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GEOTHERMAL POTENTIAL
OF THE
LANDS LEASED BY
GEOTHERMAL POWER CORPORATION
IN THE
NORTHERN MINERAL MOUNTAINS,
BEAVER AND MILLARD COUNTIES,
UTAH

for

GEOTHERMAL POWER CORPORATION

by

GeothermEx, Inc.

January, 1977

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CONCLUSIONS

1. Geothermal Power Corporation has leases on several sections of land with potential to be within the Roosevelt Hot Springs geothermal field. Of most interest are Sec. 13, 24, 25, 33, 34, and 35, T. 27 S., R. 9 W.; Sec. 25, T. 26 S., R. 9 W.; and Sec. 19, T. 26 S., R. 8 W.

2. Other acreage in Milford Valley or on the eastern slope of the Mineral Mountains is frankly speculative, and does not require exploration to the same degree that is warranted for sections listed above or adjacent thereto.

3. The Roosevelt geothermal field is characterized by production of chloride-rich hot water from fractured crystalline gneiss, schist and possibly granite, at temperatures to 260°C (500°F). Holes have encountered this reservoir at depths of 1,250 to 7,500 feet.

4. Both Phillips Petroleum Co. and the Natomas Company have commercially producible wells in the areas. Numerous large and very many small companies have acquired adjacent acreage in a major geothermal exploration boom.

5. Exploration has included geologic mapping, hydrochemistry, seismic, gravimetric, aeromagnetic and geoelectric surveys, and the drilling of numerous temperature-gradient holes. The latter, plus gravimetry and geology, appear to be most useful in determining whether and where to drill deep exploratory holes. However, the shallow thermal-gradient anomaly appears to be displaced downslope slightly from the principal geothermal reservoir.

6. Gravity data suggest the presence of a molten or high-temperature intrusion beneath several square miles of the Mineral Mountains.

7. It is unlikely that further attractive acreage can be leased in the area. Farm-outs or joint ventures, and pooling of acreage with other small companies, appear to be useful exploration strategies. Trade of exploration data is useful.

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8. Electric-power potential found to date by drilling probably is between 50,000 and 100,000 kW. Phillips expects to install 110 mW of generating capacity by 1982.

9. Exploration results suggest that drilling will proceed to the east and southeast, entering higher elevations of the Mineral Mountains. Geothermal Power Corporation thus has lands directly in the path of exploration.

RECOMMENDATIONS

1. Sites for 10 to 20 300-foot-deep gradient holes are selected (plate 1) on the more attractive of Geothermal Power Corporation's acreage.

2. Auxiliary geologic work and radiometric age-dating of volcanic rocks is recommended to help interpret results from gradient drilling.

3. A single 2,000-foot gradient hole, or two 1,000-foot holes may be warranted, depending upon results from the shallow gradient survey.

4. Trade of gradient and age-dating data with other companies is recommended as a means of optimizing value received for exploration dollars.

5. Joint venture or pooling of lands is recommended where other companies hold adjoining acreage of similar prospective value. Lands held by Geothermal Exploration Co., Getty Oil Company, and O'Brien Gold Mines are within this classification.

6. Selection of a deep drill site would follow thereupon.

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INTRODUCTION

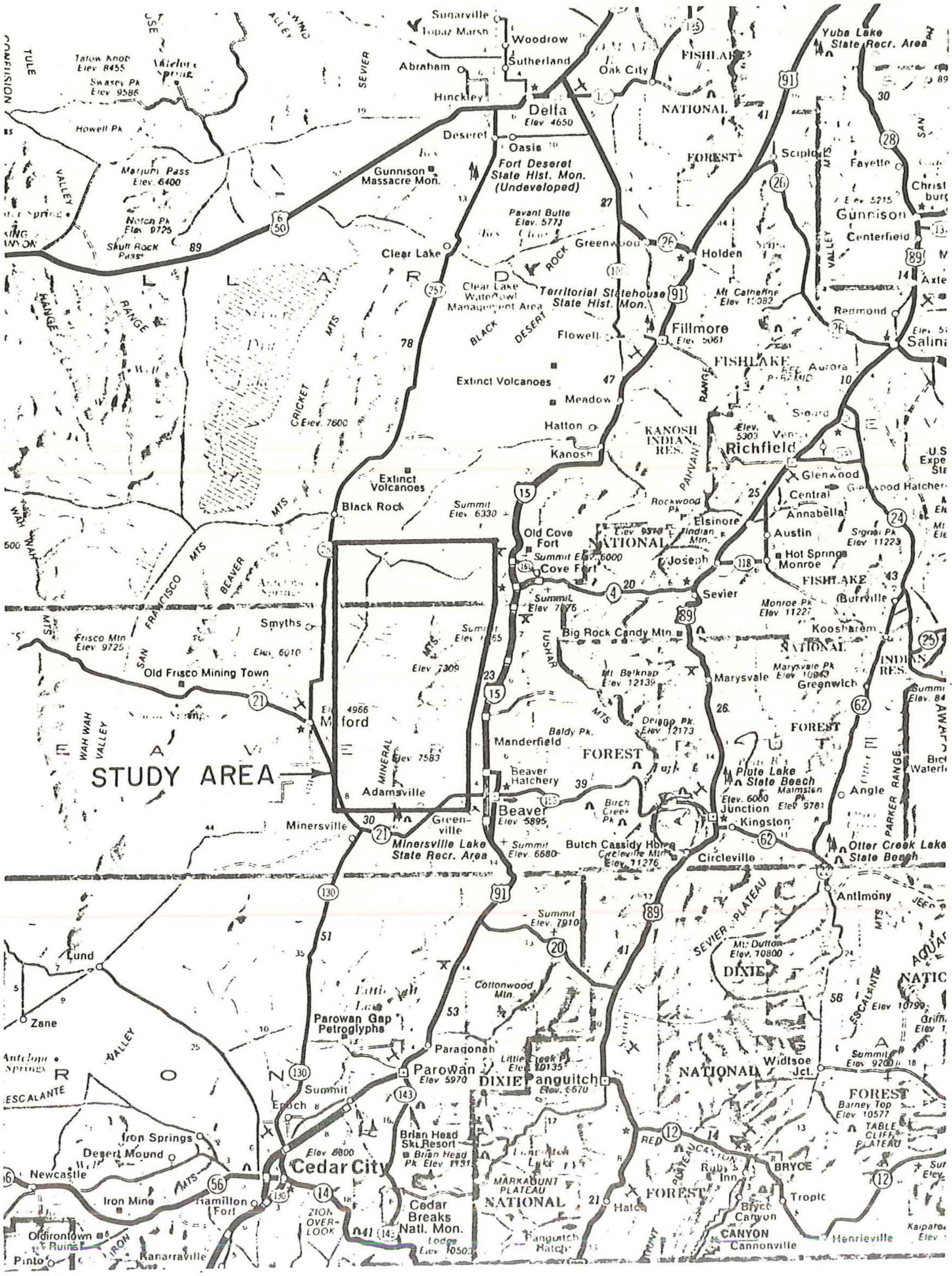
Location

This report deals with the geology, geophysics, and geothermal potential of the northern Mineral Mountains, located in Beaver and Millard Counties, Utah (figure 1). More specifically, it concerns the commercial geothermal energy potential of lease holdings of the Geothermal Power Corporation, which total some 39 sections (approximately 25,000 acres) spread over some 8 townships (plate 1).

These holdings may be grouped into several separate blocks: parts or all of 17 sections are located on the west flank of the Mineral Mountains, near Ranch and Corral Canyons and extending westward to the bottom of Milford Valley, around Milford; 5 sections are within the range, between Bailey and North Twin Flat Mountains; and 12 sections are on the east side of the mountains, in the northwest arm of Beaver Valley. In addition, nearly a dozen contiguous sections extend across the northernmost Mineral Mountains, from 5 to 8 miles north of the southern block.

Milford, with a population of about 1,500 people, is the most important town in the area. The main line of the Union Pacific Railroad traverses Milford Valley en route between Los Angeles and Salt Lake City, and passes through the town. The area is also served by State Highway 21, connecting Beaver, Minersville, and Milford. Highway 257 connects Milford and Delta. Numerous farm roads, mine roads and desert tracks also traverse the lowlands and lower slopes of the mountains. Because of past mining and present-day geothermal exploration, access into the higher elevations is good, except during winter.

Electric utility service is provided to the Milford area by the Utah Power and Light Company. Their line passes within a few miles of the project area. California-Pacific Utilities Company serves an extensive area farther south. If significant amounts of power were to be generated in the project area, it could be transmitted to distribution centers outside the area via moderate to high-voltage lines extending from Sigurd, Utah, 50 to 70 miles away.



LOCATION OF STUDY AREA

FIGURE I

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Physiography, Climate, and Land-Use

The project area is in the eastern part of the Basin and Range province. The main physiographic features of the area are north-trending, fault-bounded, Mineral Mountains; the Milford Valley section of Escalante Desert, which flanks it on the west; and Beaver Valley on the east. Basically, the physiographic framework was defined by Late Cenozoic normal faulting. It has been modified by both constructional and erosional features. Rhyolite domes and flows have been extruded through the Mineral Mountains, in the area between Bearskin Mountain on the north and Twin Flat Mountain on the south. The drainage pattern within the range is one of numerous intermittent streams flowing in steep-sided canyons trending mainly east or west from the crest. Streams are longer on the west than on the east flank. Erosion has caused the western range front to recede by a mile or more from the western range-bounding fault zone. The fault zone along the east front seems to be closer to the present topographic escarpment (plate 1).

Extensive coalescing fans on the range flanks lead down into the adjacent valleys on the east and west. During Pleistocene time, an arm of Lake Bonneville intermittently occupied the Milford Valley up to an altitude of about 5,120 feet. During high-water phases, deltas, bars and spits were built into the lake. However, the most notable of these lie outside the area of this report.

Holocene faulting along the eastern edge of Milford Valley has formed a system of small horsts and grabens in fan materials in Ranch Canyon and Negro Mag Wash. Total vertical displacement reaches 150 to 200 feet, along a 3-mile reach. The width of the grabens is less than a quarter of a mile (Mower and Cordova, 1974). Ranch Canyon, and to a lesser extent Negro Mag Wash, have been incised into the fan gravels at the front of the range. This is probably a result of both uplift of the range and fluctuations in base level with that of Lake Bonneville.

Hot springs have built low mounds of siliceous sinter and silica-cemented gravel along the range front. The most notable of these mounds is near the center of the north line of section 16, T. 27 S., R. 9 W. This and other hot-springs deposits lie along the Dome fault, one of the recently active faults mentioned above (Petersen, 1975).

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Elevations within Milford Valley range from about 4,900 feet at the Beaver River to about 6,000 feet at the valley edge. Beginning at the range front, relief is high, rising to a general summit elevation of 7,000 to 8,000 feet within a distance of 3 or 4 miles. The maximum elevation is 9,582 feet, at Milford Needle.

The chief stream in the region is the Beaver River, which rises in the Tushar Mountains east of Beaver Valley. It flows westward across that valley and through the gap between the southern Mineral Mountains and the Black Mountains, to Minersville. It then flows northward through the Milford Valley, past Milford, to Beaver Bottom. Here, any remaining water is lost to underflow. Due to the diversion of water for irrigation, the river usually is dry below Minersville.

The climate of the study area is characterized by warm, dry summers and cool winters. Mean annual temperature at Milford is 49°F. Annual precipitation is less than 10 inches in the valleys, but ranges up to about 25 inches in the higher mountains. Precipitation occurs principally as snowfall in winter, but there are occasional summer thunderstorms.

Stock raising is the principal land-use in the area, although there is irrigated farming in the valley around Milford. Mining was of some limited importance in the past, but no mines now are active in the Mineral Mountains. The Union Pacific railroad maintains extensive facilities in Milford.

GEOLOGY

Regional Setting and History

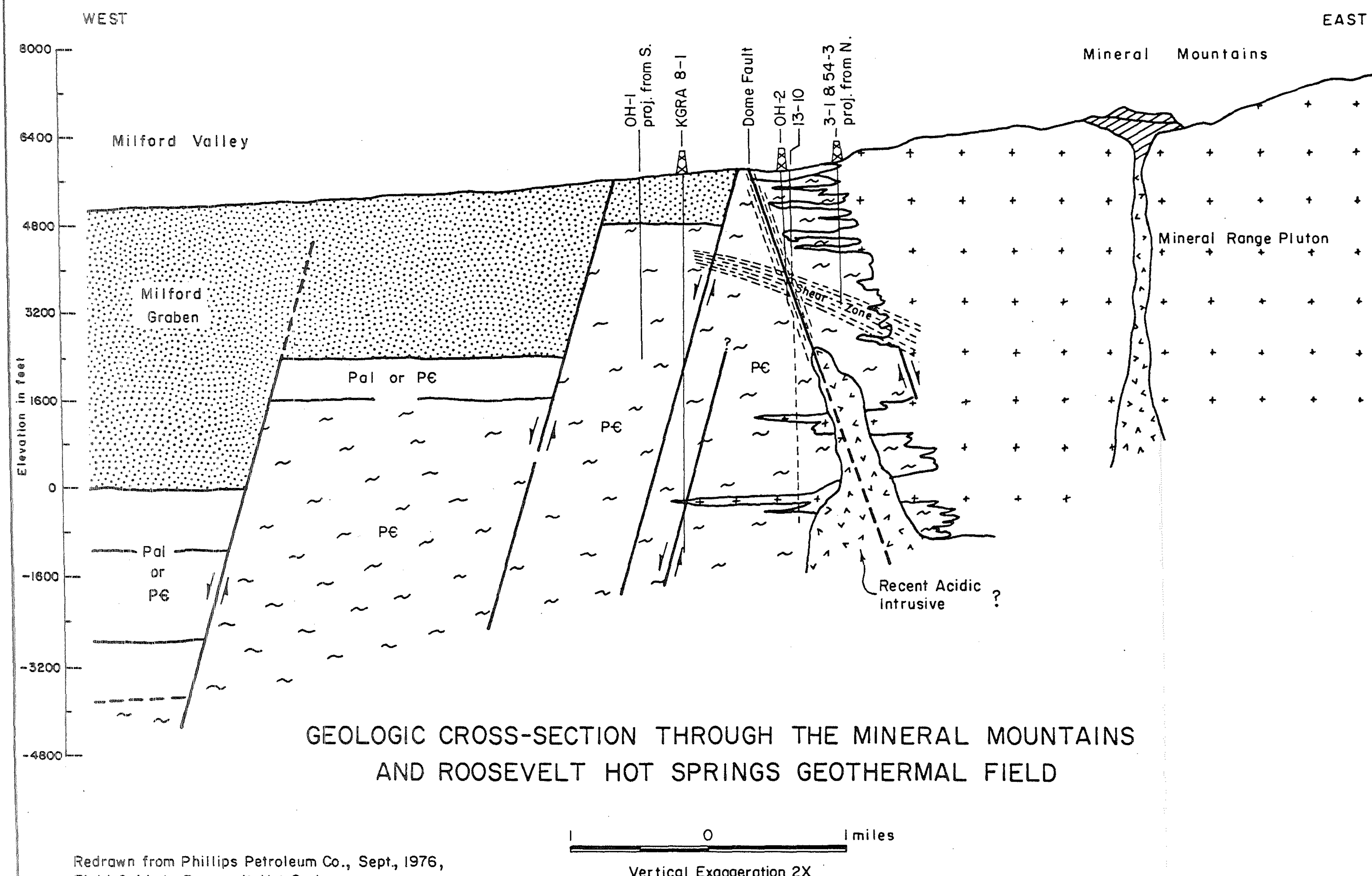
The project is located in the transition zone between two geologic provinces, each with a distinct character and history. The basic tectonic framework of the region was established in Precambrian time. West of the project area, Precambrian rocks of the Utah-Nevada province comprises a thick sequence of slightly metamorphosed quartzite, carbonate rocks and argillite ranging in age from 1.0 to 0.6 billion years. To the east, beneath the Colorado Plateau, Precambrian basement of the Churchill province consists of crystalline schist, gneiss, and other high-grade metamorphic rocks; ages in this suite range fron 1.8 to 1.6 billion years. Rocks of probable Precambrian age in the Mineral Mountains appear to belong to the Colorado Plateau province, on the basis of lithology, and may represent the western edge of that province.

From Cambrian to Triassic time, the main regional tectonic provinces were the cordilleran miogeosyncline in eastern Nevada and western Utah, and a crational area to the east, under the Colorado Plateau. Stratigraphic sections (table 1) in both the Mineral Mountains and Star Range indicate that the project area lay within and immediately east of the transition zone between these two provinces (figures 2 and 3 and plate 2). Depositional history during this long time-span comprises episodes of marine transgression, during which sedimentation extended eastward over the craton; and of regression, when deposition was confined to the axial regions of the geosyncline. The most extensive deposits are those of Cambrian, Upper Devonian, Lower Mississippian, Pennsylvanian, Permian and Triassic time; the least extensive deposits are those of Ordovician, Silurian, Lower and Middle Devonian and Upper Mississippian time.

Throughout this long Paleozoic-Early Mesozoic interval, the main rock types deposited were limestone, dolomite and quartz arenites. Shales were laid down only during brief intervals.

Based on very limited deep drilling for oil and gas in the region, it appears that most of the Paleozoic sedimentary rocks in this interval lack primary porosity. Any significant porosity now existing is likely the result of fracturing, or solution-channel development (in carbonate rocks). Furthermore, the limited amounts of shale in the section would seem to be insufficient to form cap rocks or to break hydraulic continuity within the carbonate sequence. Thus, it is likely that fluid storage capacity exists throughout the entire section, and there is no reason to anticipate that one part of this sequence has more attractive reservoir potential than another. Rather, reservoir may be best developed where there is most active tectonism.

By Middle Triassic time, deposition in both the miogeosynclinal and cratonal areas had become continental in type. A short-lived seaway was established in Middle to Late Jurassic time.



GEOLOGIC CROSS-SECTION THROUGH THE MINERAL MOUNTAINS AND ROOSEVELT HOT SPRINGS GEOTHERMAL FIELD

Redrawn from Phillips Petroleum Co., Sept., 1976, Field Guide to Roosevelt Hot Springs.

FIGURE 2

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Table 1. Stratigraphy of the Mineral Mountains
(adopted from Condie, 1960)

Period	Epoch	Thickness (ft)	Formation
Quaternary		0 - 3,500	lake beds, terrace gravels, alluvium
		0 - 2,000	Ranch Canyon Volcanics - rhyolite flows & tuffs
Tertiary	Oligocene	0 - 2,500	andesite flows & agglomerate; quartz latite tuffs, flows & agglomerate
	Eocene	--	Claron Formation - conglomerate
Jurassic	Upper	570	Carmel Formation - argillaceous limestone
	Middle	1,540	Navajo Sandstone - massive cross-bedded
Triassic	Lower	600 - 1,000	Moenkopi Formation (upper member - red (ss, sh, siltstone
		570	Moenkopi Formation (middle limestone
		140	Moenkopi Formation (lower member - sh, (siltstone
Permian	Lower?	700	Kaibab Limestone - massive, cherty
		1,180	Talisman (Coconino?) Quartzite - cross-bedded
Mississippian	Upper	915	Topache (Redwall) Limestone - massive, crinoidal
Lower Paleozoic		2,700+	Undifferentiated limestone & dolomite
Cambrian	Upper & Middle	1,300+	Undifferentiated limestone
	Middle	100	Pioche Shale
	Lower	775	Prospect Mountain Quartzite
Precambrian	Lower?		Whitehorse Canyon Series - biotite schist & gneiss

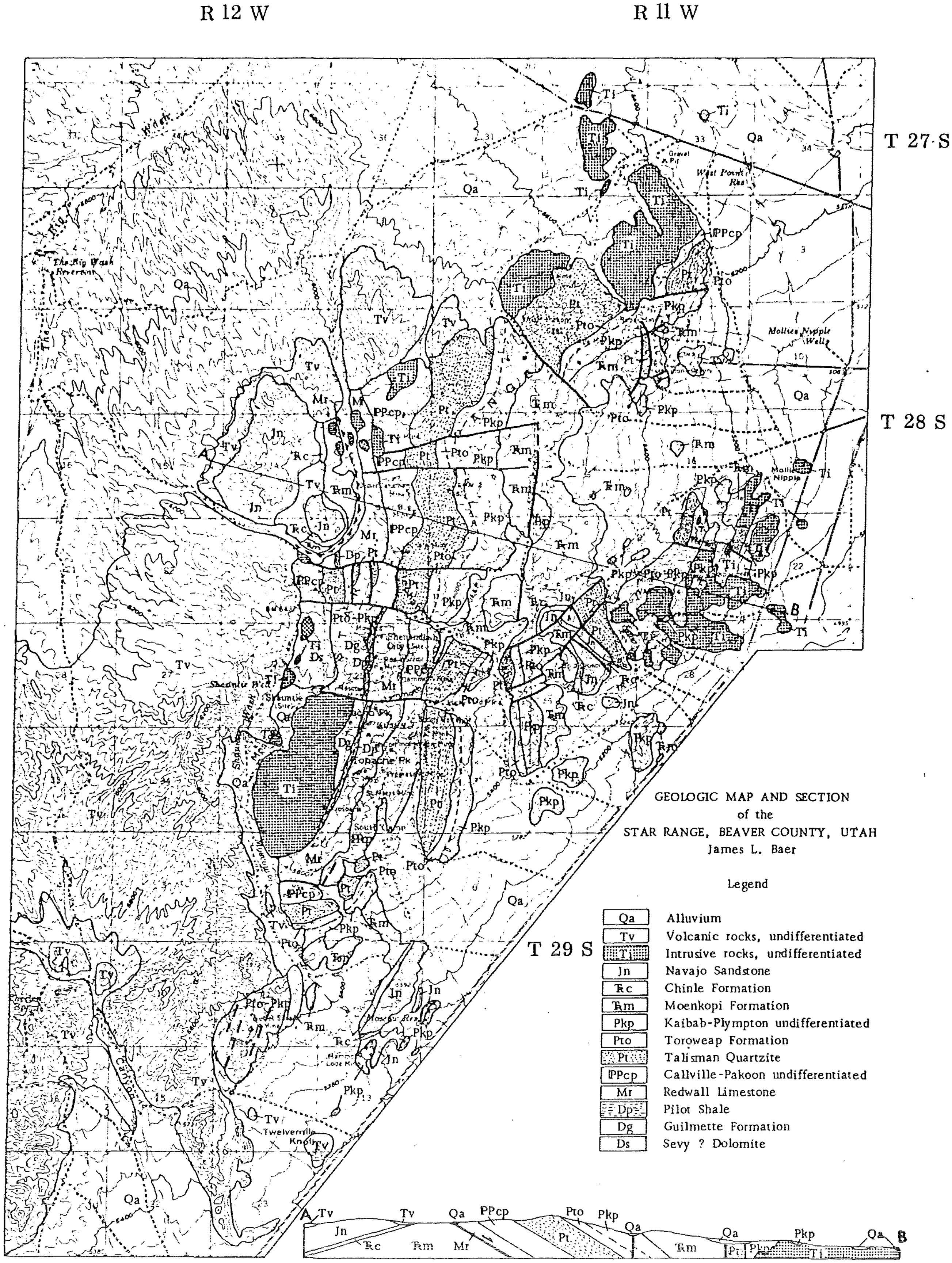

Figure 3. Geologic map and section of the Star Range, Beaver County, Utah. (from Baer, 1973)

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Called the Twin Creek-Arapien Sea, it extended from Montana, through Wyoming and Idaho, southward into central Utah. Deposits of this sea are present in the Mineral Mountains, but have not been recognized farther to the west.

During Cretaceous time the old Paleozoic miogeosyncline to the west of the project area was uplifted and deformed. Some of the major structures developed in this period are extensive low-angle thrust faults, which developed along the transitional zone between the Paleozoic miogeosyncline and the craton. This faulting resulted in the east to southeastward displacement of large sheets of miogeosynclinal rocks over cratonal or transition zone areas. One such fault enters the project area in the northern Mineral Mountains. To the east of the zone of thrusting, less-intense deformation produced folding and minor thrusting in the rocks of the transition zone and foreland (craton). Although obscured by later intrusion and a cover of younger rocks, folding of this period has been recognized in the southern Mineral Mountains (Condie, 1960).

East of the major zone of uplift and deformation in central Utah, a major new seaway was established in Upper Cretaceous time. Large amounts of clastic deposits were transported eastward from the deformed belt into this basin, but none of these sediments have been recognized in the project area.

In Early Cenozoic time, the region was the site of deposition of extensive fluvial and lacustrine sediments. Conglomerates of this age are present in the southern Mineral Mountain and they may be present elsewhere beneath the graben valleys bordering the range. In upper Eocene to Oligocene time, the fluvial and lacustrine phase was followed by onset of the igneous activity which characterizes the later Cenozoic history of the region.

The major Cenozoic volcanic episodes began with the eruption of thick and extensive rhyodacitic welded tuff in Oligocene time (30-28 m.y.). These were followed by tuffs and volcanic breccias of Oligocene-Miocene age (25-19 m.y.). All of these volcanic rocks appear to have originated at eruptive centers outside the limits of the study area. A considerable thickness of these deposits is present at the south end of the Mineral Mountains and in the adjacent Black Mountains. Regionally, these deposits appear to thin in a northerly

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direction. They are not exposed in the northern part of the Mineral Mountains uplift and they may not be present beneath the adjacent graben valleys.

The Cenozoic igneous history of the Mineral Mountains is dominated by intrusion of the granitic stock which makes up the bulk of the range. This is the largest of the exposed Tertiary stocks in Utah. The age of this pluton is variously reported to be 9.2 m.y. (Armstrong, 1970) and 15.5 ± 1.5 m.y. (Park, 1968). However, these ages may be too young, as a result of subsequent reheating during Late Tertiary or Quaternary volcanic phases; if so, the intrusion may belong to one of the intrusive episodes represented in adjacent areas by stocks which were emplaced in the 27-28 m.y. and 20-22 m.y. time intervals. All of the proposed ages of the pluton are too old to permit the known parts of the body to act as a heat source for local geothermal manifestations. Quaternary intrusions at depth have been postulated by geologists with Phillips Petroleum Company and by others, including D. D. Blackwell (oral communication, 1976).

Late in Cenozoic time, there was a major episode of normal faulting in the region, resulting in the development of the present fault-block ranges and graben valleys. The Mineral Mountains are the easternmost of the typical basin-and-range mountain blocks at this latitude. Faulting along the west side of the range has continued at least into the Pleistocene epoch.

Concurrently with the climactic period of faulting, intermontane basins were occupied by lakes and were filled with great thicknesses of fluviatile and lacustrine sediments originating from the erosion of the adjacent range blocks. In Quaternary time, an arm of Lake Bonneville occupied the Milford Valley. These valley-filling sediments contain aquifer gravels as well as fine-grained impervious materials. The latter may serve as cap rocks to potential reservoirs at the valley margin.

Local volcanic activity continued sporadically in the region throughout Late Cenozoic time. Examples in and adjacent to the project area are the basaltic eruptives of Cove Fort and northern Beaver Valley immediately east of the project area, and the rhyolite domes and flows in the Mineral Mountains. The ages of some of these rhyolite eruptives have been determined as ranging in age from 0.78 to 0.49 m.y. (Nash, 1976). The Cove Fort basalts probably range from about one million years to less than 20,000 years (Condie and Barsky, 1971).

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Several general conclusions can be drawn from the regional setting which have a bearing on the geothermal potential of the target.

1. As noted above, most of the pre-Late Cenozoic rocks in the region lack effective porosity and permeability unless they have been fractured. Thus, fractured rocks afford the most probable reservoir locations, and proximity to active fault zones appears to enhance this reservoir potential.

2. Regionally, impervious strata are lacking in parts of the section older than the Late Cenozoic basin fill. Thus, intercommunicating reservoirs may exist in large portions of these older rocks. In areas covered by valley-fill, such reservoirs may be capped by impervious Cenozoic lacustrine sediments.

3. There are two possible sources of heat in the region, and both may be factors in the project area: deep circulation of water along faults in this area of high regional geothermal gradients; and heating associated with local young intrusions. The first type of heating is probably the source of the minor thermal anomaly near Minersville. The second may be the principal mode at Roosevelt Hot Springs.

Stratigraphy

Only a small part of the stratigraphic column recognized elsewhere in the Mineral Mountains is present in the project area.

Precambrian(?) Whitehorse Canyon Series

These are mainly biotite gneiss, with minor associated schist and phyllite. The gneiss is about 50 percent biotite, 40 percent quartz, 8 percent orthoclase and 2 percent minor constituents. The Precambrian age assignment of these rocks is based on their metamorphic style and grade, and their lack of compositional similarity to any of the Paleozoic or younger rock types of the region.

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Rocks assigned to this series are exposed intermittently along the west side of the Mineral Mountains from the Millard County line southward for a distance of about 18 miles. They are in contact with the west side of the Mineral Mountains stock, and many blocks of gneiss have been engulfed in granite near the contact (Petersen, 1975).

Precambrian(?) rocks are overlain by alluvium along the edge of Milford Valley. Their relationship to and possible presence beneath the Paleozoic rocks elsewhere in the range is unknown.

Cambrian

Two Cambrian sections are present in the north end of the range. One of these is an allochthonous unit carried into the area from the northwest along a major thrust fault. The other section, below this thrust, may be autochthonous, although its relationship to Precambrian(?) and younger units is unknown.

The allochthonous section occurs along the crest of the range (in sec, 23, 28, 35 and 36, T. 25 S., R. 9 W.) as isolated klippen, and comprises a few hundred feet of Prospect Mountain Quartzite. A much more extensive thrust section is exposed in the Beaver Lake Mountains and San Francisco Mountains a few miles to the west of the project area. All of these isolated localities are believed to be parts of a formerly continuous geosynclinal-marginal thrust sheet.

The autochthonous section consists of the following units.

Prospect Mountain Quartzite. This unit is represented by about 775 feet of white to buff-colored, thick-bedded quartzite. The base of the section is not exposed. It is conformably overlain by Pioche Shale.

Pioche Shale. This unit is represented by about 100 feet of grey to greenish grey shale. Its thickness is similar to that encountered in the cratonal area to the east and is considerably less than that found in the geosynclinal areas to the west. This indicates that the section it occurs in is probably autochthonous.

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Undifferentiated Limestone and Dolomite. Limestones and dolomites of Middle and Upper Cambrian age conformably overlie the Pioche Shale. An incomplete section of these rocks is about 1,300 feet thick. Near the contact with the Mineral Range stock these rocks have been metamorphosed to tremolite marble.

Permian

Several small, isolated outcrops of Permian rocks occur along both the eastern and western edges of the Mineral Mountains intrusion, in the southern part of the project area.

Talisman (Coconino?) Quartzite. Outcrops of pure, well-sorted, medium-grained, cross-bedded arenite with siliceous cement occur in two localities in the project area. In the western locality, the base of the unit is covered by alluvium and, in the eastern, it is in contact with the granitic stock. In both localities it is overlain by the Kaibab Limestone. The section is thus incomplete at both localities, but exposures farther south in the range indicate that the complete section is about 1,180 feet thick.

The local name applied to this unit in the San Francisco mining district is the Talisman Quartzite. This is one of several cross-bedded quartz arenites which are apparently correlative with the better known Coconino Sandstone of the Grand Canyon area.

Kaibab Limestone. Overlying the Talisman Quartzite is a dense, bluish-grey, fossiliferous limestone (Kaibab). The section is incomplete in both of the localities noted above, but reaches about 900 feet in thickness in the southern part of the range. In many places, the Coconino-Talisman arenites and the Kaibab Limestone are separated by interbedded sandstone and carbonate rocks of the Toroweap Formation. The Toroweap is recognized in the Star Range, west of Milford, but has not been reported in the Mineral Mountains (Baer, 1973); in the Star Range, it includes gypsum.

The Kaibab Limestone sections in the project area are overlain by alluvium. In well-exposed sections farther south, and perhaps also in the project area beneath the valley fill, the Kaibab is overlain by a thick section of Mesozoic rocks (see plate 2).

Near the contact with the east side of the Mineral Mountains stock, the Kaibab Limestone locally has been converted to a scheelite-bearing skarn (Hobbs, 1945).

Tertiary

Pliocene(?) Mineral Mountains granite. The central Mineral Mountains are made up largely of granite with composition as follows: 50 percent orthoclase, 25 percent oligoclase, 15 percent or more quartz and 5 percent or more biotite and magnetite (Condie, 1969). In outcrop, the pluton contacts Precambrian rocks on the west and Permian on the east. At its north edge, the granite intrudes Cambrian marble along an east-northeast-trending contact, which is parallel to and partly coincident with a steep aeromagnetic gradient (plate 4).

The age of the granite is reported to be 9.2 m.y. by Armstrong (1970) and 15.5 ± 1.5 m.y. by Park (1968). As noted earlier, both ages are younger than those of any other stocks known in the region, and may be erroneously low. The stock has been cut by numerous faults and dikes, and is intruded and overlain by Quaternary rhyolite.

Post-Intrusion Dikes. Rhyolite (dellenite) porphyry dikes, varying in thickness from 20 to 200 feet, cut the stock but are not known to intrude other rocks. These are composed of up to 65 percent quartz, with subordinate oligoclase and orthoclase. Minor amounts of biotite and magnetite are present in the ground-mass. The phenocrysts are mainly quartz and orthoclase.

The dikes occur both as steeply dipping and nearly horizontal sheets. They have an average strike of N. 45° W. (Condie, 1960). North-striking, steeply dipping, lamprophyre dikes occur throughout the length of the range. Many are porphyritic, containing up to 20 percent plagioclase phenocrysts. Their overall composition is 60 to 65 percent andesine, 20 to 30 percent brown hornblende, 8 to 10 percent magnetite, and minor apatite. The dikes show considerable alteration.

Condie (1960) reported that the lamprophyre dikes occur only along the west side of the pluton, and that the rhyolite dikes are present only on the east and south sides.

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Quaternary

Ranch Canyon Volcanics. These consist of rhyolite plugs, flows, and associated minor tuffs resting upon an erosional surface developed on the Mineral Mountains granite. The main eruptive centers were at North and South Twin Flat Mountain and Bearskin Mountain. Flows extend down the west side of the range from these eruptive centers. The basal part of the section includes local deposits of tuff and pumice up to 1,000 feet thick. These are overlain by rhyolite and rhyolite porphyry flows up to several hundred feet thick, then by obsidian and vitrophyre flows up to 60 feet thick, and finally by more rhyolite tuffs. The total thickness of the section may locally reach a maximum thickness of 2,000 feet (Condie, 1960). The linear distribution of some of the eruptive centers suggests that they occur along one or more fault zones. On the basis of composition, it has been suggested that the source of the rhyolite could be granite remelted at depth (Evan and Nash, 1975). Nash (1976) reported that the ages of these volcanics range from 0.78 to 0.49 m.y., which makes them amongst the youngest rhyolite eruptives in Utah.

Basalt. Basalt occurs in the project area in one isolated locality along the east flank of the range (sec. 36, T. 25 S., R. 9 W. and sec. 31, T. 25 S., R. 8 W.). At the north end of Beaver Valley near Cove Fort, there is a large basaltic andesite volcano of probable Quaternary age.

Quaternary Valley-Fill. The alluvial filling of Milford Valley ranges from coarse-grained alluvial fans on range flanks to sand, silt, and clay of fluvial and lacustrine origin near the center of the valley. In the Milford area, at depths less than about 800 feet, these sediments are not well indurated and contain important shallow aquifers. Induration increases and permeability decreases with depth. The total thickness of valley-fill sediments varies from zero at the mountain front to as much as 4,500 feet in the valley, based on gravity data (Thangsuphanich, 1976). Estimates of fault displacement along the east side of the Mineral Mountains suggest that in excess of 6,000 feet of low-density sediments may be present in Beaver Valley.

The near-surface parts of this thick section are made up of Holocene fluvial deposits and Pleistocene sediments deposited in an arm of Lake Bonneville. The lake had a high-stand elevation of about 5,120 feet. Beneath these deposits, the stratigraphy of the Late Cenozoic section is poorly known.

Structure

The only evidence of folding in the study area is found at the north end of the range, where a faulted syncline is centered in sec. 23, T. 25 S., R. 9 W. This syncline involves both Cambrian limestones and a conglomerate unit which is of either Late Cretaceous or Early Tertiary age. Pre-Cenozoic sedimentary rocks beneath Milford Valley also are likely to have been folded by the Late Mesozoic-Early Tertiary orogeny.

Two main ages and types of faulting are present. One is thrusting of Late Mesozoic age. The only feature known definitely to be in this category is a low-angle thrust fault in the northern part of the range. The other and dominant type is normal faulting of Cenozoic age (plate 2 and figure 2).

Several allochthonous klippen of Cambrian Prospect Mountain Quartzite overlie younger Cambrian units in the area extending from sec. 35 and 36 northeast to sec. 23, T. 25 S., R. 9 W., in and beyond the northern part of the study area. These isolated masses are believed to be remnants of a formerly continuous thrust sheet. This thrust may be an extension of the Grampian-Pavant Range line of thrust faults, which themselves are part of a great system of thrust faults that extend for hundreds of miles along the geosyncline-craton boundary zone. Displacement on the thrust system in the project area appears to be in a southeasterly direction. Unless it was removed by Early Tertiary erosion, the thrust sheet is likely to be present in adjacent areas of northern Milford Valley, only a few miles from the Roosevelt geothermal field. The effect of the thrust is to introduce a slab of Early Paleozoic or Precambrian sedimentary rocks into the section immediately beneath the pre-Tertiary unconformity.

The basic structural framework of the area is determined by high-angle normal faults of Late Cenozoic age. The youngest and most important of these faults occur in north-trending zones along the east and west sides of the Mineral Mountains horst. Gravity data indicate that these zones are made up of several sub-parallel faults along which step-like displacements have

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taken place. Total displacement along the western zone is estimated to be about 4,500 feet, and along the eastern side about 6,200 feet (Thangsuphanich, 1976). The horst between the two fault zones appears to be tilted westward.

The range-bounding faults are located valleyward from the major bedrock escarpments and are covered by alluvium. However, detailed photogeologic mapping in the area from Ranch Canyon to Negro Mag Wash, along the west side of the range, shows that Holocene fault scarps are present in the alluvium (Petersen, 1975). The zone in which these scarps occur is as much as 6 miles wide in the Roosevelt Hot Springs area. Trends of these small faults are mainly northerly, but some are northeasterly or northwesterly. The largest of them is the Dome fault, which has a length of about 3 miles. This fault has been the locus of past hydrothermal activity, indicated by the development of a sinter mound and silica-cemented gravels along it. Deposits of this type have been fault-offset by as much as 20 feet in sec. 16, T. 27 S., R. 9 W. (Petersen, 1975). Another area with strongly defined Quaternary fault offsets is in Ranch Canyon (Mower and Cordova, 1974).

A prominent and unusual group of east-trending normal faults is present in this region. Important examples occur in the southern Mineral Mountains between Minersville and Pass Canyon, south of the project area. Other prominent faults of like trend occur in the Star Range, west of Milford. In the project area, probable faults in Negro Mag Wash and in sec. 15 and 22, T. 27 S., R. 9 W. also trend easterly. Long, straight, east-west topographic lineations in the range suggest that jointing or faulting with this trend may be more common than indicated by available reconnaissance mapping. The significance of this fault trend to geothermal prospecting is uncertain. The faults in sec. 15 and 22 may somehow limit the thermal anomaly along the southern Dome fault, and the fault in Negro Mag Wash appears to correlate with a perturbation in temperature-gradient contours.

A prominent zone of cataclastic metamorphism has been described by Condie (1960) in the east-central part of the Mineral Mountains, extending to the southern edge of the project area. This low-dipping shear zone ranges in thickness from about 50 feet in Rock Corral to 200 feet thick in Cave Canyon, to the south. The zone is present along the contact between

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Precambrian gneiss or Tertiary granite and overlying sedimentary rock (figure 2). Believing the Mineral Mountains granite to be Cretaceous in age, Condie (1960) thought the cataclasite probably formed as a result of thrust-fault movements. Since the age of the granite is now thought to be Late Miocene or Pliocene, it is no longer tenable to associate the cataclasite with Cretaceous tectonism. Tertiary intrusives have been described in the Snake Range of western Utah and in other localities in the Basin and Range province. They may be related to "relaxing" of Cretaceous-age thrusts in post-Miocene time.

The cataclasite is a mylonite in which large blocks of Paleozoic rock, Precambrian gneiss and Tertiary granite occur in a matrix of pulverized material from a gneiss or granite source. Quartz is the most abundant mineral, but feldspars, usually altered to clay, also are present.

The significance of the cataclastic zone to geothermal prospecting is uncertain, but such a zone (or zones) may be present along the west side of the range under the alluvial cover in the project area.

GEOPHYSICS

Geophysical data are available from gravity, aeromagnetic, resistivity, microearthquake, and temperature-gradient surveys. They show a major, apparently active, normal-fault zone along the west side of the Mineral Mountains, containing a strong temperature-gradient anomaly. Pronounced vertical zones of high and low resistivity parallel faults in this zone, but have no simple relationship to the geothermal reservoir as presently known.

None of the above-listed surveys is detailed throughout the study area; rather, data densities vary widely across the area. Furthermore, of the available data only gravimetry appears to offer strong evidence for a magma body within a few kilometers of the surface.

Most of the published geophysical data come from the University of Utah, which has had National Science Foundation (NSF) funding continuously since 1974 for detailed earth-science investigations in the Roosevelt KGRA.

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Gravity

Much of the area is covered by a Bouguer gravity map (originally at a scale of 1:250,000) containing some 100 gravity stations within the study area west of longitude 112°45' (Peterson, 1972; Crebs, 1976); their maps are combined and reproduced as plate 3. An unpublished master's thesis (Sontag, 1965) covers the area east of 112°45', but is not reproduced due to strict copyright observance by the University of Utah. However, a gravity map of the State of Utah (Cook et al., 1975) (originally at 1:1,000,000) has been used for the area east of 112°45' on plate 3. Recently, Thangsuphanich (1976) completed a gravity survey of the Mineral Mountains south of latitude 38°25'. His stations are much more closely spaced than those of Peterson. However, the data reveal no significant anomalies not shown by Peterson or by Crebs farther to the north, and therefore have not been reproduced here.

Briefly summarized, gravity measurements show that the Mineral Range is a horst (expressed as a gravity high) flanked by normal faults of major displacement. Escalante Valley is a deep graben (expressed as a gravity low) with pre-Tertiary bedrock as much as 7,000 feet deep near its center. Basement is significantly shallower along the valley margins. Beaver Valley also is a deep graben, and bedrock there has a maximum depth of about 6,000 feet. On both sides of the horst, steep gravity gradients indicate that a series of step faults is present, as diagrammed in figure 4. The data are not detailed enough to show individual faults.

Within the Mineral Range, the Bouguer anomaly varies considerably from north to south along the range axis. At its north and south ends there are closed gravity highs, with maximum values of -178 and -182 mgal, respectively. Near the middle, there is a gravity "saddle" with values as low as -200 mgal. The cause of this large variation is unknown, and cannot be explained readily in terms of surface geology. However, the minimum does coincide approximately with the presumed eruptive center of the Ranch Canyon Volcanics, in the vicinity of North and South Twin Flat Mountains. The coincidence suggests the possibility that a large, relatively low-density intrusion is associated with these young volcanics.

Relative to the gravity field produced by a simple, homogeneous prism of granite, the saddle-anomaly appears as a

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relative gravity low of about 20 milligals. This can be modeled by a variety of hypothetical low-density mass distributions at depth; for example (D. D. Blackwell, oral communication, 1976), as a horizontal cylinder with a diameter of 5 km and a length of 7 km, with its top about 1-1/2 km below the ground surface, and a density about 7% less than the surrounding granite (figure 4). Were its density still lower, its volume would be correspondingly smaller. In any case, data suggest that the anomalous body may have a volume of some 500 cubic kilometers, and may approach a density corresponding to the melting point for rhyolite.

An elongate Bouguer gravity low in Sec. 17-19, T. 27 S., R. 8 W. may represent a molten or near-molten body (S. H. Ward, oral communication, 1976), perhaps as an apophysis rising from the postulated larger and deeper magma.

Aeromagnetic Data

A detailed aeromagnetic map, prepared for the University of Utah under NSF funding, covers the project area. Originally at a scale of 1:24,000, the map has been reduced to 1:62,500 for this report (see plate 4). The survey was flown at a mean altitude of 1,000 feet above ground level, with a flight-line spacing of 1/4 mile. A pronounced east-west herring-bone effect in the magnetic data is an artifact and must be ignored.

In this area, as throughout western Utah, magnetic grain has prominent north-south and east-west trends. North-south grain reflects Late Cenozoic basin and range structure. East-west grain appears to be related to Precambrian basement-structural trends. There is weak correlation between topographic elevation and magnetic intensity, but this may be safely ignored.

Looked at very broadly, we see that areas of low magnetic intensity and low intensity relief generally are over Quaternary alluvium or pre-Tertiary sedimentary rock; areas of high intensity and high relief are over Cenozoic igneous rocks. Also, north-south alignments of magnetic features (highs, lows, and gradients) occur predominantly in areas of Cenozoic igneous rocks. Therefore, where such alignments occur over sedimentary materials, it is likely that they are underlain by Cenozoic igneous rocks. Thus, the north-trending alignments along the east flank of the Mineral Range suggest that the granitic pluton extends at least one mile east of its surface outcrop.

Several strong anomalies deserve to be identified and treated separately. A north-trending anomaly, comprising a

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paired high and low, coincides approximately with the Dome fault. This feature may simply represent the granite or Precambrian gneiss believed to be present at shallow depth there. Alternatively, and more likely, it could represent a tabular-shaped silicified zone centered on the Dome fault.

A series of weak highs extends some 4 miles north from Negro Mag Wash, and is offset about 1 mile east of the Dome fault. Although this might reflect a northward continuation of faulting and mineralization comparable to the Dome fault, most probably it does not. If both of these high magnetic-intensity alignments represent the same geologic structure, then their offset indicates the presence of a right-lateral fault in Negro Mag Wash, as suggested by several workers. This and several other hypothetical faults based upon aeromagnetic data are shown in plate 5.

Within the Mineral Range, several small, high-relief, east-trending anomalies occur from Bailey Mountain to North Twin Flat Mountain. These are located over eruptive centers of the Ranch Canyon Volcanics, composed of Quaternary high-silica rhyolites containing about 1/2 percent magnetite (Nash, 1976). The Mineral Range granite contains some 5 percent of biotite and magnetite combined (Condie, 1960), and it may be reasonably assumed that not more than 1 percent of whole rock is magnetite. Hence, differences in magnetite content between the rhyolite and the granite are likely not large enough to explain the magnetic anomalies. Condie (1960) reported that inclusions within the granite contain up to 35 percent dark minerals. Possibly, such inclusions may be so concentrated as to produce the observed magnetic highs. Another possibility is that unexposed basic intrusions or pendants of Precambrian gneiss are present.

Finally, the strong north-trending anomaly just west of Shag Hollow is noted. As with the above-described features, no ready explanation can be given. In both cases, magnetite-rich inclusion zones seem to be the most plausible cause, although undocumented.

Geoelectrical Surveys

A number of geoelectrical surveys have been conducted in the project area by both private and public agencies. These include dipole-dipole resistivity surveys, electromagnetic (EM)

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soundings, and magnetotelluric soundings. The only published work is that by the University of Utah, which has done dipole-dipole surveys and preliminary EM soundings in the Roosevelt KGRA under National Science Foundation support (Ward and Sill, 1976; Petrick, 1974). These are described below. A series of magnetotelluric soundings by Geotronics Corporation, under contract to the University of Utah, has been released, and is described below, also. Geoelectrical work has been conducted for several private companies active in exploration in the region, but is unreported. Amongst these, Senturion Sciences performed a magnetotelluric survey for several participating companies in 1976.

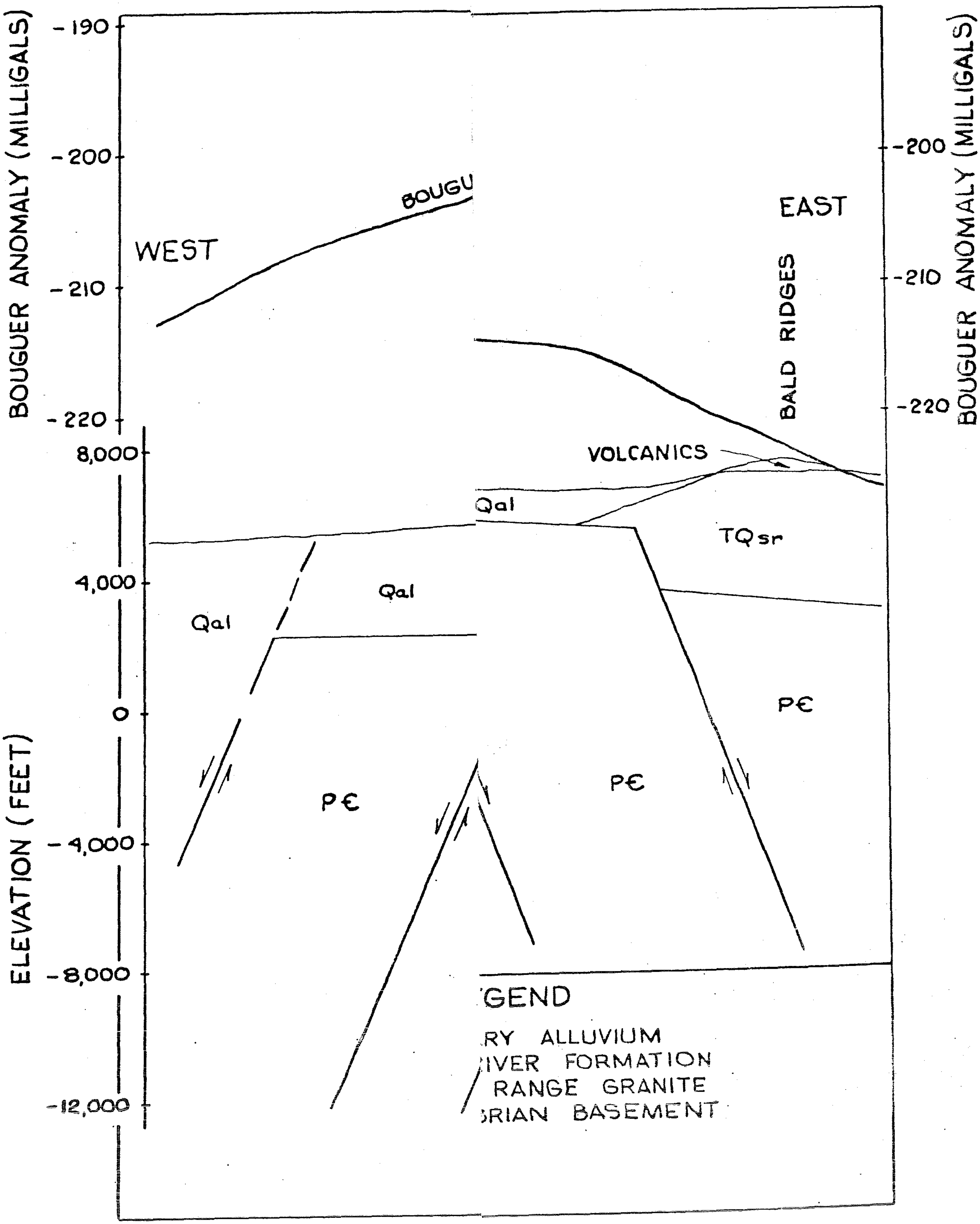
Dipole-Dipole Surveys

Dipole-dipole resistivity surveys by the Department of Geology and Geophysics of the University of Utah cover a long, narrow strip along the west flank of the Mineral Range. This strip is some 13 miles long by 4 miles wide, and runs from Ranch Canyon on the south to latitude 38°37' on the north, near the north end of the Mineral Range. Some 100 km of traverse line were surveyed with 100 m, 300 m, and 1,000 m dipoles.

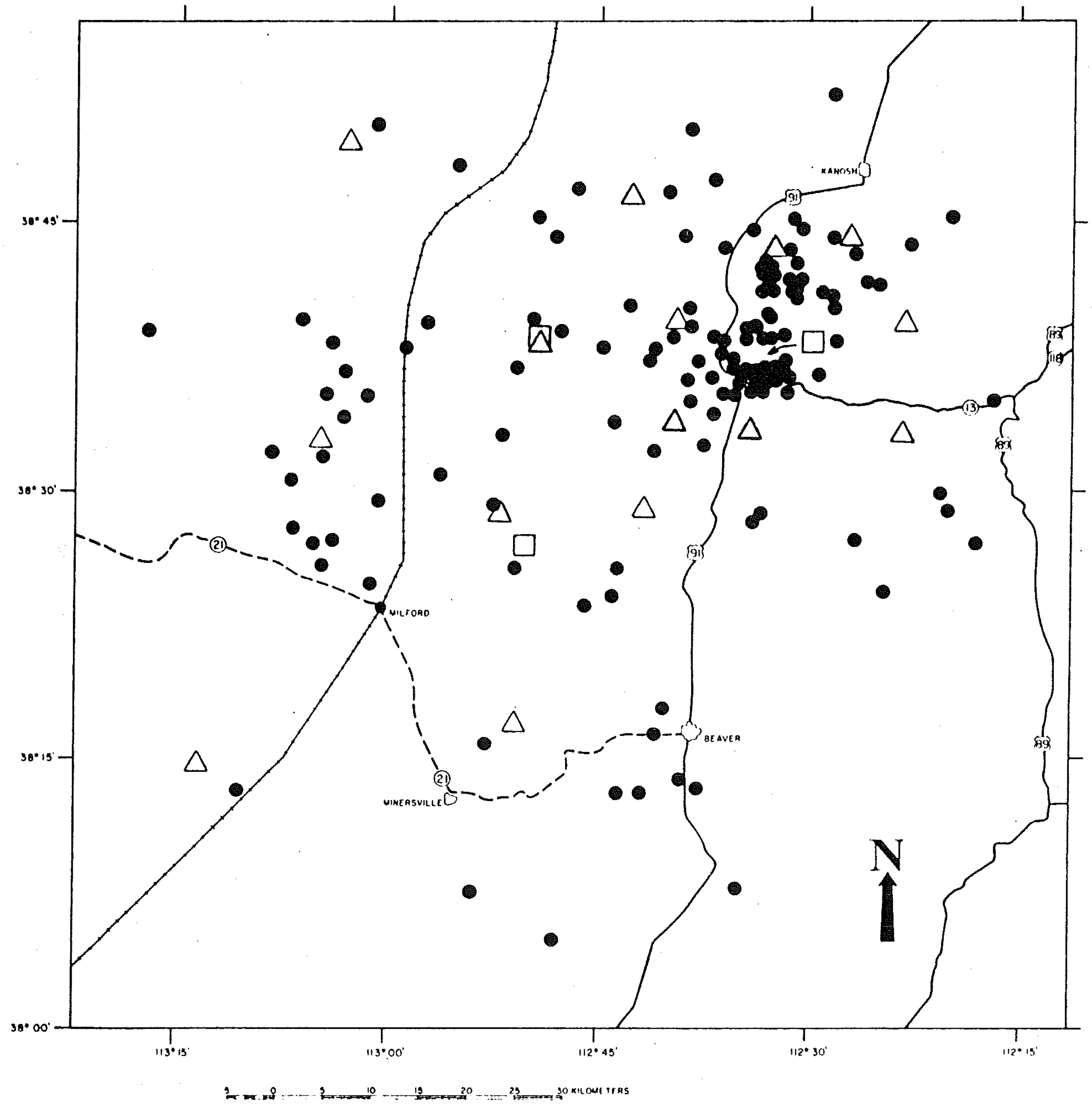
The data reveal three dense fracture sets in the vicinity of three steam-producing wells; hydrothermal alteration and brines in these fractures produce pronounced resistivity lows at shallow depth (less than 500 m). These fracture sets appear to carry fresh water into, and brine away from, the center of a convective hydrothermal system.

The low resistivities ($\leq$ 5 ohm-meter) of the fractures above 500 m in depth are ascribed to clay and pyrite alteration or to hot brine, or both. The marked increase in resistivity (to 300+ ohm-meter) along fractures deeper than 500 meters is attributed to (1) reduction in alteration, (2) replacement of brine by steam, (3) tightening of the fractures, or (4) lack of resolution of these surveys; alternatives (1) and (4) are believed most likely to be important (Ward and Sill, 1976).

The resistivity data have revealed very little of the deep geothermal system. Therefore, included herein is only a map showing fractures interpreted from shallow dipole-dipole results (figure 6); this plate also shows fractures interpreted from surface geologic mapping, photogeology, and aeromagnetics.


BOUGUER ANOMALY (MILLIGALS)
-190
-200
-210
-220
BOUGU
WEST
EAST
BALD RIDGES
-200
-210
-220
BOUGUER ANOMALY (MILLIGALS)
VOLCANICS
8,000
4,000
0
-4,000
-8,000
-12,000
ELEVATION (FEET)
Qal
Qal
Qal
TQsr
PЄ
PЄ
PЄ
GEND
RY ALLUVIUM
IVER FORMATION
RANGE GRANITE
RIAN BASEMENT

FIGU5



EPICENTER MAP OF MILFORD-BEAVER-COVE FORT AREA OF UTAH. DATA FROM 1974-1975 SUMMER SURVEYS.

● EPICENTER

△ TEMPORARY SEISMOGRAPH SITE

□ PROPOSED PERMANENT SEISMOGRAPH STATIONS

FIGURE 5

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Maximum depth of dipole-dipole exploration was just over one km. To this depth, the data do not reveal a heat source for the hydrothermal system. More importantly, perhaps, the data do not define that system at depths greater than 500 m. Furthermore, Ward and Sill (1976) reported that large-scale bipole-dipole surveys done by Phillips were no more successful in defining the hydrothermal system at depth.

Magnetotelluric Soundings

Geotronics Corporation of Austin, Texas conducted a series of 25 magnetotelluric (MT) soundings in the area, extending eastward across the Mineral Mountains into T. 27 S., R. 8 W., under contract to University of Utah. This work includes several interpretive resistivity cross-sections.

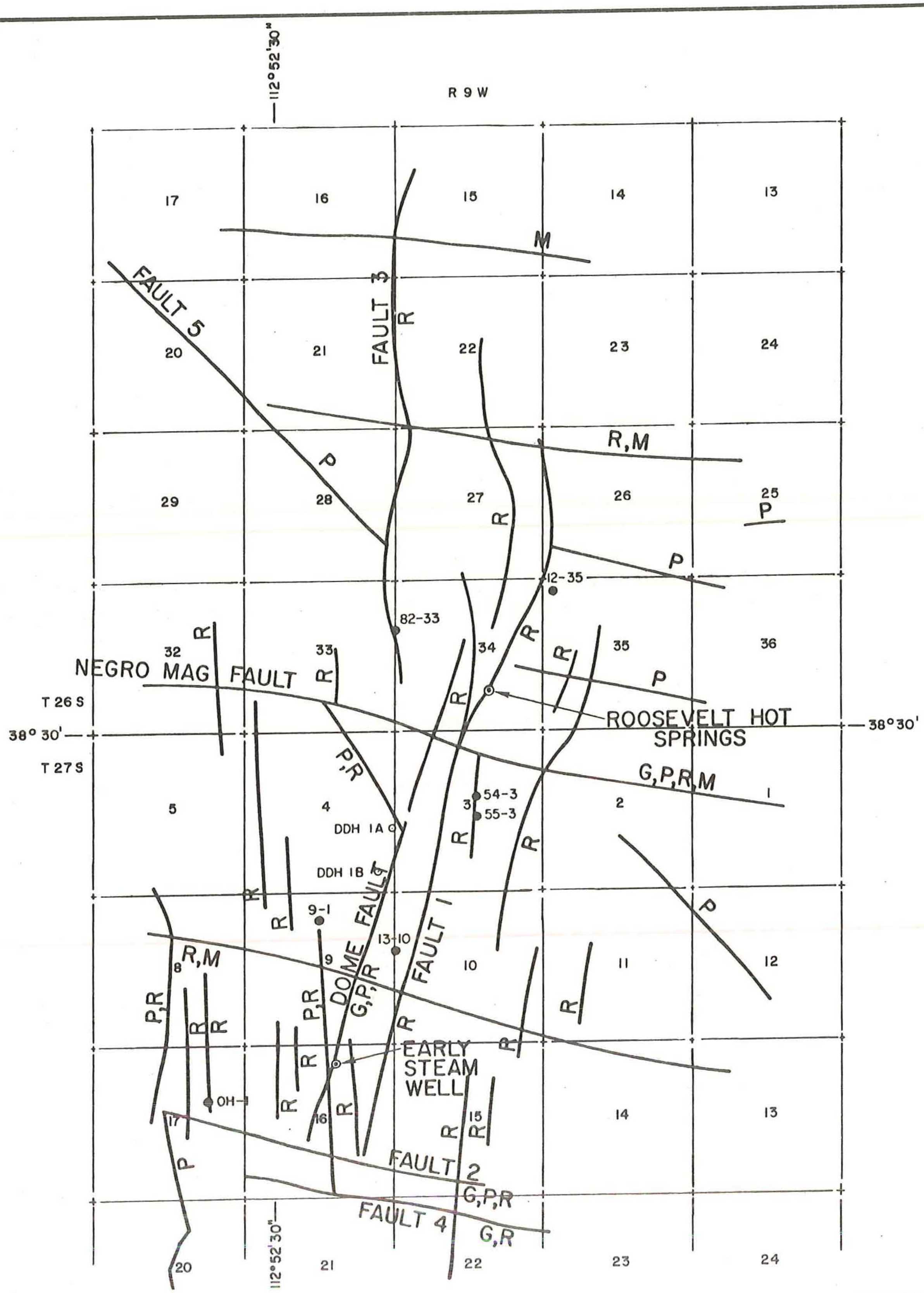
The cross-sections show apparent resistivities to a depth of 14 kilometers, but it must be pointed out that interpretation of MT data is highly ambiguous in nature. In order to compute resistivities, one must know electric-field skin depths; but skin depths are dependent upon the resistivities of the penetrated rock. Therefore, any MT cross-section must be highly interpretive.

The sections show a deep low-resistivity zone along the Dome fault, dropping to 3 ohm-meters at a depth of 3 km; highest values are about 20 ohm-meters at depths of 500 to 900 m. This fits approximately with the zone of high resistivities observed in dipole-dipole surveys beyond 500 m; however, the values are vastly out of agreement with the characteristic 300+ ohm-meters observed in the dipole-dipole surveys.

These discrepancies cannot be resolved herein, and cast some doubt on the utility of geoelectric surveys in this geologic terrain.

Seismicity

The project area lies within the Intermountain Seismic Belt, which extends along the Wasatch frontal zone in Utah, northward through the Idaho-Wyoming thrust belt, and at least to the vicinity of Helena, Montana.



FRACTURES INTERPRETED FROM RESISTIVITY AND OTHER DATA
ROOSEVELT HOT SPRINGS KGRA

LEGEND

- Interpreted fracture
- G,P,R,M Geology, Photo, Resistivity, Magnetics
- ● Well by Phillips Petroleum Co.
- ⊙ DDH by University of Utah

N
16°

0 1mile
Scale 1:62,500

Note: See Plate 2 for location within study area.

FIGURE 6

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During the summer of 1974 and 1975, high-gain portable seismographs were deployed in the Mineral Mountains region by the University of Utah. The networks were centered on the Roosevelt Hot Springs and Cove Fort areas. Calculated magnitudes ranged from -0.5 to +2.8. Focal depths were usually less than 8 km.

As may be seen from figure 5, most of the microseismicity was concentrated in the area from Cove Fort to Kanosh. However, several events occurred on the west flank of the Mineral Range, perhaps along the Dome fault; also, there was a number of events along the east flank of the range (Olson and Smith, 1976).

Activity in the Cove Fort area was characterized by swarms containing large numbers of shocks. The Dog Valley station frequently recorded from 10 to 30 shocks per day, most of which were too small to be recorded at other, nearby stations. By far, this station recorded the greatest number of events. Fault-plane solutions for events in this area indicate normal faulting (with some right-slip) on planes striking northeasterly and dipping northwesterly. Interestingly, unpublished data from Dog Valley and vicinity show thermal gradients of up to 350°C/km (20°F/100 ft.), making it the strongest thermal anomaly in the area outside of the proven geothermal field at Roosevelt Hot Springs.

P-wave delays and S-wave attenuation were also evaluated in the study of local seismicity. If sufficient in magnitude, these parameters can sometimes provide strong evidence of a local magma body which interferes with seismic wave transmission. At the Ranch Canyon station, these parameters may have been significant for travel paths southwest from the Cove Fort area. However, as presented and analyzed by Olson and Smith (1976), the results are far from conclusive. They allow, but do not confirm, the presence of a shallow magma body (depth less than about 10 km) between Cove Fort and Ranch Canyon. Much more collection and analysis of data will be required to answer this question.

Heat Flow

Heat flow and thermal gradients in the Wasatch frontal zone are somewhat higher than average for the western United States. Heat-flow values range from 1.9 HFU at Bingham and

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2.0 HFU at Eureka to 2.2 HFU near Milford; average for the zone is about 2.0 HFU. Background geothermal temperature gradient is probably about 36°C/km (2°F/100 ft.) in consolidated rock of the Milford area. In unconsolidated sediment of lower thermal conductivity, gradient may average 55°C/km (3°F/100 ft.). These elevated thermal parameters correlate with the thin crust (30 km at Delta) and intense Late Tertiary igneous activity which characterize the Wasatch frontal zone. Although temperature gradients between 36° to 55°C/km are not indicative of a commercial geothermal resource, they are encouraging in a regional context. Much higher gradients have been observed in holes drilled in the vicinity of Roosevelt Hot Springs, in rocks having higher thermal conductivities than alluvium. This becomes strongly attractive for exploration (see p. 27-29, below).

HYDROLOGY

Surface Water

Perennial streams are non-existent in the Mineral Range. The Beaver River, which drains the region, rises in the Tushar Mountains and flows westerly through Beaver Canyon and northward into Milford Valley. It is the only perennial stream in the region but, due to diversions for irrigation, is almost perennially dry north of Minersville. A number of intermittent streams drain the Mineral Range on both sides. These have water in them only after thunderstorms and during the spring season of snow melt.

Upon reaching the flanking alluvial fans, water from these ephemeral streams is largely lost to evaporation and transpiration; about one-third of it infiltrates coarse alluvial materials and joins the shallow ground-water reservoirs present in the basin-filling Cenozoic sediments. Diversion of the Beaver River for irrigation has further increased evapotranspirative losses, and therefore reduced infiltration into the Escalante Valley ground-water reservoir.

Some cool springs discharge on the slopes of the southern Mineral Mountains. Their contribution to the regional water budget is trivial.

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Ground Water

In northern Escalante (Milford) Valley, the ground-water reservoir, as it is known and utilized, comprises three zones of high permeability alternating with three of low permeability. The series is penetrated by irrigation and municipal wells at an average depth of 500 to 800 feet. Pumping tests show that all three aquifers are interconnected.

Principal sources of water recharge into this shallow reservoir are major streams, irrigation ditches, irrigated fields, and underflow from rainfall infiltrating into the consolidated rocks of the mountains. Total volume of recharge was estimated at 58,000 acre-feet for the 1970-71 water year; this may be representative of the average annual amount. Discharge occurs principally by evapotranspiration and pumping of irrigation wells, and was 81,000 acre-feet in 1970-71.

Because discharge exceeds recharge, as it has for some 23 years, piezometric water levels have continued to drop in Milford Valley since 1953. Water wells are heavily concentrated in the area between Milford and Minersville. Therefore, largest cumulative water-level declines are in this area, and had reached some 30 feet by 1972. Away from this area, declines were generally less than 10 feet. At 1972 piezometric levels, a 1-foot decline in level represents a change in storage of 84,000 acre-feet. Expressed alternatively, each 10,000 acre-foot deficit in the water-budget corresponds to a level-drop of 0.12 feet per year. Thus, at the present deficit of 23,000 acre-feet per year, the average (valley-wide) level-decline is some 1/4 foot per year.

Interrelationship between this shallow circulation system and the deeper geothermal system probably is slight. Subsurface outflow from the geothermal system moves downslope within the alluvial fans toward the Beaver River channel, becoming dispersed and diluted en route. The minimum depth to the fractured Precambrian(?) gneiss and Tertiary granite of the geothermal reservoir is 1,200 to 1,600 feet in the vicinity of Roosevelt Hot Springs. Production probably will come from twice those depths on the average. Beneath Milford Valley, depth to the geothermal system may be many thousands of feet, if indeed the geothermal system is present. Upward leakage from the vicinity of Dome Fault may enter shallow, cool-water aquifers with time, especially

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if pressures continue to decline in shallow wells as a result of overdrafts for irrigation. However, R. Lenzer of Phillips Petroleum Company estimated (oral presentation, Beaver, Utah, April 29, 1976) that outflow from the geothermal system might take 300 to 700 years to reach shallow wells along the course of the Beaver River several miles north of Milford. It is unlikely that underflow would go southwestward toward the intensively irrigated farmland south of Milford.

At the urging of the South Milford Water Pumpers Association, Phillips has agreed to monitor a number of stock wells, special observation wells, Roosevelt saline seep, and one of its deep but dry holes for evidence of thermal outflow and contamination of potable aquifers.

Long-term effects of production and reinjection cannot be predicted with certainty, given the present-day level of understanding of the hydrothermal system. However, careful monitoring will reveal any abnormalities as soon as they arise, and may lead to a more comprehensive understanding of relationships between the shallow, cool hydrologic system and the geothermal production parameters (locations, amounts, and compositions of fluids withdrawn and reinjected).

Hydrochemistry

Shallow ground water stored in the alluvium of Milford Valley has total dissolved solids (TDS) of about 400 ppm; TDS ranges no higher than 1,000 ppm. Composition is predominantly Ca-HCO_3 and Ca-Na-HCO_3-SO_4. Relative abundances of principal ions is: Ca>Na>Mg>K; $HCO_3 > SO_4 \sim Cl$. In both absolute and relative terms, abundances of these species are quite typical of shallow, cool ground waters of the Basin and Range province, and indicate meteoric origin, and subsurface movement measured in months or years. Because of irrigation practice, evaporation and ion-exchange is increased in the near-surface zone. This has led to local enrichment of Na and Cl ions in the cool water aquifer. This might become confused in interpretation with NaCl water derived from the geothermal system.

Chemically, the deep thermal well-waters of the Roosevelt Hot Springs area are NaCl in character, and contain 6,000 to

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8,000 mg/ℓ TDS. Mundorff (1970) reported Roosevelt Hot Springs to contain TDS of 1,040 and 7,800 mg/ℓ. Other chemical concentrations (in mg/ℓ) were: Na (2,500 and 2,080), Ca (19 and 22), K (472 and 488), Cl (4,240 and 3,810), SO_4 (73 and 65), SiO_2 (313 and 405), HCO_3 (156 and 158), B (38), and F (7.1 and 7.5). Minor constituents included Li (0.27), Br (3.3) and I (0.3) mg/ℓ. Mg had nearly completely been combined in low-temperature minerals (0 and 3.3 mg/ℓ). Trace quantities of various metals probably are present, but were unreported.

Clearly, the composition of this fluid is very different from that of shallow, cool groundwater in Milford Valley. The thermal fluids are indicative of a very high temperature reservoir, and are generally comparable to fluids found in the Ahuachũpan, El Salvador and Cerro Prieto, Mexico geothermal fields.

A very long residence time is suggested by oxygen and deuterium isotope data reported orally by R. Lenzer of Phillips Petroleum Company. Lenzer's data are suggestive of enrichment patterns observed at other geothermal fields in North America. They are consistent with a model of recharge via infiltration of rainwater or snowmelt into fractured granite of the Mineral Mountains. Travel times and residence at depth may be estimated in decades or centuries.

GEOTHERMAL REGIME

Thermal Springs

Boiling water (to 195°F) discharged from Roosevelt Hot Springs (sec. 34, T. 26 S., R. 9 W.) until about 1963, when either blocking of the spring system by mineral deposition or lowering of the water table caused a cessation of flow. Thereupon, wisps of water vapor at about 205°F issued from warm ground. A tepid chloride-water seep about one-quarter mile north of the former hot spring area probably represents minor upward leakage from the reservoir along the Dome fault. Soil temperature was measured at 204°F at about 4 feet in depth in an auger hole near the former main orofice for Roosevelt Hot Springs. A nearby group of springs in Negro Mag Wash (NW/4 sec. 3, T. 27 S., R. 9 W.) may also have been active to about the same period. Extensive

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siliceous sinter deposits and elevated temperatures (to about 195°F) are also reported in shallow trenches at Negro Mag Wash.

Deposits of sinter, opal and hematite-stained silicified gravel occur over a distance of about 2-1/2 miles, south of Negro Mag Wash, along the Dome fault. These deposits indicate formerly extensive leakage of thermal water from along the fault. The large deposit in sec. 16, T. 27 S., R. 9 W. is offset by the fault, with vertical displacement of about 20 feet.

Temperature Gradients and Shallow Wells

Two large areas are characterized by temperature-gradient anomalies of 100°C/km (5.5°F/100 ft.) to more than 500°C/km (28°F/100 ft.) in holes of 50 meters to 500 meters in depth. These are on the west flank of the Mineral Range, and in the vicinity of Cove Fort. Available temperature-gradient data for Roosevelt are plotted on plate 5. Unpublished and proprietary data confirm this picture, but extend the anomaly on the north and east.

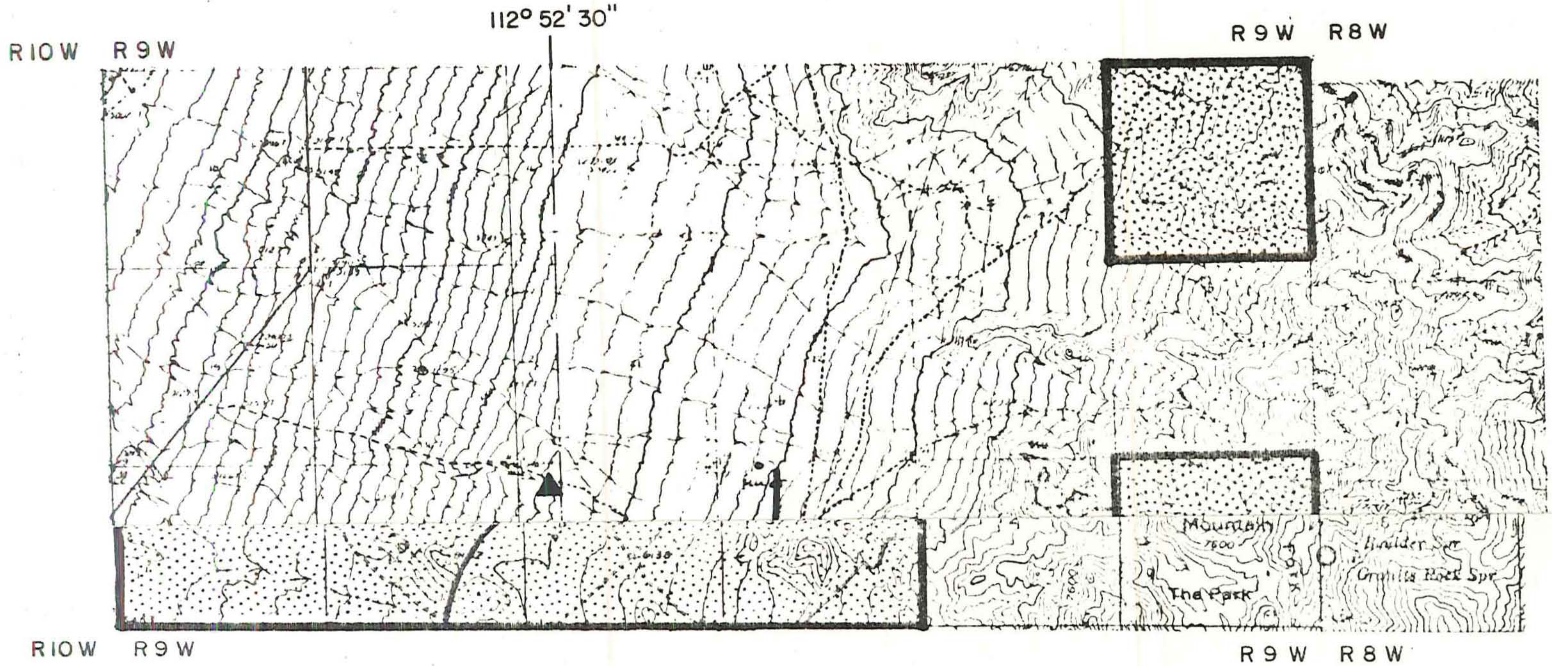
Several holes were drilled around the opalite deposit in sec. 16, T. 27 S., R. 9 W. in 1968 in the search for gem-quality opal. One of these penetrated to approximately 275 feet and produced low-pressure, water-saturated steam at a temperature of about 270°F before being plugged. This equals 80°F/100 ft., or 1,450°C/km. It obviously represents thermal convection along the Dome Fault. More recently, temperature-gradient holes were drilled in the area by Phillips Petroleum Company, Thermal Power Company of Utah, and other parties. Gradients range from 2.5°F (equivalent to background) to 26.8°F per 100 feet (45°C/km to 485°C/km). The gradient contours outline an elongate north-trending anomaly, the most intense part of which is almost coincident with the Dome fault in sec. 4, 9 and 16, T. 27 S., R. 9 W. and the Bouguer low or saddle discussed above. A magnetic high anomaly in the area changes trend and amplitude to the north of Negro Mag Wash. The anomaly is at least 8.5 miles long (north-south), and 2.5 miles wide (east-west), as contoured on the 100°C/km isograd (plate 5).

Based on both publishable and proprietary data, gradients drop off equidimensionally and rapidly east and west of the Dome fault. Termination at the north and especially the south ends of the main anomaly is more rapid. A lobe or arm of higher-than-normal gradient extends northwesterly into Milford Valley. This high corresponds to the direction of subsurface thermal outflow from the deep geothermal reservoir, and probably represents a thermal plume from the vicinity of the Dome fault.

The rather abrupt termination of high gradients on the south is based on relatively few drill holes. It probably reflects a fault or other fracture bounding the thermal cell on the south (see plate 5). The lack of publishable gradient data farther south makes it difficult to conclude if another thermal cell is present from Ranch Canyon south. More gradient data definitely are needed in that direction.

To the east, the rapid decrease in gradient in the mountains is surprising, as the principal mass of Pleistocene rhyolite is exposed to the east. The number of available gradient holes probably is inadequate for decisions regarding the deep geothermal regime. It is possible that terrain factors and the higher amount of precipitation in the mountains serve to depress gradients in holes of 50 meters or less. Further, the center of the complete Bouguer minima (described earlier) lies 2 or 3 miles west of the volcanic axis, which is near the crest of the Mineral Mountains (figure 7). Therefore, the center of a presumed intrusion may lie west of the volcanic axis. This is strange, for it means that Pleistocene volcanism expressed itself along the longest, most difficult course, through the granitic pluton rather than along the fractured boundary of the range. This violates the geologic concept of parsimony. Further and deeper drilling may reveal a heated cell to the east beneath the cold-water recharge cap. As evidence to support this, a very high temperature well was drilled by Natomas Company on the east edge of the temperature anomaly of plate 5, near a shallow hole having a calculated gradient of only 69°C/km (sec. 2, T. 27 S., R. 9 W.).

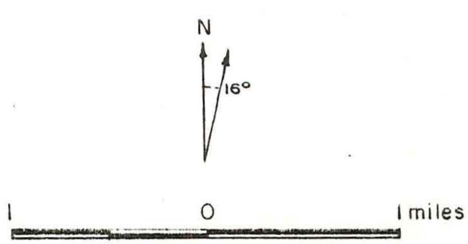
Gradients of course vary inversely with thermal conductivity of the rocks or sediments penetrated. Gradients of 35° to 40°C/km in dense bedrock of the Mineral Mountains might be comparable to 70° to 100°C/km gradients in alluvium of Milford Valley, in terms of heat flow. Values in the bedrock as low as 65° to 70°C/km may thus be attractive for exploration, representing as



EXPLORATORY DRILLING AT ROOSEVELT HOT SPRINGS GEOTHERMAL FIELD

LEGEND

- ▲ Future drilling sires approved for Phillips Petroleum Co.
- N 14-2 (7324) Geothermal well with number and depth (feet); N= Natomas.
- Apparently encountered producible geothermal aquifer.
- Mapped or interpreted faults (Phillips Petroleum Co.), barb on down side.
- Axis and center of Bouguer gravity low.
- Geothermal Power Corp. leases in R 9 W.



Scale 1:62,500

FIGURE 7

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they do potential temperatures of 200°C at 3 km (10,000 ft.). By contrast, gradients in unconsolidated sediment should exceed 80° or 90°C/km to be attractive for deep exploration, as the gradient can be expected to drop sharply upon drilling into denser rock at depth. Data are not shown on plate 5 for the Cove Fort thermal anomaly, as it is beyond the scope of this report.

Heat Source

The project area is characterized by high heat flow and Quaternary silicic volcanism. Rock temperatures, therefore, may be significantly above average at any given depth, and may be extremely high in the vicinity of presumed silicic plutons. Meteoric water entering fractured granitic and volcanic rocks of the surface may be heated to temperatures of 200°C (400°F) or more by (1) deep circulation in fault zones under regional gradient conditions; (2) less-deep circulation within fractured zones in the vicinity of buried hot plutons. In the study area, the existence of a significant volume of Pleistocene silicic volcanics in the Mineral Mountains suggests that a buried pluton is the more likely heat source there.

Evans and Nash (1975) determined intrusion temperatures of about 700°C for the Quaternary silicic rocks, with a source region at 13 to 16 km depth below sea level. D. D. Blackwell (unpublished data, 1974) has estimated emplacement of such a silicic pluton at about 4 km beneath ground surface. Its cross-sectional area he estimated at 9 km^2 (3.5 mi^2), which seems minimal when considering the surface distribution of Quaternary rhyolite and the size of the thermal gradient anomaly (over 20 mi^2 within the 100°C/km isograd). This feature extends across Secs. 22, 27 and 34, T.27 S., R. 9 W.; this is 2 miles south of the southernmost productive geothermal well, and is on the southern boundary of high gradient in shallow holes.

More recently, Blackwell (oral communication, January, 1977) has expressed his belief that perhaps 15 square miles (35 km^2) are underlain by young silicic plutons, based upon Crebs' (1976) gravity data. Not all of this mass need be at near-molten temperatures; the average deep gradient across this zone might be 50° to 70°C/km. This would make portions of the area underlain by Quaternary plutons non-commercial for geothermal development.

A differing view, held by Dr. S. H. Ward and associates Dr. R. B. Smith and W. P. Nash of the University of Utah, is that the intrusive center is represented by an elongate Bouguer low centered on Sec. 17-19, T. 27 S., R. 8 W., and covering some

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3.5 square miles. This might represent a molten or near-molten body, according to Ward (oral presentation, Golden, Colorado, September 1976).

In either case, acreage held by Geothermal Power Corporation falls on or immediately adjacent to the presumed Quaternary intrusion (plates 1 and 3), and becomes prospectively more attractive accordingly.

Reservoir

Production in the developing Roosevelt geothermal field is obtained from fracture systems in Precambrian(?) gneiss and possibly the Tertiary granite. Prospectively valuable lands may be sought along the contact zone between the Mineral Mountains granite and Precambrian(?) gneiss, and within deeply fractured zones in the granite. It is possible that highly cemented and fractured sections of Tertiary sediment may serve locally as reservoir in the deeper portions of Milford Valley, but this is not likely. It appears that reservoir potential in all of these rock types is of fracture type. Obviously, the best environment for fracture development is within or near fault zones (see Figure 6). This appears to be borne out by the location of the geothermal field as presently known.

In carbonate rocks, permeability may be enhanced locally by through-going solution activity. However, exposures of carbonate rocks are limited in the region of Pleistocene volcanism and probable intrusion to a zone just south of Ranch Canyon.

In the Roosevelt geothermal system, various factors can be significant in limiting and localizing the reservoir. Deposition of silica, clay, or other minerals may occur around the periphery of the reservoir, thus sealing the fracture systems. In addition, clay-mylonite in fault zones or a zone of so-called cataclastic metamorphism (Condie, 1960) might act as a seal. Finally, fine-grained lacustrine facies of the valley-fill probably are very poorly permeable to the geothermal fluid.

Quaternary, and possibly active, tectonism may serve to re-open sealed fractures and to create additional fracture channels. Therefore, areas along the Dome fault, or cut by other presumed Quaternary faults offer better prospecting possibilities.

It is apparent that the location of the Roosevelt geothermal-gradient anomaly is controlled significantly by the north-trending zone of faulting and fracturing along the west side of the Mineral Mountains. However, it is not apparent whether other individual faults and fractures in this zone have special significance. As stated earlier, east-west faults may terminate or deflect the strike of the Roosevelt anomaly.

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LEASEHOLD EVALUATION

Exploration History and Results

Exploration began with the accidental drilling of the 270-foot-deep hole on the opalite mound in 1968. That event yielded an eruption of 270°F water, and began a leasing rush that is still in progress; this in turn led to the discovery of the Roosevelt geothermal field.

Figure 7 shows the location of deep holes (greater than 400 meters) in the Roosevelt area, and table 2 gives their characteristics. These holes were drilled either by Phillips Petroleum Company or by Thermal Power Company (a subsidiary of the Natomas Company). In addition to this deep drilling, which has reached approximately 7,500 feet in maximum depth, there have been dozens of gradient holes drilled in the broad area from north of Cove Fort to south of Thermo. This has been accompanied by tens of line miles of resistivity and magnetotelluric soundings, several months of microseismic recording, and correspondingly great efforts in hydrogeochemistry, seismic profiling, passive noise recording, gravimetry, aeromagnetometry, photogeology and field geologic mapping, and other exploration techniques.

This work has been accomplished by private companies, members of the U. S. Geological Survey and Utah Geological and Mineralogical Survey, faculty and student researchers at the University of Utah, and private contractors. Relatively little data are in the public domain, although proprietary information does circulate informally by trade or privileged release. These efforts in the Roosevelt Hot Springs area rival those accomplished at The Geysers or in Imperial Valley, California. Phillips Petroleum Company alone acknowledges spending $6 million on leasing, exploration and drilling since beginning work in 1973; they estimate a total outlay of $30,000,000 by 1982, to develop 110 mW of electric power generation (Gary Crosby, oral presentation, September 1976).

Drilling results reveal a hot-water reservoir, with temperatures as great as 260°C (500°F) at depths as shallow as 2,800 feet. Production comes from highly sheared and fractured Precambrian(?) gneiss and schist, and possibly from fractured

Table 2. Geothermal Wells Drilled at Roosevelt Hot Springs, Utah

Well Number	Location	Date Drilled	Depth, ft.	Casing	Results and Status
					Phillips Petroleum Company
OH-2	SW/4 NW/4, 10-27S-9W	2/2/75-2/15/75	2,250	N.D.	Deep temperature-gradient hole; reportedly high gradient
OH-1 (also 17-1)	SE/4 NE/4, 17-27S-9W	3/3/75-3/12/75	2,321	N.D.	Deep temperature-gradient hole; "high" temperature; low permeability
9-1	NE/4 NW/4, 9-27S-9W	3/13/75-4/8/75	6,885	N.D.	"High" temperature; poor permeability
3-1 (also 55-3)	NW/4 SE/4, 3-27S-9W	4/20/75-5/24/75	2,728	N.D.	Tested at 1.2 million #/hr of hot water
54-3	SW/4 NE/4, 3-27S-9W	7/5/75-8/28/75	2,882	N.D.	∿1million #/hr of hot water at >500°F and >500 BTU/#; rated as "best" well
12-35	NW/4 NW/4, 35-26S-9W	8/6/75-10/1/75	7,324	7" liner to 4,500'	Suspect shallow-zone cool-water contamination; ∿440°F thermal aquifer now lined off; cannot test satisfactorily
13-10	SW/4 NW/4, 10-27S-9W	10/2/75-11/4/74	5,351	N.D.	Tested above 1 million #/hr of hot water at 75-125 psig
82-33	NE/4 NE/4, 33-26S-9W	11/5/75-12/23/75	6,028	13-3/8" to 575'	>300°F, <350°F; possible future injection well
25-15	NW/4 SW/4, 15-27S-9W	8/26/76-11/12/76	∿7,500	9-5/8" at ∿2,500'	Shallow-zone cool-water contamination; less satisfactory than wells to north
(Note: All Phillips' wells are on Federal lease blocks)					
					Thermal Power Company (Natomas Company)
Utah State 14-2 (ML27536)	SW/4 NW/4, 2-27S-9W	9/11/76-10/21/76	6,108	9-5/8" at 1,805'	Reported >400°F hot water at ∿4,000'
Utah State 72-16 (ML25128)	NW/4 NE/4, 16-27S-9W	10/22/76-1/5/77	1,254	N.D.	Reported 1 million #/hr of hot water at 432°F and 355 psig

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Tertiary granite. The extent of Precambrian(?) rocks within the range is unknown: it may have been terminated beneath the Mineral Mountains by the Pliocene granitic intrusion or by the younger generation of rhyolite magma represented by the rhyolite domes and flows. Precambrian(?) rocks do crop out farther to the south along the range front, extending at least to the vicinity of Cave Canyon in T. 29 S.

Figure 2 reveals the conceptualization by scientists at Phillips Petroleum Company that pervasively fractured rock, rather than individual fault planes, forms the reservoir. Those holes not cutting the "shear zone" of figure 2 reportedly exhibit low permeability. However, all youthful faults may serve to carry hot fluids toward the surface, thus generating high temperature gradients in shallow holes.

The fault trending east-west across Negro Mag Wash apparently does not terminate the field: high temperature (∿440°F) was reported from hole 12-35, nearly 1.5 miles north of this south-dipping feature (G. Crosby, oral presentation, September 1976). Similarly, the southern boundary of the field is unknown.

Wells drilled very close to the range front commonly exhibit low gradients in their upper positions, reflecting cold-water recharge through fractured rocks of the mountains. Those drilled west of Dome fault exhibit high gradients in their upper portions, because of outflow of thermal fluid up Dome fault or other faults shown in figures 2 and 7. However, deeper gradients may be disappointing, and permeability often is limited.

It is interesting to note that the high gradients (as shown in plate 5) are displaced slightly westward from the proven geothermal field (figure 7). This recharge-discharge effect (described above) imposes a constraint on the use of gradient holes in the siting deep exploratory wells at or beyond the field boundaries. Structural and petrologic geology, results from earlier holes, and gravimetry all should be considered carefully, along with data on seismicity or the electromagnetic field, as these become available in the future.

Reservoir fluid is water-dominated and chloride-rich (∿3,000 mg/ℓ), with TDS of 6,000 to just over 8,000 mg/ℓ, average enthalpy of 500 BTU/pound, and temperature at one kilometer of

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160°C (320°F) to 260°C (500°F). Mass flow in productive wells averages about one million pounds per hour of hot water, at pressures slightly above hydrostatic. Individual well tests up to 1.5 million pounds per hour have been reported, but stabilized flow may be expected to be less than this. An average steam flash of 18 to 20 percent is anticipated, although pressure, mass flow, and therefore percentage of steam flash and steam enthalpy, vary somewhat from hole to hole.

Using "average" conditions, a productive well may be expected initially to yield 200,000 pounds of steam per hour, after flash separation. This should serve to generate 10,000 kW per hour, or 10 mW. This is quite high, and therefore attractive commercially. Ultimately, stabilized flow may be somewhat lower.

It is probable that more than one thermal zone is present, one being a shallow system fed by leakage up faults, and a second being a deeper system of pervasively fractured rock. Differences may be expected in pressure, temperature, enthalpy, and possibly mass flow and well life in these two systems. Because field dimensions are unknown, and because no data are available on long-term well productivity, ultimate generating capacity is unknown. Well spacing probably will be determined empirically, using results of interference tests between existing wells to determine optimum locations.

Reinjection will be required for all waste fluids, and probably for any condensed steam that is not evaporated in the cooling process. Such wells may be located to the northwest and west of the producing field, and a ratio of one injector for two producers is anticipated (G. Crosby, oral presentation, September 1976).

Phillips has applied to drill 21 additional wells to define field boundaries and parameters. Still additional wells will be required for development purposes.

Competitive Interest

A Known Geothermal Resources Area (KGRA) was established at Roosevelt Hot Springs prior to the beginning of leasing in the public domain in January 1974. Therefore, no applications for non-competitive leases were accepted for a zone of 23,000

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acres centered on the former hot spring and the opalite mound. Figure 8 shows the location of the KGRA, and table 3 lists the successful bids entered in the July 30, 1974 competitive lease sale.

The principal bidders at this sale were Phillips Petroleum Company, Getty Oil Company, Union Oil Company (all of whom were successful in varying degree), Gulf Oil Company, Al-Aquitaine Oil Company and American Oil Shale Corporation (all of whom were unsuccessful). Phillips was the major winner, purchasing nearly 19,000 acres for a bonus of $800,000, or $43 per acre, averaged. Actual bids by Phillips ranged up to $128.06 per acre for lease units 6 and 4. This revealed their preference for the western side of the Dome fault; this, of course, was prior to their first deep drill holes.

One parcel of 40 acres was claimed under grandfather rights by A. L. and W. L. MacDonald, of Milford, Utah, for the equivalent of $58.38 per acre, thereby matching Phillips' bid.

On June 12, 1975, 1,200 acres in the KGRA was reoffered, and were bid on (and won by) a private party, Gary Seltzer.

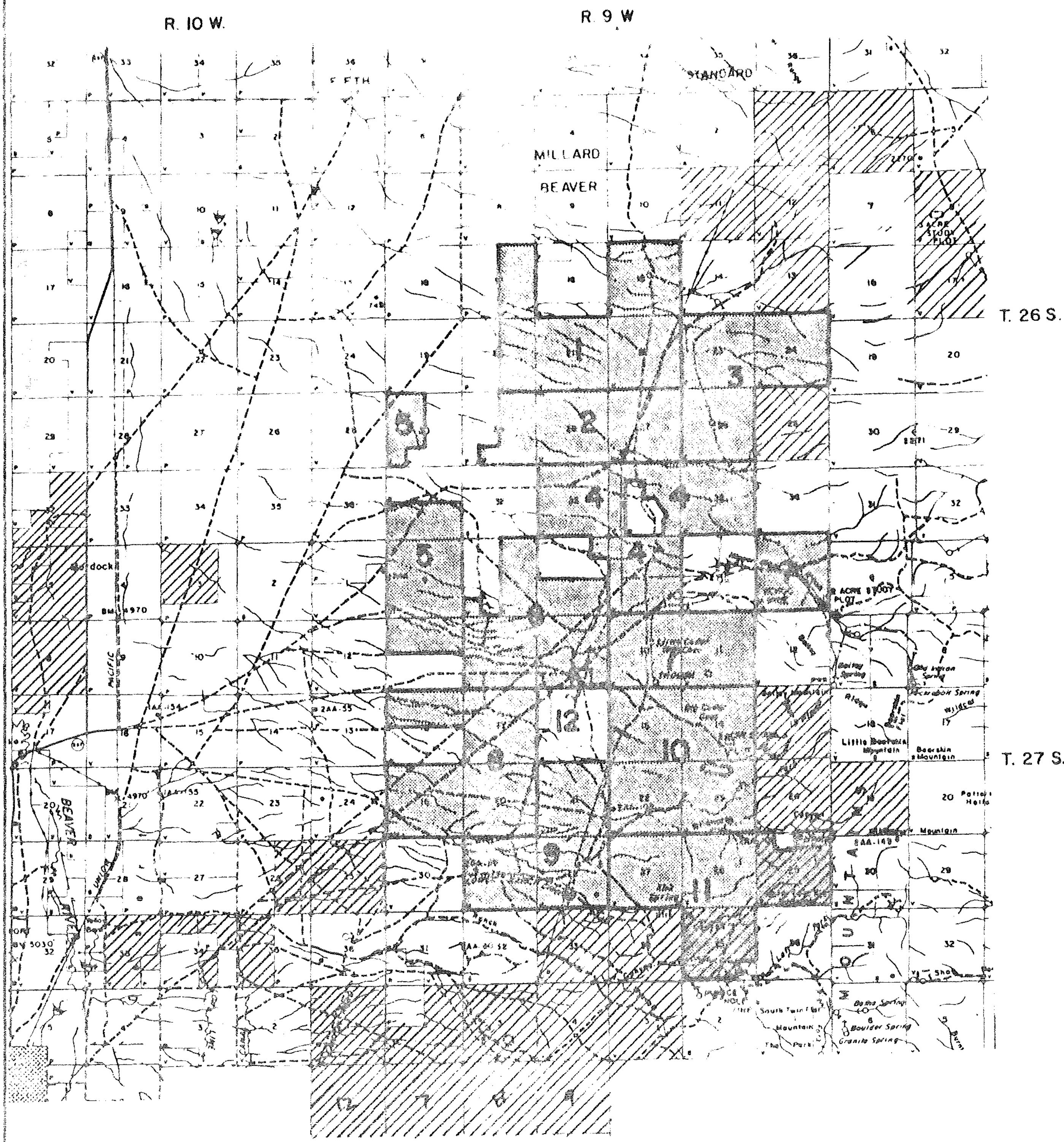
The largest block of fee leases in the area is held by Thermal Power Company of Utah (TPU). Acreage in these leases has been optioned or re-leased to Natomas Company, AMAX Exploration, Inc., and others. In addition to fee leases, several companies and private parties have applied for non-competitive leases to public domain. These include Phillips, Union, Getty, AMAX, American Oil Shale (now American Geothermal Energy Co.), TPU, Davon and Geothermal Exploration Company, among many others. In addition to Seltzer, private applicants include Milton Fisher (associated with American Geothermal Energy), Malcolm Justice, Christopher Marks, Trevor Windsor and Cecil Folmar, to name a few.

Federal acreage held by Seltzer, Windsor and Folmar have been assigned to Geothermal Power Corporation.

Several sections of State land also have been applied for and awarded for lease.

Taken together, these leases and applications cover at least 85 percent of a nearly continuous zone 17 miles long (north-south) and 9 miles wide (east-west).

Leasing extends in discontinuous fashion westward across the floor of Milford Valley; southerly and southwesterly toward



THE ROOSEVELT HOT SPRINGS KGRA

LEGEND

4 KGRA lease units

Acre held by Geothermal Power Corp

FIGURE 8

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Table 3. Summary of KGRA lease sales in Utah

		ROOSEVELT HOT SPRINGS, JULY 30, 1974		
		Bids Received		
Unit	Acreage	Amount	$/Acre	Bidder
1	2,560	$ 51,994	20.31	Union Oil*
		23,372		Gulf Oil
		13,082		Phillips Petroleum
2	1,640	87,543	53.38	Phillips Petroleum*
		62,090		Union Oil
		14,973		Gulf Oil
3	1,920	9,812	5.11	Phillips Petroleum*
4	2,454	314,199	128.04	Phillips Petroleum*
		93,234		Union Oil
		22,400		Gulf Oil
5	1,644	8,401	5.11	Phillips Petroleum*
		5,877		Aquitaine
6	1,940	248,392	128.04	Phillips Petroleum*
		53,350		Getty Oil
		42,672		Union Oil
		17,709		Gulf Oil
		6,139		Aquitaine
7	1,961	41,856	21.34	Phillips Petroleum*
8	2,273	62,903	27.67	Phillips Petroleum*
		28,412		Getty Oil
		20,747		Gulf Oil
9	1,920	24,000	12.50	Getty Oil*
		17,529		Gulf Oil
		9,811		Phillips Petroleum
		4,992		American Oil Shale Corp.
10	2,560	13,082	5.11	Phillips Petroleum*
11	2,480	12,673	5.11	Phillips Petroleum*
12	40	2,335	58.38	A.L. & W.L. McDonald* (grandfather applicant)
		2,335		Phillips Petroleum
				JUNE 12, 1975
1	1,200	2,586	2.16	Gary Seltzer

*indicates bid accepted by Dept. Interior

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and beyond Thermo Hot Springs; and northeastward into the Cove Fort region. The scope and intensity of this leasing operation rivals leasing at The Geysers geothermal field in California, and clearly exceeds activities elsewhere in Utah, or in adjacent Nevada, Arizona, Idaho or Wyoming.

Many companies that have not established satisfactory leasehold positions at Roosevelt have gone farther afield, or have attempted to purchase positions. Therefore, although not listed as active at Roosevelt, the interest of Chevron Oil Company, Hunt Oil Company, Earth Power Corp., Sun Oil Company and Atlantic Richfield Co. should be noted.

It can be said fairly that at this time a market exists for the farm-out, sale or joint venture of all leases and applications within the 150-square-mile zone described above, even though less than one-tenth of that area can be classified as proven geothermal field. Therefore, the acreage held by Geothermal Power Corporation (plate 1 and figure 7) is to a very large degree of interest for farm-out, sale or joint venture, especially acreage in T. 26 and 27 S., R. 9 W., and to a lesser degree T. 28 S., R. 9 W. Further, were Geothermal Power Corporation to drop any leases or applications, it is highly likely that another entity immediately would attempt to obtain leases to those lands.

Because of the very intense competition for attractive acreage, no significant new position can be acquired within T. 26 and 27 S., R. 9 W. without either bonus payments in cash, a commitment to expend money on exploration and deep exploratory drilling, or both.

Undoubtedly there will be unsuccessful holes drilled in the Roosevelt area as exploration proceeds. At that time, the value of various lease blocks will decline, depending upon position relative to these dry holes. Conversely, further drilling probably will expand the perimeter of production, especially eastward, thus raising the value of certain acreage.

At this time, the acreage held by Geothermal Power Corp. in T. 27 S., R. 9 W. prospectively is worth several tens of dollars per acre; that in T. 26 S., R. 9 W., only slightly less. Acreage in T. 28 S., R. 9 W. is worth perhaps half as much, prospectively; and acreage elsewhere may be valued at a few dollars per acre.

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Therefore, it would be realistic to expect another company to be willing to spend several hundred thousand dollars in bonus, exploration and drilling in order to obtain fractional interest on the most favorable of Geothermal Power Corporation's acreage.

Exploration Program

In recent months, very good data on complete Bouguer anomalies and aeromagnetic intensity have become available for the majority of leases held by Geothermal Power Corp. It is not anticipated that further gravimetry or aeromagnetometry will be useful in classifying acreage or siting deep holes.

Chemical data are available for wells drilled in Milford Valley (although not included herein) and for a few springs of the Mineral Mountains. Chemistry of the lowland wells rarely is revealing of the deep geothermal system; data from the highland springs are dominated by precipitation and infiltration. Therefore, no further hydrochemical work is warranted at this time.

Geologic mapping, including photogeology, for the central and western Mineral Mountains is adequate to very good in quality and detail. However, geology of the eastern and northeastern flanks of the Mineral Mountains is less well known, and may benefit from some intensive photogeology. This would have as its goals the recognition of fault and fracture patterns and establishment of volcanic stratigraphy. Probably it would be useful to collect some volcanic rock samples of that area for radiometric age-dating.

Seismic and geoelectrical techniques continue to provide important data for the region, especially in the vicinity of Cove Fort. However, because of work released or in progress by public agencies, and because of the high cost of obtaining additional data, and the uncertainty of collecting and interpreting seismic records, no further seismic or geoelectric work is recommended at this time. However, efforts should be made to obtain data from publically funded surveys as soon as they are released, for integration with other data. Additionally, if private contractors offer to provide data at lower cost to a group of participating companies, or if a trade of private data is suggested by other companies, this should be considered for cost-effectiveness.

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The burden of exploration will have to be borne by gradient drilling and heat-flow calculation. This is so despite the twin constraints of (1) the effects of recharge and outflow on gradients, and (2) the need to convert gradient data to heat flow, to compensate for variations in thermal conductivity between sediment and basement rock. A third possible constraint is the cost of obtaining these data.

Costs for permitting, drilling and logging holes, and for calculating heat flow should not exceed $10 per foot for holes to 100 meters (328 feet) and may be as little as $5 per foot. Holes must be deeper than 200 feet, to penetrate beyond seasonal effects and the effect of cold-water recharge. However, in some areas cold-water recharge may be detected to several hundred meters.

A series of over 20 locations is recommended on plate 1 for 300-foot-deep gradient holes. These are designed to test the acreage held by Geothermal Power Corp. in T. 26-28 S., R. 8-9 W., especially Sec. 13, 24 & 25, T. 27 S., R. 9 W. and Sec. 25, T. 26 S., R. 9 W. The latter, overlying parts of the Quaternary volcanic field, are considered promising for exploration. Also, Sec. 33-35, T. 27 S., R. 9 W. and Sec. 4-5, T. 28 S., R. 9 W. lie within the anomalous Bouguer gravity low (figure 7), and should be tested for gradient.

If anomalies are detected at 100 meters, and sustained by calculation of heat flow, consideration should be given to testing deep heat flow in holes 300 to 600 meters (1,000 to 2,000 feet) in depth. Additionally, if encouragement is received from gradient drilling, it may be advisable to perform further analyses of the gravity, aeromagnetic, seismic and geoelectric data. By encouragement is meant gradients above 100° to 150°C/km in poorly consolidated materials, and over 70° to 80°C/km in crystalline rock.

Costs for a 300-foot-deep hole, including logging, calculation of heat flow, and reporting, should average $1,500 to $3,000. Therefore, a 10-hole program might cost $15,000 to $30,000. This is the minimum number of holes recommended. Fifteen to twenty holes, with a corresponding increase in total cost, is preferable for so large and scattered an acreage position, if budget permits.

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It may be possible to augment this total of gradient data points by conducting trades with other companies active in the region.

It is far too early to predict location of a deep geothermal test on this property. However, it is likely that deep drilling will be warranted, if merely on the proximity to high-temperature, high-yield wells as little as two miles distant. In 1976 dollars, costs for deep holes at Roosevelt have averaged $80 per foot, including completion, but exclusive of extensive testing.

Acreage should be reviewed periodically for retention or release. Acreage undergoing exploration, or scheduled for exploration, should be retained until work is completed and evaluated. Acreage that is judged of lower quality, either as the result of new data or as based upon presently existing criteria, should be offered for farm-out or sale prior to being dropped. Farm-outs, sales and joint ventures should not be considered for the most attractive acreage, unless budgetary constraints force this.

There is little likelihood of leasing new acreage of high quality in the area. Therefore, consideration should be given to pooling acreage with other small companies holding adjoining acreage of high quality, to thereby increase leverage for exploration and drilling. The single section (12, T. 27, S., R. 9 W.) held by Geothermal Exploration Co. obviously fits this concept.

Several sections of land leased by Geothermal Power Corp. are attractive for exploration, and may overlie commercial reserves of geothermal fluid. These should be explored promptly, efficiently and with an adequate budget. Drilling of shallow gradient holes, perhaps two or three deep gradient holes, and supportive geologic and geophysical work probably can be accomplished for $82,500 to $135,000, as follows:

Fifteen 300-foot gradient holes	$22,500 - $ 45,000
Photogeology, radiometric age-dating	5,000
Two 2,000-foot gradient holes <u>or</u> three 1,500-foot holes	$60,000 - 80,000
Reporting, data trade, data interpretation, miscellany	5,000
	$82,500 - $135,000

This would certainly place Geothermal Power Corp. in the position to site one or more deep exploratory holes.

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It is premature to estimate the depth or location of a deep geothermal hole. However, in today's dollars, drilling and completion, exclusive of testing, at Roosevelt Hot Springs costs \$80 to \$100 per foot. Recent holes there have averaged 6,000 to 7,000 feet in depth. By extension, it is possible to prepare hypothetical budgets, again in 1977 dollars, for holes assumed to be 6,000 to 7,500 feet in depth.

1 hole (7,500 feet), drilled, completed, logged and tested (\$80-\$120 per foot)	\$600,000 - \$ 900,000
2 holes (6,000 feet), drilled, completed, logged and tested (\$80-\$120 per foot)	960,000 - 1,440,000
	\$1,560,000 - \$2,340,000

If to this is added the costs of drilling and logging gradient holes (see above), \$82,500 to \$135,000, the total hypothetical cost range is \$1,642,500 to \$2,475,000. By averaging, this yields a figure of \$2,000,000 as a possible cost range for gradient drilling and logging of nearly 9,000 feet, followed by siting, drilling and testing of 3 deep holes with a total of nearly 20,000 feet around the Roosevelt geothermal field.

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