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AN EVALUATION OF ROOSEVELT HOT SPRINGS GEOTHERMAL RESERVOIR

BEAVER COUNTY, UTAH

PHILLIPS PETROLEUM COMPANY

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AN EVALUATION
OF
ROOSEVELT HOT SPRINGS GEOTHERMAL RESERVOIR

BEAVER COUNTY, UTAH

VOLUME II, RESERVOIR DESCRIPTION

APRIL 1979

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TABLE OF CONTENTS - VOLUME II

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES
(Continued)

ROOSEVELT HOT SPRINGS GEOTHERMAL RESERVOIR DESCRIPTION

I. INTRODUCTION

Location

The Roosevelt Hot Springs Unit (RHSU) is located in Beaver County, Utah, approximately 165 miles south of Salt Lake City and 12 miles northeast of the town of Milford (Fig. 1). The RHSU is 8 miles long (north-south) and 6 miles wide (east-west). (Figure 2)

General Geologic Setting

Regionally, the RHSU is located on the eastern edge of the Basin and Range Physiographic province. This portion of the basin and range has been subjected to repeated igneous activity during the past 30 million years (Reference 15).

Locally, the RHSU thermal area is situated at the boundary between the western foothills of the Mineral Range pluton and the northeastern edge of the Escalante Valley (Figures 1, 3, and 4). This northern portion of the Escalante Valley is commonly referred to as the Milford Valley and is a basin and range graben structure. The graben is about 30 miles north-south and 12 miles east-west, with approximately 5,000 feet of valley fill sediments in the deeper portions. The Mineral Range is a horst block with the transition between the Milford Valley and the Mineral Range marked by a sequence of normal basin and range faults.

Structurally, the mineral range is a basin and range horst approximately 30 miles long and 6 miles wide. The central part of the range is a late Cenozoic granitic pluton 20 miles long and covering 67 percent of the range. This is the largest pluton in the state of Utah. Located along the crest of the granitic pluton are nine known Pleistocene rhyolite centers.

The southern third of the range is composed of folded and faulted Paleozoic and Mesozoic sedimentary rocks which have been intruded by small igneous stocks. This area represents about 29 percent of the entire range.

The northern Mineral Range is composed of Cambrian and Cretaceous sedimentary rocks which are in fault contact with the Tertiary granitic pluton. The sediments extend for about 3 miles in a northerly direction from the fault contact and occupy 4 percent of the range area. Pre-Cambrian metamorphic gneisses and schists are exposed on the western flank of the range. These have been intruded by and were partially assimilated into the late Cenozoic igneous intrusives. There is surface evidence of recent faulting and numerous hot spring deposits along the western range flank within the RHSU (Figure 5).

In the thermal area, the rocks encountered in drilling beneath the thin veneer of alluvium are either igneous intrusive rocks of the late Cenozoic granitic pluton or metamorphic rocks of Pre-Cambrian age. These rocks have almost no intergranular porosity or permeability. The geothermal reservoir is associated with interconnected fracture zones and faults which give the crystalline rocks local high fracture permeability. The reservoir is confined beneath a cap varying in thickness from 300 to several thousand feet. The cap was formed by precipitation of silica and carbonate minerals in the fractures. The geothermal resource is a moderate-to-high temperature, low-salinity, liquid-dominated type (Reference 20).

Land Status

The area prospectively underlain by a geothermal reservoir was unitized in April 1976. The RHSU was the first geothermal unit approved by the United States Department of the Interior. Figure 2 is a Unit area map showing tract locations, lessors, lessees, and locations of deep wells and stratigraphic test holes. At the time of this writing, Phillips holds Federal leases totaling 17,040.97 acres (65.68%) within the unit.

As presently known, the geothermal reservoir boundary falls entirely within the area of the RHSU.

Historical Background

The Roosevelt Hot Springs (RHS), located in Sec. 34, T26S, R9W, was a small area of springs discharging sodium chloride water highly charged with silica. At various times, the settlers used the springs in the area for washing, bathing, stock watering, and swimming. The springs were reported to have a small discharge of hot water as late as in 1957; but, by 1966, the springs were dry (Reference 11). Small fumeroles emit water vapor and gases at the present time within the spring area.

Earliest drilling for geothermal resources occurred in December 1967 when Eugene Davie and A. L. MacDonald jointly drilled 80 feet into opaline hot spring deposits in Sec. 16, T27S, R9W. They encountered hot water and plugged and abandoned the hole. They moved the rig 300 feet to the east and drilled a 165 foot hole which encountered hot water that flashed to steam. The well was plugged and then redrilled in March 1968 to 265 feet at which depth the well flowed a mixture of steam and hot water. This last hole was eventually plugged and abandoned with some difficulty. It is this well site that is generally described as the "discovery well" for the RHS geothermal area.

Phillips Petroleum Company's exploration activities in Utah began in late 1972, and a chronological listing of these is given in Table 1. Results of the surveys completed prior to the Roosevelt KGRA lease sale indicated that the Roosevelt area showed exceptional geothermal promise. The KGRA lease sale in July 1974 was the first to be held in Utah. Of 12 tracts offered, Phillips acquired nine totaling 18,871 acres.

After the leases were issued in October 1974, exploration activity shifted to drilling the acquired acreage. During 1975, six exploratory wells and two observation holes were drilled. The commercial discovery well (No. 3-1) was completed near the end of April. Subsequent work in the period from 1976 to the present was designed to further our understanding of the geothermal reservoir.

Many other individuals, companies, institutions, and organizations have contributed to the large data base available for the Roosevelt geothermal area, but these are too numerous to mention in this report. For additional information, the reader is referred to the annotated bibliography of the RHS geothermal area in Reference 9.

Present Level of Development

As of February 1979, 11 geothermal test wells had been drilled within the RHSU (Figure 2). Six of the wells are considered capable of producing fluid in commercial quantities: Phillips #3-1, #54-3, #13-10, and #25-15; Amax-Thermal Power-O'Brien (ATO, #14-2 and #72-16). Phillips well #12-35 is productive but presently not commercial. Four wells have not encountered the geothermal reservoir: Phillips #9-1 and #82-33; Getty Oil Co., #52-21; and ATO, #24-36.

In addition to the deep tests, eight observation holes ranging in depth from 1760 to 2317 feet have been drilled in the area. Information on these 19 test wells and observation holes is presented in Table 2.

II. GEOLOGY OF THE ROOSEVELT HOT SPRINGS AREA

The geology of the RHSU has recently been mapped (Reference 5, 13, and 16). Figure 6 from Reference 13 depicts the detailed geology of the area.

Lithologies of the Roosevelt Hot Springs Area

The lithology of the RHS area is characterized by metamorphic rocks of Precambrian age, plutonic rocks of Tertiary age, and volcanic rocks of Pleistocene age. Quaternary alluvial wash and valley fill deposits lightly mantle the area near the Mineral Range and thicken toward the basin center. Recent deposits include opal, chalceodony, and silica-cemented alluvium whose origins are related to the geothermal system.

Metamorphic and Plutonic Igneous Rocks

The Precambrian metamorphic rocks are subdivided into five lithologic units: banded gneiss, quartzite, sillimanite schist, biotite gneiss, and hornblende gneiss (Reference 13).

The gneissic units all contain as major constituents, quartz, alkali feldspar, plagioclase feldspar, biotite, and hornblende. They differ in the relative proportions of the major mineral constituents in texture and in grain size. The quartzite includes up to about 5 percent feldspar. The sillimanite schist contains sillimanite, quartz, biotite, and plagioclase as major constituents.

The metamorphic rocks are exposed in the western foothills of the range (Figure 6) and have been encountered beneath the alluvium to the west of the surface exposures.

The Tertiary plutonic rocks, underlying the eastern side of the Roosevelt Hot Springs Unit, are no older than 35 million years (Reference 8) and may be as young as 15.5 to 9.2 million years (Reference 1 and 14). Five major felsic phases were identified: quartz monzonite, porphyritic granite, syenite, granite, and fine-grained granite (Reference 13). Textural and compositional similarities among the major felsic phases make specific identification problematical.

The plutonic igneous rocks have intruded the Precambrian rocks on the west and have partially assimilated xenoliths of the latter over a zone several miles wide. The resulting rocks of mixed origin might best be termed migmatites or injection gneisses.

Both the metamorphic rocks and the plutonic igneous rocks are crystalline rocks with extremely low primary porosities and permeabilities. Because of these similarities, no stratigraphic or lithologic control over the location of the geothermal reservoir has been noted. The reservoir is localized by fracture porosity and permeability induced into the crystalline rocks, apparently as a result of recurrent motion along fault zones within the unit area.

Volcanic Igneous Rocks

Exposed within the Tertiary granitic pluton are nine Pleistocene rhyolite domes emplaced in a NNE trending line bordering the eastern side of the unit area. Figure 6 shows locations of five of the domes. The line of domes cuts the crest of the Mineral Range at an oblique angle. Obsidian rich rhyolitic lava flows and pyroclastic deposits, which include air-fall tuffs, water-laid tuffs, and non-welded ash-flow tuffs, are associated with the domes.

Subsurface water has been sampled at virtually all existing springs, seeps, and wells on and in the area surrounding Roosevelt KGRA (Figure 8). Chemically identified water types are a) sodium chloride, b) sodium sulfate, c) sodium bicarbonate, d) calcium chloride, e) calcium sulfate, and f) calcium bicarbonate. It is clear that sodium chloride type water is leaking from the geothermal reservoir into the shallow groundwater flow system and moving down the potentiometric surface into the central portion of the valley.

The reservoir water composition closely matches the data reported for both RHS and for a small cold water seep located in Section 34 to the north of the Negro Mag Fault and east of the Dome Fault. A comparison of analyses from these sites and the #54-3 well is included in Table 3. These springs are the only known active natural leakages from the reservoir. The volumes of opal and sinter deposits which presently extend along the Dome Fault attest to more widespread leakages in the past. Reservoir waters also presently leak into the shallow groundwater system and, in fact, form a leakage plume which extends for tens of square miles down the hydraulic gradient to the north and northwest. Wells and springs throughout this area document the plume by the presence of dissolved ionic species that are characteristic to the reservoir waters.

The recharge to the reservoir is derived from precipitation falling in the Mineral Range and recharging through fractures and joints in the igneous and metamorphic units. Low tritium values (less than 1 TU), Reference 12, reported for the reservoir waters suggest an age of at least 20 years for the reservoir water and no appreciable contribution of rainfall within the past 20 years to the produced reservoir waters. For comparison, a local cold water spring in the Mineral Range contains 50 to 70 TU (Reference 17). The conclusion from this data is that watermass in storage within the reservoir is large in comparison to the natural discharge. This is somewhat confirmed by the low carbon-14 values reported for the reservoir waters (0.7% of modern), but this value may be due to dilution by carbon-13 remobilized from the country rocks during thermal metamorphism.

The waters circulate within the reservoir as is indicated by significant isothermal sections in wells that penetrate into the reservoir. The chemistry indicates equilibrium conditions by the excellent agreement between observed temperatures and those calculated by metal ion ratio geothermometers (Reference 7). The oxygen shift from the meteoric line on the deuterium-oxygen-18 plot also spells out equilibrium and long residence times in a high temperature environment (Reference 6).

III. THE ROOSEVELT HOT SPRINGS GEOLOGIC MODEL

Discussion of Data Utilized in Developing the Geologic Model

The development of the RHSU geologic model has progressed as an outgrowth of the exploration philosophy which led to the discovery of the Roosevelt field. The exploration model has been refined as well control from deep tests became available and as research interest resulting from the initial discovery was increased. The present interpretation is an integration of geology, geophysics, and well log data derived primarily from Phillips, other operators, the University of Utah, the UURI group, and additionally from published data from the state of Utah and the USGS.

Phillips entry into the Roosevelt area was made with the knowledge of the shallow Davie steam well drilled in the opaline deposits occurring along the Dome Fault. The association of shallow hot water and silica having been recently deposited along an active fault zone presented the model of a high-temperature hot-water reservoir leaking to the surface along the fault system. The literature report on the regional hydrology included analyses of the then dry Roosevelt Hot Springs, and metal ratio geothermometers calculated from this data indicated temperatures near 500°F (Reference 10).

Surface manifestations of the system included the opaline deposits along the Dome Fault, the dry RHS system, and sulfur mineralization along the Negro Mag Wash. The magma chamber which had fed the young rhyolite Domes to the east was a potential heat source. As surface reconnaissance operations progressed, additional surface features were discovered. Weak fumeroles and steaming ground were observed in the Negro Mag Wash in the vicinity of the sulfur mineralization. Temperatures near boiling were found within a foot of the surface of the alluvial cover. Ongoing sulfur mineralization was observed in mineral test pits. Degassing of carbon dioxide and hydrogen sulfide was also taking place along the Negro Mag Wash.

The conceptual model was a hot water system with an overlying self-sealed silica cap broken in places by recent faults which act as conduits for fluids and gases to leak to the surface from the reservoir. The reservoir was inferred to be in either the valley alluvial fill or a sedimentary sequence adjacent to the Mineral Range pluton. The spatial relation relative to the Dome Fault was unknown.

A shallow temperature gradient program and a more detailed water chemistry study were undertaken to refine the model. These surveys were followed by resistivity, aeromagnetic, lineament, and gravity studies to refine the known geology and to investigate the geometry of the geothermal system.

The water survey located an additional leak from the reservoir to the north of the dry RHS. This seep has a chemistry very similar to that of the RHS (Table 3). Both waters are sodium-chloride type and carry high values of potassium, lithium, and boron. As the survey progressed, this water type was found to extend far to the north and west of the Dome Fault area (Figure 8), becoming diluted and losing potassium and boron in the same direction. This water was interpreted as overflow from the geothermal system and is progressively diluted as it flows northward in the regional hydrologic system. The potassium and boron are incorporated into clay minerals of the valley fill as the waters flow northward. The survey indicated that the main system, or at least the main overflow from the system, was in the area of the Dome Fault.

The initial temperature gradient program delineated an area of anomolous heat which is closely associated with the Dome Fault trend. The contoured temperature gradient map has changed somewhat in detail as additional data have been acquired; but even the early data showed gradients in excess of 10°F/100 feet over an area of roughly 16 square miles straddling the Dome Fault. The shallow data do not differentiate between the productive ground to the east of the fault and what appears to be non-productive ground to the west of the fault. The very high gradients in excess of 25°F/100 feet show an even stronger correlation with the Dome Fault and may reflect, to some degree, the upwelling of thermal waters along the structure. A program of 2,000 foot temperature observation (gradient holes) was initiated in 1976. This program has been extremely useful in discriminating between shallow seated thermal anomalies (thermal plumes) which show decreased gradient or even reversals at depth and anomalies due to conductive gradients which better reflect the deeper seated portions of the main reservoir. Figure 13 summarizes the thermal gradient data from all presently available sources.

Electrical surveys at Roosevelt Hot Springs Unit area have been performed by or for the following:

Phillips Petroleum Company: dipole-dipole resistivity, self-potential, and magnetotelluric soundings.

University of Utah: electromagnetic soundings, Schlumberger soundings, magnetotelluric soundings, 100-m, 300-m, and 1-km dipole-dipole resistivity, self-potential, and electrical energizing of well casings.

Getty Oil Company: 300-m dipole-dipole resistivity survey.

The electrical surveys run to date have provided a three-dimensional glimpse of the electrical behavior of the rocks in the thermal area. However, the inhomogeneous nature of the area, coupled with physical problems inherent in each of the tools, has resulted in a significant gap between the expectations for obtaining quantitative solutions and the actual results obtained.

One of the most useful and representative of the electrical surveys is the dipole-dipole resistivity work done by the University of Utah. Figure 9 is a contour map of apparent resistivity for the first separation of the 300-m dipole-dipole survey (Reference 18). The observed resistivities are interpreted to result from the distribution of brine-soaked clays in the upper 500-m of the geothermal system. The clays are feldspar alteration products primarily localized along faults and fractures (Reference 18). Of significance is the rise in apparent resistivity values south and east of the production wells and the low values associated with the known production zone and the Dome Fault zone.

Gravity surveys were particularly useful in providing information on the regional structure, especially in those areas covered by alluvium. Figure 10 is a terrain-corrected Bouguer gravity anomaly map (Reference 3) which is a compilation of several individuals' work. The north-south trending gravity contours reflect the trend of the Mineral Range and Milford Valley. Gravity gradients indicate that north-south basin and range type faults are present beneath the alluvium, dropping the consolidated rocks downward to the west in stair-step fashion. The large gravity low located along the west edge of Figure 10 represents the deepest part of the Milford graben where the thickness of poorly consolidated valley fill reaches approximately 5,000 feet. The gravity lows (indicated by the symbols D & E) in the southeast corner of the figure are coincident with the larger rhyolite domes and possibly indicate a shallow, low density intrusive body at a depth of about 2-km (Reference 3 and 4).

The aeromagnetic data are more useful than the gravity data in delineating the geothermal system. Figure 11 is a total aeromagnetic intensity residual anomaly map of the Roosevelt Hot Springs area (Reference 19). The western flank of the Mineral Range is characterized by short wave-length anomalies with magnitudes of 250 gammas. The style of the magnetic anomalies changes eastward to longer wave lengths and more negative values. The short wavelength anomaly appears to be related to shallow Precambrian metamorphic rocks or younger plutonic igneous rocks having higher magnetic susceptibilities and conversely, the longer wave-length style appears to be related to a lack of Precambrian rock units and to igneous plutonic and volcanic phases with low magnetic susceptibilities (Reference 19).

The large negative anomaly centered 4 miles southeast of the Roosevelt Hot Springs correlates with the reversely polarized Bailey Springs lava flow. The negative anomalies located 6 to 8 miles further southeast appear to correlate with the rhyolite domes.

A magnetic high corresponds to the horst block paralleling the west side of the Dome Fault (Opal Mound Fault), where there is no production at present. The magnetic low east of the Dome Fault occurs in the area underlain by the geothermal reservoir. The contrast is attributed in part to the destruction of magnetic minerals in the area east of the Dome Fault by hydrothermal solutions from the geothermal reservoir (Reference 3). This hypothesis is supported by drilling data.

The magnetic contours show a dramatic change in trend from N-S to E-W just south of the surface termination of the Dome Fault (Figure 11). This is caused by a local magnetic low which projects into the range. The axis of the low, which may represent a volcanic unit, lies immediately south of the southern boundary of the productive reservoir.

Faults have been interpreted from several geophysical methods including aeromagnetic surveys, gravity surveys, and dipole-dipole apparent resistivity surveys. An interpreted lineament-fracture-fault map (Figure 12) was prepared by the University of Utah group after integrating these techniques with the known surface geology (Reference 18).

While the information mentioned above is valuable for the formulation of the geologic model, deep well data are preferable. The data summarized in Table 2 are but a portion of a staggering amount of information which has been examined and utilized in preparing the model. The production size wells are the best source of information since the productivity of a block of ground is confirmed. However, it is not practical to drill production wells everywhere one would like. The drilling of observation holes to several thousand feet is a compromise which permits predictions to be made with more confidence than is possible with only shallow gradient hole data. The observation holes are drilled to sufficient depth to minimize the masking affects which shallow groundwater may have upon heat transfer. This allows the establishment of isotherms in the subsurface. Isotherm elevation maps at 25°C intervals have been prepared and utilized in interpreting the reservoir system.

Model Boundaries

The boundaries of the Roosevelt system range from well defined structures such as the Dome Fault which limits the system on the west to inferred boundaries defined by economic considerations on the east.

The well defined Dome Fault acts as a leaking conduit from the reservoir. Along this fault, hot spring deposits of opal and silica cemented alluvium, gas seeps, and fumerole activity attest to this connection to the reservoir both in the past and the present. This fault marks the boundary between pervious reservoir rocks to the east and an impervious horst block on the west.

Well control on both sides of the Dome Fault zone further demonstrates its importance as a reservoir boundary feature. The deep test holes, the

Phillips #3-1, #54-3, #13-10, #25-15, and #12-35, plus the ATO #14-2 and #72-16 are commercially successful producers and are located to the east in the downthrown block. Immediately to the west of the Dome Fault are the nonproductive Phillips #82-33 and #9-1 deep tests and observation holes #1 and #4 which show a significant decrease in temperature gradient in the lower parts of the holes.

In Phillips nonproductive well #9-1, drilled to 6,885 feet, few fractures were encountered and the temperature profile logs on this hole revealed a low temperature gradient of 2.79°F/100 feet for the 5,800 feet to 6,600 feet interval with the highest temperature at 440°F in the bottom of the well. The linear, constant increase of temperature with depth is indicative of a heat transfer by conduction. This is further supported by the fact that the well would not accept fluids during pump-in tests. By contrast, Phillips producing well #54-3 hit interconnected open fractures at 1,950 feet and from 2,640 feet continuously to the total depth of 2,882 feet. The temperature profile log shows a temperature gradient averaging 24°F/100 feet to a depth of 1,800 feet, then a change in slope to isothermal below that point. The isothermal temperature profile is evidence for convective heat flow caused by the circulating movement of fluids in the interconnected open fracture system of the reservoir. The wells drilled west of the Dome Fault have the characteristics of #9-1. Those to the east are similar to #54-3.

The Dome Fault appears to be a major conduit for geothermal fluids. However, it separates a western block which has so far proven to be tight and unproductive from an eastern fractured block containing the reservoir. The fault dip is not known, but well #13-10 may have intersected the fault zone between 4,700 feet and 4,860 feet. This would place the fault dip at about 77°E.

The southern boundary of the geothermal reservoir appears to be located between the commercial wells Phillips #25-15 and ATO #72-16 and the nonproductive Getty well #52-21. The Getty well, a 7,500 foot drill hole, encountered two minor deep fracture intervals; one at 6,630 feet and another at 7,400 to 7,500 feet. The temperature profile log from this well shows a low but constant 1.9°F/100 feet temperature gradient for the interval 5,800 feet to 7,490 feet, with a maximum temperature of 402°F in the bottom of the well. The temperature profile indicates that heat movement is primarily by conduction. This nonproductive well is only 0.7 miles south of the Phillips #25-15 productive well and about 1 mile south of the ATO #72-16 productive well.

Approximately halfway between the productive wells mentioned and the Getty non-productive well is the southern termination of the surface expression of the Dome Fault, implying that some structural change occurs south of this point.

Also, several geophysical surveys indicate a geologic boundary between the Getty well and the two productive wells to the north. The shallow temperature gradient map indicates a rapid drop in the temperature gradients between the ATO Well 72-16 and the Getty well (Figure 13). Apparent resistivities increase from 10 ohm meters near ATO well #72-16 to 200 ohm meters near the Getty well (Figure 8). The magnetic contours change in trend in this area (Figure 11). The University of Utah workers inferred that two east-west faults lie between the Getty well and the wells to the north (Figure 12). One, or both of these faults may be the boundary separating the productive reservoir from the Getty well #52-21. Fault #4 in Figure 12 was chosen as the southern boundary of the reservoir.

Currently, the northern boundary of the geothermal reservoir is open. However, several lines of evidence may be cited to establish the approximate northern limit of the field. One is the marginal production obtained from the Phillips #12-35 well, a 7,324 foot test. This well does produce from the reservoir but only in limited amounts. Temperature profile logs show several isothermal intervals indicating that convective heat transfer does occur within the well. The diminished production may indicate that the well is near the northern edge of the geothermal reservoir.

Low resistivities of magnitudes similar to those associated with productive areas extend northward beyond well #12-35 (Figure 9) as do anomalous temperature gradients (Figure 13). Since geology had not dictated the northern reservoir boundary, the reservoir was extended 3,300 feet to the north of #12-35 along a line parallel to the Dome Fault.

The eastern boundary has not been definitely established. The production well farthest from the Dome Fault is the ATO #14-2 located approximately 4,800 feet in an easterly direction perpendicular from the fault as shown on Figure 12. The deep well (6,118 feet) farthest from the Dome Fault is the ATO #24-36 which is about 9,000 feet east of the fault. Well #24-36 apparently did not encounter the reservoir nor did it encounter commercial temperatures. Figure 14, an E-W geologic cross section through well 82-33 also shows the relationship of the isotherms in the vicinity of well #24-36 which is near the east side of the unit area. The isotherms are closest together at the Dome Fault and separate very little at least as far east as well #12-35. Beyond #12-35, they plunge downward to the east. The isotherms through Observation Holes 7 and 8 show a pattern similar to the upper part of well #24-36, suggesting a similar deepening of the isotherms beneath these holes.

A producing reservoir zone requires two things: interconnected fractures filled with fluid and sufficiently high temperatures. In the absence of deep drilling evidence to the contrary, the presence of interconnected fractures is assumed in the eastern part of the unit area. The depths to commercial temperatures can be estimated with some confidence by using data from well #24-36 and by projecting the isotherms beneath Observation Holes 7 and 8.

The eastern reservoir boundary will be based upon an economic limit which will be a function of drilling costs and lowered steam quality factors from deeper wells. In producing wells, the top of the geothermal reservoir is chosen as the depth at which the equilibrium temperature profile from each well becomes isothermal, indicating a change from conductive heat flow to convective heat flow. The reservoir top and horizontal distance to the Dome Fault is listed below for each well:

	Depth to Top	Distance
ATO #72-16	1400' Est.	.3 mile
PPCo. #13-10	1800'	.2 mile
PPCo. # 3-1	1800'	.5 mile
PPCo. #54-3	1800'	.5 mile
PPCo. #12-35	1600'	.6 mile
PPCo. #25-15	2800' Est.	.8 mile
ATO #14-2	2400'	.9 mile

East of wells #14-2, #25-15, and #12-35, where well control is lacking, the reservoir top is assumed to be the projected 200°C isotherm.

The base of the geothermal reservoir has not been established. The temperature profiles in the productive wells are still isothermal at the bottom of the holes.

RHSU Geologic Model

The RHSU geologic model identifies the geometry of the reservoir as follows:

1. The 4 mile long NNE trending Dome Fault zone is the western boundary.
2. The 2.5 mile, east-west fault #4 is the southern boundary.
3. The northern boundary is established at a point 3,300 feet north of well #12-35 along the extention of the Dome Fault and extends perpendicular to the fault 10,000 feet to the east.
4. The eastern boundary has not been truly established. All indications based on well control identify a possible 2 to 2.25 mile east "economic risk limit" zone 4 miles in length and parallel to the Dome Fault.

Future deep test drilling for commercial production may eventually define the eastern boundary. Until this occurs, the boundary presently is an "economic limit" based on a combination of the depth required to drill to reach 400°F and the assumption that a sufficient number of interconnected open fractures in the reservoir will be encountered. In the reservoir model, the above boundaries are assumed vertical.

5. The top of the reservoir dips east from shallow depths of about 1,000 feet adjacent to the Dome Fault zone to depths from 1,900 to 4,000 feet reached about 0.75 miles east of the Dome Fault. Then, at a distance of 1.5 miles east, the reservoir top is interpreted to be approximately 5,300 feet. At a distance of 2 miles east of the Dome Fault, the top of the reservoir has been projected to be approximately 7,400 feet.

Temperature profile cross sections and three-dimensional fence diagrams with well control effectively demonstrate the size and shape of the reservoir. The critical factors used in constructing these diagrams were:

1. Selected temperatures with depth.
2. Major fracture intervals.
3. Key faults controlling, influencing, and acting as barriers to the reservoir.

Tables 2 and 4, selected temperature gradient hole information, were the sources for developing the temperature profile cross-sections, three-dimensional fence diagrams (Figures 18-20), and the index map (Figure 27).

The six selected temperature profile cross-sections used (Figures 21-26) cut the Roosevelt Hot Springs Unit reservoir at significant angles. The fence diagrams illustrate the reservoir from key positions. This very effectively demonstrates the geometry of the Roosevelt Hot Springs Unit reservoir.

In addition, a selected set of geologic cross-sections east-west cut through the RHSU are included as Figures 14-17.

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TABLE 1

CHRONOLOGY OF PHILLIPS' ACTIVITIES AT THE ROOSEVELT PROSPECT

LATE	1972	LITERATURE SURVEY & FIELD RECONNAISSANCE
FEB	1973	RECONNAISSANCE GEOCHEMICAL SURVEY
MAR	1973	GRAVITY SURVEY
MAY	1973	GEOCHEMICAL SURVEY (CONTINUING)
MAY	1973	EARLY LEASING ACTIVITIES (CONTINUING)
JUN	1973	BIPOLE - DIPOLE SURVEY
JUN	1973	GROUNDNOISE SURVEY
JUL	1973	TEMPERATURE GRADIENT SURVEY (CONTINUING)
OCT	1973	MAGNETOTELLURIC SURVEY
JUL	1974	COMPETITIVE LEASE SALE (∼18,000 ACRES)
OCT	1974	LEASES ISSUE
DEC	1974	REFLECTION SEISMIC SURVEY
FEB	1975	SPUDDED OBSERVATION HOLE #2
MAR	1975	SPUDDED OBSERVATION HOLE #1
MAR	1975	SPUDDED ROOSEVELT KGRA #9-1
APR	1975	SPUDDED ROOSEVELT KGRA #3-1 - COMMERCIAL DISCOVERY WELL
APR	1975	GROUND LEVEL MAGNETIC SURVEY
MAY	1975	MAGNETOTELLURIC SURVEY
JUN	1975	PETROLOGIC STUDIES
JUL	1975	SPUDDED ROOSEVELT KGRA #54-3
AUG	1975	SPUDDED ROOSEVELT KGRA #12-35
OCT	1975	SPUDDED ROOSEVELT KGRA #13-10
NOV	1975	SPUDDED ROOSEVELT KGRA #82-33
JAN	1976	WATER OBSERVATION SYSTEM
FEB	1976	MAGNETOTELLURIC SURVEY
FEB	1976	THREE DAY FLOW TEST (#54-3)
MAR	1976	ISOTOPIC STUDIES
APR	1976	WATER APPROPRIATION HEARING
APR	1976	UNIT APPROVED
MAY	1976	HELIUM SURVEY
AUG	1976	SPUDDED ROOSEVELT HOT SPRINGS UNIT #25-15
OCT	1976	MICROEARTHQUAKE AND GROUNDNOISE SURVEYS
OCT	1976	SPONTANEOUS POTENTIAL SURVEY
NOV	1976	HIGH RESOLUTION SEISMIC SURVEY
DEC	1976	LANDSAT IMAGERY STUDY
FEB	1977	SPUDDED OBSERVATION HOLE #4
MAR	1977	SPUDDED OBSERVATION HOLE #5
OCT	1977	COMMENCE LONG TERM RESERVOIR TEST #54-3
OCT	1977	COMMENCE ENVIRONMENTAL BASE LINE STUDY
MAY	1978	SHUT IN WELL #54-3
AUG	1978	SPUDDED OBSERVATION HOLE #8
SEP	1978	SPUDDED OBSERVATION HOLE #7

TABLE 2

ROOSEVELT HOT SPRINGS

- Observation Holes and Deep Test Holes
Complete Data List

The table in the plastic envelope following this page depicts the information above.

ROOSEVELT HOT SPRINGS - Observation Holes and Deep Test Holes Complete Data Sheet   Date: November 21, 1978

#	Well Name, Location, and Ground Elevation	Total Depth in Feet	Starting Date of of Well + Maximum Temperature and Depth	Temperature in °C. & °F. + Equivalent Depth to Reach It 50°C 122°F	75°C 167°F	100°C 212°F	125°C 257°F	150°C 302°F	175°C 347°F	200°C 392°F	225°C 437°F	250°C 482°F	Gradient °F/100' Interval	Lithology Depth to Top of Bedrock in Feet	Identified Fault and Fracture Zones	Bedrock Types in Bore Holes	Nature of Drill Hole Test and Final Results	Depth to Top of Reservoir and Temperature at that Point	Wells Are Chronologically Numbered
1	Phillips OH - #2 T27S, R9W, Sec. 10 5,884.2'	2,250'	2/1/75 403°F @ 2,194 (4/21/75)	226'	391'	620'	895'	1173'	1538'	2044'	-	-	19.93°F/100' (200' to 500') 6.90°F/100' Bottom Hole	±280'	None	Quartz Diorite Biotite Granodiorite	Stratigraphic Test Observation Hole	Adjacent to Phillips #13-10	1
2	Phillips OH - #1 T27S, R9W, Sec. 17 5,644.4'	2,317'	3/3/75 232.8°F @ 2,320' (7/14/75)	473'	Isotherm Depths Based on Projection of Bottom Hole Gradient 955'	1700'	3342' Proj.	4984' Proj.	6626' Proj.	8268' Proj.	-	-	12.70°F/100' (400' to 500') 2.74°F/100' (2100'-2320') 7/14/75	1950'	None	Granite (Chlortized)	Stratigraphic Test Observation Hole	West of Reservoir	2
3	Phillips #9-1 (#42-9) T27S, R9W, Sec. 3 5,833.8'	6,885'	3/13/75 439.08°F @ 6830' (10/1/77)	490'	925'	1408'	1988'	2775'	3870'	5400'	6800'	8413' Proj. Using B.H. Gradient	11.53°F/100' (400' to 600') 2.79°F/100' (5800'-6600')	±705'	None	Granodiorite Qtz. Monzonite	Deep Test Non-Commercial "Tight"	Just West of Reservoir	3
4	Phillips #3-1 T27S, R9W, Sec. 3 6,111.4'	2,728'	4/19/75 496.6°F @ 2,700' (10/5/75)	543'	638'	745'	880'	1052'	1248'	1416'	1600'	1950'	23.0°F/100' (400'-600')	±660'	1900'-2400' Fractures @ 2723' (L.C.)	Granodiorite Qtz. Monzonite	Deep Test Commercial Discovery Completed as Monitoring Well	1800' 472°F.	4
5	Phillips #54-3 T27S, R9W, Sec. 3 6,104.5'	2,882.1'	7/6/75 508°F @ 2500'-2600' (R) (10/15/75)	174'	368'	570'	748'	940'	1120'	1314'	1487'	1760'	22.0°F/100' (400'-600')	±402'	Fracture 1950' 2640'+	Granodiorite Qtz. Monzonite Qtz. Diorite Diorite	Commercial Deep Test	1800' 485°F	5
6	Phillips #12-35 T26S, R9W, Sec. 35 6,171.8'	7,324.4'	8/9/75 414.2°F @ 3500'-3600' (R) (4/9/76)	272'	476'	678'	890'	1084'	1273'	2637' Reversal 4148'	-	-	19.70°F/100' (300-500') Reversal in Well	±255'	Fractures 3580'-3640' 4780'-4830' 5320'-5350'	Granodiorite Qtz. Monzonite Qtz. Diorite	Sub Commercial Deep Test	1600' (R) 380°F 2400+' @ 400°F.	6
7	Phillips #13-10 T27S, R9W, Sec. 10 5,890.1'	5,351'	10/2/75 485.6°F @ 5343' (9/22/76)	150'	295'	510'	745'	985'	1224'	1520'	3010'	4280'	20.80°F/100' (300'-500')	±245'	Fluid Loss @ 4350' Fractures 4100'-4950'	Diorite Qtz. Monzonite Qtz. Diorite Grandodiorite	Commercial Deep Test	1800' 401°F 3400' @ 456°F.	7
8	Phillips #82-33 T26S, R9W, Sec. 33 5,832.9'	6,032'	11/5/75 358.7°F @ 5824' (1/14/77)	378'	567'	744'	975'	3653'	5264'	7851' Proj. Using B.H. Gradient	-	-	23.0°F/100' (400'-500') Temp. Reversal at 1500' 2.22°F/100' (4800'-5800')	±340'	L.C. @ 1656'-2010' Fracture: 3200' 3400'-3600'	Qtz. Diorite Granodiorite	Deep Test Non-Commercial Re-injection Well	West of Reservoir	8
9	Phillips #25-15 T27S, R9W, Sec. 15 6,002.0'	7,500'	8/26/76 473.8°F @ 7459' Within 24 hour after drilling. NOT STATIC! (10/6/76)	Temporary Depths Based on Combination of Temp. Log Runs 10/22/76 and 9/30/77, (10/13/76)	±670'	±1005'	±1375'	±1755'	±2280'	±2995'	±4015'	4553'	10.60°F/100' (300-500')	±140'	2840'-80' 3020'-30' 3510'-20' 4430'-70' 4600'-50'' 4835'-70' 5030'-5110' 7350'-7500'	Granodiorite Qtz. Monzonite	Commercial Deep Test	(Not Static) 2800' 380°F	9
10	Thermal Power #14-2 T27S, R9W, Sec. 2 6,240'	6,100'	9/ /76 512.63°F @ 5600' (9/29/77)	221'	455'	679'	912'	1156'	1666'	1902'	2107'	2397'	14.86°F/100' (400'-500')	±260'	Fractures (1000'-1800') 2800' 3900' 4050' 5000' 6000'	Biotite- Hornblende Monzonite Microgranite Granodiorite	Commercial Deep Test	2400' 482°F	10
11	Thermal Power #72-16 T27S, R9W, Sec. 16 ±5,880'	1,254'	10/ /76 468°F @ 1229' (3/30/77)	15'	23'	62'	112'	198'	280'	461'	776'	1400' Proj.	59.0°F/100' (400'-500')	485'	312' (Blow Out) 480' 1100' 1245'	Qtz. Monzonite Granite & Diorite Granite	Commercial Deep Test	1200' 464°F	11
12	Phillips OH-#4 T26S, R9W, Sec. 33 ±5,695'	1,760'	2/5/77 198.5°F @ 1384' (5/10/77)	First Two Projected Values are Based on Bottom Hole Temperature Gradient of This Hole and for Last Two Projected Values from Gradient in Phillips' #82-33. 478'	900	1510' Proj.	2119' Proj.	±4000' Proj.	±5800' Proj.				9.57°F/100' (300'-500') 7.38°F/100' (700'-1376')	1550'	Tight	Granodiorite	Stratigraphic Test Observation Hole	West of Reservoir	12
13	Phillips OH #5 T26S, R9W, Sec. 28 ±5,755'	1,820'	3/12/77 232.8°F @ 1140'-1240' (5/10/77) (R) 1927°F @ 1786'	440'	587'	Projected Values are Based in Combination on Phillips #82-33 and Phillips #12-35 Deep Tests (R) 762' 1583' 2150' Proj.	- 3500' Proj.	- 6000' Proj.	- 8000' Proj.	-	-	-	34.25°F/100' (300'-500')	471'	L.C. @ 1570'-90' @ 1750' @ 1810'	Qtz. Diorite Granodiorite	Stratigraphic Test Observation Hole	North and West of Reservoir	13
14	Phillips OH #3 T27S, R8W, Sec. 8 ±7,700'	2,200'	4/29/77 68.7°F @ 2186' (6/20/77 & 10/19/77)	-	-	-	-	-	-	-	-	-	0.72°F/100' (300'-500') 1.12°F/100' (2080'-2180')	±40'	Fractures: ±1100' 1340' 2040'	Granodiorite Qtz. Diorite	Stratigraphic Test Observation Hole	East of Reservoir	14
15	Thermal Power #24-36 T26S, R9W, Sec. 36 6,700'	6,118'	11/20/77	DATA PROPRIETARY										Data Proprietary	Data Proprietary	Data Proprietary	Deep Test Apparently Non-Commercial	Data Proprietary	15
16	Getty Oil #52-21 T27S, R9W, Sec. 21 5,860'	7,500'	2/7/78 402.4°F @ 7490' (10/22/78)	356'	1106'	1813'	2604'	3560'	4665'	7000'	9327' Proj.	11659' Proj.	6.20°F/100' (400'-500') 1.92°F/100' (5800'-7490')	±585'	Fractures 6630' 7400'-7500'	Granodiorite Qtz. Monzonite	Deep Test Non-Commercial	Just South of Reservoir	16
17	Geothermal Power Corp. GPC-#15 T27S, R9W, Sec. 18 ±5,539'	1,890'	7/30/78 158.45°F @1880'	1047.5'	Projected Values Based on Bottom Hole Temperature Gradient Interval for This Hole - Proj. & Extrap. 2100'	- Proj. & Extrap. 3269'	-	-	-	-	-	-	7.83°F/100' (400'-500') 3.85°F/100' (1700'-1880')	Bedrock not reached	None	Unconsolidated Sand Clay Silt Gravel	Stratigraphic Test Observation Hole	West of Reservoir	17
18	Phillips OH #8 T27S, R9W, Sec. 14 ±6,338'	2,094'	7/3178 176.7°F @ 2085' (10/24/78)	1318'	Projected Values Based on Bottom Hole Temperature Gradient Interval for This Hole 1976'	2625' Proj.	3250' Proj.	3895' Proj.	4535' Proj.	5175' Proj.	-	-	5.7°F/100' (400'-500') 8.1°F/100' (1960'-2060')	325'	Alteration Fracture, Fault Zones	Granodiorite Quartz Diorite Diorite Qtz. Monzonite	Stratigraphic Test Observation Hole	Extrapolated: 5305' 400°F	18
19	Phillips OH #7 T27S, R9W, Sec. 1 6,442'	2,006'	9/7/78 130.5°F @ 2000' (10/24/78)	1750'	Projected Values Based on Bottom Hole Temperature Gradient Interval of Thermal Powers #24-36 - 2691' Proj.	- 3632' Proj.	- 4574' Proj.	- 5516' Proj.	- 6458' Proj.	- 7400' Proj.	-	-	3.85°F/100' (400'-600') 2.60°F/100' (1800'-2000')	248'	L.C. @ 1435' 1770' Fractures	Qtz. Monzonite Granodiorite Granite	Stratigraphic Test Observation Hole	Extrapolated: 7400' 400°F.	19

TABLE 3

	(a) ROOSEVELT HOT SPGS.	(b) ROOSEVELT SEEP	(b) 54-3 FLOW TEST	(c) 54-3 FLOW TEST	(c) 54-3 FLOW TEST	(c) 54-3 FLOW TEST	(b) 54-3 FLOW TEST
Na	2100	1770	2000	2000	1950	1700	2540
K	470	470	400	417	460	320	469
Li			20	20	14	9	21.6
Rb				4.1			3.89
Cs				4.81			< 4.05
NH_4		.13	< 1	2			< 1
Ca	19	10.6	6.7	6.49	6.5	110	6.5
Mg	3.3	0.5	0.13	.12	0.2	19	0.1
Sr				< 3			2.0
HCO_3	42	165	200	180	168	275	243
CO_3	57			0			0
SO_4	65	69	56	51	94.7	105	70
Cl	3800	2820	3600	3400	3600	2900	3600
F	7.1		6.0	5.3		3.5	5.6
NO_3	1.9	1.6	< .05	< .05	< .04	2.3	0
B	3	29	29	28.2	27	26	35
Al				0.2			< 0.45
SiO_2	400	662	533		660	76	
pH	8.5	7.45	7.0	6.3	8.14	6.35	7.7
Cond	11500	10100		10890	11950	9430	
Date	11-4-50	10-11-75	10-11-75	2-15-76	2-15-76	10-3-77	5-4-78

EXPLANATION

(a) State of Utah, Technical Publication No. 43, Water Resources of the Milford Area, Utah, With Emphasis on Ground Water.

(b) AMTECH Laboratories for Phillips Petroleum Co.

(c) Phillips Petroleum R & D analytical branch

All species reported in ppm & conductivity in μmho/cm

PHILLIPS PETROLEUM COMPANY
GEOTHERMAL OPERATIONS
431 SOUTH 300 EAST SALT LAKE CITY, UTAH 84111

ROOSEVELT HOT SPRINGS UNIT
REPRESENTATIVE ANALYSES OF RESERVOIR WATERS FROM PRODUCTION TESTS AND NATURAL SPRINGS
BEAVER COUNTY, UTAH

SCALE

GEOLOGIST S. JOHNSON		DATE FEBRUARY, 1979
DRAFTSMAN D. OLSON		DATE FEBRUARY, 1979
REVISED		DATE

TABLE 4

ROOSEVELT HOT SPRINGS SHALLOW TEMPERATURE GRADIENT DATA SHEET

	Call Letter	Well Name	Temperature Gradient	Total Depth in Feet	Location
Line E - E'	L	U.U.-76 T.G.-1	7.2°F/100'	196'	T26S, R9W, Sec. 15
	M	EV-2300	3.9°F/100'	400'	T26S, R9W, Sec. 16
	N	GREP-1-29	8.6°F/100'	359'	T27S, R9W, Sec. 29
Line A - A'	O	U.U.-76 T.G.-3	2.8°F/100'	225'	T26S, R9W, Sec. 19
	P	GREP-1-21	24.4°F/100'	475'	T26S, R9W, Sec. 21
Line B - B'	Q	EV-2000	1.1°F/100'	300'	T26S, R10W, Sec. 36
	R	T - #3	9.6°F/100'	328'	T27S, R9W, Sec. 5
	S	U.U.-75 BBC	3.9°F/100'	323'	T27S, R9W, Sec. 18
Line D - D'	T	U.U.-75 T.G.-12	26.3°F/100'	135'	T26S, R9W, Sec. 27
	U	T - #8	10.6°F/100'	250'	T27S, R9W, Sec. 21
Line F - F'	V	EV-4600	4.6°F/100'	230'	T26S, R9W, Sec. 23

"Data Sheet of Selected Shallow Temperature-Gradient Drill Holes Used in the Temperature Profile Cross Sections and Fence Diagrams"

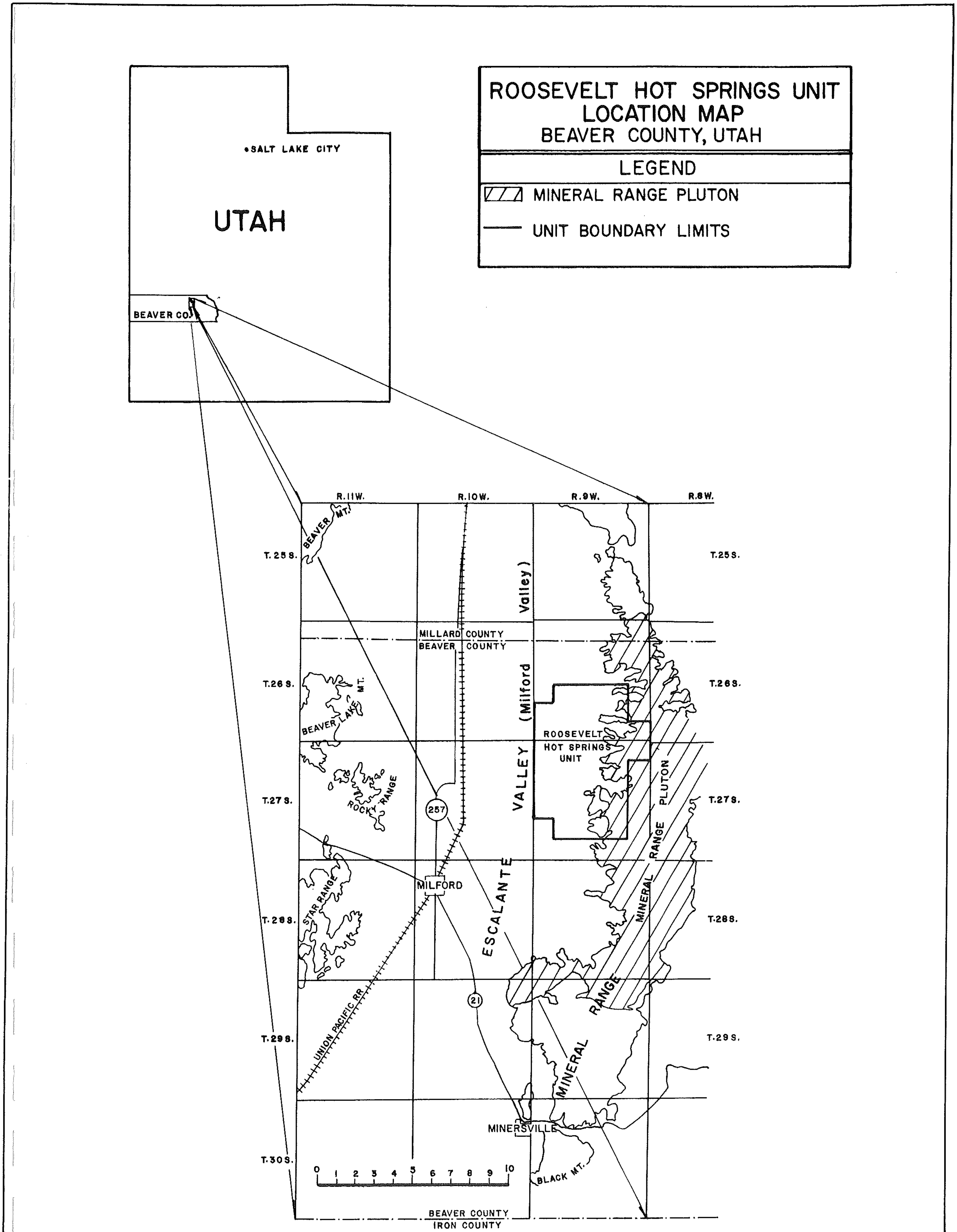

ROOSEVELT HOT SPRINGS UNIT
LOCATION MAP
BEAVER COUNTY, UTAH
LEGEND
MINERAL RANGE PLUTON
UNIT BOUNDARY LIMITS
SALT LAKE CITY
UTAH
BEAVER CO.
R.11W.
R.10W.
R.9W.
R.8W.
T.25S.
T.26S.
T.27S.
T.28S.
T.29S.
T.30S.
BEAVER MT.
Valley)
MILLARD COUNTY
BEAVER COUNTY
(Milford
BEAVER LAKE MT.
ROOSEVELT
HOT SPRINGS
UNIT
ROCKY RANGE
257
VALLEY
PLUTON
RANGE
MINERAL
ESCALANTE
MILFORD
STAR RANGE
UNION PACIFIC RR
21
RANGE
MINERAL
MINERSVILLE
BLACK MT.
0 1 2 3 4 5 6 7 8 9 10
BEAVER COUNTY
IRON COUNTY

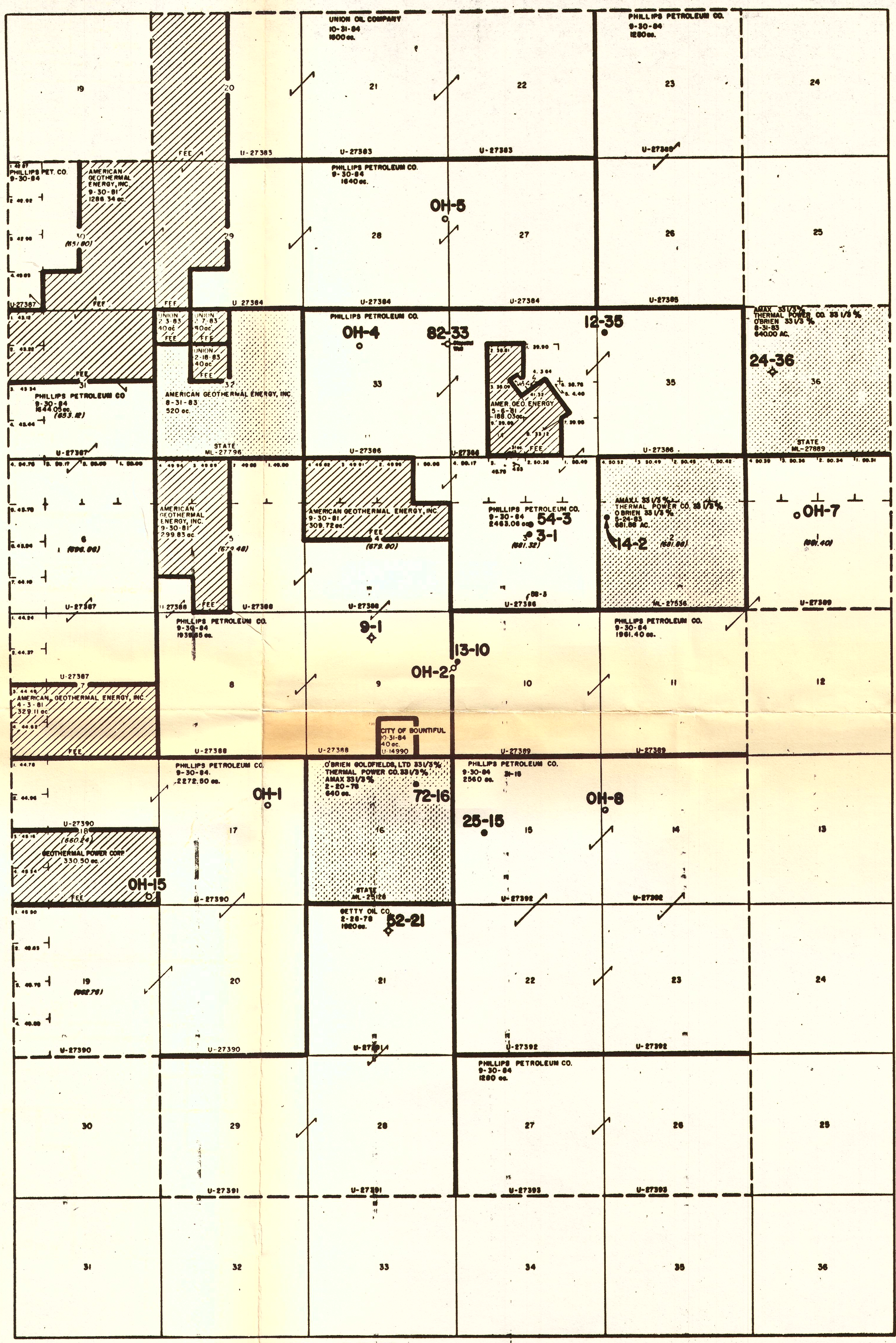
FIGURE 1

FIGURE 2

ROOSEVELT HOT SPRINGS UNIT - UNIT MAP

The figure in the plastic envelope following this page depicts the information above.

PLATE 1
A00034-2 of 14



UNIT OUTLINE

FEE LANDS 2,863.53 Ac. - 11.04%

STATE LANDS 2,481.86 Ac. - 9.56 %

FEDERAL LANDS 20,600.97 Ac. - 79.40%

25,946.38 total acres

COMPANY	LEASED ACRES		% OF UNIT
AMAX	653.96	STATE	2.52 % (% figures are approx.)
AMERICAN	520.	STATE	2.00
	2393.2	FEE	9.22
	2913.2	total	11.22
CITY OF BOUNTIFUL			
	40.	FED.	.15
GETTY	1920.	FED.	7.40
O'BRIEN	653.96	STATE	2.52
PHILLIPS	17040.97	FED.	65.68
THERMAL	653.96	STATE	2.52
UNION	1600.	FED.	6.17
	120.	FEE	.46
	1720.	total	6.63
GEOTHERMAL POWER CORP.	330.5	FEE	1.27

- O OBSERVATION WELL
- ● PRODUCTION WELL
- -O- SERVICE WELL (Inj. disp. etc.)
- PLUGGED & ABANDONED
- DRY HOLE

REVISIONS	
T.L. GRIFFIN	12-6-77
D.L. OLSON	12-15-78

FIGURE 2

PHILLIPS PETROLEUM COMPANY
GEOTHERMAL OPERATIONS
431 SOUTH 300 EAST SALT LAKE CITY, UTAH 84111

ROOSEVELT HOT SPRINGS UNIT
UNIT MAP
BEAVER COUNTY, UTAH

0 2000 4000 6000 FT.
SCALE

GEOLOGIST	DATE
DRAFTSMAN	DATE
REVISED D. L. OLSON	DATE FEBRUARY, 1979

FIGURE 3. GENERAL GEOLOGIC MAP OF THE MINERAL MOUNTAINS AND VICINITY, BEAVER AND MILLARD COUNTIES, UTAH. GEOLOGY COMPILED FROM EVANS (1977), HINTZE (1963), WHELAN (1973, 1977), BAER (1973), AND WELSH (1973). CARTER & COOK (1978).

EXPLANATION

SEDIMENTARY ROCKS

CENOZOIC	Qal	QUATERNARY ALLUVIUM
	Qos	QUATERNARY OPAL AND OPALINE SINTER
	Qcal	QUATERNARY CEMENTED ALLUVIUM
	C	CENOZOIC SEDIMENTARY ROCKS
MESOZOIC	M	MESOZOIC SEDIMENTARY ROCKS
PALEOZOIC	P	PALEOZOIC SEDIMENTARY ROCKS

METAMORPHIC ROCKS

PRECAMBRIAN	Pc	PRECAMBRIAN METAMORPHIC ROCKS

IGNEOUS ROCKS

CENOZOIC	Ti	TERTIARY INTRUSIVE ROCKS
	Qb	QUATERNARY BASALT
	Qrd	QUATERNARY RHYOLITE DOMES
	Qrf	QUATERNARY RHYOLITE FLOWS
	Qvt	QUATERNARY VOLCANIC TALUS
	Qra	QUATERNARY ASH FLOWS
	T_2bf	LATE TERTIARY BASALT FLOWS
	T_2rf	LATE TERTIARY RHYOLITE FLOWS
	Tvrp	TERTIARY ROGER PARK BRECCIA
	Tvu	TERTIARY VOLCANICS, UNDIFFERENTIATED
	Tvbc	TERTIARY BULLION CANYON RHYOLITE
	Tvdh	TERTIARY DRY HOLLOW LATITE
	Tvmb	TERTIARY MOUNT BELKNAP RHYOLITE
	Tvji	TERTIARY JOE LOTT TUFF
	Tvnr	TERTIARY NEEDLES RANGE LATITIC IGNIMBRITES
	Tvl	TERTIARY ISOM ANDESITIC-LATITIC IGNIMBRITES
	T_2ap	LATE TERTIARY ANDESITE-TRACHYTE-LATITE PYROCLASTICS

GEOLOGY CONTACT

NORMAL FAULT (BALLS INDICATE DOWNTHROWN SIDE)

STRIKE-SLIP FAULT (ARROWS INDICATE DIRECTION OF RELATIVE MOTION)

THRUST FAULT, BARBS ON THRUST SHEET

RAILROAD

HIGHWAY

ROAD

HIGH THERMAL GRADIENT ANOMALY AREA, OUTLINE FOLLOWS 300°C/KM CONTOUR

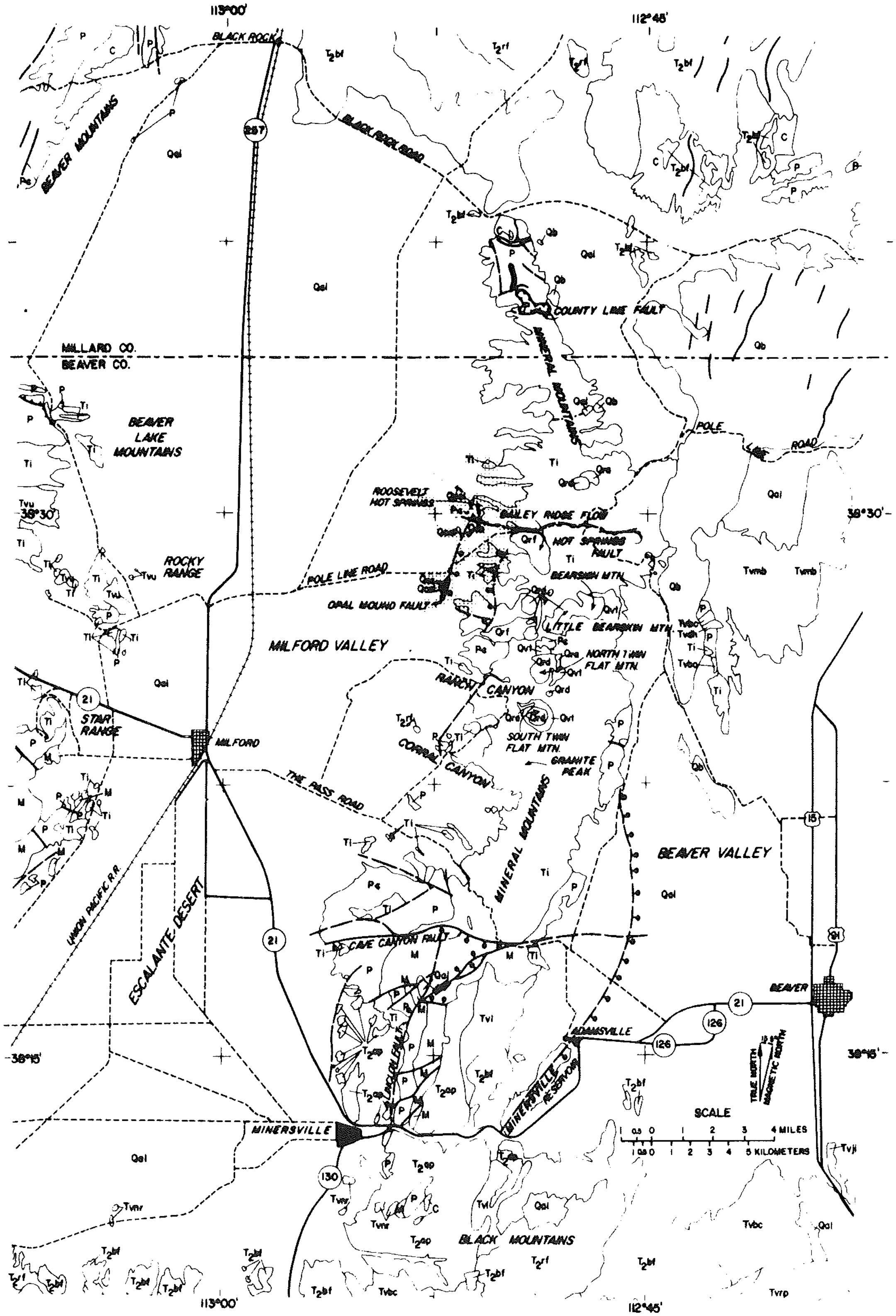
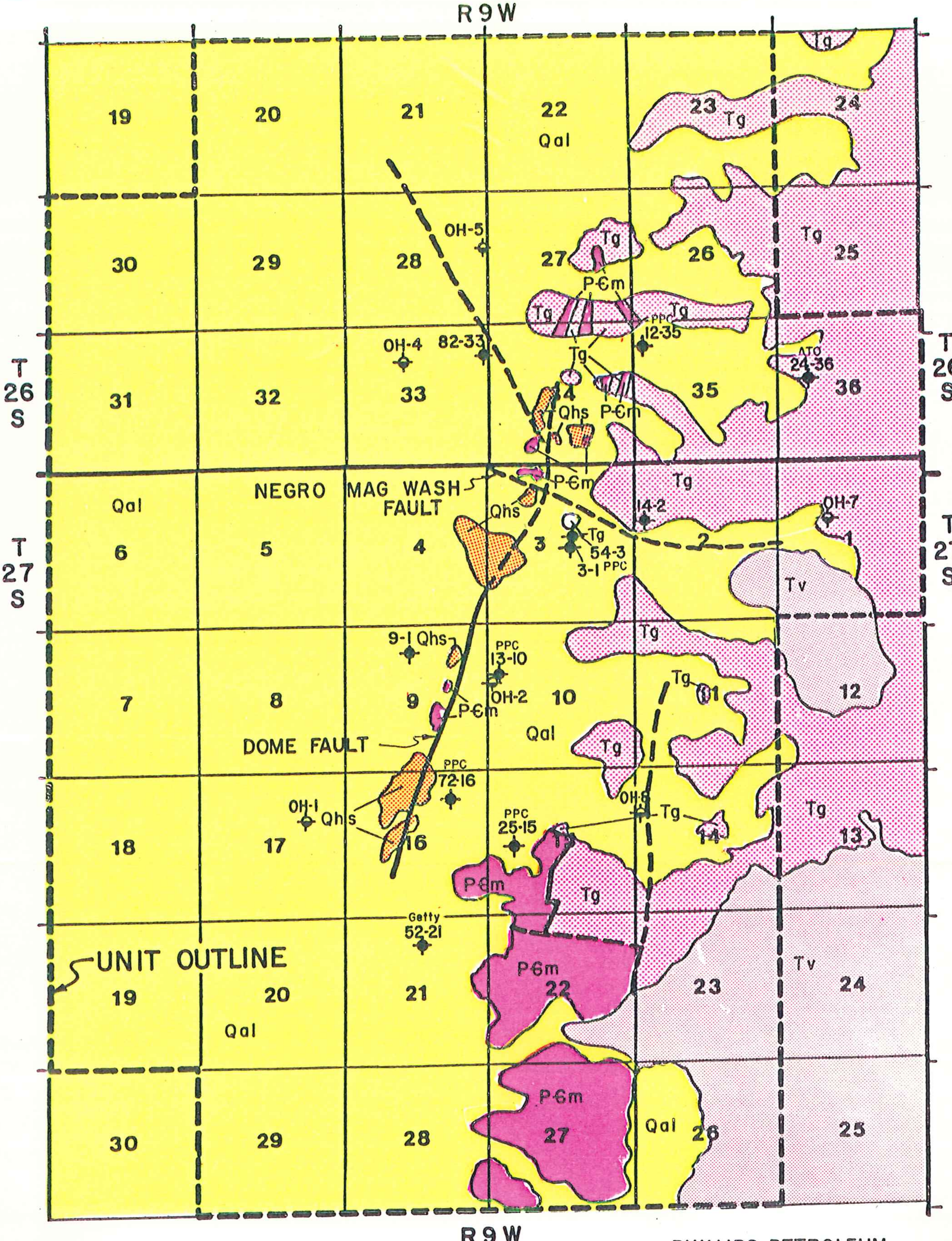


FIG. 4. GEOLOGY MAP



LEGEND

Qal	ALLUVIUM
Qhs	HOT SPGS DEPOSIT
Tv	VOLCANICS
Tg	GRANITE
PЄm	METAMORPHICS
◆	GEOTHERMAL WELL
⌖	OBSERVATION HOLE

PHILLIPS PETROLEUM
GEOTHERMAL OPERATIONS

ROOSEVELT HOT SPRINGS UNIT
GENERALIZED GEOLOGIC MAP
BEAVER COUNTY, UTAH

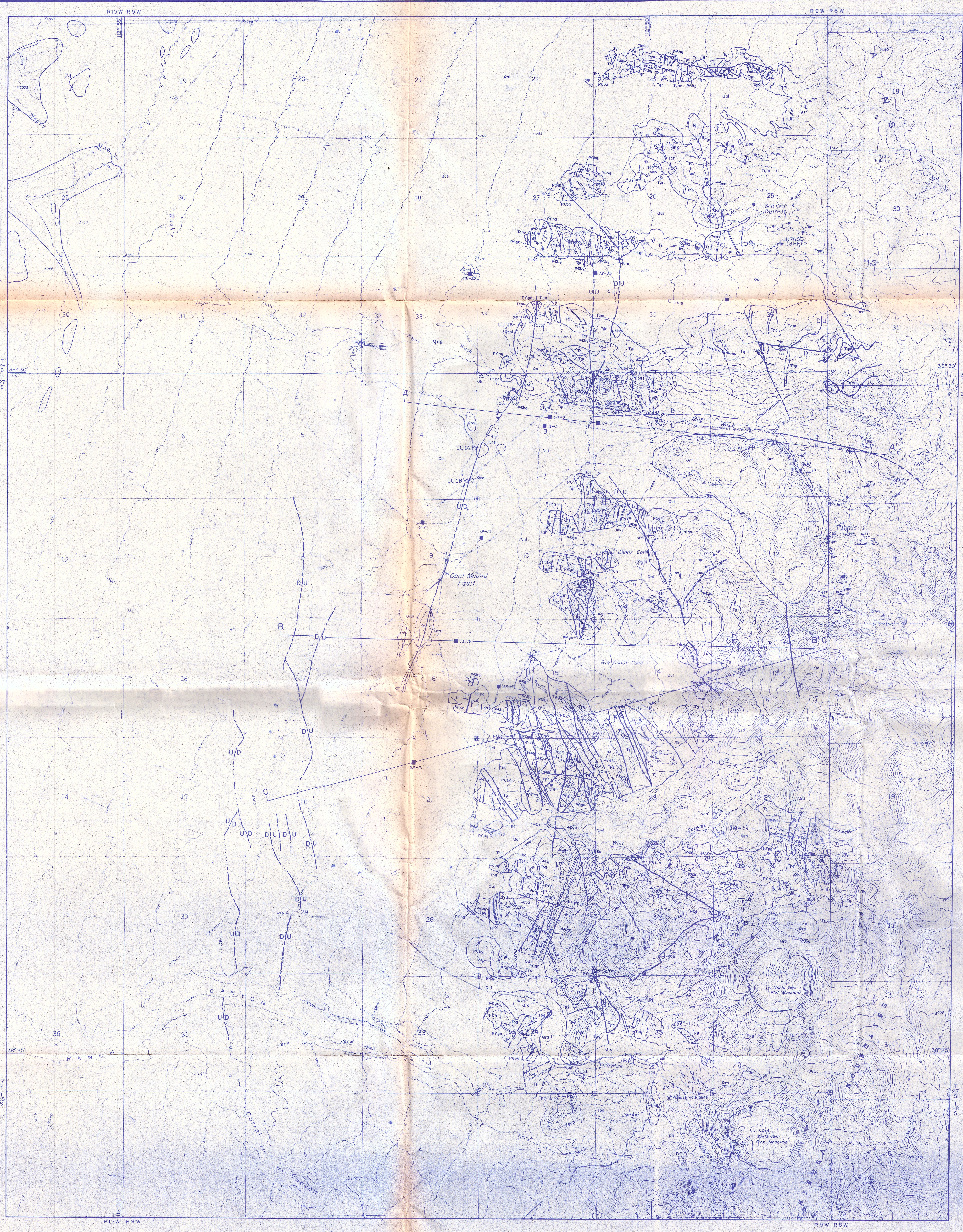
Modified From C.A. Petersen

FIGURE 5

FIGURE 6

ROOSEVELT HOT SPRINGS KGRA -
DETAILED GEOLOGIC MAP

The figure in the plastic envelope following this page depicts the information above.



EXPLANATION

QUATERNARY

Qls	Landslide
Qs	Opaline and Chalcedonic sinter
Qcal	Silica-cemented alluvium
Qh	Hematite-cemented alluvium
Qm	Manganese-oxide cemented alluvium
Qal	Alluvium
Qrd	Rhyolite Domes Glassy, 1-5 % phenochrysts, perlite and pumice mantles.
Qra	Pyroclastics Air fall and non-welded ashflow tuff. White to light tan. Weakly consolidated.
Qrf	Rhyolite Flow Non-porphyritic glassy, gray, flow banded lava and obsidian. Perlitic rubble on flow tops.

TERTIARY

Trd	Rhyolite Dikes Aphanitic, gray rhyolite dikes with approximately 5% orthoclase phenocrysts and minor biotite. Often silicified and typically strongly jointed.
Tds	Diabase Dikes Aphanitic, light brown or light gray green, with 3% plagioclase phenocrysts. Typically strongly jointed.
Tmd	Microdiorite Dikes Dark green, dark gray, or black fine-grained dikes, plagioclase phenocrysts often present.
Tgr	Granite Dikes Fine-grained phaneritic, resistant, dark brown, closely joined outcrops, forming blocky to rouned talus. Joints are typically limonite-stained. Unlabeled dikes are Tgr.
Tg	Granite Coarse to medium-grained, xenomorphic, even texture with 22% quartz. Forms massive rounded outcrops, weathers to grus.
Ts	Syenite Medium-grained, xenomorphic, with 1 to 3% sphene. Forms white or very light brown stained, massive, rounded outcrops, weathers to grus.
Tpg	Porphyritic Granite Porphyritic with 25% 1 to 3 cm microcline phenocrysts. Medium to coarse grained matrix. Forms resistant outcrops.
Tqm	Quartz Monzonite Coarse grained, massive, rounded light brown outcrops. Flow foliation and mafic xenoliths typical in the contact zone. 1 to 2 cm anhedral to subhedral microcline crystals present in parts of the contact zone. Forms some talus in the contact zone, but weathers to grus in the interior of the pluton.
Td	Diorite Medium-grained hornblende diorite.

PRECAMBRIAN

PЄgn	Hornblende Gneiss Medium-grained hornblende gneiss; weakly to strongly foliated. Forms resistant outcrops.
PЄn	Biotite Gneiss Highly variable biotite and biotite-hornblende gneisses which occur as inclusions within younger units. Typically massive to weakly foliated, dark colored, sphene rich and medium-grained. Alkalai feldspar porphyroblasts are common.
PЄs	Sillimanite Schist Dark gray to green fine-grained, finely laminated schist containing abundant biotite, fibrolitic sillimanite, and minor garnet porphyroblasts.
PЄq	Quartzite White, bedded metaquartzite containing minor biotite and feldspar.
PЄbg	Banded Gneiss Gray to white conspicuously layered biotite gneiss, schist and migmatite. Highly variable in composition. Well developed isoclinal and ptygmatic folding.

Contact, dashed where approximate

Fault, intruded by microdiorite dike.

Fault, dashed where inferred, dotted where covered. Breccia zones shown where mappable.

Fault, mapped from linears on areal photos, may have some topographic relief.

40 Joints

80° Foliation

40 70 Foliation with plunge of linear

41 Dip of dike, thickness not shown to scale. Unlabeled dikes are Tgr.

Fumarole

Spring

Geothermal well

Thermal gradient hole

Lake Bonneville shore features

Prospect pit

Shaft

Adit

EARTH SCIENCE LABORATORY
UNIVERSITY of UTAH RESEARCH INSTITUTE

SCALE 1:24,000

1 MILE; 7000 FEET; 1 KILOMETER

From: Nielson, D.L., Sibbett, B.S., McKinney, D.B., Hulen, J.B., Moore, J.N., & Samberg, S.M., 1978, Geology of Roosevelt Hot Springs KGRA, Beaver County, Utah: University of Utah Research Institute, Earth Science Laboratory Report, Department of Energy Contract Number EG-78-C-07-1701

GEOLOGIC MAP OF ROOSEVELT HOT SPRINGS KGRA BEAVER COUNTY, UTAH

GEOLOGY, 1978, BY
DENNIS L. NIELSON, BRUCE S. SIBBETT, D. BROOKS McKINNEY AND SUSAN M. SAMBERG

APPROXIMATE MEAN DECLINATION, 1958

MAP LOCATION

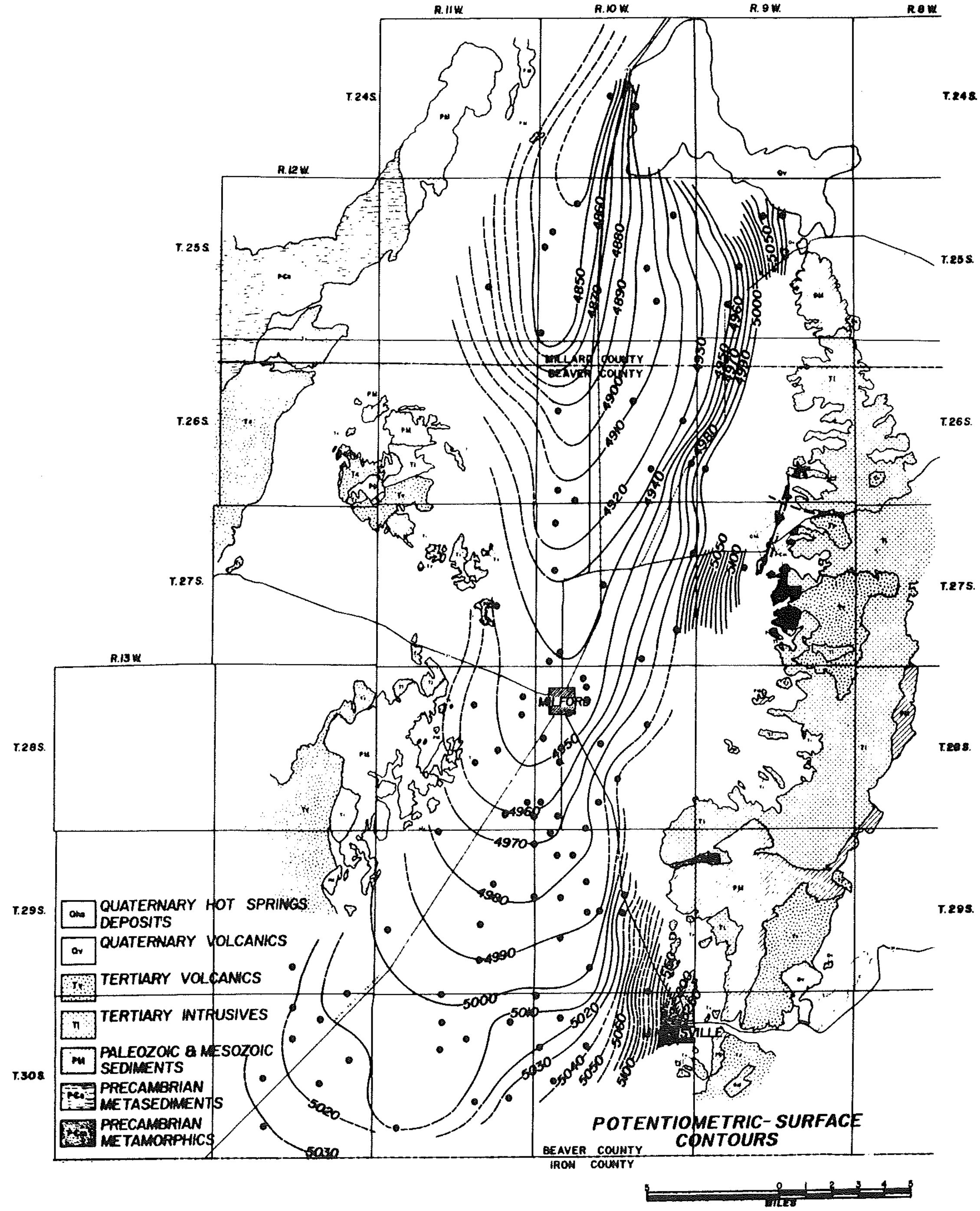


Fig. 7 Map of the Milford area showing potentiometric surface contours for the principal groundwater reservoir. (Modified after Mower and Cordova, 1974).

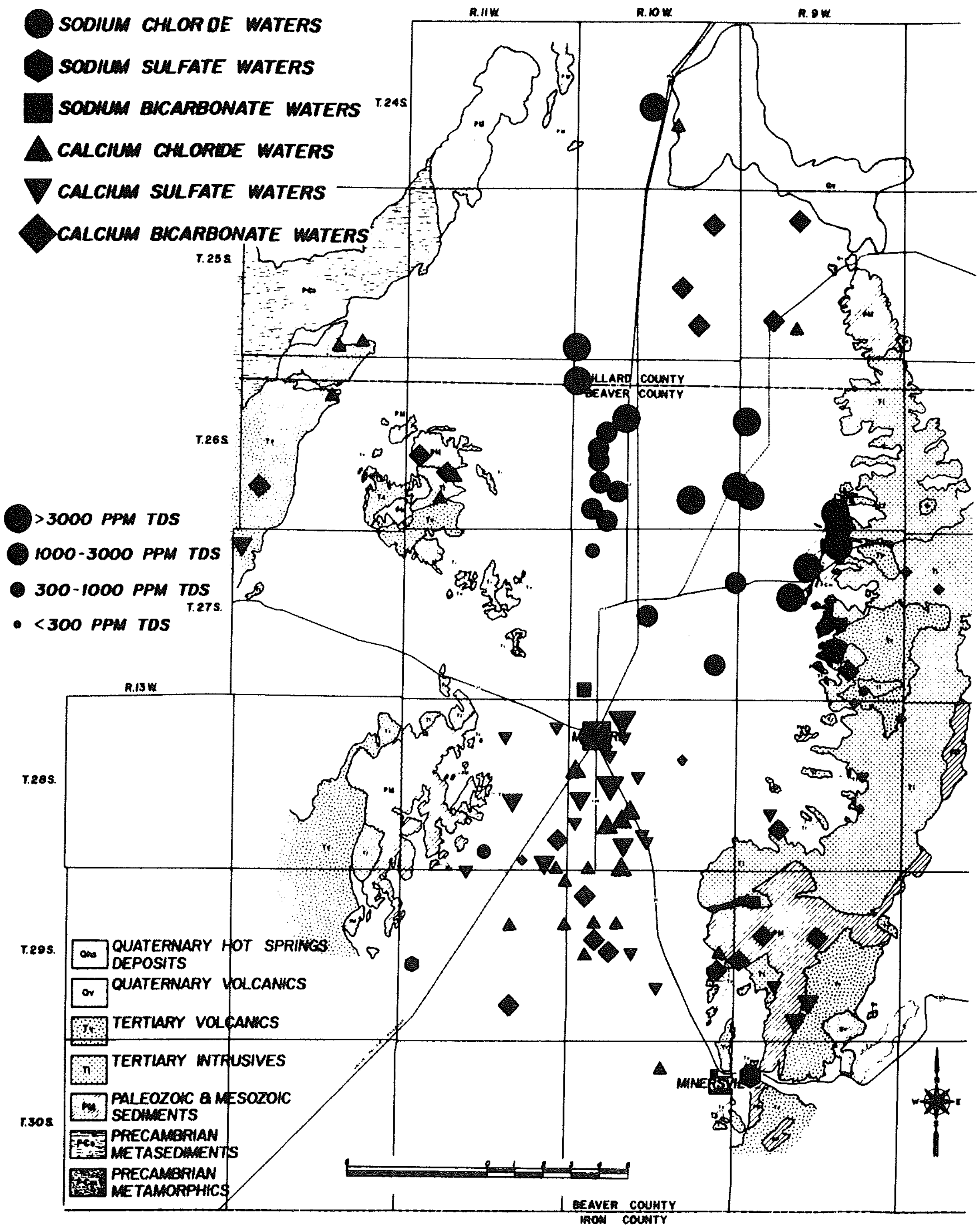


Fig. 8 Water characterization map showing sample locations, water types, and water quality.

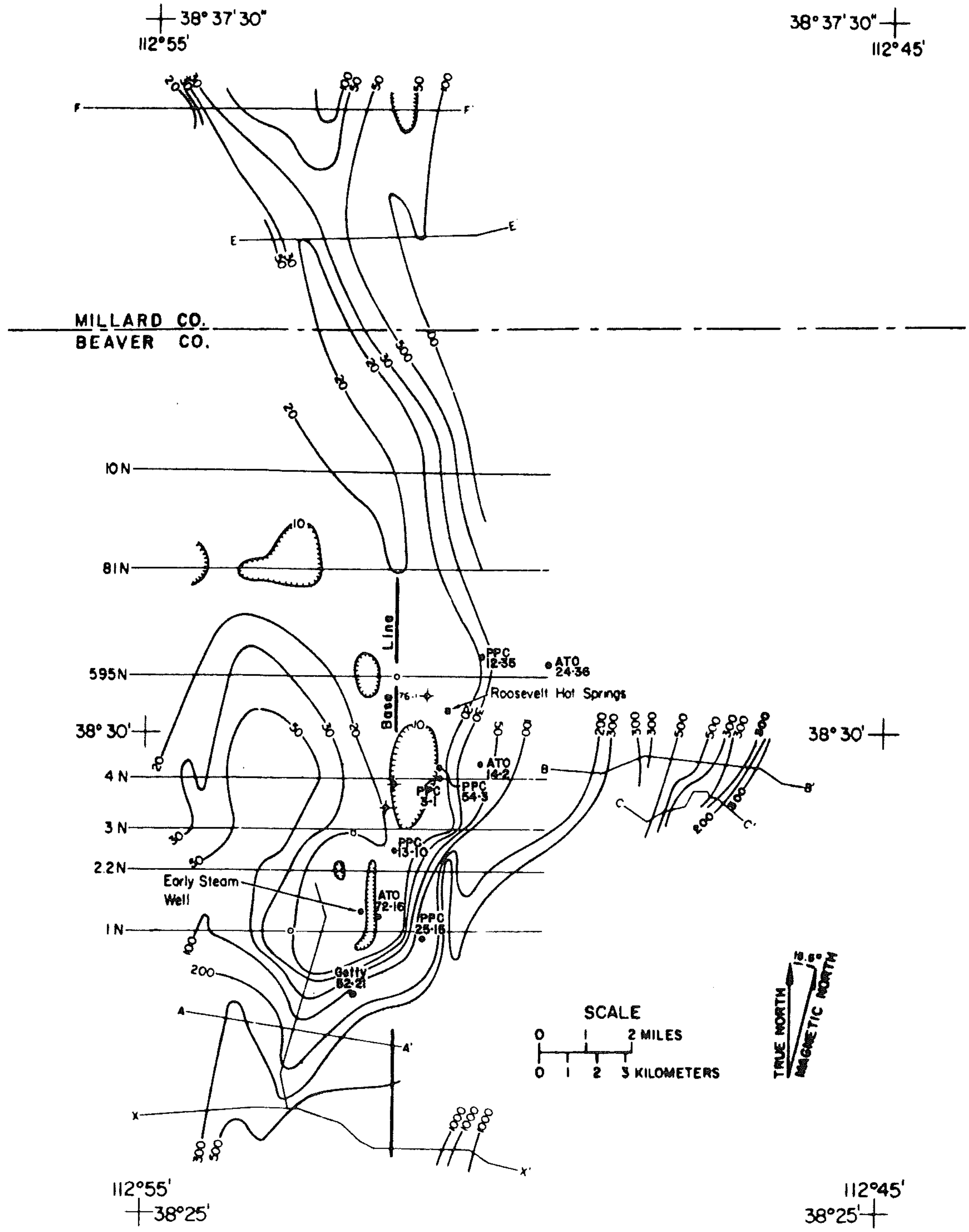


FIG. 9. Contours of apparent resistivity obtained with dipole-dipole array, first separation, over the Roosevelt Hot Springs thermal area. Contours at 10, 20, 30, 50, 100 Ω-m and multiples of ten times these figures. Productive wells shown by solid dots, "dry wells" by open circles, shallow alteration holes by circles with crosses. Traverse lines are shown. (Ward and Sill, 1976a).

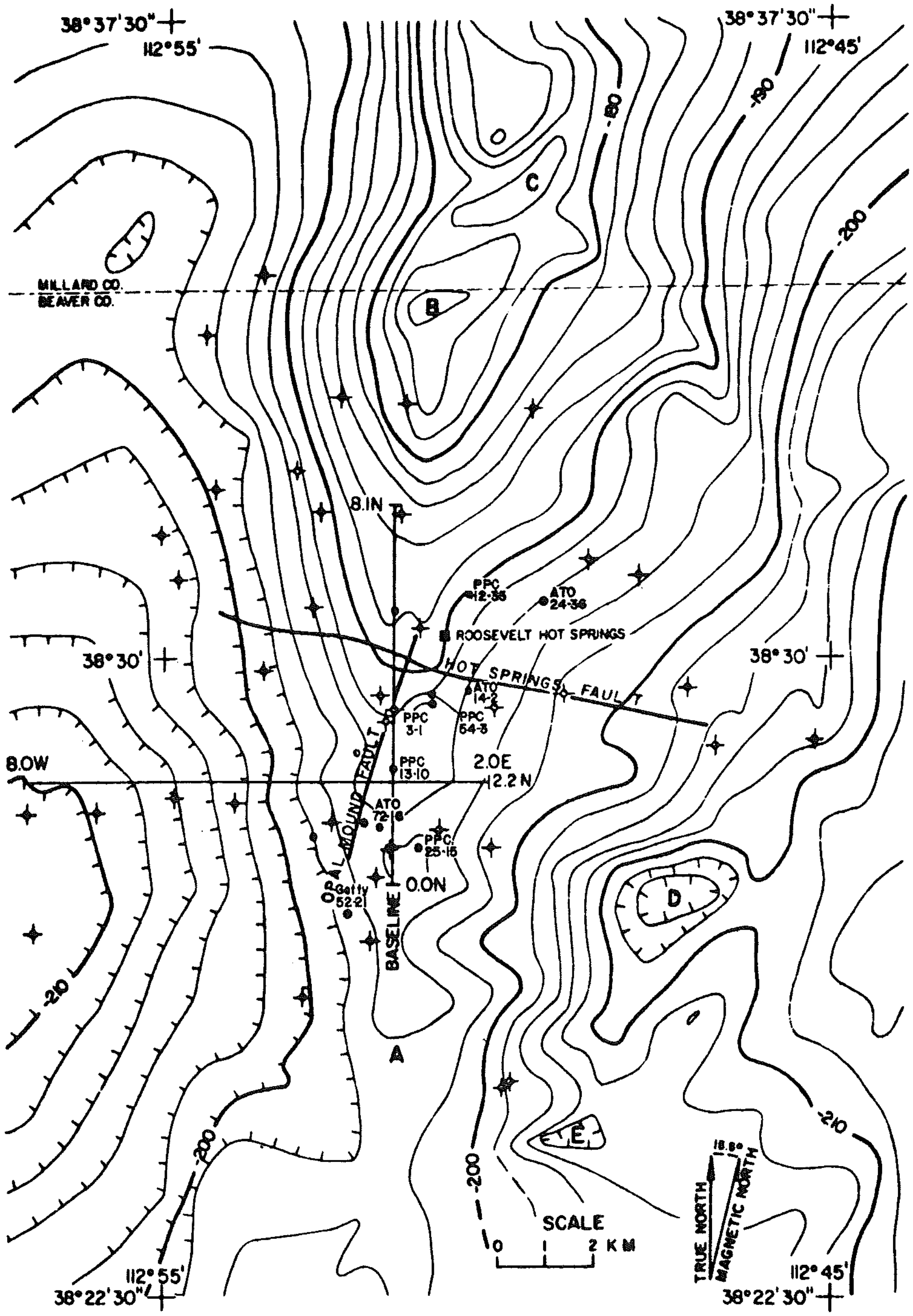


FIG. 10. Terrain-corrected Bouguer gravity anomaly map of the Roosevelt Hot Springs thermal area. Contour interval = 2 mgal. Well designations: solid circle, productive well; plain open circle, nonproductive well; open circle, with crosses, thermal gradient well. Letter designations are described in text.
(Carter, and Cook, 1978).

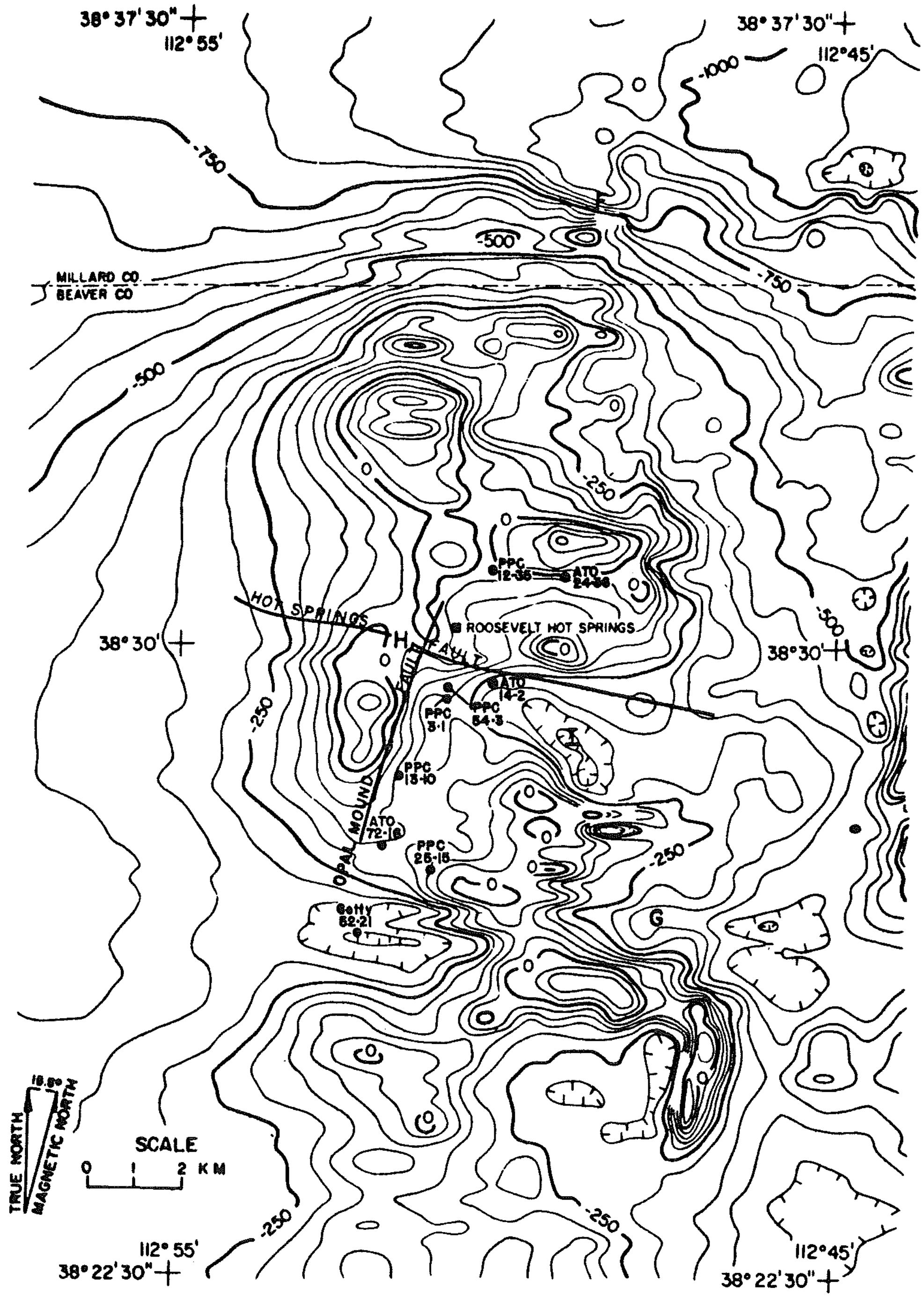


FIG.11. Total aeromagnetic intensity residual anomaly map of the Roosevelt Hot Springs thermal area. Contour interval = 50 gammas. Data were obtained along east-west lines at 1/4-mile (402-m) spacing, drape flown at an elevation of 1000 ft (305 m) above ground. International Geophysical Reference Field (IGRF), updated to 1975, is removed from data. Letter designations are described in text. (Ward et al., 1978)

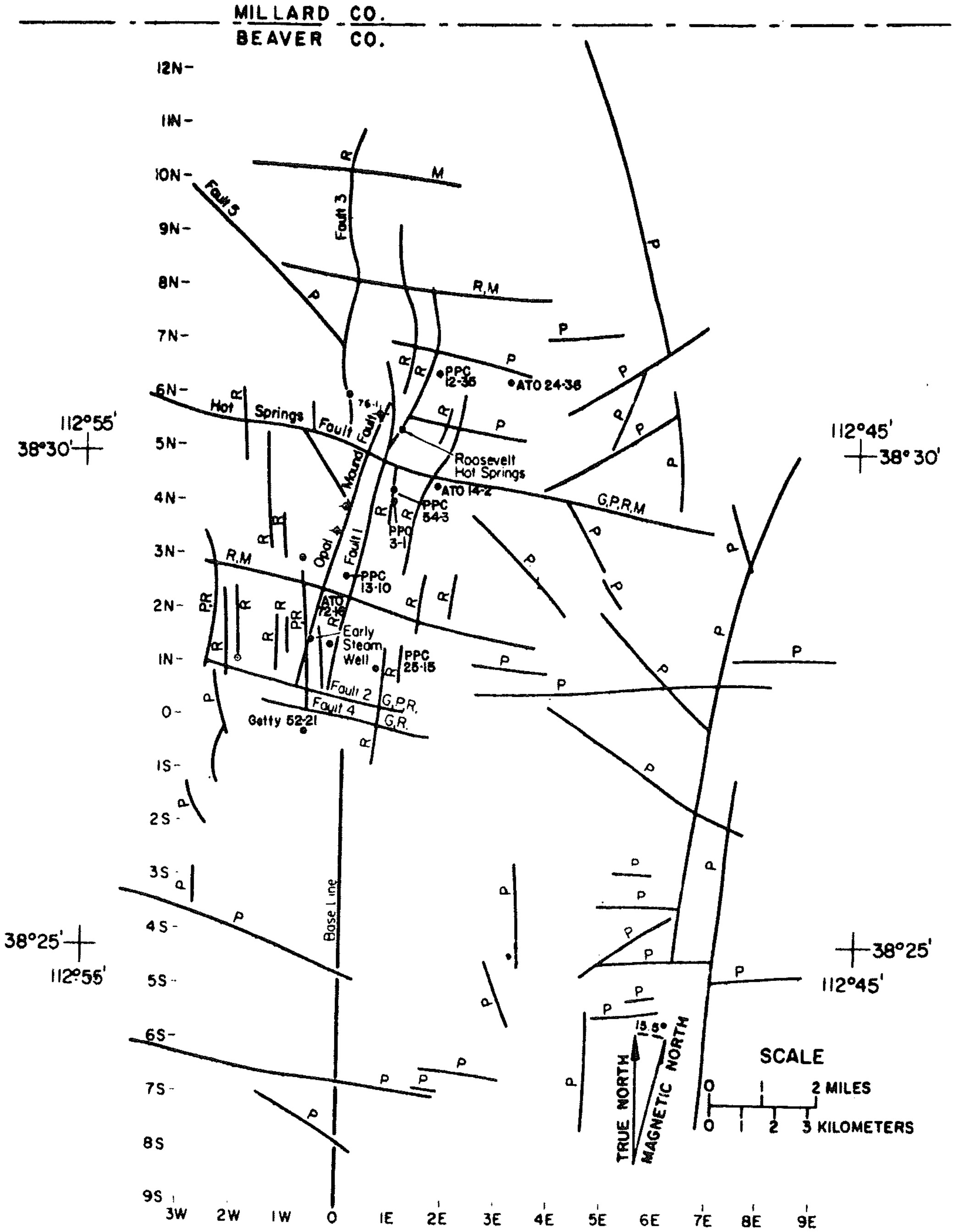


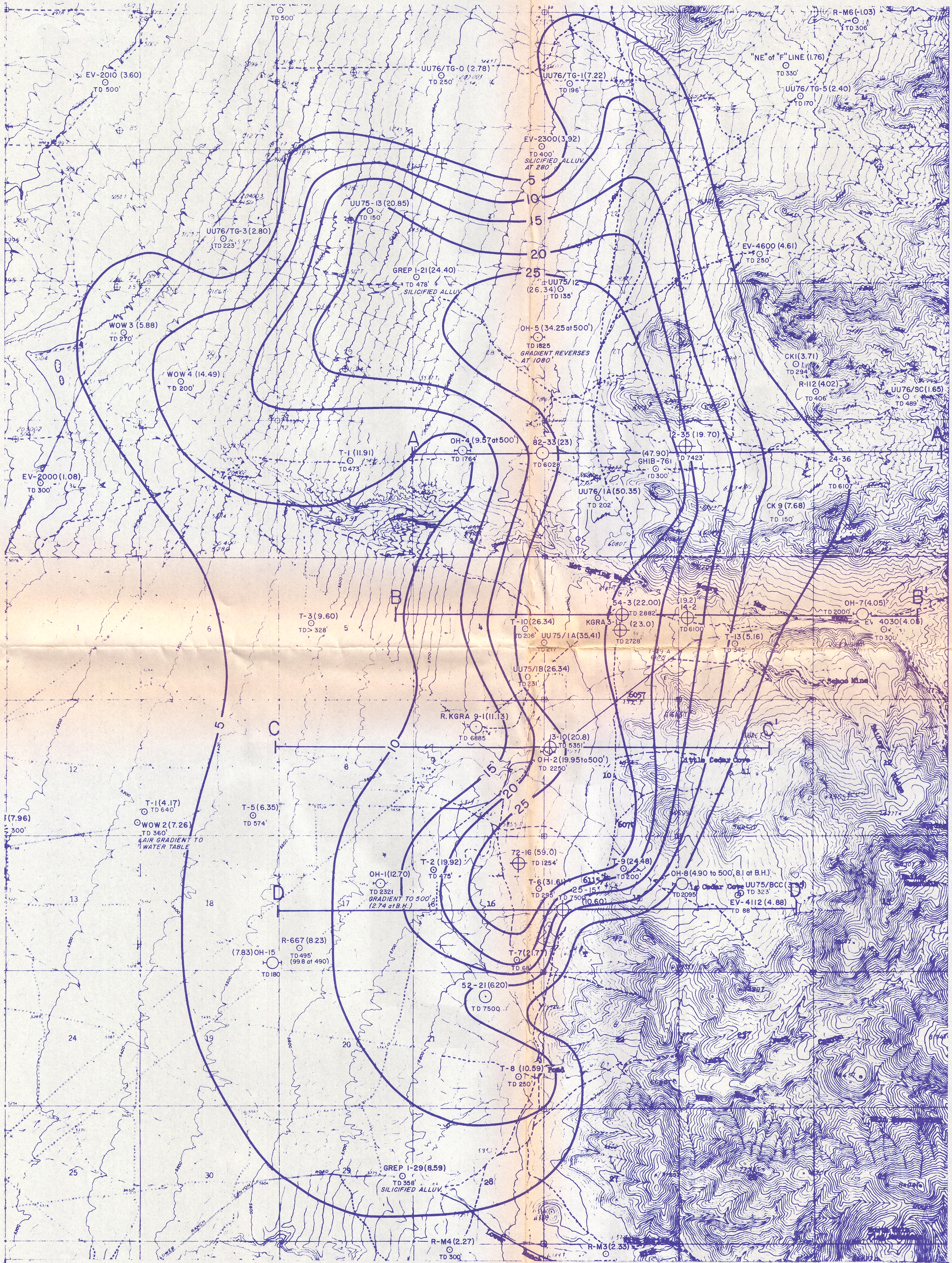
FIG. 12.-Lineaments, interpreted as fractures and faults, mapped by photos (*P*), geologic observation (*G*), resistivity survey (*R*), and aeromagnetic survey (*M*) over the Roosevelt Hot Springs thermal area. Producing wells shown by solid dots, "dry wells" by open circles, shallow alteration holes by circles with crosses. **(Ward and Sill, 1976 a).**

FIGURE 13

ROOSEVELT HOT SPRINGS UNIT AREA
TEMPERATURE GRADIENT CONTOUR MAP

The figure in the plastic envelope following this page depicts the information above.

A00034-4 of 14



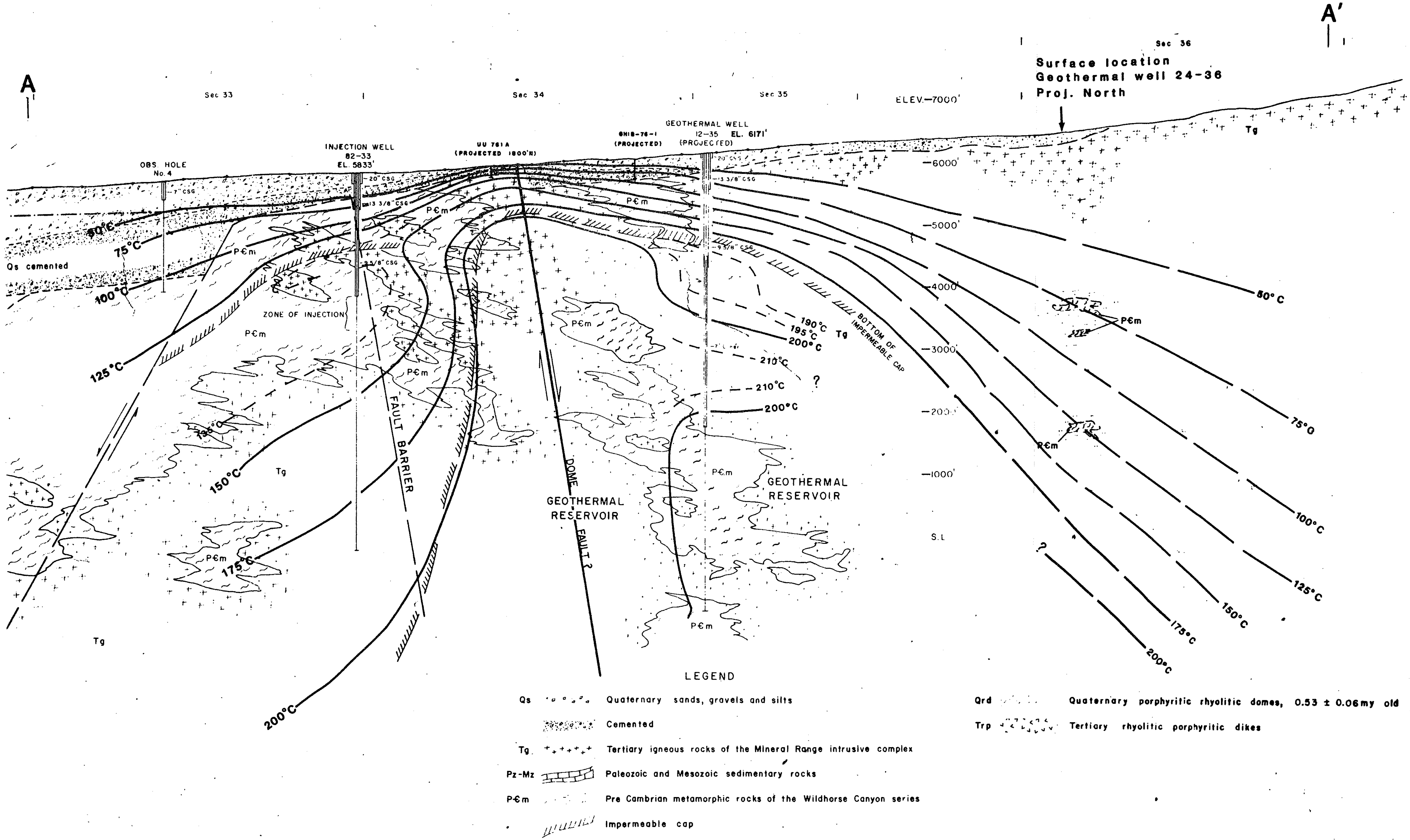
LEGEND

⊙ GRADIENT HOLE	T-14 — HOLE NUMBER
OBSERVATION HOLE	(7.67) — TEMPERATURE GRADIENT (°F/100')
GEOTHERMAL WELL (SHUT IN)	TD 360' — TOTAL DEPTH
GEOTHERMAL WELL (DRY HOLE)	WATER TABLE 423' — SPECIAL NOTES

ROOSEVELT HOT SPRINGS UNIT AREA TEMPERATURE GRADIENT CONTOUR MAP

DATE: JANUARY 9, 1978
DRAWN BY: T.L. GRIFFIN
REVISED: D.L. OLSON 2/20/79

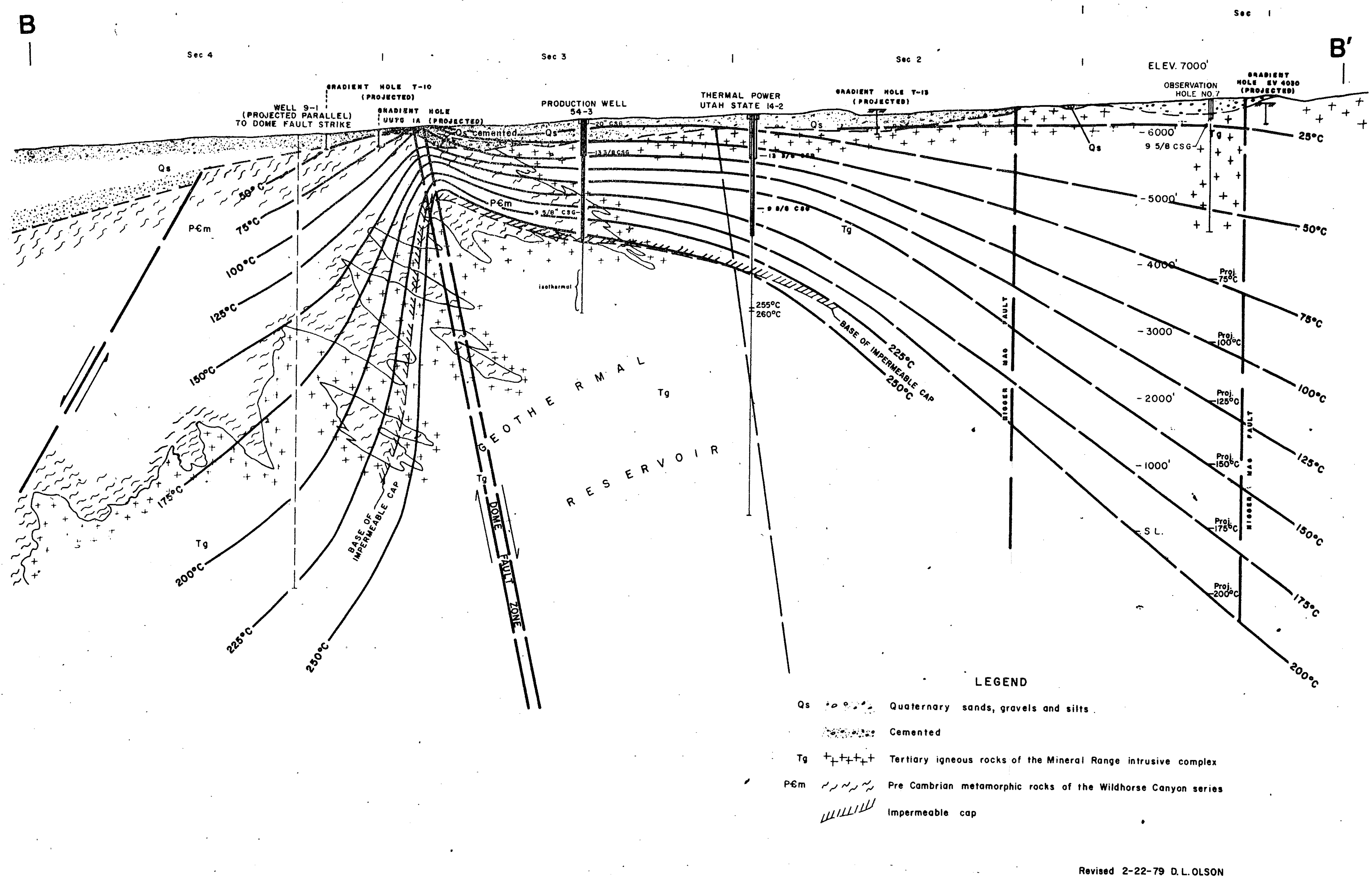
0' 2000' 4000'



(Revised 2-23-79)

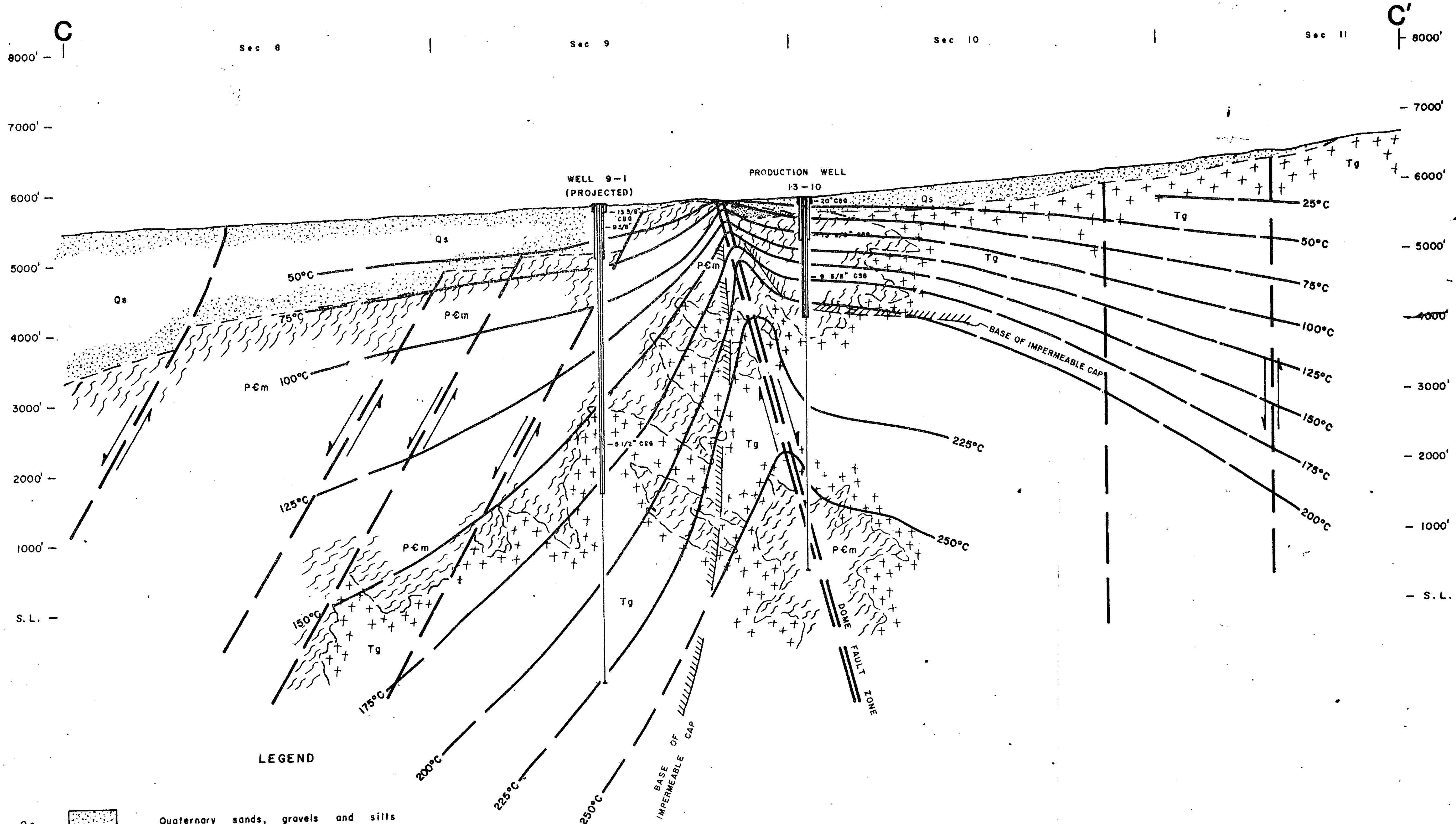
FIG. 14

EAST-WEST GEOLOGIC CROSS SECTION THROUGH WELL 82-33, ROOSEVELT HOT SPRINGS UNIT



EAST-WEST GEOLOGIC CROSS SECTION THROUGH PRODUCTION WELL 54-3 ROOSEVELT HOT SPRINGS UNIT

FIG. 15



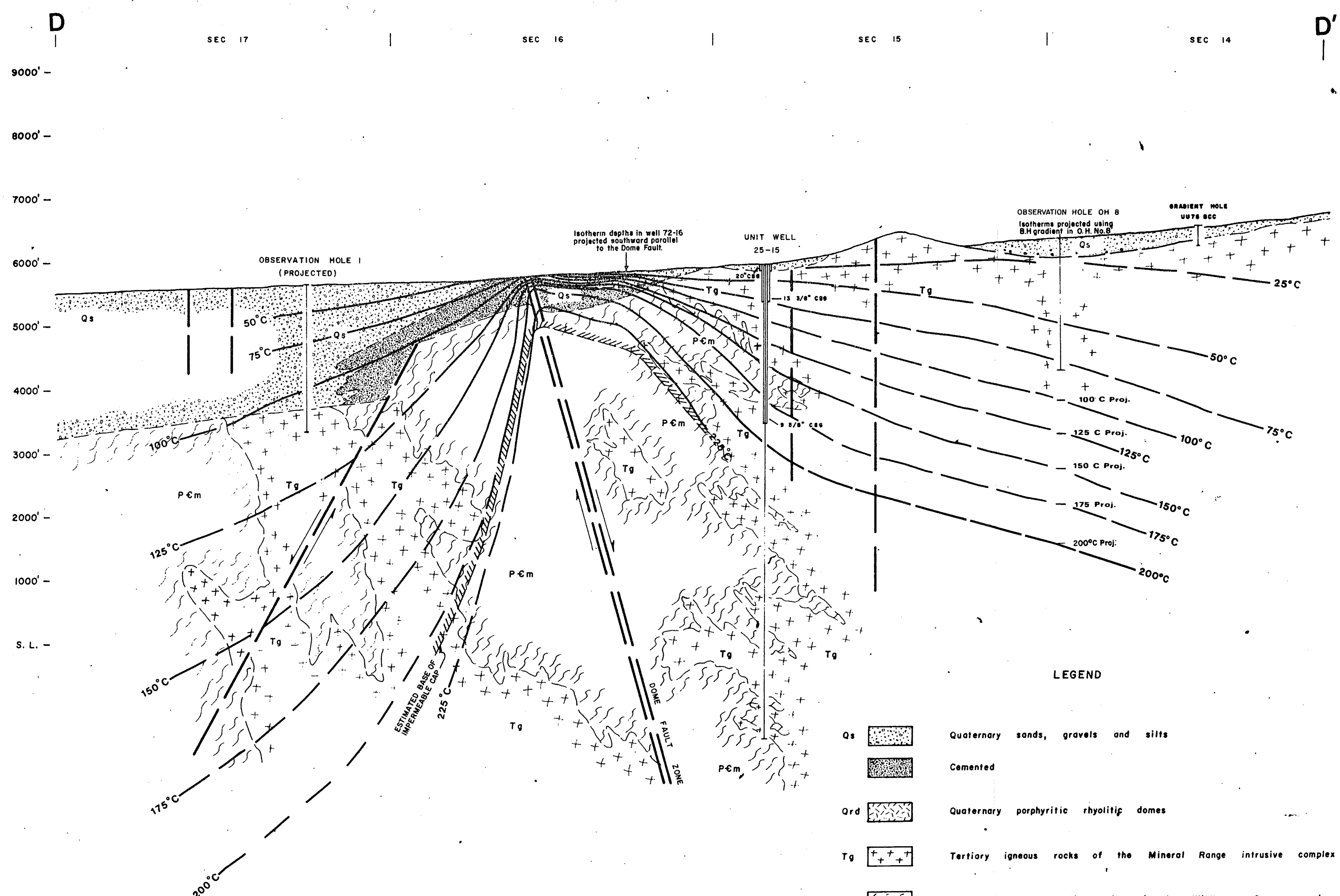
LEGEND

Qs		Quaternary sands, gravels and silts
		Cemented
Qrf		Quaternary flow layered rhyolite
Tg		Tertiary igneous rocks of the Mineral Range intrusive complex
P€m		Precambrian metamorphic rocks of the Wildhorse Canyon series
		Base of impermeable cap

Revised 2-23-79, D. L. OLSON

EAST-WEST GEOLOGIC CROSS SECTION THROUGH WELL 13-10

FIG. 16



EAST — WEST GEOLOGIC CROSS SECTION THROUGH WELL 25-15

(Revised 2-23-79, R. Copenhaver)

FIG. 17

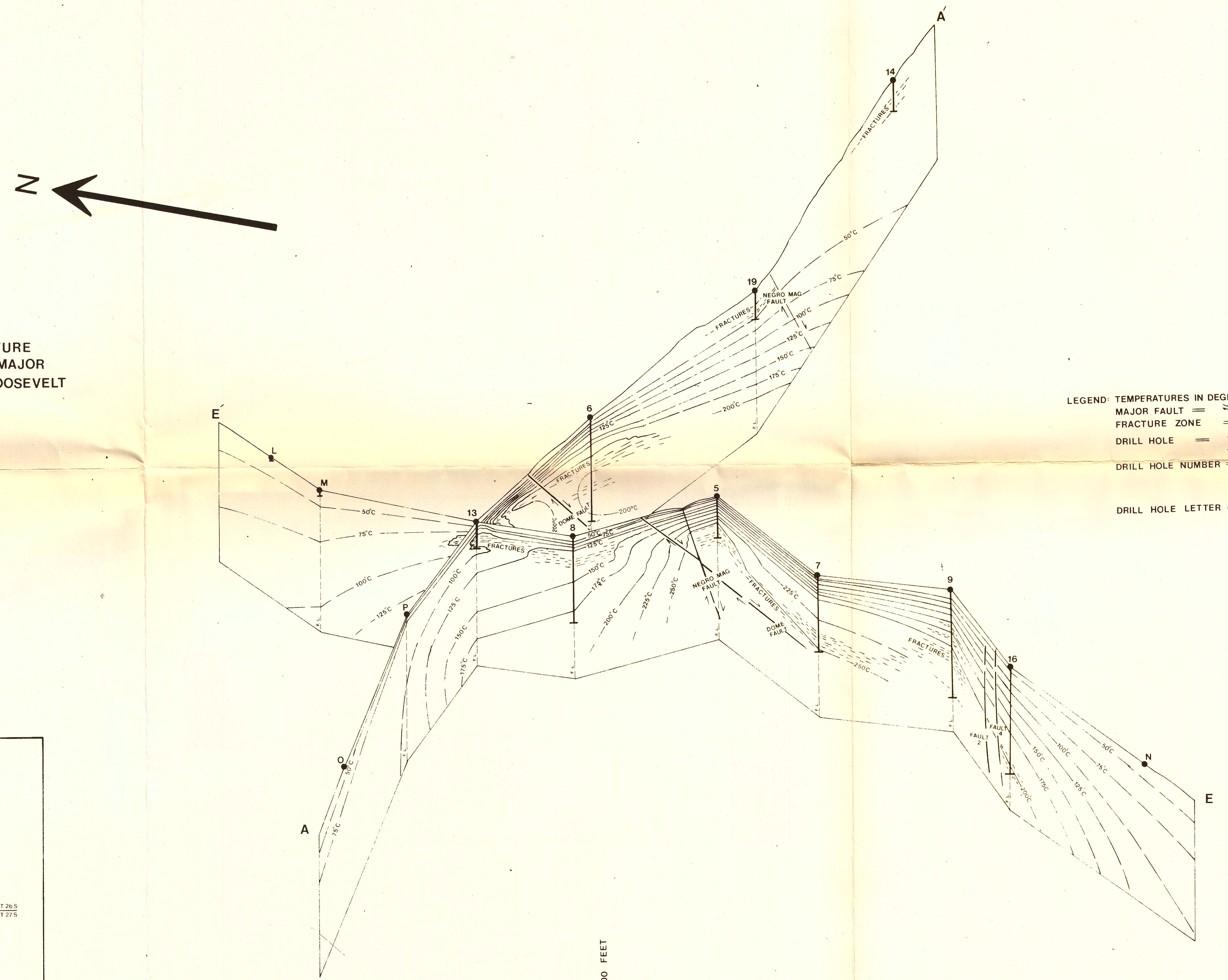
FIGURE 18

FENCE DIAGRAM - EAST-NORTHEAST VIEW

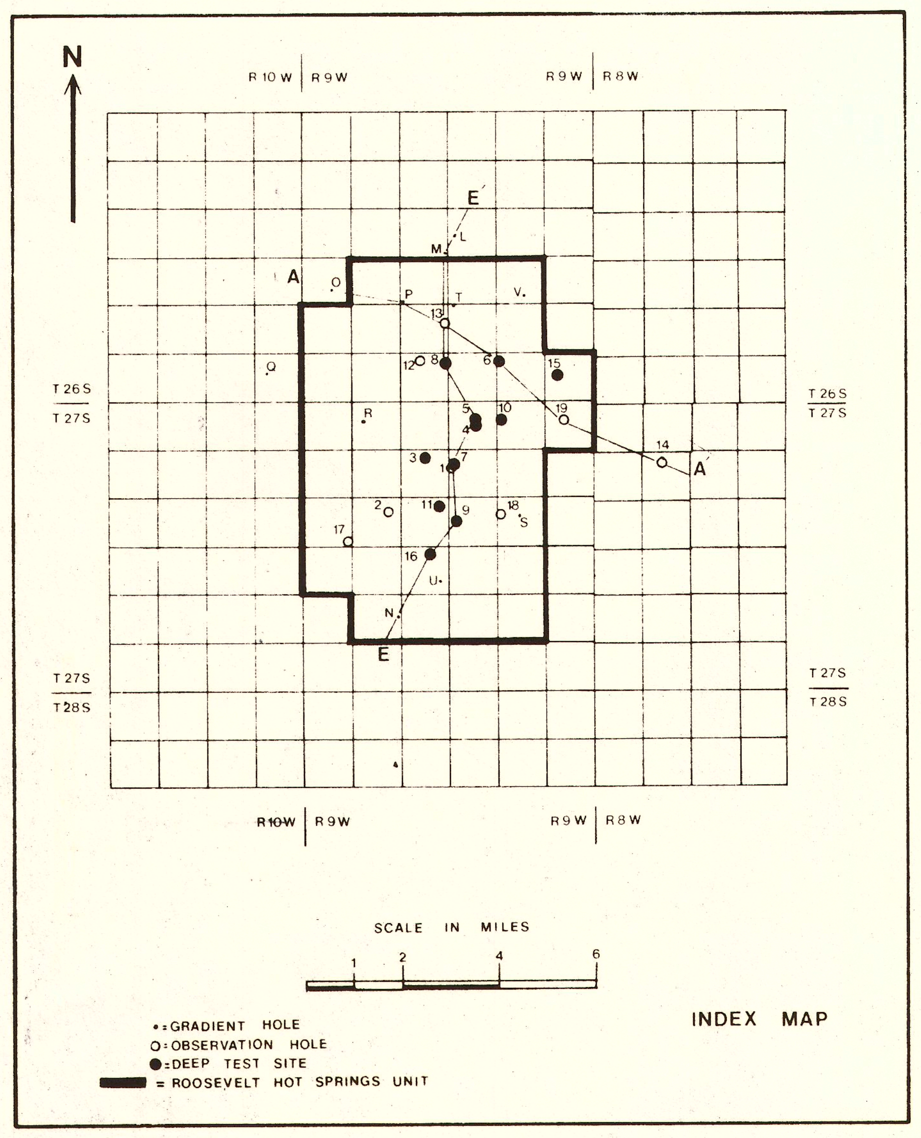
The figure in the plastic envelope following this page depicts the information above.

1

FENCE DIAGRAM SHOWING TEMPERATURE PROFILE LINES WITH DEPTH PLUS MAJOR FAULTS - FRACTURES WITHIN THE ROOSEVELT HOT SPRINGS UNIT

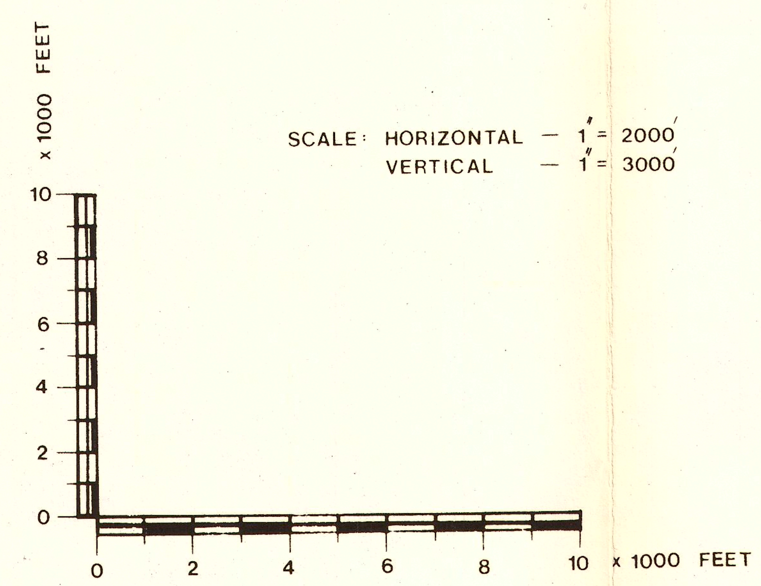


LEGEND: TEMPERATURES IN DEGREES CENTIGRADE = °C
MAJOR FAULT =
FRACTURE ZONE =
DRILL HOLE =
DRILL HOLE NUMBER = SEE DATA SHEET FOR NAME, ETC. "LISTED CHRONOLOGICALLY" FOR DEEP TEST SITES & STRATIGRAPHIC SITES
DRILL HOLE LETTER = SEE DATA SHEET FOR SHALLOW TEMPERATURE GRADIENT HOLE IDENTIFICATION



INDEX MAP

SCALE: HORIZONTAL — 1" = 2000'
VERTICAL — 1" = 3000'



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ENERGY MINERALS DIVISION

ROOSEVELT HOT SPRINGS UNIT
BEAVER COUNTY UTAH

FENCE DIAGRAM
EAST NORTHEAST VIEW

REVISIONS	DATE
ORIGINAL	1/79

DRAFTED BY RON FORREST GEOLOGIST

1

FIGURE 19

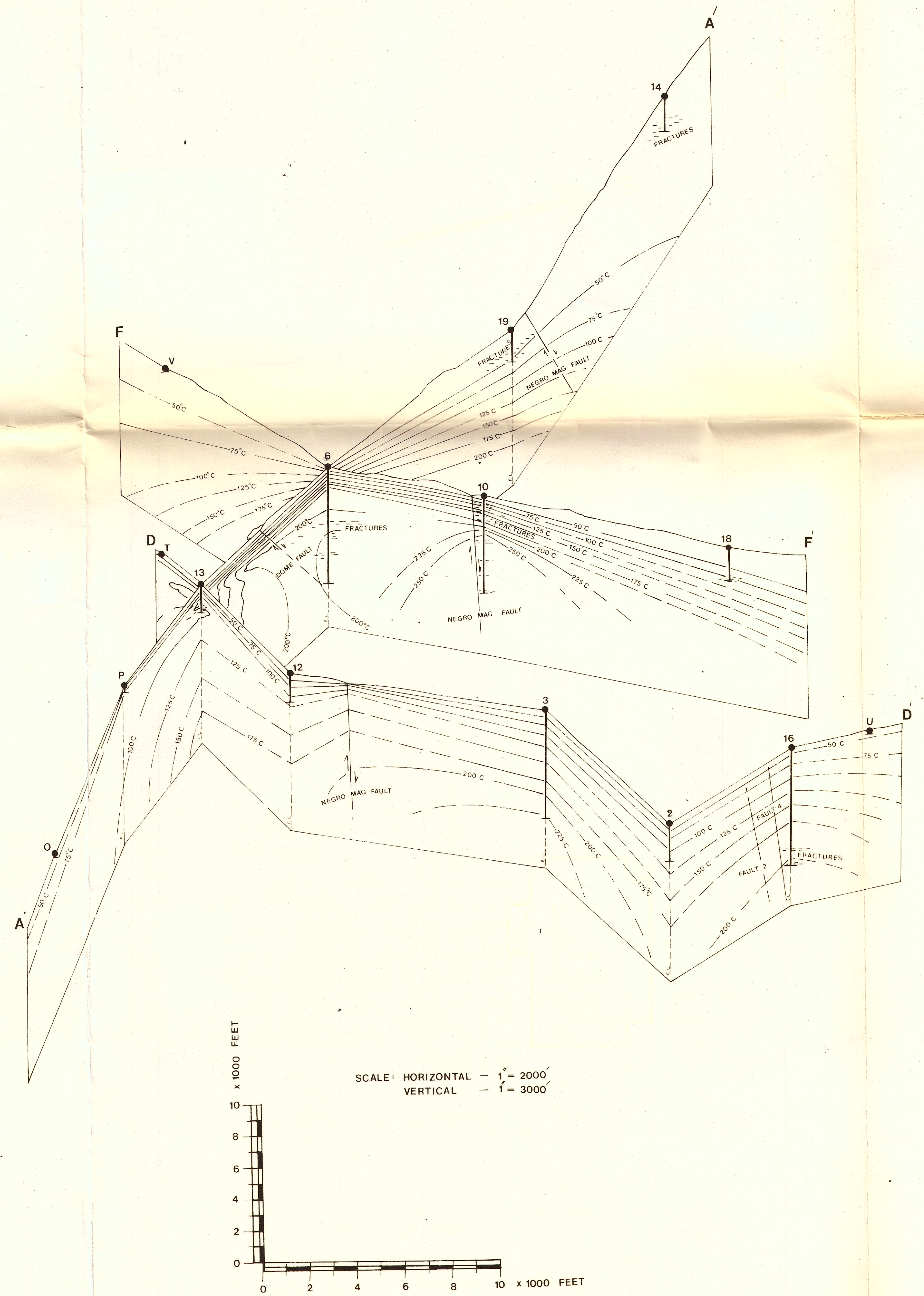
FENCE DIAGRAM - EAST VIEW

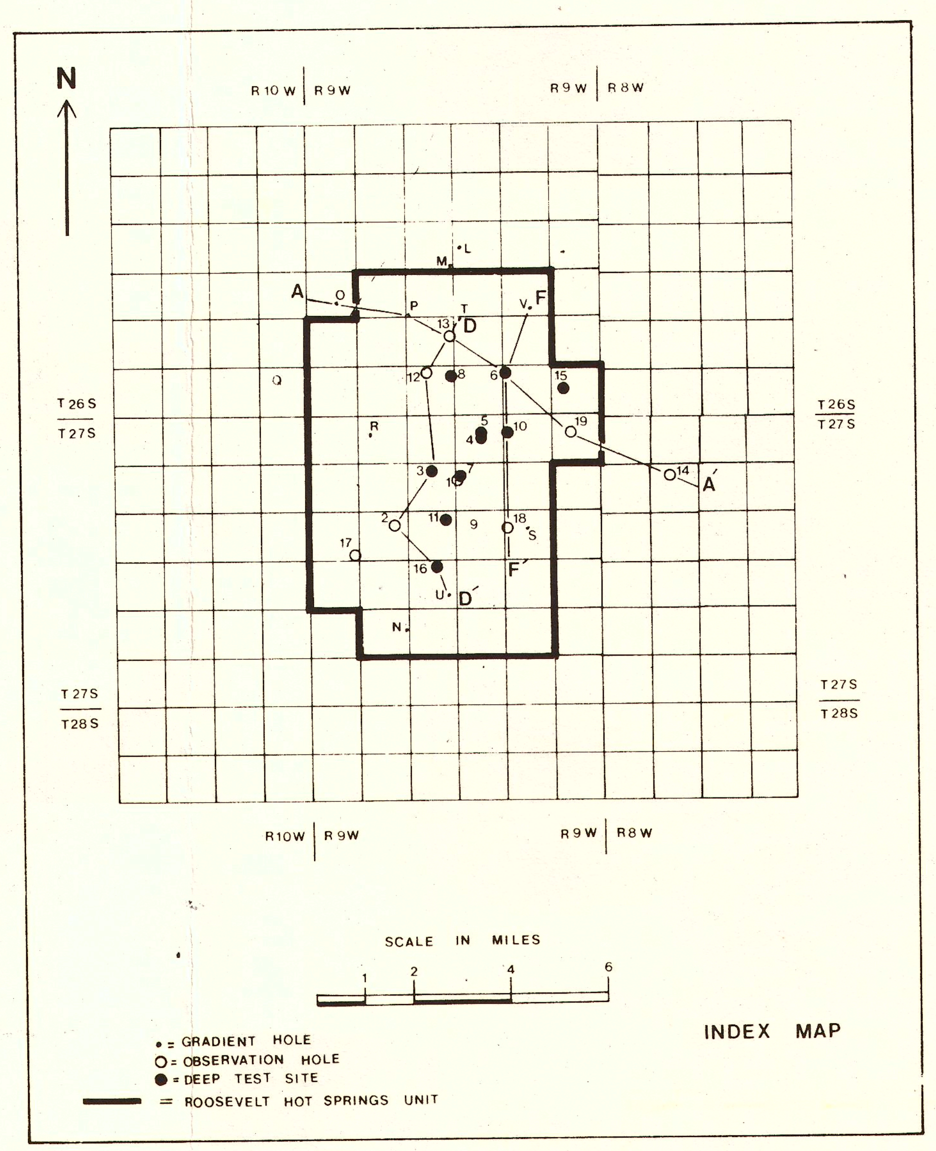
The figure in the plastic envelope following this page depicts the information above.

A0034-6 of 14

2

FENCE DIAGRAM SHOWING TEMPERATURE PROFILE LINES WITH DEPTH PLUS MAJOR FAULTS—FRACTURES WITHIN THE ROOSEVELT HOT SPRINGS UNIT.





LEGEND: °C = DEGREES CENTIGRADE
= MAJOR FAULT
= FRACTURES
= DRILL HOLE

DRILL HOLE NUMBER = DEEP TEST SITES & OBSERVATION HOLES LISTED CHRONOGICALLY SEE DATA SHEET FOR IDENTIFICATION

DRILL HOLE LETTER = GRADIENT HOLE SEE DATA SHEET FOR IDENTIFICATION

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BEAVER COUNTY UTAH
FENCE DIAGRAM
EAST VIEW

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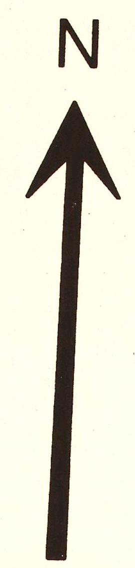
2

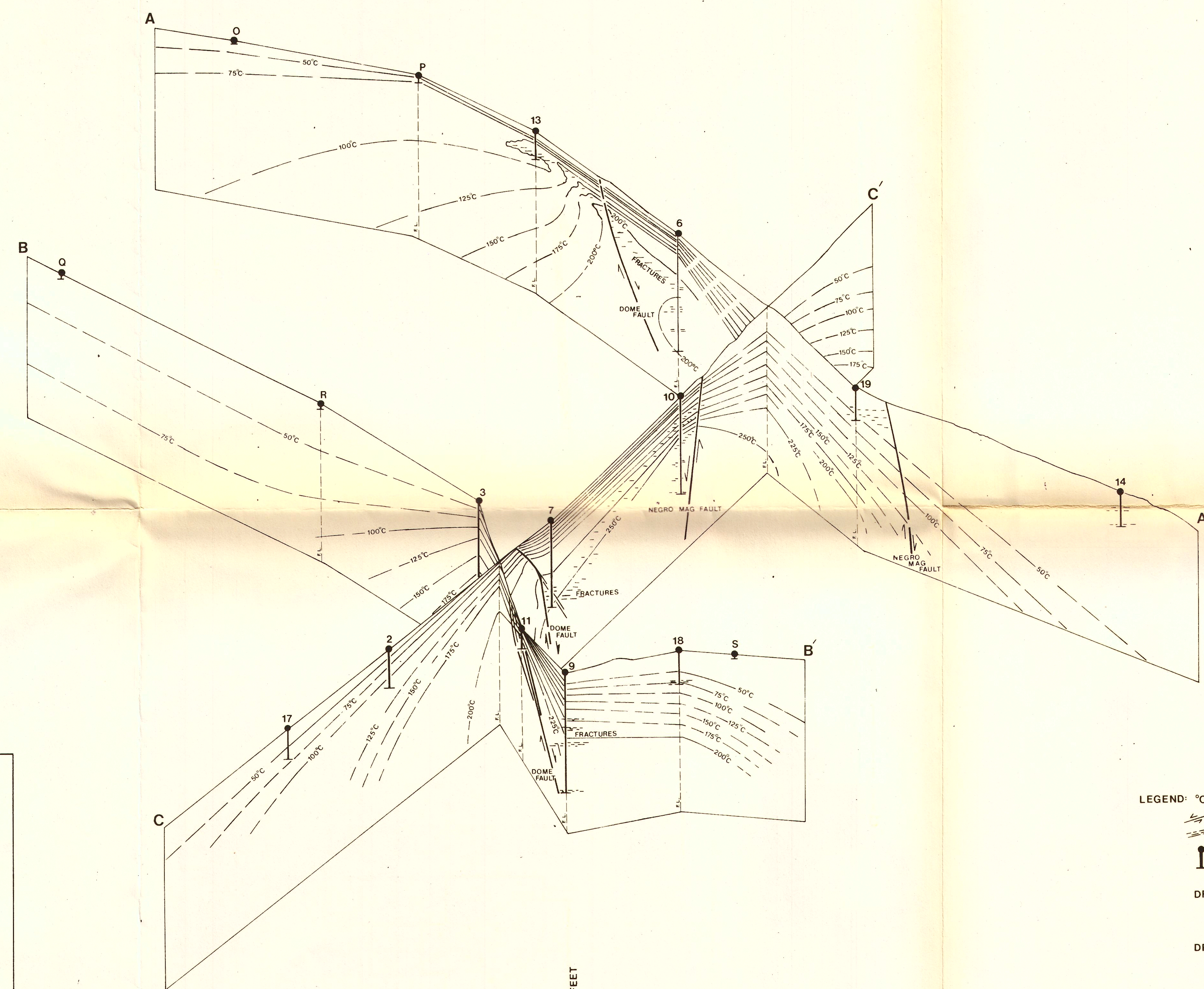
FIGURE 20

FENCE DIAGRAM - NORTH VIEW

The figure in the plastic envelope following this page depicts the information above.

3



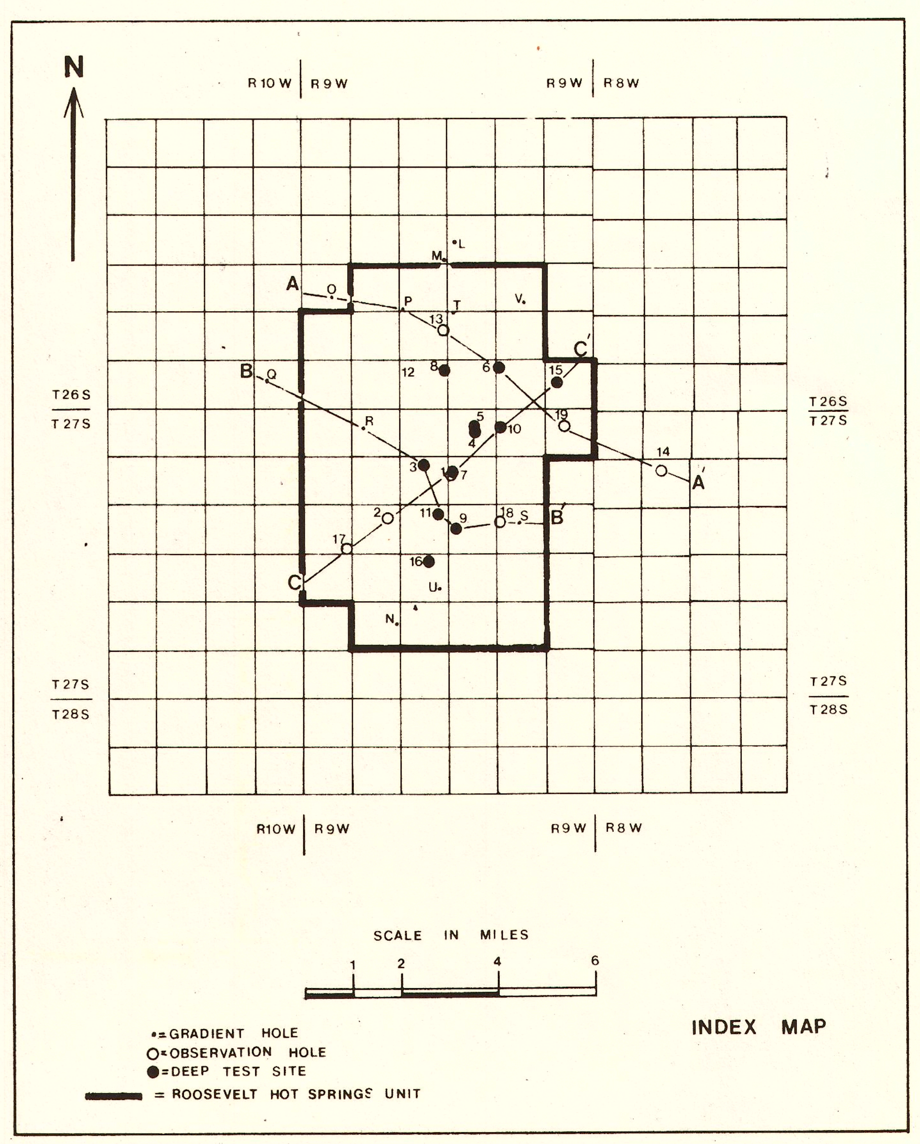


FENCE DIAGRAM SHOWING TEMPERATURE PROFILE LINES WITH DEPTH PLUS MAJOR FAULTS — FRACTURES WITHIN THE ROOSEVELT HOT SPRINGS UNIT.

LEGEND: °C = DEGREES CENTIGRADE
= MAJOR FAULT
= FRACTURES
= DRILL HOLE

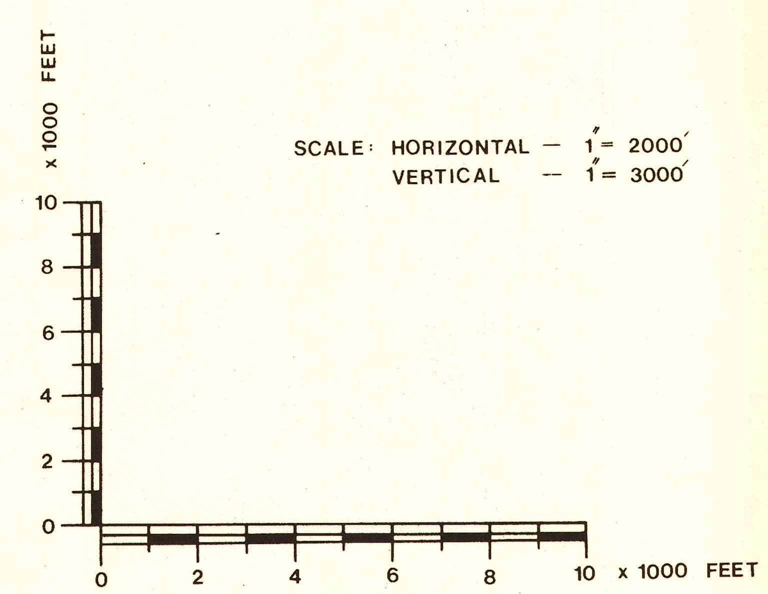
DRILL HOLE NUMBER = DEEP TEST SITES & OBSERVATION HOLES LISTED CHRONOLOGICALLY SEE DATA SHEET FOR IDENTIFICATION

DRILL HOLE LETTER = GRADIENT HOLE SEE DATA SHEET FOR IDENTIFICATION



INDEX MAP

SCALE: HORIZONTAL — 1″ = 2000′
VERTICAL — 1″ = 3000′



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FENCE DIAGRAM
"NORTH VIEW"

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3

A00034-8 of 14

TEMPERATURE PROFILE
CROSS SECTION

LEGEND °C = DEGREES CENTIGRADE
= FRACTURES
= FAULT
= DRILL HOLE

FIG. 21

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BEAVER COUNTY UTAH

TEMPERATURE PROFILE CROSS SECTION

REVISIONS	DATE
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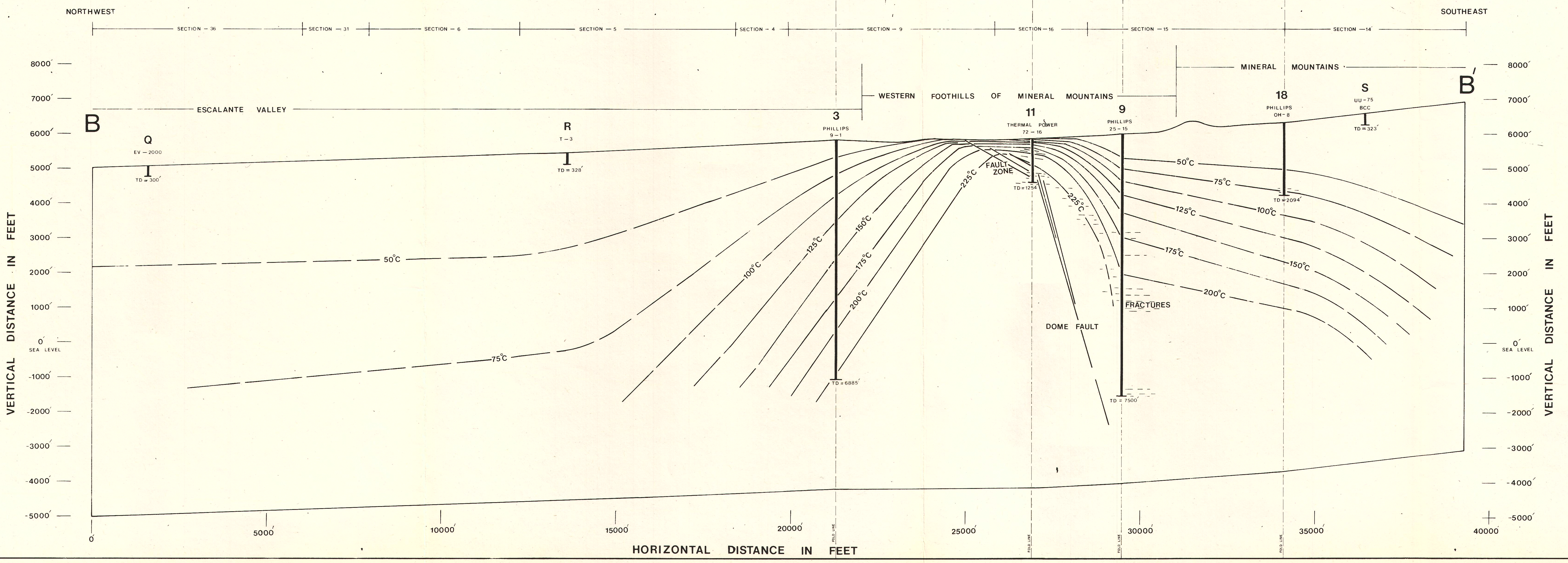
A00034-9 of 14

TEMPERATURE PROFILE CROSS SECTION



LEGEND: °C = DEGREES CENTIGRADE
= FRACTURES
= MAJOR FAULT
= DRILL HOLE

FIG. 22

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TEMPERATURE PROFILE CROSS SECTION

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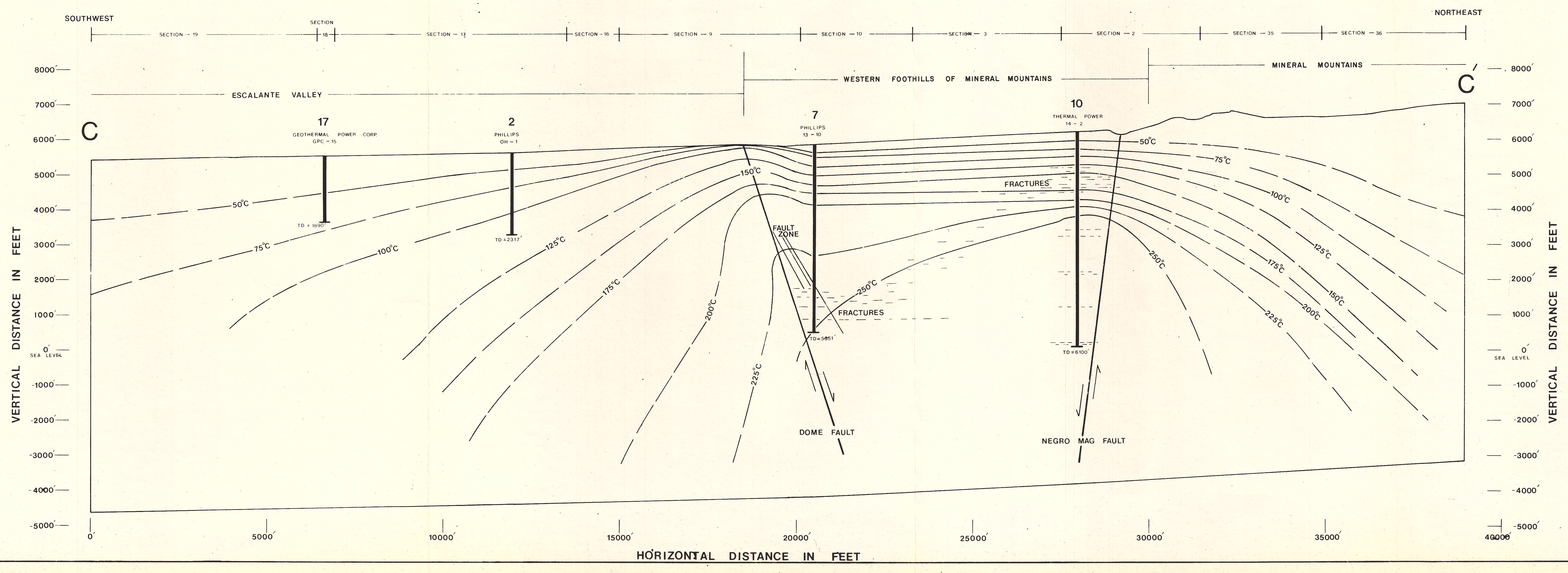
A00034-10 #14



TEMPERATURE PROFILE CROSS SECTION

LEGEND: °C = DEGREES CENTIGRADE
= FRACTURES
= MAJOR FAULT
= DRILL HOLE

FIG. 23

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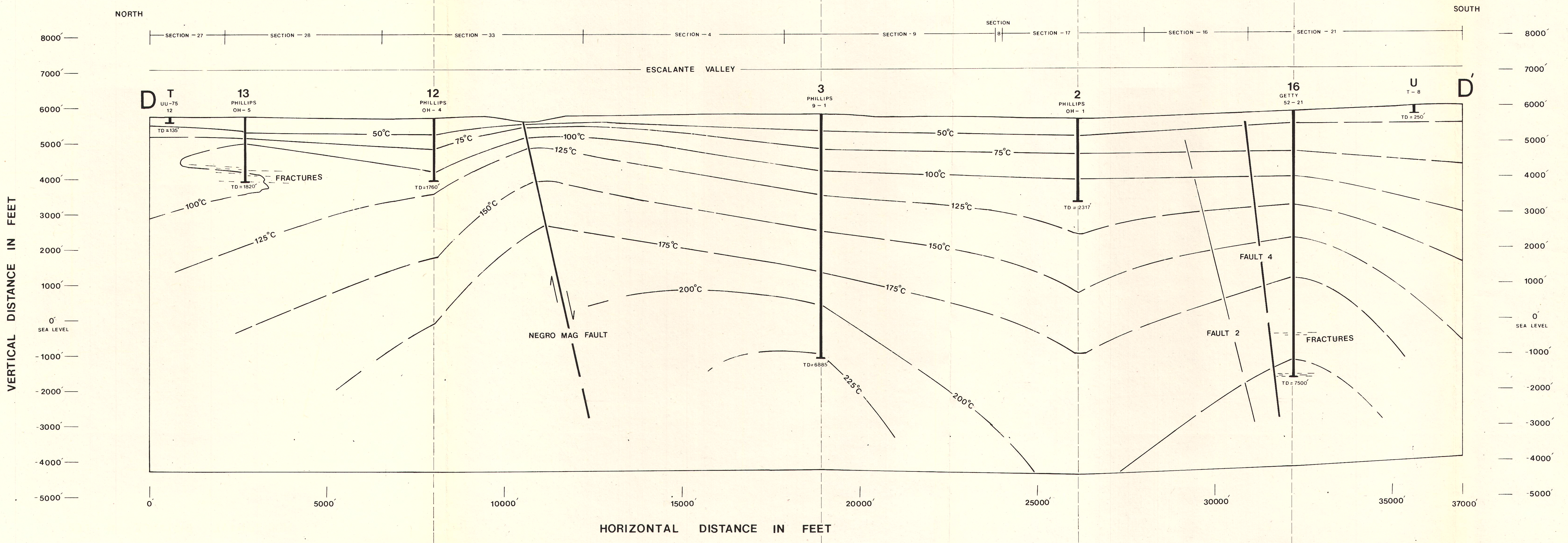
BEAVER COUNTY UTAH

TEMPERATURE PROFILE CROSS SECTION

REVISIONS		DATE
ORIGINAL	RON FORREST	2/79

A00034-11of14

TEMPERATURE PROFILE CROSS SECTION



LEGEND: °C = DEGREES CENTIGRADE
= FRACTURES
= MAJOR FAULT
= DRILL HOLE

FIG. 24

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BEAVER COUNTY UTAH

REVISIONS	DATE
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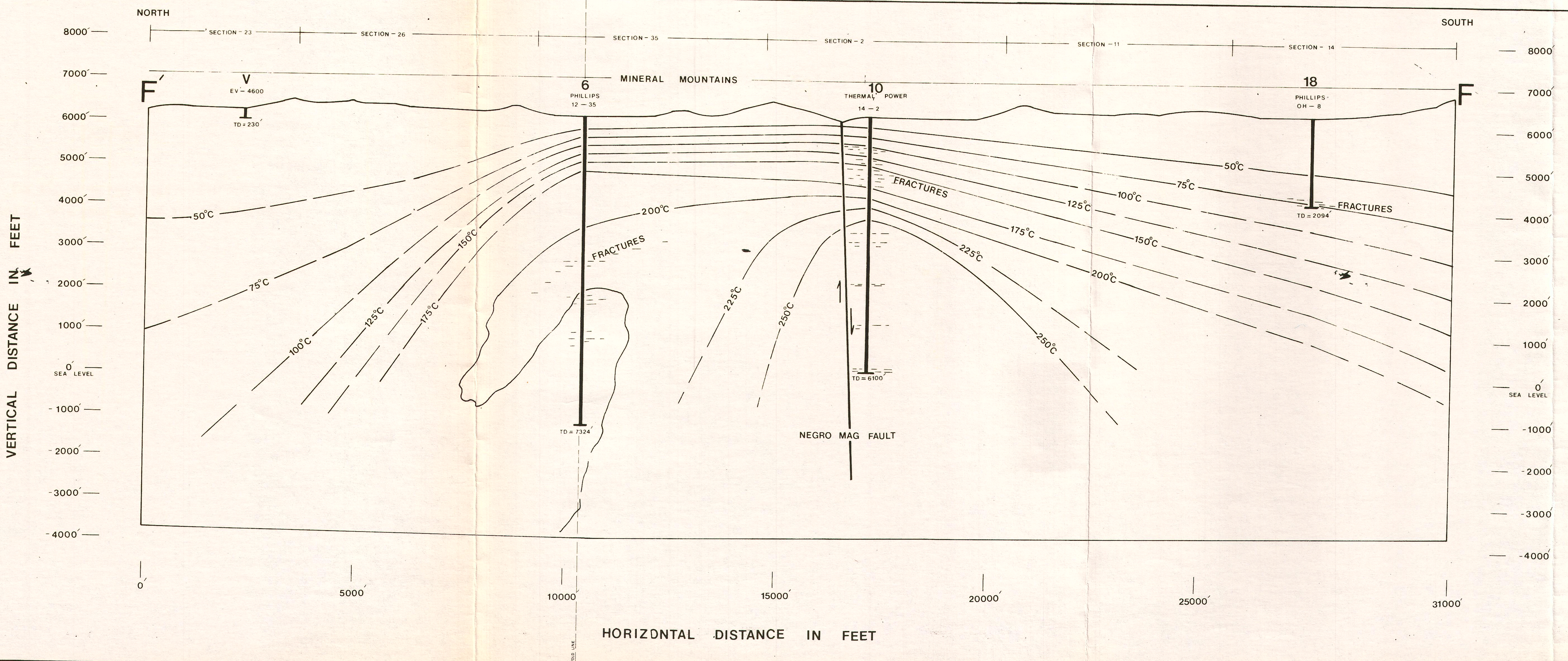
A00034-12 of 14

FIG. 25

AC0034-13 of 14



TEMPERATURE PROFILE CROSS SECTION

LEGEND: °C = DEGREES CENTIGRADE
= FRACTURES
= MAJOR FAULT
= DRILL HOLE

FIG. 26

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BEAVER COUNTY UTAH

REVISIONS		DATE
ORIGINAL	RON FORREST	2/79

FIGURE 27

INDEX MAP

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A0034-14 of 14