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GEOTHERMAL POTENTIAL

Kelly Hot Spring Area
Modoc County, California

Prepared for

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REGISTERED GEOLOGIST • STATE OF CALIFORNIA •
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No 859

June 1, 1973

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CONCLUSIONS AND RECOMMENDATIONS

1. The Kelly Hot Spring area Ts. 41-44 N., Rs. 9-13 E. is an excellent geothermal prospect and should be explored.

2. A three phase exploration program to define the geothermal potential and drill a demonstration well can be executed in 12 to 18 months and will cost as follows:

Phase 1-Reconnaissance exploration	$81,500.00
Phase 2-Detailed exploration	190,500.00
Phase 3-Demonstration well	350,000.00
Total	$612,000.00

INTRODUCTION

Purpose and Scope

The Kelly Hot Spring area is in a region where natural thermal phenomena are common (fig. 1). It is only 35 miles west of the Surprise Valley area--currently the site of intensive geothermal exploration, principally by Magma Energy, Inc., American Geothermal Resources Corporation, and Gulf Oil Co. It is southwest of Klamath Falls, Oregon-site of one of the world's largest developments of natural thermal energy for space heating. It is about 80 miles northeast of Mount Lassen, the only active volcano in California.

In addition to being in a region where natural thermal phenomena are common (fig. 1) the Kelly Hot Spring area stands out as a geothermal prospect because the geologic and hydrologic factors seem favorable, and because the geographic factors are suitable.

This report has five objectives. These are:

(1) To summarize the geographic features of the area;
(2) To present the available information about the geology and hydrology of the area;
(3) To assign limits to the area that should be prospected;
(4) To evaluate and access the merits of the delimited area as a geothermal prospect so that an appropriately high priority will be assigned for its exploration; and
(5) To outline an exploration program that takes into account the geology and hydrology of the area.

This report summarizes and reinterprets data obtained from published reports and maps; as well as data in the files of the California Division of Mines and Geology, California Division of Oil and Gas, California Department of Water Resources, and the U. S. Geological Survey.

Geothermal Resources International, Inc., supplied the lithologic log of Kelly Hot Spring Ranch #1. No new data have been obtained.

Previous Exploration

In 1969 Geothermal Resources International, Inc., drilled the Kelly Hot Spring Ranch #1. This is the only test that has been made of the area's geothermal potential. Unfortunately, it was drilled to avoid action related to a penalty clause in a lease, rather than for specific information. As a consequence, no geophysical logs were run and the only temperature measurements were made by hanging a maximum reading thermometer on a survey bar lowered into the hole.

During drilling lost circulation problems caused the driller to circulate large volumes of cold water into the hole so natural down-hole temperatures were diminished (probably a great deal) and the longest period after drilling ceased until a temperature measurement was made was 12 hours. No flow test was attempted and no water sample was collected for chemical analyses. In short, the only effort to test the geothermal potential of the area was totally inadequate.

GEOGRAPHIC FEATURES

Location and Size

The Kelly Hot Spring area includes the Warm Spring Valley portion of the Pit River Basin in Central Modoc County, California. The area of easily defined surface anomaly consists of about 25 square miles in T. 42 N., Rs. 9-10 E. (fig. 2). The area considered here includes part or all of Ts. 41-43 N., Rs. 9-13 E. (fig. 2-3).

Topography and Drainage

The area considered here lies mostly in the Pit River Basin and is for the most part north of the Pit River. Figure 2b shows the relation of the area to the Pit River Basin and the basins of its principle tributaries.

Altitudes in the area range from about 4280 feet southwest of Canby to 5241 feet on Mahogany Ridge. Slopes in Warm Spring Valley are moderate, less than 100 feet per mile. Bordering the valley on the north is a relatively steep scarp that accounts for much of the reliaf in the area. The uplands along the Pit River Basin divide are rolling plains marked by mounds that could be shield volcanoes or eruptive centers. These uplands have slopes of more than 100 feet per mile, but should not be considered well drained. Near the basin divide there are extensive swamps.

As figure 2 shows in addition to reserviors such as Big Sage and Wood Flat, which contain water continiously, there are a number of reserviors that contain water intermittently.

Climate

The climate of the Kelly Hot Spring area is characterized by moderately severe winters and warm dry summers. Temperatures during the winter drop below -30°F and during the summers may be more than 100°F.

About three-quarters of the seasonal precipitation occurs during the winter months. However, localized summer thunderstorms of heavy intensity, but short duration, are common.

In this part of the United States, topography influences the precipitation rather profoundly. Precipitation on the Warner Mountains (along the eastern divide of Pit River Basin) averages more than 30 inches per year; whereas at the lower altitudes of the Kelly Hot Spring area precipitation averages only 8 to 16 inches per year.

The mean annual air temperature at Alturas (altitude = 4365) is about 47°F.

Land Ownership

In the area under discussion, here the land is divided between the U. S. Forest Service and private owners. A few small parcels are owned by the State of California, Modoc County, LXR Indian Reservation. Figure 3 shows the Forest Service ownership.

Cultural Features

Access to the Kelly Hot Spring area is convenient. North-south U. S. Highway 395 and east-west California Highway 299 meet at Alturas. The Southern Pacific Railroad crosses the area. Alturas has an excellent landing strip.

An REA transmission line crosses the area.

As the following table shows, Modoc County, which has an area of 4092 square miles, is sparsely populated.

Census	Population	Population density (persons/ sq. mi.)
1950	9678	2.3
1960	8308	2.0
1970	7469	1.8
1972*	8000	1.9

*estimate for July 1, 1972 by California Dept. Water Resources.

About one-third of the population lives in Alturas, the county seat.

Discussion

Not only is access to the Kelly Hot Spring area convenient but there are also no serious inpediments to movement within it. So no unusual site factors should increase the cost of exploration for or the development of geothermal power.

A large percentage of the land is privately held land, and the federally controlled acreage is not in a KGRA. Equally important the people in Modoc County seem to be receptive to the idea of geothermal development, because it will provide jobs and help with economic growth.

The other potential geothermal areas in the region (fig. 1) share the principle geographic constaints to development, which area
(1) The severe winters make exploration and development more costly.
(2) The distance to market is relatively large and available transmission lines may not be adequate.

In general, the geographic features of the Kelly Hot Spring area enhance the prospective quality of the area, because few areas are as favorably situated.

GEOLOGIC FACTORS

Regional Setting

Physiographically the Kelly Hot Spring area is in the Modoc Plateau, which MacDonald and Gay (1966, p. 46) described beautifully when they wrote:

> The Modoc Plateau is a highland region capped by vast late Tertiary and Quaternary basalt plains and numerous volcanic shield cones that largely overlap older basin-range structures. These structures are typified by fault-block mountains of Tertiary volcanic rock, with intervening basin-like grabens that commonly contain sedimentary rocks deposited in large Pliocene and Quaternary lakes that had resulted from interruption of the drainage by faulting or volcanism. To the east and southeast the Modoc Plateau merges with the Great Basin, across an arbitrary boundary. The Warner Range, which borders the Modoc Plateau on the east, is generally regarded as a part of the Great Basin, but its rocks and general structure are continuous with those of the Modoc region. On the west, the border of the Modoc Plateau with the Cascade Range is also indefinite; the faulting characteristic of the Modoc region extends into the edge of the Cascade Range, and some types of rocks are common to both provinces.
>
> The oldest rocks of the Modoc region are a series of interbedded lava flows, pyroclastic rocks, and lake deposits forming some of the block-faulted ranges, and generally tilted at an angle greater than 20 degrees. Through similar lithology and structural relationships, they are correlated with the Cedarville Series, which is best exposed in the Warner Range, where it ranges in age from late Oligocene to late Miocene. The Cedarville Series is mainly andesitic, but ranges from basalt to rhyolite. Several small gold, copper, and mercury deposits have been found in rocks associated with it.
>
> Rocks of Pliocene age include both volcanic and lake deposits. The latter include the Alturas Formation, which occupies the basin west of the Warner Range in the vicinity of Alturas, and similar rocks in the basin of lake Britton and valley of Willow Creek west of Tulelake. The lake sediments are tuffaceous siltstones and ashy sandstones-the latter commonly ranging to current-bedded, water-laid tuffs-and thick, extensive deposits of diatomite with variable ash content. The Pliocene volcanic rocks include basalt and andesite lava flows and mudflows, and cacitic to rhyolitic pyroclastic rocks. Southwest and west of Alturas, the Alturas Formation is locally associated with beds of pumiceous welded Pliocene ash-flow deposits are also present in the mountains between Canby and Adin, where they are interbedded with lava flows and mud-flow deposits, as well as stream-and lake-deposited sediments.

The older Pliocene rocks, like those of Miocene age, are found in block-faulted mountain ranges. Later volcanic rocks, also tentatively assigned to the Pliocene, are much less faulted and retain to a much greater degree their original constuctional land forms. These include a series of small sheild volcanics between Honey Lake and the Madeline Plains.

Throughout much of the Modoc Plateau region the basins between the fault-block ranges were flooded by wide-spreading, very fluid flows of basalt, erupted mostly from fissure vents, that formed flat plain surfaces rather than volcanic cones. These "plateau" basalts have generally been referred to as "Warner Basalt" but because of uncertainty of the correlation with the basalt farther northeast, the basalt in the region just north of Lassen National Park has been called the Burney Basalt. At the north edge of Lake Britton, pillow lavas at the base of Warner Basalt are intermingled with Pliocene diatomaceous lake sediments, and are almost surely of Pliocene age; but near Lassen Park the Burney Basalt overlaps folded and eroded andesites that cannot be older than latest Pliocene, and it is therefore unlikely that the basalt is older than earliest Pliostocene. In the Modoc Plateau region as a whole, the rocks called Warner Basalt probably range from late Pliocene to Pliostocene in age.

Younger than the Warner Basalt is a series of lower Pleistocene to Recent basalt flows and associated cinder cones; small shield volcanoes, many of them capped with cinder cones; and lake beds. The lakesediments resemble those of Pliocene age. The shield volcanoes are mostly basalt, but party andesite. Chemically, mineralogically, and texturally, many of these flow basalts resemble the Warner Basalt. Many of them are of pahoehoe type, like most of the Warner flows, and in places contain many lava tubes such as those of the Lava Beds National Monument and Hat Creek Valley, where the lavas are probably less than 200 years old.

Other very recent flows are of the aa or block lava type. These include the Callahan and Burnt Lava flows on the flanks of the Medicine Lake Highland, and the quartz basalt flows at Cinder Cone in the north-eastern part of Lassen National Park, which last erupted in 1851.

The fault of the Modoc region trend in a northwesterly to northerly direction. The Likely fault is believed to have had appreciable right-lateral movement, but most of the faults are normal, with primarily vertical displacement. The normal faulting reached a maximum near the end of the Miocene, but has continued into Recent time. Occasional earthquakes suggest that some of the faults, such as that along the east side of Hat Creek Valley, are still active.

Large volumes of water issue from the Warner and later basalts at several places, including Big Spring, near Old Station on Hat Creek; Rising River, farther north in the same valley; the springs at Burney Falls and along Burney Creek just above the falls; and those at the headwaters of Fall River. The latter, with a flow of about 900 million gallons daily, are among the largest springs in the United States.

Local Geology

Stratigraphy

The Kelly Hot Spring area is part of the California Dept. of Water Resources (CDWR) Alturas Ground-water Basin. As a consequence the geology of the area has been mapped in some detail. Table 1 summarizes the geologic formations of the Alturas Basin. Astrisks show those that occur in the Kelly Hot Spring area. Figure 4 is a geologic map of the area.

Rocks older than Miocene do not crop out nearby nor have they been reached by drill holes in the area. To speculate upon occurrence and character of specific formations would be fruitless. However, based upon the extent of local volcanic activity and regional tectonic features, we can expect that the older rocks have been partly to completely metamorphosed.

The overlying rocks consist of interbedded volcanic and clastic sedimentary rocks, including extensive lake deposits. Although plugs of andesite of Pliocene age occur nearby, none crop out within the Kelly Hot Spring area.

The exact relation between the Cedarville Series, (Tmc) the Turner Creek Formation (Tmtc) and the Alturas Formation (TQa) shown in table 1 is not clear.

The Cedarville Series crops out along the Warner Mountain and Hay Canyon Range. It consists of bedded tuff, tuff breccia, and a few basalt and andesite flows. The Turner Creek Formation crops out in the mountainous area west of Warm Springs Valley; it consists of mudflows and tuff with lesser amounts of basalt flows and interbedded sandstone, conglomerate, and diatomite. The Alturas Formation overlies both the Cedarville and the Turner Creek. The Turner Creek probably correlates to the upper part of the Cedarville and according to table 1 grades with the lower part of the Alturas Formation.

However, the outcrop pattern and table 1 suggest that basalts of Early Pliocene age (Tpvb) should separate the Turner Creek Formation and the Alturas Formation over at least part of the area. So for present purposes the Cedarville Series and the Turner Creek are presumed equivalent.

Table 1.--Geologic Formations in Alturas Basin (after CWRD, 1963)

			Geologic Formation	Symbol	Thickness Feet	Lithology
CENOZOIC	QUATERNARY	RECENT	Talus	Qta	0-75	Unconsolidated blocks of rocks of small areal extend.
			Muck and Peat	Qmp	0-50	Unconsolidated deposits of organic muck and fibrous peat. Found only in Jess Valley.
			Basin Deposits	Qb*	0-50	Unconsolidated, interstratified clay, silt, & fine sand.
			Intermediate Alluvium	Qal*	0-75	Unconsolidated, poorly sorted silt and sand with some lenses of gravel.
			Alluvium Fans	Qf	0-75	Unconsolidated to poorly consolidated rudely stratified sand, silt & gravel, with lenses of clay.
			Landslide	Qls	50-100	Semiconsolidated mixture of blocks of basalt in matrix of clay and sand.
		PLEISTOCENE	Pleistocene	Qpvb*	50-150	Highly jointed, flat-lying olivine basalt flows with interbedded scoriaceous zones.
			Pyroclastic Rocks	Qpvp*	?	Semiconsolidated red and black cinders.
			Near Shore Deposits	Qps*	0-200	Slightly consolidated & cemented, poorly to well stratified pebble & cobble gravel with lenses of sand & silt.
		PLIO-PLEISTOCENE	Upper Member Alturas Formation	TQa*	400	Lake deposited tuff, ashy sandstone, gravel, & diatomite. Indistinguishable from lower member.
			Plio-Pleistocene Basalt Member	TQvb*	50-250	Jointed, nearly flat-lying flows of basalt with zones of scoria.
			Warm Springs Tuff Member	TQvt*	100-400	Massive pumice lapilli tuff, jointed beds of welded tuff, minor beds of ashy sandstone.
			Lower Member Alturas Fm.	TQa*	400	Indistinguishable from upper member. May be Miocene in part.

Table 1.--Continued

Geologic Age				Geologic Formation	Symbol	Thickness Feet	Lithology
CENOZOIC	TERTIARY	PLIOCENE		Andesite	Tpva*	?	Plugs of massive and platy andesite.
				Basalt	Tpvb*	?	Jointed, dipping flows of basalt.
				Rhyolite	Tvr	?	Massive, light-colored plugs of rhyolite.
		MIOCENE	MIOCENE VOLCANIC ROCKS	Basalt	Tmvb	300	Flows of jointed vesicular basalt.
				Pyroclastic Rocks	Tmvp	1000	Bedded mudflows, tuffs, ashy sandstone, & diatomite. May be correlative to Turner Creek Formation. Upper portion may grade into lower member of Alturas Formation.
				Turner Creek Formation	Tmtc*	4000	Massive mudflows, tuffs, with beds of ashy sandstone, & diatomite. Upper portion may be correlative to lower member of Alturas Formation.
				Cedarville Series	Tmc*	7500	Massive tuff breccia, basalt & andesite.

Table 2.--Geologic Formations of the Kelly Hot Spring area.

Geologic age			Geologic Formation		Symbol	Thickness Feet	Lithology
CENOZOIC	QUATERNARY	RECENT	Alluvium		Qal	0-75	Clay, silt, sand, and gravel
		PLEISTOCENE	Gardens Basalt		Qpvb	50-100	Olivine basalt with interbedded scoriaceous zones
			Pyroclasitc		Qpvp	?	Red and black cinders
			Near Shore Deposits		Qps	0-200	Pebble and cobble gravel with lenses of sandsilt
	TERTIARY	PLIO-PLEISTOCENE	ALTURAS FORMATION	Upper Member	TQau	400	Tuff, ashy sandstone, gravel & diatomite
				Warm Spring Tuff Member	TQvt	100-400	Massive pumice lapilli tuff, welded tuff with ashy sandstone
				Lower Member	TQal	400	Tuff, ashy sandstone, gravel and diatomite
			Basalt		TQvb	?	Basalt with zones of scoria & with beds of silt, clay diatomite and tuff
		PLIOCENE	Basalt		Tpvb	?	Basalt (gray-black)
		MIOCENE	Cedarville Series		Tmc	4000 - 8000	Massive mudflows and tuff with beds of ashy sandstone & diatomite Massive tuff breccia, basalt, & andesite

The relation between Plio-Pleistocene basalt and the Alturas Formation is also not clear. CDWR (1963, p. 61, plate 7 explanation, and fig. 10) (see table 1 in this report) shows that the Plio-Pleistocene basalt occurs above the Warm Spring Tuff Member of the Alturas. Yet in the cross-sections (p. 100-101) this is not the case. On cross-section A-A' the Plio-Pleistocene basalt is shown only in fault contact with the Alturas and the Warm Springs Tuff Member is shown between the upper and lower member of the Alturas. On sections BB' and CC', the Plio-Pleistocene basalt is shown to be below the Alturas-Warm Springs Tuff -Alturas sequence. Relations on the geologic map suggest that the Plio-Pleistocene basalt generally underlies the Alturas Formation.

The major difference between the Pliocene basalt and the Plio-Pleistocene basalt seems to be that the Pliocene basalt dips; whereas the Plio-Pleistocene is flat-lying. Thus, younger rocks overly the Pliocene basalt with an angular unconformity.

The Plio-Pleistocene basalt will be considered here to underly the Alturas Formation and to be independent of it. In practice the two formations probably interfinger so that precise distinction of formation limits would be difficult.

Moreover, in drill holes distinction of the Pliocene basalt from the Plio-Pleistocene basalt may not be possible.

The Alturas Formation of Plio-Pleistocene age in here considered to consist of three members. The upper and lower members (TQal & TQau) are near identical. They are lake deposits consisting of flat laying, light colored sandstone gravel, diatomite, and tuff.

The middle member is the Warm Springs Tuff (TQvp) consists of 100 to 400 feet of gray to brown, massive pumice lapilli tuff, light colored ashy sandstone, and resistant basalt-like welded tuff.

In places the lower member seems to be missing and the middle member rests directly upon older rocks. Figure 4c shows my interpretation of the relation between the three members.

The Near Shore Deposits of a Pliestocene lake and an extensive basalt flow overlying the Alturas Formation. A cinder cone of Pleistocene age with associated local pyroclastic deposits occurs in secs. 33 & 34, T. 42 N., R. 9 E. Alluvium occurs in the drainageways.

The lithologic log of the Kelly Hot Spring Ranch #1 is far from ideal because a great deal of mixing occurred due to sloughing in an uncased hole and to lost circulation zones. Even so the basic sequence is evident. In the interval from 0-1190 feet the log shows beds of clay, siltstone, and sandstone with beds of tuff. In the interval 1190-1670 the log shows that beds of basalt occur. In the interval from 1670-3206 TD the log shows that tuff is interbedded with sandstone and clay with some volcanic breccia. This sequence equates to:

0-1190	Alturas Formation
1190-1670	Plio-Pleistocene Basalt
1670-3206	Cedarville Series

Slickensided particles indicate that faults were crossed in the intervals 2885-2900 and 3000-3015.

A drill hole can thus except to encounter (ignoring alluvium, local pyroclastics, and possible andesite plugs) the following rock sequence.

Age	Thickness	Formation and Lithology
Pleistocene	50-100	Gardens Basalt--Olivine basalt with interbedded Scoriaceous zones
	0-200	Near Shore Deposits--Coarse clastics with lenses of silt and sand
Plio-Pleistocene	to-400	Upper Member, Alturas Formation--Tuff, ashy, sandstone, gravel, and diatomite
	100-400	Warm Springs Tuff Member, Alturas Formation--Massive pumice lapilli tuff, welded tuff with ashy sandstone
	to-400	Lower Member, Alturas Fotmation--Tuff, ashy sandstone, gravel, and diatomite
	50-250	Plio-Pleistocene Basalt--Basalt with zones of scoria and with beds of silt, clay, diatomite, and tuff
Pliocene	?	Pliocene Basalt--gray black basalt
Miocene	4000-7000	Cedarville Series-- Massive mudflows and tuffs with beds of ashy sandstone and diatomite, massive tuff breccia, basalt, and andestie.

Because the Cedarville Series is so thick, only the deepest test holes are likely to penetrate it and reach older rocks.

One or more of the post-Cedarville Series Formation may be missing in a drill hole sequence because of their make of origin, unconformable relations, or because of geologic structure.

Structure

The Bouguer Gravity Map of California, Alturas Sheet (Chapman and Bishop, 1968) shows that the crust thickens from west to east across the Modoc Plateau. It also suggests that Basin and Range structural features persist beneath the Modoc Plateau. Features such as the north-south trough that includes the South Fork Pit River Valley and Goose Lake are easily equated with the structural troughs of the Basin and Range Province.

The geologic-age pattern on the geologic map of California (Alturas Sheet) suggests that the Pleistocene basalts of the Kelly Hot Spring area occur in an almost circular structural basin, a small positive gravity anomaly (5 mgals) centered over this basalt covered region is probably due to an extraordinary thickness of basalt. A somewhat large positive anomaly (15 mgals) in T. 41 N., R. 11 E. south of the structural basin probably reflects a buried horst block of the basin and range type.

In the Kelly Hot Spring area both folding and faulting are evident (fig. 6). The Likely fault is about 50 miles long and Gay (1959, p. 5) suggest that major right lateral movement has occurred. A north south fault along the east side of T. 48 N., R. 9 E. may have a mile or more of left lateral movement, according to my analyses of the Alturas Formation (fig. 4b).

Two groups of normal faults standout. One group parallels the Likely fault and trends northwest. The other group parallels the north-south trending basin and range features. These faults have little strike slip. As figure 4 shows these two groups of faults intersect in the Kelly Hot Spring area.

There is no reason to believe that the tectonic activity that created these faults has ceased.

Three gentle faulted synclines occur (fig. 4b). The axis of one passes in a northwesterly direction through the City of Alturas; the second is roughly parallel to the first and passes just east of Rattlesnake Butte; the third is also generally parallel and passes just west of the town of Canby. The synclines are separated by gentle anticlines.

HYDROGEOLOGIC FACTORS

Introduction

In circulating through a natural thermal area ground-water increases in temperature and undergoes changes in chemistry. If the non-thermal features are understood then variations caused by the natural thermal phenomena can be recognized and used to predict the location and size of a geothermal reservoir. Therefore, in this section we shall quantify the natural ground-water flow system to the limits of the available data.

Elements of Theory

Precipitation in a region may runoff on the surface, infiltrate into the ground, or evaporate back into the atmosphere. Of the portion that infiltrates some becomes soil moisture and is captured by plants which transpire it back into the atmosphere and some enters the subsurface once again. The flow may be either through the unsaturated zone or through both the saturated and the unsaturated zones. Only the water in the saturated zone (below the water table) is properly called ground-water. The area in which infiltration consistently reaches the water table is called the recharge area. The area in which ground-water emerges at the surface is called the discharge area. Under natural conditions ground-water discharges as evapotranspiration to the atmosphere or as streamflow and springflow.

Wells intercept circulating ground-water. Each volume of water discharged by a well diminishes natural discharge downstream. If wells discharge sufficiently great amounts of water, natural discharge may be stopped and streamflow, water circulating in the unsaturated zone, and precipitation falling on discharge area may be induced to move toward the discharging well. This water is called induced recharge.

In general recharge does not occur in discharge areas. However, one recharge area may support several discharge areas. Thus, we recognize local, intermediate and regional flow systems--distinguished by the relation between recharge and discharge area. In a local flow system discharge derives from local precipitation on local recharge areas. If, however, some of the recharge underflows the nearby discharge area to discharge at some more distant point, then an intermediate or regional system exists.

In the Pit River Basin recharge flowing a short distance to small tributaries such as the North Fork Pit River or Pine River (southeast of Alturas) is moving in a local flow system. However, recharge which has it's origin in the North Fork Pit River or Pine River surface drainage area may underflow these streams to discharge in the main stem of the Pit River and a small part of this may underflow the Pit River to discharge to the Sacramento River. That which discharges to the Sacramento River would be in the regional flow system.

The Ground-Water Flow Continuum

The rocks that make up the ground-water flow continuum consist of lake beds and volcanic rocks plus alluvium. The porosity and hydraulic conductivity of these rocks derives from interstitial, fracture, and tubular porosity. Although lava tubes produce locally high permeability and the interstitial porosity of the lake beds and tuffs produce extreme variations between beds locally, the "average" hydraulic conductivity is probably controlled by the fractures developed during faulting. Because faulting causes beds of different lithology to abut and the fracture porosity produced by faulting pervade the entire rock mass, the fracture porosity is effective through out the rock mass and creates a homogeneity on a regional scale that one would not expect by considering lithology only.

The fracture system does not extend into the alluvium and in all probability the average hydraulic conductivity of the alluvium is larger than that of the other rocks of the flow continuum.

The valleys of the Pit River and its larger tributaries probably occur in areas where fractures formed zones of weakness to erosion. We might expect, therefore, that the hydraulic conductivities in these valleys are somewhat larger than those near the divides.

Recharge and Discharge

In recharge areas the water table is concave downward. In discharge areas the water table is concave upward. As a crude approximation for Modoc County discharge areas include the areas underlain by alluvium by swamp or marsh, or by modern lake basins such as Goose Lake Basin. The rest of the county is recharge area. Figure 6a shows the water table and figure 6b the recharge and discharge areas in the Kelly Hot Spring area.

In Modoc County much of the ground-water discharge is via evapotranspiration during the summer months and the discharge to the atmosphere during the warm dry season is probably about 30 inches from swamp, lakes, flowing water surface, or where the water table is less than 2 feet below the surface. This is a rate of about 2 cfsm (2 cubic feet per second per square mile). This rate diminishes to zero at the recharge-discharge boundary. It also diminishes rapidly with increasing depth to the water table in the discharge area. Unfortunately the rate at which it diminishes is indeterminate with available data. The average ground-water discharge to evapotranspiration over the entire discharge is probably larger than 0.2 cfsm and is certainly smaller than 2.0 cfsm. The ground-water discharge to streams can be approximated from stream flows duration data by using an unpublished separation technique developed by Allen Gutjahr and W. K. Summers in 1971.

The value determined is expressed is cfs (cubic feet per second) and represents the total ground-water discharge that flows past a gaging station. Table 3 summarizes the estimates obtained for 12 gaging stations in the Pit River Basin (no. 1-12) and 3 gaging stations in the Goose Lake Basin (no. 13-15).

The total ground-water discharge upstream from a gaging station is the sum of the evapotranspiration and streamflow discharge plus any additional evapotranspiration caused by diversion of streamflow for irrigation. Table 4 summarizes the estimated total ground-water discharge for each gaging station. Figure 7 shows the relation of the estimated total ground-water discharge per square mile plotted against apparent recharge area. We expect the apparent recharge area to approach the actual recharge area as the apparent recharge area becomes larger. This is indeed the case except for points 2, 3, and 4 which are for stations on streams (South Fork Pit River and Pine River) that drain the highest part of the Warner Range. The high values for these stations may be due to one or more of the following: (1) the much larger than average precipitation at higher altitudes, (2) significantly greater relief, (3) substantially lower hydraulic conductivity at depth due to intrusives that cause a significantly larger proportion of the ground-water to discharge rather than underflow the local flow system.

On the average about 9 percent of the precipitation on the recharge area appears to discharge in the local or intermediate flow system. However, the Warner Mountain streams show a discharge on the order of 12 percent of the precipitation. This suggests that overall somewhat more than 12 percent of the precipitation becomes ground-water and that 9 percent discharges through the intermediate and local flow systems and 3 percent underflows. I estimate, therefore, that the average ground-water recharge in the Upper Pit River Basin is about 12 percent of the precipitation or about 0.16 cfsm. The recharge will be less than this value near the recharge-discharge boundary where it decreases to zero, and larger near the surface drainage divide where precipitation tends to be a maximum. The maximum rate is probably on the order of .32 cfsm.

Underflow is on the order of .04 cfsm. As a crude check the Pit River Basin is about 40 miles wide at Canby and if we assume that 90 percent of the underflow occurs in a slab 1000 feet thick under a gradient of 60 feet in 12 miles through rocks having an average hydraulic conductivity of 0.01 ft/day, we estimate the underflow at

$$.9 x Q = \frac{10 \text{ ft}}{\text{day}} \text{ x } \frac{60 \text{ ft}}{12 \text{ miles}} \text{ x } \frac{1000 \text{ ft x } 40 \text{ miles}}{86400 \ \frac{\text{sec}}{\text{day}}} = 23 \text{ cfs}$$

Q = 26 cfs. The recharge are is about 1100 square miles. The recharge rate to underflow is then $\frac{26}{1100}$ = .021 cfsm.

Table 3.--Summary of drainage basin data by stream gaging station

*		Location				Area (square miles)			Discharge (cfs)		
No.	Name	¼ sec	TN	RE	Alt.	Total	Rec.	Disc.	Total	SW	GW
1	North Fork Pit R. nr. Alturas	NE 8	42	13	4380	203	141	62	10.8	10.3	.5
2	South Fork Pit R. nr. Jess Valley	NE 9	39	14	5000	96	77	19	32	16	14
3	South Fork Pit R. nr. Likely	SE 11	39	13	4600	247	173	74	34.5	28	6.5
4	Pine Cr. nr. Alturas	SW 35	42	13	4700	31	26	5	14.5	9.5	5.0
5	Pit R. below Alturas	NE 13	42	11	4340	1150	805	345	95	77	18
6	Pit R. nr. Canby	SW 10	41	9	4280	1431	1001	430	90	81	9
7	Turner Cr. nr. Canby	SE 35	42	8	4650	46	37	9	1.1	.88	.22
8	Rush Cr. nr. Adin	NW 36	40	9	4400	28	26	2	5.2	4.3	.9
9	Butte Cr. nr. Adin	NE 24	38	9	4300	120	84	36	.90	.65	.25
10	Pit River nr. Lookout	NE 11	40	7	4200	1585	1110	475	96	83	13
11	Ash Cr. nr. Adin	SW 21	39	9	4250	258	180	78	31	25	6
12	Willow Cr. nr. Adin	SE 35	38	9	4500	51	49	2	5.4	2.8	2.6
13	North Fork Davis Cr. nr. Davis Cr.	SW 15	45	14	5100	5.9	4.7	1.2	3.0	2.4	.6
14	Lassen Cr. nr. Willow Ranch	SE 27	47	14	5100	26	25	1	5.4	4.8	.6
15	Willow Cr. nr. Willow Ranch	NE 26	47	14	5000	30	24	6	2.1	1.6	.5

* see figure 7 and table 4.

Table 4.--Summary of ground-water discharge above each gaging station

* No.	Obs. at gage (cfs)	Evapotranspiration (cfs)			Precipitation			
		From Irrigated Area	From Discharge Area	Total	Range (in.) From	Range (in.) To	Rate on Recharge Area (cfs)	% Discharged as Ground-water
1	.50		12	13	12	16	147	8.8
2	14		3.8	18	18	34	144	12.5
3	6.5	7.0	15	24	10	34	280	11.6
4	5.0		.90	5.9	12	34	45	13.2
5	18	22	69	110	8	34	1250	8.8
6	9.0	29	86	124	8	34	1550	8.0
7	.22		1.8	2.0	18	22	55	3.6
8	.90		.30	1.2	16	22	37	3.3
9	.25		7.2	7.5	16	22	123	6.1
10	13	31	95	150	8	34	1770	8.7
11	6.0		16	22	14	22	250	8.8
12	2.6		.30	2.9	18	22	77	3.8
13	.60		.20	.80	18	30	6.7	12.0
14	.62		.30	.92	18	32	46	2.0
15	.50		1.2	1.7	18	32	44	3.9

* see table 3 and figure 7.

This relative agreement may be fortuitous. The assumption of an average hydraulic conductivity of 10 ft/day is consistent with the value we would expect for fractured volcanic rocks and unconsolidated sands and gravels interbedded with rocks of low hydraulic conductivity. Moreover, the large yield deep (300-800 feet) irrigation wells in the Alturas region suggest that the hydraulic conductivity is larger than individual lithologies would suggest. The other assumptions will tend generally to make the underflow larger than estimated here.

In summary, then, of the precipitation that falls in the Upper Pit River Basin 12 percent becomes ground-water. Of this most 9 percent discharges through local or intermediate flow system and 3 percent becomes underflow.

The portion of the ground water that discharges through the known area of thermal anomaly shown on figure 2 derives from an area of 515 square miles north and west of the Pit River that extends to the divide. Approximately 150 square miles are the discharge area and 360 are the recharge area. Approximately 60 percent of the discharge area occurs upstream from the thermal anomaly. Thus, using figure 6, we may estimate that 40 percent of the recharge on 360 square miles (.4 x 360 x .12 = 17.2 cfs) discharges in the Kelly Hot Spring area. Underflow through the area both from the apparent recharge area and from the Warner Mountain may be substantial. If recharge from only 20 percent of the available recharge underflows the Kelly Hot Spring area, it amounts to (.2 x .04 x 1000 =) 8 cfs.

SUBSURFACE TEMPERATURES

Observed ground-water temperatures

The observed temperatures in the Kelly Hot Spring area range from 55 to 205°F (Appendix 1 and figure 8). In nonthermal areas ground-water temperatures may be estimated by the following relation.

T (°F) = Average annual air temperature + 4 + 1.8 x hundreds of feet of depth.

Using this relationship we would expect ground-water temperatures in wells to be in the range of 51 to 65°F in the area. Any temperature in excess of 75°F is surely anomalous. Ground-water temperatures larger than 75°F occur over a relatively small area (fig. 8) of less than 10 square miles.

Natural ground-water systems are in dynamic equilibrium--that is ground-water recharge equals discharge and heat flow into the flow continuum is equal to the heat flow out by conduction plus the heat carried away by the circulating ground water. At equilibrium isothermal surfaces do not vary with time.

If heat is added to a mass of water moving along a flow line in a ground-water flow system, that heat is transported in the mass. If the movement is into a region of higher temperature more heat will be added to the water; if the movement is along an isotherm the heat content will remain constant, but if the movement is into a region of decreasing temperature (at equilibrium) heat will be lost by dispersion-diffusion and by conduction at a rate which will maintain the constant position of the isotherms.

Thus, every point (or mass of water) along a flow line will have its own unique temperature. The temperature observed in discharging ground-water is then the "average" for all of the terminating flow lines. As an example consider the simple case of a spring where 90 % of the terminating flow lines derive from a local (shallow) flow system where the average temperature is 60°F and 10 % from an intermediate (deep) system, where the average temperature will be $\frac{90 \times 60^\circ + 10 \times 90^\circ}{100}$ or 63°F. The anomalous warm water is almost completely masked.

Three factors influence the observed temperature shown on figure 8. First, local shallow flow systems are contributing water of nonthermal character. Second, an intermediate flow system is contributing thermal water. Third, an influx of induced recharge due to irrigation and infiltration from the Pit River have a squelching effect on temperature locally. The temperature of discharging water in the discharge area are greater than predicted by the usual gradient relationships. I interpret the temperature anomaly of figure 8 to mean that in this area a portion of the flow of an intermediate flow system is surfacing and these flow lines pass through a region where a substantial amount of heat was added. The temperature of Kelly Hot Spring indicate that the flow distance is relatively short or the amount of heat added is so large that it does not disappear through conduction or by dispersion-diffusion and that mixing with the local system is minimal.

Temperature measured in the Kelly Hot Spring Ranch #1

The following temperatures were observed in the Kelly Hot Spring Ranch #1.

Depth (feet)	Temperature (°F)	Remarks
318	less than 200°	
1060	do	
1573	do	
1805	do	
2106	175±	
2666	185-	
2797	223	after fishing for about 24 hours
3206	220	after 6 hours
3206	230	after 12 hours

These temperatures are probably too low. During drilling fluid was lost at a depth of 1573 feet. This lost circulation problem was solved by increasing the amount of cold fluid circulated during drilling. Flow-line temperature during drilling were generally 50 to 70 less than the bottom hole temperature. In all probability had the bottom hole temperature measurements been made when the hole had returned to temperature equilibrium the observed temperature would have been much higher.

Hydrogeothermometry

The temperature at which ground-water was last at chemical equilibrium can be estimated through the use of several geochemical thermometers. For the Kelly Hot Spring area data were available for Na-K-Ca geothermometer. These estimates are given in Appendix 1 and shown in figure 8.

This thermometer has two pitfalls. If calcium precipitates the estimated temperature is too large. If mixing occurs estimates are usually too low. The temperatures estimated here show the influence of both mixing and calcium precipitation and consequently are less than ideal.

Judging from the observed temperatures the amount of intermediate flow system water that discharge is probably only a few percent of the total. However, since it carries the bulk of the dissolved solids, the temperature estimates are probably consistently low as evidenced by the difference between the observed and the estimated at Kelly Hot Spring.

Although the estimated temperatures representaverages based on concentration and are only a guide to the maximum potential temperature, they may be combined with ground-water flow system information to infer the location of the heat source. Combining the estimated temperature pattern of figure 8 with the water-table contours of figure 6a shows that a heat source north and east of Kelly Hot Spring would explain the thermal features of the area. The 300° F contour may encompass the heat source but could easily be displaced south and west. The amount and direction of this displacement is probably minor.

Heat Discharge

Heat discharges from the earth in the mass transport of water and by conduction. We can only conjecture about the amount of heat in Kelly Hot Spring area since it is dependent upon the distribution of temperature, the rate of mass transfer, and the thermal conductivity.

We may speculate about the amount of discharging heat by assuming temperature and thermal conductivity that are reasonable for the conditions that we know about or believe to exist.

Heat flow by conduction depends upon the temperature gradient and the thermal conductivity. Presumably we can estimate the heat flow by assuming some average condition operating over some average area. A conservative estimate of the average thermal conductivity of the rocks of the area would be about 1 BTU/ft^2-hour at a gradient of 1°F/ft. The average temperature gradient is more difficult. Using the Kelly Hot Spring Ranch #1, the temperature gradient appears to be about 180°F/3206 feet or .056°F/ft. If we assume arbitrarily that the estimated temperature of 380+ °F estimated from the Na-K-Ca geothermometer occurs at depths of 4000, then the temperature gradient is 330/4000 or .083°F/ft. The world wide average gradient is .018°F/ft.

The gradient used must be choosen arbitrarily. Therefore, in the interest of a conservative estimate, twice normal (.036°F/ft) is less than possible but more than expected in a nonthermal area, and is assumed to be the average within the 200° geothermometer isotherm of figure 8. The estimated heat flow is then 8 x 10^4 BTU/sec.

Ground-water discharges from the Kelly Hot Spring area at a rate of about 17.2 cfs. If only 10 percent of this water has its temperature raised a total of 300°F by circulation in the intermediate ground-water flow system. Then the heat removed by mass transfer in the water is about (300°F x 1.7 cfs x 62.4 lbs/ft^3 x 1 BTU/lb-°F =) 3.2 x 10^4 BTU/sec. If we assume the 8 cfs of underflow estimated earlier has its temperature raised 300°F then it transports about 1.8 x 10^5 BTU/sec.

The lost circulation zone in Kelly Hot Spring Ranch #1 indicates a zone of high hydraulic conductivity. Such a zone could concentrate underflow and be the conduit for a much larger portion of the underflow then is estimated here.

This estimate of 3.2 x 10^4 and 1.8 x 10^5 BTU/sec are vary conservative estimates of the heat transport in water from the postulated heat source. The estimates do not take into account conductive losses nor do they take into account the mass of water heated less than 300°F, nor does it take into account density variations with temperature or dissolved solids. Variations due to pressure have also been ignored.

The total heat discharged from the area is conservatively estimated at 3.0 x 10^5 BTU/sec. This quantity of heat is not large in terms of a producing steam well, but is certainly a clear indication of a geothermal anomaly.

GEOTHERMAL POTENTIAL

Existing geothermal fields occur in a variety of geologic settings. In general these settings have only a few features in common:

(1) Although the natural steam or hot water may discharge from rocks of any age igneous rocks, of late Tertiary or Quaternary age usually crop out nearby.
(2) Faults are common, but the relation between the occurrence of natural steam and specific faults is often vague.
(3) Commonly, but not always, thermal water discharges within a few miles.
(4) Locally heat flow may be anomalous.

The Kelly Hot Spring area merits exploration because it has these features. Volcanic rocks of Pleistocene age are common. The intersecting faults provide a potential "plumbing system" for geothermal fluids. The geohydrologic characteristics of the Upper Pit River Basin suggest that the area north and east of Kelly Hot Spring contains a significant subsurface source of geothermal fluids.

In toto the weight of evidence suggests the possibility of a geothermal field in T. 42 N., Rs. 10 and 11 E. The potential size of the field can only be estimated upon the basis of primitive assumptions, but a field on the scale of 4 to 8 square miles in T. 42 N., R. 11 E. and T. 42 N., R. 12 E. would account for the thermal features observed.

The surficial geothermal features of the Kelly Hot Spring area compare favorably with those of Surprise Valley. Surprise Valley occurs in a classic graben-horst-structure. The rocks, however, are essentially the same as those in the Kelly Hot Spring area or are older. Within Surprise Valley there exists a geochemical anomaly similar to that of the Kelly Hot Spring area.

Thermal water discharges at more places in Surprise Valley but apparently not in greater volume. The observed temperature and the geothermometer estimates are not unlike those in the Kelly Hot Spring area, as the following tabulation shows:

Location	Temperature (°F)	
	observed	Geothermometer estimate
well 46 N 16 E 31 R 1	82	320
well 44 N 15 E 24 B 1	190	261
Old Leonard Sp. 43 N 16 E 13 B 1	104	160
well 43 N 16 E 12 D 1	184	169
well Menlo Resort 39 N 17 E 7 A 1	122	130
do 39 N 17 E 7 A 2	136	124
do 39 N 17 E 6 R 1	126	124
Menlo Spring 39 N 17 E 7	134	287

The Kelly Hot Spring area (on the basis of internal evidence and by comparison with the well-studied Surprise Valley KGRA) is a viable geothermal area that should be prospected.

ENVIRONMENTAL ASPECTS

Environmental hazards should be anticipated in the Kelly Hot Spring area. Chemical analyses of the water discharging from Kelly Hot Spring show concentrations of arsenic and flouride that are above the recommended limits for public water supply and boron concentrations that would be harmful to all but the most tolerant crops if the water were used for irrigation. Since these ions occur in thermal water and are not common in nonthermal water we can expect that development of the thermal water will generate the concommitant problem of disposing of these ions. Reinjection seems a reasonable technique---especially in view of the lost circulation zone encountered in drilling the Kelly Hot Spring Ranch #1.

Hydrogen sulfide gas may be a problem. Although no chemical analysis reports the gas, the air at Kelly Hot Spring occassionally contains a slight odor of H_2S, so development of the thermal water may increase the amount of H_2S discharge.

Fortunately, the environmental problems that may come from developing a geothermal field in the area fall well within the capability of existing technology. Potential problems, such as subsidence, can only be evaluated when more data have become available.

EXPLORATION PROGRAM

Outline

To establish the presence of a geothermal field, I recommend the following exploration program.

Phase 1.---Reconnaissance exploration

a. Geohydrology and geochemistry
In this phase all wells and springs in the area T. 41-44 N., Rs. 9-13 E. should be sampled. Bicarbonate-carbonate, chloride, flouride, and silica concentrations should be measured in the field together with temperature, pH, and specific conductance. All samples should be submitted for sodium, potassium, and calcium analyses. About 20 percent of the samples should be analyzed completely including arsenic, boron, and selected trace metals. About 10 percent of the samples should be sent for isotope analyses.

This phase of exploration would confirm the present data and expand it.

b. Preliminary geophysics

In this phase ground-noise surveys, Schlumberger resistivity, and gravity survey should be made by contracting with specialists. Ground-noise should include a minimum of 99 stations in Ts. 41-44 N., Rs. 9-13 E. (a rectilinear three mile grid). A gravity survey should be made over the same area with a station density of 1 station/square mile or 576 station. This data should be tied to existing gravity data. The resistivity effort should be restricted to Ts. 42 N., Rs. 9-10 E. and should be limited to about 8 deep soundings along a profile from Canby to the Alturas landing strip.

Phase 2.--Detail exploration

This phase depends in part upon the results of Phase 1. It should include the following elements:

a. Detailed resistivity

b. From 5 to 7 test holes to obtain heat-flow data and to obtain fluid samples as a function of depth.

c. At least one slim-hole stratigraphic test to 5000 feet--not on the anomaly--should be drilled and a complete suite of logs and drill-stem tests should be obtained.

Phase 3.--Demonstration well

The location and depth of this well will depend upon the results of Phase 2. Its purpose is to confirm the presence of a geothermal reservoir. For preliminary planning purposes, I anticipate its depth will be 7000 feet.

Budget

This exploration program is designed to gather useful information at a rate that increases the cost of prospect tool with increasing confidence in the presence of a drillable anomaly. The following costs are approximate:

Phase 1.--Reconnaissance exploration

a. Geohydrology and geochemistry

Field geologist (3 months)		$ 5,000.00
Field expenses and mileage		1,500.00
Chemical analyses		10,000.00
Isotope analyses		5,000.00
Overhead, administrative, etc.		10,000.00
	Total	$ 31,500.00

b. Preliminary (Geophysics contracts)

Ground noise 100 sta. @ $200/sta.		$ 20,000.00
Gravity 600 sta. @ $20/sta.		12,000.00
Schlumberger resistivity 8 sta. @ $1000/sta.		8,000.00
Overhead, administrative, etc.		10,000.00
	Total	$ 50,000.00

Phase 2.--Detailed exploration

a. Detailed resistivity		30,000.00
b. Test holes		
To drill 5 holes @ 1000 feet each est. cost $5/foot with 100 feet of core		40,000.00
Logs, fluid samples, etc.		5,000.00
Geologist and expenses		1,500.00
Heat flow meas. and analysis		10,000.00
c. Slim-hole test stratigraphic		
5000ft @ 10/ft		50,000.00
Logs, etc.		10,000.00
Geologist, etc.		2,000.00
Heat flow		10,000.00
Overhead, administrative, etc.		20,000.00
	Total	$190,500.00

Phase 3.--Demonstration well

7000 ft @ $50/ft includes all logging, geological, testing, costs in addition to drilling charges.	$350,000.00

Summary:

Phase 1.--Preliminary exploration		$ 81,500.00
Phase 2.--Detailed exploration		190,500.00
Phase 3.--Demonstration well		350,000.00
	Total	$622,000.00

Timing

The time required to complete each phase is about as follows:

Activity		Time (months)
Phase 1.--Reconnaissance exploration		
a. Geohydrology and geochemistry		
Field work		3
Office review and evaluation		2
	Total elapsed time	5
b. Preliminary geophysics		
Ground-noise contract		1
Gravity		1
Schlumberger resistivity		1
Office review and evaluation		1
	Total elapsed time	2
Phase 2.--Detailed exploration		
a. Detailed resistivity		2
b. Heat-flow tests		3
c. Stratigraphic test		1
d. Office review and evaluation		1
	Total elapsed time	4
Phase 3.--Demonstration well		3

The total elapsed time depends upon when the individual elements begin. For example, if Phase 1a and 1b are carried on simultaneously, the elapsed time would be about 5 months; if carried on sequentially 7 months. Thus, the time to complete the program range' from a minimum of one year to a maximum of about 19 months, excluding delays caused for adminstrative, governmental, or environmental reasons.

Discussion

The exploration program as outlined serves two purposes. First, and foremost, it is aimed at defining a geothermal field. Second, it will generate much of the information required to define environmental factors so that environmental impacts may be predicted and controlled.

This program will not provide the data required to resolve all questions of environmental hazards. A program to resolve these questions should be initiated only after the geothermal potential has been demonstrated.

The reconnaissance exploration phase covers a much larger area (16 townships) than the present report. The reasons for this are:
(1) A broad base is needed to adequately define anomalies.
(2) Thermal features in Modoc County are not limited to the Kelly Hot Spring area or to Surprise Valley. To do a reconnaissance survey of the whole of Modoc County would be prohibitively expensive, but to do reconnaissance work on this somewhat larger area adds only a small increment to the cost. This choice of area is an economic compromise, between a reconnaissance study of the whole of Modoc County and the two townships of specific interest.

REFERENCES CITED

California Department of Water Resources (1963) Northeastern Counties ground water investigation: The Resource Agency of California, Bull. 98, 224 p.

Chapman, R.H. and Bishop, C.C. (1967) Bouguer Gravity Map of California--Alturas sheet: California Division of Mines and Geology, 1:250,000.

Gay, T.E., Jr. (1959) Reconnaissance geology of the northeastern portion of the Westwood sheet: California Division of Mines and Geology, unpublished, 1:62,500.

MacDonald, G.A. and Gay, T.E., Jr. (1966) Geology of the southern Cascade Range, Modoc Plateau, and Great Basin areas in Northeastern California (in Mineral Resources of California): California Division of Mines and Geology, Bull. 191, p. 43-48.

APPENDIX I ESTIMATED EQUILIBRIJM TEMPERATURE USING NA-K-CA GEOTHERMOMETER FOR KELLY HOT SPRINGS AREA.

FRANKS BROS. WELL 130'	44N13E36A1	7/29/58	60	82	32
A W CARLSBERG WELL 235'	44N13E36B1	7/29/58	62	80	31
P G SHEDD WELL 26'	44N13E25H1	7/29/58	56	51	12
GREISS WELL 330'	42N13E34K1	6/ 5/58	56	111	51
EDWIN SWANSON DOM 80' WELL	42N13E32G1	7/14/69	57	111	51
EDWIN SWANSON DOM 80' WELL	42N13E32G1	9/10/63	***	113	52
EDWIN SWANSON DOM 80' WELL	42N13E32G1	8/28/62	***	105	47
EDWIN SWANSON DOM 80' WELL	42N13E32G1	8/24/61	55	107	48
EDWIN SWANSON DOM 80' WELL	42N13E32G1	7/29/60	59	105	47
EDWIN SWANSON DOM 80' WELL	42N13E32G1	8/27/59	56	113	52
ERWIN SWANSON WELL 80'	42N13E32G1	8/27/59	56	108	49
ERWIN SWANSON WELL 80'	42N13E32G1	6/ 3/58	54	99	43
YOUNGER DOM 179' WELL	42N13E31G1	9/10/63	***	183	97
YOUNGER DOM 179' WELL	42N13E31G1	8/28/62	***	170	89
YOUNGER DOM 179' WELL	42N13E31G1	7/24/61	61	167	87
JOBE AND YOUNGER WELL	42N13E31G1	8/25/59	62	177	93
YOUNGER DOM 179' WELL	42N13E31G1	8/22/59	62	184	98
JOBE AND YOUNGER WELL	42N13E31G1	6/ 3/58	59	170	89
YOUNGER DOM 179' WELL	42N13E31G1	7/29/ 0	63	177	93
BAILEY DORRIS DOM & STOCK WELL 125'	42N13E30C1	6/ 3/58	65	132	64
ALLAN WALL WELL 300'	42N13E28K1	6/ 5/58	59	83	33
BERRY STEVENS WELL 200'	42N13E22D1	6/ 4/58	58	118	55
HANS A HEESCH DAIRY WELL 200'	42N13E17D1	6/ 3/58	57	110	50
W M RAGER DOM & STOCK WELL 800'	42N13E 6G1	6/ 4/58	64	116	54
MAYER GRAVEL CO. WELL 210'	42N13E 5M1	6/ 4/58	62	118	55
SHARKY DORRIS WELL 280'	42N12E25H1	6/ 3/58	58	136	67
SOUTHERN PACIFIC RR WELL 500'	42N12E24C1	6/ 3/58	60	138	68
M A HORNING WELL 300'	42N12E12F1	6/ 3/58	57	100	44
ALT MUN NO 6 DEPTH 444' WELL	42N12E11J1	8/ 7/67	64	110	50
ALTURAS CITY WELL	42N12E11Q1	9/10/63	***	170	89
ALTURAS CITY WELL	42N12E11Q1	8/23/61	***	166	86
CITY OF ALTURAS MUN 350'	42N12E11Q1	8/27/59	72	152	77
ALTURAS CITY WELL	42N12E11Q0	72/96/ 0	***	161	83
JAY GRIFFITH WELL 144'	42N12E10E1	6/ 4/58	56	127	61
LEONA FISHER WELL 75'	42N12E 9F1	6/ 4/58	62	139	69
JOHN CUMMINGS WELL 130'	42N12E 8E1	6/ 4/58	62	96	41
JOHN KELLY DOM & SLAUGHTER HOUSE 260'	42N12E 7M1	6/ 4/58	57	111	51
K W ADAIR WELL 330'	42N12E 2A1	6/ 4/58	66	107	48
E E EGLE WELL 280'	42N12E 1R1	6/ 4/58	59	104	46
J J HATFIELD IRR WELL 500'	42N11E35R	8/ 4/58	66	149	75
CARLTON O ROUSE WELL 34'	42N11E33E1	8/ 4/58	62	320	185

NAME	LOCATION	DATE	OBSERVED TEMP. F.	ESTIMATED TEMP. F.	ESTIMATED TEMP. C.
HARRY HUGHES WELL 86'	42N11E25P1	8/ 4/58	56	153	78
LLOYD GOINGS DOM & STK 114' WELL	42N11E24A1	9/11/63	***	113	52
LLOYD GOINGS DOM & STK 114' WELL	42N11E24A1	8/28/62	***	110	50
LLOYD GOINGS DOM & STK 114' WELL	42N11E24A1	8/24/61	61	110	50
LLOYD GOINGS DOM & STK 114' WELL	42N11E24A1	7/29/60	57	113	52
LLOYD GOINGS DOM & STOCK WELL 114'	42N11E24A1	6/ 4/58	58	100	44
WM HAGGE WELL 150'	42N11E22M1	8/ 5/58	62	321	186
FRANK MARTIN DOM 204' WELL	42N11E19E1	9/20/66	***	309	178
FRANK MARTIN DOM 204' WELL	42N11E19E1	9/11/63	***	317	183
FRANK MARTIN DOM 204' WELL	42N11E19E1	8/24/61	63	309	178
FRANK MARTIN DOM 204' WELL	42N11E19E1	7/29/60	***	298	171
FRANK MARTIN DOM 204' WELL	42N11E19E1	8/25/59	***	304	175
FRANK MARTIN WELL 204'	42N11E19E1	8/25/59	***	307	177
FRANK MARTIN WELL 204'	42N11E19E1	8/ 4/58	59	320	185
MARION FISHER IRR & STOCK WELL 20'	42N11E 9K1	8/ 4/58	90	135	66
MARION FISHER IRR & STOCK WELL 20'	42N11E 9K1	8/25/59	92	153	78
EVERETT W CALDWELL WELL 200'	42N10E31J1	8/ 5/58	57	155	79
J HARRY MICHAEL WELL	42N10E29H1	9/11/61	***	2	-19
J HARRY MICHAEL WELL	42N10E29H1	8/24/61	***	58	17
J HARRY MICHAEL WELL	42N10E29H1	7/29/60	***	57	16
J HARRY MICHAEL WELL 77'	42N10E29H1	8/25/59	***	156	80
J HARRY MICHAEL WELL	42N10E29H1	8/ 5/58	84	233	129
J HARRY MICHAEL WELL 77'	42N10E29H1	8/ 5/58	84	236	131
KELLY HOT SPRING	42N10E29	10/30/57	204	149	75
KELLY HOT SPRING	42N10E29A1	8/21/57	198	155	79
J L ENYART WELL 100'	42N10E27E1	8/ 5/58	63	332	193
NORMAN QUIGLY WELL 180'	42N10E22B1	8/ 5/58	59	79	30
PELISSA & HALE D, S, & IRR SPRING	42N10E13G1	8/ 5/58	82	242	135
FRANK BAYS DOM, STOCK & IRR WELL 160'	42N 9E36L1	8/ 5/58	55	114	53
PETER OHM WELL 280'	42N 9E35R1	8/ 5/58	60	346	202
CHARLEY GRANT WELL 140'	42N 9E26J1	8/ 5/58	56	116	54
RAY MILLER WELL 110'	42N 9E23K1	8/ 5/58	60	160	82
H BELL WELL 120'	41N13E30L1	6/ 2/58	56	108	49
C E MASSAE DOM 280'	41N13E18O1	7/24/68	59	90	37
C E MASSAE DOM 280'	41N13E18P1	9/10/63	***	97	42
C E MASSAE DOM 280'	41N13E18P1	8/28/62	***	94	40
C E MASSAE DOM 280'	41N13E18P1	8/24/61	64	85	34
C E MASSAE DOM 280'	41N13E18P1	7/29/60	67	102	45
C E MASSAE DOM 280'	41N13E18P1	8/28/59	62	91	38
MORGAN BROS WELL 280'	41N13E18P1	8/28/59	62	85	34
MORGAN BROS WELL 280'	41N13E18P1	6/ 5/58	60	91	38
HERMAN WEBER WELL 200'	41N13E 5B2	6/ 3/58	55	94	40
PACIFIC TELE & TELE DOM 160' WELL	41N12E15H1	9/12/63	***	155	79

NAME	LOCATION	DATE	OBSERVED TEMP. F.	ESTIMATED TEMP. F.	ESTIMATED TEMP. C.
PACIFIC TELE & TELE DOM 160' WELL	41N12E15H1	8/24/61	***	144	72
PACIFIC TELE & TELE DOM 160' WELL	41N12E15H1	7/29/60	74	149	75
PACIFIC TELE & TELE DOM 160' WELL	41N12E15H1	8/25/59	74	149	75
PACIFIC TEL & TEL DOM WELL 160'	41N12E15H1	6/ 3/58	64	138	68
PACIFIC TELE & TELE DOM 160' WELL	41N12E15H1	7/27/21	70	142	71
PACIFIC TEL & TEL DOM WELL 160'	41N12E15H1	8/25/59	74	141	70
JOE WISTOS DOM & STOCK 120'	41N12E10J1	11/18/55	***	118	55
B A JACKSON DOM & STOCK 85'	41N12E 2N1	6/ 3/58	57	119	56
ROBERT MACKEY WELL 85'	41N11E29H1	8/ 4/58	65	108	49
ROBERT MACKEY SPRING	41N11E29J1	8/ 4/58	57	93	39
HUGH GORDON WELL 111'	41N11E26B2	8/ 4/58	62	125	60
ROBERT MACKEY DOM & STOCK SPRING	41N11E21P1	8/ 4/58	78	133	65
HARVEY CLARK WELL 50' NO3=310PPM	41N11E 5L1	8/ 4/58	57	130	63
CAL PINES IRR. & DOM. 320'	41N11E 2J1	7/28/71	70	419	249
CAL PINES IRR. & DOM. 320'	41N11E 2J1	9/11/63	***	174	91
CAL PINES IRR. & DOM. 320'	41N11E 2J1	8/28/62	***	365	214
CAL PINES IRR. & DOM. 320'	41N11E 2J1	8/24/61	***	373	219
CAL PINES IRR. & DOM. 320'	41N11E 2J1	7/29/60	***	326	189
CAL PINES IRR. & DOM. 320'	41N11E 2J1	8/25/59	***	365	214
MAXINE EDWARD WELL 144'	41N11E 2G1	8/ 4/58	62	119	56
PATRICIA MOYER DOM & IRR WELL 320'	41N11E 2J1	8/ 4/58	64	158	81
PATRICIA MOYER DOM & IRR WELL 320'	41N11E 2J1	8/25/59	***	186	99
JACK NORTHUP WELL 153'	41N11E 1A1	8/ 5/58	64	343	200
FRANK CALDWELL WELL 320'	41N10E 2N2	8/25/59	***	174	91
FRANK CALDWELL WELL 320'	41N10E 2N2	8/ 7/58	65	247	138
LEE WRIGHT WELL 135'	41N10E 2Q1	8/ 7/58	72	144	72
DETTEFF DERNEZ DOM & IRR WELL 140'	41N 9E13E1	8/ 7/58	64	82	32
K MOHR WELL 152'	41N 9E10C2	8/ 5/58	55	97	42
WM VON BORESEL DOM & STOCK WELL 208'	41N 9E 2B1	8/ 5/58	60	153	78
CARY WILLIAMS DOM 100'	40N13E31E1	6/ 2/58	110	144	72
H MONROE DOM 80'	40N12E26A1	6/ 3/58	56	138	68
HAROLD MONROE DOM 144' WELL PT R RANCH	40N12E25J1	7/27/71	64	183	97
HAROLD MONROE DOM 144' WELL PT R RANCH	40N12E25J1	7/24/68	64	158	81
HAROLD MONROE DOM 144' WELL PT R RANCH	40N12E25J1	9/12/63	***	167	87
HAROLD MONROE DOM 144' WELL PT R RANCH	40N12E25J1	8/28/62	***	167	87
HAROLD MONROE DOM 144' WELL PT R RANCH	40N12E25J1	8/24/61	66	167	87
HAROLD MONROE DOM 144' WELL PT R RANCH	40N12E25J1	7/29/60	69	164	85
HAROLD MONROE DOM 144' WELL PT R RANCH	40N12E25J1	8/28/59	64	161	83
M H MONROE DOM 150'	40N12E25J1	6/ 3/58	58	155	79
M H MONROE DOM 150'	40N12E25J1	11/18/55	***	158	81
M H MONROE DOM 150'	40N12E25J1	8/28/59	69	155	79
NELSON MONROE ART.WELL PERF300' 800'STK	40N12E11F1	9/12/63	***	399	236
NELSON MONROE ART.WELL PERF300' 800'STK	40N12E11F1	8/24/61	71	139	69

NAME	LOCATION	DATE	OBSERVED TEMP. F.	ESTIMATED TEMP. F.	ESTIMATED TEMP. C.
NELSON MONROE ART.WELL PERF300' 800'STK	40N12E11F1	7/29/60	69	147	74
NELSON MONROE ART.WELL PERF300' 800'STK	40N12E11F1	38/25/59	***	147	74
NELSON MONROE STOCK 800'	40N12E11F1	6/ 3/58	66	142	71
NELSON MONROE STOCK 800'	40N12E11F1	11/21/55	62	136	67
NELSON MONROE STOCK 800'	40N12E11F1	8/25/59	***	136	67
R FLOURNOY DOM 108'	39N13E18A1	6/ 2/58	58	91	38
K D VAN LOAN DOM 10'	39N13E 9D1	6/ 2/58	***	102	45
S P R R DOM & IND	39N13E 8K1	6/ 2/58	59	130	63
S P R R DOM & IND	39N13E 8K1	11/18/55	***	105	47
K FLOURNOY DOM 80'	39N13E 7N1	6/ 2/58	54	69	24
DIN FLOURNEY DOM 300' WELL	39N13E 6N1	7/22/70	68	147	74
DON FLOURNEY DOM 300' WELL	39N13E 6N1	9/12/63	***	150	76
DON FLOURNEY DOM 300' WELL	39N13E 6N1	8/28/62	***	147	74
DON FLOURNEY DOM 300' WELL	39N13E 6N1	8/24/61	***	146	73
DON FLOURNEY DOM 300' WELL	39N13E 6N1	7/29/60	69	149	75
DON FLOURNEY DOM 300' WELL	39N13E 6N1	8/25/59	70	155	79
DON FLOURNOY DOM 300'	39N13E 6N1	6/ 2/58	70	146	73
DON FLOURNOY DOM 300'	39N13E 6N1	8/25/59	70	147	74
K D VAN LOAN DOM 70'	39N13E 5D2	6/ 2/58	59	144	72
B CHRISTENSE DOM 60'	39N12E 2L1	6/ 2/58	64	133	65
EDGERTON SAWMILL IND	39N 9E21Q1	9/18/57	70	114	53
M E KRESGE DOM 12' WELL	39N 9E 2P1	7/23/56	***	99	43