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GEOTHERMAL SURVEYS, INC.

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DIRECT USE GEOTHERMAL INVESTIGATIONS

ELKO, NEVADA

PHASE I - RESOURCE ASSESSMENT

GEOLOGICAL AND GEOPHYSICAL SURVEYS

<u>PART I - TEXT</u>

PART II - APPENDIX

Geothermal Surveys, Inc.
South Pasadena, California

16 November 1979

CONTENTS

Contents - (Cont'd)

List of Tables

List of Plates

List of Figures

List of Figures (Cont'd)

List of Figures (Cont'd)

List of Figures (Cont'd)

INTRODUCTION

General Statement

This report presents results and conclusions from a geological and geophysical assessment of the geothermal resources available for direct use in the vicinity of Elko, Nevada. This work comprises a part of the Resource Assessment Phase of the program outlined in a proposal to the U.S. Department of Energy entitled "Field Experiments for Direct Uses of Geothermal Energy: Elko, Nevada", dated 18 July 1979. The City of Elko is located in the northeastern part of the state, as shown in Figure 1.

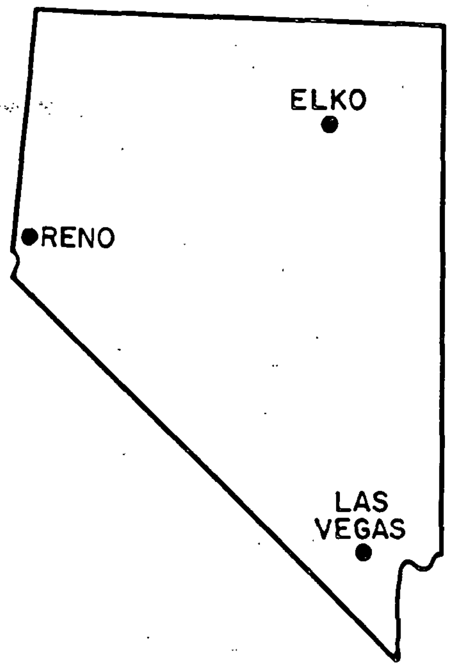
The objectives of the Resource Assessment Phase are threefold:

1) to locate the sites most favorable for drilling hot-water wells,

2) to assess sufficiently that portion of the reservoir being produced to assure long-term continuance,

3) to develop information that can be used to assess the characteristics of the entire reservoir.

Attainment of these goals involves an evaluation of the geologic and geohydrologic characteristics of the geothermal reservoir. In addition, certain engineering and economic factors play a significant role in determining the optimum drill-site locations.



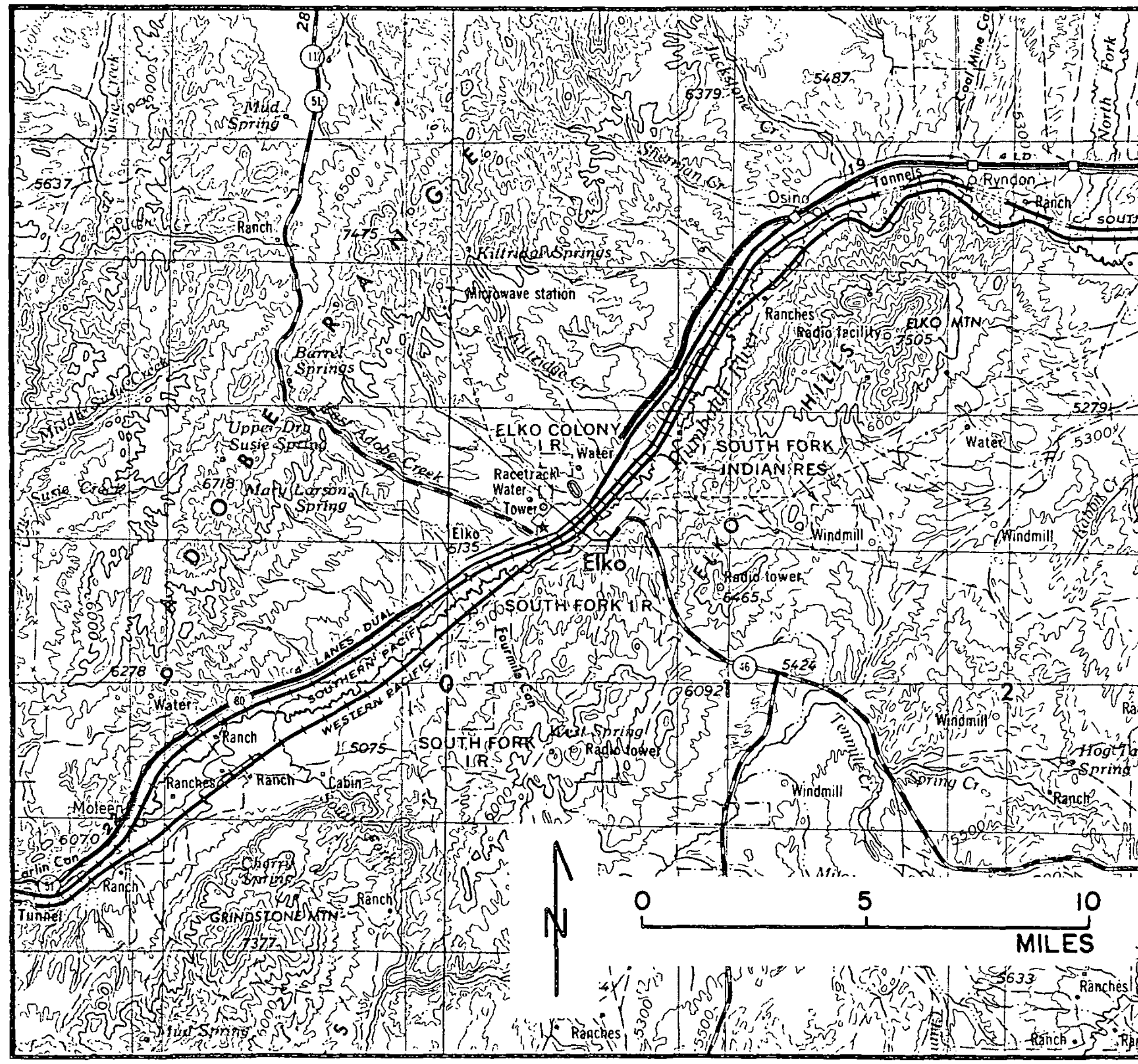


FIGURE 1

LOCATION MAP

ELKO, NEVADA

The work described herein consists of reconnaissance geologic mapping, geochemical analyses of water from springs and wells, and a number of geophysical surveys. Reconnaissance geologic mapping was conducted to examine exposed rock types and geologic structures that relate to the distribution and control of the hot water systems. Water samples were collected and analyzed to estimate possible source temperatures and to characterize the chemical constituents of the geothermal waters. Thermal, direct-current electrical, and electromagnetic geophysical surveys were carried out to obtain further information on the extent of the thermal resource.

Background

In June, 1977 Geothermal Surveys, Inc. (GSI) conducted a thermal exploration survey for the City of Elko. The purpose of the survey was to locate favorable sites for drilling municipal water wells. The results of the early work revealed an anomalous trend of higher temperatures extending northeast beneath the City from a group of well-known hot springs. This zone of high temperatures was interpreted as an extension of a mapped fault to the southwest. This discovery encouraged further interest in the local geothermal resources which lead to the development of an exploration and utilization program for the purposes of assessing, developing and using the available geothermal energy.

GEOLOGIC SETTING

General Statement

The City of Elko is located on and along the flood-plain of the Humboldt River as shown in Figure 1. The river flows in an alluvial valley from northeast to southwest through the study area, between the Adobe Range to the northwest and the Elko Hills to the southeast.

The Humboldt River valley divides the area into two different terranes. To the northwest are exposures of Late Tertiary Humboldt Formation, a continental sedimentary deposit (Sharp, 1939). A series of northwest trending cuestas, with the longer slopes to the northeast, rise gently from the valley floor to the Adobe Range.

South of the River the Elko Hills rise rather abruptly from the valley floor. Some units of the Humboldt Formation occur locally in this area but outcrops of the Tertiary Elko Formation, which underlies the Humboldt Formation, are most abundant. The Elko Formation also consists of continental sediments. Higher ridges in the area are composed of very resistant Paleozoic rocks which unconformably underlie the Humboldt and Elko Formations.

Tributary streams to the Humboldt River from the north flow southeasterly. From the south, the tributaries flow almost due north. The Humboldt Valley, which is somewhat constricted at Elko, opens more widely upstream and downstream where broad terraces and fans of older alluvium occur.

Thermal activity in the Elko area is indicated by hot springs and seeps, by local alteration, and by abnormal temperatures encountered in some of the water wells. Faulting occurs in at least two northeasterly sets and provides some control for rising geothermal fluids.

Geologic Mapping and Air-Photo Interpretation

Objectives

As part of the present program, reconnaissance geologic mapping was conducted in the field over a four day period to examine exposed bedrock and structures associated with thermally anomalous areas. In addition, black and white stereo-photo coverage, flown in 1955 (scale 1:24,000), was interpreted and partially field-checked. The results of this work, presented in Plate 1, should be considered tentative pending detailed field mapping.

Stratigraphy

Paleozoic Rocks - The oldest rocks exposed in the study area are Late Paleozoic quartzites and marine sediments consisting of shale, sandstone and carbonates (Sharp, 1939). These sediments are strongly indurated and make up the higher and more rugged topographic elements in the mountains flanking the Humboldt River Valley. The oil well shown on Plate 1 (Section 16) reportedly encountered Paleozoic rocks at a depth of 5490 feet. Primary porosity of the Paleozoic rocks is very low due to induration, however, the rocks are generally brittle and closely fractured.

Elko Formation - This unit consists mainly of fine-grained sediments including light-colored shales and sandstones with lesser amounts of conglomerate, limestone, chert, rhyolite, tuff and oil shale. It unconformably overlies the Paleozoic rocks. Recent work on sediments by Smith and Ketner (1976) indicates that the oil shales are Eocene or Oligocene in age. Smith and Ketner therefore renamed this unit the Elko Formation, which had been originally described by Sharp as the lower member of the Miocene Humboldt Formation.

Humboldt Formation - This formation is widely exposed in the study area north and south of the Humboldt River. It consists largely of clastic sediments ranging from fine conglomerate near the base to weakly consolidated silts, clays, sands and gravels near the top. The lower portion is characterized by abundant rhyolitic tuff and ash.

The age of the Humboldt Formation is presently known from vertebrate and plant remains. The lower portion is not older than late Miocene and the youngest sediments may have been deposited into lower Pliocene time (Sharp, 1939, p.154). A sample of rhyolitic tuff from a locality immediately south of the River at Elko has been submitted for radioactive age dating. At the time of this writing the results are not yet available.

The Humboldt Formation is fluviatile and lacustrine in origin and unconformably overlies the Elko Formation. The log of the oil well shown on Plate 1 indicates that the Humboldt Formation is at least 3400 feet thick at that locality.

Quaternary Deposits - The alluvial fill of the Humboldt River Valley consists of unconsolidated deposits of silts, sands and gravels. These sediments overlie the Humboldt Formation unconformably. According to Fredericks and Loeltz (1947, p.9) the alluvium is not more than 75 feet thick. Based on our own observations related to water wells, we believe the Quaternary deposits may be at least 200 feet thick away from the valley edges. The exposed width in the immediate vicinity of Elko is about 3500 feet. Northeast and southwest of Elko, the exposed width of Quaternary alluvial deposits is about one mile.

Older alluvium occurs outside of and stands higher than the present Humboldt River floodplain. It is only slightly more compact than the younger alluvium, but it is locally dissected, 20 to 50 feet.

Hot Spring Deposits - These deposits occur in the vicinity of Hot Hole and several other hot springs to the southwest. They consist of buff colored tufa mounds a few feet to about twenty feet thick. The reconnaissance geologic mapping did not reveal these deposits away from known hot springs. However, more detailed examination would be necessary in order to determine whether or not other hot spring deposits occur within the older formations.

If such deposits are restricted to existing hot springs, this would imply that the surface geothermal activity is geologically recent in the area of Elko.

Structure

A significant number of faults is shown on Plate 1. Their existence and locations are based largely on air-photo interpretation, the results of the ground temperature surveys, and some field observation. Detailed geologic mapping would undoubtedly eliminate some of the suspected faults, reveal others, and clarify their age relationships.

As shown, faulting occurs primarily in northeasterly and east-northeasterly-trending sets. Although there may be some overlap in age, present observations suggest that the youngest faulting is the more easterly trending set. Both sets displace the Humboldt and older formations. Whether they displace alluvial deposits is not clear from surface observations.

A number of northeast-trending faults, here called the Hot Hole Fault Zone, occur along the western base of a ridge formed of Paleozoic rocks in Section 28. The Hot Hole Fault Zone appears to be a few hundred to almost 1000 feet wide. Hot Hole and several other hot springs occur along and within the zone. Revealed as a ground temperature anomaly, the Hot Hole Fault Zone can be traced northeasterly across the Humboldt River alluvium into the southwest quarter of Section 15. There, exposures in bluffs just north of U.S. Highway 40 do not show evidence of northeasterly continuation of the zone.

Based on topography and the ground temperature data, we believe that the bluffs are controlled by an easterly-trending fault along which the Hot Hole Fault Zone is displaced about 1500 feet to the east. The Hot Hole trend then continues northeasterly through Section 15 and the southeastern part of Section 10. The fault is well-exposed in new highway roadcuts in the eastern part of Section 10.

South and southeast of the City of Elko the southern margin of the Humboldt River Valley appears to be fault controlled, separating the rugged topography and older formations to the south from the more gentle topography and younger formations to the north. Tentatively, we interpret the indicated faulting along the southern margin of the valley as normal faulting, along which the block to the north has been rotated downward and the block to the south has been rotated upward exposing the older, more resistant formations. At a locality in the northwest quarter of Section 23, about 500 feet south of the southernmost part of Highway 46, a measured dip on the fault is 60 degrees to the northwest.

The linear configuration of the temperature anomaly in the alluvium suggests that much of this faulting is young. Unless the alluvium is extremely thin the linear shape suggests that the faulting cuts the alluvium and controls the rise of hot fluids to or near the surface. Another indication that the faulting is young is that it appears to influence the older alluvial surface in Sections 28 and 29.

Exposures in the steep faces of the cuestas northwest of the Humboldt River do not show the type of outcrop pattern that would allow the cuestas to be explained as a product of differential erosion. They may be due to northwest-trending faults, although in this case one must accept a large number of curving, subparallel faults rather equally spaced over a distance extending many miles up-river and down-river from Elko. If these faults are present they do not cross the northern margin of the Humboldt River Valley but are cut off by the east-northeasterly trending fault set.

Another explanation of the cuesta topography is that the area is being tilted progressively toward the north-east, thus causing the southeast-flowing tributaries to cut their left banks. If so, tectonic activity is still going on in a regional sense.

In the northwestern part of the mapped area, in Section 4 and in Sections 33 and 34 to the north, the cuesta faces expose a gently folded unit of volcanic ash within the Humboldt Formation. This expresses a broad anticline with a northeast-trending axis.

Geothermometry

Hot Hole and four neighboring springs were sampled in May, 1979 for quantitative analysis of the major cations. The results were used to estimate reservoir temperatures using standard geothermometric techniques.

The results of the geothermometric analysis are shown in Table 1.

Table 1

Estimated Source Temperatures from Geothermometric Analysis

	Na-K-Ca with Mg correction Temp. °C	Silica Calculated Temp. °C
Hot Hole	150	114
Spring 2	163	114
Spring 3	166	111
Spring 4	161	111
Spring 5	163	111

The silica-calculated temperature for Hot Hole is in excellent agreement with that given by White and Williams (1975, p.42). They give an assumed source temperature of

115°C, based on the silica geothermometer, and also show the Na-K-Ca values higher than the silica calculated temperature. The Na-K-Ca temperature may be high due to deposition of travertine by the thermal waters (White and Williams, 1975). All of the sampled springs show values very close to those for Hot Hole and indicate that they probably arise from a single source.

GEOPHYSICAL SURVEYS

General Statement

In this study, four geophysical methods were applied to the evaluation of the Elko geothermal resource. Two of these were temperature techniques, one was a direct-current electrical method, and a few selected lines of ground electromagnetic data were also acquired.

Each survey was run with one or more specific objectives, either to detect localized presence or effects of hot water and/or structures such as faults controlling its distribution, or to gain more information on subsurface stratigraphic and structural conditions. A significant factor affecting the geophysical surveys is that the area of interest lies directly beneath the City of Elko which is a strong source of electrical and, to some extent, thermal noise unrelated to the geothermal resource.

Temperature Methods

The temperature methods employed in this project by Geothermal Surveys, Inc. were ground temperature surveying and downhole thermal logging. Both of these methods were also employed in our 1977 survey. In the present study the objectives were to specifically investigate the hot-water regime and to obtain more detailed information than previously acquired.

The thermal techniques employed in this study are based on the following: (1) bedrock, dry alluvium and saturated alluvium have markedly different values of thermal diffusivity, (2) the thermal regimen characterizing zones of moving fluid is derived in part from the thermal characteristics of the fluid, and (3) the presence of water in a porous medium causes attenuation of any external temperature cycle from an ambient source (such as the diurnal and seasonal temperature changes). At Elko two moving fluid systems were already known to exist - one of hot water and the other a cold-water system. Thermal and well log probes containing thermistors as sensing elements are manufactured and individually calibrated by GSI to an accuracy of 0.01°C.

Ground Temperature Surveying

Purpose - This survey was conducted to delineate the ground temperature anomaly associated with occurences of hot fluid and to more fully understand the interaction between the hot and cold water systems. In May, 1979, ninety-five probes were emplaced in holes drilled in a predetermined areal array extending in a northeast trend from about a mile southwest of Hot Hole to about two-and-a-half miles northeast of Elko. The survey was designed to gather temperature information in areas of suspected hot-water occurrences and to detail the high-temperature thermal anomaly discovered in the 1977 survey.

Method - Each temperature probe consisted of a 10-ft long plastic tube containing a thermistor at one end and terminal connections at the other end. Holes were drilled with a power auger, fitted with probes and then backfilled. The 10-ft depth at which the sensors were placed is below the detectable extent of the diurnal temperature cycle but well within the reach of the annual wave.

Before measurements were made, all probes were allowed to achieve thermal equilibrium with their surroundings. Thermistor resistance was then measured at the surface with a Wheatstone Bridge and null detector and converted to temperature by means of individual probe calibration curves.

Data - Plate 2 is a contour map of interpreted ground temperatures in the vicinity of Elko, Nevada. This map was compiled by combining data from the 1977 and 1979 thermal surveys. The 1977 data have been corrected by subtracting the difference in mean temperatures between the 1977 and 1979 surveys from the measured temperature at each probe location occupied in the 1977 survey. The temperatures measured on May 14, 1979 are listed in Table 2 in the appendix. Listed in Table 3 (appendix) are the measured and corrected temperatures at the probe locations occupied on July 8, 1977.

Results - The temperature pattern seen in Plate 2 is in excellent agreement with that revealed by the 1977 thermal survey. Except locally, the same pattern of interpreted cold water flow routes and the distinct N 20° E trend of higher temperatures is present.

The most recent work revealed two distinct, high temperature anomalies centered at probe stations 51-A and 80-A. One of these is in the vicinity of Hot Hole; the measurement was made approximately 150 feet to the north. The second anomaly is located within the City of Elko, on Court Street between Third and Fourth Streets. The extreme magnitude of the second anomaly should be treated with caution. Because of its local setting it may be an artifact in part. These two zones of anomalously high temperature are interpreted as being caused by heated ground water ascending from depth to the near-surface along faults or fractures in the underlying rocks.

Downhole Temperature Logging

Purpose - The primary objective of this logging was to identify areas with higher-than-normal geothermal gradient, suggesting the presence of hot fluids at depth. As part of our work in 1977, six holes were thermally logged. Although an average geothermal gradient for this area is about 1.5°C per 100 feet, several of the logged holes showed geothermal gradients greater than 2°C per 100 feet and Well No. 56 showed a gradient greater than 4°C per 100 feet.

The most recent work was designed to acquire thermal log information in several additional available drill holes.

Method - Each downhole temperature log was made by lowering a cable-mounted thermistor probe into the drillhole. Resistances were measured at specified depth intervals and converted to temperature. Each measurement was determined after the probe achieved thermal equilibrium with its environment.

Data - Only two additional drillholes were available for thermal logging in the survey area, the Archurra No. 2 Well and City Well No. 24 (Plate 2).

Though other wells that have not yet been logged exist in the area of interest, they were either being pumped or were plugged at shallow depth at the time of the survey. All available thermal logs from wells in the Elko area are presented in Figure 2.

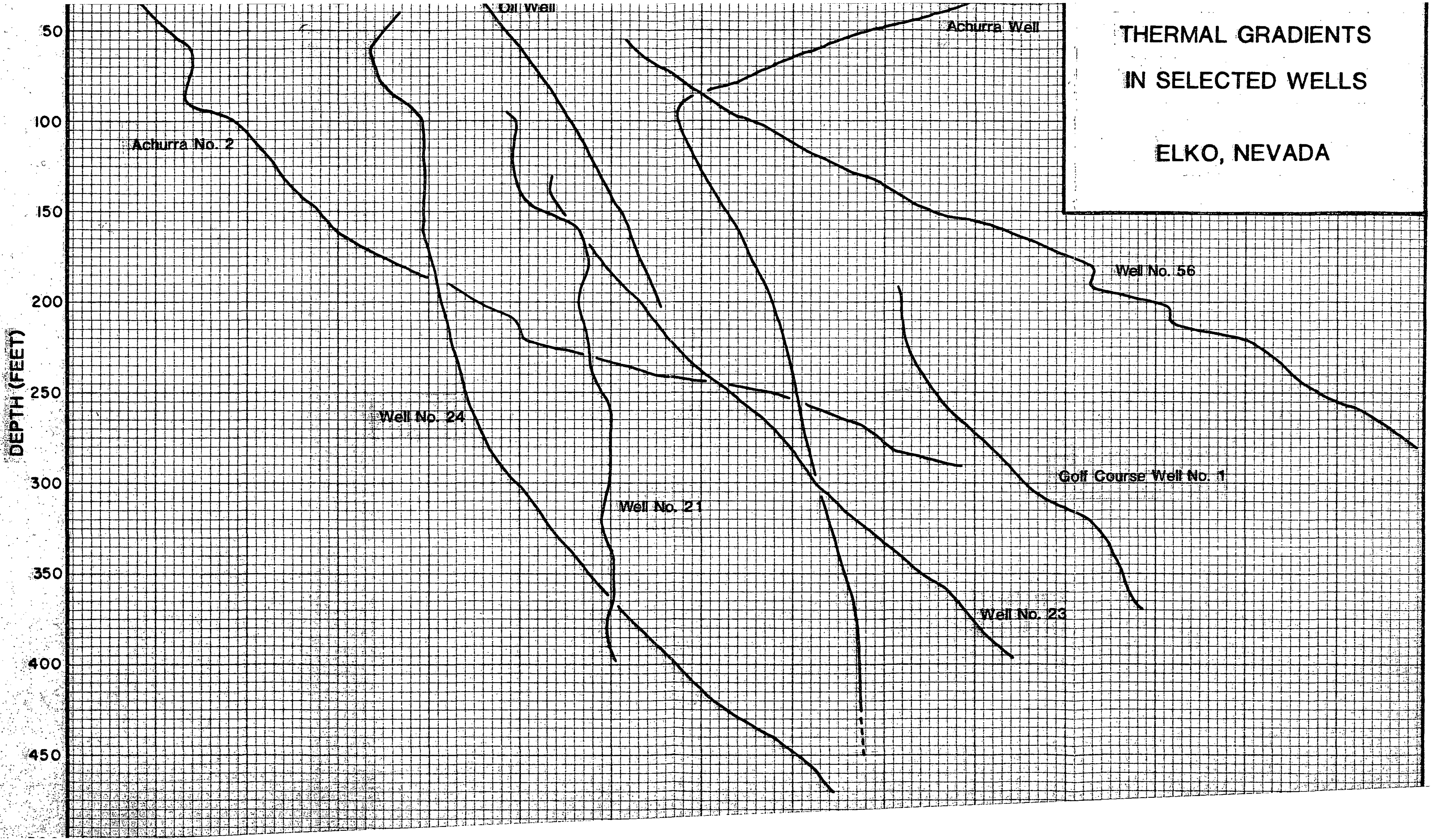
Results - The two highest thermal gradients in the Elko area are both greater than $4^{o}C$ per 100 feet and are found in the Archurra No. 2 well and Well No. 56. Both of these gradients suggest hot water sources at depth.

Well No. 56 lies close to the suspected northeast-trending faulting that is marked by the zone of high ground temperatures already described. The Archurra No. 2 well is located near the southern contact of the alluvium with the lower Humboldt Formation.

Vertical Electrical Resistivity Soundings

Purpose

This method was employed to examine the vertical resistivity distribution at each sounding location. Resistivity of subsurface earth materials is determined primarily by their water content. The quantity, quality and temperature of the water affects the measured value as does the lithology, texture and fabric of the rock in that these parameters determine the porosity of the rock. The quantity measured in the field is apparent resistivity, dependent not only on the true bulk resistivity


THERMAL GRADIENTS
IN SELECTED WELLS
ELKO, NEVADA
DEPTH (FEET)
50
100
150
200
250
300
350
400
450
Oil Well
Achurra Well
Achurra No. 2
Well No. 56
Well No. 24
Golf Course Well No. 1
Well No. 21
Well No. 23

of the material under investigation but also on the electrical properties of the surrounding environment and on the geometry of the measuring array.

Soundings were conducted to gain more information on subsurface stratigraphy and to identify anomalously low resistivity areas and zones at depth which may be saturated with hot water.

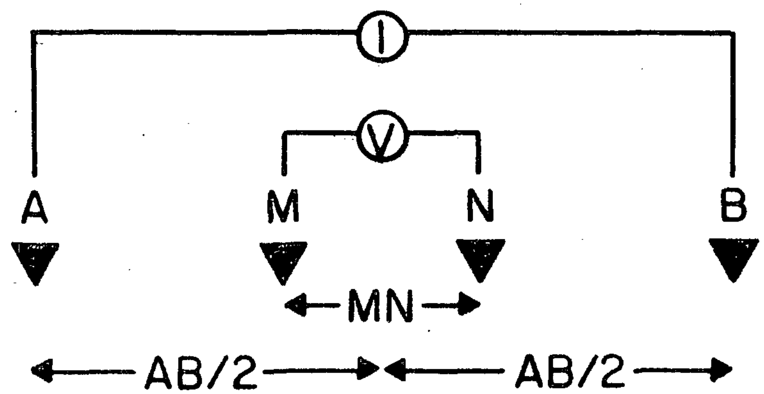
Method

The resistivity equipment used in this investigation was an ABEM Terrameter. A low frequency (4 Hz), alternating, square-wave surrent was passed through the ground between two copper-stake electrodes. The potential difference (arising from the applied current) between two other electrodes was measured. Voltage-measuring electrodes were of the non-polarizing type (i.e. ceramic porous pots containing a copper electrode immersed in a copper sulfate solution) to minimize spurious signals caused by the electrode polarization effects.

The soundings were made using the Schlumberger array, shown in Figure 3. In this configuration the current electrodes, designated A and B, were moved outward from the center of the array after each measurement. Potential electrodes, designated M and N, were moved only periodically, in order to maintain a detectable voltage signal. The depth of exploration is approximately one half the current electrode spacing. Thus, each sounding yields a curve related to the resistivity vs. depth distribution.

In the field, instrument readings of current and voltage were converted to apparent resistivity, and log-log plots of this value vs. the AB/2 spacing were made.

SCHLUMBERGER RESISTIVITY ARRAY



$$K = \frac{(AB/2)^2 - (MN/2)^2}{MN/2} \cdot \frac{\pi}{2}$$

K=GEOMETRIC FACTOR

R= (V/I)·K

R=APPARENT RESISTIVITY (ohm-meters)

V= MEASURED VOLTAGE (volts)

I=APPLIED CURRENT (amps)

FIGURE 3

This allowed immediate recognition of spurious signals caused by geologic or cultural noise (i.e. fences, power lines, etc.) and in some cases steps could be taken to minimize the effects.

Data

Resistivity soundings were conducted at eighteen locations in the Elko area as shown on Plate 3. Field work for this survey lasted approximately six days. The sounding data and field curves are included in the Appendix (Table 4 and Figures 6 through 23, respectively). Field curves for ER Lines 3, 4, 5, 7, 10, 12, 13, 15 and 16 show effects of electrical noise (from nearby fences, power lines and railroad tracts) and lateral resistivity changes. These effects do not allow an exact interpretation of the data to be made. In the case of ER12, the field data are severely effected by noise and the results are not interpretable.

Interpreted geoelectric sections for ER Lines 1 - 11 and 13 - 18 are presented in the Appendix, Figures 24 through 40. The layered-earth models are derived through the combined use of manual curve-matching techniques and a versatile computer program developed at the Colorado School of Mines. The interpretive procedure is based on the assumption that the earth is horizontally layered. In the cases where the resistivity changes laterally the interpreted model is approximate.

A contour map of apparent resistivity at an AB/2 spacing of 50 meters is presented in Plate 3. This type of data presentation allows identification of lateral resistivity changes at the effective probing depth. Because of the great amount of noise affecting ER 12, data from that sounding was not used in construction of Plate 3.

Results

As shown in Plate 3, the lowest resistivity area extends from southwest of Hot Hole to the northeast, along the trend of high temperatures and faulting previously described. The low resistivity may be due to the presence of hot water within the fault zone or to the composition of the sedimentary materials along this trend. Faulting may have caused the rocks along the fault zone to have been mechanically and/or chemically altered to more fine-grained materials of typically low resistivity.

Results similar to these are obtained by contouring the data at various other AB/2 spacings. In general, the lowest resistivities occur in the vicinity of Hot Hole (ER 15, ER 16, ER 17 and ER 18) and at ER 9 and ER 4. At AB/2 spacings greater than 200 meters (effective probing depths greater than about 600 feet) the data indicate that the entire area southeast of ER lines 1, 2 and 6 is generally of lower resistivity. This could be due to greater water saturation, finer grained sediments or the presence of hot water at depth.

The interpreted geoelectric sections for ER Lines 1, 2, 3, 6 and 11 (Figures 24, 25, 26, 29 and 34) are interpreted as fairly typical soundings of the alluvium and Humboldt Formation, showing resistivity values characteristic of interbedded silts, sands, gravels and volcanics. The field curves for Lines 2 and 3 show minor lateral variations in lithology and water saturation. Lithologic logs from Well 1 and Well 15 support these conclusions.

ER Lines 4, 8, 9, 15, 16, 17 and 18 all show zones of low resistivity at depth which are believed to be caused either by saturation of the materials with fluids or by the presence of clays in fault zones.

Lines 5 and 13 show high to moderate resistivities and are interpreted as fairly typical soundings over alluvium and perhaps Humboldt Formation sediments at depth. Cultural noise was apparent on the field curves at both of these locations and makes a unique layered-earth interpretation difficult.

ER Lines 7, 10 and 14 show fairly low resistivities at depths less than 300 feet. This is probably due to the presence of fine-grained materials (lower Humboldt Formation?) beneath alluvial fill.

Along this east side of the valley the Humboldt is older and more fine-grained than to the northwest.

In summary, the Humboldt Formation northwest of the Humboldt River is marked by moderate resistivities of 20 to 50 ohm-meters. In the vicinity of Hot Hole and other suspected fault zones measured resistivities range from 3 to 10 ohm-meters. This effect may be explained by water saturation or by the presence of clays in the fault zones. The alluvium is comparatively moderate-to-high in resistivity, 30 to 150 ohm-meters, owing to its coarser-grained composition, and appears to be up to a few hundred feet thick. In the eastern and southeastern portions of the surveyed area low to moderate resistivities occur at depths below the alluvium which are believed to be typical of the lower portion of the Humboldt Formation.

Horizontal-Loop Electromagnetic Profiling

Purpose

This technique was employed in an attempt to precisely define the position and width of some of the faults and fractures believed to be related to the near-surface expression of the geothermal resource.

Method

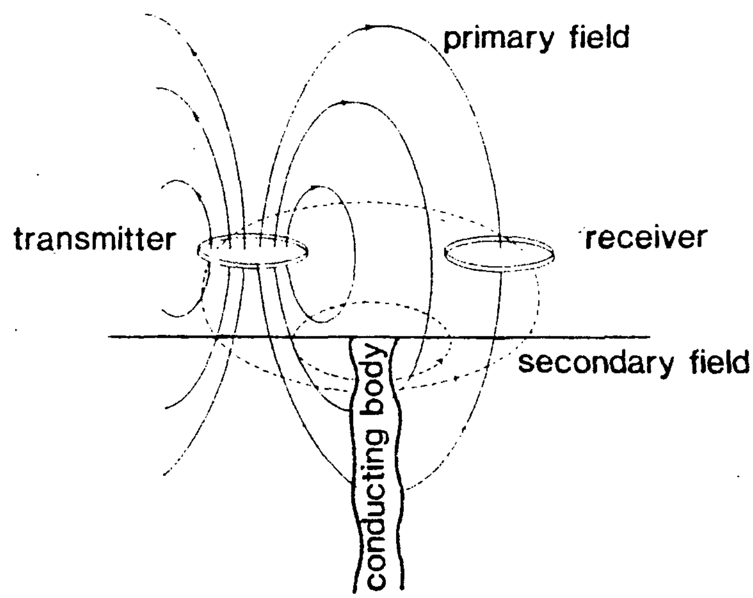
In this method two wire loops separated by a specific distance are moved in-line along a profile line. The loops are held horizontal and coplanar and for this reason the technique is called horizontal-loop or slingram profiling.

The equipment employed in these measurements was the APEX MAXMIN II portable electromagnetic system. Transmitter and receiver operators move together along the profile line. The transmitter is a wire coil capable of transmitting an electro-magnetic field at five different frequencies. The receiver is another coil capable of measuring the resultant magnetic field at each of these five frequencies.

The measured field consists of two parts, a primary or real component and secondary or imaginary component. The primary field is that created by the transmitter whereas the secondary field is that created by any conductive body which is intersected by the primary field. Thus, anomalies arise in the presence of conducting bodies. This effect is illustrated in Figure 4.

FIGURE 4

PRINCIPAL OF HORIZONTAL-LOOP ELECTROMAGNETIC PROFILING



Data

Seven lines of Max-Min electromagnetic data were collected during 1-1/2 days of field work at locations shown on Plate 3. These were all positioned to investigate the suspected northeast-southwest Hot Hole Fault trend. The data are listed in Table 5 (Appendix) after topographic and line-spacing corrections were applied.

Results

Lines SL 1 and SL 2 were run in an area southwest of Hot Hole, across and along the Hot Hole Fault trend. Both of these lines do reveal anomalously conducting zones related to the faulting. The response may be caused by the presence of warm water along the faults and/or by the presence of clay materials in the fault zones.

Although the possibility of acquiring interpretable Max-Min data within the City was considered small, Line SL 3 was run down Fifth Street in an effort to identify the position of the Hot Hole Fault Zone. As expected, the presence of many power lines and buried pipelines render the data uninterpretable.

Lines SL 4, 5 and 6 were run near and slightly northeast of Hot Hole. Interpretation of the data from lines SL 4 and SL 6 is difficult due to the short profile lengths. SL 5 shows a clear anomaly, identifying an anomalously conducting zone approximately 500 feet wide. This is interpreted as the Hot Hole Fault Zone.

Line SL 7 was run across new freeway road cuts northeast of the City that reveal several faults. An approximately 750 feet wide anomalously conductive zone is indicated by the data.

CONCLUSIONS AND RECOMMENDATIONS

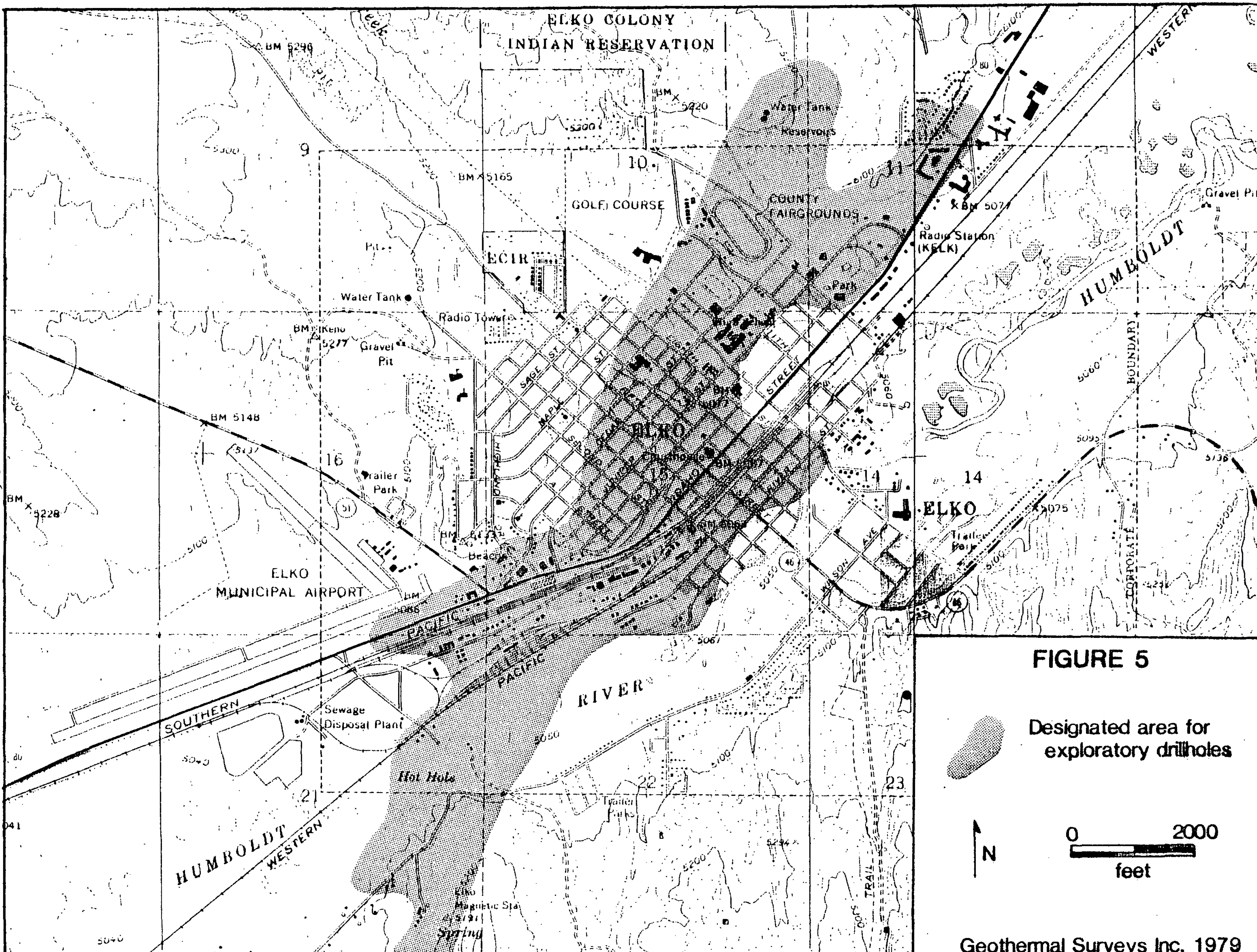
The present geological, geophysical, and geochemical investigations support the earlier indications that a hot water resource extends northeasterly beneath the City of Elko as shown by Figure 5. This is based on several sets of areally distributed ground temperature surveys, downhole temperature gradient logging in water wells, electrical resistivity and electromagnetic surveys, chemical geothermometry, and reconnaissance geologic mapping.

There appears to be strong control of thermal fluids by faults and considerable mixing of the hot fluids and cold ground water.

Temperatures observed at the hot springs are on the order of $60^{\circ}C$ and original source temperatures, indicated by chemical geothermometry, are on the order of 110°-$150^{\circ}C$.

The strong control of the near-surface thermal anomaly by faulting and the relatively low salinity of the thermal fluids indicates a convective geothermal model. It appears at this time that at least some of the Elko thermal resource is provided by ground water occurring or migrating deep enough to become heated by a temperature source still unknown and rising to the surface along some of the faults in the Elko area.

This model does not preclude the possibility that higher temperature geothermal fluids occur at greater depths than so far investigated by the present study.


ELKO COLONY
INDIAN RESERVATION
BM 5296
BM 5220
Water Tank
Reservoirs
BM 5165
GOLF COURSE
COUNTY
FAIRGROUNDS
BM 5077
Gravel Pit
Radio Station
(KELK)
ECIR
Water Tank
Radio Tower
BM Keno
5277
Gravel
Pit
Park
HUMBOLDT
BOUNDARY
CORPORATE
WESTERN
SAGE ST
MAPLE
ELKO
Courthouse
BM 5148
Trailer
Park
BM 5228
BM 5133
Beach
ELKO
MUNICIPAL AIRPORT
ELKO
STREET
WILSON AVE
PACIFIC
SOUTHERN
Sewage
Disposal Plant
RIVER
Hot Hole
Trailer
Parks
HUMBOLDT
WESTERN
Elko
Magnetic Sta
Spring
TRAIL
9
10
11
14
14
15
16
21
22
23
FIGURE 5
Designated area for
exploratory drillholes
N
0
2000
feet
Geothermal Surveys Inc. 1979

Moreover, the thermal trend shown in Figure 5 shows only the zone of the maximum near-surface thermal anomaly supported by the electrical resistivity work. Extensions and/or other thermally active faults occur outside the zone indicated in Figure 5. This is known from some of the thermal gradients and anomalous temperatures observed in water wells east of the Hot Hole thermal trend.

In general, water wells are of better quality east (up-drainage) of the Hot Hole Fault. Hot water rising along fractures in the bedrock enters the alluvium of the Humboldt River Valley and mixes with the shallow ground water. Thus, wells west (down-drainage) of the Hot Hole Fault are of poorer quality.

Water wells drilled in the general vicinity of Elko have encountered hot caving mud and higher-than-normal gradients a few hundred feet or less beneath the surface. It is likely that in the upper few hundred feet the transmissivity of the young valley alluvium is high enough that cold water flushing is dominant. In the older, less permeable formations, hot water and high temperatures are not quickly removed by the ground water.

It appears at this time that geothermal reservoir potential may occur in the brittle, highly fractured Paleozoic quartzites and carbonates (especially if solution cavities are present) and in the coarser sediments of the Humboldt Formation. Calcareous tufa around some of the hot springs suggests that some of the geothermal fluids may be passing through Paleozoic carbonates. The fine-grained shaly nature of the Elko Formation suggests poor reservoir conditions and the Quaternary alluvium is probably not able to store hot fluids because of flushing by ground water.

Low-to-moderate-temperature thermal fluids are probably available at depths of 500 to 1000 feet within the Humboldt Formation. Higher temperature fluids may be available at significantly greater depths in the Paleozoic formations.

Exploratory drilling should be concentrated within but not limited to the shaded area shown in Figure 5. Additional exploratory drilling may be done outside the shaded area to test the additional extent of the thermal resource.

We believe that the thermal fluids are controlled mainly by the faults, which are numerous in the Elko area. To the extent that fluids rising along faults have migrated into adjacent formations of high permeability, this would increase the target area and the volume of the available geothermal resource. Until the lateral extent of such migration is known, further exploration should be undertaken with the expectation that production may have to be limited to the zones of favorable permeability caused by faulting or extensive jointing.

The shaded area shown in Figure 5 is not meant to represent the entire area within which there may be viable geothermal potential. There may be further extension northeasterly along U.S. Highway 40, northerly beyond the City water tanks, and southwesterly along the airport and the highway. The producing City water wells are along the margin of the northeasterly extension of the indicated anomalous zone. If these had been drilled deeper, thermal fluids or anomalous temperatures might have been encountered.

The choice of sites for gradient drillholes take into account both the geological-geophysical results of the present investigation and the facilities for which the thermal resource is intended to be used.

If the holes are to be used only for measurements of gradients, they can be of small diameter and not deeper than 500 feet. Their objective would be to provide further information on the lateral extent of the anomalous zone or zones and temperatures that can be expected at greater depth by extrapolation of the gradients. This would be in the nature of further investigation of the anomaly. If the results are favorable, testholes for production would be planned for the resource.

From the information presently at hand regarding the geothermal potential at Elko, we believe that deeper gradient holes are now justified and with somewhat larger diameters so that limited testing of the geothermal resource can be done. For this we would recommend drilling to depths in the range 500 to 1000 feet. With gradient holes of at least 6 inches diameter, the gradients could be measured, the fluid sampled for quality, and production rates at selected intervals could be done.

Tentatively five sites for drilling have been chosen. These are: (1) in the railroad yard in the northwest corner of Section 22; (2) near the corner of Fourth Street and Silver Street; (3) near Fourth Street and north of Court Street; (4) east of Fifth Street, between Ash Street and Fir Street; and (5) between Cedar Street and College Avenue and west of Twelfth Street. Numerical designation is for convenience in discussion and does not imply the order of preference.

Location 1 is directly along the main thermal trend between Hot Hole and the high temperature anomaly within the City. Location 2 is along the eastern edge of the main anomaly but located near Stockmens Motor Hotel and the Vogue Laundry, both intended as facilities for use. Location 3 is in the City within the thermal trend along one of the main faults of the Hot Hole trend. Location 4 is within the anomaly west of the main fault but near the location of Well No. 56 which provided the most favorable gradient of the wells which were logged. Location 5 is within the northeastern part of the thermal trend and at a site where use could be applied at two very important facilities. The near-surface expressions of the thermal anomaly are weaker here than farther to the south, and drilling at this locality would provide very important information as to whether the geothermal indications continue to be strong at depth or whether they are decreasing to the northeast.

In addition to the five sites described above, consideration should be given to deepen the Achurra No. 2 well recently drilled but not yet completed near the center of Section 14, aoout half a mile east of the main anomaly. This well, already logged to 280 ft depth, shows a strong thermal gradient. It is in an area shown by our first ground temperature survey as slightly anomalous. Further testing in this area would provide valuable information outside the main thermal trend.

References

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