CDC-80-1

GEOPHYSICAL SURVEY, PASO ROBLES GEOTHERMAL AREA, CALIFORNIA

PART OF THE RESOURCE ASSESSMENT OF LOW- AND

MODERATE-TEMPERATURE GEOTHERMAL RESOURCE AREAS

IN CALIFORNIA

Part of the Second Year Report, 1979-80 of the
U.S. Department of Energy-California State-Coupled Program

for

Reservoir Assessment and Confirmation

By

RODGER H. CHAPMAN[1]
GORDON W. CHASE[1]
LES G. YOUNGS[1]

November 10, 1980

This work was performed under Grant No. DE-FG03-79ET37035
for the U.S. Department of Energy, Division of Geothermal Energy,
by the California Department of Conservation,
Division of Mines and Geology

[1] Geophysicist, California Division of Mines and Geology

DISCLAIMER

1979-80 GEOPHYSICAL SURVEY, PASO ROBLES GEOTHERMAL AREA, CALIFORNIA

PREFACE

This report presents the details of new geophysical work for the Paso Robles geothermal area, California performed under terms of the second year contract, 1979-80 between the U.S. Department of Energy (DOE) and the California Division of Mines and Geology (CDMG). The report contains two sections. The first section is to provide background for the reader and consists of a reprint from CDMG's first year report (1979-80) to DOE. It describes only the Paso Robles studies performed by CDMG in its first year effort. The second section provides new information developed by CDMG in its 1979-80 studies concerning the geophysical survey of the Paso Robles geothermal area.

Included in the first section is some general background information concerning the geology and geothermal occurrences in the Southern Coast Ranges, as well as the more detailed information dealing with the Paso Robles area proper. The second section is concerned only with discussion and interpretation of results for two geophysical methods that have so far been used by CDMG in the area: the ground magnetic and gravity surveys. The CDMG studies of the Paso Robles area are not yet complete and additional studies using newly acquired resistivity equipment are planned for the near future, as are more complete surveys of existing wells and new studies of the geothermal aquifers present in the area. A final report to DOE on the Paso Robles area is planned following completion of those studies.

TABLE OF CONTENTS

List of Plates

LIST OF FIGURES

LIST OF TABLES

PART I

1978-79 GEOTHERMAL STUDY

PASO ROBLES GEOTHERMAL AREA

THE PASO ROBLES GEOTHERMAL AREA OF THE SOUTHERN COAST RANGES OF CALIFORNIA

Low-and moderate-temperature geothermal resources are present in several places in the southern Coast Ranges of California. All are marked by thermal springs and/or thermal water wells and may be sufficient local sources of heat energy for the future. At present, the Paso Robles area appears to be the most significant of these sources.

GEOGRAPHY

The southern Coast Ranges of California form a system of parallel ridges and valleys that extends from Monterey Bay southeastward to Santa Barbara County, a distance of about 200 km. The ranges are bound on the west by the Pacific Ocean and on the east by the San Joaquin Valley. Summit elevations reach 600 m to 1200 m, while valley floors range from near sea level at Monterey Bay to about 450 m at the southern end of the range. There is little or no coastal plain along this section of the coast, and sea cliffs are formed where the ranges intersect the coast. In addition, the ridges and valleys along the coast provide good exposures of the structure and allow development of prominent headlands and inlets (Oakeshott, 1960). Several elevated wave-cut terraces, mostly Pleistocene in age, are also present along the coast.

The predominant topographic feature of the region is the Salinas Valley, which extends nearly the length of the Coast Ranges and separates the Santa Lucia Range on the west from the Gabilan Range on the east. The drainage pattern generally follows the northwest-trending direction of the ranges, but many small streams flow at sharp angles to this trend. The Salinas River is the dominant drainage channel, carrying run-off to Monterey Bay.

CLIMATE

The climate of the region is mediterranean, characterized by warm, dry summers and cool, wet winters. In general, the northern portion of the province has more contrast between winter and summer than the southern region, and the entire coast is subject to frequent fog. Snow is uncommon at the lower elevations, but rainfall is common and of varying amounts, depending on location and elevation. Precipitation ranges from 5 inches per year at the margin of the San Joaquin Valley to over 50 inches locally in the Santa Lucia Range south of Monterey.

REGIONAL GEOLOGY

The geology of the southern Coast Ranges is dominated by two types of basement,a northwest-trending granitic-metamorphic complex, termed the Salinian Block, and the Franciscan Complex, which consists of Jurassic-Cretaceous sedimentary, metamorphic, and volcanic rocks. The Salinian Block is bounded on the northeast and southwest by the Franciscan Complex, as shown in Figures 23 and 24. A third important group of rocks, the Great Valley Sequence, composed predominantly of Cretaceous marine sedimentary rocks, is associated with both complexes discussed above.

The age of the metamorphic rocks in the Salinian Block is unknown, but poorly preserved fossils suggest a Paleozoic age (Page, 1966). The granitic rocks, on the other hand, have been dated as Late Cretaceous and are not only younger than the metamorphic rocks, but are also younger than some Franciscan rocks. The granitic rocks occur as plutons in the Salinian Block and are exposed in the Santa Lucia, La Panza, and Gabilan Ranges.

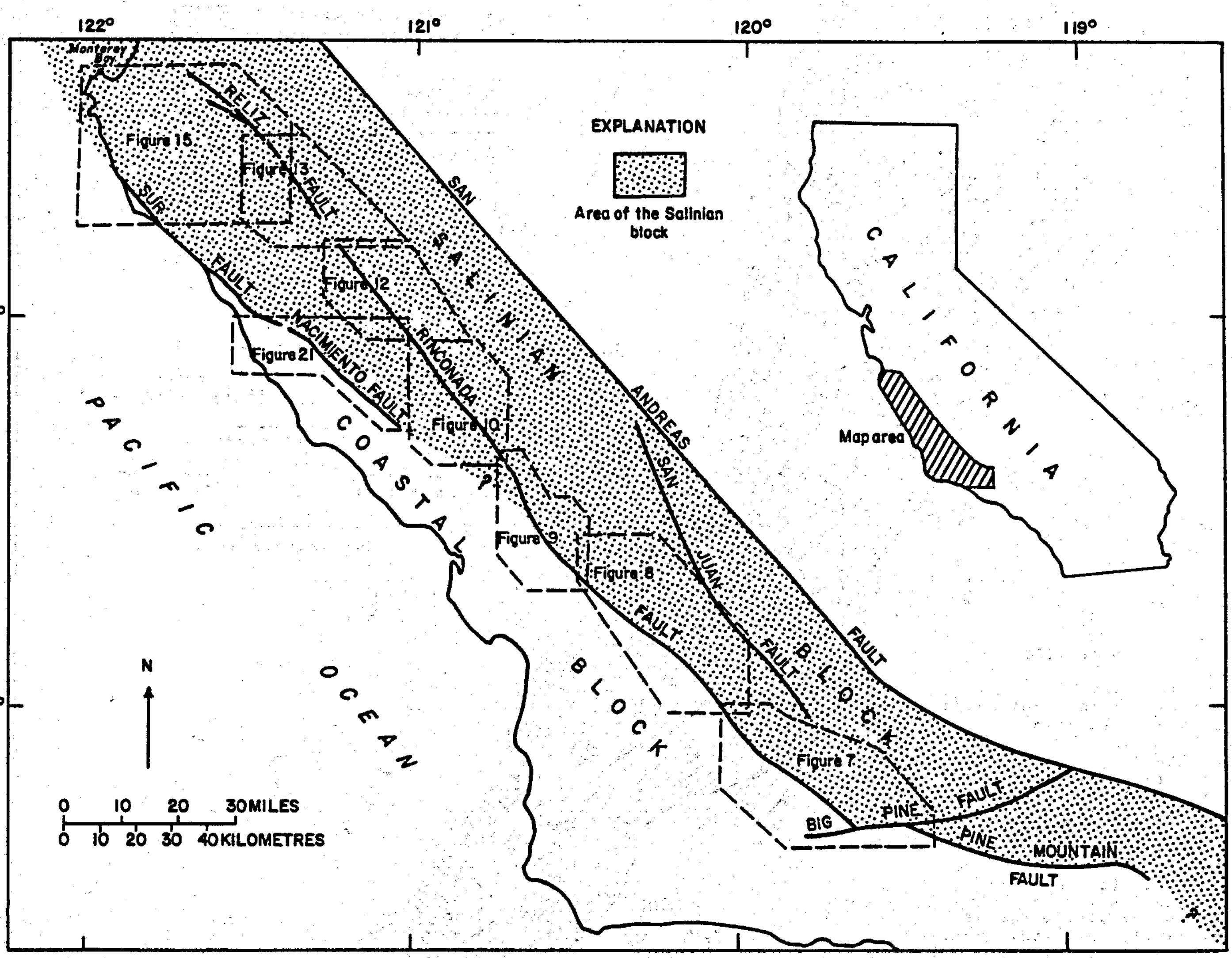


Figure 23. Positions of the Rinconada and Reliz faults relative to the Salinian block and the San Andreas fault. White areas underlain by Franciscan Complex. After Dibblee (1976).

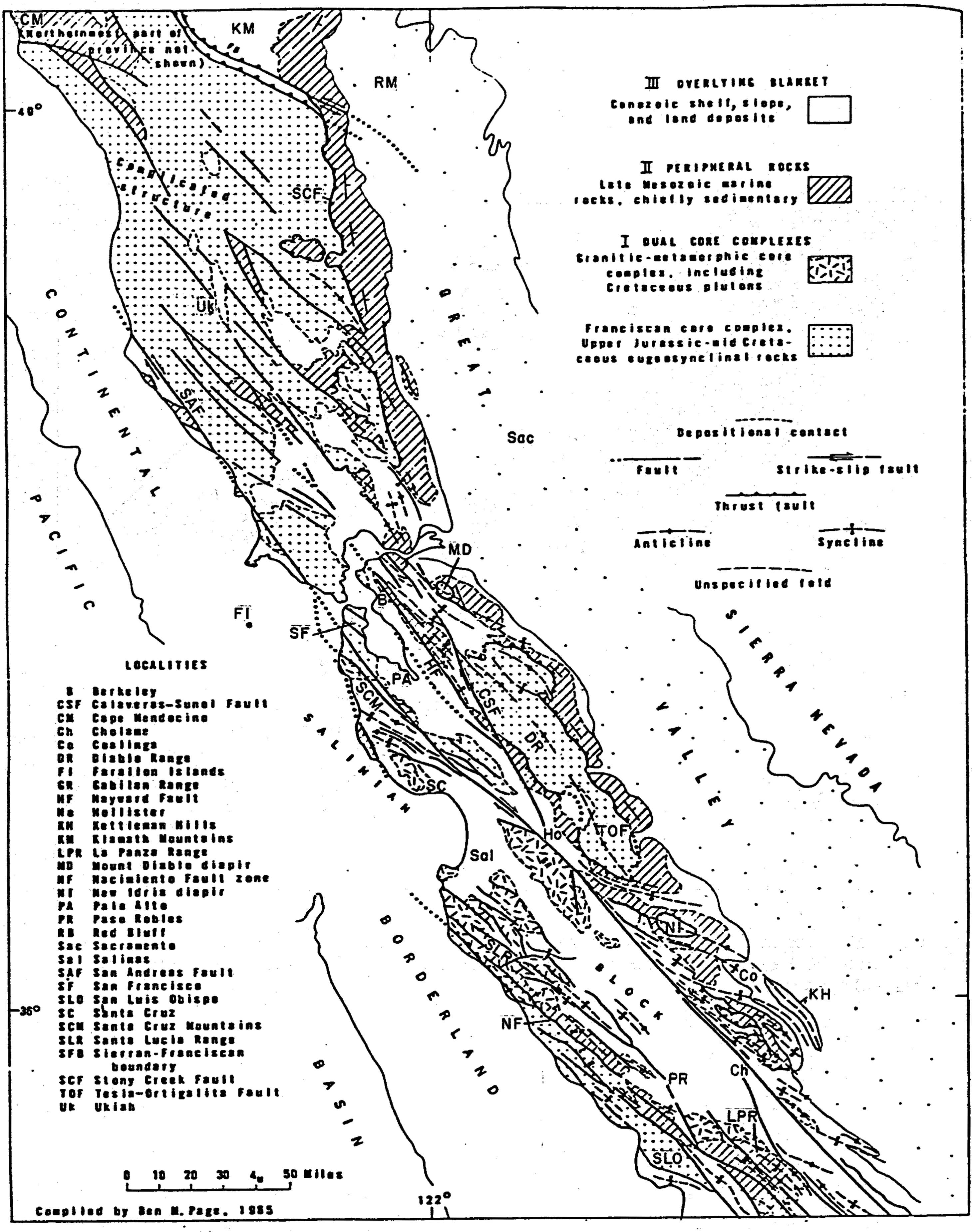


Figure 24. Tectonic map of the California Coast Ranges.

The Franciscan Complex is believed to represent ocean-floor sediments and volcanic rocks that were scraped off against an overriding edge of the North American plate during Andean-type subduction. Fossils within the Franciscan have been dated as Late Jurassic to Early Cenozoic. Most of the Franciscan is composed of graywacke sandstone.

The southern Coast Ranges are blanketed by Tertiary and Quaternary marine sedimentary formations, which are usually discontinuous in lateral extent due to orogenic interruptions and subsequent erosion. The oldest Tertiary rocks, which are shallow marine sandstone, conglomerate, and shale of Paleocene Age, crop out only in small, local areas. Eocene rocks, on the other hand, consist of sandstone and mudstone composed of turbidite sediments deposited at depths ranging from littoral to bathyal. Fossil remains indicate a period that was warmer and moister than the rest of the Tertiary. Much of the Oligocene record has been lost to erosion, but it can be found locally as marine shale and sandstone, interfingering with submarine basalt flows and tuff. Nonmarine Oligocene strata are also found in the region.

From Eocene to Miocene, the region consisted of lowlands and shallow seas, with a mild climate. The lower Miocene seas were the site of accumulation of conglomerate, sandstone, shale, and limestone. The middle and upper Miocene witnessed an advance of the seas and the subsequent deposition consisted of siliceous sediments, mainly shale. Volcanic activity was also common during the Miocene, depositing flows, tuffs, and bentonite layers. The shallow seas of the Miocene continued into the Pliocene, but became more restricted in size. Rocks of this age consist of marine sediments and volcanic rocks along the San Andreas Fault zone, in the southern Gabilan Range, and in the southern Diablo Range.

The present southern Coast Range structures were formed in the late Pliocene, when the region underwent folding and faulting due to strong compressive forces. The subsequent erosion and deposition of coarse sediments over the lowlands gave rise to the continental Plio-Pleistocene formations seen today. These sediments will be more thoroughly discussed in a later section of this report.

Early Tertiary thrusting caused the emplacement of rocks of the Great Valley Sequence over the Franciscan assemblage at the east side of the region. This appears to be one of the important periods of orogeny in the Coast Ranges. Tertiary strata lying on the Franciscan basement complex is always found to be folded, while sediments on the granitic-metamorphic core complex may or may not be disturbed. Most of the structure of the Coast Range is very complex, however, because of folding and faulting during the Miocene and later. All of the great fault zones (most are still active today) were active during this period. Among these, steep reverse faults are common, especially in the Santa Lucia Range of the Salinian Block, west of Paso Robles. The motion on this system was mainly during the Pliocene and early Pleistocene. The Rinconada Fault, in particular, will be discussed in detail in the Paso Robles portion of this discussion.

HOT SPRINGS

Geothermal resources in the southern Coastal Ranges are generally low-temperature, that is, less than 90°C. In fact, the temperatures of most thermal springs and hot wells in the region are only slightly elevated above ambient temperature. The distribution of the resource as currently understood is shown by the locations of natural hot springs in Figure 25.

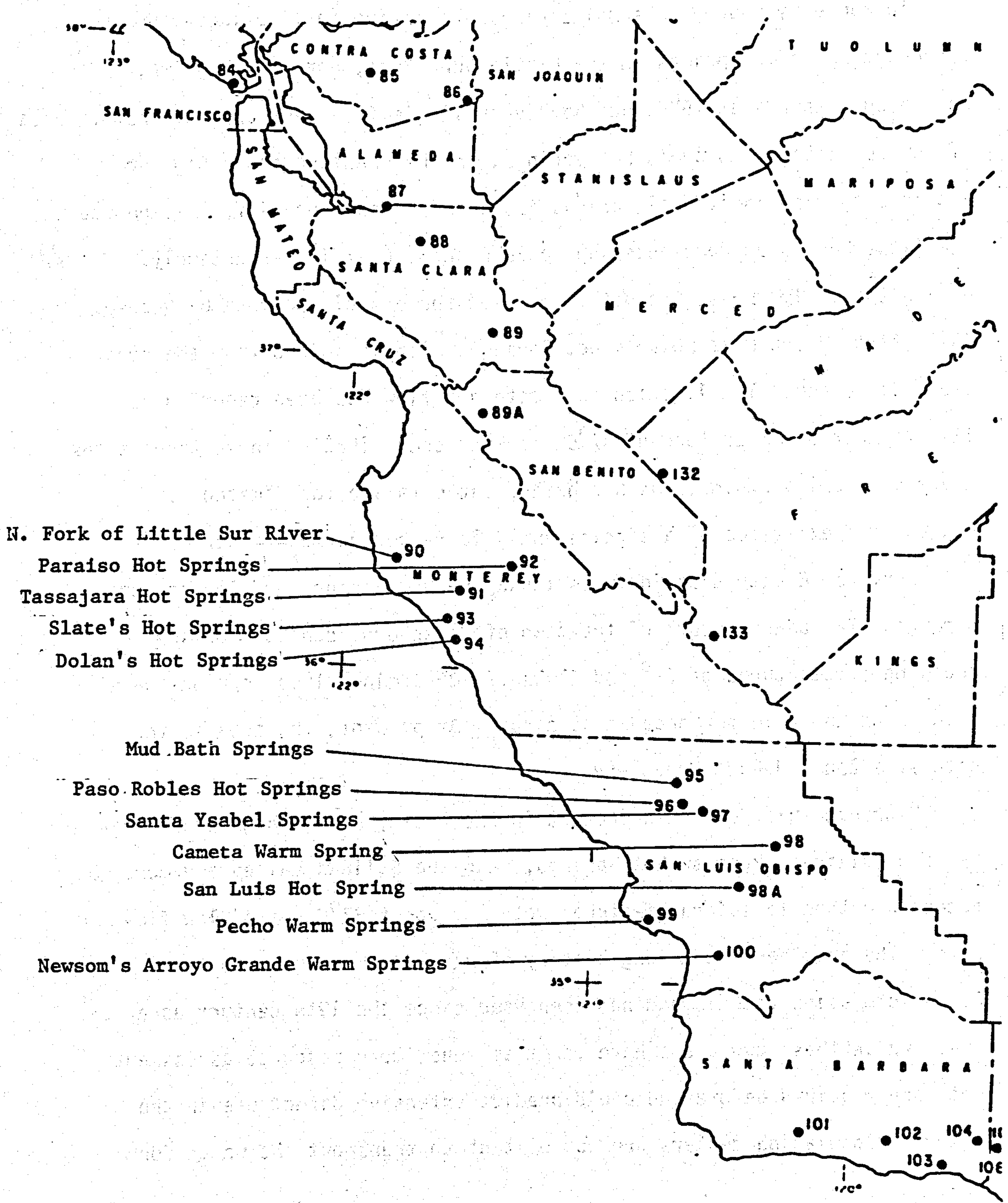


Figure 25. Hot Springs of the Southern Coastal Ranges.

In Monterey County, thermal springs are active in five locations in the Coast Ranges. Springs on the Little Sur River, north of Big Sur, have been measured at 46°C, but have very little flow and are in a remote area of low population. Slate's Hot Springs, on the coast south of Big Sur, consists of many individual springs issuing from the sea cliff. Temperatures and flows have been documented up to 50°C and 150 l/min respectively. During the early 1900's, the water was used for a small private bathhouse. Still farther south is Dolan's Hot Spring, which is inland from the coast along Big Creek. The location is remote and flow has been reported as 114 l/min at a temperature of 37°C (Berkstresser, 1968). These three sites may have local usefulness as hot baths, but data are too limited to suggest the existence of a significantly large geothermal resource.

Monterey County also includes Tassajara Hot Springs and Paraiso Hot Springs. Tassajara, south of the town of Jamesburg, consists of springs reaching temperatures of 62° and flows of 189 l/min. These springs have been known and used for decades as a spa. At present, the area is the site of a Zen Buddhist Monastery.

Hydrogen sulfide gas is present in the water, as are high concentrations of silica. Paraiso Hot Springs, near the Salinas Valley and more accessible than Tassajara, features water of about 37°C but of low flow rate. The area has had a long history of use. It was known to the Catholic mission fathers and has been used since the 19th century as a spa. While these two areas have merit as spas, more resource assessment data are required before one could predict extensive direct use in the future. Population centers are too distant to transport the water for use.

In San Luis Obispo County, there are also numerous surface expressions of geothermal potential in the form of hot springs and hot water wells. Newsom's Hot Spring is about 4 km east of the town of Arroyo Grande, and produces water at a temperature of about 37°C. The spring has been used for bathing for over 100 years, but the temperature and low rate of flow do not indicate a large resource. Pecho Warm Springs, west of San Luis Obispo and about two miles inland, produce low volumes of 35°C water and hydrogen sulfide gas and have been used for bathing. San Luis Hot Spring, south of San Luis Obispo and near the ocean, is actually a deserted oil well that flows hot water at over 38°C. The water, high in sulfide and salinity, has been used for a spa, and a hotel exists at the site. Nearby, just east of Avila Beach, is another well that flows hot water. Known as Hidden Valley Hot Springs or Budan Spring, the temperature is over 75°C with moderate flow and has been used as a spa.

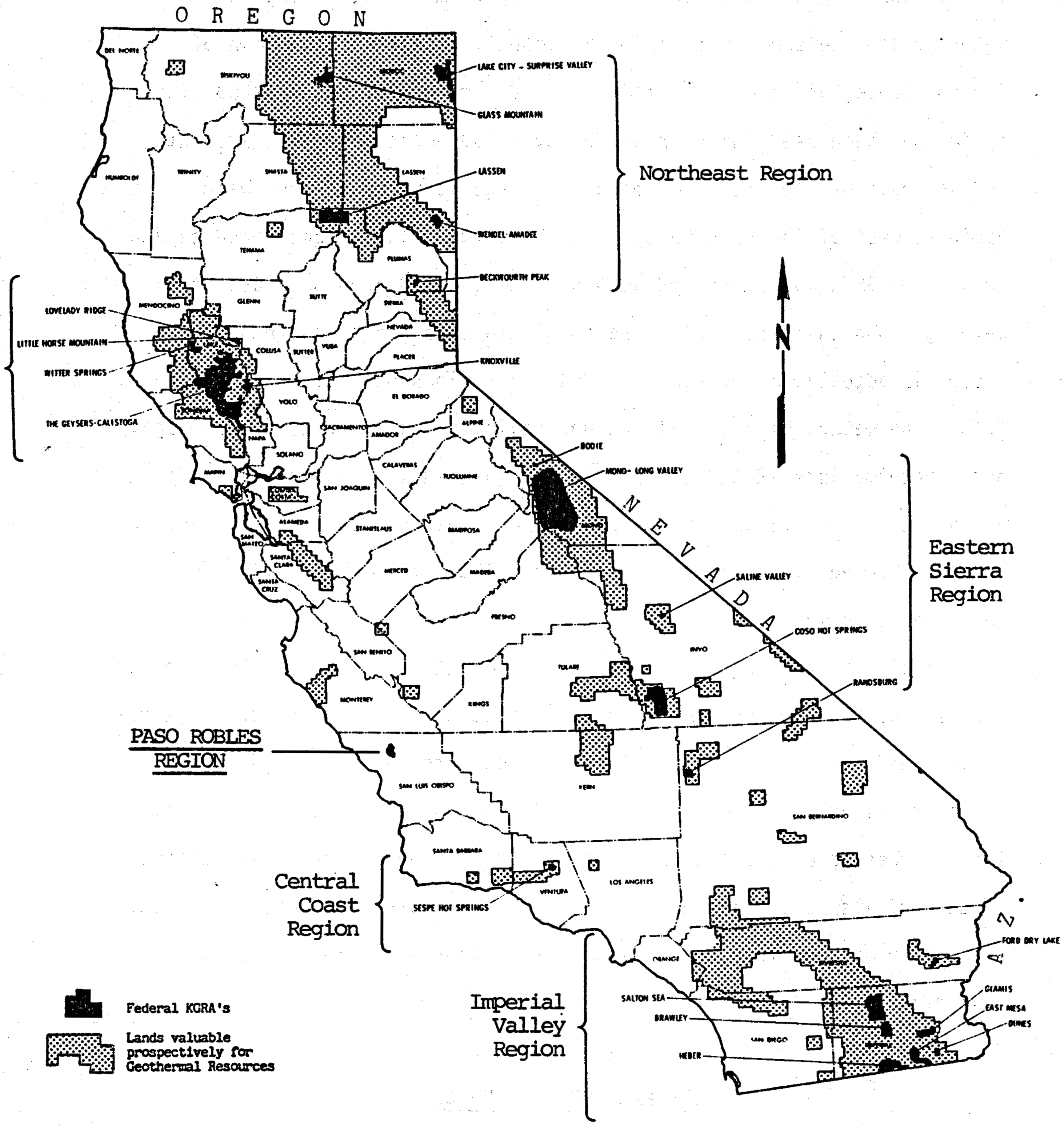
Of all the indicators of geothermal potential in the southern Coast Ranges, the Paso Robles area surpasses those already mentioned. Numerous springs and wells over a large area produce water at high flows and temperatures up to 47°C. The artesian nature of the water and moderate temperatures have made the area popular for its baths, and this region, because of its population and agrarian economy, lends itself well to the evaluation of low- to moderate-temperature geothermal resources in California.

THE PASO ROBLES REGION

BACKGROUND AND HISTORY

The Paso Robles low-temperature geothermal resource is in the southern Salinas Valley (Figure 26); it extends at least 15 km east and southeast

LOCATIONS OF CALIFORNIA KNOWN GEOTHERMAL RESOURCE AREAS (KGRA'S)



SOURCE: Jet Propulsion Laboratory, Geothermal Energy Resources In California: Status Report for ERCDC (June 1976), pp. 1-3.

Figure 26. Location of Paso Robles region relative to California's KGRA's.

from the town of Paso Robles. This area occupies most of the central and eastern Paso Robles 15' quadrangle and covers an area of over 230 square kilometers. The western extent of the known hot water lies beneath the town of Paso Robles. The region of known hot water is shown by Figure 27.

The area is bordered by the Santa Lucia Range on the west and the Temblor Range on the east, both reaching elevations of over 600 m within 33 km of the town of Paso Robles. The floors of the valleys in the resource area are from 210 m to 300 m above sea level and trend north-northwest. Durham (1974) referred to the topography as a "dissected old land surface". The Salinas River at Paso Robles is the lowest point in the region of known warm water, while the highest are the hilltops 15 km to the east. The region is drained by the Salinas River, which occupies a flood plain approximately 0.5 km in width, and its tributaries, Huerhuero Creek, Dry Canyon and the Estrella River. Mean seasonal precipitation in the region for the period 1897-98 to 1946-47 is shown in Figure 28.

The low-temperature geothermal resource of the Paso Robles area has a long history of use, mainly for spas and mud baths. The natural hot springs at the present location of downtown Paso Robles provided easy access to the resource in the early days. The earliest recorded use was by the Franciscan Padres who constructed mineral baths at the San Miguel Mission in 1797 and transported warm water by an eight-mile aqueduct from the springs. The water was again put to use starting in about 1857, when the Paso de Robles Rancho was occupied, and again in the early 1860s, when the Hotel Paso Robles was opened. The area with it's hotel, spa, mud baths, and health treatments soon became one of California's most popular health resorts. Several springs were developed for use as spas, including the Main Spring in downtown Paso Robles and the Soda Spring and

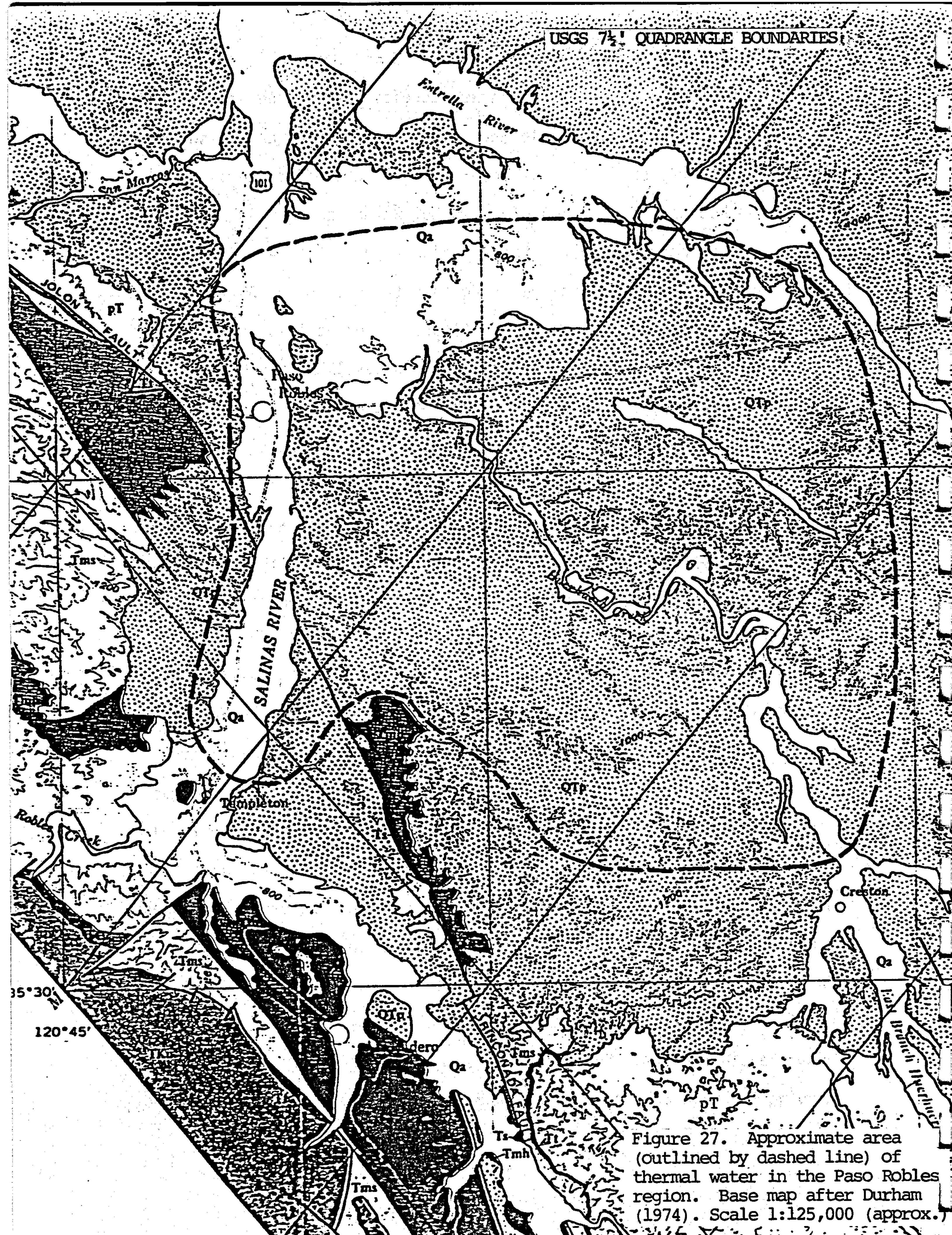


Figure 27. Approximate area (outlined by dashed line) of thermal water in the Paso Robles region. Base map after Durham (1974). Scale 1:125,000 (approx.)

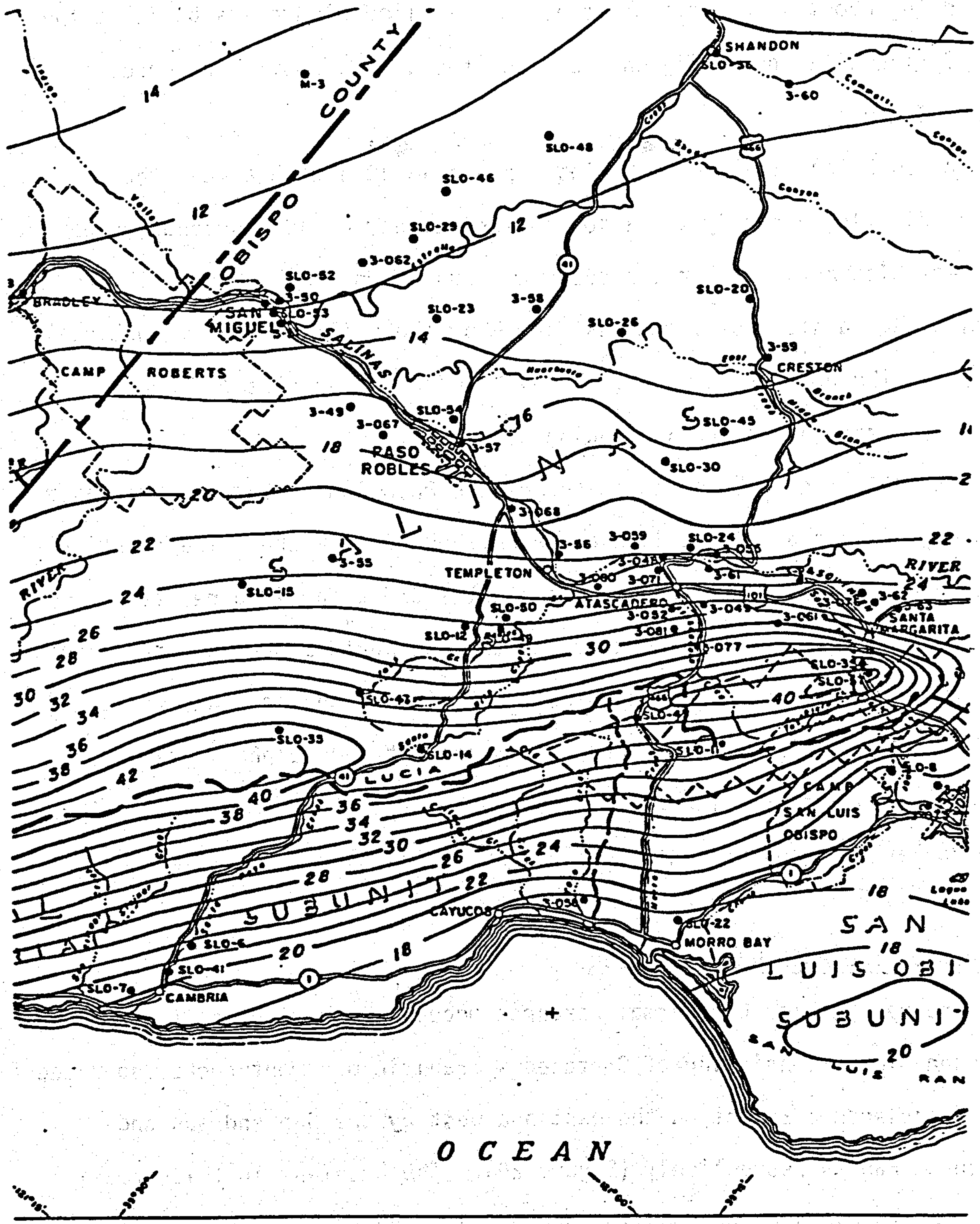


Figure 28. Lines of equal mean seasonal precipitation (inches) for the period 1847-98 to 1946-47. Dots mark precipitation stations. After California Department of Water Resources (1958).

Mud Spring about 4 km north of town. A so-called plunge was built at the Main Spring site and during this period, the town was often referred to as Hot Springs.

A new hotel, El Paso De Robles, opened in 1891 with a well that reportedly flowed nearly 4 million liters per day of 49^{o}C sulphurous water. This establishment further enhanced the reputation of the area. The new hotel became a stage stop and was served by the railroad when it was built in 1901. The hotel's location, midway between Los Angeles and San Francisco, made it an ideal stopping point.

In 1903, twelve businessmen formed the Paso Robles Hot Sulphur Water Company, drilled a well at 11th and Pine, and built a spa. The establishment later was to become the Municipal Baths and today is a realty office. The many springs and wells used during the spa perid produced water ranging from about 27^{o}C to 60^{o}C. Today, the popularity of the spas has waned and many of the wells have been abandoned to prevent the sulphur water from becoming a pollutant. Table 17 lists the early springs and wells in the Paso Robles area and presents chemical and physical data on them.

GEOLOGY OF THE PASO ROBLES REGION

The Paso Robles geothermal resource occupies a portion of the Salinian Block, consisting of Cretaceous granitic basement rocks separated from Franciscan basement on the east and west by the San Andreas and Rinconada Faults respectively (Figure 29). The basement in this area is commonly granodiorite, adamellite, and granite, dated in many locations as Cretaceous (70 to 89 my BP) by the K-Ar method. Metamorphic rocks, older than the Cretaceous rocks that intrude them, also occur in the Salinian basement. Two outcrops of the granite are exposed in the

Table 17. EARLY HOT SPRINGS AND WELLS: CHEMISTRY

Map No.	Name of Spring	Location	Flow	Temp °F	Total Depth	Ca ppm	Mg ppm	Na ppm	K ppm	SiO_2 ppm	HCO_3 ppm	CO_3 ppm	$CaCO_3$ ppm	Cl ppm	SO_4 ppm	NO_3 ppm	B ppm	odor, color	pH	mhos/cm $ECX10^6$ at 25°C	TDS	Remarks
1	Paso Robles Hot Spring	11th and Spring Street																			1336	Original natural spring. Swimming Plunge constructed.
2	Mud Bath Spring	2½ mi. N of Paso Robles Hotel: 100 yds W of River		104 to 126		119	1.2	665	11	105		27		805	538			7.1 H_2S			2407	High in sulfate and Chloride
3	Soda Spring	75 yd NW of Mud Bath Spring	4 gpm	77		132	45	419	7.4	107		142		496	310			.5 H_2S				Bottled for drinking.
4	Santa Ysabel Spring	4 mi SE of Paso Robles	220,000 gpd	94		28	46	350	8.1	29		361		188	173			31 H_2S				Still flowing in 1979. Fe: 8.1 ppm Al: 6.6 ppm
5	Iron Spring	200 yds NW of Mud Baths	1 gpm	64		45	66	313	trace	15		308		241	224							Fe: 12 ppm Trace H_2S
2	Lithium Spring	30 yds W of Mud Baths	8 gpm	122																		
	Name of Well				**Total Depth**																	
6	Grand Central "Spring"	NW of 10th and Park Street	"strong"	hot	510 ft.																	Drilled 1911, used for spa, Abandoned about 1925
7	Main Sulphur Spring	W of 11th and Spring Street	2,000,000 gpd	107.6	640 ft.	38	16	331	20	66		350		206	31			52 H_2S				Used for Hotel and spa.
8	Municipal Baths	SW of 11th and Pine Street	380,000 gpd	108.6	392 ft.	38	16	331	20	66	726	350		206	31		Trace	52 H_2S			1517	Large public spa.
9	R. C. Heaton Well	NE of 13th and Park Street	est. 500,000 gpd	106	230 ft.	22.4	18.1	432.6			890.6	0		238	4.3	0		H_2S Odor	7.4	1739	1164	Drilled about 1905. Once used in a bath house.
10	Lithium "Spring"	30 yds W of Mud Bath	small	118	140 ft.																	Used for drinking.

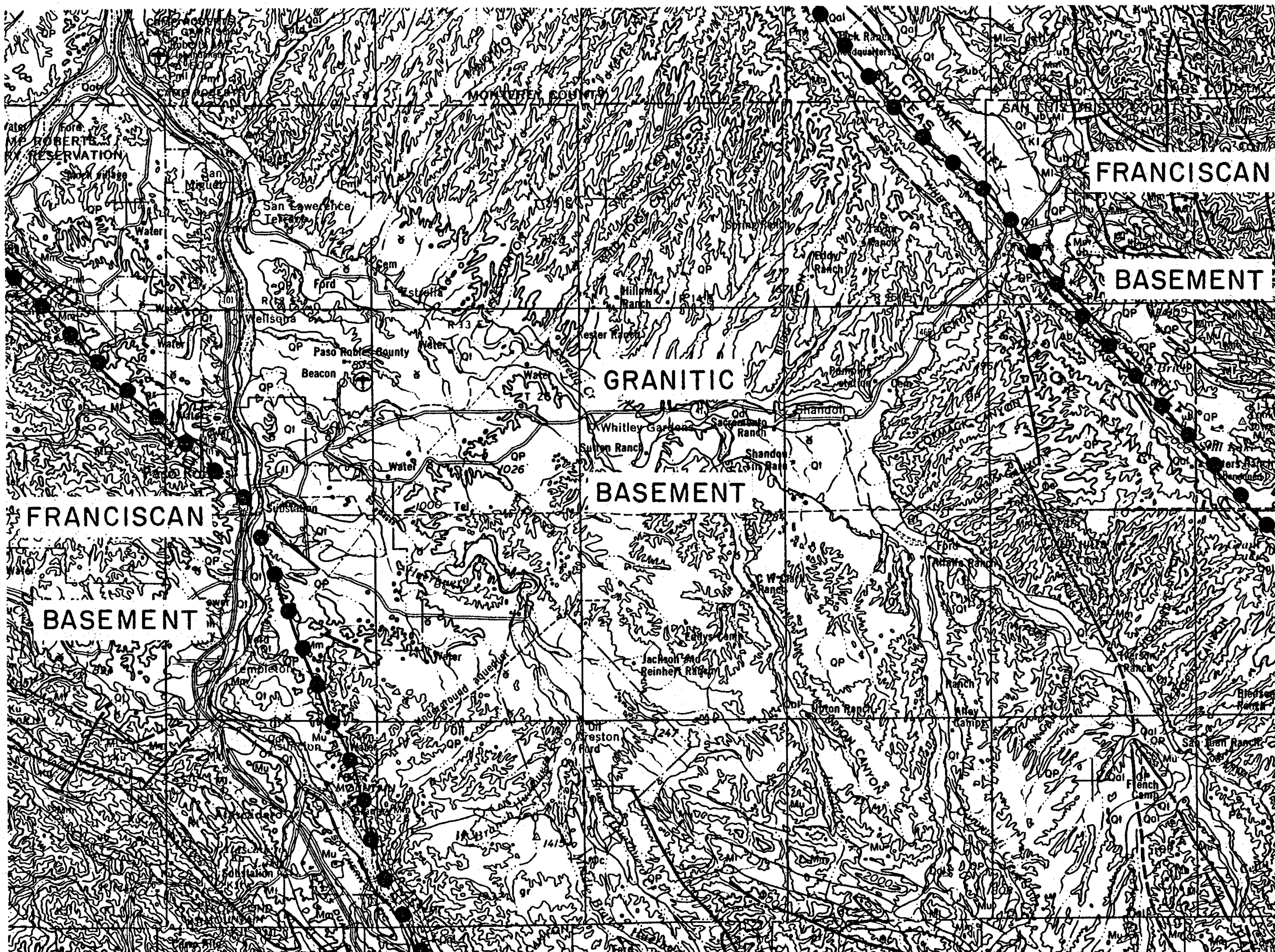


Figure 29. Distribution of basement rock in Paso Robles region. Base map is California Division of Mines and Geology Atlas, San Luis Obispo Sheet, 1958, 1:250,000.

vicinity of the geothermal resource: one large outcrop 18 km to the southeast of Paso Robles (the La Panza High) and a smaller exposure 5 km to the northwest (Figure 30). Durham (1974) calls the smaller exposure a possible outlying part of the La Panza High. Gravity and magnetic data indicate that granite exposure northwest of town extends 3 km under Paso Robles to about the location of an inferred fault through the natural hot springs (Dibblee, 1976). The remainder of the resource is apparently north of the La Panza High, in a depression in the basement possibly formed by folding and/or faulting.

Sediments atop the basement in the Paso Robles area consist mostly of marine arkosic sandstone, organic shale, and mudstone. These strata range in age from lower Miocene to Pliocene, and are coarser than stratigraphically-equivalent beds at greater distances from basement (Durham, 1974).

The Vaqueros Sandstone of early Miocene age overlies the granitic basement throughout much of the area and is the oldest sedimentary formation in the region. This formation, of marine origin, attains thicknesses of up to 450 meters but does not crop out in the geothermal resource area. The lithology of the Vaqueros consists of sandstone with some mudstone and conglomerate. Calcite cementing is common.

The Miocene Monterey Formation is the most widespread marine unit in the region. The formation consists of two members in the Paso Robles area: the Sandholdt (lower) and the Hames member. Where completely penetrated by wells in the study area, the formation is up to 750 meters thick. The Sandholdt Member is up to 450 meters in thickness in the resource area and is composed of calcareous mudstone, shale, and some chert. Stratigraphically above the Sandholdt is the Hames member, which

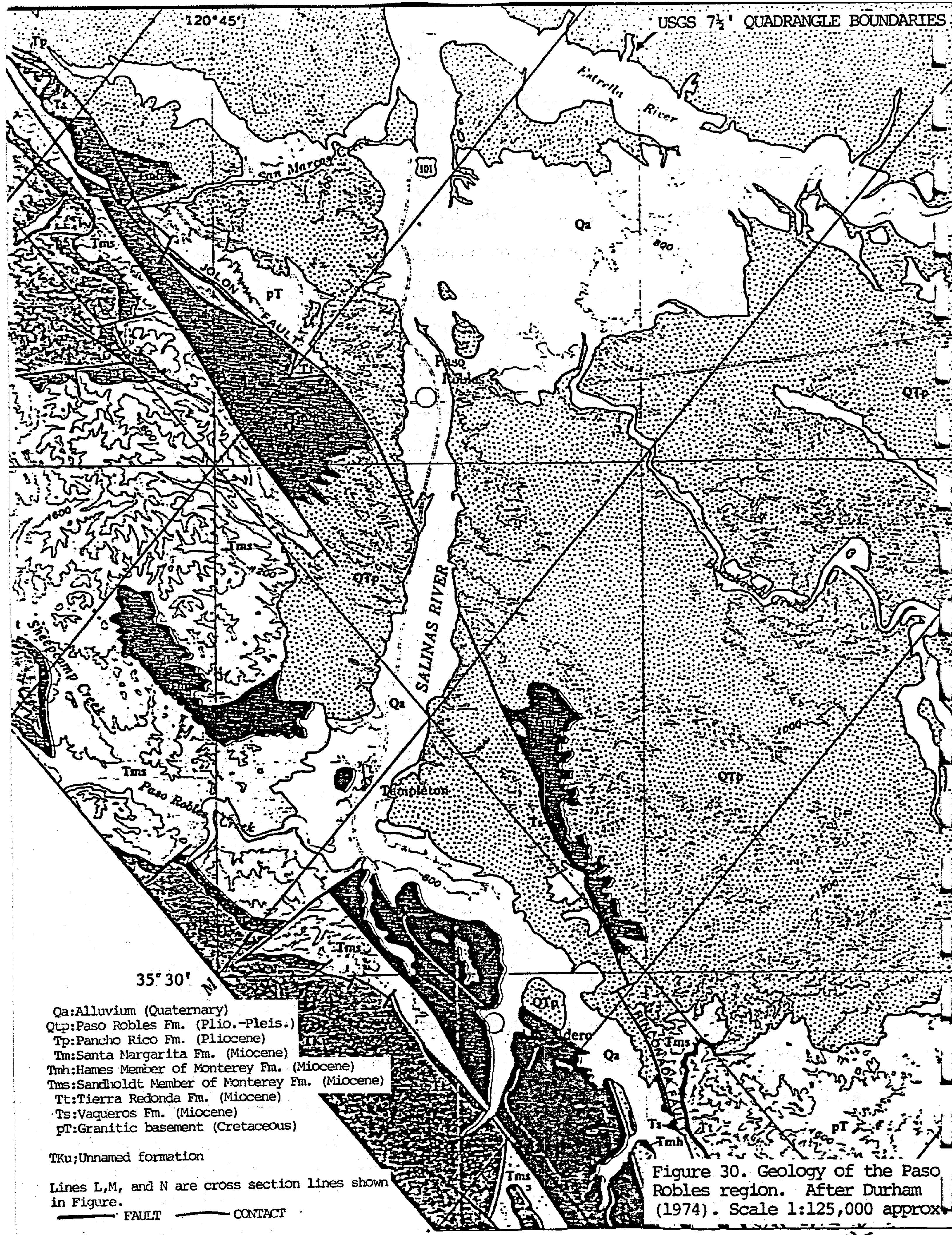


Figure 30. Geology of the Paso Robles region. After Durham (1974). Scale 1:125,000 approx.

consists of fine-grained porcelaneous rocks, siliceous mudstone, chert, and rare sands. The Hames exhibits variable color, bedding, and coarseness. Tuff, olivine basalt, diabase, and bentonitic clay in the Monterey indicate volcanic activity in the Southern Salinas Valley during the Miocene.

The Tierra Redonda Formation is a sandy rock unit equivalent to the finer portions of the Sandholdt (lower) member of the Monterey Formation. Not common in the Paso Robles resource area, this Miocene formation overlies the Vaqueros and, in places the basement, and is easily confused with the Sandholt.

A sandy formation known as the Santa Margarita Formation is the stratigraphic equivalent of the Hames member of the Monterey Formation, but is coarser textured and lenticular in character. It intertongues with or overlies the Hames and lies beneath the Paso Robles Formation. The unit varies in thickness from zero to over 600 meters in the area, and is not present in the western and southern parts of the area. Medium- to coarse-grained light-colored sandstone in massive beds characterize the Santa Margarita Formation, which contains late Miocene fossils of shallow marine origin. This formation appears to be the source of hot water from wells in some cases.

The Paso Robles Formation of Plio-Pleistocene age consists of contintental sediments that accumulated after the retreat of the Tertiary sea, an event associated with Late Pliocene diastrophism that uplifted the Coast Ranges by folding and thrusting. Sub-aerial deposition as stream and lake deposits has left widespread outcrops that consist of sandstone and conglomerate with some mudstone and limestone. Bedded gypsum and lignite are also present in places. Depositional features include crude bedding, poor sorting, channel structures and crossbedding, all of which are typical of non-marine, fluviatile deposition in valleys and basins of the recently folded Late-Pliocene landscape. Calcareous induration is common, but the friable, easily weathered nature of the formation prevents development of resistant outcrops and one must look at road cuts and stream banks for exposures. The discontinuous nature of members in this formation accounts for the difficulty in correlating beds over any distance. The source rocks for the Paso Robles Formation consisted of the uplifted marine Miocene formations, such as the Monterey and Santa Margarita, as well as debris from the nearby Franciscan or granitic basement (Taliaferro, 1943). Fossils are rare.

The Paso Robles Formation is of great interest in the study of low-temperature geothermal resources for it is reported to be the main water-bearing unit in the region. It contains clastic sediments of almost all sizes. Conglomerate beds are found up to tens of feet thick showing channels, crossbedding and discontinuous lateral extent; the strata range from friable and porous to dense and cemented. Exposures of the conglomerate are usually very light in color, due largely to the siliceous Monterey pebbles present. Sandstone members may be coarse to fine in texture, poorly sorted, and often contain pebbles of the Monterey. The strata range from massive to poorly bedded and contain the same depositional structures as those found in the conglomerate. Some siltstone and mudstone are present; surface exposures are very-light-colored gray or pale orange. Limestone occurs as rare, thin beds up to 1.5 meters thick, which exhibit a weathered appearance similar in color to the siltstones (Durham, 1974).

The Paso Robles Formation is up to 600 meters thick in the study area, but the upper portions have been lost to erosion nearly everywhere. Pleistocene activity on the Rinconada fault has folded and faulted the Paso Robles in some places, but the incompetent nature of the formation has obscured the resulting structure. Topographic lineaments and the alignment of springs may indicate faults in the formation (DWR, 1958).

In the region of the geothermal resource, the Paso Robles Formation overlies the Santa Margarita or older rocks, such as the Monterey or granite basement. The contact with the Santa Margarita must be conformable, but all other contacts are unconformable.

The only material in the region younger than the Paso Robles is Quaternary alluvium, which consists of unconsolidated gravel, sand and silt. It closely resembles the Paso Robles Formation except that it shows no apparent structural deformation. Found mainly in present river valleys, the alluvium is poorly sorted, massive to crudely bedded, and contains channel structures and cross-stratification. Originating along the upper portions of the present-day streams, it is usually less than 9 meters thick but occurs in thicknesses of up to 40 meters near the Salinas River.

The structure of the area is dominated by the Rinconada Fault, which trends northwest through the town of Paso Robles (Figures 29, 30 and 31) and forms the southwestern border of the Salinan Block. The fault is probably obscured by alluvium near the Salinas River (Durham, 1974). The fault was active in the Late Cretaceous or Early Tertiary, during crustal shortening perpendicular to the continental margin, and again in the Late Tertiary and Pleistocene when right-lateral displacement occurred (Durham, 1965; Dibblee, 1976). This activity produced offset and deformation in the lower Paso Robles Formation as well as in the

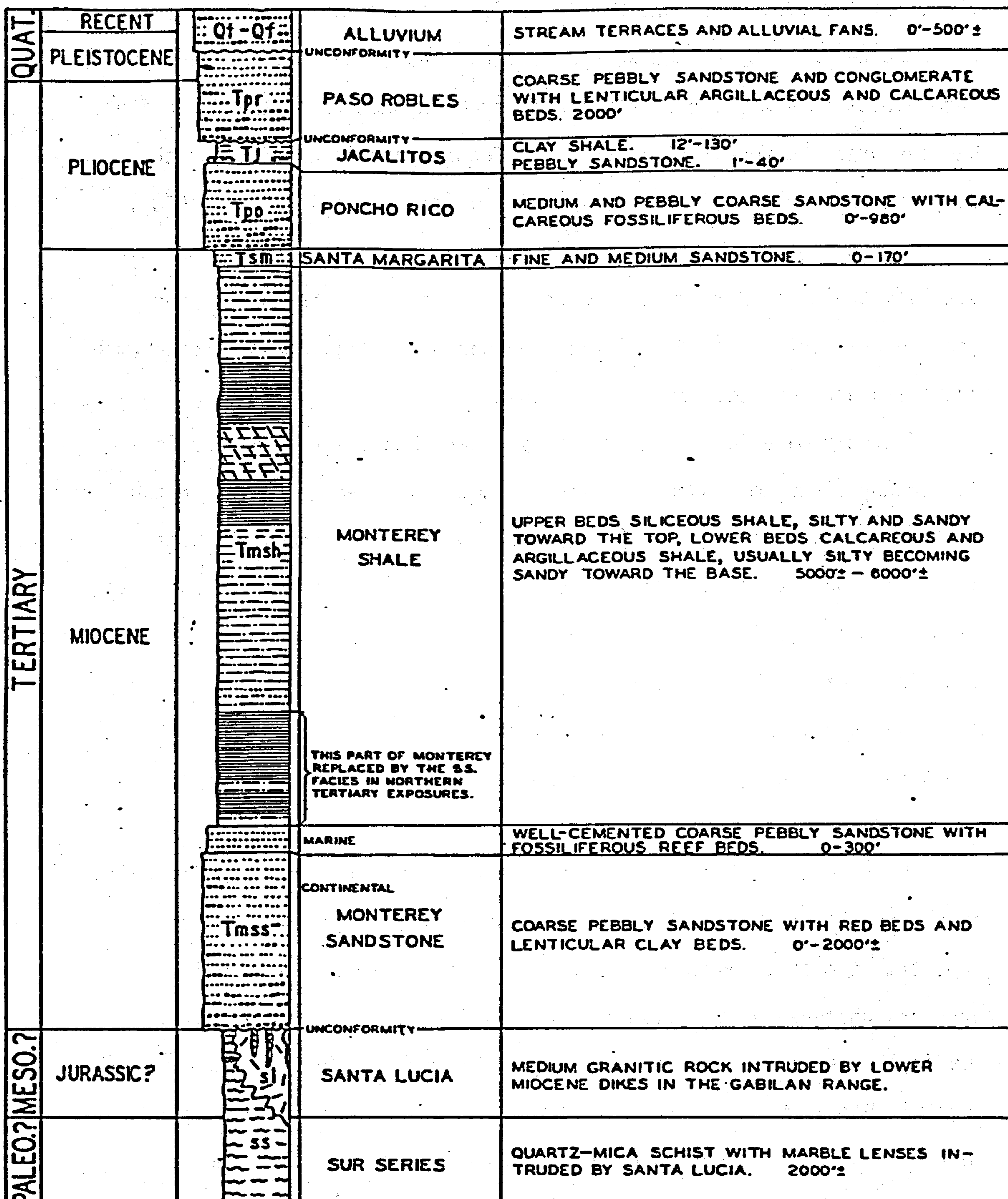


Figure 31. Composite columnar section of Paso Robles area.

older Miocene and Pliocene units (Dibblee, 1976). Zones of folding, subparallel to the Rinconada fault, are found in the Monterey and Paso Robles Formation. These zones occur in the southwestern, western, and northwestern portions of the geothermal resource area. Published cross sections of the area are shown in Figure 32, but do not include sufficient detail to show the above-reported folding.

GEOHYDROLOGY AND CHEMISTRY

The supply of water to the Coast Ranges and, in particular, to the Paso Robles area is derived directly from precipitation with some additional input from groundwater flow. Aquifers that occur beneath the rolling hills, terraces, and river beds, appear to be recharged by percolation into natural channels, with deep aquifers receiving water by deep penetration or by direct recharge in upland outcrops. The percolation of some stream run-off during storms may also be a source of groundwater recharge (Gribi and Thorup, 1963). The mountainous terrain, which consists of consolidated older rocks, is not considered to be water-producing, although granite will yield some water from fractures.

Abundant groundwater and the advent of the deep-well turbine pump in the early part of the century gave rise to irrigated agriculture and the proliferation of water wells. In the Paso Robles area, most water wells produce from the Paso Robles Formation with the exception of some city and private wells in the Salinas River bed, which produce from the alluvium. All prolific producers (some up to several thousand per day) pump from the Paso Robles Formation. Artesian wells also produce from the sands and gravels of this formation. Most warm or hot wells derive

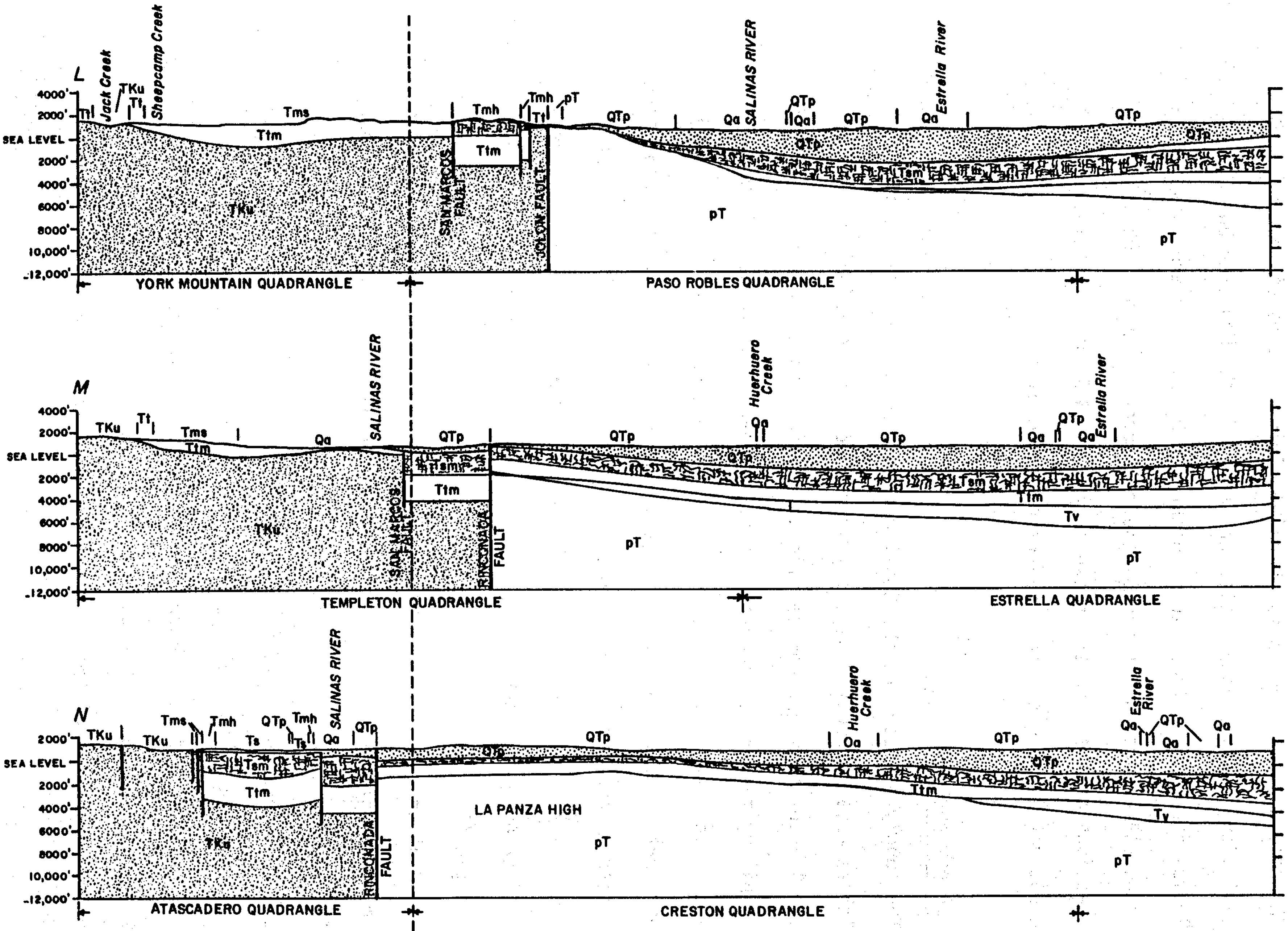


Figure 32. Geologic sections through Paso Robles area geothermal resource. Legend and locations of sections shown of Figure 30. No vertical exaggeration.

their water from the Paso Robles, although faults possibly allow this water to travel from deeper formations. The large volume of water production and potential production derives from the great thickness of the Paso Robles Formation in the area, which is over 600 meters thick in places.

Folding and faulting in the Paso Robles has affected the location and movement of ground water. In some areas, notably near the Rinconada Fault, the formation has been exposed by folding and subsequent erosion. This allows recharge into the sand and gravel members, which, in turn, are the source of water in wells at other locations. In addition, confining clay layers appear to allow artesian pressure to build up, but their lenticular nature can permit localized upward movement of ground water (DWR, 1958) in some topographically low areas. In non-flowing wells, observed standing water levels range from the surface to about 65 meters depth (Bader, 1969). Most ground water in the region of the Paso Robles geothermal resource seems to be unconfined, but flowing wells are found in many parts of the resource. Most flowing wells, both past and present, are hot.

The direction of ground water flow within the Paso Robles Formation is presumed to be toward and subparallel to surface drainage (Bader, 1969). This is supported by a ground water elevation map published by the California Department of Water Resources (DWR, 1958), shown in Figure 33. Complex and poorly understood movement also occurs due to the lenticular nature of the gravels and clays and to the above-mentioned structure.

According to Department of Water Resources reports (1958, 1971, 1978) and local residents, water levels and some artesian pressures have dropped

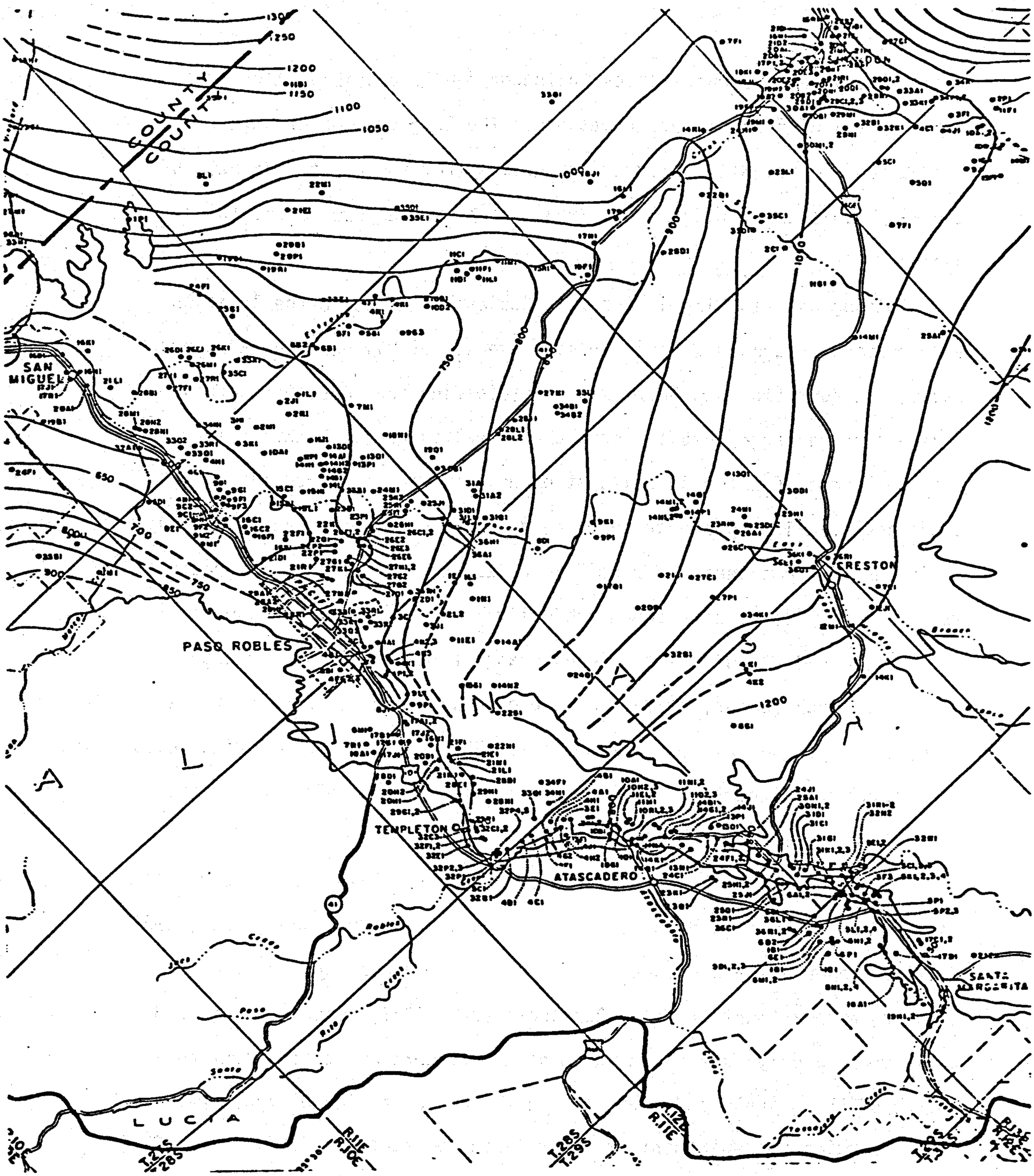


Figure 33. Lines of equal elevation (feet above mean sea level) of ground water in Fall, 1954. Dots represent locations of wells. After California Department of Water Resources (1958).

over the years. Average values from agricultural wells have shown the Paso Robles aquifers to have the following characteristics: permeability is from 4,130 to 44,570 liters per day per square meter with an average of 8,200, average production per well is 1,900 liters per minute, and specific capacity is about 49 liters per meter of drawdown (DWR, 1958).

The hot water resource in the Paso Robles region exhibits the same hydrologic characteristics as the ground water in general, but differs in distribution and chemistry. Early springs in the town of Paso Robles were used for spas because of the ideal temperature of over 38°C and steady productivity. Wells drilled in the same area reportedly flowed up to 7,600,000 liters per day from relatively shallow depths (195 meters or less). Table 17 lists early springs and wells, while Table 18 gives additional hot wells drilled since about 1940.

Hot water wells and springs appear to produce mainly from the Paso Robles Formation and probably owe their productivity to nearby faults. Most workers in the area believe that faults restrict or control ground water movement at depth (DWR, 1971). The springs and wells in downtown Paso Robles, for example, are not far from the Rinconada Fault and may be along a proposed short fault that extends northward from the Rinconada at the south end of town (Dibblee, 1976). The artesian pressure in these wells may be supplied by recharge in the hills to the west of town, where wells have produced water from the Monterey shale. This inferred fault may provide a conduit for artesian warm water at depth to reach the surface via the springs and shallow wells in the downtown area.

As Figure 34 shows, hot water is also found southeast of Paso Robles. At these locations, the resource is at depths of from 210 to 300 meters in the Paso Robles Formation. Artesian pressure is also found in parts of this region; the hot water is evidently confined by layers

Table 18. SELECTED RECENT WELLS AND THEIR CHEMISTRY

Map No.	Name of Well	Location	Approx. Flow	Temp °F	µmho/cm × 10^6 at 25°C Elec. Cond.	TDS	pH	Total Depth	Ca ppm	Hg ppm	Na ppm	K ppm	Si ppm	HCO_3 ppm	F ppm	total hardness $CaCO_3$ ppm	Cl ppm	SO_4 ppm	NO_3 ppm	B ppm	Odor	Remarks
11	Borcherdt #5	S. River Rd. at Charolais Rd.		81	1150	805	7.7	400 ft.	21	6.9	275	4.2		210	.8	112	100	92	9	1.2		
12	Butterfield Well	1 mi SW of Airport		83	756	525	7.5	1000 ft.	29	14	149	2		210		130	56	84	7	1.6		Drilled 1966.
13	Creston Park #7	Nr. Creston Rd. 4000'E of River		cold	824	479	7.5	400 ft.	39	22	104			360	0	188	74	15.4	42.2			Abandoned due to sulphur.
14	Sherwood #6	Nr. Cor. Creston Rd & Sherwood Rd.		cold	950	650	8.5	750 ft.	17	6	119	3.1		360		60	77	64	7	1.5	None	
15	Sherwood #9	Nr. Cor. Creston Rd. & Scott St.		cold	700	438	7.8	600 ft.	50	16	69	2.3		240		191	61	31	17	.25		
16	Sherwood #11	2000'NE of Well #9		cold				600 ft.												2.3		
17	Thunderbird Well	2 mi S of Paso Robles nr. River		cold	750	500	8.5	210 ft.	104	32.8	39.6	1.7	28	204	.4	400	60.4	74	2	.1	None	Probably produces from alluvium.
18	Bianchi Well	.15 mi NW of Hwy 46 and Freeway	~5gpm	cold	1890	1180	8.2		7.5	.1	430	8.2			2.4	19	163	209	0	1.2	sulphur	Flow from concrete tub.
19	Cal-Aqua Well	NW/4 14-T27S-R13E	no flow	115	850	555	8.1	1000 ft.	8	1.5	182	1.9		255	.8	25	60	135	5.2	1.3	sulphur	
20	Cal Trans Well	S of Treatment Plant ~500 ft.	50-100 gpm	105	1840	1160	8.4		4.8	0	420	7			2.6	12	153	219	2.4	1.2		
21	Fairgrounds Well	NE of Racetrack at Fairgrounds	6 gpm	79	1820	1160	8.2		5.5	1.2	430	5.6			2.6	18	180	211	3.0	1.1		Flowing in 1978.
22	Franklin Well	SE/4 of 11-T27S-R12E	5000 gpm	98±	950	650	8.2	3458 ft.	5.4	1.2	256	2.6	8	485	1.2	30	180	70	3	1.5	H_2S Odor	
23	Kleck Well	1 mi NE of Hwy 46 and Freeway	~30 gpm	90	2140	1350	8.3	300 ft.	5.5	0	500	5.8			2.6	14	250		3.0	1.2		Drilled about 1915.
24	Pioneer Museum Well	SE of 21st and Riverside	none	82	1740	1050	8.8		8.3	3.5	400	8.1			2.2	35	168	165	2.4	1.2	sulphur	Shut in.
25	Treatment Plant Well	On city sewer treatment property	50-100 gpm	97	1840	1150	8.3		34	18	370				2.2	159	177	229	0	1.2	sulphur odor	Flowing.

Variations in chemistry exist over time and different workers arrive at different values due to sampling and lab techniques.

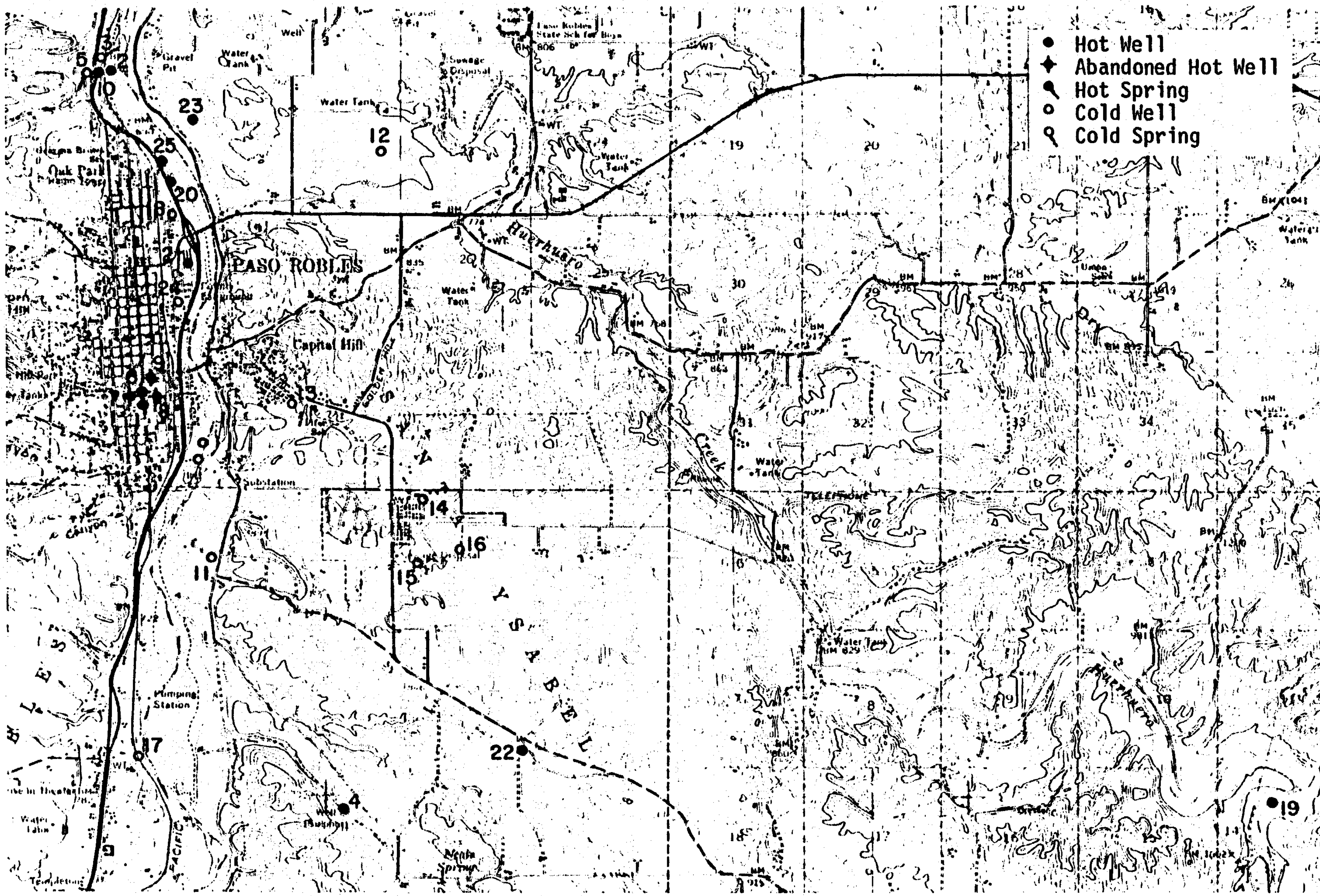


Figure 34. Paso Robles area wells and springs. Numbers refer to data on the wells and springs listed in the Table. Base map is USGS Paso Robles 15 min. Quadrangle (1961).

of "blue clay", according to local drillers. Temperatures of up to about 46°C are found in the wells southeast of Paso Robles, similar in temperature to the water found beneath the town.

GEOCHEMISTRY

The hot water resource of the Paso Robles area is distinguishable from the local cold ground water not only by its temperature, but also by its chemistry. The hot water is characterized by conspicuous H_2S content. Aeration, which can be accomplished merely by the downhill flow, appears to be a sufficient treatment to dissipate the gas. At Paso Robles, the H_2S was part of the attraction of the early springs and spas for its health-giving properties, but now, its presence has caused the abandonment of many wells by order of the Regional Water Quality Control Board. Water from these unused flowing wells was finding its way into the sewage treatment facility and was ultimately contaminating the Salinas River. Another distinguishing characteristic of the hot-water resource of the Paso Robles area is the salinity of the water. Tables 17 and 18 show Na and Cl concentrations in the geothermal waters. The Franklin well, for example, is a deep (producing interval at about 250 meters) flowing well of elevated temperature and salinity. The high salinity is not found in shallower, cold water wells in the area. The hot wells of downtown Paso Robles likewise have higher concentrations of Na and Cl than nearby cold wells.

The California Department of Water Resources (1971) grouped the Paso Robles springs with other waters of "poor quality", citing high concentrations of fluoride, boron, sodium, and chloride, as well as high total-dissolved-solids content. Cold ground water from the region tends to have a much lower solids content and no associated H_2S gas (Table 18).

The chemical characteristics of the early springs and wells have been studied since the 1800s (Table 17). In addition, some of the more recent wells have also been tested (Table 18).

POTENTIAL USES

The early uses of the Paso Robles geothermal resource have already been discussed. They consisted of spas and mud baths, using hot water derived from springs and shallow wells. But these uses were recreational or medicinal in nature. Today, in this country, we have a rapid consumption of energy, and the hot water that was once used for spas can be used as a direct heat source to reduce our consumption of imported fossil fuels.

At present, small amounts of the natural hot water are still used for bathing, for example, the water produced from the Kleck and Franklin wells. The use is negligible from the standpoint of energy consumption, however, and there are other potential uses to consider. Calaqua, Inc., a firm in the area, is entering the agribusiness sector with a plan to raise channel catfish using the hot water resource. This aquaculture ranch, about 17 km southeast of Paso Robles, may ultimately derive over 95% of its energy requirements from the hot water. This savings is due to the large amount of warm water needed for the farm, which would otherwise have to be heated using conventional sources of energy. The 46°C water from the Calaqua well, after use for the catfish production, will be used for shellfish culture and finally irrigation of crops. The water will also be used for space heating of the facilities. The Calaqua operation is still being developed and its ultimate success remains to be seen.

In addition to aquaculture, the resource could be used directly for space and water heating, especially in the downtown area. This can be expanded to include additional applications for agriculture: heating greenhouses, chicken coops, and barns. Space heating could rely on the hot water resource at Paso Robles, and greatly reduce the consumption of oil and natural gas for this purpose.

Another possible major direct use of hot water is known as process heat. This term is often applied to food processing techniques such as dehydration or sterilization. Other types of process heat applications are water supply treatment, sewage, and solid waste treatment, livestock feed production, refrigeration, and lumber processing and curing. In the long run, many of these uses could be made of the geothermal resource of Paso Robles.

SELECTED REFERENCES

Bader, J.S., 1969, Ground-water data as of 1967, Central Coastal Subregion, California: U.S. Geological Survey Open-File Report, 16 p.

Berkstresser, C.F., Jr., 1968, Data for springs in the southern Coast, Transverse, and Peninsular Ranges of California: U.S. Geological Survey, Open-File Report, 13 p.

California Department of Water Resources, 1958, San Luis Obispo County Investigation: State Water Resources Board Bulletin 18, v. 1.

California Department of Water Resources, 1971, Preliminary evaluation of the water supply of the Arroyo Grande and Paso Robles areas.

California Department of Water Resources, 1978, Water Analysis (Mineral) No. 06036-06042.

California State Water Resources Board, 1955, Salinas River basin investigation: Bulletin 19.

Dibblee, T.W., 1976, The Rinconada and related faults in the southern Coast Ranges, California, and their tectonic significance: U.S. Geological Survey Professional Paper 981.

Durham, D.L., 1965, Evidence for large strike-slip displacements along a fault in southern Salinas Valley, California: U.S. Geological Survey Professional Paper 525-D, p. 106-111.

Durham, D.L., 1974, Geology of the southern Salinas Valley area: U.S. Geological Survey Professional Paper 819, 111 p.

Franke, H.A., 1935, Mines and mineral resources of San Luis Obispo County, California Journal of Mines and Geology: v. 31, no. 4, p. 428-432.

Gribi and Thorup, 1963, Guidebook to the geology of Salinas Valley and the San Andreas Fault: 1963 Field Trip, AAPG-SEPM.

Hinds, N.E.A., 1952, Evolution of the California landscape: California Division of Mines and Geology Bulletin 158, 240 p.

Korn Kohl Labs, Inc., Paso Robles public library open file water well analyses.

Jet Propulsion Laboratory, 1976, Geothermal energy resources in California: Status Report.

Johanson, S., 1979, Ground Water in the Paso Robles Basin: California Department of Water Resources.

Laizure, 1925, San Luis Obispo County, in California State Mining Bureau, 21st Annual Report of the State Mineralogist, p. 524-527.

Logan, C.A., 1917, San Luis Obispo County, in California State Mining Bureau, 15th Annual Report of the State Mineralogist, p. 690-697.

Oakeshott, G.B., 1960, Geologic sketch of the Southern Coast Ranges, in California Division of Mines, Mineral Information Service, v. 13, no. 1.

Page, B.M., 1966, Geology of the Coast Ranges of California, in Geology of Northern California: California Division of Mines and Geology Bulletin 190, p. 255-275.

Peale, A.C., 1886, Lists and analyses of mineral springs of the U.S.: U.S. Geological Survey Bulletin 32.

Taliaferro, N.L., 1943, Geologic history and structure of the current Coast Ranges of California, in California Division of Mines and Geology Bulletin 118, p. 119-162.

Thornbury, W.D., 1965, Regional geomorphology of the United States: John Wiley & Sons, p. 540-543.

Thorpe Laboratories, Paso Robles public library open file water well analyses.

Waring, G.A., 1915, Springs of California: U.S. Geological Survey Water-Supply Paper 338, p. 72-77.

PART II

1979-80 GEOPHYSICAL STUDIES

PASO ROBLES GEOTHERMAL AREA

GEOPHYSICAL SURVEY, PASO ROBLES GEOTHERMAL AREA

INTRODUCTION

Geophysical surveys were undertaken by the Division of Mines and Geology in the Paso Robles geothermal area in order to provide additional information concerning the geology and the hot water resource. Reconnaissance aeromagnetic and gravity surveys were already available in the area. Therefore, the Division's geophysical work was planned to provide more detailed ground magnetic, gravity, electrical resistivity, and possible seismic refraction surveys. Because there was a delay in obtaining the electrical resistivity equipment, the work accomplished thus far includes only the ground magnetic and gravity surveys. A discussion of these surveys and their interpretation follows.

FIELD METHODS AND REDUCTION OF DATA

Gravity Survey

Approximately 250 irregularly distributed gravity stations were occupied in the Paso Robles area (Plate PG 1) at surveyed elevation points, bench marks, and topographic elevation points from the U.S. Geological Survey 15 minute and 7 1/2 minute quadrangle (topographic) maps. Elevations for approximately 210 stations were surveyed by the California Division of Mines and Geology and are probably determined to an accuracy of less than 1 foot. The majority of these stations are spaced 800 feet apart along roadsides in the south half of the Paso Robles 15 minute map. Approximately 25 gravity stations occupied U.S. Geological Survey and U.S. Coast and Geodetic Survey bench marks and approximately 10 stations were based on vertical control data by the City of Paso Robles. In addition, approximately 5 gravity stations in the area were located at points where elevations were estimated from 40 foot contours on U.S. Geological Survey 7 1/2 minute topographic maps. The estimated accuracy of these stations is $\pm$20 feet.

La Coste-Romberg geodetic meter G129 was used for the gravity survey. Gravity observations at occupied stations were tied to base station number 262 previously established in Paso Robles by the California Division of Mines and Geology (Chapman, 1966, p. 39).

After corrections for instrument drift and tidal effects, values of observed gravity were reduced to Bouguer anomalies for a density of 2.67 grams per cubic centimeter (g/cm^3) by means of a U.S. Geological Survey gravity reduction computer program. Inner zone terrain corrections were made manually for each station by the method of Hayford-Bowie (Swick, 1942) to a radius of 2.29 kilometers (through Zone F). The remaining corrections, out to a radius of 166.7 kilometers (km), were subsequently computed by the use of a U.S. Geological Survey terrain correction program (Plouff, 1977).

The inner zone terrain corrections for most stations were found to be less than 0.10 milligals (mgal) through Hayford-Bowie Zone F. Corrections which exceed 0.10 mgal were made for a total of 15 stations. The maximum value of the manually calculated inner zone terrain corrections for stations in this survey was 1.27 mgal. The values of the total terrain corrections for stations occupied a range from 2.10 mgal to 0.62 mgal.

The California Division of Mines and Geology gravity data were supplemented with approximately an additional 70 gravity stations from original data used to compile the San Luis Obispo sheet of the Bouguer Gravity Map of California (Burch and others, 1971). The total of about 320 gravity stations yields an average density of about one station per 2 square kilometers within the boundaries of the Paso Robles 15 minute quadrangle map. However, the distribution of stations is not uniform. The gravity station distribution is more dense in the south central portion of the survey area than elsewhere.

Aeromagnetic Survey

A portion of an aeromagnetic map by Hanna (1970) for the Paso Robles 15 minute quadrangle map is given in Plate PG2. The contours show the total-intensity magnetic field of the earth relative to an arbitrary datum with a contour interval of 40 gammas. The aeromagnetic survey was flown at a barometric elevaton of 6,500 feet along northeast-southwest flight lines spaced 1 mile apart. A regional magnetic field gradient of 9 gammas per mile in the direction N16E was removed from the original data.

Ground Magnetic Survey

Approximately 35 miles of ground magnetic traverses (lines M1-M15) were made across the Paso Robles area (Plate PG3). Total field intensity data were obtained with a Geometrics, Model G816, proton magnetometer with a sensitivity of ±1 gamma. The station spacing was usually 100 feet along each traverse. A magnetic contour map based on these data is given in Plate PG3).

INTERPRETATION OF DATA

Gravity Data

Rock densities. Values of rock densities for the Central Coast Ranges and the San Joaquin Valley have been given by Byerly (1966, p. 85-86). Most densities used in this report are based on Byerly with some modifications. In addition, a density profile (Nettleton, 1940, p. 57-58) was utilized to determine the density of the Paso Robles Formation. In this procedure, the gravity values for stations across a topographic feature are reduced, including terrain effects, for a sequence of different density values. The density value that produces the "smoothest" gravity profile across the topographic feature should be the proper density for use in the reductions. The profile was over a hill assumed to be composed entirely of rocks from the Paso Robles Formation. A density of 2.05 g/cm^3 was determined from this procedure. A summary of the density values for the rocks in the Paso Robles area are given in Table 1:

Table 1. Rock densities in the Paso Robles area

AGE	FORMATION	DENSITY (g/cm^3)
Quaternary & Tertiary	Paso Robles Formation	2.05
	Santa Margarita Formation	2.35
Tertiary	Monterey Formation	1.95
	Vaqueros Formation	2.40
Tertiary & Cretaceous	Franciscan Formation	2.67
Pre-Tertiary	Granitic Basement	2.67

Gravity contour maps. Plate PG1 is a map of the Paso Robles 15 minute quadrangle showing station locations and Bouguer gravity contours at an interval of 2 mgal.

The gravity field in this part of the California Coast Ranges is characterized by an overall decrease in gravity values of about 1.5 mgal per mile toward the northeast (Burch and others, 1971). Superimposed on this regional gradient are a number of local anomalies, most of which have a general northwest trend. In general, the local gravity anomalies tend to reflect the thicknesses of the Tertiary and Quarternary sedimentary rocks and sediments that overlie the relatively dense granitic and Franciscan Assemblage basement rocks in the area.

Prominent positive gravity anomalies with amplitudes of about 20 mgal each evidently reflect the exposures of granitic rocks located northwest of Paso Robles and near the southeastern corner of the map. The cause of a smaller positive anomaly near Templeton is not known but could be a buried hill or ridge of granitic or Franciscan basement rocks (Durham, 1974, Plate 2). Just southeast of Paso Robles, there is a southwestern reentrant in the gravity contours resulting in a negative anomaly located between the two prominent positive anomalies mentioned above. On Plate PG1, this negative anomaly appears to be a southwestern extension of a major negative anomaly that is present in the northern part of the map. South of Paso Robles, this negative anomaly is bounded on the southwest by a steep, nearly straight, northwest-trending gravity gradient. This gradient apparently coincides well with the southeastern extension of the San Marcos fault (Plate PG4 and Durham, 1974, Plate 1). This suggests a large vertical offset in the basement rocks along this fault zone, as also indicated by Durham (1974, Plate 3, Section M-M).

Trend-surface analyses for degrees 1 through 4 were made for the data on Plate PG1. The results of these analyses (not shown) do not provide significant new information about the gravity field except that the removal of low degree trend surfaces suggests a separate negative closure in the area south of Paso Robles.

Interpretation of the gravity data is aided by Plate PG4 which is a contour map of the basement surface based on well data. Although the data points are scattered, the basement contour map has a noticeable similarity to the gravity map. In particular, the northeastward-trending negative gravity anomaly south of Paso Robles apparently corresponds well with a buried depression or valley in the basement rocks in the same general area.

Plate PG4 also shows the location of the principal known hot water wells in the vicinity of Paso Robles. Some of these hot water wells are located within or near the area of the negative gravity anomaly and basement depression east and southeast of Paso Robles. Other wells in the immediate vicinity of Paso Robles appear to be on an approximately north-trending line that is close to a possible fault with a similar trend inferred in this area by Dibblee (1976, p. 21-22).

Whether the apparent association between some of the hot water wells and the negative gravity anomaly is real or not is uncertain. It is possible that a part of the negative gravity anomaly is caused by hydrothermal alteration of the basement rocks on a large scale in this area. However, it is evident from Plate PG4 that the gravity anomaly may be caused entirely by the configuration of the basement surface.

Magnetic Data

Aeromagnetic map. The aeromagnetic map (Plate PG2) has a marked similarity to the gravity map (Plate PG1) in the Paso Robles area. Northwest-trending positive aeromagnetic anomalies of more than 100 gammas each are associated with the granitic rocks just northwest of Paso Robles and near the southeastern corner of the map. Similarly, there is a magnetic low in the shape of a saddle between the two positive anomalies southeast of Paso Robles, and a negative anomaly in the northeastern part of the map.

The positive magnetic anomalies are evidently caused by the basement granitic rocks which must be moderately magnetic in this area. The negative anomalies may be related, at least in part, to the relatively large depth of burial of these rocks in some parts of the area. The size of the relative negative anomalies suggests, however, that changes in the composition of these rocks may also be involved. This evidence tends to support the gravity data that also suggest a possible difference in the basement rocks southeast of Paso Robles, possibly caused by hydrothermal alteration related to this part of the geothermal area.

Ground magnetic data. The ground magnetic contours (Plate PG3) show general agreement with the aeromagnetic map at least within the area surveyed. For example, the northwestward-trending positive anomaly, extending from northwest of Paso Robles southeast to the southeastern part of the map, is clearly shown. Also, the negative anomaly in the northeastern part of Plate PG3 corresponds to the aeromagnetic low in the same area.

Although the ground magnetic data show more detail than the aeromagnetic map, there is no obvious correlation with the known geothermal area. In detail, however, the ground magnetic data may show some indications of changes in the rock types in the near-surface Tertiary sedimentary rocks and may also show some evidence for faulting.

CONCLUSIONS

Gravity and magnetic data in the Paso Robles area generally reflect the regional trends of the basement rocks and the thickness of the overlying Tertiary sedimentary rocks. At least a part of the geothermal area is characterized by magnetic and gravity lows. The possible cause for these negative anomalies could be either a deep basin or a change in character of the basement rocks such as might result from hydrothermal alteration on a large scale. In other respects, however, there is little evidence in either the magnetic or gravity data to indicate any correlation with the known geothermal areas.

Detailed magnetic and gravity data show possible correlation in some places with known and possible faults, and may also suggest local differences in the Tertiary rocks. For example, the gravity data show good evidence for the San Marcos fault in this area.

Future work in the Paso Robles area includes planned electrical resistivity surveys, including Schlumberger vertical electrical soundings and dipole-dipole profiles, and possibly some refraction seismic work. When these additional data are available, it may be possible to delineate the location and extent of the geothermal resource in this area with more success.

References

Burch, S.H., Grannell, R.B., and Hanna, W.F., 1971, Bouguer gravity map of California, San Luis Obispo sheet: California Division of Mines and Geology, scale 1:250,000, 4 p. text.

Byerly, P.E., 1966, Interpretations of gravity data from the central Coast Ranges and San Joaquin Valley, California: Geological Society of America Bulletin, vol. 77, p. 83-94.

Chapman, R.H., 1966, The California Division of Mines and Geology gravity base station network: California Division of Mines and Geology Special Report 90, 49 p.

Dibblee, T.W., Jr., 1976, The Rinconada and related faults in the southern Coast Ranges, California, and their tectonic significance: U.S. Geological Survey Professional Paper 981, 55 p.

Durham, D.L., 1974, Geology of the southern Salinas Valley area, California: U.S. Geological Survey Professional Paper 819, 111 p.

Hanna, W.F., 1970, Aeromagnetic and gravity features of the western and Salinas basement terranes between Cape San Martin and San Luis Obispo, California: U.S. Geological Survey Professional Paper 700-B, p. 66-77.

Nettleton, L.L., 1940, Geophysical prospecting for oil: McGraw Hill Book Company, New York, 444 p.

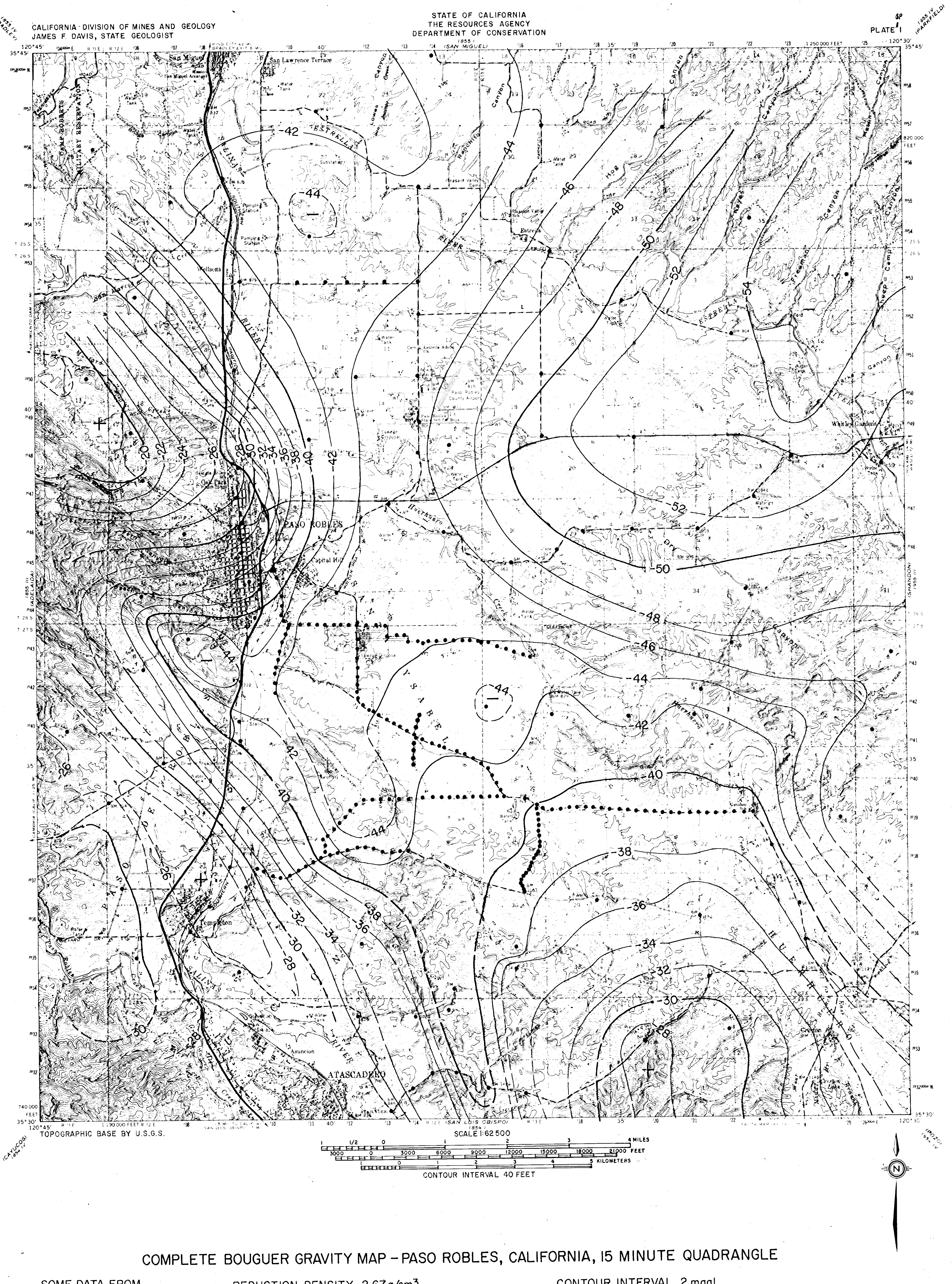
Plouff, Donald, 1977, Preliminary documentation for a FORTRAN program to compute gravity terrain corrections based on topography digitized on a geographic grid: U.S. Geological Survey Open-File Report 77-535, 45 p.

Swick, C.H., 1942, Pendulum gravity measurements and isostatic reductions: U.S. Coast and Geodetic Survey Special Publication no. 232, 82 p.

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF CONSERVATION

CALIFORNIA DIVISION OF MINES AND GEOLOGY
JAMES F. DAVIS, STATE GEOLOGIST

PLATE 1



COMPLETE BOUGUER GRAVITY MAP - PASO ROBLES, CALIFORNIA, 15 MINUTE QUADRANGLE

SOME DATA FROM
BURCH ET AL, (1971)
OTHER DATA BY L.G. YOUNGS

REDUCTION DENSITY 2.67 g/cm^3

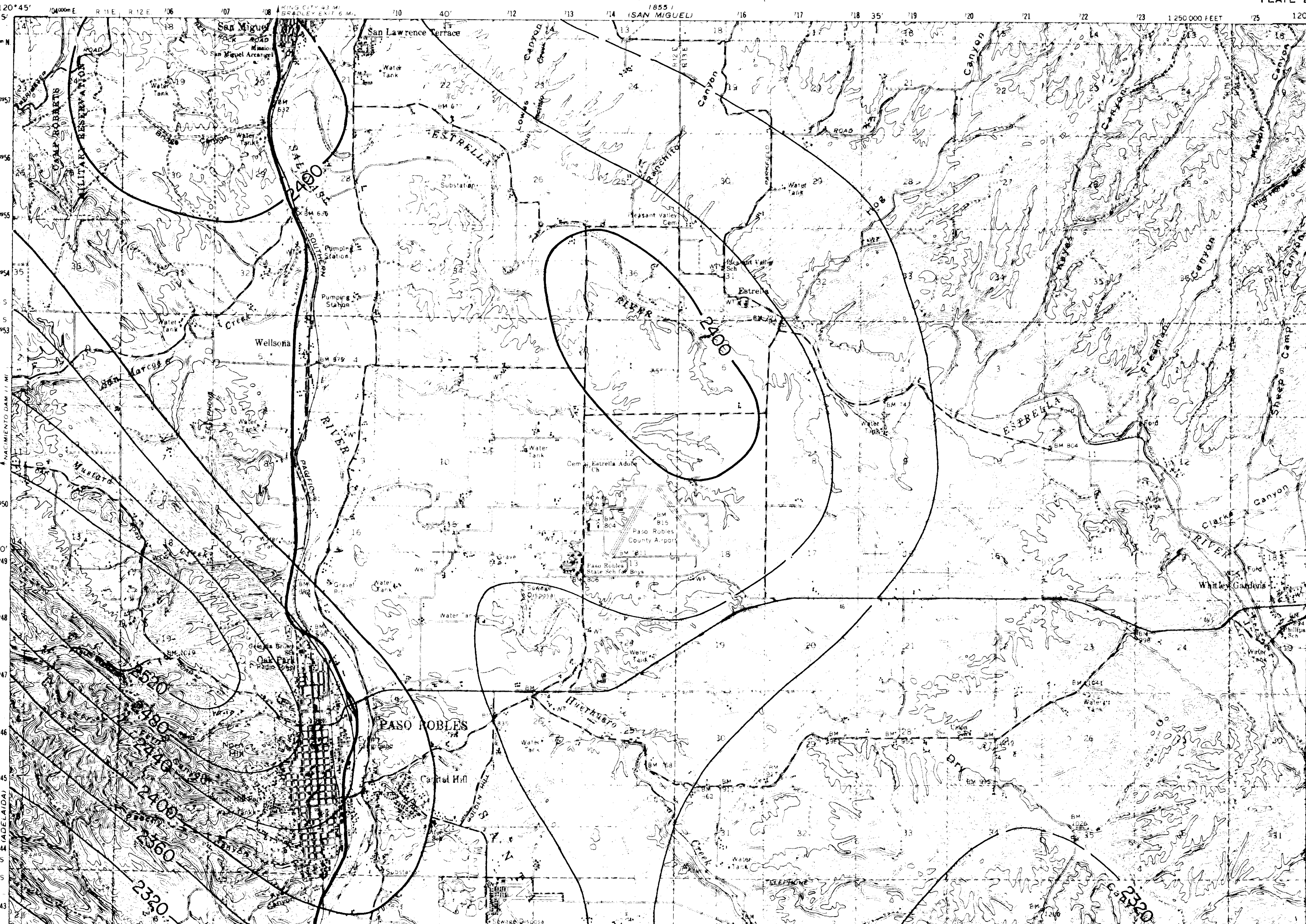
CONTOUR INTERVAL 2 mgal

• GRAVITY STATIONS

CALIFORNIA DIVISION OF MINES AND GEOLOGY
JAMES F. DAVIS, STATE GEOLOGIST

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF CONSERVATION

PLATE 2



TOPOGRAPHIC BASE BY U.S.G.S.

AEROMAGNETIC MAP OF PASO ROBLES, CALIFORNIA, 15 MINUTE QUADRANGLE (AFTER HANNA, 1970)

1 0 1 MI.

CONTOUR INTERVAL 40 GAMMAS

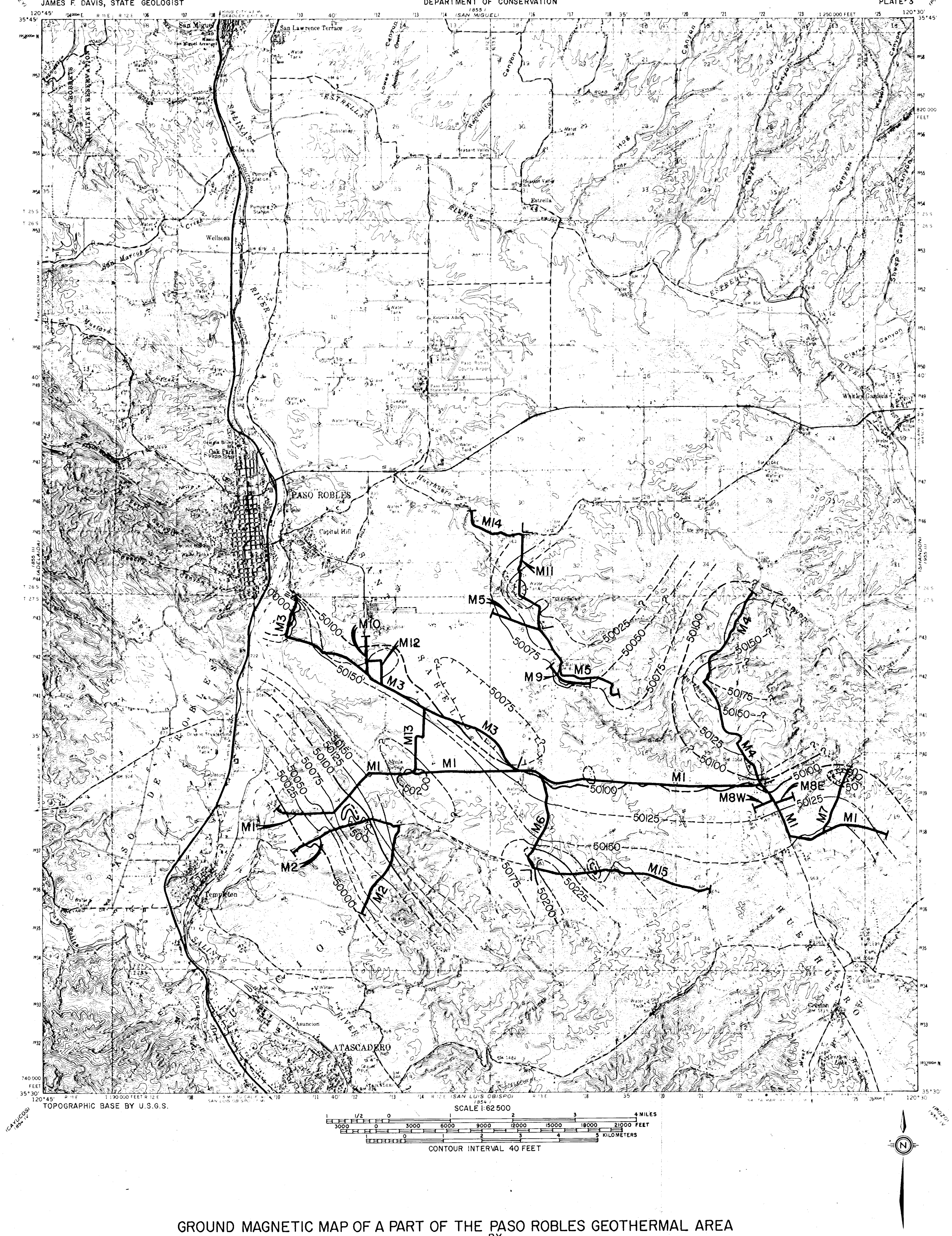
SCALE 1:62 500

CONTOUR INTERVAL 40 FEET

CALIFORNIA DIVISION OF MINES AND GEOLOGY
JAMES F. DAVIS, STATE GEOLOGIST

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF CONSERVATION

PLATE 3



GROUND MAGNETIC MAP OF A PART OF THE PASO ROBLES GEOTHERMAL AREA

BY

L.G. YOUNGS, G.W. CHASE, R.H. CHAPMAN

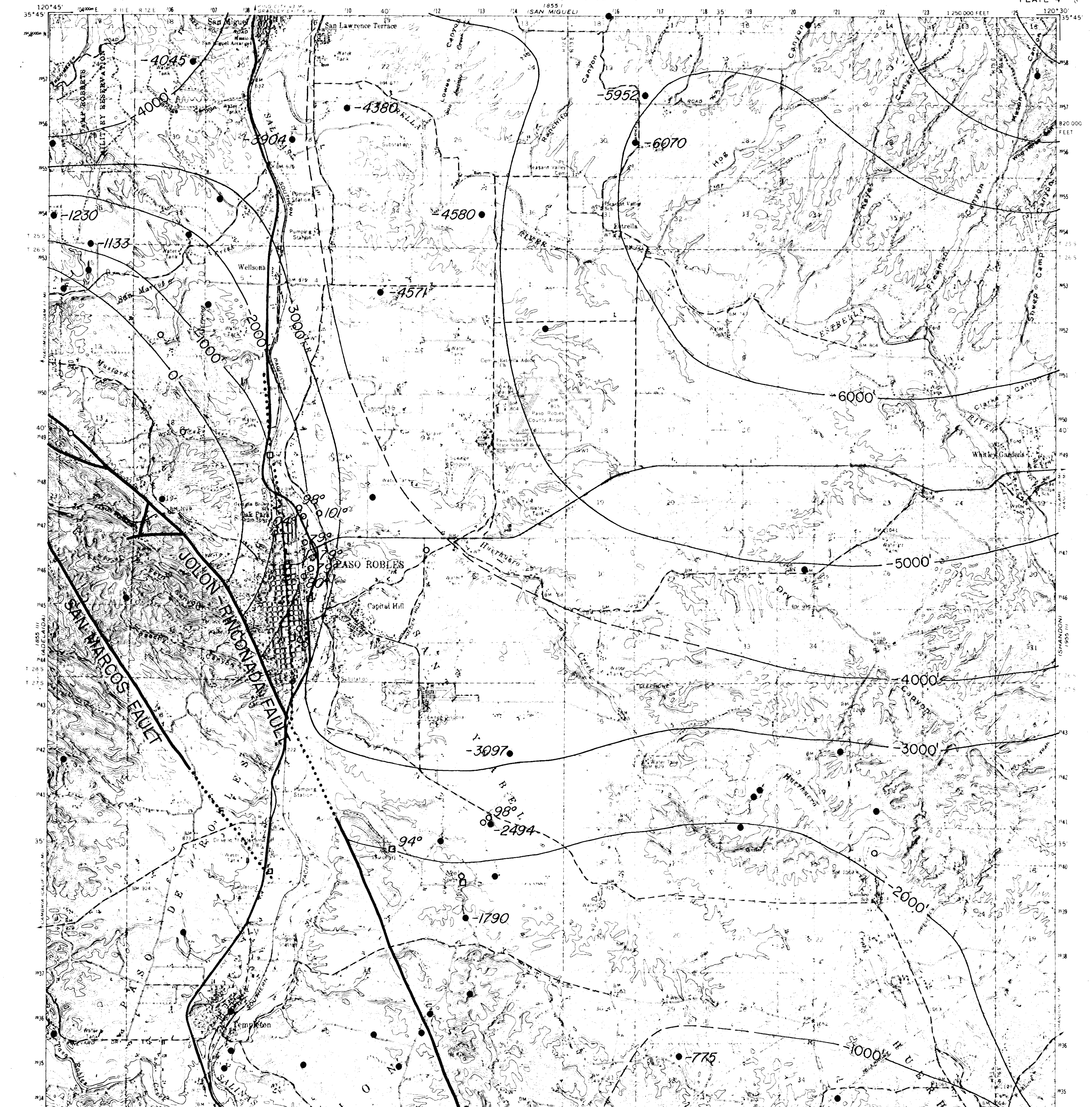
M2 MAGNETOMETER TRAVERSE

CONTOUR INTERVAL 25 GAMMAS

CALIFORNIA DIVISION OF MINES AND GEOLOGY
JAMES F. DAVIS, STATE GEOLOGIST

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF CONSERVATION

PLATE 4



TOPOGRAPHIC BASE BY U.S.G.S.

○ HOT WATER WELL, TEMP. IN °F

□ SPRING

● WELL TO BEDROCK

—— FAULT

•••••• CONCEALED FAULT

MAP SHOWING CONTOURS ON TOP OF BASEMENT, WELLS, AND MAJOR FAULTS, PASO ROBLES 15 MINUTE QUADRANGLE, CALIFORNIA

(MODIFIED FROM DURHAM, 1974, AND DIBBLEE, 1976)

(DATUM — SEA LEVEL)

BY: L.G. YOUNGS

SCALE 1:62 500

1 ½ 0 1 2 3 4 MILES

3000 0 3000 6000 9000 12000 15000 18000 21000 FEET

1 0 1 2 3 4 5 KILOMETERS

CONTOUR INTERVAL 40 FEET