THE ECONOMIC POTENTIAL OF GEOTHERMAL RESOURCES IN CALIFORNIA

The State of California is naturally endowed with notable areas of potentially productive geothermal land. The major portion of this land is owned by the Federal Government and development has been retarded by the lack of regulations for leasing, exploration, and development. However, on December 24, 1970, President Nixon signed Senate Bill 368 thereby creating a law under which federal lands may be leased for the exploration and development of geothermal resources.

STATUS OF DEVELOPMENT

Meanwhile, significant geothermal development has been taking place on state and private lands. The Geysers Geothermal field in Sonoma and Lake counties has been under development for the last fifteen years. The power facilities at The Geysers field are now capable of producing 192 megawatts*, and construction and development drilling are under way to increase the capacity to above 600 mw by the end of 1975. Total potential power capacity at The Geysers is generally calculated to be in excess of 1,000 mw and may be as high as 4,800 mw.

A limited amount of exploration and development has taken place in other areas. This activity has generally been in the form of land leasing, geologic exploration, and test drilling in the Imperial Valley, Mono Lake, Long Valley, Mt. Lassen, and Surprise Valley areas.

The Imperial Valley area was actively explored in the 1950's and early 1960's. Several wells were drilled at what is now known as the Salton Sea Geothermal field. Interest in the area is very high because of its large potential for both power generation and fresh water production. Some estimates of geothermal power potential in Imperial Valley range up to 30,000 mw, approximately equal to the present total power generation capacity in California. Additionally, the potential for desalination has been estimated to be several million acre-feet of fresh water per year.

A new power-generating concept utilizing relatively low temperature geothermal waters in a closed system, rather than requiring steam, is in the development stage. This system, if developed, will be adaptable to several areas in the state that would not otherwise be considered to have economic geothermal potential.

Development of geothermal resources in California is encouraged by existing state law and by recently enacted federal legislation. The regulatory agencies of the state have ample authority, expertise, and experience to prudently control the development of geothermal resources. The state's regulations can be augmented but not preempted by local governments in planning, zoning, and regulatory ordinances that will allow the maximum development compatible with the local environment. State agencies have the available expertise to assist and advise local governments on problems that may arise.

PROBLEMS

The Division of Oil and Gas has collected published and unpublished data on geothermal exploration in California and, in conjunction with the Geothermal Resources Board, has published the testimony given at the fact-finding hearing held in

*megawatt (mw) = 1,000 kilowatts (kw)

October, 1970. In almost all of this material, there is a general feeling of optimism regarding the future of geothermal resources in California, although many problems remain. These are economic, legal, and technological. The economics of power generation at The Geysers has already been demonstrated. However, in the Imperial Valley-Salton Sea and other areas of the state, it remains to be demonstrated that large scale power generation and/or fresh water production will be economic and environmentally acceptable. Economic problems include the scarcity of venture capital; however, the enactment of the federal land-leasing law should be a stimulant to major investors in the future. Other economic problems include the questions of taxation and tax incentives and the market economics of mineral extraction. Legal problems have been partially solved by the passage of the federal geothermal land-leasing law. Other legal problems can be solved through cooperative efforts of federal, state, and local governments and private interests. Technological problems of scale, corrosion, odor, noise, waste disposal, and well and plant design will eventually be solved through the continuing efforts of the energy industry.

POWER SUPPLY AND DEMAND

The total 1970 California electric power-generating capacity, including imports, was approximately 32,000 mw. The power demand is expected to double to 60,000 mw by 1980 and is expected to significantly increase again by 1990.

Undeveloped hydroelectric generation sites are rare; fossil fuel power plants often have unacceptable air pollution problems and fossil fuel supplies are dwindling; and the public, for several reasons, has not eagerly accepted nuclear energy as a future source of power. In California, the geothermal potential is large and, if it can be economically developed, could be a significant source of low-pollution power. Quite probably, exploration in the 1970's will find additional geothermal fields. Therefore, geothermal power could become a major source of power far into the future.

CONCLUSION

More information is needed for future planning; it is necessary to determine the extent and nature of the resource. This will enable an economic analysis to be made from which priorities can be established. Cooperation must be increased between state education institutions and state and federal agencies involved in geothermal development, and all information should be available for use in long-range planning for future development. Incentives to encourage exploration and development on state lands should continue to be given by the State Lands Commission in the terms for leasing.

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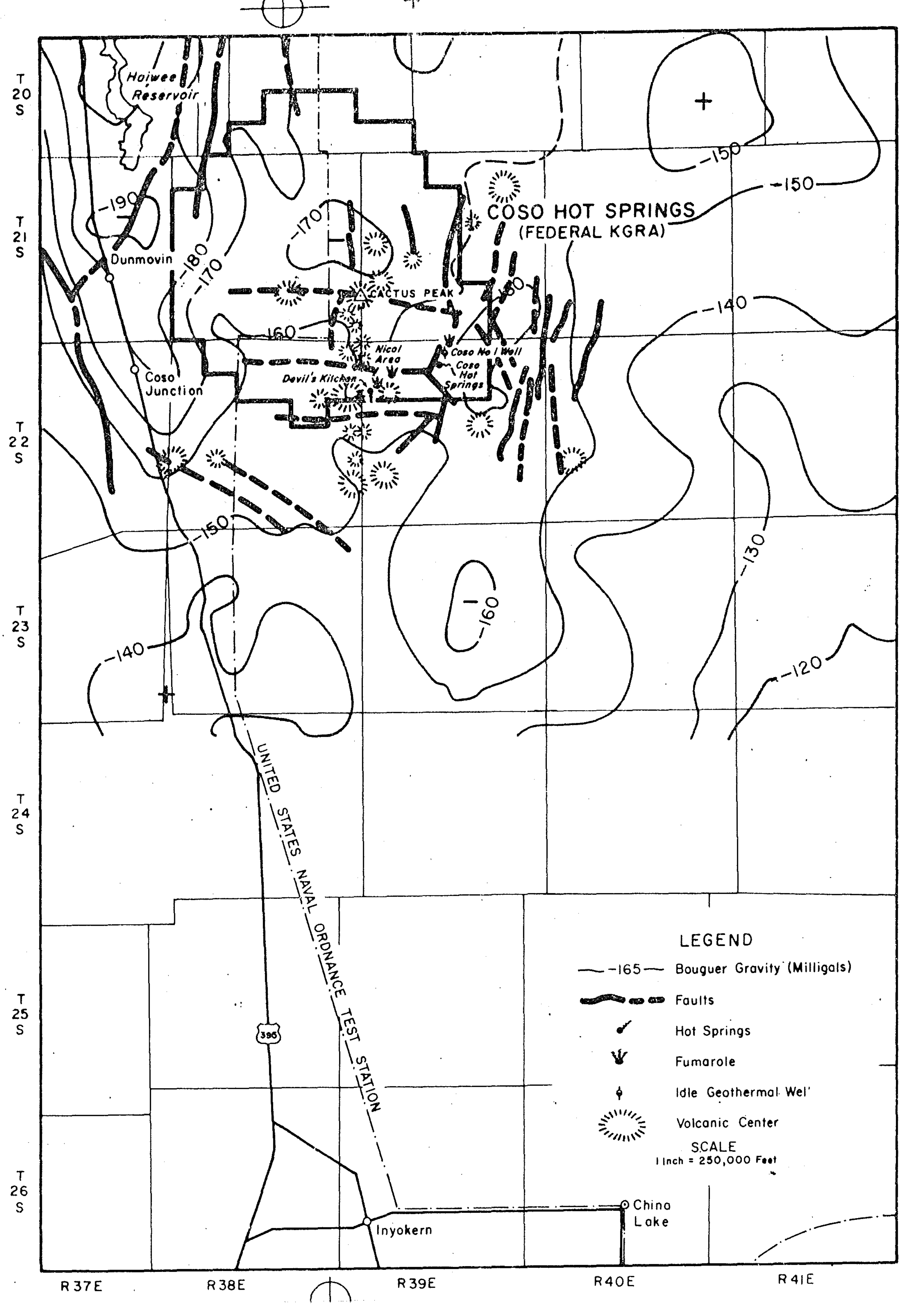


T 20 S
T 21 S
T 22 S
T 23 S
T 24 S
T 25 S
T 26 S
R 37E
R 38E
R 39E
R 40E
R 41E
Haiwee Reservoir
Dunmovin
Coso Junction
COSO HOT SPRINGS
(FEDERAL KGRA)
CACTUS PEAK
Nicol Area
Devil's Kitchen
Coso No I Well
Coso Hot Springs
UNITED STATES NAVAL ORDNANCE TEST STATION
395
Inyokern
China Lake
-190
-180
-170
-160
-150
-140
-130
-120
LEGEND
-165- Bouguer Gravity (Milligals)
Faults
Hot Springs
Fumarole
Idle Geothermal Wel'
Volcanic Center
SCALE
I Inch = 250,000 Feet

COSO HOT SPRINGS K.G.R.A., 51,760 ACRES

REGIONAL GEOLOGY: Basement in the Coso Range is composed of Mesozoic (?) granitic rocks and metasedimentary and metavolcanic pendants. Extruded through these rocks are Pliocene rhyolite tuffs and andesite breccias; Pleistocene andesite, and basalt flows and cinder cones; and Holocene (?) perlite domes, cinder cones, pumice and obsidian and basalt flows. Volcanism may have been active as recently as 5,000 to 10,000 years ago.

Interbedded with the Pliocene andesite breccias and fanglomerates are lake beds and pumicious volcaniclastic sediments known collectively as the Coso Formation. Quaternary lake beds, fan deposits, alluvium, and diatomites are interbedded with and overlie the Holocene volcanic units.

Structurally, the area appears to have been subjected to an east-west extensional couple during late Tertiary and Quaternary time, as evinced by the fault patterns of the Coso Range. There is also suggested a strike-slip component and a north-south axis of compression. Major east-west lineaments appear to be vertical shears. Several of the north-south ridges of the Coso Range have been tilted, generally to the west, and this is further evidence of east-west extension and subsequent rotational slumpage. The Coso Range has been the locus of repeated and widespread volcanism in late Cenozoic time because the tensional faults of the Range have served as abundant and long-lasting conduits for the ascension of igneous melts.

INFERRED HEAT SOURCE: Holocene volcanism

SURFACE THERMAL PHENOMENA: Areas of hydrothermal alteration are common in almost every rock type. Travertine beds, probably deposited by hot springs in Pleistocene time, are also present.

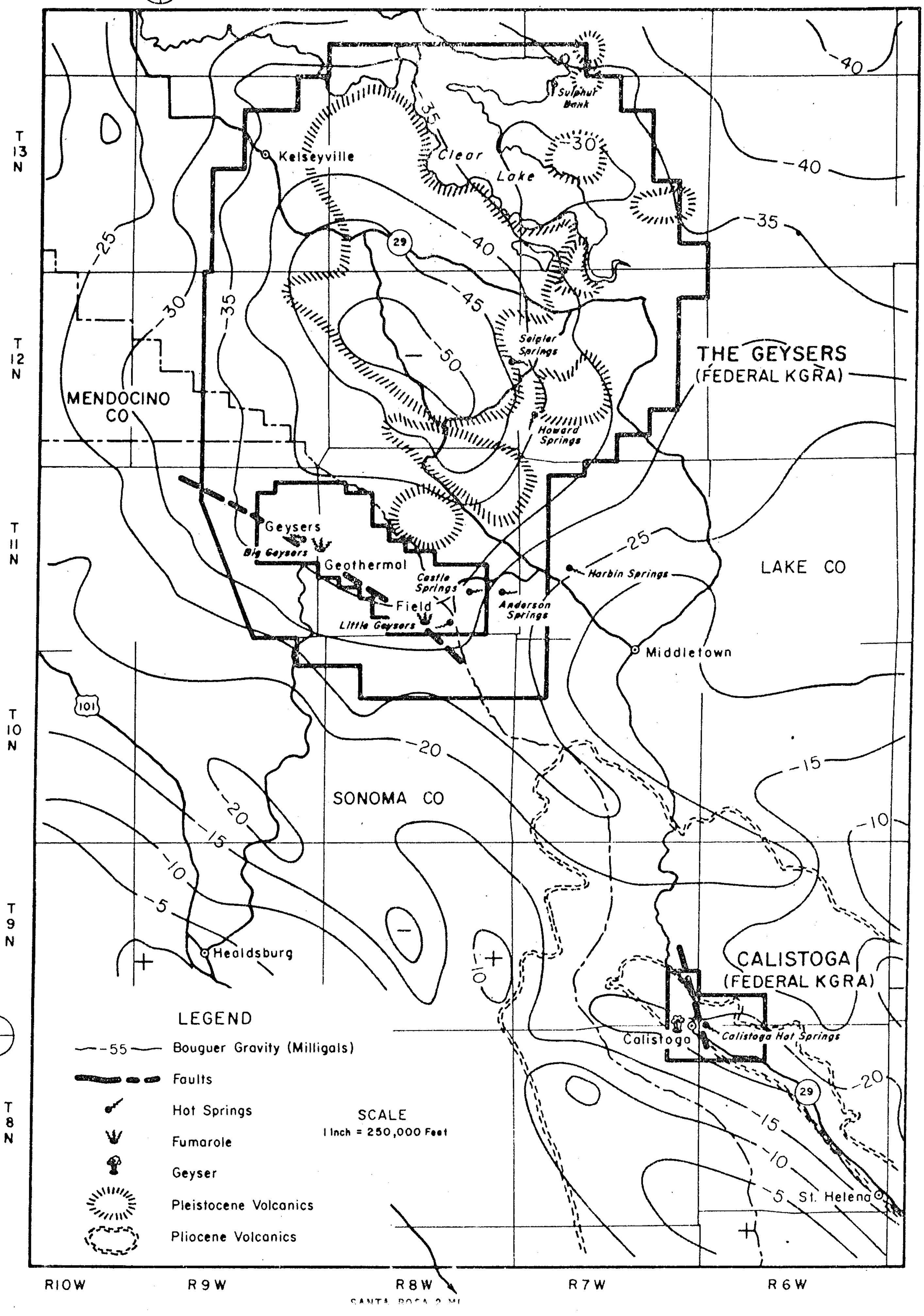
Coso Hot Springs is a 1½-mile-long zone of fumaroles, steaming ground, and hot springs issuing from hydrothermally altered alluvium which has been cut by a very young northeast-trending fault. Extending westward for over three miles is a zone of fumaroles, acid sulfate springs, low-grade mercury deposits, and patches of warm ground. This zone corresponds with one of the major east-west shears. Maximum temperatures of the fumaroles exceed 208° F.

The geothermal field is associated most closely with the perlitic domes. At the summit of one of the domes, temperatures up to 195° F have been measured at depths of less than four feet. Away from the area of perlitic volcanism, the surface expression of the heat field ends abruptly.

WELL DATA: Over 25 shallow steam wells were drilled into the steaming ground near the Coso fault during the 1920's and '30's when a resort was operated in the area.

In a geothermal test well drilled by the U. S. Navy in 1967 (Coso No. 1 - see map), maximum temperatures in excess of 285° F were encountered at a depth of about 375'.

BIBLIOGRAPHY: 22, 23, 24, 50, 57, 85, 89, and 98



T 13 N
T 12 N
T 11 N
T 10 N
T 9 N
T 8 N
R10W
R9W
R8W
R7W
R6W
Kelseyville
Clear Lake
Sulphur Bank
Seigler Springs
Howard Springs
THE GEYSERS (FEDERAL KGRA)
MENDOCINO CO
Geysers Geothermal Field
Big Geysers
Little Geysers
Castle Springs
Anderson Springs
Harbin Springs
LAKE CO
Middletown
SONOMA CO
Healdsburg
CALISTOGA (FEDERAL KGRA)
Calistoga
Calistoga Hot Springs
St. Helena
29
101
LEGEND
-55 Bouguer Gravity (Milligals)
Faults
Hot Springs
Fumarole
Geyser
Pleistocene Volcanics
Pliocene Volcanics
SCALE
1 Inch = 250,000 Feet

CALISTOGA K.G.R.A., 4,128 ACRES

GEOLOGY: The geothermal area is generally confined to the alluvial floor of the northernmost portion of the Napa Valley. The northern end of this northwest-trending valley is bordered on three sides and is underlain by the basaltic-andesitic-rhyolitic rocks of the Pliocene Sonoma volcanics. Thermal phenomena appear to be related to a north-south trending fault complex that intersects the valley from the north.

SURFACE THERMAL PHENOMENA: A group of four hot springs, a geysering well, and several other shallow wells, some of which flow hot water, lie within an area of about 1.5 square miles. The maximum temperature measured in the springs is 172° F, and water in some of the flowing wells is above boiling. The largest of the springs continues to flow at a high rate, although several wells have been drilled nearby to supply two local spas with hot water. The geyser, which erupts every 35 to 50 minutes, is located about 1.5 miles northwest of the springs.

INFERRED HEAT SOURCE: Cenozoic volcanism

WELL DATA: Over 50 shallow wells (50 to 300 feet deep) have been drilled to supply hot water for a number of uses. Numerous local residences and businesses have back-yard wells supplying hot water for spas, space heaters and swimming pools. In addition, hot water from several wells drilled in the vicinity of the geysering well is used for space heating in greenhouses.

In 1960-61 the Calistoga Power Company drilled three wells to 900, 1,100, and 2,000 feet. The maximum temperature recorded was 279° F, which was considered to be noncommercial. Drilling operations were suspended and the wells were left standing idle.

BIBLIOGRAPHY: 59, 61, 85, and 89

THE GEYSERS K.G.R.A., 10,428 ACRES

GEOLOGY: The Geysers geothermal area is in the northwest-trending Mayacmas Mountains in Sonoma, Lake, and Mendocino counties. The oldest and most widely distributed rocks exposed are the graywackes and greenstones of the Jura-Cretaceous Franciscan Formation. Within these rocks are intrusive bodies of serpentine which occur in elongated masses striking in a northwesterly direction.

Marine Cretaceous and Eocene rocks of the Martinez and Tejon Formations overlie the Franciscan and are exposed in a small area just south of the southern end of Clear Lake. These rocks are overlain by the extensive Pleistocene lake bed deposits of the Cache Formation which cover most of the northeastern portion of the K.G.R.A. Several Pleistocene and Holocene (?) volcanic flows and cones have penetrated and partially covered the older rocks. This irregular zone of volcanics ranges from basalt through pyroxene dacite to obsidian flows and cinders, and extends from the Mayacmas Mountains ridge just north of The Geysers field, northeastward across Clear Lake where it terminates in two cinder cones.

Faulting in the area generally parallels the northwest topographic trend. Faults and shear zones are very abundant in the Franciscan terrane. Cumulative displacements on some major faults are thought to be on the order of 10,000 to 20,000 feet.

SURFACE THERMAL PHENOMENA: The area is known for numerous hot springs and several fumaroles. The fumaroles are restricted to an area along the southwestern edge of The Geysers Geothermal field. Surface temperatures of the hot springs range from 122° to 158° F. It is interesting to note that this general area of thermal manifestations coincides with a belt of mercury mineralization; an area of borated, carbonated and ammoniated ground waters; and with a major gravity low of some 25 milligals closure, centered just south of Clear Lake. It has also been suggested that these are all related genetically to the Quaternary volcanism, and that perhaps a molten or near-molten body underlies portions of the region at depths of 3 or more miles.

INFERRED HEAT SOURCE: A molten or near molten magmatic body at a depth of 3 or more miles.

RESERVOIR: The reservoir in The Geysers field contains dry steam as opposed to a hot water reservoir in which a portion of the fluid produced is flashed to steam. The Geysers field, Larderello, Italy, and Matsukawa, Japan, are the only dry-steam fields presently producing electrical power. For this use, dry steam reservoirs are considered optimum. Unfortunately, it has been predicted that less than ten percent of the geothermal fields to be found in the world will be of this type.

Two distinct reservoirs exist at The Geysers: a shallow reservoir up to 1,500 feet in depth and a deeper one below 1,500 feet. Studies indicate that the shallow pool, which supplies the fumarolic vents, is a small near-surface reservoir supplied by steam leaking from the deeper reservoir. About one-fourth of the wells now producing in the field are completed in this zone. Production from this shallow zone is declining, indicating that the reservoir is depleting. The deeper reservoir has great promise in that its known area is greater than ten square miles and that deeper wells have shown no significant changes in productive capacity over the past few years.

WELL DATA: Over 110 wells have been drilled within The Geysers K.G.R.A. and more than 100 of these are within The Geysers Geothermal field area. Production per well ranges from much less than 100,000 lbs./hr. in the shallow pool to over 350,000 lbs./hr. in the deeper reservoir. Following is a table showing the status of the 110 wells drilled within the K.G.R.A.:

COMPLETED OR CAPABLE OF PRODUCTION	SUSPENDED	INJECTION	ABANDONED	TOTAL
86	9	3	12	110

POWER PLANT DATA:

PLANT NO.	UNIT	CAPACITY (KW)	ON PRODUCTION	STEAM REQUIRED - LBS./HR.
1	1	12,500	1960	250,000
	2	14,000	1963	252,000
2	3	28,000	1967	560,000
	4	28,000	1968	560,000
3	5	55,000	1971	1,100,000
	6	55,000	1971	1,100,000
4	7	55,000	(1972)*	1,100,000
	8	55,000	(1972)*	1,100,000

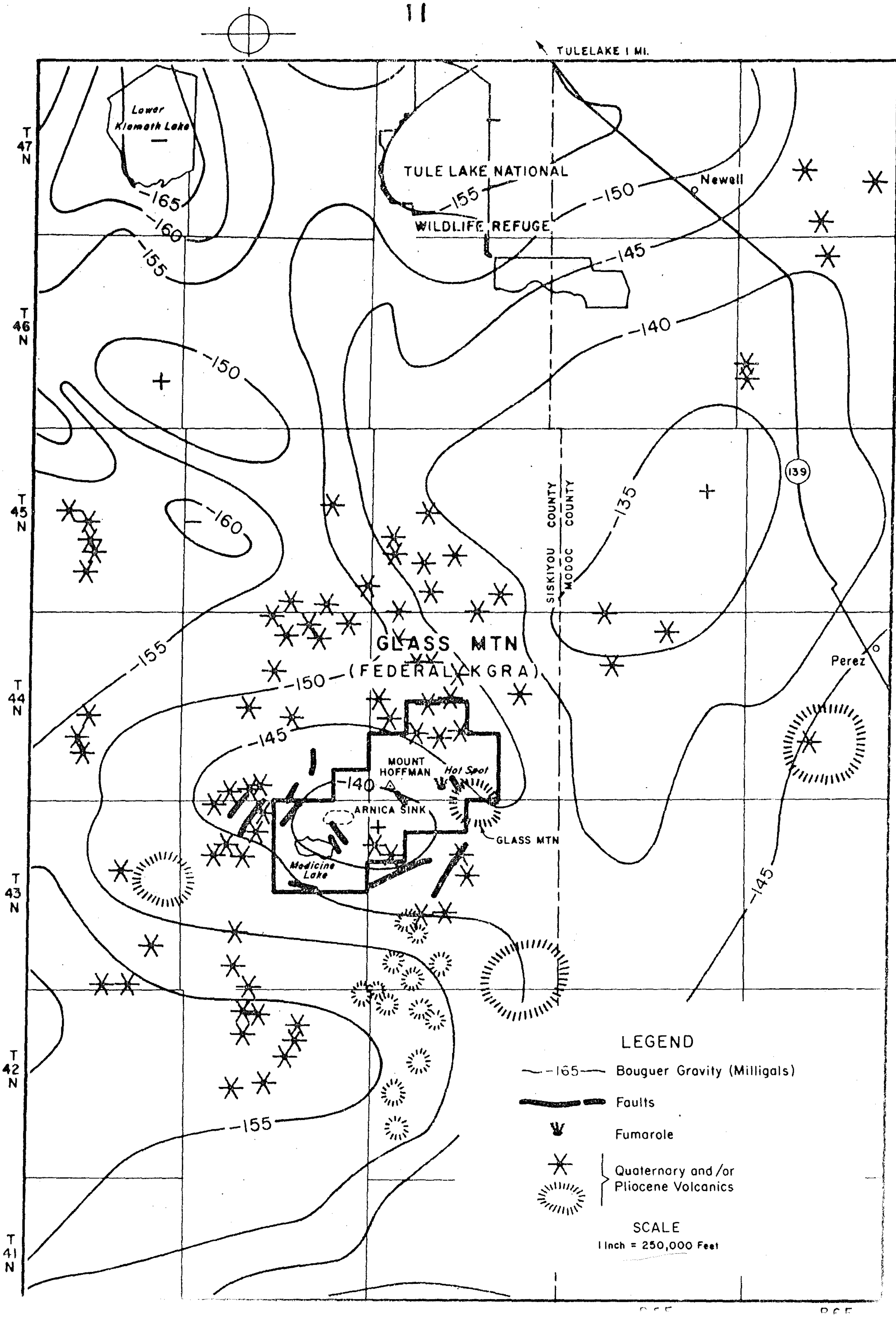
*Tentative date of completion

STEAM ANALYSIS: The principal chemical difference of geothermal steam compared with steam from a conventional boiler is the quantity of non-condensable gases. At The Geysers, non-condensable gases amount to one to two percent, by weight, for new wells. This percentage tends to decline as the wells are produced and stablizes at about 0.4 to 0.5 percent.

A test of the steam to Unit 3 in 1967 showed the following breakdown, by weight percentage, of the non-condensable gases:

CO_2	82.5
CH_4	6.6
H_2	1.4
N_2 + A	1.2
H_2S	4.5
NH_3	3.8

BIBLIOGRAPHY: 1, 5, 6, 12, 32, 33, 34, 36, 37, 45, 53, 59, 61, 66, 71, 85, 88, 89, 91, 92, and 93


TULELAKE 1 MI.
Lower Klamath Lake
TULE LAKE NATIONAL WILDLIFE REFUGE
Newell
-165
-160
-155
-150
-145
-140
-135
139
SISKIYOU COUNTY
MODOC COUNTY
GLASS MTN (FEDERAL KGRA)
Perez
MOUNT HOFFMAN
Hot Spot
ARNICA SINK
GLASS MTN
Medicine Lake
T 47 N
T 46 N
T 45 N
T 44 N
T 43 N
T 42 N
T 41 N
LEGEND
-165 Bouguer Gravity (Milligals)
Faults
Fumarole
Quaternary and/or Pliocene Volcanics
SCALE
1 Inch = 250,000 Feet

GLASS MOUNTAIN K.G.R.A., 15,371 ACRES

GEOLOGY: The Glass Mountain K.G.R.A. is centered on a concealed Miocene caldera. This ancient depression is almost totally filled by lavas from several rim volcanos, two of which are Glass Mountain and Mt. Hoffman. The present basin, which contains Medicine Lake and Arnica Sink, is three miles long and two miles wide. It is much smaller than the original caldera which was six miles long, four miles wide and 500 feet deep. Rhyolitic obsidian flows represent the most recent eruptions in the area, probably less than 1,100 years old. Faulting in the area appears to be limited to short breaks of small displacement which developed in conjunction with the volcanic activity.

SURFACE THERMAL PHENOMENA:

1. Vapor vents (no springs) at "Hot Spot," Section 33, T. 44 N., R. 4 E. In 1954, temperatures of 191° F, 160° F and 183° F were measured in three of the vents.

2. Thermal spring activity has been reported in Arnica Sink. No data available.

INFERRED HEAT SOURCE: Holocene volcanism

WELL DATA: None

REFERENCES: 2, 3, 25, 39, 85, and 89

IMPERIAL VALLEY GEOTHERMAL AREA

REGIONAL GEOLOGY: The Imperial Valley, essentially a flat, featureless, alluvium-filled, northwest-trending basin, lies within the Salton Trough geomorphic province which includes all of the Imperial and Coachella Valleys. Three gently elevated areas, underlain by deformed Tertiary marine and nonmarine sediments, are present near the western and southern margins. These include the San Felipe Hills, the Superstition Hills and the Yuha Buttes. Mesozoic granitic rock is exposed at Superstition Mountain, and five small volcanic domes of Holocene rhyolite are present at the south end of the Salton Sea.

The trough is filled with predominantly nonmarine Tertiary and Quaternary sandstones and shales, largely deposited by the ancestral Colorado River as it formed its delta. Thickness of the sediments ranges from about 5,000 feet on the north, near Desert Hot Springs, to 20,000 feet at the south near Mexicali. Basement rocks on the floor of the trough, assuming a history of sea floor spreading, probably consist largely of basalt.

Three major fault systems, all with northwesterly trends, are present in the area. They include, from northeast to southwest, the San Andreas, the San Jacinto and the Elsinore faults. Most of the numerous faults in the three systems exhibit right lateral as well as vertical movement, with the northeast block structurally higher than the southwest block.

The structural history of the area has largely been interpreted from studies made during the past decade. A wealth of new geological and geophysical evidence indicates that the Gulf of California and its northwesterly extension, the Salton Trough, are products of sea floor spreading; that the East Pacific Rise, which extends directly to the mouth of the Gulf, is a spreading center; and that segments of this spreading center extend up the Gulf and are offset en echelon by a series of northwest-trending transform faults, the most northerly being the San Andreas.

This has resulted in the Baja California peninsula being rafted away from mainland Mexico in a northwesterly direction, and has probably also resulted in a lengthwise shortening of the peninsula due to strike-slip movement along the faults. The Salton Trough and Gulf of California are tensional features with attendent ductile thinning and break-up of the crust near spreading centers. The thick sequence of sediments that covers the valley floors acts as an insulating blanket that only partially masks the high temperature anomalies associated with the spreading center

High heat derived from these spreading centers, apparently actively causing metamorphism of the sedimentary cover, is believed to be the source-heat for the several areas of high temperature gradients located on either side of the Mexican border.

SURFACE THERMAL PHENOMENA: Surface manifestations within the Salton Sea Geothermal field include a zone of mud pots and mud volcanos discharging hot water, mud, steam and carbon dioxide. Except for the thermal manifestations in the Salton Sea Geothermal field, the only indication of heat flow in the area covered by the map are the measured temperatures in shallow wells (see Imperial Valley map).

WELL DATA: In the 1930's, a commercial carbon dioxide field was developed near the southeast shore of Salton Sea, at depths between 200 and 700 feet. Production of carbon dioxide gas continued until 1954, when a continuing rise in the level of Salton Sea caused the abandonment of the field.

Between 1957 and 1965, 13 wells were drilled in what is now the Salton Sea Geothermal field. At present, eight wells are capable of production, two wells are suspended, one is an injection well and two have been abandoned. The average total mass flow per well was over 400,000 lbs./hr. Assuring that 20 percent of the mass was flashed to steam, the average steam production per well would be 80,000 lb./hr. The enthalpy of the brine is about 450 BTU's/lb. and brine temperatures ranged from 500 to 700° F.

The Salton Sea bed has been a closed evaporite sink throughout most of the Holocene epoch. This may help explain why the reservoir fluid contains an abnormal amount of dissolved solids, in some cases reading 26 percent. This high mineral content presents both scaling and extreme corrosion problems. A table showing analyses from three wells at the Salton Sea Geothermal field and one from the Cerro Prieto Geothermal field in Mexico can be found in reference No. 58.

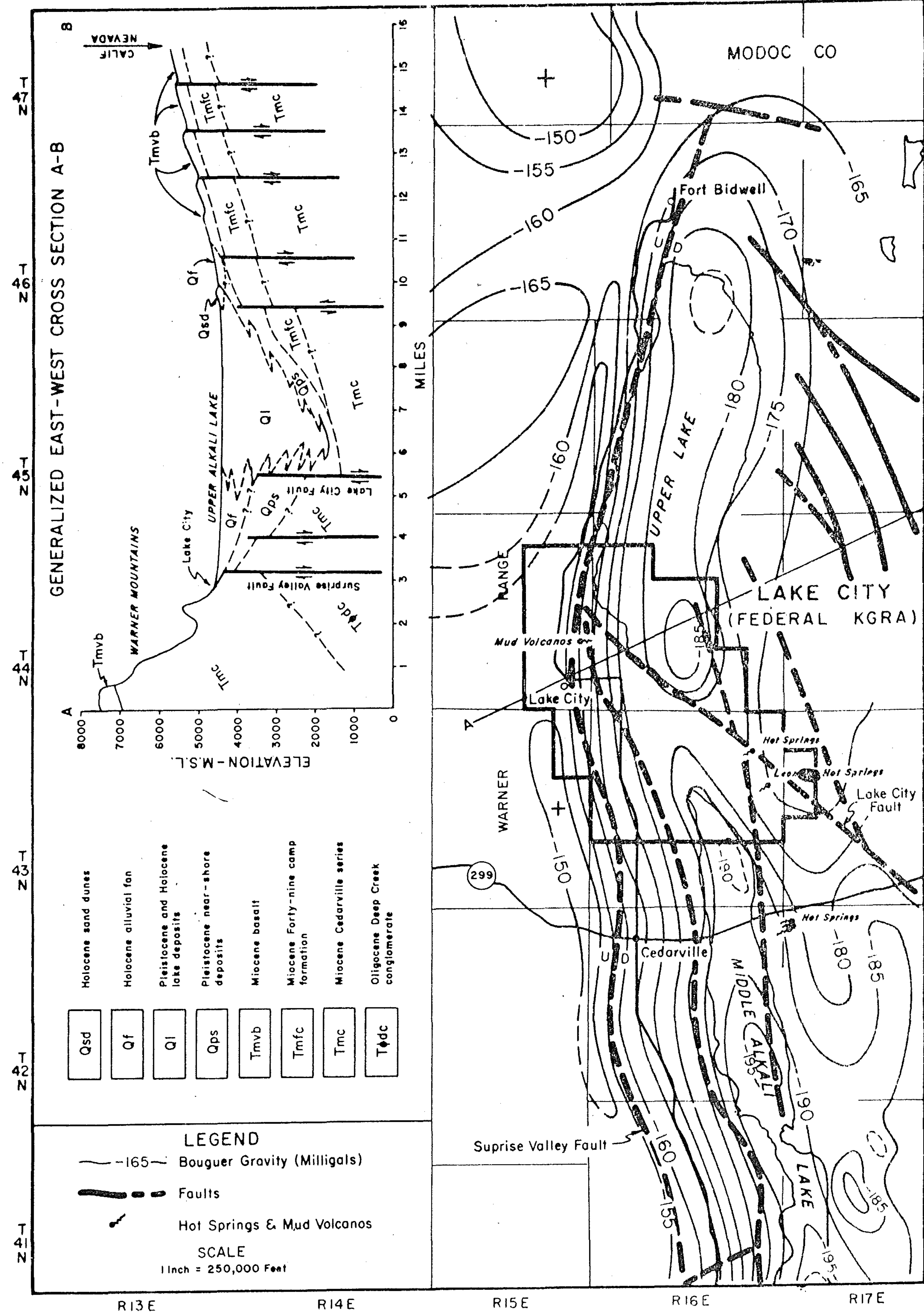
In 1965, the Morton Salt Company et al. constructed a pilot mineral recovery and power generation facility within the field area. The plant was primarily designed to recover potash; however, a drastic drop in the price of this mineral caused the suspension of the project. A similar project by Union Oil Company was also suspended for the same reason.

More than a dozen deep test wildcat oil wells have been drilled in the area between the Salton Sea and the Mexican border (see chart). Although all of these wells were non-productive of petroleum and subsequently abandoned, tests performed on them indicate that the salt contents of the reservoir fluids south of the Salton Sea brine pool are similar to that of the Cerro Prieto field and sea water. This is significant in that any development south of the Salton Sea field would not have to contend with the highly corrosive type brines found in that field.

BIBLIOGRAPHY: 7, 10, 17, 19, 31, 35, 41, 46, 47, 49, 54, 55, 56, 58, 68, 72, 77, 78, 79, 83, 85, 89, 90, and 96

ABANDONED WILDCAT OIL WELLS, IMPERIAL VALLEY

MAP NO.	OPERATOR	WELL NO.	SEC. T. R. S.B.B.& M.	TOTAL DEPTH (FEET)
1.	Anthony Rivers Dev. Co.	1	34 10S 13E	553
2.	E. J. Piatt	1	24 10S 13E	
3.	Sardi Oil Co.	"Sardi" 1	24 12S 13E	5,617
4.	Amerada Hess Corp.	"Veysey" 1	9 13S 14E	8,350
5.	Texaco Inc.	"Brawley Unit Stipek" 1	4 14S 12E	8,647
6.	Standard Oil Co. of Calif.	"Wilson (et al)" 1	20 14S 15E	13,443
7.	104 Oil & Drilling Co.	1	11 14S 16E	1,911
8.	" " " " "	2	11 14S 16E	2,300
9.	" " " " "	3	11 14S 16E	989
10.	Texaco Inc.	"F. D. Browne" 1	6 16S 12E	7,807
11.	American Petrofina Expl. Co.	"USA" 27-1	27 15S 17E	10,624
12.	Amerada Hess Corp.	"Timken" 1	28 16S 14E	7,325
13.	Texaco Inc.	"Grupe Engebretsen" 1	8 16S 16E	12,313
14.	H. W. Schafer	"Barbara" 1	16 16S 17E	8,017
15.	Texaco	"Jacobs (Nct-1)" 1	18 17S 14E	7,505
GEOTHERMAL WELLS				
A	Van Huisen & Griffin	"Grace" 1	19 12S 13E	1,200
B	Magma Energy, Inc.	"Dearborn" 1	30 12S 13E	(Drilling 1972)


GENERALIZED EAST-WEST CROSS SECTION A-B
WARNER MOUNTAINS
UPPER ALKALI LAKE
Lake City
Surprise Valley Fault
Lake City Fault
CALIF NEVADA
ELEVATION - M.S.L.
MILES
Holocene sand dunes
Holocene alluvial fan
Pleistocene and Holocene lake deposits
Pleistocene near-shore deposits
Miocene basalt
Miocene Forty-nine camp formation
Miocene Cedarville series
Oligocene Deep Creek conglomerate
Qsd
Qf
Ql
Qps
Tmvb
Tmfc
Tmc
Tφdc
LEGEND
-165- Bouguer Gravity (Milligals)
Faults
Hot Springs & Mud Volcanos
SCALE
1 Inch = 250,000 Feet
MODOC CO
Fort Bidwell
UPPER LAKE
LAKE CITY
(FEDERAL KGRA)
Mud Volcanos
Lake City
Hot Springs
Leonard Hot Springs
Lake City Fault
WARNER RANGE
299
Cedarville
MIDDLE ALKALI LAKE
Suprise Valley Fault
T 47 N
T 46 N
T 45 N
T 44 N
T 43 N
T 42 N
T 41 N
R13E
R14E
R15E
R16E
R17E

LAKE CITY K.G.R.A., 37,160 ACRES

REGIONAL GEOLOGY: Surprise Valley is an elongated, north-south trending, faulted depression (graben), bound by tilted mountain ranges. A thick section of Tertiary and Quaternary sedimentary rocks overlie a basement complex of unknown nature and age. Interspersed within the sedimentary section are andesitic and basaltic rocks. The Warner Range, to the west, consists of Miocene and possibly Pliocene volcanic and volcaniclastic rocks.

The most prominent and important structural feature is the Surprise Valley fault which parallels the west side of the valley as it strikes southward from Fort Bidwell to beyond the area covered by the map. The rugged scarp along the eastern face of the Warner Mountains is the result of over 5,000 feet of displacement on this fault.

Geophysical surveys indicate that the subsurface has been broken into many tilted fault blocks and that the depth of basin fill ranges from a few hundred feet to over 5,000 feet (see generalized cross section). Some of the faults have created fractured, permeable zones which apparently act as conduits for the upward migration of hot water and steam. Several hot springs and a mud volcano complex are associated with these subsurface structural features.

INFERRED HEAT SOURCE: Unknown

SURFACE THERMAL PHENOMENA (Hot springs are listed below):

NAME	LOCATION	TEMP.(^{o}F)	FLOW (GPM)	ASSOCIATED ROCKS
Unnamed	2 mi N Lake City	120-207	100	Alluvium
(Several springs at site of spectacular mud eruption in 1951, see Ref. No. 95)				
Leonard Springs	7 mi NE Cedarville	104	50	Alluvium, faulted volcanics
Unnamed	5 mi NE Cedarville	122; 130	500	" " "
Cedar Plunge	5 mi E Cedarville	165; 183; 202	115	" " "
Benmac Hot Springs	5 mi E Cedarville	204; 206	200	" " "

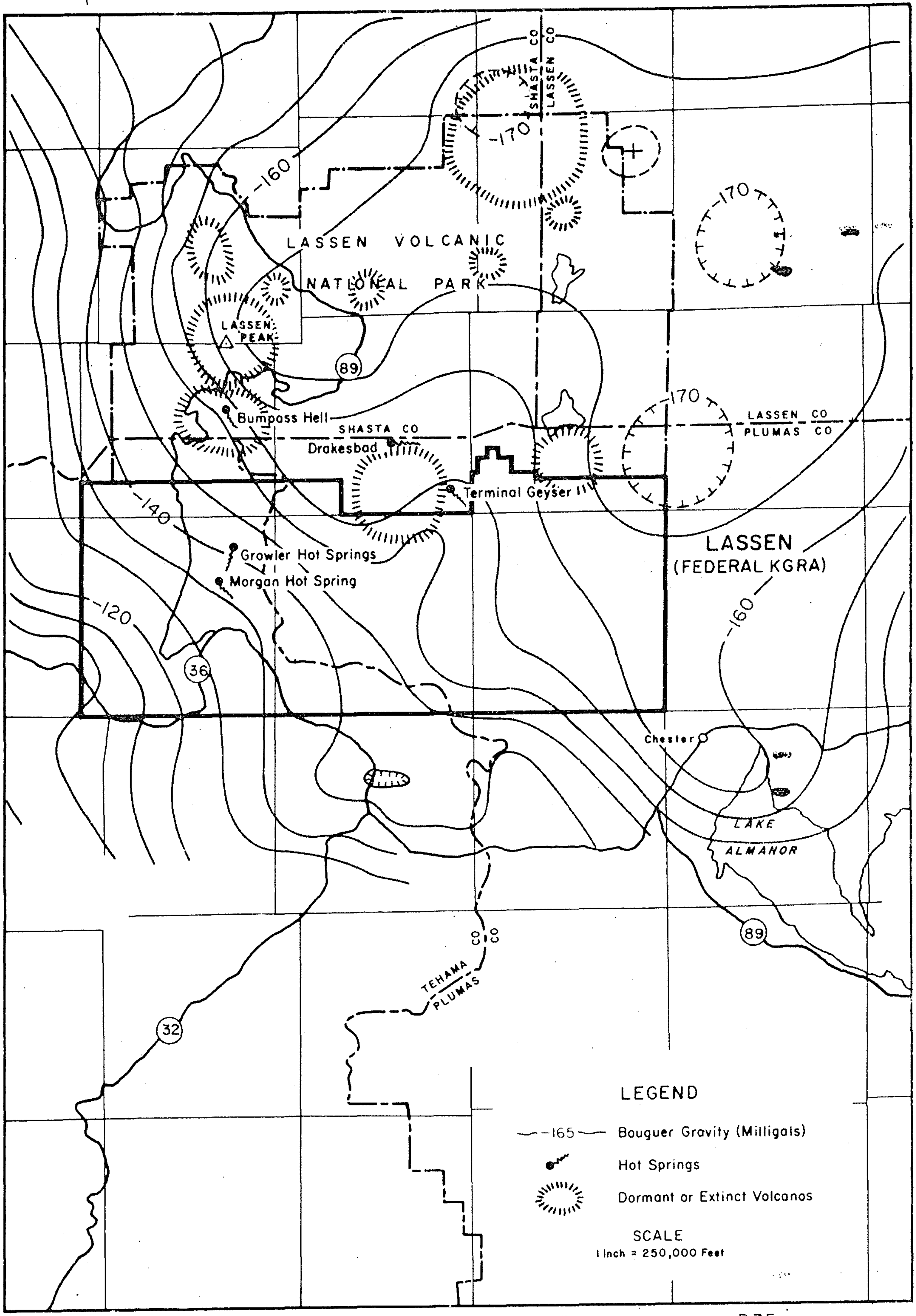
WATER QUALITY: Thermal artesian wells and hot springs yield waters high in electrical conductivity, sulfate, boron, fluoride and sodium; some also contain excessive arsenic.

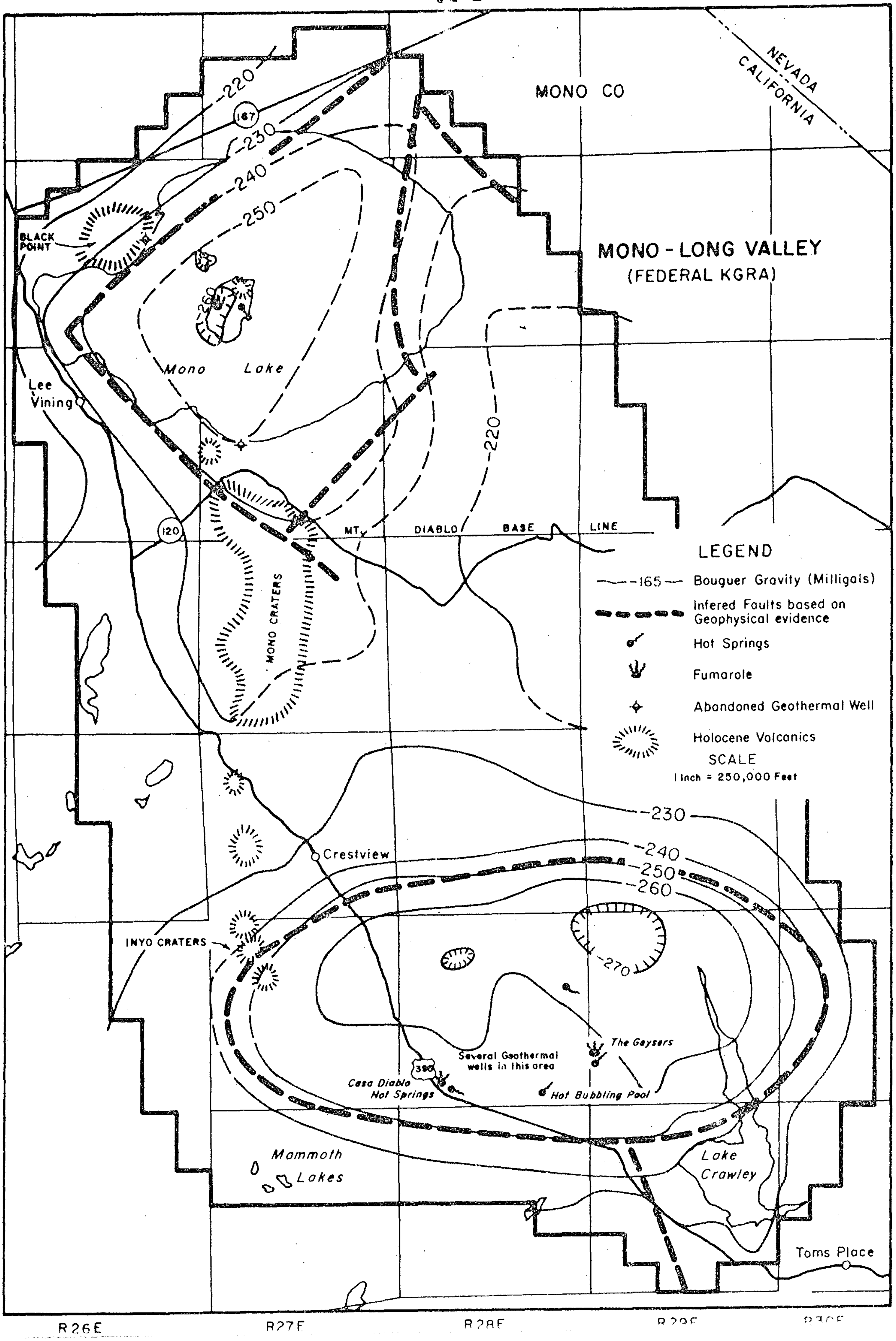
WELL DATA

LAKE CITY AREA: Magma Power Company (and associates) drilled four wells between 1959-1962 in Sections 23 and 24, T. 44 N., R. 15 E., M.D.B.& M. The greatest depth reached was 2,150 feet and the highest temperature recorded was 320° F.

CEDARVILLE AREA: Magma Power Company (and associates) drilled one well in 1962 in Section 6, T. 42 N., R. 17 E., M.D.B.& M. to a total depth of 734 feet. The maximum temperature measured was 129° F.

BIBLIOGRAPHY: 8, 65, 85, 89, and 95


T 32 N
T 31 N
T 30 N
T 29 N
T 28 N
T 27 N
T 26 N
R3E
R4E
R5E
R6E
R7E
SHASTA CO
LASSEN CO
-170
-160
LASSEN VOLCANIC
NATIONAL PARK
LASSEN PEAK
89
Bumpass Hell
SHASTA CO
Drakesbad
-170
LASSEN CO
PLUMAS CO
Terminal Geyser
-140
Growler Hot Springs
Morgan Hot Spring
-120
36
LASSEN
(FEDERAL KGRA)
-160
Chester
LAKE
ALMANOR
89
89
TEHAMA
PLUMAS
32
LEGEND
-165 Bouguer Gravity (Milligals)
Hot Springs
Dormant or Extinct Volcanos
SCALE
1 Inch = 250,000 Feet


MONO - LONG VALLEY
(FEDERAL KGRA)
MONO CO
NEVADA
CALIFORNIA
BLACK POINT
Mono Lake
Lee Vining
MONO CRATERS
MT. DIABLO BASE LINE
Crestview
INYO CRATERS
The Geysers
Several Geothermal wells in this area
Casa Diablo Hot Springs
Hot Bubbling Pool
Mammoth Lakes
Lake Crawley
Toms Place
LEGEND
165 Bouguer Gravity (Milligals)
Infered Faults based on Geophysical evidence
Hot Springs
Fumarole
Abandoned Geothermal Well
Holocene Volcanics
SCALE
1 inch = 250,000 Feet
220
230
240
250
260
270
167
120
395
T3N
T2N
T1N
T1S
T2S
T3S
T4S
R26E
R27E
R28E

LASSEN K.G.R.A., 78,642 ACRES

GEOLOGIC HISTORY: Throughout the Mesozoic Era, the Lassen region passed through several sedimentary cycles with intermittent volcanic disturbances. Mountain building began in the latter part of this era and has continued on to the present.

Low mountains, mostly of volcanic origin, became very numerous in the first half of the Cenozoic; and from this time on, mountain building activity increased. Late in the Cenozoic, tremendous volumes of basaltic lava were ejected from large fissures, forming the Modoc Plateau.

About 12 million years ago, the lavas changed in character from basaltic to rhyolitic; they became less fluid and their vents were at numerous separate sites rather than along extensive connecting fissures. The silicic eruptions have continued into recent historic time, producing separate volcanic peaks of which Mt. Shasta and Mt. Lassen are examples. The last eruption in the area occurred when Mt. Lassen burst into activity in 1914. For a year, explosions occurred at irregular intervals and then activity declined, ending in the summer of 1917. Since then Mt. Lassen has been quiescent.

INFERRED HEAT SOURCE: Holocene volcanism

SURFACE THERMAL PHENOMENA: (Some are outside of K.G.R.A.)

Bumpass Hell: Extensive fumaroles, boiling springs and mudpots. Flow averages 100 GPM; water is moderately to strongly acid; and the sulfate to chloride ratio approaches infinity. Fumarole temperatures are as high as 240° F.

Drakesbad: Four main springs at temperatures of 110° F to 145° F. Water analyses show high sulfate, no chloride, and moderate silica.

Terminal Geyser: (Not a true geyser - lacks periodicity) Six springs in the group, with temperatures measured as high as 203° F. Discharge reaches 8-10 GPM.

Morgan Hot Springs and Growler Hot Spring: Contains one of the few, true geysers in North America, which flows amidst a group of some 25 hot springs. Total discharge exceeds 75 GPM at temperatures of approximately 204° F.

WELL DATA: In 1962, Geysers Steam Co. drilled an exploratory well near Terminal Geyser in Section 36, T. 30 N., R. 5 E., M.D.B.& M. Total depth reached was 1,270' and maximum temperature recorded was 264° F.

BIBLIOGRAPHY: 4, 45, 60, 85, and 89

MONO-LONG VALLEY K.G.R.A., 460,256 ACRES

MONO BASIN

REGIONAL GEOLOGY: Mono Basin is a northeast-trending rectangular depression at the base of the steep east-facing Sierra Nevada escarpment and is flanked on the other three sides by Cenozoic volcanic rocks. The probable maximum depth to basement, in the western portion, is about 6,000 to 7,000 feet.

The Mono Craters, which extend in a broad arc nearly due south from the south shore of Mono Lake, range from 30,000 to as little as 1,300 years of age, whereas the Inyo Craters, 8 miles farther to the south, are estimated to be only 650 years old in part.

SURFACE THERMAL PHENOMENA:

a. Boiling ($200^{\circ} \pm$ F) hot springs and steam vents on Paoha Island in Mono Lake.
b. Numerous thermal springs, up to 150° F.
c. Groundwater temperatures 30°-40° F above mean ambient temperature.

WELL DATA:

OPERATOR		SEC. T. R.	DEPTH TO BASEMENT	BOTTOM HOLE TEMP.	T.D.	ABAND. DATE
Great Western Oil and Development Co. (Drilled in 1908)	Unnamed, Paoha Island, Mono Lake	32 2N 27E	Not Reached	Flowed water at 122° F	1998'	
Geothermal Resources International, Inc.	"State PRC 4397.1" 1	17 1N 27E	3870'	131° F	4110'	9/71
Getty Oil Co.	"State PRC 4572.1" 23-1	23 2N 26E	1740'	135° F	2437'	12/71

LONG VALLEY

REGIONAL GEOLOGY: Sheridan (1971) has grouped the Quaternary volcanism of the area into three stages. The first stage was the development of a basalt to andesitic-basalt lava plateau 3.2 to 2.7 million years ago.

The second stage involves the caldera cycle that corresponds closely with the patterns of resurgent cauldrons outlined by Smith and Bailey (1968). The caldera eruption of Bishop Tuff (700,000± years ago) brought about the collapse of what is now Long Valley, an area approximately 10 miles wide by 20 miles long. The eruption was followed by the intrusion of rhyolite to andesite domes in the resurgent cauldron core, and the filling of the northern and southern moats by basalts. This was followed by hydrothermal activity that persists to the present.

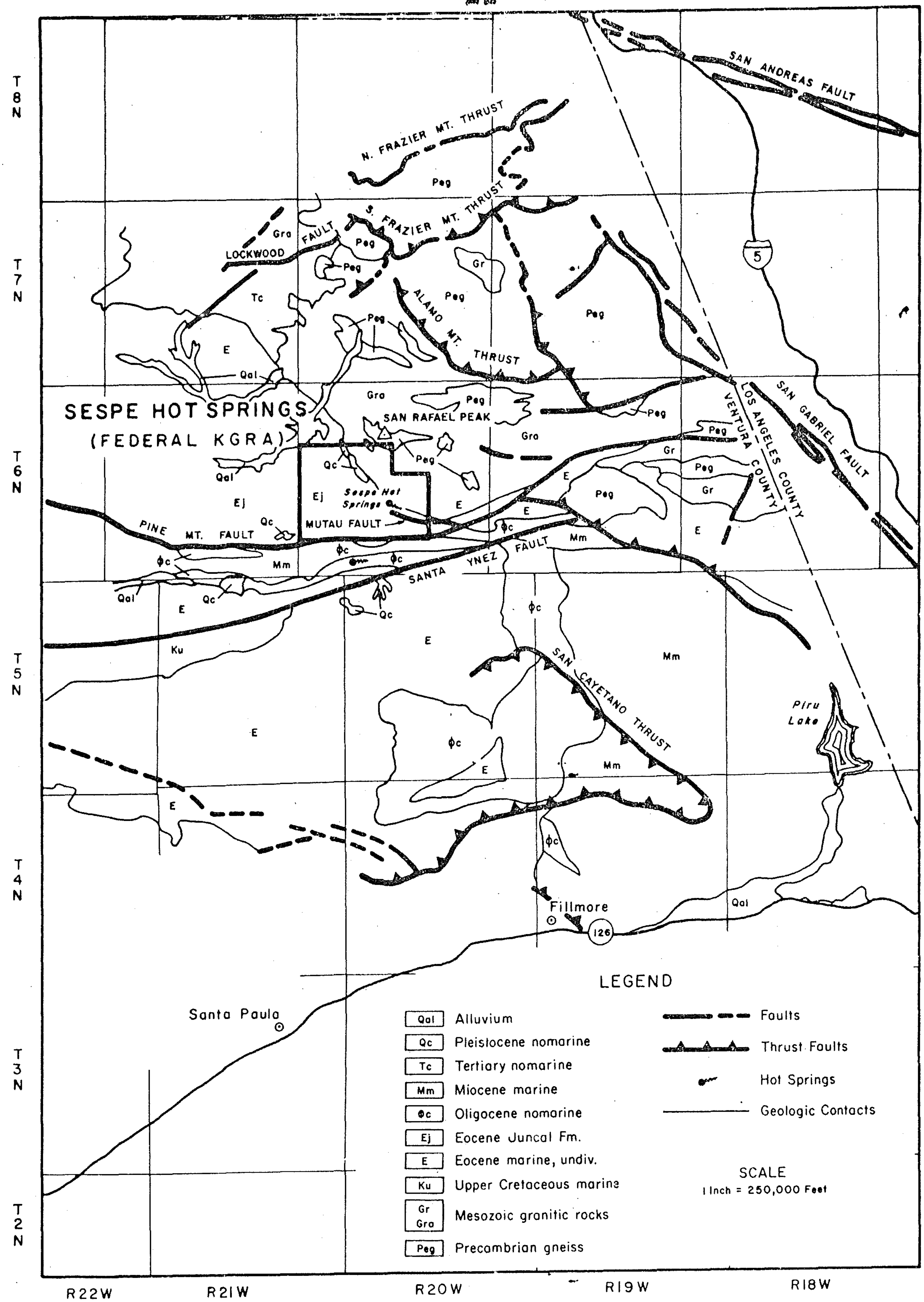
The third stage is represented by the Inyo Crater-Mono Crater belt, and may or may not be related to the caldera cycle.

SELECTED SURFACE THERMAL PHENOMENA: (Ref. No.)

Name	Springs	Fumaroles	Temp.($^{\circ}$F)	Flow (GPM)	Location
Casa Diablo Hot Springs	X	X	115-194	35	Sec. 32, T. 3S R. 28E
Hot Bubbling Pool	X		180	Intermittent	Sec. 35, T. 3S R. 28E
The Geyser	X	X	120-202	500	Sec. 30, T. 3S R. 29E
Unnamed Hot Spring	X		170	5	Sec. 13, T. 3S R. 28E

WELL DATA: Exploratory drilling began in 1959 at Casa Diablo Hot Springs and continued until the end of 1962, by which time some 20 exploratory steam wells had been reportedly drilled by the Magma Power Company and its affiliates. In addition, one well (Chance No. 1) was drilled at the Hot Bubbling pool. Depths range from 400' to 1100', maximum temperature recorded was about 350° F, and the maximum discharge per well was about 500 gallons per minute. Average concentrations of selected constituents in produced water were: arsenic 1.7 ppm, fluoride 13.6 ppm, boron 14.3 ppm and total dissolved solids 1530 ppm.

BIBLIOGRAPHY: 9, 15, 40, 42, 51, 52, 63, 73, 74, 75, 80, 82, 84, 85, and 89


SESPE HOT SPRINGS
(FEDERAL KGRA)
SAN ANDREAS FAULT
N. FRAZIER MT. THRUST
S. FRAZIER MT. THRUST
LOCKWOOD FAULT
ALAMO MT. THRUST
SAN GABRIEL FAULT
LOS ANGELES COUNTY
VENTURA COUNTY
SAN RAFAEL PEAK
Sespe Hot Springs
MUTAU FAULT
PINE MT. FAULT
SANTA YNEZ FAULT
SAN CAYETANO THRUST
Piru Lake
Fillmore
Santa Paula
5
126
Peg
Gra
Gr
Tc
E
Ej
Qal
Qc
Mm
ϕc
Ku
T8N
T7N
T6N
T5N
T4N
T3N
T2N
R22W
R21W
R20W
R19W
R18W
LEGEND
Qal Alluvium
Qc Pleistocene nomarine
Tc Tertiary nomarine
Mm Miocene marine
ϕc Oligocene nomarine
Ej Eocene Juncal Fm.
E Eocene marine, undiv.
Ku Upper Cretaceous marine
Gr Gra Mesozoic granitic rocks
Peg Precambrian gneiss
Faults
Thrust Faults
Hot Springs
Geologic Contacts
SCALE
1 Inch = 250,000 Feet

SESPE HOT SPRINGS K.G.R.A., 7,034 ACRES

GEOLOGY: Rocks in the area of the Sespe K.G.R.A. range in age from Pre-Cambrian to Holocene. In general, marine and nonmarine Cenozoic and marine Cretaceous rocks lie on a Pre-Cambrian gneiss and Mesozoic granitic basement. Important structural features are two, well-defined, east-west trending faults, and several thrust sheets.

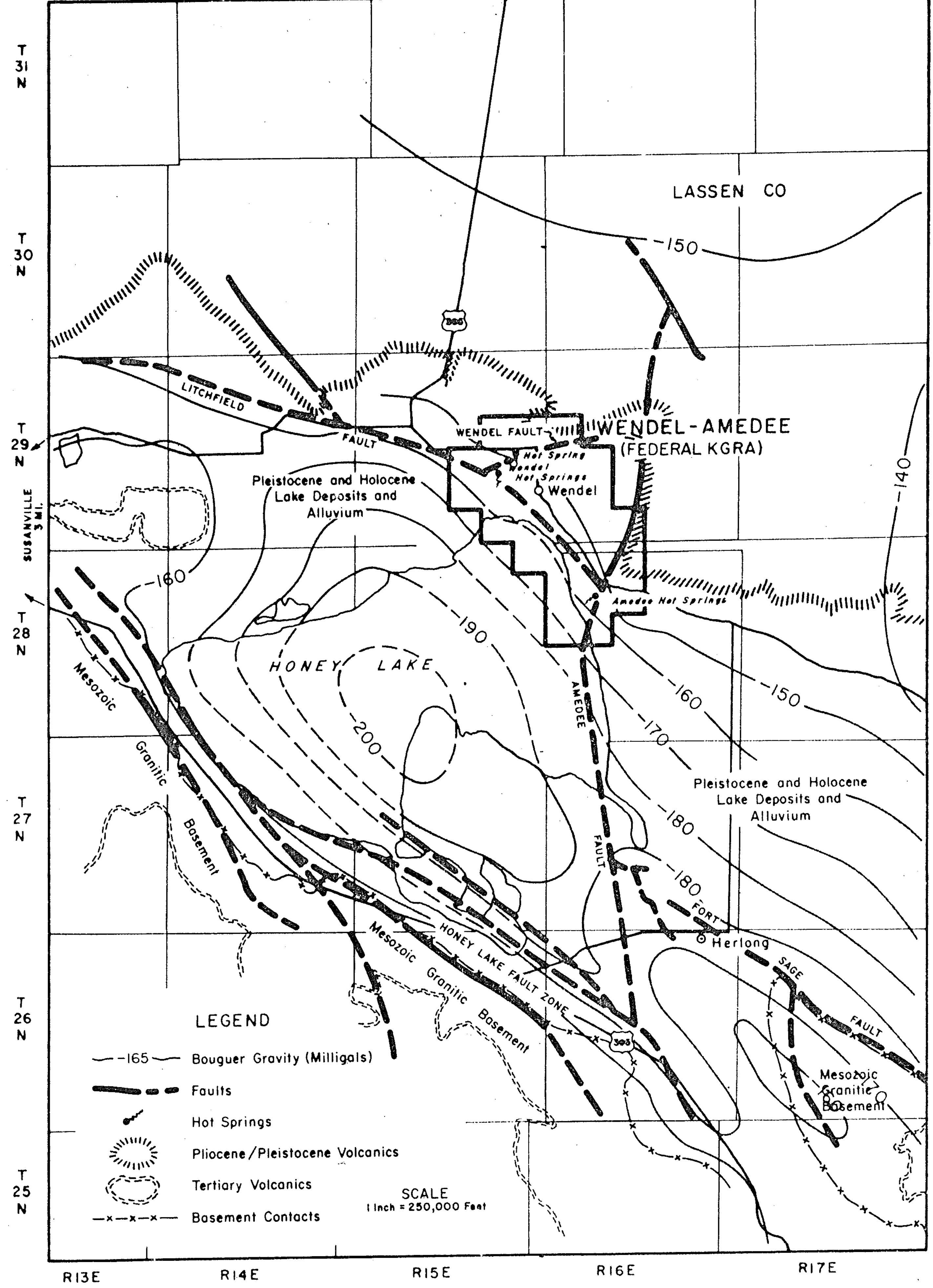
The hot springs occur along a contact between sediments of the Eocene Juncal Formation and Mesozoic granitic basement rocks. In addition to the contact, the springs are also related to the Mutau fault which is a northwest-trending branch of one of the major structural features, the Pine Mountain fault.

SURFACE THERMAL PHENOMENA: Sespe Hot Springs - SE ¼ Sec. 21, T. 6 N., R. 20 W., S.B.B.& M. Four springs, total 125 GPM, temp. 97° - 191° F.

INFERRED HEAT SOURCE: Unknown

WELL DATA: None

BIBLIOGRAPHY: 26, 69, and 89


LASSEN CO
WENDEL-AMEDEE
(FEDERAL KGRA)
WENDEL FAULT
Hot Spring
Wendel Hot Springs
Wendel
Amedee Hot Springs
LITCHFIELD
FAULT
Pleistocene and Holocene Lake Deposits and Alluvium
HONEY LAKE
AMEDEE
FAULT
FORT
SAGE
FAULT
Herlong
HONEY LAKE FAULT ZONE
Mesozoic Granitic Basement
Pleistocene and Holocene Lake Deposits and Alluvium
SUSANVILLE 3 MI.
150
140
160
190
200
170
180
T 31 N
T 30 N
T 29 N
T 28 N
T 27 N
T 26 N
T 25 N
R13E
R14E
R15E
R16E
R17E
395
LEGEND
165 Bouguer Gravity (Milligals)
Faults
Hot Springs
Pliocene/Pleistocene Volcanics
Tertiary Volcanics
Basement Contacts
SCALE
1 Inch = 250,000 Feet

WENDEL-AMEDEE K.G.R.A., 17,292 ACRES

REGIONAL GEOLOGY: Honey Lake Valley, a closed basin, contains one of the few remnants of Pleistocene Lake Lahontan. The valley is bound on the south and west by Mesozoic granitic rocks of the northern Sierra Nevada and on the north and northeast by Pliocene and Pleistocene pyroclastics and basalts. Geophysical evidence indicates that there are approximately 5,000 feet of Pliocene lake deposits in the deepest part of the basin. The Honey Lake fault zone, a series of parallel faults with a total vertical displacement of more than 8,000 feet, is responsible for the steep escarpment that bounds the entire southwestern side of the valley. The northeastern edge of the valley is bound by the Litchfield, Amedee, and Fort Sage faults. A much smaller fault, the Wendel, forms the north side of a faulted triangle roughly centered on the geothermal area.

The faults in the geothermal area probably act as conduits for the upward percolation of mineralized thermal waters. This water feeds Amedee and Wendel Hot Springs which are located along the faults bearing the same names. The springs produce water containing relatively high concentrations of boron, fluoride, nitrate and total dissolved solids.

SURFACE THERMAL PHENOMENA

WENDEL HOT SPRINGS: A group of springs, aligned roughly northeast-southwest, with temperatures from 108° to 206° F, apparently related to the Wendel and Litchfield faults.

AMEDEE HOT SPRINGS: A group of springs, aligned roughly north-south, with temperatures at or near boiling (206° F at this elevation), apparently related to the Amedee and Litchfield faults. Total flow has been estimated as 40,000 gallons per hour.

INFERRED HEAT SOURCE: Pliocene - Pleistocene volcanism

WELL DATA:

WENDEL HOT SPRINGS AREA

In 1962, Magma Power Company (and assocs.) drilled one well in Sec. 23, T. 29 N., R. 15 E., M.D.B.& M., to a total depth of 630 feet. The maximum temperature measured was 147° F.

AMEDEE HOT SPRINGS AREA

In 1962, the Magma Power Company (and assocs.) drilled three wells in Sections 5 and 8 of T. 28 N., R. 16 E., M.D.B.& M. The greatest depth reached was 1,116 feet and the highest temperature recorded was 225° F.

BIBLIOGRAPHY: 8, 48, 85, and 89

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