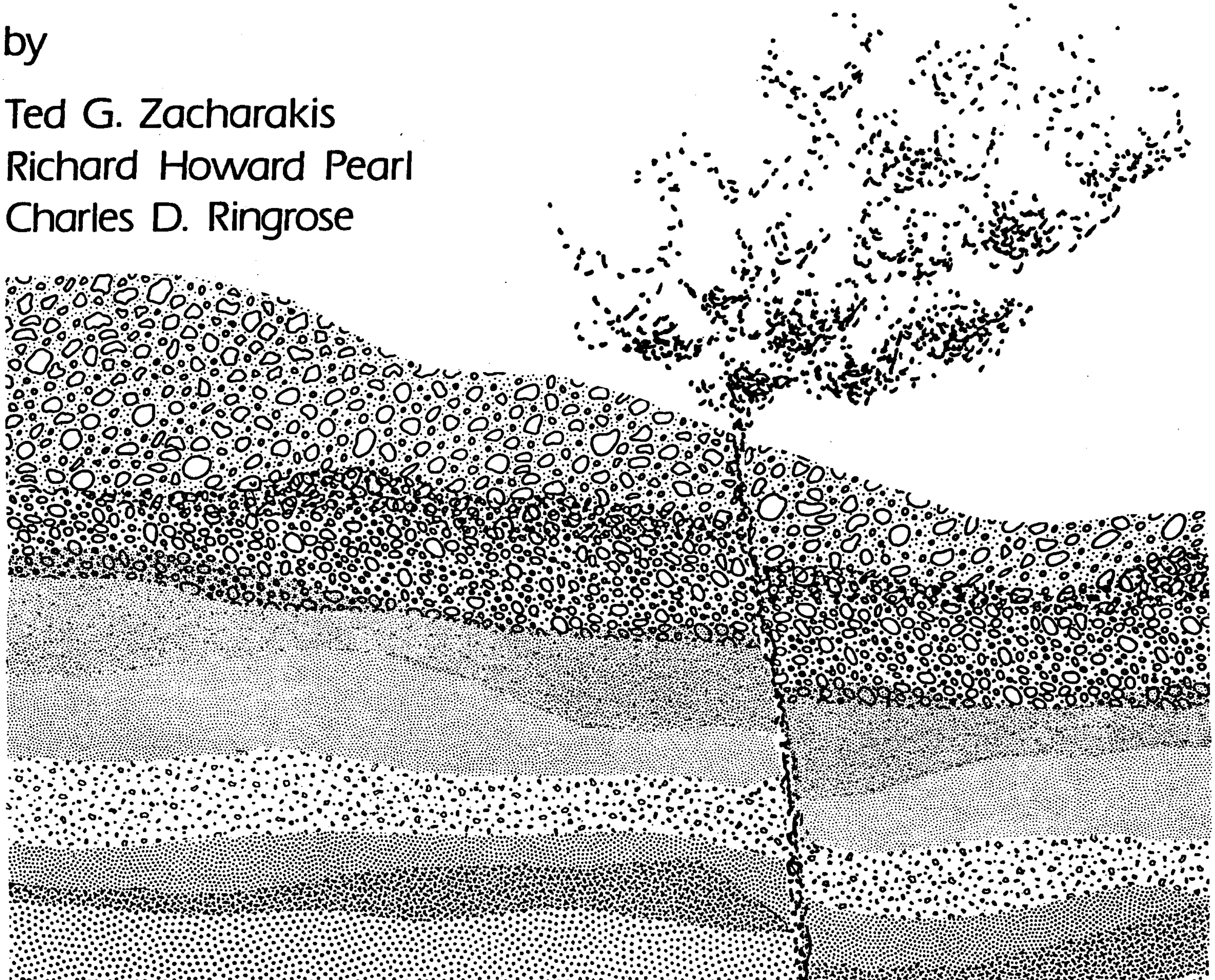
Geothermal Resource Assessment of Ranger Warm Spring, Colorado

by

Ted G. Zacharakis
Richard Howard Pearl
Charles D. Ringrose



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RESOURCE SERIES 24

GEOTHERMAL-RESOURCE ASSESSMENT OF RANGER WARM SPRING, COLORADO

by

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

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

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

NOTICE

NOTICE

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GEOTHERMAL RESOURCE ASSESSMENT OF RANGER WARM SPRINGS, COLORADO

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

ABSTRACT

In 1977 a program was initiated with U.S. Dept. of Energy funding to delineate the geological features controlling the occurrence of geothermal resources in Colorado. This program consisted of literature search, reconnaissance geologic and hydrogeologic mapping and geophysical and geochemical surveys.

During 1980 and 1981 geothermal resource assessment efforts were conducted in the Cement Creek Valley south of Crested Butte. In this valley are two warm springs, Cement Creek and Ranger, about 4 mi (6.4 km) apart. The temperature of both springs is 77-79°F (25-26°C) and the discharge ranges from 60 to 195 gallons per minute. Due to access problems no work was conducted in the Cement Creek Warm Springs area. At Ranger Warm Springs electrical resistivity and soil mercury surveys were conducted.

The warm springs are located in the Elk Mountains of west central Colorado. The bedrock of the area consists of sedimentary rocks ranging in age from Precambrian to Recent. Several faults with displacements of up to 3,000 ft (914 m) are found in the area. One of these faults passes close to the Ranger Warm Springs. The electrical resistivity survey indicated that the waters of Ranger Warm Springs are moving up along a buried fault which parallels Cement Creek.

The areal extent of the Ranger Warm Springs thermal system has been estimated to encompass between 0.30 sq. mi (1.01 sq km) and 0.88 sq mi (2.28 sq km) depending upon how much of the faulting is included. It has also been estimated that the energy contained in the system could range from 0.0021 Q's to 0.0062 Q's (10^{15} BTU's) at an average temperature of 113°F (45°C).

INTRODUCTION

In 1977, the Colorado Geological Survey, in cooperation with the U.S. Department of Energy, Division of Geothermal Energy, under Contract No. DE-AS07-77ET28365, initiated a program designed to determine the nature and extent of Colorado's geothermal resources. Priority was given to those areas with the greatest potential for near-term development. The areas evaluated under this program were: The Animas Valley, north of Durango; Canon City Area; Hartsel Hot Springs; Hot Sulphur Springs; Idaho Springs; Ouray; Ranger Hot Springs; Shaws Spring, western San Luis Valley; and the Steamboat Springs-Routt Hot Springs area. This publication reports the findings of the resource assessment program carried out in the Ranger Warm Springs area along Cement Creek in westcentral Colorado (Fig. 1). The evaluation consisted of a literature search, reconnaissance geologic and hydrogeologic mapping, and geophysical and geochemical surveys. In the Cement Creek Valley are two warm springs, Ranger and Cement Creek, about 4 mi (6.4 km) apart. Due to access problems no assessment work was conducted in the Cement Creek Warm Springs area.

The motivating factor for this study was the development of the Mt. Emmons mineral deposit by AMAX north of Crested Butte. Due to the great number of secondary projects planned, the energy demands in the area would experience a rapid increase. It was believed that hot water (geothermal energy) could be used at a very nominal cost as an energy source for some of these projects.

Normally geothermal energy, the natural heat of the earth, is either too diffuse or found at depths too great to be of practical value. However, in some instances it occurs close to the surface, where it does it can be developed and put to practical use. A brief description of geothermal energy and some of the uses it can be put to are presented in Appendix A.

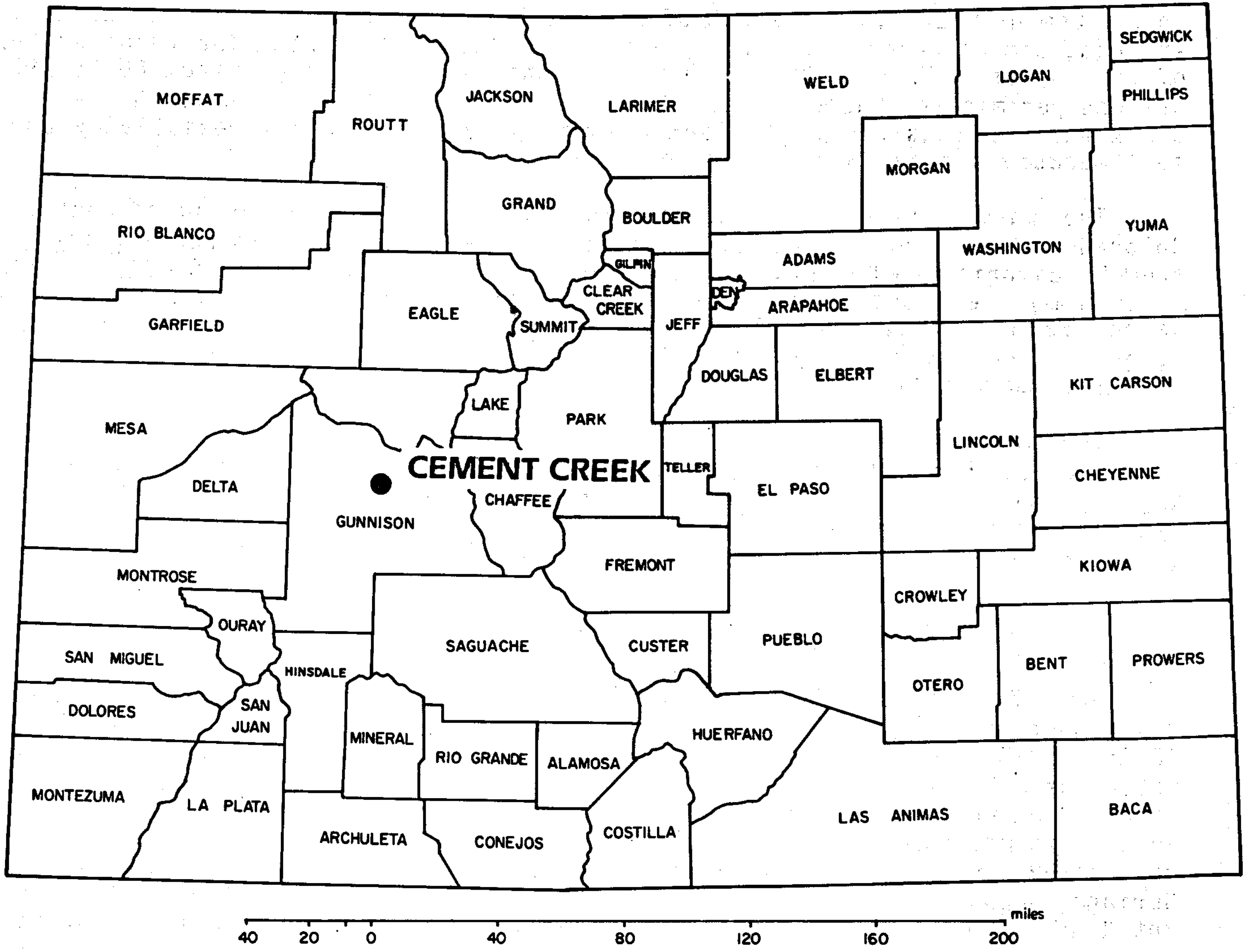


Figure 1. Index Map

THERMAL CONDITIONS OF THE RANGER WARM SPRINGS AREA

Thermal Waters

Located along Cement Creek are two warm springs - Ranger and Cement Creek. Ranger Warm Spring, which is unused and undeveloped, is located on the south side of Cement Creek about 7 miles (11.26 km) south of the town of Crested Butte, and 20 mi (32.19 km) north of Gunnison, Colorado. The spring has a temperature of 79°F (26°C), and an estimated annual average discharge of 195 gallons per minute. The waters contain approximately 465 mg/l of dissolved solids and are a calcium-bicarbonate type (Barrett and Pearl, 1976).

Cement Creek Warm Springs is located approximately 4 mi (6.4 km) east of Ranger Warm Springs at the Cement Creek Ranch. In 1978 the waters were used in a swimming pool and as a domestic water supply (Barrett and Pearl, 1978). The waters have a temperature of 77°F (25°C), and a discharge that varies throughout the year from 60 to 80 gpm. The waters, which contain approximately 390 mg/l of total dissolved solids, are a calcium-bicarbonate type (Barrett and Pearl, 1978). Chemical analysis of the Ranger and Cement Creek Warm Springs waters and other information is presented in Appendix B.

Heat Flow

Two heat-flow measurements have been made just north of Crested Butte. These measurements showed that the corrected heat flow in the area ranges from 103 to 160 mW/M^2 (Zacharakis, 1981). Based on these and other measurements in western Colorado, Zacharakis (1981) has indicated that the regional heat flow in the Cement Creek Valley is approximately 120 mW/m2 (Fig. 2).

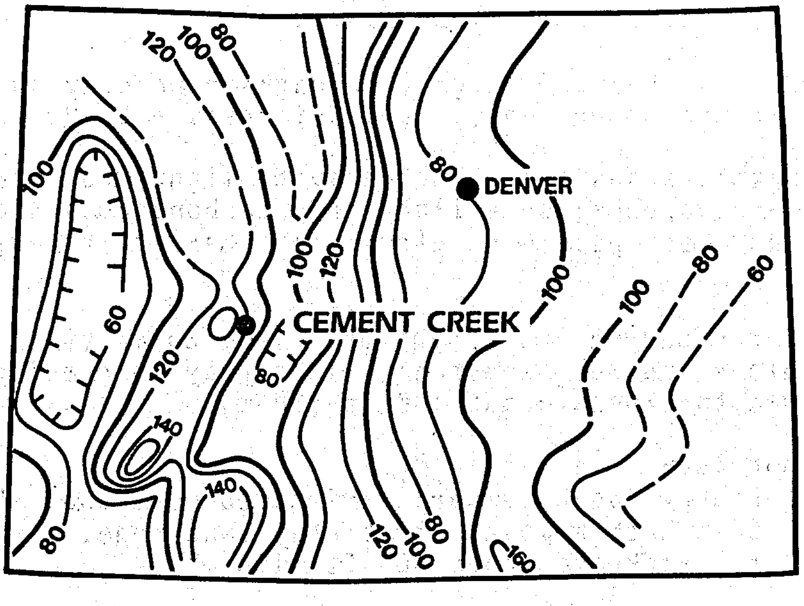


Figure 2. Heat flow map of Colorado (Adopted from Zacharakis, 1981)

GEOLOGY

Introduction

Cement Creek is located in the mountainous parts of western Colorado on the southwest side of the Elk Mountains. The West Elk Mountains largely consist largely of a volcanic breccia emplaced late in Oligocene or early Miocene time, (Steven, 1975) lie to the southwest. The Elk Mountains contain many 34-29 m.y. old (Oligocene) granodiorite plutons similar to the rocks of the West Elk Mountains (Steven, 1975). The study area lies in the Colorado Mineral Belt, a Precambrian structure reactivated during Laramide time (Tweto, 1975).

Very little has been written and published on the geological conditions of the Cement Creek Valley. The only paper describing in any depth the geological conditions of the study area was published by McFarlan in 1961. Tweto and others (1976) showed the geological conditions of the Cement Creek area as part of their 1:250,000 geological map of the Montrose 1° x 2° quadrangle. This map shows the bedrock in the vicinity of Ranger Warm Spring ranges in age from Ordovician to Mississippian (Fig. 3). A brief description of these formations is presented in Table 1. Tweto (1979) has mapped late Tertiary (3.5 - 26 m. y.) volcanic rocks approximately 1 mi (1.61 km) to the south of Ranger Warm Springs.

Table 1. Stratigraphic Section, Cement Creek Valley and immediate vicinity. (Modified from McFarlan, 1961 and Tweto and others, 1976).

Quaternary:	Alluvial valley fill deposits and gravel terrace deposits along Cement Creek and East River.
	Glacial drift. Unconsolidated clay to boulders.
Tertiary:	Rhyolitic rocks: Miocene age.
Cretaceous:	Mancos Shale: Dark gray to dark-brown clay shale, locally calcareous or sandy. Max. thickness + 5,000 ft (+1.5 km).
	Dakota sandstone: Light-gray to light-brown sandstone, locally carbonaceous; some light-gray carbonaceous shale, coal beds, and chert pebble conglomerate. Max. thickness about 200 ft. (60 m).
	Burro Canyon Fm.: Light-gray lenticular chert-pebble conglomerate and sandstone; light-gray to green claystone. Max thickness about 100 ft (30 m).
Jurassic:	Morrison Fm.: Brushy Basin member: Variegated mudstone, shale and sandstone Salt Wash member: Light-gray sandstone. Max. thickness about 500 ft (150 m).

Table 1. Stratigraphic Section (Cont.)

Jurassic:	Junction Creek sandstone: Light-yellow to white crossbedded sandstone. Max. thickness 180 ft. (55 m).
	Entrada Fm.: Pale-orange, white, and pink crossbedded eolian sandstone. Maximum thickness 85 ft (26m).
Pennsylvanian:	Maroon Fm.: Maroon and grayish-red sandstone, conglomerate, and mudstone. Thickness +9,500 ft (2.9 km). Minturn Fm.: Gray, pale-yellow, and red sandstone, grit, conglomerate, and shale and scattered beds of limestone. Max. thickness 4,000 ft (1.2 km).
	Belden Fm.: Dark-gray to black shale, carbonates, and sandtone. Max. thickness 4,000 ft (1.2 km).
Mississippian:	Leadville limestone: Light to medium gray limestone, chert. Max. thickness 195 ft (59 m).
Devonian:	Chaffee Fm.: Fine grained earthy dolomite with grey and green shale. Two cliff forming units marking off 3 "benches". Other minor cliff forming units. Max. thickness 300 ft (91m).
Ordovician:	Fremont Fm: Grey dolomite and dolomitic limestone, cliff forming. Max. thickness 77 ft (23 m).
	Harding sandstone: Max thickness 5 ft (1.5 m).
	Manitou dolomite: Grey, thin bedded, fine to medium grained dolomite and dolomitic limestone, cherty. Max. thickness: 220 ft (67 m).
Cambrian:	Sawatch sandstone: Massive, cross bedded, cliff-forming sandstone. Divided into three units. Upper member: light gray, massive cliff forming, quartzite and quartzitic sandstone. Thickness 100 ft (30.5 m). Middle member: Hematitic and glauconitic sandstone. Thin bedded with some associated shale, and little limestone. Hematite and glauconite occurs and red and green streaks in beds associated with gray sandstone. Thickness 120 ft (36.6 m). Lower member: Gray to tan quartzites and sandstones. Thickness 120 ft (36.6 m).
Precambrian:	Undifferentiated schist, granite, and pegmatite.

Structure

In the study area the generally west dipping sedimentary rocks are broken by several high angle faults (McFarlan, 1961) (Fig. 3). The eastern fault, named the "Old Camp Fault" by McFarlan (1961) has over 1,800 ft (548 m) of displacement. The western "Granite Fault" of McFarlan (1961), with over 3,000 ft (914 m) of displacement, passes close to Ranger Warm Springs. South of the warm springs this fault splits into two segments. One of the segments passes to the west of the springs (Fig.3). Intersecting these two faults and lying north of the warm springs in the bottom of Cement Creek is an obscured east trending fault.

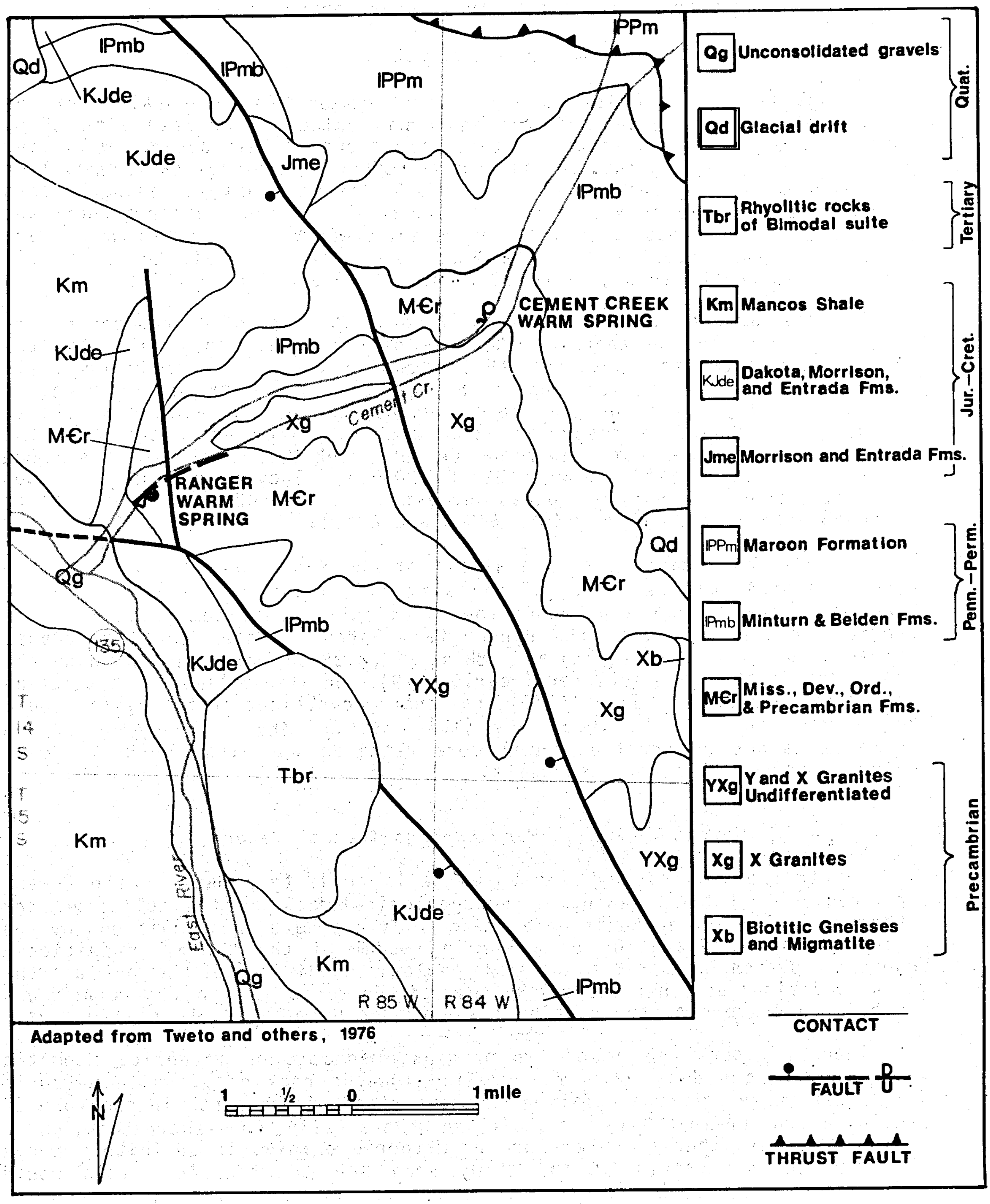


Figure 3. Geologic map of Cement Creek and surrounding area (Adopted from Barrett and Pearl, 1978)

HYDROGEOLOGY OF THE RANGER WARM SPRINGS AREA

Resource Analysis

George and others (1920) made the first comprehensive appraisal of the thermal waters of Colorado and the medicinal values associated with them. Those readers interested in the historic treatment of this subject will find this report of immense value. In addition to reporting the chemical composition of the thermal waters, George and others (1920) listed such physical parameters as temperature, radioactivity, and location of the spring. Other authors who have reported on various aspects of the Cement Creek Valley thermal waters are Barrett and Pearl (1976 and 1978), Berry and others (1980), Lewis (1966), Mallory and Barnett (1973), Pearl (1972 and 1979) and Waring (1965).

In 1978 Barrett and Pearl, following up on the work of George and others (1920), reevaluated the thermal waters of of Colorado. They relocated the thermal water sources, measured their temperature, pH, and other field parameters, and had a complete modern chemical analysis of the waters made. In addition they tried through the use of geochemical geothermometer models to estimate the subsurface reservoir temperatures. They estimated that the subsurface temperatures of Ranger and Cement Creek Warm Springs could range from a low of 84°F (29°C) to over 393°F (200°C). They noted that the good agreement between the various models suggests that the subsurface temperature is probably between 86°F and 140°F (30°C and 60°C).

In 1979 Pearl carried this analysis of the Range Warm Spring one step futher and presented estimates of the size and extent of the thermal area. Based on general assumptions about the size, extent, and temperature of the resource he estimated that the Ranger Warm Springs system could encompass between 0.30 sq mi (1.01 sq km) and .88 sq mi (2.28 sq km) depending upon how much of the faulting was included (Pearl, 1979). He also estimated that, at an average temperature of 113°F (45°C), the energy contained in the system could range from .0021 Q's to .0062 Q's (10^{15} BTU's). The accuracy of these estimates cannot be verified until more detailed appraisal work is done, including the drilling of test wells.

Origin of Ranger Warm Springs Thermal Waters

Due to the lack of any deep water wells or isotope data in the Cement Creek region from which meaningful hydrogeological data could be collected, the authors were limited in their efforts to fully evaluate the conditions of the region and the preparation of a working model of the thermal conditions. However, based on interpretation of the geologic conditions of the area and the known conditions at other thermal systems of the world, some basic assumptions can be made concerning the origin of the Ranger Warm Spring thermal waters.

Thermal waters can be of two origins, magmatic or meteoric. Magmatic waters are waters derived from a cooling igneous rock body, while meteoric waters are those which have fallen on the surface of the earth in the form of precipitation. Craig (1961) and Craig and others (1956) have shown that, under most conditions, thermal waters are of meteoric origin. To definitely prove that the thermal waters of the study area are of meteroic origin would necessitate sampling and analyzing the waters for various oxygen isotopes, which was not done, or locating a buried cooling igneous rock body. A search of the literature did not reveal any reference to such a buried igneous body and it is assumed that one does not exist. Based on Craig's (1961) findings, it is the authors' opinion that the Ranger Warm Springs thermal waters are of meteoric origin.

One of the problems left unanswered by this investigation is the mechanism by which the meteoric ground-waters became heated. Deeply migrating meteoric waters could become heated by the following possible means. 1) It has been shown that the flow of heat from the earth is very high in this area (120 mW/m^2) as compared to other parts of Colorado (Fig. 2). 2) Heat from decay of radioactive minerals. While his study did not extend to this part of the Mineral Belt, Wells (1960), showed that the Tertiary age rocks of the Colorado Mineral Belt in the Front Range are 15 to 25 times more radioactive than the average granitic rocks. 3). Another possible source of heat is the heat given off from cooling magma bodies. Tertiary age extrusive volcanic rocks are found throughout the Elk and West Elk Mountains (Steven, 1975; Tweto, 1979; and Tweto and others, 1976), however these rocks are thought to be too old (+20 million years) to be the source of the heat.

While not considered by the authors as a possible origin for the thermal waters, it should be mentioned that the waters may be, at least in part, of magmatic origin. As noted earlier, the study area is located in the Colorado Mineral Belt and hydrothermal mineral deposits occur just north of Crested Butte. If buried batholiths exist beneath the Mineral Belt as some authors have suggested (Tweto, 1975) then it is possible that thermal fluids could be coming from these features. To conclusively prove or disprove this would require isotopic analysis of the thermal waters which the authors did not do.

ELECTRICAL GEOPHYSICAL SURVEYS

Introduction

In an attempt to map the boundaries of the Ranger Warm Springs geothermal system 6 dipole-dipole and 3 gradient surveys were conducted (Fig. 4). Due to such thermal reservoir physical parameters as temperature, fluid characteristics and clay content electrical resistivity surveys are well suited for geothermal resources. As a result of these parameters geothermal systems are characterized by low resistivity zones as contrasted to the surrounding bedrock.

These two surveys gave two different pictures of the subsurface geophysical conditions. The dipole-dipole surveys give a vertical picture of the geophysical conditions under the line of traverse, while the gradient surveys gives a plan view of the electrical resistivity at a specified depth. A complete description of the various factors which might affect electrical resistivity measurements is presented in Appendix C. Presented in Appendix D is a complete description of the equipment used.

To help in determining the subsurface geological and hydrogeological conditions, pseudosections were constructed using electrical resistivity measurements (Figs. 5 to 10). These are cross sections reflecting the resistivity of the bedrock below the line of traverse. In the interpretation of any dipole-dipole pseudosection, it is easy to make the assumption that the measurements just represent the material immediately under the line of traverse. However, this is not always the case and in some instances the measurements may be influenced by lateral variations of the geological conditions. Another method, which was not used, to interpret electrical resistivity geophysical data is detailed computer models. These models would give a more accurate description of the individual faults. The gradient arrays (Fig. 12, 13 and 14) while helpful, lacked the penetrating power required to discern what was occuring at depth.

In contrast to the dipole-dipole procedure, the procedure for gradient surveys calls for two distant fixed current electrodes, A and B and a pair of potential-measuring electrodes that are used to traverse a rectangular area between them (Fig. 11)

In addition, a map was constructed using data from the pseudosections (Fig. 15). This map, which depicts the varability of the resistivity measurements throughout the area at a depth of approximately 300 ft (91 m), clearly defines a north-south trending zone through the center of the area. This zone parallels the projected buried fault parallel Cement Creek. This map correlates quite well with the dipole-dipole sections lines A, B, and F.

Conclusions

The only obstacle that presented any problems in conducting the electrical resistivity surveys was Cement Creek. Due to the water saturated alluvium low resistivity readings were recorded along the creek. The resistivity surveys determined that Ranger Warm Springs thermal waters appear to be fault controlled. The north-south fault located in the bottom of Cement Creek could be the conduit at depth, along which the thermal waters are migrating to the surface.

Due to equipment limitations and geological conditions it was not possible possible to acquire any measurements below a depth of ± 700 ft (122 m), therefore the conditions beyond this depth are unknown. Additional resistivity surveys for more structural control would be desirable.

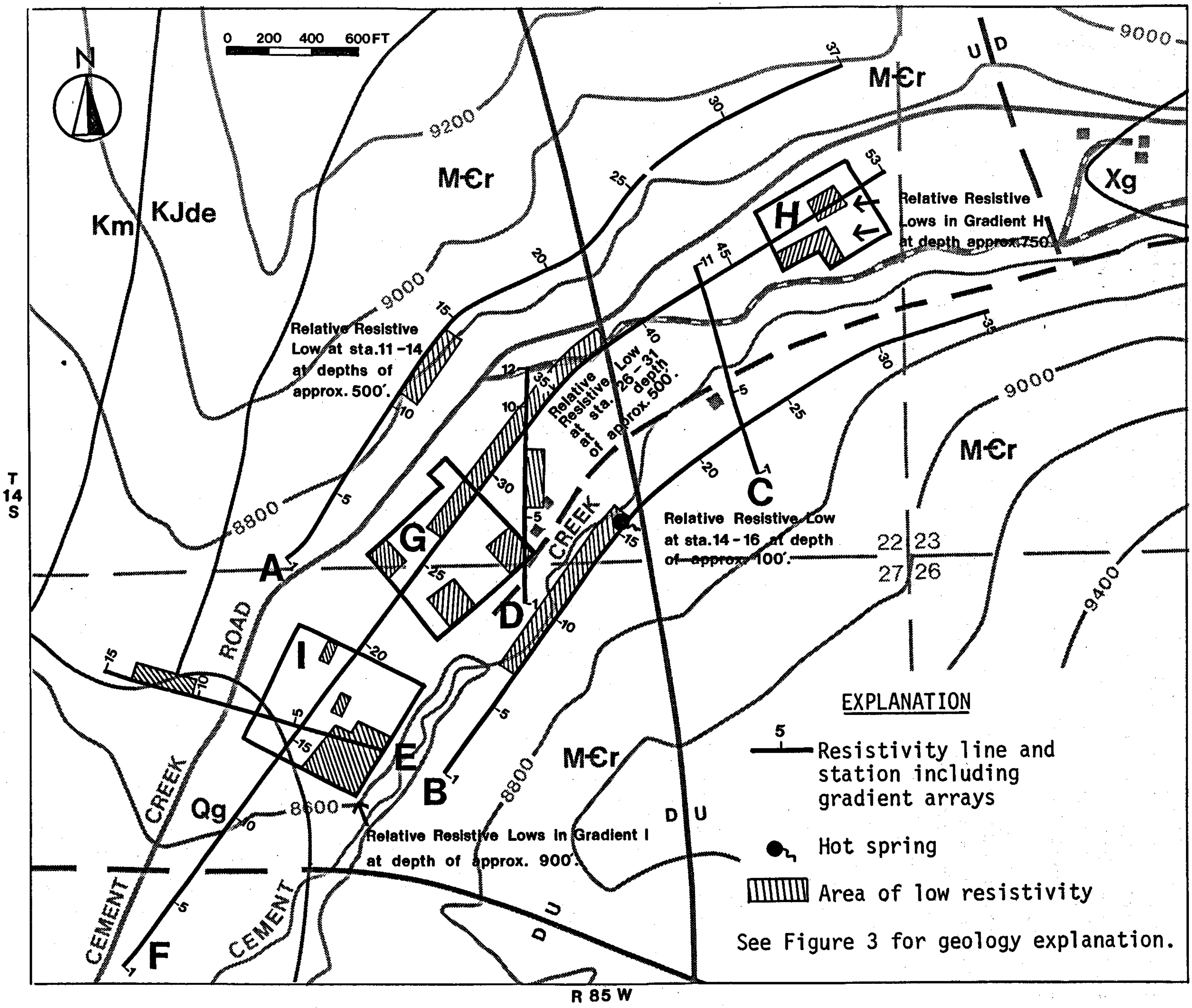


Figure 4. Ranger Warm Springs dipole-dipole resistivity survey index map.

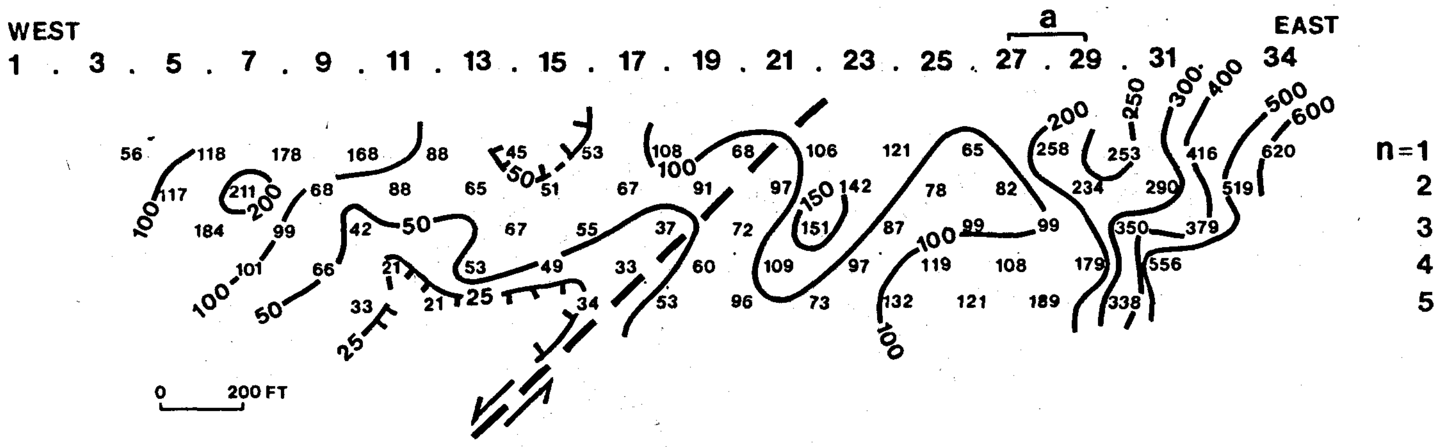


Figure 5. Dipole-Dipole Pseudosection Line A: A low resistivity zone was mapped between stations 11 and 15 with the lowest values being less than 25 ohm meters. These low values occur at a depth of approximately 500 ft (152.4 m) (n = 5 level). A mapped fault downthrown to the southwest in the vicinity of station 20 is shown. Due to an apparent change in the lithology of the bedrock the resistivity values increase from this station to the northeast.

LENGTH: 3700 ft (1128 m)
SEPARATION: n Value
DATE: 6/9/81, 6/10/81
TYPE: Dipole-Dipole
SPREAD: a = 200 ft
RESISTIVITY: In ohm meters
POSSIBLE FAULT: ▬ ▬

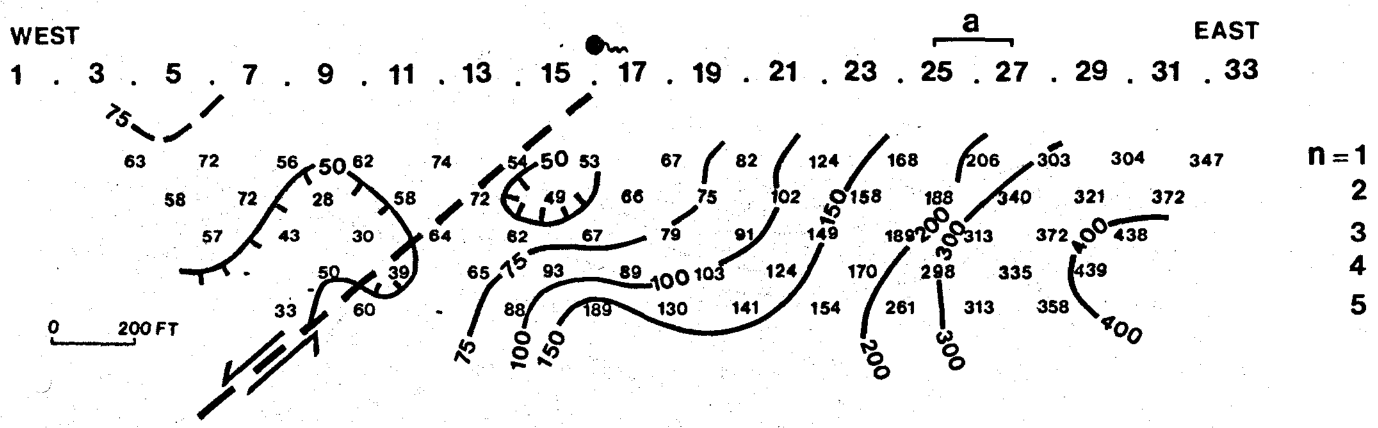


Figure 6. Dipole-Dipole Pseudosection Line B: This northeast trending line passes through the warm spring. A distinct low resistivity zone was mapped between stations 7 through 16 in the vicinity of the warm spring. The values in this zone are as low as 28 ohm-meters, which is quite similar to the low zone on line A and shows good alignment with the north-south fault that passes just east of the spring. Resistivity values increase dramatically to the east due to lithologic changes.

LENGTH: 3500 ft (1067 m)
SEPARATION: n Value
DATE: 6/10/81
TYPE: Dipole-Dipole
SPREAD: a = 200 ft
RESISTIVITY: In ohm meters
POSSIBLE FAULT: ▬ ▬
HOT SPRING: ●

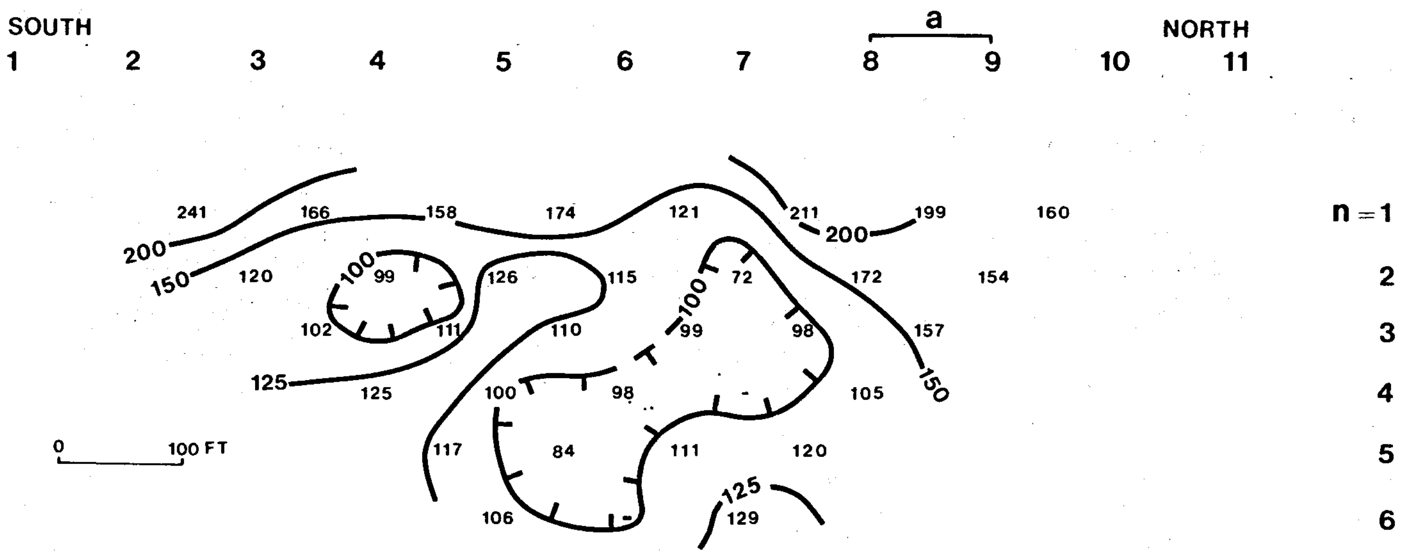


Figure 7. Dipole-Dipole Pseudosection Line C: This 1,100 ft (335 m) north-south line located east of the warm springs crosses Cement Creek. Resistivity measurements were affected by the water saturated alluvium along the creek. The near surface values are much higher than the deeper values which is probably due to water saturated aluvium. From the examination of the data no faulting was apparent.

LENGTH: 1100 ft (335 m)
SEPARATION: n Value
DATE: 6/11/81
TYPE: Dipole - Dipole
SPREAD: a = 100 ft
RESISTIVITY: In ohm meters

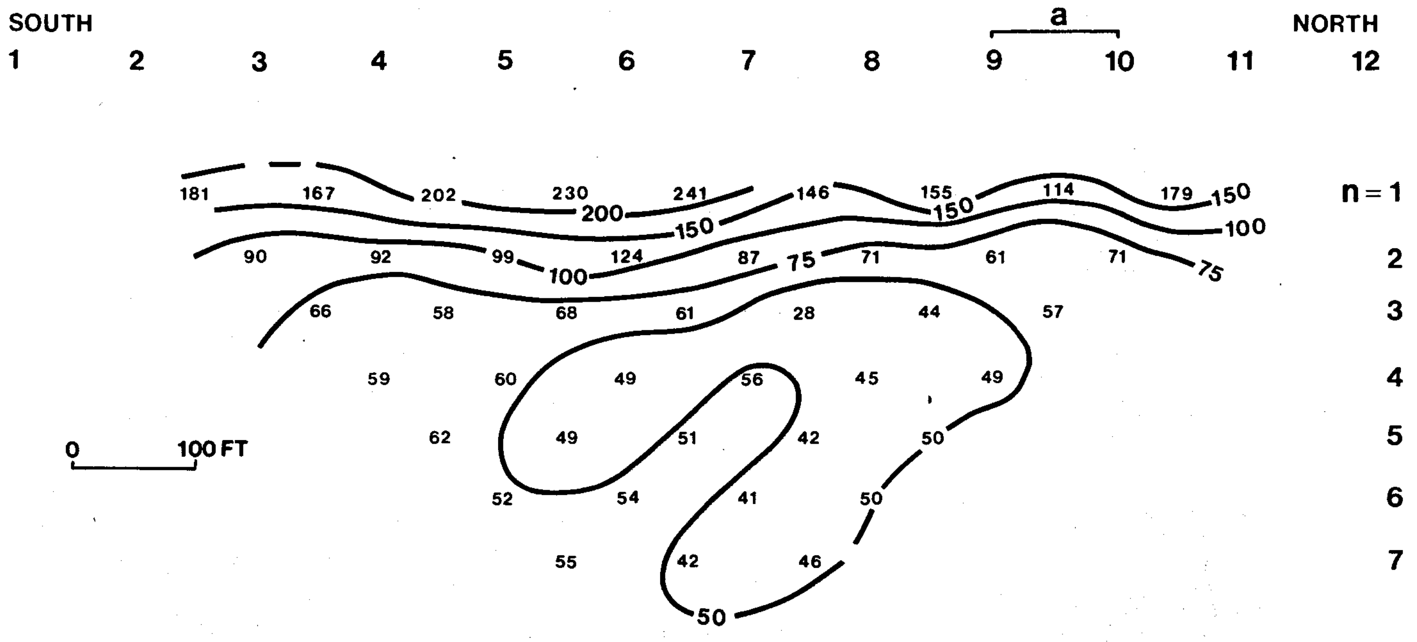


Figure 8. Dipole-Dipole Pseudosection Line D: This north-south line located west of the warm spring also crosses Cement Creek. It is 1,200 ft (366 m) in length and shows similar characteristics as line C with resistivity values decreasing with depth. These measurements indicate that the alluvium along Cement Creek is quite thick. No faulting is apparent.

LENGTH: 1200 ft (366 m)
SEPARATION: n Value
DATE: 6/12/81
TYPE: Dipole - Dipole
SPREAD: a = 100 ft
RESISTIVITY: In ohm meters

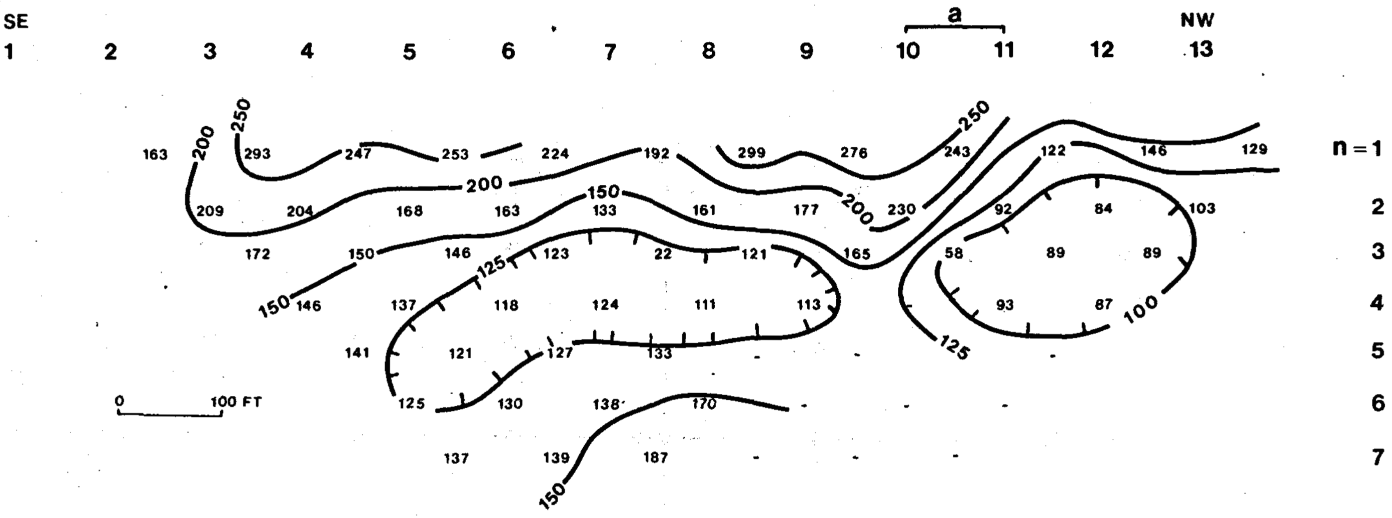


Figure 9. Dipole-Dipole Pseudosection Line E: This resistivity line trends in a northwest-southeast direction and is approximately 1,500 ft (457 m) in length. No evidence of faulting was noted. However, the contact between the alluvium of Cement Creek and the underlying bedrock is well illustrated by an increase of resistivity values at stations 6 through 8.

LENGTH: 1500 ft (457 m)
SEPARATION: n Value
DATE: 6/15/81
TYPE: Dipole-Dipole
SPREAD: a = 100 ft
RESISTIVITY: In ohm meters

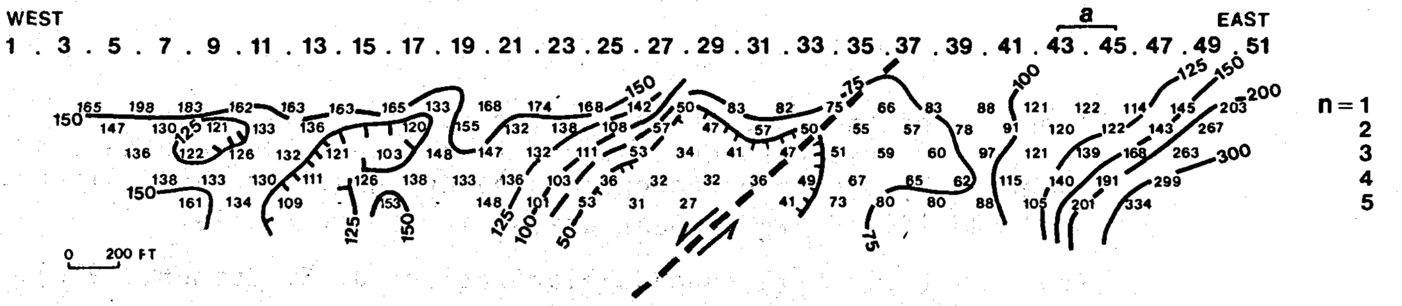
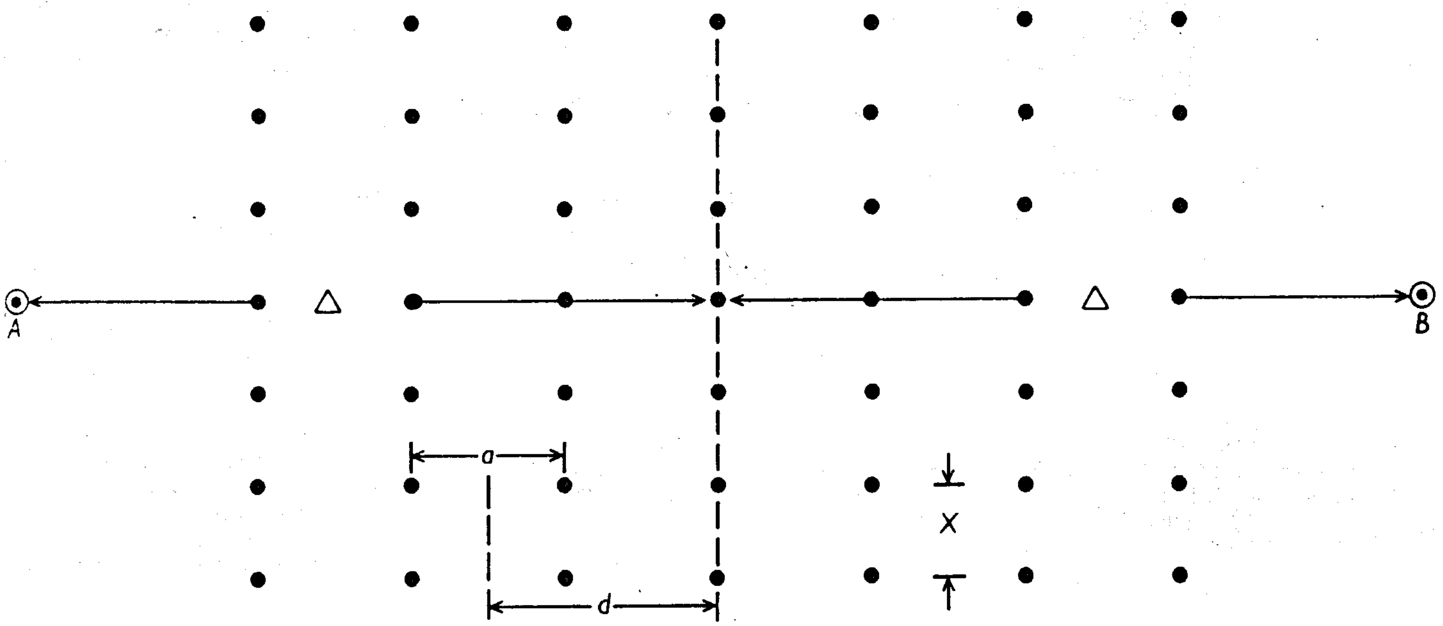


Figure 10. Dipole-Dipole Pseudosection Line F: This 5,300 ft (1.62 km) northeast trending line parallels the Cement Creek road. Resistivity measurements indicate similar characteristics with line A. A deep seated low resistivity zone was noted between stations 26 and 38 where the line crossed the north-south fault. This zone aligns itself well with the same fault illustrated on lines A and B. The resistivity values increase rapidly to the northeast, indicating a lithologic change in the bedrock.

LENGTH: 5300 ft (1615 m)
SEPARATION: n Value
DATE: 6/15/81, 6/16/81
TYPE: Dipole-Dipole
SPREAD: a = 200 ft
RESISTIVITY: In ohm meters
POSSIBLE FAULT: ▬ ▬

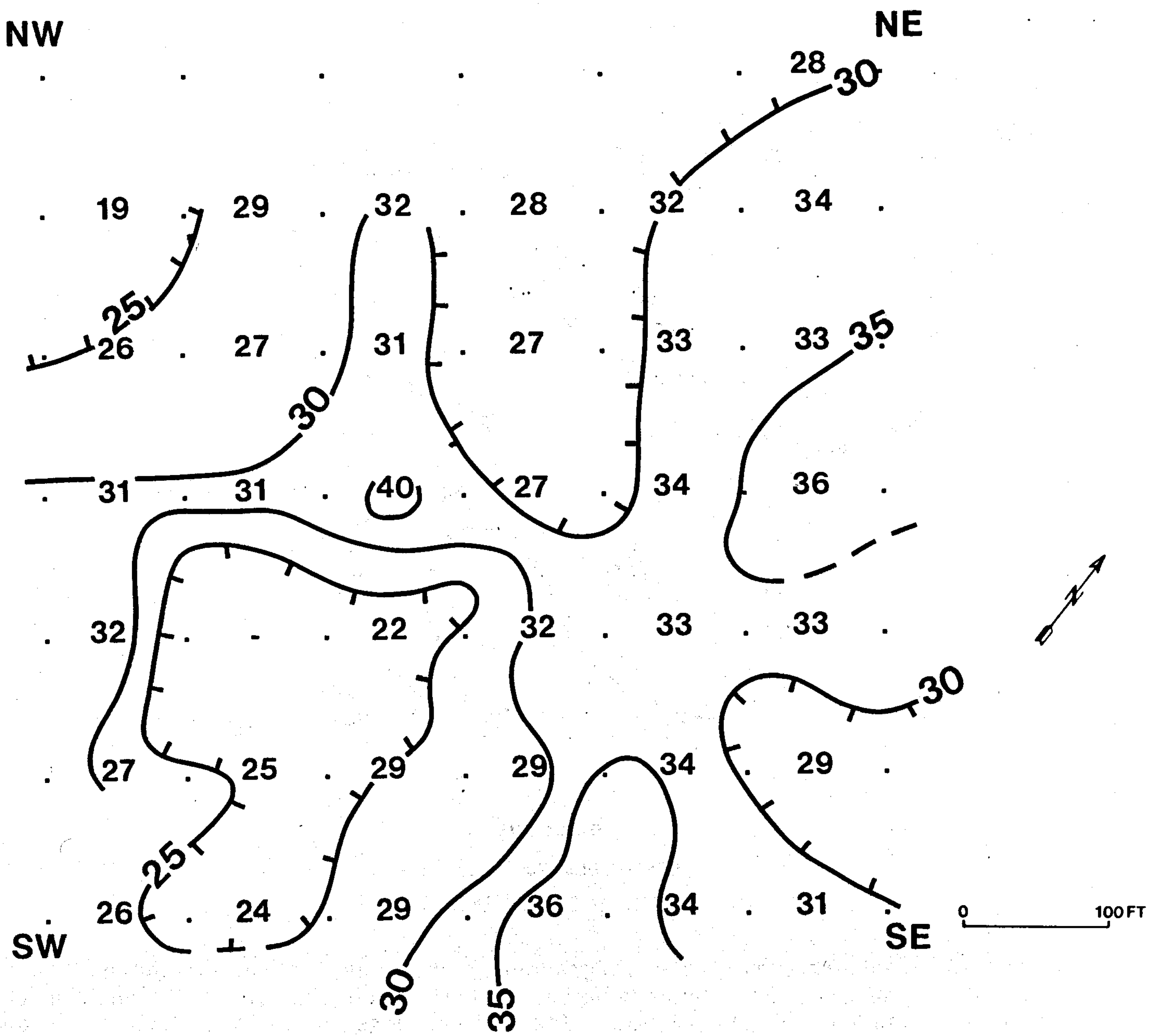


$$\rho_a = \frac{\Delta^2}{a} K_{AB} \frac{V_p}{I_p}$$

$a = 100$
$X = 100$

Figure 11. 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.

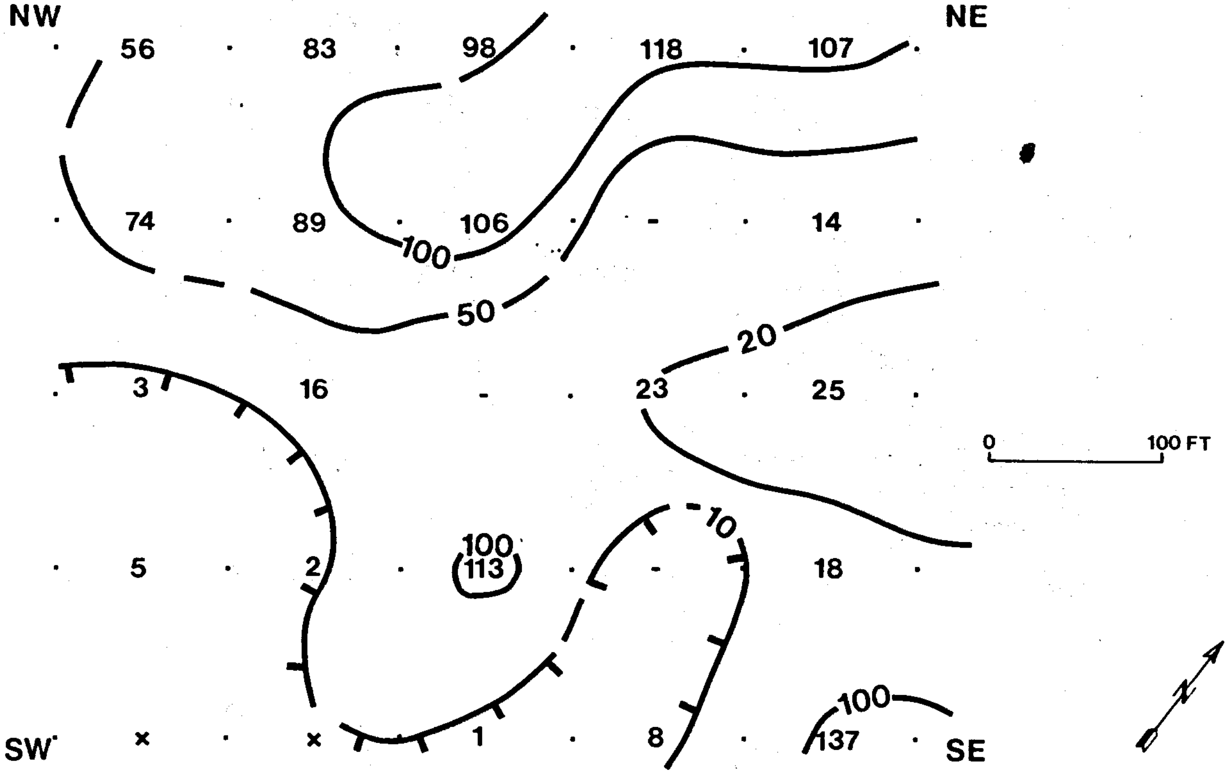
(From Principles of Induced Polarization, J. S. Sumner, 1976).



DATE : 6/17/81

DEPTH: 600-700 ft (183 - 213 m)

Figure 12. Gradient Array G: The measured resistivity values ranged from 20 to 35 ohm-meters, which appears to be an averaging affect of the sediments resistivity values. It is possible that the electrical current did not penetrate much deeper than the alluvium along Cement Creek.

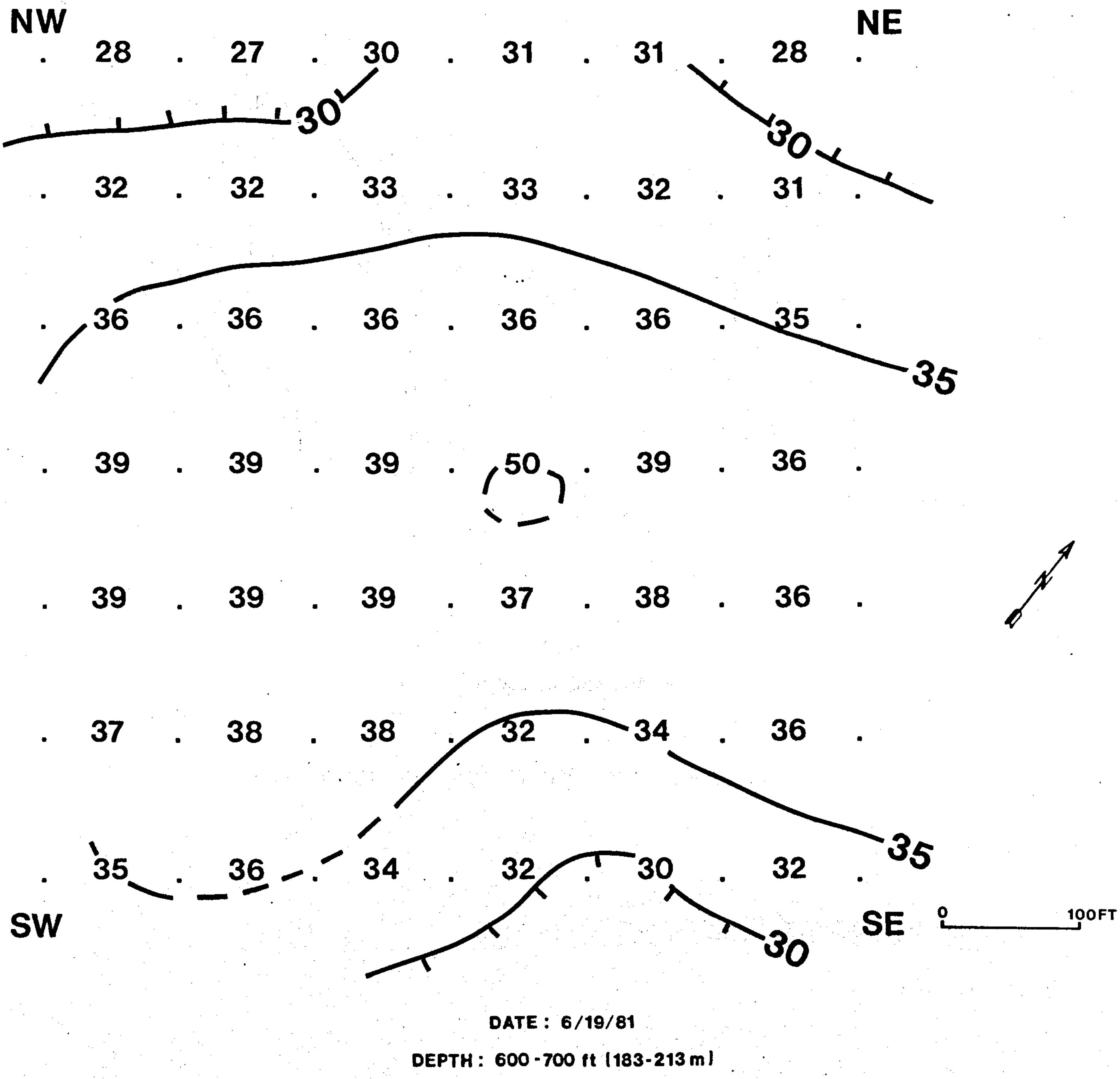


DATE: 6/18/81

DEPTH: 600-700 ft [183-213 m]

X = No data

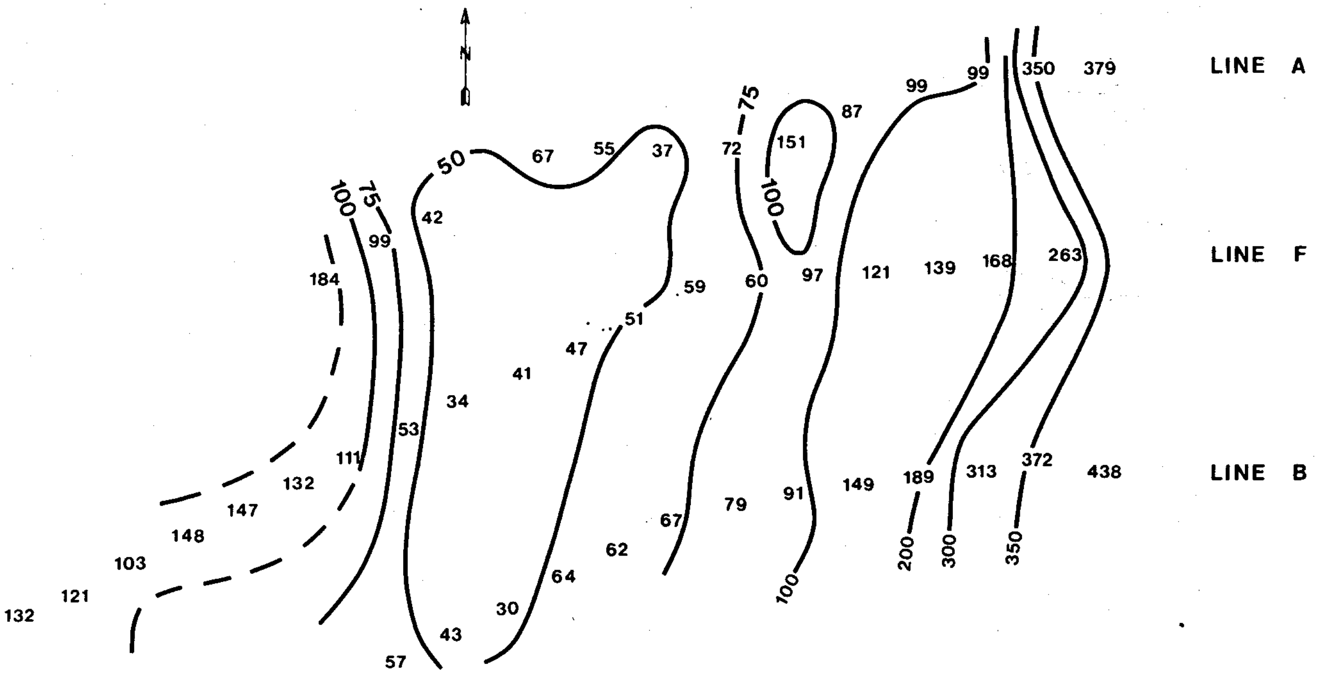
Figure 13. Gradient Array H: This gradient array was located in the northeast portion of the area and demonstrated a strong low resistivity zone in the southwest quadrant of the array. The values were very low, down to 3 ohm meters, whereas the values in the north portion of the array exceeded 100 ohm meters. This suggests a lithologic contact change in this portion of the area. As calculated, the depth of penetration exceeded a depth of 700 ft (213 m).



DATE: 6/19/81

DEPTH: 600-700 ft (183-213 m)

Figure 14. Gradient Array I: This gradient did not indicate any anomalous zones except that the resistivities decreased as the valley floor of Cement Creek was approached. The resistivity values varied very little, suggesting an averaging effect of the sediments. The values ranged from 25 to 50 ohm meters.



DATE: 6/81

DEPTH: Approx. 300 ft [91 m]

Figure 15. Composite electrical resistivity map, N = 3 level.

SOIL MERCURY SURVEYS

Introduction

The majority of 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. As part of the Ranger Warm Springs resource assessment program soil mercury geochemical surveys were conducted.

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

Matlick and Buseck (1976), in presenting the geochemical theory behind the associations of mercury with geothermal deposits, noted that mercury has great volatility and 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 four case studies where they used soil mercury concentrations as an exploration tool. Three of the four areas tested, Long Valley, California, Summer Lake, Oregon 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 Hot Springs Known Geothermal Resource Area, Utah. They analyzed the soil samples with a Jerome Instrument Corp. gold film mercury detector. The results of their investigation showed that mercury surveys can be useful for identifying and mapping faults and other structures controlling the flow of thermal waters and for delineating areas overlying near-surface thermal activity.

Objectives

The aim of the geochemical sampling program 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.

Sampling Methods

At selected sample sites, one to eight samples were taken at points within 15 to 20 ft (4.6 m to 6.1 m) of each other. The notation of sampling locality is explained in Miesch (1976). The interval between sampling sites depends on the target being considered. For areas investigated, the sample site interval was either 100 ft to 200 ft or 400 ft (30.5 m to 61 m or 122 m). When using a 400 ft (122 m) interval, the area in the immediate vicinity of the hot spring was considered the target rather than any particular fault. Sampling intervals of 200 ft (61 m) or less were used where attempts were made to delineate controlling faults. This spacing was used by Capuano and Bamford (1978). However, Klusman and Landress (1979) seem to think that the sample must be taken directly over the faulting for detection. Considering the empirical results 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 is entirely or partially 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 then collected at predetermined intervals (usually 100 ft) collected 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 15 in (38.1 cm); the depth at which the profile peaks determines the sampling depth. The other method consistently samples a soil horizon, such as the A or B horizon. The problem with using the A horizon is that its normally high organic content has been shown to have strong secondary effects in controlling mercury in the soil. Also, the sampling depth in the A horizon may not be deep enough to avoid the "baking" effect of the sun.

The method used during 1979 consisted of using profiles to determine sampling depths. A sampling depth of approximately 6 in (15.2 cm), with an interval of about .4 in (1 cm), was used for most of the profiles. During 1980, each sample was taken over an interval of 5 to 7 in (13 to 18 cm). It was hoped that some of variance due to depth would be smoothed out by sampling over a wider interval. Also at that depth it was hoped that the sun would not be affecting the soil's ability to retain mercury.

To collect a sample, the ground was broken with a shovel to a depth of 8 to 10 in (20 to 25.4 cm). A spatula and metal cup were then 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, 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 (Cupuano and Bamford, 1978; Lepeliter, 1969; Levinson, 1974).

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

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

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

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

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

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

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

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

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

For those cases where the data were sparse 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.

GEOCHEMICAL SURVEYS IN THE CEMENT CREEK AREA

Introduction

As part of the resource assessment program in the Cement Creek Valley, 19 soil samples were collected and analyzed for mercury from the Ranger Warm Springs area. The location of these sites and the analytical data are shown on Fig. 16. Unlike some of the other areas in Colorado where this method was employed, the method proved less than satisfactory in delineating the hydrogeological conditions of Ranger Warm Springs.

Soil Description

Most of the soil sampling around the Ranger Warm Spring was done at the break in the slope, just about the valley bottom (Fig 16). The soil appeared to have formed on colluvium on the hillside and on alluvium in the valley bottom. The B horizon, from which the samples were taken, was usually dark brown and quite thick, 1' to 2'. It varied from a silty texture on the hillside to clayey in valley bottom. Surrounding the warm spring is a large outcrop of travertine.

Mercury Anomalies

For representative background values, samples were collected northeast of the spring. Except for one value of 86 ppb, the values ranged from 2 ppb to 16 ppb and as such were of no use in determining the background level. Background levels were determined by analyzing data collected around the hot spring. When the data were arranged in ascending order (Table 2) it became apparent that the background level of soil mercury probably ranges from less than 1 ppb to about 30 ppb.

The analytical data are not too meaningful except for the 86 ppb value north of Cement Creek. This high value may indicate the presence of faulting or it might in some way be related to the nearby guard station. The high mercury values found in the spring or in the travertine surrounding the spring are thought to have precipitated from the spring water. It was hoped that the survey might delineate the location and direction of faulting, but, as illustrated, the data doesn't show any trends that would not be expected from the known geology.

Table 2. Mercury content (ppb) of samples collected from the Ranger Warm Springs area.

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16
17
22
22
31
62
86
94
1185

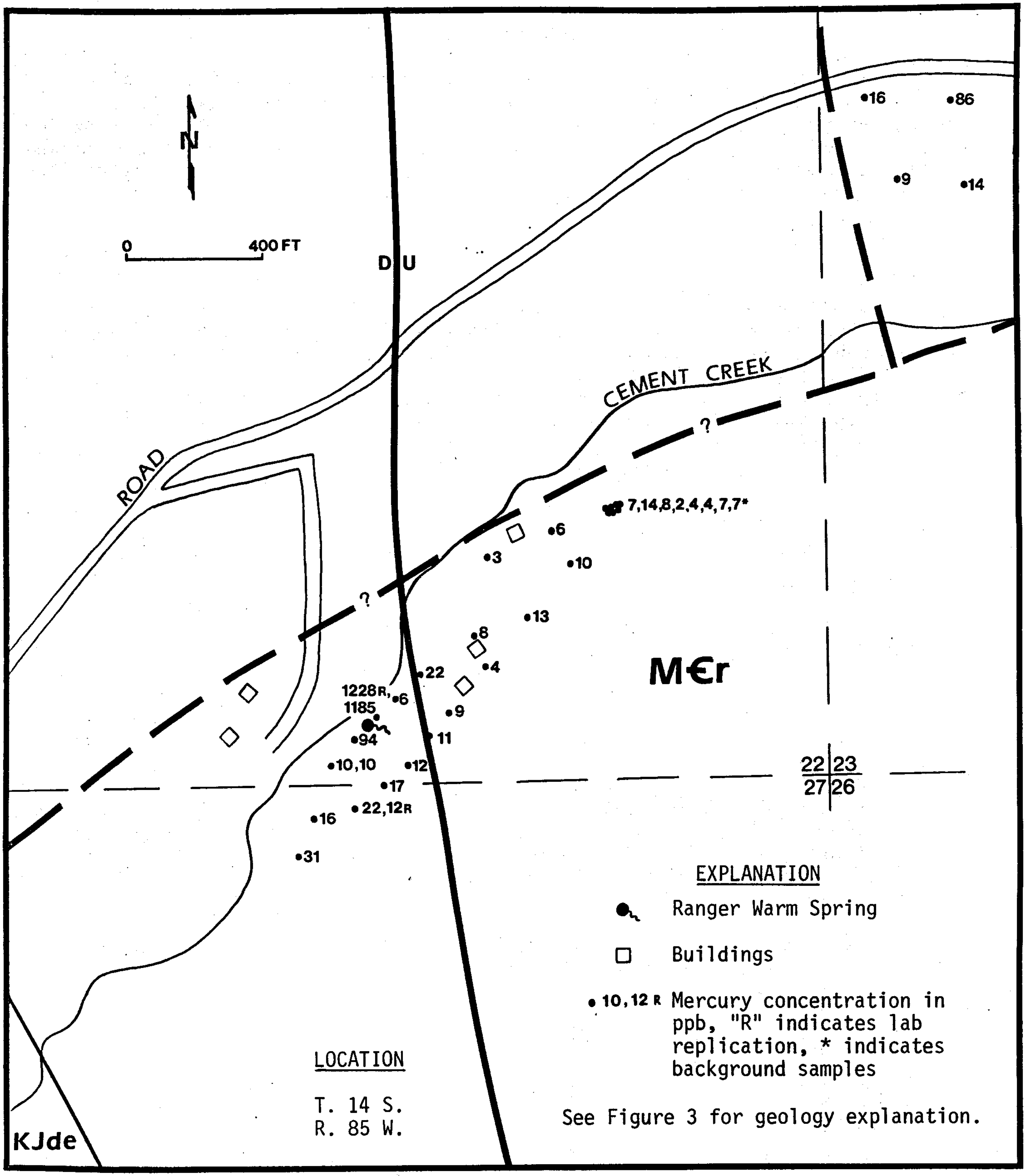

Figure 16. Location of soil mercury sample sites, Ranger Warm Springs.

SUMMARY AND CONCLUSIONS

The geothermal resources of the Cement Creek Valley north of Gunnison, Colorado were evaluated as part of a state wide resource assessment program. In this valley there are two thermal springs--Ranger and Cement Creek, approximately 4 miles apart (6.4 km). Due to access problems, this investigation was limited to the area immediately surrounding the Ranger Warm Springs. The investigation consisted of: library research; reconnaisance field geological investigation; electrical resistivity geophysical surveys; and soil mercury geochemical surveys.

The investigation showed that Ranger Warm Springs most likely is fault controlled. Geological mapping by McFarlan (1961) and Tweto (1975 and 1979) determined that there are several high angle faults in the immediate area. A branch of one of these faults, the "Granite Fault" of McFarlan (1961), passes through the Ranger Warm Springs. The geophysical surveys showed that the thermal waters are probably moving along an obscured fault lying in the valley of Cement Creek.

As part of their preliminary evaluation of the Cement Creek geothermal resources, Barrett and Pearl (1978) ran geothermometer model analyses. These models showed that the maximum reservoir temperature of the Ranger Warm Spring may range between 84°F (29°C) and 393°F (200°C). Depending upon how much of the faulting in the area is involved, the Ranger Warm Spring reservoir areal extent has been estimated to vary from 0.30 sq mi (1.01 sq km) to 0.88 sq mi (2.28 sq km) (Pearl, 1981). It was also estimated that the reservoir could contain as much as .0062 Q's (10^{15} BTU's) of heat energy (Pearl, 1981). Lacking any more precise subsurface information, the authors believe that the above estimates are a reliable indicator of the size and extent of the Ranger Warm Springs thermal system.

Studies at the Mount Princeton Hot Springs, Colorado, and elsewhere in the world have shown that most thermal waters are of meteoric origin. Hydrogeological models developed for the Ranger Warm Springs region based on geological evidence indicate that the thermal waters are probably of meteoric origin. However, they also could be of magmatic origin or a mixture of the two. Thermal waters of meteoric origin originate as deep circulation of normal groundwaters along faults in an area of above normal heat flow. Recharge of the thermal system occurs from melting snows and precipitation falling on the surrounding highlands. Thermal magmatic waters would be waters originating from the cooling of batholiths which have been postulated to underlie the Colorado Mineral Belt (Tweto, 1975).

The geothermal resources of the Ranger Warm Springs area do not appear to be of extremely high temperatures and the reservoir probably does not extend over a large geographic area. Due to the apparent low subsurface temperature of the resource, it most likely would be suited for direct uses such as space heating, recreation, or some light industry requiring low temperature heat.

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APPENDIX A

GEOTHERMAL ENERGY AND ITS POSSIBLE USES

Geothermal energy, the heat generated by natural processes beneath the earth's surface, normally occurs at great depths. In some places, however, it can be found close to or at the surface in the form of volcanoes, geysers, or hot springs. Where it occurs near the surface it can be developed and put to beneficial use. Geothermal energy in the form of hot springs has been used by mankind for medicinal and cooking purposes since the earliest days of recorded history. In the last 100 years, development of this energy source for other uses has occurred, and it is now used for such purposes as: generation of electricity; heating and cooling of buildings; processing of food and other goods; heating cattle barns, greenhouses and fish ponds; milk pasteurization; and recreation and medicinal uses. It is anticipated that in years to come, development of this energy source will increase. Figure 17 lists some of the uses geothermal energy could be put to and the temperatures required.

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

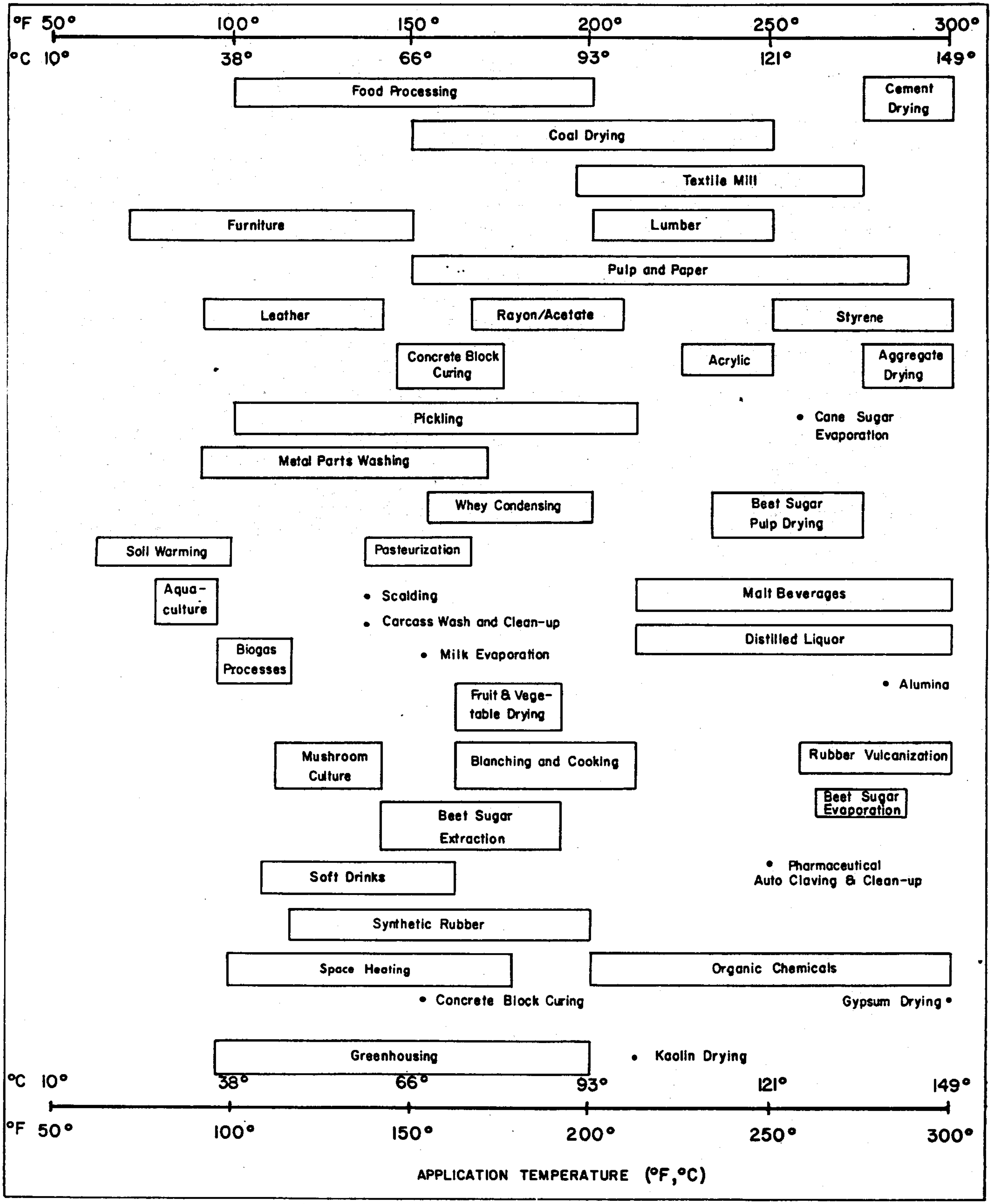


Figure 17. Temperature range for some direct uses of geothermal energy. (Adopted from Anderson and Lund, 1979, p. 4-26).

APPENDIX B

Table 3. Physical Properties and Chemical Analysis of Ranger Warm Springs and Cement Creek Warm Springs Thermal Waters

	Ranger		Cement Creek	
Arsenic (ug/l):	12	15	10	10
Boron (ug/l):	80	80	60	60
Cadmium (ug/l):	0	0	0	0
Calcium (mg/l):	73	70	75	69
Chloride (mg/l):	17	18	11	10
Fluoride (mg/l):	1.8	0.2	1.9	1.4
Iron (ug/l):	10	20	10	30
Lithium (ug/l):	140	160	90	90
Magnesium (mg/l):	22	20	22	18
Manganese (ug/l):	0	0	10	0
Mercury (ug/l):	0	0	0.2	0
Nitrogen (mg/l):	0.10	0.08	0.14	0.11
Phosphate				
Ortho diss. as P, (mg/l):	0.01	0	0.01	0
Ortho, (mg/l):	0.03	0	0.03	0
Potassium (K), (mg/l):	7.2	7.7	5.8	6
Selenium (ug/l):	0	0	0	0
Silica (mg/l :	20	18	19	17
Sodium (mg/l):	59	61	36	41
Sulfate (mg/l):	89	90	81	74
Zinc (ug/l):	30	10	10	0
Alkalinity				
As Calcium Carb. (mg/l):	285	298	248	253
As Bicarbonate (mg/l):	347	363	302	308
Hardness				
Noncarbonate (mg/l):	0	0	30	0
Total, (mg/l):	270	260	280	250
Specific Conductance (Micromohs):	700	730	640	540
Total dissolved solids (TDS), (mg/l):	461	465	401	389
pH, Field	-	7.1	-	7.2
Discharge (gpm):	132	250E	-	80
Temperature (°C):	26	27	26	25
E = Estimated				
Date sampled:	7/75	10/75	7/75	10/75

Location: Ranger Warm Springs: SW,SE, Sec 22, T.14 S., R. 85 W., 6th P.M. Gunnsion, County

Cement Creek Warm Springs: SW, SE, Sec. 18, T. 14 W., R. 84 W. 6th. P.M., Gunnison, County

Source: Barrett and Pearl, 1976.

TABLE 4. Trace Elements In Ranger Warm Springs and Cement Creek Warm Springs Thermal Waters (From Barrett and Pearl, 1976).

Values reported in Micrograms/liter (UG/L)

	Ranger W. S.	Cement Creek W.S.
Aluminum	100	30
Barium	140	82
Beryllium	0	0
Bismuth	< 4	< 3
Chromium	< 4	< 3
Cobalt	< 4	< 3
Copper	8	0
Gallium	< 2	< 1
Germanium	< 5	< 3
Lead	< 4	< 3
Nickel	< 4	< 3
Silver	0	0
Strontium	360	480
Tin	< 5	< 3
Titanium	3	10
Vandium	< 4	< 3
Zirconium	< 7	< 4

APPENDIX C

FACTORS AFFECTING ELECTRICAL RESISTIVITY MEASUREMENTS

One of the more favorable techniques used in geothermal resource exploration is electrical geophysical surveys. The basic prinicipal behind this method is that the resistence of the subsurface rocks to the passage of an electrical current can be measured.

The transmission of the electrical current is dependent upon such factors as: 1) subsurface temperature; 2) porosity of the rocks; 3) salinity of fluids contained in the rocks; and 4) clay content of the rocks. As these factors tend to be higher in geothermal systems than nongeothermal systems, the geothermal systems are distinguished by lower resistance measurements than the surrounding areas. However, it must be kept in mind that under favorable conditions nonthermal areas may be confused with thermal areas. For example, a low temperature, highly saline ground water can provide the same readings as a high temperature, moderately saline geothermal fluid. Therefore, to be most effective, electrical resistivity surveys should be used in conjuction with other methods, such as gradient temperature measurements, which are of value in determining the reason for the resistivity measurements recorded.

The method used by the Colorado Geological Survey involves inducing a manmade electrical current into the subsurface and measuring the resultant potential at two receiving electrodes (Soil Test Inc., 1968). A complete description of the equipment and field procedures used is presented in Appendecies D and E.

APPENDIX D

SCINTREX RAC-8 LOW FREQUENCY RESISTIVITY SYSTEM

During the course of this investigation a Scintrex RAC-8 Low Frequency Resistivity System was used by the Colorado Geological Survey. The following description of this system is taken from the Scintrex Manual (1971).

The Scintrex RAC-8 electrical resistivity system 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 of 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 E

RESISTIVITY FIELD PROCEDURES

Introduction

One of the most widely used electrical processing techniques for geothermal resource exploration is the resistivity profiling and sounding method. The method utilizes various arrays, but the most common are the Wenner, the Schlumberger and the Dipole-Dipole arrays. 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 data.

Before discussing the various methods used, it is necessary to consider what is actually measured by an array of current and potential electrodes (Fig. 18). By measuring (V) and current (I) and knowing the electrode configuration, a resistivity (p) is obtained. Over homogeneous isotropic ground this resistivity will be constant for any current and electrode arrangement. That is, if the current is maintained constant and the electrodes are moved around, the potential voltage (V) will adjust at each configuration to keep the ratio (V/I) constant (Sumner, 1976).

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

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

The following formula is used by all methods to calculate the apparent resistivity at a site.

General Resistivity Formula

$P_a = 2PIaV/I$

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

See Figure 18 for a resistivity schematic diagram.

Wenner Array

In the Wenner Spread (Fig. 19) the electrodes are uniformly spaced in a line (Sumner, 1976). In spite of the simple geometry, this arrangement is often quite inconvenient for field work and has some disadvantages from the theoretical point of view as well. For depth exploration using the Wenner Spread, the electrodes are expanded about a fixed center, increasing the spacing in steps. For lateral exploration or mapping the spacing remains constant and all four electrodes are moved along the line, then along another line, and so on. In mapping, the apparent resistivity for each array position is plotted against the center of the spread.

This method was not used in the study 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 elecrtode spacing is expanded symmetrically about the center of the spread. For large values of L it may be necessary to increase 2l also in order to maintain a measurable potential. This procedure is more convenient than the Wenner expanding spread because only two electrodes need move. In addition, the effect of shallow resistivity variations is constant with fixed potential spread (Sumner, 1976).

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

Dipole-Dipole Array

The potential electrodes are closely spaced and remote from the current electrodes which are close together. There is a separation between C and A, usually 1 to 5 times the dipole lengths (Fig. 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 23.

With reference to Figures 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

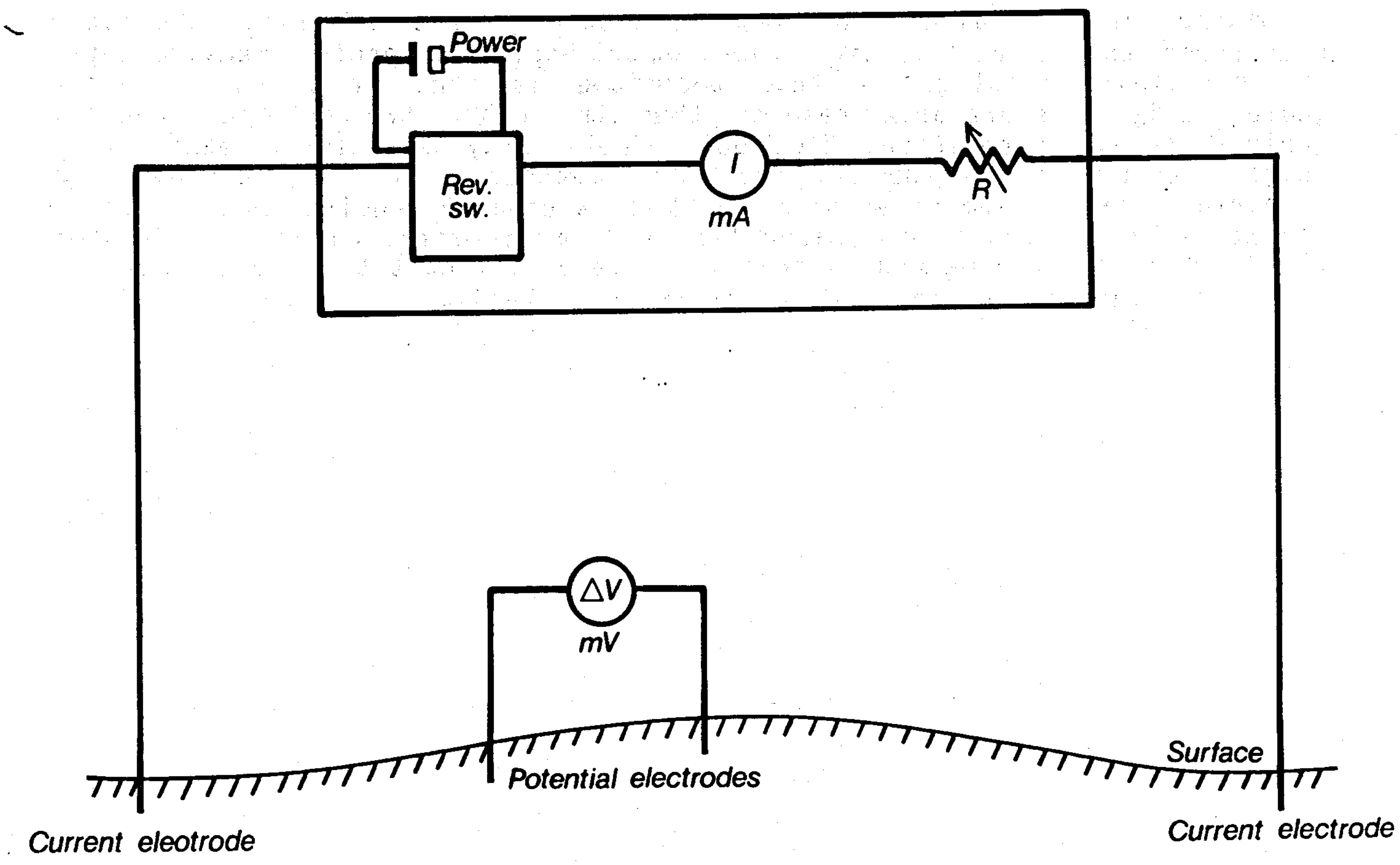
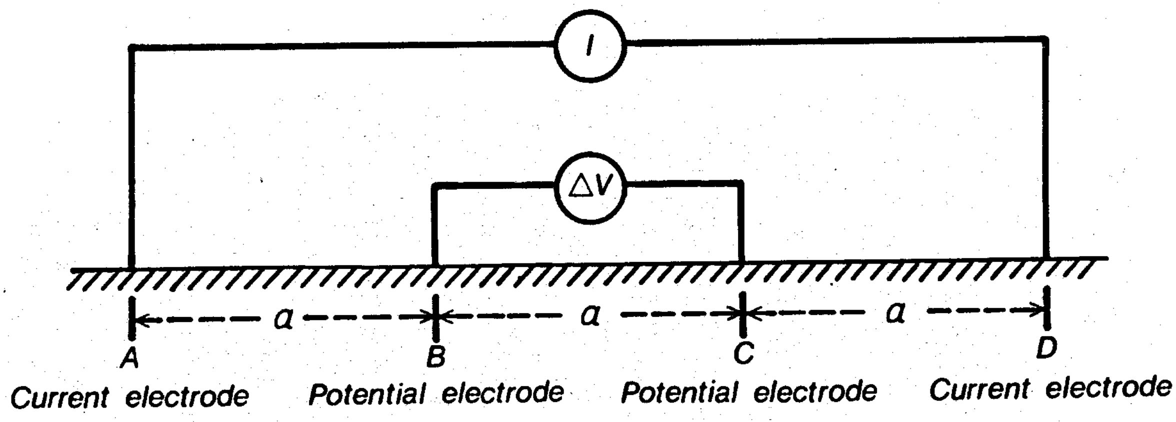


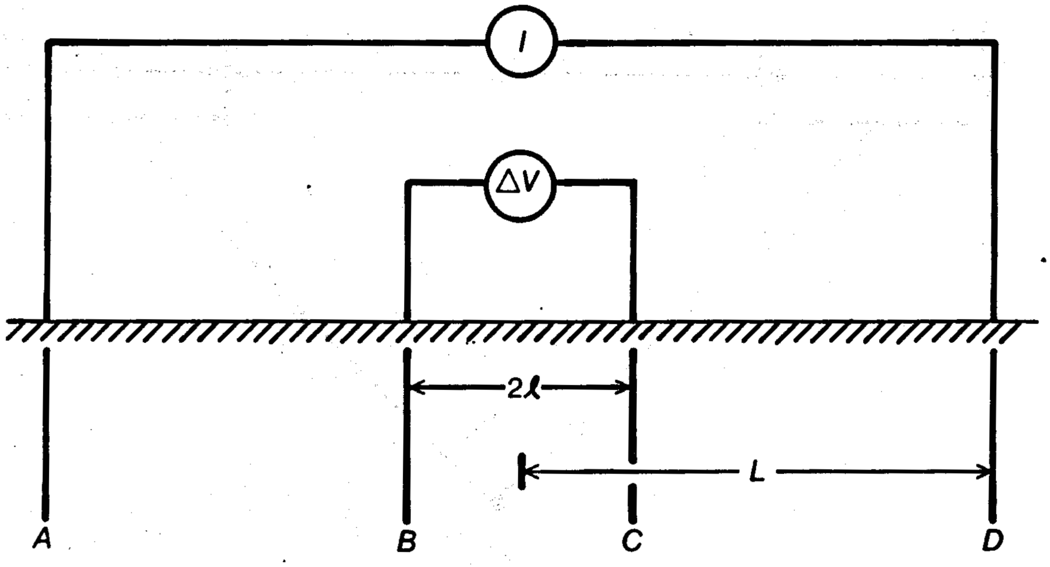
Figure 18. Schematic diagram for resistivity (from J. Combs, 1980).



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

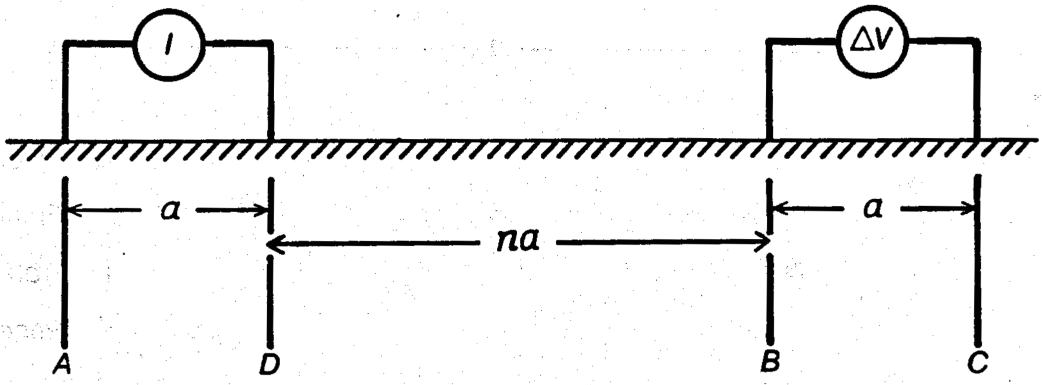
Figure 19. Wenner array (from J. Combs, 1980).

resolution of vertical and horizontal resistivity contrasts since the field procedures generate both vertical sounding and horizontal profile measurements. The principal advantage of this technique is that it produces better geologically interpretable results than the other two methods (Wenner, Schlumberger). In addition, the dipole-dipole array is easier to maneuver in rugged terrain than either of the other methods. Its main disadvantage compared to the Schlumberger array is that is usually requires more current, and therefore a heavier generator for the same penetration depth. Another disadvantage of this method is that it is very difficult to make an accurate interperation from the data collected (Sumner, 1976).



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

Figure 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).

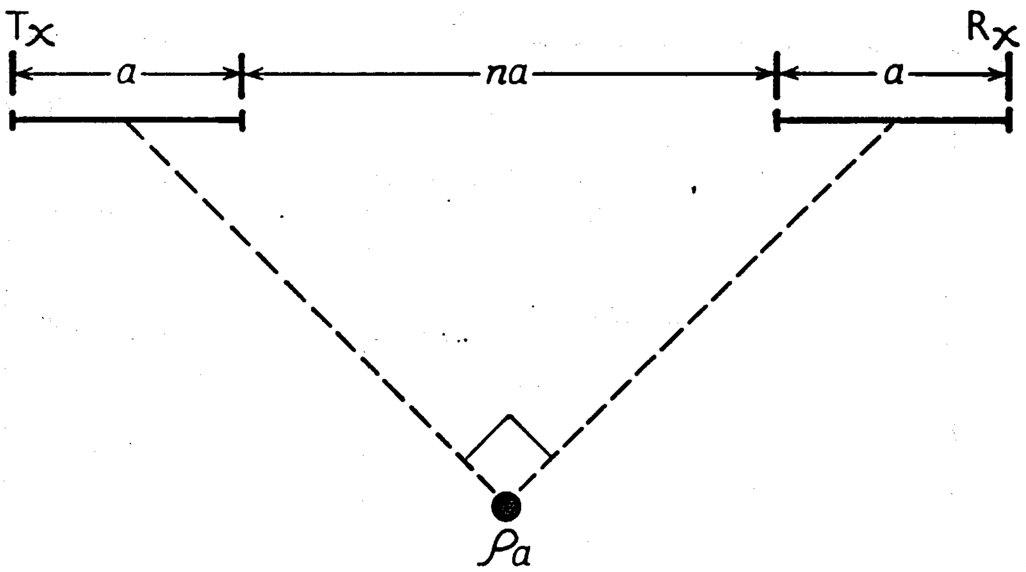


Figure 22. Data plotting scheme for dipole-dipole array (from J. Combs, 1980).

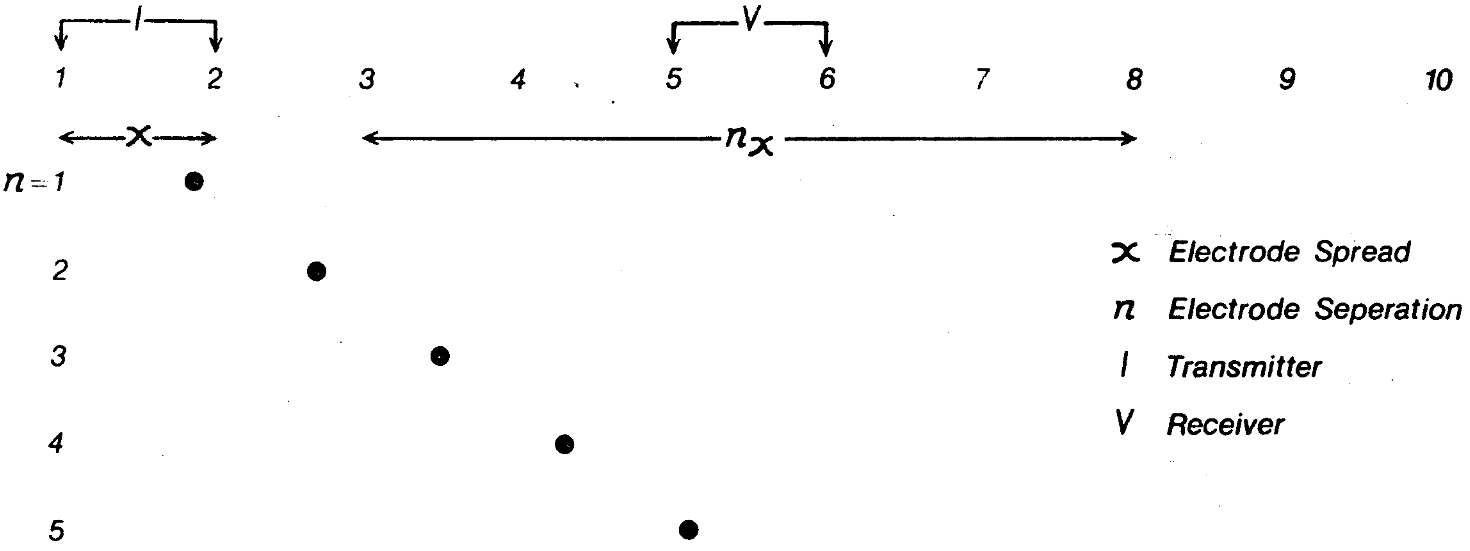


Figure 23. Typical dipole-dipole array (from J. Combs, 1980).

APPENDIX F

TABLE 5. LINE A

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Ranger Warm Springs	Line A	9 June 1981
CHIEF OPERATOR	ASSISTANTS	METHOD
Robert Fargo	Memmi and Strong	Dipole-Dipole (Nx200')

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C1-3							
5-7	10	.01	66	.49	.049	1149.07	56.30
7-9	10	.001	200	2.54	.0254	4596.28	116.75
9-11	10	.001	200	1.60	.0160	11490.69	183.85
11-13	1	.001	200	4.41	.00441	22981.38	101.35
13-15		- N.R. -					-N.R.-
C3-5							
7-9	10	.01	66	1.03	.103	1149.07	118.35
9-11	100	.001	133	0.46	.046	4596.28	211.43
11-13	10	.001	133	0.86	.0086	11490.69	98.82
13-15	1	.001	133	2.88	.00288	22981.38	66.19
15-17	1	.001	133	.82	.00083	40217.41	33.38
C5-7							
9-11	100	.001	66	1.55	.155	1149.07	178.11
1 -13	0	.001		1.49	.0149	4596.28	68.48
13-15	10	.00031	133	1.22	.00366	11490.69	42.05
15-17	1	.00031	133	3.01	.000903	22981.38	20.75
17-19	1	.00031	133	1.76	.000528	40217.41	21.23
C7-9							
11-13	100	.001	100	1.46	.146	1149.07	167.76
13-15	10	.001	100	1.92	.0192	4596.28	88.25
15-17		.001	100				-N.R.-
17-19	1	.001	100	2.30	.00230	22981.38	52.86
19-21							-N.R.-
C9-11							
13-15	10	.01	66	.77	.077	1149.07	88.48
15-17	1	.01	66	1.41	.0141	4596.28	64.81
17-19	1	.001	166	5.83	.00583	11490.69	66.99
19-21	1	.001	166	2.15	.00215	22981.38	49.41
21-23	1	.001		.84	.00084	40217.41	33.78

TABLE 5. LINE A (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C11-13							
15-17	1	.01	66	3.94	.0394	1149.07	45.27
17-19	1	.01	66	1.12	.0112	4596.28	51.48
19-21	1	.001	166	4.82	.00482	11490.69	55.39
21-23	1	.001	166	1.44	.00144	22981.38	33.09
23-25	1	.001	166	1.31	.00131	40217.41	52.68
C13-15	1	.01	66	4.65	.0465	1149.07	53.43
19-21	10	.001	166	1.46	.0146	4596.28	67.11
21-23	1	.001	166	3.22	.00322	11490.69	37.00
23-25	1	.001	166	2.61	.00261	22981.38	59.98
25-27	1	.001	200	2.39	.00239	40217.41	96.12
C15-17							
19-21	10	.01	66	.94	.094	1149.07	108.01
19-23	1	.01	66	1.99	.0199	4596.28	91.47
23-25	10	.001	200	.63	.0063	11490.69	72.39
25-27	1	.001	200	4.73	.00473	22981.38	108.70
27-29	1	.001	200	1.82	.00182	40217.41	73.20
C17-19							
21-23	10	.01	66	.59	.059	1149.07	67.80
23-25	1	.01		2.10	.0210	4596.28	96.52
25-27	10	.001	100	1.31	.0131	11490.69	150.53
27-29	1	.001		4.21	.00421	22981.38	96.75
29-31	1	.001	133	3.28	.00328	40217.41	131.91
C19-21							
23-25	100	.001	100	.92	.092	1149.07	105.71
25-27	10	.001		3.08	.0308	4596.28	141.57
27-29	10	.001		.76	.0076	11490.69	87.33
29-31	1	.001	100	5.16	.00516	22981.38	118.58
31-33	1	.001	100	3.02	.00302	40217.41	121.46
C21-23	10	.01	66	1.05	.105	1149.07	121.65
27-29	1	.01	66	1.69	.0169	4596.28	77.67
29-31	10	.001		.86	.0086	11490.69	98.82
31-33	10	.001		.47	.0047	22981.38	108.01
33-35	10	.001		.47	.0047	40217.41	189.02
C23-25							
27-29	100	.001		.57	.057	1149.07	65.50
29-31	10	.001		1.78	.0178	4596.28	81.81
31-33	10	.001		.86	.0086	11490.69	98.82
33-35	10	.001		.78	.0078	22981.38	179.25
35-37	10	.001		.84	.0084	40217.41	337.83

TABLE 5. LINE A (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C25-27							
29-31	100	.001	133	2.19	.219	1149.07	257.65
31-33	100	.001		.51	.051	4596.28	234.41
33-35	10	.001		3.05	.0305	11490.69	350.47
35-37	10	.001		2.42	.0242	22981.38	556
C27-29							
31-33	100	.001		2.20	.2207	1149.07	252.8
33-35	100	.001		.63	.063	4596.28	289.75
35-37	10	.001		3.30	.033	11490.69	379.19
C29-31							
33-35	100	.001	100	3.62	.362	1149.07	415.96
35-37	100	.001		1.13	.113	4596.28	519.38
C31-33							
35-37	1000	.001		.54	.54	1149.07	620.50

LEGEND: Range = Gain
MA = Dummy TX Current Switch
Vp = Balance Control to Null Meter
G.F. = Geometric Factor
Pa = Apparent Resistivity
DV/I = Range x MA x Vp
N.R. = No Reading

APPENDIX F

TABLE 6. LINE B

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	**PROJECT**	**DATE**
Ranger Warm Springs	Line B	10 June 1981
CHIEF OPERATOR	**ASSISTANTS**	**METHOD**
Robert Fargo	Memmi and Strong	Dipole-Dipole (Nx200')

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C1-3							
5-7	10	.001	133	5.50	.055	1149.07	63.20
7-9	10	.001		1.27	.0127	4596.28	58.37
9-11	10	.001		.50	.0050	11490.69	57.45
11-13			700	LOW?		22981.38	-N.R.-
13-15	1	.001		.82	.00082	40217.41	32.98
C3-5							
7-9	100	.001	200	.63	.063	1149.07	72.39
9-11	10	.001	200	1.56	.0156	4596.28	71.70
11-13	10	.001	225	.37	.0037	11490.69	42.52
13-15	1	.001	200	2.17	.00217	22981.38	49.87
15-17	1	.001	225	1.51	.00151	40217.41	60.73
C5-7							
9-11	100	.001	200	.49	.049	1149.07	62.05
11-13	10	.001	200	.60	.0060	4596.28	27.58
13-15	1	.001		2.60	.0026	11490.69	29.88
15-17	1	.001		1.70	.0017	22981.38	39.06
17-19							-N.R.-
C7-9							
11-13	100	.001	100	.54	.054	1149.07	62.05
13-15	10	.001	100	1.27	.0127	4596.28	58.37
15-17	10	.001	100	.56	.00563	11490.69	64.35
17-19	1	.001	100	2.82	.00282	22981.38	64.81
19-21	1	.001	100	2.18	.00218	40217.41	87.67
C9-11							
13-15	100	.001	100	.65	.065	1149.07	74.69
15-17	10	.001		1.56	.0156	4596.28	71.70
17-19	10	.001		.54	.0054	11490.69	62.05
19-21	10'	.00031	200	1.35	.00405	22981.38	93.07
21-23	10'	.00031	200	1.57	.00471	40217.41	189.42

TABLE 6. LINE B (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C11-13							
15-17	100	.001	100	.47	.047	1149.07	54.01
17-19	10	.001	100	1.07	.0107	4596.28	49.18
19-21	10'	.00031	200	1.94	.00582	11490.69	66.88
21-23	10'	.00031	200	1.30	.00390	22981.38	89.63
23-25	10'	.00031	200	1.08	.00324	40217.41	130.30
C13-15							
17-19	100	.001	100	.46	.046	1149.07	52.86
19-21	10	.001	100	1.43	.0143	4596.28	65.73
21-23	10	.001	100	.69	.0069	11490.69	79.29
23-25	10	.001	100	.45	.0045	22981.38	103.42
25-27	1	.001	133	3.50	.0035	40217.41	140.76
C15-17							
19-21	100	.001	100	.46	.046	1149.07	52.86
21-23	10	.001	100	1.64	.0164	4596.28	75.38
23-25	10	.001	100	.79	.0079	11490.69	90.78
25-27	10	.001	133	.54	.0054	22981.38	124.1
27-29	1	.001		3.82	.00382	40217.41	153.63
C17-19							
21-23	100	.001	100	.71	.071	1149.07	81.58
23-25	10	.001		2.22	.0222	4596.28	102.04
25-27	10	.001	133	1.30	.0130	11490.69	149.38
27-29	10	.001		.74	.0074	22981.38	170.06
29-31	10	.001	133	.65	.0065	40217.41	261.41
C19-21							
23-25	100	.001	100	1.08	.108	1149.07	124.1
25-27	10	.001	100	3.43	.0343	4596.28	157.65
27-29	10	.001	100	1.64	.0164	11490.69	188.45
29-31	10	.001	133	1.30	.0130	22981.38	298.76
31-33	10	.001	133	.78	.0078	40217.41	313.70
C21-23							
25-27	100	.001	100	1.46	.146	1149.07	167.76
27-29	100	.001	100	.41	.041	4596.28	188.45
29-31	10	.001	100	2.73	.0273	11490.69	313.70
31-33	10	.001	100	1.46	.0146	22981.38	335.53
33-35	10	.001	100	.89	.0089	40217.41	357.93
C23-25							
27-29	100	.001		1.80	.180	1149.07	206.83
29-31	100	.001		.74	.074	4596.28	340.12
31-33	10	.001	100	3.24	.0324	11490.69	372.3
33-35	10	.001	100	1.91	.0191	22981.38	438.94

TABLE 6. LINE B (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C25-27							
29-31	100	.001	100	2.64	.264	1149.07	303.35
31-33	100	.001		.70	.070	4596.28	321.74
33-35	10	.001		3.81	.0381	11490.69	437.80
C27-29							
31-33	100	.001	100	2.65	.265	1149.07	304.50
33-35	100	.001	100	.81	.081	4596.28	372.30
C29-31							
33-35	100	.001	133	3.02	.302	1149.07	347.02

LEGEND:
Range = Gain
MA = Dummy TX Current Switch
Vp = Balance Control to Null Meter
G.F. = Geometric Factor
Pa = Apparent Resistivity
DV/I = Range x MA x Vp
N.R. = No Reading

APPENDIX F

TABLE 7. LINE C

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Ranger Warm Springs	Line C	11 June 1981
CHIEF OPERATOR	ASSISTANTS	METHOD
Robert Fargo	Memmi and Strong	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C1-2							
3-4	1000	.001	200	.42	.42	574.53	241.30
4-5	100	.001	200	.52	.052	2298.14	119.50
5-6	10	.001	200	1.78	.0178	5745.34	102.27
6-7	10	.001	200	1.09	.0109	11490.69	125.25
7-8	10	.001	200	.58	.0058	20108.71	116.63
8-9	1	.001	225	3.29	.00329	32173.93	105.85
C2-3							
4-5	100	.001	166	2.89	.289	574.53	166.04
5-6	100	.001	166	.43	.043	2298.14	98.82
6-7	10	.001	166	1.93	.0193	5745.34	110.89
7-8	10	.001	166	.87	.0087	11490.69	99.97
8-9	10	.001	166	.42	.0042	20108.71	84.46
9-10							-N.R.-
C3-4							
5-6	100	.001	166	2.75	.275	574.53	158.00
6-7	100	.001	166	.55	.055	2298.14	126.40
7-9	10	.001	166	1.91	.0191	5745.34	109.74
8-9	1	.001		8.55	.00855	11490.69	98.25
9-10	10	.001		.55	.0055	20108.71	110.60
10-11	1	.001		4.0	.0040	32173.93	128.70
C4-5							
6-7	100	.001	166	3.03	.303	574.53	174.08
7-8	100	.001		.50	.050	2298.14	114.91
8-9	10	.001		1.73	.0173	5745.34	99.31
9-10	1	.001	166				-N.R.-
10-11	1	.001	166	5.96	.00596	20108.71	119.85
C5-6							
7-8	100	.001	133	2.11	.211	574.53	121.23
8-9	10	.001		3.14	.0314	2298.14	72.16
9-10	10	.001		1.70	.01703	5745.34	97.67
10-11	10	.001		.92	.0092	11490.69	105.71

TABLE 7. LINE C (CONT).

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C6-7							
8-9	10	.01	66	3.67	.367	574.53	210.85
9-10	10	.01		.75	.075	2298.14	172.36
10-11	1	.01		2.74	.0274	5745.34	157.42
C7-8							
9-10	100	.001	133	3.47	.347	574.53	199.36
10-11	100	.001	133	.67	.067	2298.14	153.98
C8-9							
10-11	10	.01	66	2.78	.278	574.53	159.72

LEGEND: Range = Gain
MA = Dummy TX Current Switch
Vp = Balance Control to Null Meter
G.F. = Geometric Factor
Pa = Apparent Resistivity
DV/I = Range x MA x Vp
N.R. = No Reading

APPENDIX F

TABLE 8. LINE D

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Ranger Warm Springs	Line D	12 June 1981
CHIEF OPERATOR	ASSISTANTS	METHOD
Robert Fargo	Memmi and Strong	Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C1-2							
3-4	10	.01	66	3.15	.315	574.53	180.98
4-5	10	.01		.39	.039	2298.14	89.63
5-6	1	.01		1.14	.0114	5745.34	65.50
6-7	10	.001	300	.57	.0051	11490.69	58.60
7-8	1	.001		3.06	.00306	20108.71	61.53
8-9	1	.001		1.63	.00163	32173.93	52.44
9-10	1	.001		1.14	.00114	48260.90	55.02
C2-3							
4-5	10	.01	100	2.90	.290	574.53	166.61
5-6	10	.01		.40	.040	2298.14	91.93
6-7	1	.01		1.01	.0101	5745.34	58.03
7-8	10	.001	400	.52	.0052	11490.69	59.75
8-9	1	.001	400	2.45	.00245	20108.71	49.27
9-10	1	.001	400	1.67	.00167	32173.93	53.73
10-11	1	.001	433	.87	.00087	48260.90	41.99
C3-4							
5-6	10	.01	100	3.51	.351	574.53	201.66
6-7	10	.01		.43	.043	2298.14	98.82
7-8	10	.001	400	1.19	.0119	5745.34	68.37
8-9	10	.001		.43	.0043	11490.69	49.41
9-10	1	.001		2.55	.00255	20108.71	51.28
10-11	1	.001		1.26	.00126	32173.93	40.54
11-12	1	.001		.96	.00096	48260.90	46.33
C4-5							
6-7	100	.01	66	.40	.40	574.53	229.81
7-8	10	.01	66	.54	.054	2298.14	124.10
8-9	10	.001	225	1.06	.0106	5745.34	60.90
9-10	10	.001	225	.49	.0049	11490.69	56.30
10-11	1	.001	225	2.10	.00210	20108.71	42.23
11-12	1	.001	225	1.54	.00154	32173.93	49.55

TABLE 8. LINE D (CONT.)

Sta.	Range	MA	Voltage	V_P	DV/I	G.F.	P_a
C5-6							
7-8	100	.01	66	.42	.42	574.53	241.30
8-9	10	.01		.38	.038	2298.14	87.33
9-10	10'	.00031	200	3.61	.00483	5745.34	27.75
10-11	10'	.00031		1.31	.00393	11490.69	45.16
11-12	10'	.00031		.83	.00249	20108.71	50.07
C6-7							
8-9	100	.001	133	2.54	.254	574.53	145.93
9-10	10	.001	133	3.10	.0310	2298.14	71.24
10-11	10	.001	133	.77	.0077	5745.34	44.24
11-12	10	.001	133	.43	.0043	11490.69	49.41
C7-8							
9-10	100	.001	225	2.69	.269	574.53	154.55
10-11	1	.01	66	2.67	.0267	2298.14	61.36
11-12	1	.01		1.00	.010	5745.34	57.45
C8-9							
10-11	10	.01	66	1.98	.198	574.53	113.76
11-12	10	.01	66	.31	.031	2298.14	71.24
C9-10							
11-12	10	.01		3.12	.312	574.53	179.25

LEGEND: Range = Gain
MA = Dummy TX Current Switch
Vp = Balance Control to Null Meter
G.F. = Geometric Factor
Pa = Apparent Resistivity
DV/I = Range x MA x Vp
N.R. = No Reading

APPENDIX F

TABLE 9. LINE E

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION Ranger Warm Springs	**PROJECT** Line E	**DATE** 15 June 1981
CHIEF OPERATOR Robert Fargo	**ASSISTANTS** Memmi and Strong	**METHOD** Dipole-Dipole (Nx100')

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C1-2							
3-4	100	.001	300	2.83	.283	574.53	162.59
4-5	100	.001		.91	.091	2298.14	209.13
5-6	10	.001	275	3.00	.0307	5745.34	172.36
6-7	10	.001		1.27	.0064	11493.4	73.56
7-8	10	.001		.70	.0070	20108.71	140.76
8-9	1	.001		3.90	.0039	32173.93	125.48
9-10	1	.001		2.83	.00283	48260.90	136.58
C2-3							
4-5	100	.01	66	.51	.510	574.53	293.01
5-6	100	.001	166	.89	.089	2298.14	204.53
6-7	10	.001		2.61	.0261	5745.34	149.95
7-8	10	.001		1.19	.0119	11490.69	136.74
8-9	10	.001		.60	.0060	20108.71	120.65
9-10	1	.001	166	4.04	.00404	32173.93	129.98
10-11	1	.001		2.89	.00289	48260.90	139.47
C3-4							
5-6	100	.01	66	.43	.43	574.53	247.05
6-7	10	.01		.73	.073	2298.14	167.76
7-8	10	.001	166	2.54	.0254	5745.34	145.93
8-9	10	.001		1.03	.0103	11490.69	118.35
9-10	10	.001		.63	.0063	20108.71	126.68
10-11	10	.001		.43	.0043	32173.93	138.35
11-12	1	.001	200	3.87	.00387	48260.90	186.77
C4-5							
6-7	100	.01	66	.44	.44	574.53	252.80
7-8	10	.01		.71	.071	2298.14	163.17
8-9	10	.001	300	2.15	.0215	5745.34	123.52
9-10	10	.001	300	1.08	.0108	11490.69	124.10
10-11	10	.001	300	.65	.0066	20108.71	132.72
11-12	10	.001	300	.53	.0053	32173.93	170.52
12-13		.001	333				-N.R.-

TABLE 9. LINE E (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C5-6							
7-8	100	.01	66	.39	.39	574.53	224.07
8-9	10	.01	100	.58	.058	2298.14	133.29
9-10	1	.01		2.13	.0213	5745.34	122.38
10-11	1	.01		.97	.0097	11490.69	111.46
11-12		.01					-N.R.-
12-13		TX would not lock onto higher					-N.R.-
13-14			power settings				-N.R.-
C6-7							
8-9	10	.01	100	3.34	.334	2 574.53	191.89
9-10	10	.01	100	.70	.070	2298.14	160.87
10-11	1	.01	100	2.10	.0210	5745.34	120.65
11-12	1	.01	100	.98	.0098	11490.69	112.61
12-13		TX getting too close to buried telephone					-N.R.-
13-14	cables to line between stations 11 & 12 and at						-N.R.-
14-15	Station #9 (?)						-N.R.-
C7-8							
9-10	100	.01	100	.52	.52	574.53	298.76
10-11	10	.01		.77	.077	2298.14	176.96
11-12	1	.01		2.88	.0288	5745.34	165.47
12-13	1						-N.R.-
13-14							-N.R.-
14-15							-N.R.-
C8-9							
10-11	100	.01	66	.48	.48	574.53	275.78
11-12	10	.01	66	1.00	.0100	2298.14	229.8
12-13	1	.01	66	1.01	.0101	5745.34	58.03
13-14	1	.01		.81	.0081	11490.69	93.07
14-15							-N.R.-
C9-10							
11-12	100	.01	100	.51	.51	574.53	293.01
12-13	1	.01		4.01	.0401	2298.14	92.16
13-14	1	.01		1.55	.0155	5745.34	89.05
14-15	1	.01		.76	.0076	11490.69	87.33

TABLE 9. LINE E (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C10-11							
12-13	100	.001	200	2.12	.212	574.53	121.80
13-14	10	.001	200	3.64	.0364	2298.14	83.65
14-15	10	.001	200	1.55	.0155	5745.34	89.05
C11-12							
13-14	100	.001	275	2.54	.254	574.53	145.93
14-15	100	.001	275	.45	.045	2298.14	103.42
C12-13							
14-15	100	.001	275	2.24	.224	574.53	128.70

LEGEND:
Range = Gain
MA = Dummy TX Current Switch
Vp = Balance Control to Null Meter
G.F. = Geometric Factor
Pa = Apparent Resistivity
DV/I = Range x MA x Vp
N.R. = No Reading

APPENDIX F

TABLE 10. LINE F

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	**PROJECT**	**DATE**
Ranger Warm Springs	Line F	16 June 1981
CHIEF OPERATOR	**ASSISTANTS**	**METHOD**
Robert Fargo	Memmi and Strong	Dipole-Dipole (Nx200')

Sta.	Range	MA	Voltage	V_P	DV/I	G.F.	P_a
C1-3							
5-7	10	.01	100	1.44	.144	1149.07	165.47
7-9	10	.01		.32	.032	4596.28	147.08
9-11	1	.01	133	1.18	.0118 *	11490.69	135.59
11-13	10	.001	333	.60	.0060	22981.38	137.89
13-15	10	.001		.40	.0040	40217.41	160.87
C3-5							
7-9	10	.01	66	1.72	.172	1149.07	197.64
9-11	1	.01		2.82	.0282	4596.28	129.61
11-13	10	.001	166	1.06	.0106	11490.69	121.80
13-15	1	.001	166	5.79	.00579	22981.38	133.06
15-17	1	.001		3.32	.00332	40217.41	133.52
C5-7							
9-11	10	.01	66	1.59	.159	1149.07	182.70
11-13	10	.001	133	2.63	.0263	4596.28	120.88
13-15	10	.001		1.10	.0110	11490.69	126.40
15-17	1	.001	166	5.65	.00565	22981.38	129.84
17-19	10	.001		.27	.002728	40217.41	108.59
C7-9							
11-13	10	.01	66	1.41	.141	1149.07	162.02
13-15	10	.001	166	2.89	.0289	4596.28	132.83
15-17	10	.001	166	1.15	.0115	11490.69	132.14
17-19	1	.001	166	4.84	.00484	22981.38	111.23
19-21							-N.R.-
C9-11							
13-15	10	.01	66	1.42	.142	1149.07	163.17
15-17	1	.01		2.95	.0295	4596.28	135.59
17-19	10	.001	200	1.05	.01053	11490.69	120.65
19-21	10	.001		.55	.0055	22981.38	126.40
21-23	10	.001	225	.38	.0038	40217.41	152.83

TABLE 10. LINE F (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C11-13							
15-17	10	.01	66	1.42	.142	1149.07	163.17
17-19	1	.001	275				-N.R.-
19-21	10 or 1	.001	275	8.94	.00894	11490.69	102.73
21-23	10	.001	275	.60	.0060	22981.38	137.89
23-25		.001					-N.R.-
C13-15							
17-19	10	.01	66	1.44	.144	1149.07	165.47
19-21	10	.001	225	2.62	.0262	4596.28	120.42
21-23	10	.001		1.29	.0129	11490.69	148.23
23-25	10	.001		.58	.0058	22981.38	133.29
25-27	1	.001		3.70	.0037	40217.41	148.80
C15-17							
19-21	100	.001	133	1.16	.116	1149.07	133.29
21-23	10	.001	133	3.37	.0337	4596.28	154.89
23-25	10	.001	133	1.28	.0128	11490.69	147.08
25-27	10	.001	133	.59	.0059	22981.38	135.59
27-29	10	.001	133	.25	.0025	40217.41	100.54
C17-19							
21-23	10	.01	66	1.46	.146	1149.07	167.76
23-25	1	.01		2.87	.0287	4596.28	131.91
25-27	10	.001	133	1.15	.0115	11490.69	132.14
27-29	10	.001	133	.45	.0045	22981.38	103.42
29-31	1	.001		1.32	.00132	40217.41	53.09
C19-21							
23-25	10	.01	66	1.51	.151	1149.07	173.51
25-27	10	.001	200	3.00	.0300	4596.28	137.89
27-29	10	.001	200	.92	.0092	11490.69	111.46
29-31	1	.001	200	1.55	.00155	22981.38	35.62
31-33	1	.001		.77 *	.00077	40217.41	30.97
C21-23							
25-27	10	.01	66	1.46	.146	1149.07	167.76
27-29	1	.01		2.35	.0235	4596.28	108.01
29-31	10	.001	166	.46	.0046	11490.69	52.86
31-33	1	.001		1.40	.0014	22981.38	32.17
33-35	1	.001		.67	.00067	40217.41	26.95
C23-25							
27-29	10	.01	66	1.24	.124	1149.07	142.48
29-31	10	.001	100	1.23	.0123	4596.28	56.53
31-33	1	.001	100	2.92	.00292	11490.69	33.55
33-35	1	.001	100	1.38	.00138	22981.38	31.71
35-37		.001	133				-N.R.-

TABLE 10. LINE F (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C25-27							
29-31	10	.001	100	4.33	.0433 *	1149.07	49.75
31-33	10	.001	133	1.03	.0103	4596.28	47.34
33-35	1	.001		3.55	.00355	11490.69	40.79
35-37	1	.001		1.58	.00158	22981.38	36.31
37-39	1	.001		1.01	.00101	40217.41	40.62
C27-29							
31-33	100	.001	100	.72	.072	1149.07	82.73
33-35	10	.001	133	1.24	.0124	4596.28	56.99
35-37	10	.001	133	.41	.0041	11490.69	47.11
37-39	1	.001	133	2.14	.00214	22981.38	49.18
39-41	1	.001		1.81	.00181	40217.41	72.79
C29-31							
33-35	10	.01	66	.71	.071	1149.07	81.58
35-37	10	.001	225	1.09	.0109	4596.28	50.10
37-39	1	.001	225	4.44	.00444	11490.69	51.02
39-41	1	.001		2.90	.0029	22981.38	66.65
41-43	1	.001		2.00	.0020	40217.41	80.43
C31-33							
35-37	10	.01	66	.65	.065	1149.07	74.69
37-39	10	.001	250	1.19	.0119	4596.28	54.70
39-41	10	.001	250	.51	.0051	11490.69	58.60
41-43	1	.001	250	2.81	.00281	22981.38	64.58
43-45	10	.001		.20	.0020	40217.41	80.43
C33-35							
37-39	10	.01	66	.57	.057	1149.07	65.50
39-41	1	.01		1.25	.0125	4596.28	57.45
41-43	10	.001	166	.52	.0052	11490.69	59.75
43-45	10	.001		.27	.0027	22981.38	62.05
45-47	10	.001		.22	.0022	40217.41	88.48
C35-37							
39-41	10	.01	66	.72	.072	1149.07	82.73
41-43	10	.001	200	1.70	.0170	4596.28	78.14
43-45	10	.001	200	.84	.0084	11490.69	96.52
45-47	10	.001	200	.50	.0050	22981.38	114.91
47-49	10	.001		.26	.0026	40217.41	104.57
C37-39							
41-43	10	.01	66	.77	.077	1149.07	88.48
43-45	1	.01		1.97	.0197	4596.28	90.55
45-47	10	.001	166	1.05	.0105	11490.69	120.65
47-49	10	.001		.61	.0061	22981.38	140.19
49-51	10	.001		.50	.0050	40217.41	201.09

TABLE 10. LINE F (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.	P_a
C39-41							
43-45	10	.01	66	1.05	.105	1149.07	120.65
45-47	10	.001	200	2.62	.0262	4596.28	120.42
47-49	10	.001	200	1.21	.0121	11490.69	139.04
49-51	10	.001	200	.83	.00835	22981.38	190.75
51-53	10	.001		.83	.0083	40217.41	333.80
C41-43							
45-47	10	.01	66	1.06	.106	1149.07	121.80
47-49	10	.001	200	2.66	.0266	4596.28	122.26
49-51	10	.001		1.46	.0146	11490.69	167.76
51-53	10	.001		1.30	.0130	22981.38	298.76
C43-45							
47-49	10	.01	66	.99	.099	1149.07	113.76
49-51	10	.001	200	3.11	.0311	4596.28	142.94
51-53	0	.001	200	2.29	.0229	11490.69	263.14
C45-47							
49-51	10	.01	66	1.26	.126	1149.07	144.78
51-53	10	.01		.58	.058	4596.28	266.58
C47-49							
51-53	10	.01	66	1.77	.177	1149.07	203.39

LEGEND: Range = Gain
MA = Dummy TX Current Switch
Vp = Balance Control to Null Meter
G.F. = Geometric Factor
Pa = Apparent Resistivity
DV/I = Range x MA x Vp
N.R. = No Reading
* = Questionable Reading

APPENDIX F

TABLE 11. LINE G.

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Ranger Warm Springs	Line G	16 June 1981
CHIEF OPERATOR	ASSISTANTS	METHOD
Robert Fargo	Memmi and Strong	Gradient Array a = 100' = 900'

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.			P_a
1	10	.001	300	1.47	.0147	.11	.28	.76	27.58
2	10	.001	275	1.79	.0179	.11	.28	.76	33.59
3	10	.001		1.50	.0150	.11	.17	.875	32.40
4	10	.001	250	1.18	.0118	.11	.06	.96	27.97
5	10	.001		1.35	.0135	.11	.06	.96	32.00
6	10	.001		1.34	.0134	.11	.17	.875	28.95
7	10	.001		1.06	.0106	.11	.28	.76	19.89
8	10	.001		1.40	.0140	.11	.28	.76	26.27
9	10	.001		1.26	.01236	.11	.17	.875	27.22
10	10	.001		1.29	.0129	.11	.06	.96	30.57
11	10	.001		1.14	.0114	.11	.06	.96	27.02
12	10	.001		1.55	.0155	.11	.17	.875	33.48
13	10	.001		1.74	.0174	.11	.28	.76	32.65
14	10	.001		1.92	.0192	.11	.28	.76	36.03
15	10	.001		1.57	.0157	.11	.17	.875	33.92
16	10	.001		1.12	.0112	.11	.06	.96	26.55
17	10	.001		1.70	.0170	.11	.06	.96	40.29
18	10	.001		1.45	.0145	.11	.17	.875	31.32
19	10	.001		1.66	.0166	.11	.28	.76	31.35
20	10	.001		1.69	.0169	.11	.28	.76	31.71
21									
22	10	.001		.92	.0092	.11	.06	.96	21.81
23	10	.001		1.37	.0137	.11	.06	.96	32.47
24	10	.001	300	1.53	.0153	.11	.17	.875	33.05
25	10	.001		1.75	.0175	.11	.28	.76	32.84
26	10	.001		1.53	.0153 *	.11	.28	.76	28.71
27	10	.001		1.58	.0158	.11	.17	.875	34.13
28	10	.001		1.21	.0121	.11	.06	.96	28.68
29	10	.001		1.23	.0123	.11	.06	.96	29.15
30	10	.001		1.14	.0114 *	.11	.17	.875	24.63
31	10	.001		1.44	.0144	.11	.28	.76	27.02
32	10	.001		1.41	.0141	.11	.28	.76	26.46
33	10	.001		1.10	.0110	.11	.17	.875	23.76

TABLE 11. LINE G (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.			P_a
34	10	.001		1.21	.0121	.11	.06	.96	28.68
35	10	.001		1.50	.0150	.11	.06	.96	35.55
36	10	.001		1.55	.0155	.11	.17	.875	33.48
37	10	.001		1.66	.0166	.11	.28	.76	31.15

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

APPENDIX F

TABLE 12. LINE H.

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION
Ranger Warm Springs
CHIEF OPERATOR
Robert Fargo

PROJECT
Line H
ASSISTANTS
Memmi and Strong

DATE
18 June 1981
METHOD
Gradient Array
a = 100' = 750'

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.			P_a
H-1	100	.001	166	.78	.078	.13	.27	.80	106.98
H-2	100	.001		.74	.074	.13	.13	.93	117.99
H-3	100	.001		.59	.059	.13	0	.97	98.12
H-4	10	.001		5.21	.0521	.13	.13	.93	83.07
H-5	100	.001		.41	.041	.13	.27	.80	56.24
H-6	100	.001		.54	.054	.13	.27	.80	74.07
H-7	100	.001		.56	.056	.13	.13	.93	89.29
H-8	100	.001		.64	.064	.13	0	.97	106.44
H-9		.001							-N.R.-
H-10	100	.001		.10	.010 *	.13	.27	.80	13.72
H-11	100	.001		.18	.018 *	.13	.27	.80	24.69
H-12	100	.001		.15	.015 *	.13	.13	.93	23.92
H 13		.001							-N.R.-
H-14	100	.001		.10	.010 *	.13	.13	.93	15.94
H-15	10	.001		.21	.0021 *	.13	.27	.80	2.88
H-16	10	.001		.38	.0038 *	.13	.27	.80	5.21
H-17	10	.001		.10	.0010 *	.13	.13	.93	1.59
H-18	100	.001		.68	.068	.13	0	.97	113.09
H-19	100	.001		.13	.013				-N.R.-
H-20	100	.001		1.00	.100	.13	.27	.80	17.83
H-21	100	.001		.05	.005 *	.13	.27	.80	137.06
H-22	10	.001		.08	.0008 *	.13	.13	.93	7.97
H-23						.13	.13	.93	1.28

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

APPENDIX F

TABLE 13. LINE I.

COLORADO GEOLOGICAL SURVEY
Geophysical Exploration
(Resistivity Survey)

LOCATION	PROJECT	DATE
Ranger Warm Springs	Line I	19 June 1981
CHIEF OPERATOR	ASSISTANTS	METHOD
Robert Fargo	Memmi and Strong	Gradient Array a = 100' = 900'

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.			P_a
1	10	.001	166	1.50	.0150	.11	.28	.76	28.15
2	10	.001		1.42	.0142	.11	.17	.875	30.68
3	10	.001		1.32	.0132	.11	.06	.96	31.29
4	10	.001		1.27	.0127	.11	.06	.96	30.10
5	10	.001		1.27	.0127	.11	.17	.875	27.44
6	10	.001		1.47	.0147	.11	.28	.76	27.58
7	10	.001		1.69	.0169	.11	.28	.76	31.71
8	10	.001		1.46	.0146	.11	.17	.875	31.54
9	10	.001		1.40	.0140	.11	.06	.96	33.18
10	10	.001		1.40	.0140	.11	.06	.96	33.18
11	10	.001		1.50	.0150	.11	.17	.875	32.40
12	10	.001		1.67	.0167	.11	.28	.76	31.34
13	10	.001		1.85	.0185	.11	.28	.76	34.71
14	10	.001		1.65	.0165	.11	.17	.875	35.64
15	10	.001		1.53	.0153	.11	.06	.96	36.26
16	10	.001		1.51	.0151	.11	.06	.96	35.79
17	10	.001		1.65	.0165	.11	.17	.875	35.64
18	10	.001		1.91	.0191	.11	.28	.76	35.84
19	10	.001		2.09	.0209	.11	.28	.76	39.22
20	10	.001		1.82	.0182	.11	.17	.875	39.32
21	10	.001		1.66	.0166	.11	.06	.96	39.34
22	10	.001		2.11	.0211	.11	.06	.96	50.01
23	10	.001		1.82	.0182	.11	.17	.875	39.32
24	10	.001	166	1.94	.0194	.11	.28	.76	36.40
25	10	.001		1.92	.0192	.11	.28	.76	36.03
26	10	.001		1.74	.0174	.11	.17	.875	37.59
27	10	.001		1.56	.0156	.11	.06	.96	36.97
28	10	.001		1.64	.0164	.11	.06	.96	38.87
29	10	.001		1.82	.0182	.11	.17	.875	39.32
30	10	.001		2.06	.0206	.11	.28	.76	38.65
31	10	.001		1.95	.0195	.11	.28	.76	36.59
32	10	.001		1.76	.0176	.11	.17	.875	38.02
33	10	.001		1.59	.0159	.11	.06	.96	37.68
34	10	.001		1.34	.0134	.11	.06	.96	31.76

TABLE 13. LINE I (CONT.)

Sta.	Range	MA	Voltage	V_p	DV/I	G.F.			P_a
35	10	.001		1.59	.0159	.11	.17	.875	34.35
36	10	.001		1.94	.0194	.11	.28	.76	36.40
37	10	.001		1.70	.0170	.11	.28	.76	31.90
38	10	.001		1.40	.0140	.11	.17	.875	30.24
39	10	.001		1.37	.0137	.11	.06	.96	32.47
40	10	.001		1.43	.0143	.11	.06	.96	33.89
41	10	.001		1.67	.0167	.11	.17	.875	36.08
42	10	.001		1.85	.0185	.11	.28	.76	34.71

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

APPENDIX G
GEOMETRIC FACTOR TABLES

TABLE 14. SCHLUMBERGER GEOMETRIC FACTOR TABLE

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

TABLE 15. DIPOLE-DIPOLE GEOMETRIC FACTOR TABLE

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

TABLE 16. WENNER GEOMETRIC FACTOR TABLE

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