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RESOURCE INVESTIGATION OF
LOW- AND MODERATE-TEMPERATURE GEOTHERMAL AREAS IN
SAN BERNARDINO, CALIFORNIA

Part of the Third Year Report, 1980-81, of the
U.S. Department of Energy-California State-Coupled Program
for
Reservoir Assessment and Confirmation

by

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MASTER

August, 1981

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CITY OF SAN BERNARDINO

SAN BERNARDINO COUNTY CAL.

1871.

Frontispiece

ABSTRACT

Resource Investigation of Low- and Moderate-Temperature Geothermal Areas in San Bernardino, California

The California Division of Mines and Geology (CDMG) selected the San Bernardino area for detailed geothermal resource investigation because the area was known to contain promising geothermal resource sites, the area contained a large population center, and the City of San Bernardino had expressed serious interest in developing the area's geothermal resource.

Ninety-seven geothermal wells and springs were identified and plotted on a compiled geologic map of the 40-square-mile study area. These wells and springs were concentrated in three distinguishable resource areas: Arrowhead Hot Springs; South San Bernardino; and Harlem Hot Springs -- in each of which detailed geophysical, geochemical, and geological surveys were conducted. The Arrowhead Hot Springs geothermal area lies just north of the City of San Bernardino in the San Bernardino Mountains astride a shear zone (offshoot of the San Andreas fault) in pre-Cambrian gneiss and schist. The Harlem Hot Springs geothermal area, on the east side of the City, and the south San Bernardino geothermal area, on the south side, have geothermal reservoirs in Quaternary alluvial material which overlies a moderately deep sedimentary basin bound on the southwest by the San Jacinto fault (a ground water barrier). Geothermometry calculations suggest that the Arrowhead Hot Springs geothermal area, with a maximum reservoir temperature of 142°C, may have the highest maximum reservoir temperature of the three geothermal areas. The maximum temperature

recorded by CDMG in the south San Bernardino geothermal area was 56°C from an artesian well, while the maximum temperature recorded in the Harlem Hot Springs geothermal area was 49.5°C at 174 meters (570 feet) in an abandoned water well.

The geophysical and geological surveys delineated fault traces in association with all three of the designated geothermal areas. The gravity survey revealed a heretofore unmapped, east-west trending fault that bisects the Harlem Hot Springs geothermal area. The dipole-dipole resistivity survey suggested a more refined location of a segment of the Loma Linda fault, slightly to the southwest of the previously reported location in the South San Bernardino geothermal area. Interpretation of data from the geophysical, geological, and geochemical surveys and from temperature data indicates the presence of a major geothermal fluid up-welling, or "plume", along this segment of the Loma Linda fault. The data also suggest that other geothermal fluid "plumes" in association with faulting are present within the three designated geothermal areas.

PREFACE

This report presents the results of the California Division of Mines and Geology's (CDMG) geothermal resource investigation of the San Bernardino area, California. The project was conducted in compliance with the terms of the third year contract (1980-81) with the U.S. Department of Energy (DOE) under the state-coupled program. The investigation was performed under CDMG's Phase II site-specific geothermal resources studies program. Phase II type studies involve the generation of new data and evaluation and interpretation of the data to make quantitative and qualitative statements about the resource potential of a given geothermal reservoir.

The purpose of the study was to determine the low- to moderate-temperature geothermal energy potential of the many known "hot" water wells and several hot springs occurring in or very near the San Bernardino area. A low- to moderate-temperature geothermal resource in association with an urban center suggests many potential uses of the resource. The City of San Bernardino, which has a population of approximately 117,000 according to the 1980 census, and other local government agencies have expressed interest in utilizing the geothermal resource. This is particularly true of the City of San Bernardino Municipal Water Department.

Concern over dwindling fossil fuel supplies and interest in finding alternate forms of energy in recent years has been responsible for renewed activity in efforts aimed at utilization of low- and moderate-temperature geothermal resources statewide. The City of San Bernardino Municipal Water Department, recognizing this trend, is currently undertaking a project to use

the geothermal resource at San Bernardino to heat the sludge digester at their waste water treatment plant. They are also currently conducting feasibility studies to determine the possibility of establishing a municipally owned direct-use geothermal heating district in San Bernardino.

Historically, the geothermal resources at San Bernardino have been considered as a benefit for health and recreation uses and as a nuisance in any ground water development project.

Health spas and amusement parks were erected at original hot springs sites. When water tables lowered as population and agricultural usage of ground water increased, wells were drilled into the old hot springs to keep geothermal water supplies available to the spas and parks. The health spas and amusement parks eventually succumbed to progress and a loss of popularity. Most were closed and abandoned by the 1930's.

Increasing agricultural growth and, later, urban expansion created a greater demand for fresh ground water supplies at San Bernardino. In the quest for sufficient fresh water, more and deeper water wells were drilled. Geothermal water-bearing aquifers were sometimes encountered during drilling. The hot water generally made these wells useless as a fresh water supply. Great effort was made to backfill wells to seal off the "hot" water aquifers. Many wells were eventually abandoned because the water was too hot or too mineralized for agricultural or domestic uses.

Once considered a nuisance, the abandoned geothermal resources at San Bernardino are now being considered as a viable alternate energy source for the area.

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INTRODUCTION

The purpose of this study is to provide insight into the properties of the geothermal resources at San Bernardino. Areal extent, depth, maximum temperature, volume, and water quality are properties that must be ascertained before effective and economical development of a low- or moderate-temperature geothermal resource is undertaken. This report outlines the steps taken to accomplish this end and presents results, conclusions, and recommendations obtained from the study. Included are new studies of historical development of the resource, detailed and regional geology investigations, geophysical surveys, regional seismicity study, geothermometry calculations, and results of geochemical sampling and temperature measuring of geothermal wells and springs in the area. Valuable down-hole geothermal well data is included in the appendixes of this report. At the end of the report is a list of selected references. The list contains 126 entries of geological, hydrological, geophysical, geochemical, and geothermal studies of the San Bernardino area. The reference list should prove useful for finding further geotechnical information about the area.

This report presents a wealth of new material as well as a compilation of previously performed studies singularly assembled for the purpose of investigating the geothermal resources of the San Bernardino area. The report should be useful in a number of ways. Firstly, data presented and conclusions drawn from the data provide a direct insight into the physical and geochemical character of the geothermal resources of San Bernardino. This report is perhaps the first major work to be wholly focused on investigating these geothermal resources. Secondly, the report serves as a source of geothermal data that

could be analyzed in different ways by other geothermal resource investigators. For instance, other geothermometry calculations than the Na-K-Ca geothermometer (Fournier and Truesdell, 1973 and Fournier and Potter, 1978) may be applied to the geochemical data in Appendix A. A different geologic and hydrologic cross-section than the one presented on Plate 2 may be constructed from the geologic well logs in Appendix C. Or perhaps some useful information may be obtained by calculating temperature gradients from the down-hole temperature logs in Appendix B. And thirdly, this report can serve as a reference for some low- and moderate-temperature geothermal investigative techniques complete with an evaluation of their effectiveness in the San Bernardino geothermal resource assessment area.

This report may be the first comprehensive detailed geothermal study of the San Bernardino area, but it is not meant to be the last geothermal study of the area. Concepts and conclusions arrived at in this report should be continually revised, modified, and upgraded as new data from other researchers are developed for the geothermal resources at San Bernardino.

DEVELOPMENT OF THE GEOTHERMAL RESOURCES
OF THE SAN BERNARDINO AREA

Introduction

One of the the major and least expensive elements of a geothermal resource area evaluation program should be the researching and compiling of the historic development of that resource. This is an especially applicable exploration technique of low- and moderate-temperature geothermal resource areas of California.

Most often, in the past, California's warm or hot springs were developed as resort spas or tuberculosis sanitariums where guests arrived for relaxation and to take "the treatments". As a result much literature has survived from that era advertising and extolling the chemical and physical properties of various hot springs. A search of such material and other information can yield valuable clues to the past character of a particular geothermal area. Areal extent of the resource, changes in flow rates over the years, changes in water quality, changes in temperature, and changes in hot water table evaluations can often be discerned from the historical record of a geothermal area.

The City of San Bernardino area at one time contained six developed "hot springs". There is much historic literature available for some of these "springs" and little available for the others. The geothermal historic record of the area is not only augmented with material written about these "springs", but also by early ground water investigations and reports.

Development of the Hot Springs

Arrowhead Hot Springs

The Arrowhead Hot Springs are located on the south flank of the San Bernardino Mountains slightly less than 10 km (6.3 miles) north of the center of the City of San Bernardino (Plate 1, Locations No. 3-7). The springs and wells at Arrowhead Hot Springs are generally located in a narrow band along a small mesa or plateau and in an adjoining narrow gully or canyon.

One of the earliest recorded accounts of temperature and flow rate at Arrowhead Hot Springs is from Blake (1856):

"Around the borders of the valley (San Bernardino Valley) there are numerous localities of thermal springs. The warm and hot waters gush out from the granitic rocks on the flanks of San Bernardino and the adjacent heights. In one place the springs are so numerous, and the water rises in such volume, that a good sized mill-stream of hot water is formed, which flows down into the valley and is one of the principal tributaries of the Santa Ana River. This brook of hot water retains a temperature of 100°F three or four miles from its source...I regret that I could not visit its source, as the springs must be numerous, and of great volume and high temperature, to send forth such a large stream of water, retaining its temperature a long distance from the mountains."

When Blake passed near the hot springs no structures had as yet been built there. In fact the hot springs were not apparently named. The name "Arrowhead Hot Springs" seems to have been adopted circa, 1875-1876. The name was derived from a large arrowhead shaped patch of vegetation on a hillside above the springs (Figure 1).

Figure 1. The Arrowhead Springs sanitarium facility and adjoining pond in 1883. Note arrowhead shaped landmark on hillside in background. (From Thompson, R.D., 1976, p.5).

Bauer (1959) cites another early account, issued in 1858 by a committee of the California State Agricultural Society, about the undeveloped hot springs:

"Some six miles from the town (San Bernardino) is a series of springs issuing from the side of the mountain, of such a variety of temperature as to afford bathing to suit any class of nerves, and of such medicinal properties as to promise great benefit to the invalid-world who may be favored with its use. In a few years these springs will become as popular as the celebrated White Sulphur Springs of Virginia, and he who shall prudently invest there, making improvements as they are demanded, will insure a fortune."

The advice to "prudently invest" apparently did not go unheeded. David Noble Smith purchased the hot springs property in 1863 and established a rudimentary, if not ramshackle, tuberculosis sanitarium. Some improvements were made, but eventually the facilities had to be leased and subsequently mysteriously burned to the ground in 1885. The replacement facilities and hotel were at least partially geothermally heated (Figure 2). According to the advertisement (Figure 2) from the 1887 San Bernardino City and County Directory, Arrowhead Hot Springs Hotel was "the only hotel in the world warmed by hot water from natural heat..." The resort was destroyed in an 1895 fire. A new hotel of great grandeur was erected at Arrowhead Hot Springs in 1905 (Figure 3). The new owner also bought the adjacent Waterman Ranch which was the site of Waterman Hot Springs approximately 0.8 km (0.5 mile) west of Arrowhead Hot Springs.

The hotel at Arrowhead Hot Springs burned again in 1938. In 1939 a lavish new structure was dedicated with an opening party attended by "Hollywood's finest" and broadcast nation wide on radio. After a succession of owners and lapses into disarray, including a two year stint as a hospital during World War II, the ownership of the resort fell into the hands of the "Campus Crusade for Christ" in 1962. The Arrowhead complex, including the Waterman Hot

Arrow-Head Hot Springs,

SAN BERNARDINO CO., CALIFORNIA.

Are located six miles north of San Bernardino.

Altitude, 2,000 feet.

They derive their name from a peculiar blaze on the mountain side, just above and pointing toward the Springs, and in its outlines exactly resembling the well-known Indian arrow-head; its length being 1,220 feet, and greatest width 350 feet, and area five acres. Plainly visible 25 miles.

No Fog, Pure Air and Pure, Cool Mountain Water, and the extent of Mountain Scenery is Unsurpassed. Hotel Accommodations First-Class.

A steam bath over a spring of mineral water, whose temperature is 190 degrees, is something unknown, except at Arrow-Head Springs, and as a curative agent challenges the investigation of all who are suffering from disease that may be reached by such remedies.

We now have pipes laid and our building heated by hot water just as it comes from the Springs, giving a heat far superior to stove or grate, and as a novelty we claim it is the only hotel in the world warmed by hot water from natural heat, which keeps the temperature equalized day and night.

This popular but new resort will be kept open Summer and Winter, and we most cordially invite all to come and test the truth of what we claim for these Springs. Bring a pair of sweat blankets.

LAUNDRY WORK DONE AT THE HOTEL.

A Daily Stage Conveys Passengers and Mail Between San Bernardino and the Springs.

BOARD AND LODGING \$8.00 TO \$12.00 PER WEEK.

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SAN BERNARDINO, CAL.

Figure 2. Advertisement for the Arrow-head Hot Springs resort from page 46 of the 1887 San Bernardino City and County Directory. Note the paragraph of small print in the center of the advertisement reports 190° (F) temperature and that the hotel has utilized the geothermal resource for direct use space heating.

ARROWHEAD HOT SPRINGS

FIVE MILES NORTH OF
SAN BERNARDINO

Hottest Curative Springs in the World
Hotel First Class in Every Respect

For Booklet, etc., Address
Arrowhead Hot Springs Hotel Company
Arrowhead, California

Arrowhead Hot Springs Hotel

Urbita Hot Springs

Nature's Own Laboratory

Tub Baths

Large Bathing Pavilion

Beautiful Lake,
Gasolene Launch
and Row Boats

Large Picnic
and Pleasure
Grounds

FOR PLEASURE, HEALTH AND RECREATION, URBITA HOT SPRINGS
IS UNSURPASSED. OPEN DAILY FROM 8:00 a. m. to 9:00 p. m. SPECIAL
DAY AND HOURS FOR LADIES, TUESDAYS, 11:00 a. m. to 3:30 p. m.

REACHED VIA

The San Bernardino Valley Traction Co.

Electric Car Depot, Third Street, between C and D, San Bernardino,
WALTER E. SMITH, SUPERVISOR A. C. BERMAN, JR., GENERAL MANAGER

Figure 3. Advertisements for two developed hot springs in the City of San Bernardino area from the souvenir program for the "San Bernardino Festival of the Arrowhead", May 19-23, 1908.

Springs, is now the International Headquarters of that organization. Many improvements have been made and the facility completely restored.

There is no current direct usage of the geothermal resources at Arrowhead Hot Springs other than natural steam room facilities in the basement of the refurbished hotel. There is some interest in exploring the feasibility of geothermal space heating at the facilities once again.

The following is a cronological listing of historical statements about the geothermal temperatures at Arrowhead Hot Springs:

San Bernardino Weekly Argus, March 18, 1875.

"Bath rooms are also fitted up inside the building (the original tuberculosis infirmary at Arrowhead Hot Springs), and there you can get whatever temperature of (geothermal) water you desire, up to 140 degrees (F) (60°C). The vapor baths, situated about 200 yards from the house, are strongly impregnated with sulphur, and are said to be the hottest in the state. This has been thoroughly overhauled and you can enjoy the luxury of a (natural) steam bath".

California Division of Mines and Geology, 1886.

"One spring (at Arrowhead Hot Springs) actually boils, having a temperature of 210°F (99°C).

San Bernardino City and County Directory, 1887.

"A steam bath over a spring of mineral water, whose temperature is 190 degrees (F) (88°C), is something unknown, except at Arrow-Head Springs..."

The Journal of the American Medical Association, 1893, reprinted in The San Bernardino Sun, June 7, 1968.

"The springs (Arrowhead Hot Springs), 20 in number, occupy an area of about two acres...Their temperature ranges from 99 degrees to 193 degrees F (37°-89°C)--or not far below the boiling point of water--their average being much higher than at either Carlsbad or Arkansas."

At some time in the past a few of the larger springs at Arrowhead were developed and given individual names. These names have since fallen into disuse. Bailey, 1910, (below) recorded temperatures for each of these individually developed hot springs at Arrowhead.

Bailey, 1910.

Arrowhead Hot Springs:

Penyugal Hot Spring—198°F (92°C), Plate 1, Location No. 5.

Palm Hot Spring—180°F (82°C), Plate 1, Location No. 6a.

Granite Hot Spring—158°F (70°C), Plate 1, Location No. 4.

Wheeler, 1912.

"There are thirty-four hot-water springs ranging in temperature from 180 degrees to 202 degrees Fahrenheit (82°-94°C), and two cold-water springs (at the Arrowhead Hot Springs)...

Natural steam-caves with an air-temperature of 210 degrees Fahrenheit (99°C) are an odd attraction in themselves."

Waring, 1915.

"...The springs form two groups situated about 400 yards apart. The upper group comprises perhaps half a dozen springs whose observed temperatures range from 110°(F) (40°C) to 145°(F) (63°C). The Palm Spring, on the mesa north of the hotel, is in this group. The second group lies in a ravine to the west and also comprises about half a dozen springs...The hottest water is in the spring known as El Penyugal, in the lower group...A temperature of 187°(F) (86°C) was recorded in the basin and in sampling for one of the analyses the basin was drained and a temperature of 202°(F) (94°C) registered."

Craig, et al, 1980.

Figure 4 is a graph of recorded temperatures in the "Granite Hot Spring" at Arrowhead Hot Springs from 1975-1980.

CDMG, 1980-81 (For this report).

Table 1 is a comparison of recorded temperatures at Arrowhead Hot Springs from CDMG's (1980-81) geothermal investigation versus Bailey's (1910) measurements.

The geothermal temperatures at Arrowhead Hot Springs have changed very little in the past 100 years. Today there still is near boiling water issuing

Figure 4. Recorded temperatures in a 3 feet diameter 2 feet high brick or rock, open and flowing reservoir at site of "The Granite Spring" at Arrowhead Hot Springs from Craig, H., et al. 1980, p. 16.

FOOTNOTE *1 Temperature of 81°C recorded during CDMG Geothermal Survey on November 14, 1980.

	Bailey, 1910	CDMG, 1980-81
Arrowhead Hot Springs		
"Palm Hot Spring"	(82°C), 180°F	84°C, (183°F)* ¹
"Penuygal Hot Spring"	(94°C), 202°F	87°C, (189°F)
"Granite Hot Spring"	(70°C), 159°F	81°C, (178°F)
Waterman Hot Springs* ²	(70°-93°C), 158°-200°F	81°C, (178°F)* ³

Table 1. A comparison of recorded temperatures at Arrowhead Hot Springs by CDMG (1980-81) and Bailey (1910).

FOOTNOTES: *¹ Temperature measured by maximum recording thermometer lowered 100 feet into "Mud Bath Well."

*² Waterman Hot Springs included for comparison.

*³ Temperature measured in discharge of flowing well of unknown depth at Waterman Hot Springs.

at the surface in many places. The waters at "Palm Hot Spring" and "Granite Hot Spring" are currently hotter than the 1910 measurements (Table 1). Wells were drilled into these springs and the hot water now flows from some unknown depth rather than naturally emitting at the surface. This probably accounts for the current hotter temperatures. On the other hand, "Penyugal Hot Spring" is cooler than the 1910 temperatures. No well has been drilled at this site. The spring has fallen into complete disarray over the years possibly with the result that sediment or debris may be impeding the natural flow to the surface. This impedance may allow the waters to cool more near the surface than in the past when the spring was clear of debris and maintained. However, the "Penyugal Hot Spring" still registers the hottest surficial temperature of all the springs/wells at Arrowhead. With the drilling of the wells at Arrowhead Hot Springs, temperatures appear to be more homologous, including the water temperature in a well at the nearby Waterman Hot Springs (Table 1).

Although no flow rates were directly measured during the CDMG (1980-81) survey, an estimate was made that from 100-200 gpm of geothermal waters flow from all sources at Arrowhead Hot Springs, compared to Waring's (1915) estimate of 50 gpm. The difference is probably due to the past drilling of the wells now flowing at Arrowhead.

Waterman Hot Springs

The Waterman Hot Springs are approximately 0.8 km (0.5 miles) west of the Arrowhead Hot Springs (Plate 1, Location No. 1). The hot waters issue from an alluvial terrace deposit that, along a short stretch, forms the east bank of the Waterman Canyon.

Blake (1856) visited these springs and described them in his report as well as made temperature measurements. There were no structures at the springs in 1856.

(At Waterman Hot Springs) "I visited several of the springs on the side of the Sierra, between San Bernardino mountain and the Cajon Pass...Small springs rise at intervals of ten to twenty feet, along a distance of thirty or forty rods. Their waters unite and form a little stream that empties into the brook, a short distance below...The rocks and gravel, in contact with the water, were covered with a snow-white incrustation...

...Some of (the springs) boil up among a mass of granite boulders and gravel, and others run out from the side of a bank of loose detritus or drift overlying the granite.

...The rock around the springs is sensibly warm to the hand, at a distance of four feet or more from the orifices. There are no indications of...volcanic rocks in that vicinity; nor is it at all probable that San Bernardino is volcanic. It has the appearance of granite."

An apparent attempt to establish a health spa or sanitarium at Waterman Hot Springs at about the same time as Smith's enterprises at the nearby Arrowhead Hot Springs failed and the property sold to Robert Waterman in 1874 to be used as a ranch retreat. The springs thereafter bore his name. (Waterman was elected governor of California in 1887).

The Waterman Ranch and hot springs were purchased and added to the Arrowhead Hot Spring complex in 1904 and the properties have been adjoined ever since. Wooden cabins and small bath houses were built around the springs at some unknown date. Eventually concrete "steam caves" were erected against the gravelly east bank of Waterman Canyon. The rear of each "cave" was left open into the gravel where hot water seeped into the structure.

Waring (1915) visited Waterman Hot Springs in 1908 and found the place in disrepair.

"...These springs have been used to some extent for bathing, but when visited in 1908 the accommodations had evidently not been kept in repair for several years and there was only a slight flow of water from a small marshy area and a pool beneath a bank at the creek side."

Apparent revitalization occurred at Waterman Hot Springs over the next two years including projects to utilize the geothermal heat from the springs. Bailey (1910) writes a glowing account of Waterman Hot Springs:

"...The springs issue from the hot belt formation for a distance of several hundred feet in length along the face of the exposed section, the water bursting forth at many points between the level of the creek and the base of the conglomerate which lies from five to 25 feet above the creek. Caves have been formed in several places in the conglomerate that will be enlarged into ideal vapor bath rooms...In fact there is sufficient water here to supply a large Sanitarium that could be wholly independent of the Arrowhead group of springs...Only one spring has been welled in so as to pipe the waters down to the buildings where Governor Waterman lived many years ago. The waters of this spring are piped to the chicken house where thousands of chickens are kept to supply the Arrowhead Hotel table. The hot water is used in the incubators, as well as for all domestic purposes at the Waterman ranch."

Little development remains at the Waterman Hot Springs today. Only the concrete "steam caves", partially broken and partially debris filled, and a well (Plate 1, Location No. 2) are visible at the site. No use is made of the resource save for an occasional trespasser who partakes of the decaying "steam caves".

Small to medium-size hot water seeps are evident in the rear of each of the "steam caves". The gravels at the rear of most of the "caves" are mineralized as described by Blake (1856) above.

A chronological historical list of temperature measurements and comments on flow of Waterman Hot Springs follows:

Blake, 1856.

"The following temperatures of different springs were observed:
172°(F) (78°C), 169°(F) (76°C), 130°(F) (54°C), 128°(F) (53°C),
108°(F) (42°C)

...The temperature of the hot stream, below all the springs, was found to be 130°(F) (54°C)..."

Frazee, 1876.

At Waterman Hot Springs there is..."about forty hot springs and a stream of cold mountain water."

Waring, (1915) on data collected in 1908.

Waring reports..."a slight flow of water from a small marshy area...." He further reports on one spring at the Waterman Hot Springs site as yielding 5 gpm at 123°F (51°C).

Bailey, 1910.

"...the water bursting forth at many points...In fact there is sufficient water here (Waterman Hot Springs) to supply a large Sanitarium...

The temperature of these springs ranges from 158 to 220 degrees F (70°-93°C)."

CDMG, 1980-81 (For this report).

There is perhaps a 75-100 feet wide area of hot water seeps that yielded less than 10 gpm collectively in April, 1981. A well at the site (of unknown depth) was opened (April, 1981) and flowed at approximately 30-50 gpm. The temperature in the discharge was 81°C (178°F).

If all the accounts above are believable, then there may have been some large fluctuations in surficial temperature and flow rate at Waterman Hot Springs over the past 100 years or so. However, the data are very limited and the springs have been in various stages of development and maintenance when temperatures were recorded. The variation in temperatures of the small seeps

or springs at the site may be caused by the different circulation paths, amount of contact and mixing with cooler surficial fresh waters, transmissibility of the aquifer, etc.

The best indication of surficial or near surficial temperatures available at Waterman Hot Springs today is the 81°C (178°F) measured by CDMG in the flowing well at the site. The temperature compares favorably with present day temperatures at nearby Arrowhead Hot Springs (Table 1).

Urbita Hot Springs

The Urbita Hot Springs were located south southeast of the "Y" intersection of Colton Avenue and "E" Street in San Bernardino (Plate 1, Locations No. 42 and 43). Unlike Arrowhead or Waterman Hot Springs, Urbita was originally developed as a tourist attraction or recreational park rather than a tuberculosis sanitarium (Figure 3).

Crafts (1906) claims Urbita Hot Springs were born of an 1812 earthquake in the following account:

"The year 1812, known in history as "el ano de los temblores" (the year of earthquakes), found the valley (San Bernardino) peaceful and prosperous...

"When the strange rumblings beneath the earth commenced and frequent shocks of earthquake were felt,...The hot springs of the valley increased in temperature to an alarming extent; a new hot mud spring appeared near Politano, now called Urbita."

The Urbita Hot Springs area may have been first developed into a mineral bath and amusement park in the late 1860's. Apparently the facilities

slightly declined over the next forty years, but a revitalization at the turn of the century turned Urbita into a major and very popular amusement and resort area. Water from natural hot springs was piped 1,000 feet (305 meters) into the plunge (swimming pool). A man-made lake was filled apparently from artesian hot water wells and hot mineral baths were available. The amusement park declined and was sold in 1924.

Circa 1929 an article appeared in a local newspaper describing a plan to drain Urbita Springs because commercial development of peat deposits is "contemplated along Pickering Slough and the swampy land adjacent to Lytle Creek in the Urbita District...where peat has been found to a depth of three feet over a considerable area." In 1950, the San Bernardino Audubon Society established the area in and around Urbita Hot Springs as a wildlife refuge. The refuge did not survive for in 1966 the first contracts for the Inland Shopping Center were let.

The Urbita Hot Springs were destroyed. The site is completely buried under parking lots and department stores of the Inland Shopping Center complex. Old wells cannot be found. Apparently the site was excavated and removed to a depth of 12 feet (3.7 meters) and backfilled prior to construction of the shopping center. There is a large subteranean drain that passes under part of the shopping center and surfaces just east of the Interstate 15E freeway. A trickle of water in this drain is the last vestige of Urbita Hot Springs.

An account of historically measured geothermal water temperatures at Urbita Hot Springs follows:

Mendenhall, 1905.

"The water of the Urbita Springs well has a temperature of 102° to 105°(F) (39°-41°C), and other wells which have been mentioned near the Bunker Hill dike exhibit temperatures ranging from 70° to 90°(F) (21°-32°C)."

Waring, 1915.

Waring lists Urbita Hot Springs as consisting of 6 artesianing wells ranging in temperature from 80°-106°F (27°-41°C). "The warmest well yields about 200 gallons a minute of mildly sulphureted water that is said to have a temperature of 106°(F) (41°C)..." Apparently all 6 wells in toto flowed at about 250 gpm.

CDMG, 1980-81 (For this report)

No wells were found at the Urbita Hot Springs site during the CDMG geothermal investigation. Hence, no modern temperatures of the resource (if there still is a resource) could be recorded.

De Sienna (Siena) Hot Springs

The De Sienna Hot Springs spa (Plate 1, Location No. 40) was located on the southeast flank of a small knoll, sometimes referred to as "Bunker Hill", approximately 1 km (0.6 miles) southwest of the Urbita Hot Springs site (Inland Shopping Center). None of the early publications cited above mention "De Sienna Hot Springs."

Mendenhall, 1905, shows a well (Plate 1, Location No. 39) of 48 meters (158 feet) deep and 85°F (29°C) at this site on his "Hydrologic Map of San Bernardino, Redlands, and Vicinity". A local resident recalls swimming in the "De Sienna Hot Springs" plunge in the 1920's and 1930's. It appears that the spa was developed between 1910 and 1920 and nourished by a hot water well rather than a natural spring.

The geologic log, in Appendix C, for the well at Location No. 40 on Plate 1 indicates that this well was drilled in 1926 at "De Sienna Hot Springs" and had a temperature of 37°C (99°F) at 148 meters (485 feet). The well was drilled to 167 meters (547 feet).

The facility was completely bulldozed down in 1974. No trace of the wells, swimming pool, bath house, nor small wooden office tower remains.

Harlem Hot Springs

The Harlem Hot Springs spa is just north of the intersection of Baseline Road and Victoria Avenue (Plate 1, Locations No. 15a-d). Originally, natural hot springs issued forth at the site and flowed into Warm Creek. But, in 1898, according to Mendenhall (1905), a well (Plate 1, Location No. 15a) was drilled 91 meters (300 feet) into the spring and produced geothermal waters of 46°C (115°F).

The hot springs were developed very early in San Bernardino history as a recreation park and picnic area and provided mineral water and mud baths. Swett (1967) recounts the following from a 1910 "San Bernardino Sun" article:

"Harlem Springs is one of the oldest pleasure resorts in the valley, and for many years was practically the only resort of any proportions near this city...Besides the hot springs and buildings, which cost several thousand dollars, the resort includes twenty acres of land."

Facilities at Harlem Hot Springs gradually deteriorated through fires and changing public interest in such spa activities. However, some spa type

activities associated with the geothermal resource have periodically been revitalized at Harlem Hot Springs.

Currently an old green painted hotel type structure and out cabins are being utilized as a low rent apartment complex at the Harlem Hot Springs site. A nearby one story spa structure with an imitation Roman colonnade facade is being operated as a spa and massage parlor. Apparently, a hot water well located in the parking lot next to the spa is used in the operation of the facilities. No information about the well or the spa's use of it could be obtained from employees or the owner of the facility.

The maximum reported temperature found in historic literature for a well at Harlem Hot Springs was 130°F (54°C) at 194 feet (59 meters) in a well drilled in 1912 (Plate 1, Location No. 15c). Comments on the lowering geothermal water table and water temperatures at Harlem Hot Springs are mentioned below in the account of the nearby Rabel Hot Springs.

Rabel Hot Springs (Base Line Laundry)

The Rabel Hot Springs were located approximately 0.4 km (.25 mile) west of the Harlem Hot Springs (Plate 1, Locations no. 14, 16, and 17). Little can be learned of the early days of Rabel Hot Springs. Records show that on January 5, 1858, Henry Rable bought 40 acres including hot springs near San Bernardino. The springs thereafter retained his name. The development of Rabel Springs probably very closely paralleled that of Harlem Hot Springs so close by. The two spas were connected by a tree lined path and apparently hot

mineral mud baths were offered at Rabel Springs. Rabel Hot Springs was closed as a resort or spa in 1912. A hog ranch occupied the site from then until 1916 when a laundry was established on the site. The following excerpt from an article in "The San Bernardino Sun", February 3, 1966 capsulizes the geothermal development at the laundry:

The laundry, the Baseline Laundry (Figure 5), is today operated by Fred O. Wolfe and his son-in-law, Paul Chandler. Fred Wolfe said when his family established a laundry there the warm soft mineral water flowed from artesian wells at a temperature of 130 degrees (F). The excess water flowed into Warm Creek. Today, he said, there is no Warm Creek, at least there is no flow in the channel."

The Baseline Laundry is still operating at the site. The facility water supply is a geothermal well next to the laundry building (Plate 1, Location No. 17). At least one old abandoned well is evident on the laundry property. The operating well is used heavily (the laundry managers did not know how much water they pump from the well). The temperature of the well discharge was measured as 28°C (82°F) on April 22, 1981 during the CDMG geothermal survey. Obviously the laundry must not heat its water before it can be utilized in its operations.

A succession of repeated articles about Rabel Hot Springs and the nearby Harlem Hot Springs appearing in "They Tell Me" column of "The San Bernardino Sun" comments on dropping water levels at these sites:

February 3, 1966

"The wells at Harlem and Rabel springs are no longer flowing. Instead, the water level has dropped to 160 to 170 feet and whereas the water was once hot, registering 130 degrees (F), (54°C), it is now lukewarm."

BASE LINE LAUNDRY

**Twenty-Two Years of Progress
ON EAST BASE LINE**

SINCE 1916 this laundry has been in continuous operation, adopting and installing advanced laundry equipment and methods, as laundry experts and engineers, who make a constant study of laundry problems, produced machinery and equipment to overcome them.

TODAY this laundry is one of the foremost laundries in Southern California, with "up-to-the minute" equipment that represents a tremendous investment. All of which has been made possible by the loyal support of the entire Orange Belt over which our service extends.

NATURAL HOT, SOFT WATER from our own wells, and pure soap, together with ultra modern machinery, assure every housewife the very acme of perfection in household laundry.

VISITORS are always WELCOME. Come and see the plant where your laundry is done. Call our service department at any time.

BASE LINE LAUNDRY
GEO. W. WOLF & JAMES MILLER, OWNERS
EAST BASE LINE SAN BERNARDINO

Figure 5. Advertisement for the Base Line Laundry appearing in "The San Bernardino Sun" on October 12, 1947.

March 8, 1970

"The wells at Rabel and Harlem Springs were originally hot, registering 130 degrees (F) (54°C). Now the water is lukewarm and is pumped from levels of from roughly 175 to 190 feet."

June 28, 1973

"The wells at both Rabel and Harlem Springs, once popular amusement parks are no longer flowing. Instead, the water in the wells is pumped from levels of approximately 200 feet or more (61+ meters) and is lukewarm."

If these reports are correct, then in the seven year span 1966-73 the warm water table at Harlem Hot Springs and Rabel Hot Springs (Now the Baseline Laundry site) dropped nearly 12 meters (40 feet).

Development of Geothermal Wells

In the early 1880's water wells were beginning to be drilled in San Bernardino to augment the water supply to the irrigation canals ("ditches") that supplied the expanding citrus groves. Also, wells were drilled to augment municipal water supplies. Often these wells intersected warm water aquifers and became artesianing geothermal wells. The geothermal waters were detrimental to agricultural and near useless for cold drinking water supplies. Therefore, geothermal wells were most often backfilled to a point above a geothermal zone or totally abandoned. This practice has generally been the norm through the present.

One private water company supplying domestic water to the City of Colton, California struck an artesian geothermal aquifer when attempting to increase their fresh water supply (Plate 1, Location No. 32). However, this geothermal

resource was utilized in 1920 to supply naturally heated water at 82°F (28°C) for a municipal swimming pool called "The Colton Municipal Park Plunge". The water was piped approximately 1.2 km (0.75 miles) from the well to the pool. This well was later deepened in 1929 and now produces geothermal waters of approximately 90°F (32°C) seasonally artesian. The well no longer supplies the swimming pool.

Some wells were deliberately driven into the hot springs of San Bernardino to gain control over the discharge and increase production for spa use. These wells became even more necessary when water tables began to subside due to cultural pressure.

Mendenhall, 1905, cataloged all the geothermal wells in San Bernardino known to him at that time. All of those wells and others derived from more recent literature and those "discovered" during the CDMG geothermal investigation are posted on Plate 1. A summary of each well is presented in the explanation.

Current Geothermal Usage

At Arrowhead Hot Springs natural steam is used in steam rooms or "caves" in the basement of the hotel. Geothermal water from a well is currently being used in some spa type fashion at Harlem Hot Springs. The Base Line Laundry draws from a geothermal well, but additional heat must be supplied for laundry operations. The well at Location No. 10, Plate 1 is used for domestic water supply, after the water cools in a tank, at Patton State Hospital. There is

some interest in utilizing the geothermal water from this well for space heating at the hospital. Geothermal wells at Locations No. 57, 59, and 62 are used for irrigation water sources. There are a few other warm water wells that are incorporated into municipal and private domestic water systems in the San Bernardino area.

Conclusions

The hottest surficial geothermal resource temperatures in the San Bernardino area are at Arrow Head Springs (including the nearby Waterman Hot Springs) where boiling or near boiling temperatures can be measured. Hot springs naturally flow there as they did more than 100 years ago. Total flow may have increased at Arrowhead Hot Springs over the years due to several artesianing wells drilled at the site. However, currently much less consumption is made of the geothermal resource than in past years when the facilities were operated as an internationally renowned health and resort spa.

Rabel and Harlem hot springs originally were naturally flowing springs discharging a large amount of geothermal water into Warm Creek. In fact these springs appear to have been the principle source of the flow in Warm Creek. The springs are now dried up. All wells in this area of known depth and producing geothermal water are at least 390 feet (119 meters) deep (Plate 1, Locations No. 8, 9, 10, 23, 24, 25, 27, and 28). The warm water table may be more shallow than this depth in some areas especially at the Harlem Hot Springs and the Base Line Laundry area.

Along with the subsiding geothermal water table came a decrease in surficial resource temperatures in the Rabel and Harlem hot springs area. In the past, artesianing wells at the Base Line Laundry were discharging water at 130°F (54°C). The temperature has decreased to approximately 82°F (28°C). The current hottest known well in this area is at Location No. 24, Plate 1 with a temperature of 49.5°C (121°F) measured at a depth of 570 feet (174 meters).

The apparent historical decrease in this geothermal area may suggest that the available geothermal resource there has a finite volume.

The Urbita Hot Springs are gone. All existing geothermal wells of known depth in the general area of Urbita Hot Springs are greater than 600 feet (183 meters) in depth and most are deeper than 800 feet (244 meters) (Plate 1, Locations No. 32, 47, 48, 50, 62, 57, 58, 59, and 62. The implication is that the hot water table in this area has subsided several hundred feet over the past 100 years. However, the hot water table may be somewhat shallower at the old site of the Urbita Hot Springs. The temperature of the water from the wells at the old hot springs site was reported to be about 106°F (41°C). An existing nearby geothermal well, some 600 feet (183 meters) deeper than the old wells at the Urbita site, flows with a surface temperature of 133°F (56°C) (Plate 1, Location No. 57). We may at least conclude that the geothermal resource increases in temperature with depth in this area.

AREAL EXTENT OF GEOTHERMAL RESOURCES IN THE SAN BERNARDINO AREA, CALIFORNIA

Introduction

Accuracy in defining the boundaries of a geothermal resource depends on the quality and quantity of the data base used and interpretation of that data base. Therefore, the geothermal resource boundaries presented for the San Bernardino study area should be considered tentative and subject to ongoing refinement as new data are acquired from exploratory drilling, geochemical analyses, and geophysical surveys.

Methodology

Plate 1 shows the location of 97 geothermal springs and wells in the San Bernardino area. These occupy Locations No. 1-92 (some location numbers are subdivided such as 6a and 6b). For this report a well or spring with a temperature of equal to or greater than 20°C (68°F) is defined as "geothermal". The locations of these geothermal wells and springs were obtained from the references cited in the explanation of Plate 1. Some of the geothermal well locations are from very old references such as Mendenhall, 1905. Most of the wells shown by Mendenhall can no longer be found.

The circular symbols on Plate 1 indicate geothermal locations obtained from literature or personal communications, while the triangular symbols are locations of geothermal wells or springs investigated by CDMG. The tentative

geothermal area boundaries presented on Plate 1 were drawn inclusive of all the geothermal well and spring locations.

Arcs of possible lateral extent of thermal waters chosen at 1,000 feet (305 meters) radii were scaled around the perimeter geothermal locations of a clustered group of locations. A tangential boundary was drawn and manually smoothed about these arcs. The result is the establishment of tentative geothermal area boundaries extending approximately 1,000 feet (305 meters) beyond any known geothermal well or spring.

Results

The geothermal areas are named and described below:

Arrowhead Hot Springs Geothermal Area

The Arrowhead Hot Springs geothermal area boundary includes both the abandoned Waterman Hot Springs (Plate 1, Locations No. 1 and 2) and the Arrowhead Hot Springs (Plate 1, Locations No. 3-7). The area enclosed by the tentative geothermal boundary is 1.2 km^2 (0.5 mi^2). Although this is the smallest designated geothermal area on Plate 1, it contains the "hottest" geothermal waters in the area.

Harlem Hot Springs Geothermal Areas

The Harlem Hot Springs geothermal area has been divided into East and West Branches. The division was made to highlight a northwest alignment of geothermal wells of greater than 40°C (104°F) temperature in the eastern branch. This alignment occurs along a possible fault trace (Fault F2). Also the geothermal area was divided to show an area between the two segments that appears to be devoid of any known geothermal wells. It is expected that when a geothermal well is drilled in this void area, the two branches will be joined and any subsequent name change of the geothermal area will be avoided when the east and west branch designation is dropped.

The east branch contains six known geothermal wells. It is 2.9 km² (1.1 mi²) in area. The west branch contains 18 known geothermal locations and is 3.6 km² (1.4 mi²) in area. The combined area of the Harlem Hot Springs geothermal areas is 6.5 km² (2.5 mi²).

There is a noticeable east-west trend of geothermal wells in the west branch of the Harlem Hot Springs geothermal area. This trend generally parallels the trend of Warm Creek and includes the alignment of Harlem Hot Springs, Rabel Hot Springs, and the Base Line Laundry hot well, and other wells further westward (Plate 1, Locations No. 15 [a-d], 24, 26, 27, 28, 23, and 24). This trend subparallels the trace of Fault F1 (Plate 1) that was established from the CDMG gravity surveys performed in this area.

South San Bernardino Geothermal Area

The south San Bernardino geothermal area is the largest designated geothermal area in San Bernardino. It comprises 16.0 km² (6.2 mi²) of area and contains slightly more than 60 known and historical geothermal locations.

The southwest boundary of this geothermal area is the San Jacinto fault zone. The 1,000 foot (305 meter) geothermal well boundary limit does not apply along the San Jacinto fault. Literature does not record any known geothermal wells or springs in the immediate vicinity southwest of this fault. It is apparent that this fault serves as a highly impermeable barrier to geothermal fluids.

The major trend of the South San Bernardino geothermal area is northwest, parallelling the San Jacinto and Loma Linda faults.

There are two minor trends somewhat perpendicular to the major trend. One is a southwest then south trend of wells along the Gage Canal in the southern part of the geothermal area. All of these wells were listed in Mendenhall's 1905 report. It is not known if these wells or wells in this area have present day temperatures equal to or greater than 20°C (68°F). The second minor trend is northeastward along an extension in the northern part of the geothermal area along Warm Creek.

Discussion

The construction of the tentative geothermal area boundaries does not mean that a geothermal resource is continuous throughout these enclosed areas. The well locations shown on Plate 1 are geothermal wells. However, there are many water wells in these areas that have maximum temperatures of less than 20°C (68°F) (Mendenhall, 1905, Plate XII and Dutcher and Garrett, 1963, Plate 4). No formal survey was made of "cool" wells and "warm" wells versus depth or location, but it appears many "cool" wells are of comparable depth to "warm" wells within the geothermal boundary limits. The implication is that the geothermal reservoir is of a discontinuous nature. The exception is the Arrowhead Hot Springs geothermal area where all known wells within the boundary limits are geothermal wells.

The extension of the south San Bernardino geothermal area along Warm Creek and the trend of the West Branch of the Harlem Hot Springs geothermal areas also along Warm Creek may be of some significance. In much earlier days Warm Creek flowed from natural hot springs in the Harlem Hot Springs general area. Later, just after the turn of the century, runoff from artesian wells drilled in the area flowed into Warm Creek. Warm Creek was then the drainage for this area. Now the springs are dry and there are no artesian wells currently to be found in this area. The warm water table is currently a few hundred feet deep around Harlem Springs, but the drainage of the geothermal waters probably still is along the Warm Creek channel, at some depth, into the deeper basin of the south San Bernardino geothermal area.

It should be emphasized again that the geothermal area boundaries on Plate 1 do not signify a continuous geothermal resource at some specific depth within the enclosed limits. The geothermal area boundaries do, however, focus on the most likely areas to do future detailed geothermal exploration.

GEOLOGIC SETTING

Introduction

The San Bernardino study area is predominately an alluvial basin bounded by the San Bernardino Mountains on the north and the Crafton Hills and Badlands to the south (Figure 6). The San Jacinto fault separates the San Bernardino Valley basin from the Rialto bench and Fontana plain to the west. The San Andreas fault, which crosses the study area north of San Bernardino, forms a boundary in this area between two major geomorphic provinces, the Transverse Ranges to the north, which includes the San Bernardino Mountains, and the Peninsular Ranges to the south, of which the San Bernardino Valley is a part.

Basement Rocks

Within the basement rocks of the San Bernardino Mountains north of the San Andreas fault zone are highly variable biotite and biotite-hornblende gneiss, and schist with augen gneiss and migmatite. These rocks are considered to be pre-Cambrian in age but may, at least in part, be younger. Tectonically mixed with these rocks are lenses of marble and dolomitic marble considered to be Paleozoic in age. Marble in the vicinity of Big Bear Lake has been dated as Carboniferous (Merriam, 1954).

Intruding the older rock are late Mesozoic granitic rocks. They range in composition from biotite-hornblende quartz diorite to biotite quartz

Figure 6. Location map of the San Bernardino study area showing faults, geomorphic features, and hydrologic basins. Modified from Fife and others, 1976.

monzanite. Potassium-argon dates of 66 to 77 million years (m.y.) have been obtained for the quartz monzanite.

Shandin Hills and Perris Hill are uplifted blocks of exposed basement within the alluvial basin. Lying south of the San Andreas fault, the rock type is distinct from that of the San Bernardino Mountains. Exposed in these hills is the Pelona Schist. The schist is a chlorite-quartz-albite-white mica schist containing minor greenstone and quartzite. The age is uncertain but considered to be Paleocene or late Cretaceous (Miller, 1979). Intruding the Pelona Schist are hypabyssal dikes of hornblende-biotite granodiorite in the Shandin Hills and leucocratic biotite-quartz-plagioclase porphyry in Perris Hill (Miller, 1979).

Within the study area, south of San Bernardino Valley, basement rocks are exposed in a few isolated outcrops overlain by Tertiary sediments. The exposed basement is biotite-hornblende quartz diorite and granodiorite of Cretaceous age.

Tertiary Deposits

Pliocene continental alluvial deposits are found north and south of the San Bernardino basin. Within the San Andreas fault zone the Tertiary sediments are indurated sandstones and conglomerates lying in fault bounded wedges. The Tertiary rocks east of Waterman Canyon have been correlated with the Potato Sandstone to the east (Morton, 1974), which has been dated as early to middle Pliocene (Dutcher and Burnham, 1960). Similar sediments occur to the north in the San Bernardino Mountains near Crestline.

South of San Bernardino, in the Badlands, are exposed unconsolidated gray, yellow, or brown gravelly and sandy sediments with silt and clay called the San Timoteo Beds (Frick, 1921). These deposits are cut by numerous faults and in places are greatly to intensely folded. The San Timoteo Beds are late Pliocene in age.

The Pliocene sediments likely underlie the alluvium of the San Bernardino Valley, at least in the southern portion. However, due to the similarity of lithologies between the unconsolidated San Timoteo beds and the older alluvium it is not possible to correlate the exposed Pliocene beds with well logs. Some wells in the basin, such as Location No. 82, Plate 1, penetrate coarse cemented sediments which may be the Pliocene sediments.

Quaternary Deposits

The Quaternary alluvial deposits are the most significant deposits in terms of the geothermal resources of San Bernardino in that they contain the hot water aquifers of the San Bernardino Valley. They are divided into three units on the geologic map (Plate 1), older alluvium, younger alluvium, and active-river-channel alluvium. The active-river-channel alluvium is actually a part of the younger alluvium. It is differentiated from the younger alluvium, however, because it forms a distinct unit. This unit is for the most part unsaturated with water and does not yield water to wells.

The older alluvium comprises all alluvial deposits laid down during the late Pleistocene. Lying unconformably over all older rocks the deposition

occurred in large part after the middle Pleistocene orogeny. The older alluvium includes terrace deposits in the canyons of the San Bernardino Mountains, older dissected conglomerates at the base of the mountains, and alluvial deposits overlying San Timoteo beds in the Badlands of the southern portion of the study area. Although multiple stages of deposition are represented by these deposits, no attempt has been made to distinguish them.

The older alluvium is typically poorly sorted, unconsolidated to indurated deposits of sand, gravel, boulders, and clay. Weathered zones, products of weathering, and iron staining distinguish the older alluvium from the overlying younger alluvium.

The older alluvium was deposited on a surface developed by the major diastrophism of the middle Pleistocene (Dutcher and Garrett, 1963). The late Pleistocene represents a period of accumulation of considerable alluvial material. Wells drilled in the deepest portion of the basin indicate alluvial deposits are over 1200 feet (366 meters) thick. Diastrophism continued during deposition of the older alluvium as indicated by faulting of this unit. In the Bunker Hill area the older alluvium is folded along the pressure ridge that is developed along the San Jacinto fault.

The younger alluvium is composed entirely of unweathered and largely undissected deposits of gravel, sand, silt, and clay laid down during the present cycle of alluviation by streams, excluding recent river channel deposits. Except for the active traces of the San Jacinto and San Andreas faults the younger alluvium is unaffected by faulting. Thickness of the unit is difficult to determine as the similar lithologies of the younger and older

alluvium are difficult or impossible to distinguish in well logs. Dutcher and Garrett (1963) estimate that the younger alluvium attains a maximum thickness of 110-125 feet (34-38 meters) where the Santa Ana River crosses the San Jacinto fault.

Structure

The San Bernardino Valley lies in a northwest trending structural trough between the San Andreas fault zone on the northeast and the San Jacinto fault zone on the southwest. The crest of the San Bernardino Mountains rises over 5,000 feet (1524 meters) above the valley floor north of the study area. Granite basement rock is exposed southwest of the San Jacinto fault in the southwest corner of the map (Plate 1). Less than three miles (4.8 km) to the northeast across the fault, wells over a thousand feet (305 meters) deep were drilled entirely in alluvial deposits.

The most recently active fault trace in the San Jacinto fault zone is called the San Jacinto or Claremont fault. This fault trace runs along the western side of the fault zone. The trace has been studied in detail by Sieh and others (1973) and Sharp (1972). Trenching across the fault trace indicates the younger alluvium is offset by the fault. However the active river channel deposits in the Lytle Creek flood control channel at Warm Creek are undisturbed (Fife and others, 1976). From San Bernardino City College southeast to the ridge (Bunker Hill) occupied by the Greek Orthodox Church, just south of Colton Avenue, a series of pressure ridges mark the trace of the fault. These ridges are referred to as the "Bunker Hill dike" (Mendenhall, 1905).

The Loma Linda fault lies on the east side of the San Jacinto fault zone and is exposed in the Badlands south of San Bernardino. Dutcher and Garrett (1963) observed that the east side of the fault is down dropped. No topographic expression of the fault has been observed on the valley floor. However, based upon geophysical surveys (this report and Fife and others, 1976) and based upon ground water hydrology (Dutcher and Garrett, 1963), it appears that the fault extends across the valley. At the northwestern edge of the valley the Glenn Ellen fault (Sharp, 1972) lies on the projected strike and is probably the northwest continuation of the Loma Linda fault. The absence of any topographic expression of the fault indicates that the fault has probably been inactive in recent time.

The trough between the two major faults (San Andreas and San Jacinto) is divided into a series of horsts and grabens. The more pronounced horsts form isolated basement hills which protrude above the alluvial valley floor. The presence of a northeast trending basement low is indicated by the Bouguer gravity map and from well log data (Plates 5 and 6). This basement low is likely a graben bounded by inactive northeast trending faults which do not offset the younger alluvium while no northeast trending faults are exposed in the San Bernardino area, southeast of the area the trough is cut by a number of northeast trending faults. These faults include the Crafton Hills, Chicken Hills and Redlands faults. (The Redlands fault appears in the southeastern corner of the geologic map, Plate 1.)

DETAILED GEOTHERMAL AREA GEOLOGY

Arrowhead Hot Springs Geothermal Area

Arrowhead Hot Springs is situated in the San Bernardino Mountains between Waterman Canyon and Coldwater Canyon. The hot water at Arrowhead issues from a shear zone in pre-Cambrian gneiss and schist. The zone, possibly a splay of the San Andreas fault, is marked by mineralized seeps and unstable ground west of the hotel.

The area immediately around the hotel is underlain by older alluvium. The older alluvium forms a terrace on which the buildings of Arrowhead Hot Springs are sited and along which the road leading into the springs from Waterman Canyon is built. "Palm Hot Spring" north of the hotel (Plate 1, Location No. 6) flows from older alluvium.

Sheared gneiss is exposed in the bottom of the canyon west of the hotel. Hot water flows directly from fractures in the gneiss in the bottom of the canyon at "Penyugal Spring" (Plate 1, Location No. 5). "Granite Hot Spring" (Plate 1, Location No. 4), along the road on the west side of the canyon, issues from the unstable ground marking the shear zone. The hot artesian well (Plate 1, Location No. 3) above "Granite Hot Spring" was drilled in the shear zone.

Waterman Hot Springs (also included in the Arrowhead Hot Springs geothermal area) is a group of hot water seeps along the base of a terrace of older alluvium in the bottom of Waterman Canyon (Plate 1, Location No. 1). A well

drilled into the creek bottom is artesian at 81°C (178°F) (Plate 1, Location No. 2). Situated just northwest of Arrowhead Hot Springs, the hot water at Waterman Hot Springs is undoubtedly derived from the same shear zone.

Harlem Hot Springs Geothermal Areas

The geothermal wells of the Harlem Springs geothermal areas are situated on the alluvial fans of Sand Creek, Warm Creek, and City Creek, south of the San Bernardino Mountains. With the exception of the Palm well (Plate 1, Location No. 25) and the Dunkirk well (Plate 1, Location No. 28), the hottest water is found near Warm Creek.

Recognizing that the hot water likely issues from faults on the basement rocks in this area, Dutcher and Garrett (1963) postulated two northwest trending faults, "K" and "L" (Figure 13). The location of fault "K" is based in part on the hot well at Palm Avenue (Plate 1, Location No. 25). Other evidence cited for fault "K" includes the large change in elevation between the bench of older alluvium north of East Highlands and the younger alluvium, the entrenchment of small streams crossing the area, and the somewhat inconsistent ground water gradients in the area.

Hot wells at Harlem Springs (Plate 1, Location Nos. 15a-d) and on Pacific Street near San Geronio High School (Plate 1, Location No. 12) delineate fault "L". A well 600 feet (183 meters) deep with 550 feet (168 meters) of clay, stated to be in or near the presumed fault, is cited as additional evidence for the fault. This well lies just east of the Dunkirk wells (Plate 1, Locations No. 27 and 28).

Geophysical surveys (gravity and magnetic) in the Harlem Springs area and the distribution of known warm water wells "discovered" by CDMG do not support the presence of faults "K" and "L" in the orientation postulated by Dutcher and Garrett. The majority of known geothermal wells in the area lie on or near a line which extends in a slightly south of west direction from Harlem Springs wells (Plate 1, Locations No. 15 a-d) to the East San Bernardino Water District "bone yard" well (Plate 1, Location No. 24). This trend, which roughly parallels Warm Creek, is associated with gravity anomalies on gravity lines G-1, G-3, and G-4 (Figure 13). This trend of geothermal wells and geophysical anomalies is likely the result of a fault extending west-southwest from near Harlem Springs (Fault F1, Plate 1).

A northwest trending fault can be inferred by Patton Hospital well no. 11 (Plate 1, Location No. 10), Palm no. 1 (Plate 1, Location No. 25), and Dunkirk no. 2 (Plate 1, Location No. 28). This fault lies roughly in the same position as Dutcher and Garrett's fault "K", but strikes in a more northerly direction (Fault F2, Plate 1). Geophysical evidence for Fault F2 includes a magnetic anomaly on the ground magnetic traverse M 9 (Fife and others, 1976, Plate 8) and (Plate 4, in this report). In addition, the 600-foot (183 meters) well with 550 (168 meters) feet of clay cited as evidence for fault "L" lies on this trend.

Well Locations No. 11, 12, 13 and 15 form a linear trend which strikes more northerly than fault "L". This linear trend, possibly a fault, is also the most easterly extent of the geothermal wells in the west branch of the Harlem Hot Springs geothermal areas. No warm wells are known between this northwest trending zone of warm wells and the northwest trending zone to the east. A magnetic anomaly at approximately station 20 on magnetic traverse SBM-3 (Figure 8) coincides with the proposed Fault F3.

The Bouguer Gravity Map (Plate 5) does not show evidence of northwest trending faults in the Harlem Springs area. Possibly there is insufficient vertical offset of the basement to be reflected in the gravity contours. The proposed Fault 2 lies along the southwestern edge of the San Andreas fault zone which is approximately one mile wide in this area according to Fife and others (1976).

South San Bernardino Geothermal Area

The south San Bernadino geothermal area lies in an alluvial plain drained by the Santa Ana River, Warm Creek, Lytle Creek, and San Timoteo Creek (Plate 1). When the area was first settled in the mid-19th century, ground water rose to the surface in this region producing swampy areas, known as a "cienegas". Pumping of ground water for irrigation and domestic purposes have since lowered the water table to below ground level drying up the cienegas. Recently (winter of 1980-81), the ground water level has risen to near the surface. This has resulted in flooding of some basements and underground utility vaults as well as some wells returning to artesian conditions (San Bernardino Municipal Water Department, 1981).

The geothermal area is bounded on the southwest by the San Jacinto fault which, as discussed under the HYDROLOGY Section, is a major ground water barrier. No wells drilled on the immediate southwest side of the fault are known to produce geothermal water. The northern edge of the geothermal area is a northeast trending line which intersects the San Jacinto fault just north of Mill Street and crosses Waterman Avenue near 6th Street. This geothermal

fluids barrier (Plate 1) roughly parallels the northern edge of a northeast trending gravity low in the basin suggesting a northeast trending fault, which is down-dropped on the southeast. The northeast extension of this line corresponds to the alignment of geothermal wells of the Harlem Springs area along Warm Creek.

Warm water wells are reported along the San Jacinto fault as far south as Loma Linda. The warm water wells along the Gage Canal lie along the southern edge of the geothermal area as well as along the southern edge of the northeast trending basement low.

The hottest wells of the south San Bernardino area either observed during this study or reported in the literature were drilled along the inferred extension of the Loma Linda fault. This observation is reported by Dutcher and Garrett (1963). It suggests that the Loma Linda fault may be either a source of hot water circulating up from the basement or a ground water barrier for hot water bearing aquifers. During this study, it was observed that well Locations No. 37, 57, 59, 81 and 82 (Plate 1) were flowing whereas well Locations No. 47, 48, 50, 51, 52 and 58 to the east were not. This, together with the northwest incursion of the 0-15-foot (0-4.6 meters) water depth boundary (Plate 3), suggests that the Loma Linda fault may act as a ground water barrier at least for deeper confined aquifers south of Warm Creek. If this is the case, the location of the fault is to the west of the hot water wells rather than to the east as inferred by earlier workers (Dutcher and Garrett, 1963, and Fife and others 1976). Electrical resistivity surveys near well Locations No. 58 and 59 indicate possible faulting between these two wells (Figure 12 and 33).

HYDROLOGY

Introduction

Two major papers have been written on the hydrology of the San Bernardino area. The one by W. C. Mendenhall (1905) discusses the development of the water resources in the San Bernardino basin, the nature of the aquifers, the origin of artesian waters, and the importance of the Bunker Hill dike as a ground-water barrier. The paper by L. C. Dutcher and A. A. Garrett (1963) is a more detailed study of the geology and hydrology of the basin. It includes water-level contour maps and an analysis of ground water movement with emphasis on ground-water barriers and water level fluctuations. More recent hydrologic studies by the U.S. Geological Survey, the California Department of Water Resources, and the San Bernardino Water District deal with modeling of the ground-water basin, artificial recharge of the basin, and the increased hazard of earthquake triggered liquefaction in the basin as a result of rising ground water levels.

The study area is occupied by the Bunker Hill ground water basin. This basin, described by Dutcher and Garrett (1963), is bounded by the San Bernardino Mountains on the northeast, the Crafton Hills and the Badlands on the south, and by the San Jacinto fault on the southwest. Barrier "G" and the Loma Linda fault (also called the Glen Ellen fault) separate the Bunker Hill basin from the Lytle Creek basin to the northwest. Inflow into the basin is principally runoff from the San Bernardino Mountains with the bulk of the water from the Santa Ana River and Mill Creek. Water also enters the basin from the San Gabriel Mountains by way of Lytle Creek and Cajon Creek. Artificial recharge basins have been constructed on the alluvial fans near the foot of the mountains to catch water from major streams.

Water-Bearing Deposits

The principal aquifer in the Bunker Hill basin is the older alluvium. This unit is saturated nearly everywhere that it is overlain by younger alluvium. Wells that tap coarse grained material of old major stream channels yield water in appreciable quantities. Thickness of the unit is generally not well known in the basin. In most of the basin the older alluvium probably overlies unconsolidated to consolidated late Tertiary continental deposits such as those which crop out south of the basin. The unconsolidated older deposits are indistinguishable from older alluvium in well logs. Near the center of the basin, east of the Loma Linda fault, Fife and others (1974, Plate 5B) estimate the thickness of fresh water bearing alluvium to be in excess of 1200 feet (366 meters). This is the deepest part of the basin as indicated by the Bouguer gravity map and deep wells (Plate 6).

The younger alluvium is mostly saturated in the area of confined water (see later discussion). Upstream from this area the saturated portion of the younger alluvium decreases. In the northeast portion of the basin where the zone of saturation is 150 feet (46 meters) or more below the surface the younger alluvium is believed to be unsaturated. The younger alluvium is estimated to be about 50 feet (15 meters) thick over much of the San Bernardino Valley. In the vicinity of the San Jacinto fault beneath the Santa Ana River the thickness is estimated to be 110-125 feet (34-38 meters). Throughout most of the basin accurate estimates are not possible from well logs due to the similar lithologies of the younger and older alluvium.

San Jacinto Fault - The "Bunker Hill Dike"

The San Jacinto fault forms a major ground water barrier on the southwest edge of the Bunker Hill basin. This was noted by Mendenhall (1905) who observed that, upstream from the fault, ground water rose to the surface in springs forming a "cienega". He attributed the barrier, known as the Bunker Hill dike, to a fold or arch of older alluvium.

Dutcher and Garrett (1963) observed that the water level contour lines (Plate 3) intersect the fault at right angles indicating that the direction of flow is not across the fault. Wells drilled just northeast of the fault are, or have been artesian, while wells to the southwest have not been artesian. However, at Colton narrows, where the Santa Ana River crosses the fault, ground water outflow does occur in the younger alluvium.

The San Bernardino artesian basin was discovered about 1870 when it was found that wells about 50 to 100 feet (15-30 meters) deep in the marshy "cienegas" yielded flowing water. Mendenhall (1905) delineated the area of artesian wells (Plate 3). These wells were drilled through a shallow deposit of low permeability which acts as a confining member. Dutcher and Garrett (1963) describe this unit as the "upper confining member". It is thickest along the Santa Ana River. In the vicinity of Warm Creek the upper confining member is thin or discontinuous, this leaking water to Warm Creek when the

hydrostatic head is at or above ground level. The upper confining member generally restricts recharge of the Bunker Hill basin to outside the artesian area.

Dutcher and Garrett (1963) describe two additional confining members below the upper confining member. These are termed the "middle" and "lower" confining members (Plate 2). Beneath each confining member is a water bearing zone referred to as the "middle and lower water bearing zones". Generally, the deeper wells yield the higher heads but this is not consistent throughout the basin due to the discontinuous nature of the confining zones which allow upward movement of water into the shallower zones.

The middle and lower confining members are found only in wells drilled east of the Loma Linda fault and can be traced eastward about four miles. Between the Loma Linda and San Jacinto faults these units are not recognizable. Ground water between the two faults, blocked from westward movement by the San Jacinto fault, moves upward into the younger alluvium and flows across the fault at Colton narrows.

GEOPHYSICAL INVESTIGATIONS

Introduction

Geophysical surveys were undertaken by the California Division of Mines and Geology (CDMG) as a part of the San Bernardino geothermal investigation in order to provide additional information concerning the geology as related to the geothermal resources. A reconnaissance gravity study was already available for the area. Therefore, CDMG's geophysical work consisted for the most part of relatively detailed ground magnetic, gravity, and electrical resistivity surveys. A discussion of each of these surveys and their interpretation follows.

Ground Magnetic Survey

Twelve ground magnetometer lines were run as a part of the San Bernardino geothermal investigation in the vicinity of the South San Bernardino, Harlem Hot Springs, and Arrowhead Hot Springs geothermal areas. The locations of most of these lines are shown on Plate 4 along with the locations of other magnetometer lines from the same general area from an earlier CDMG investigation (Fife and others, 1976, Plate 8). The magnetic survey was conducted to determine whether or not this type of geophysical data would be useful for locating faults or other geologic features that might be associated with the geothermal resources in this area.

Unfortunately much of the magnetic data that were obtained from this urbanized area are strongly affected in places by the presence of man-made features such as pipelines, fences, culverts, and bridges. Thus, much of the data are of limited value. Only the lines that are relatively free of cultural anomalies are shown in Figures 7-11 and discussed in the sections below.

Equipment and Procedure

The magnetometer used is a Geometrics Model 816 total-intensity instrument with a sensitivity of one gamma. In general, stations were occupied at intervals of 100 feet (30 meters) by pacing. The magnetic data were plotted both as profiles of observed field data, and as running averages of the nearest 5 field points. For the 5 point averages, obvious cultural anomalies were removed prior to the averaging process.

Interpretation of Data

South San Bernardino Geothermal Area. Line SBM 1 (Figure 7) follows a part of the Warm Springs Channel that trends approximately north in the south San Bernardino geothermal area (Plate 4). This line coincides in part with the location of a dipole-dipole resistivity profile DD1 (Figure 28). A number of short-wavelength, possibly cultural, magnetic anomalies distort parts of the magnetic profile, but near station 31, on the 5-point average line, there is a magnetic anomaly with a relatively long wavelength and an amplitude of about

GROUND MAGNETIC TRAVERSE
SBM-1
SOUTH SAN BERNARDINO GEOTHERMAL AREA

By
L. G. YOUNGS
R. H. CHAPMAN

Figure 7

GROUND MAGNETIC TRAVERSE

SBM-3

HARLEM HOT SPRINGS GEOTHERMAL AREAS

By
L.G. YOUNGS
R.H. CHAPMAN

Figure 8

Figure 9

GROUND MAGNETIC TRAVERSE
SBM-5
ARROWHEAD HOT SPRINGS GEOTHERMAL AREA

By
S. P. BEZORE
L. S. YOUNGS
R. H. CHAPMAN

Figure 10

Figure 11

100 gammas (higher on the south side). This anomaly could represent a fault or other contact within the buried basement rocks. It is located about 500 feet (178 meters) south of a possible fault anomaly observed on dipole-dipole resistivity section DD1 (Figure 12 and 30). Further north on the magnetic profile, however, there is no indication of any magnetic anomalies either in the vicinity of the trace of the Loma Linda fault or near the possible zone of warm water (Figure 12).

Harlem Hot Springs Geothermal Areas. Line SBM 3 (Figure 8) follows a part of the Sand Creek Channel that trends approximately north in the Harlem Hot Springs geothermal areas, (Plate 4). Line SBM 6 (Figure 9) is a short south extension of line SBM 3 offset about 1,000 feet (305 meters) to the west. Both lines pass near hot water wells as indicated on the profiles. There are no apparent magnetic anomalies that correspond either to the locations of the hot water wells or to the gravity anomaly near this area (Figure 13). Line SBM 3 has a broad negative anomaly with an amplitude of about 200 gammas, located approximately between stations 20 and 40, north of Harlem Hot Springs. The cause of this anomaly is not known. It apparently is not associated with the hot water at Harlem Hot Springs, however.

Arrowhead Hot Springs Geothermal Area. Lines SBM 5 (Figure 10) and SBM 12 (Figure 11) are both located near Arrowhead Hot Springs, north of the City of San Bernardino. Line SBM 5 traverses a part of Waterman Canyon west of Arrowhead Hot Springs in a direction generally just west of north (Plate 4). Line SBM 12 traverses a part of East Twin Creek (Coldwater Canyon) east of Arrowhead Hot Springs, in a direction just east of north.

Figure 12. Composite geophysical anomaly map of a portion of the South San Bernardino geothermal area. (By G. W. Chase and R. H. Chapman, 1981, CDMG.)

Figure 13. Composite geophysical anomaly map of portions of the Harlem Hot Springs geothermal areas. (G. W. Chase and R. H. Chapman, 1981, CDMG.)

Arrowhead Hot Springs is located in a part of the San Andreas fault zone that is approximately one mile north of the main traces of the San Andreas fault at the edge of the San Bernardino Mountains. Both profiles are characterized by local magnetic anomalies with amplitudes up to 200 gammas in the general vicinity of the fault zones near Arrowhead Hot Springs. Precambrian gneiss and schist and Mesozoic granitic rocks crop out in this area and these rocks may cause the magnetic anomalies. There is no apparent association between the magnetic anomalies and the geothermal resource, however. South of Arrowhead Hot Springs line SBM 12 (Figure 11) shows no notable anomalies where it crosses the main traces of the San Andreas fault near station 120.

Gravity Survey

Gravity measurements are often used to supplement other geophysical data in geothermal areas both to aid the study of regional geology and to provide information on local structure that may be related to geothermal resources.

A regional gravity study by Willingham (1968) and a few additional lines of data by McWhirter (1979) were available in the San Bernardino area. Additional gravity measurements consisting of four lines of data were completed during this study in the Harlem Hot Springs geothermal area.

Equipment and Procedure

Gravity measurements were made in the Harlem Hot Springs geothermal area using La Coste and Romberg gravity meter G-129. Data from a total of 91 stations were obtained along four lines each more than 8,000 feet (2,438 meters) long, with a station spacing of 400 feet (122 meters) (Plate 5). Three of the lines were run along north-trending streets (Sterling, Victoria, and Palm Avenues) and the fourth line is located along east-trending Base Line Road.

All gravity measurements (including the earlier data) were referenced to gravity base stations in San Bernardino and Riverside (Chapman, 1966, p. 33, 40). All of the gravity data were reduced to complete Bouguer anomalies using reduction densities of 2.67 g/cm^3 and 2.20 g/cm^3 . Terrain corrections for all stations were made out to a radius of 166.7 km.

Gravity Data

Regional and residual gravity maps. Plate 5 is a complete Bouguer gravity map of the San Bernardino area contoured at an interval of two milligals (mgal). The gravity field in much of this area is dominated by a very steep gravity gradient which probably is caused in part by displacement on the San Jacinto and associated faults, and also by an increase in the thickness of the earth's crust toward the northeast (Willingham, 1968, p. 25; Oliver and others, 1980, p. 17). Northeast of the area of the steepest gravity gradient in San Bernardino Valley (Plate 5), gravity values tend to level out, then rise somewhat near the San Andreas fault and San Bernardino Mountains. Willingham (1968,

Plate II) made a residual gravity map of the area by removing a calculated regional trend from the data. The resulting map indicates that there is a deep graben in the San Bernardino Valley, generally between the San Jacinto fault, on the southwest, and the San Andreas fault, on the northeast.

Interpretation of Willingham's residual map in terms of the thickness of Cenozoic deposits has been only partly successful, probably because of changes in densities of the basement rocks underlying the valley. However, the general configuration of the basement surface is probably reflected by both the residual gravity and complete Bouguer anomaly maps. For example, a drill hole located about one-half mile east of E Street and just south of 3rd Street in San Bernardino (Plate 6), encountered basement rocks at the relatively shallow depth of 875 feet (267 meters). This drill hole is located close to a local gravity high shown on Plate 6. Depth of Cenozoic deposits from other basement drill holes in the area also generally show a correlation with the gravity data (Plate 6).

Local gravity anomalies - south San Bernardino geothermal area. No detailed gravity surveys were done in the south San Bernardino geothermal area. The majority of the known "hotter" water wells in this area are located close to the projected location of the Loma Linda fault (Plate 1 and Figure 12). The regional gravity data in this area (Plate 6) show no apparent anomalies that might be related to either this fault or the hot water resource.

Local gravity anomalies - Harlem Hot Springs geothermal areas. The north-trending gravity lines (G1, G3, and G4) in the Harlem Hot Springs geothermal area all show a relatively steep local gravity gradient (upward toward the

north) (Figures 14 and 15). This local gradient, representing a total amplitude change of about two milligals (mgal), can be interpreted as a fault (Fault F1) that offsets basement rocks, but other causes are also possible. Figure 16 shows a comparison of the gravity data from the Victoria Avenue line (gravity profile G-1) and the anomaly calculated for Fault F1 with a vertical offset of basement rocks of about 300 feet (91 meters). The fault model was obtained first by the method of Nettleton (1976, p. 194-195), then the gravity anomaly was checked by means of a two dimensional hand calculator program (Haines and Campbell, 1979). A density contrast of 0.50 g/cm^3 between basement rocks (2.67 g/cm^3) and Cenozoic sediments (2.17 g/cm^3) was assumed based on density data given by Willingham (1968). The model which represents the best fit between the observed and calculated gravity data indicates a depth to basement rocks of about 1,100 feet (335 meters), north of the fault, and 1,400 (427 meters) feet, south of the fault, as indicated in Figure 16. These depths, however, are only estimates and are subject to large errors. The location of the interpreted Fault F1 is just north of Harlem Hot Springs on Victoria Avenue.

For purposes of interpretation of this local anomaly in the Harlem Hot Springs area, no regional gradient was removed from the data. This was not done because in this area the regional gradient is largely offset by a local rise in gravity, probably caused by thinning of Cenozoic sediments toward the northeast. The result is that the flat-lying bedrock shown in the model (Figure 16) should in reality dip toward the southwest. The location and offset shown for the fault are not affected, however.

Figure 14. Gravity profiles G-1 and G-4, Harlem Hot Springs geothermal areas.

Figure 15. Gravity profiles G-2 and G-3, Harlem Hot Springs geothermal areas.

The estimated locations of Fault F1 from the gravity data on the lines adjacent to Victoria Avenue (Sterling Avenue and Palm Avenue), are also shown on Figure 13. The plotted fault location has a nearly east-west trend between Victoria and Sterling Avenues, but turns northeast between Victoria and Palm Avenues. A projection of this trend toward the northeast would intersect or join the San Andreas fault east of Highlands.

Many, but not all, of the hot water wells in the Harlem Hot Springs area appear to be located near this possible fault trend. Most of these wells are located on the south, or downthrown, side of this possible fault. Thus, the apparent trend of the known hot water wells may support the evidence from gravity data for the presence of the proposed Fault F1. However, there is no other known supporting geological or geophysical evidence for this fault. In fact, the proposed fault crosses both the "K" and "L" faults suggested by Dutcher (1963) in the Harlem Hot Springs area (Figure 13).

Electrical Resistivity Survey

Electrical resistivity data were obtained in both the south San Bernardino and Harlem Hot Springs geothermal areas during the San Bernardino geothermal study. These data consist of 12 vertical electrical soundings (VES) and two dipole-dipole profiles. Most of the soundings were obtained in the south San Bernardino area, but one dipole-dipole section was completed in each of the two areas.

Resistivity surveys are commonly used in geothermal studies because hot, saline water is a good electrical conductor and, therefore, geothermal reservoirs are usually characterized by low values of electrical resistivity. In the San Bernardino area, however, the temperature of the warmest water known is only about 56°C, or less, except for the Arrowhead Hot Springs geothermal area, and the water is not very saline (see Table 3 and Appendix A). Thus, the conditions necessary for hot water related resistivity anomalies may not be present here (Meidav, 1979, p. 5). In such a case it may be that other characteristics of the alluvial section, such as water saturation and clay and gravel content, will have more effect on the resistivity results than the presence or absence of hot water. However, the electrical resistivity data may provide other information concerning the geology that will be useful in a study of the geothermal resources.

Equipment and Field Procedure

Electrical resistivity data were obtained with the following equipment:

- A Geotronics Model FT4 transmitter with a maximum output of 4 amperes and 800 watts (3.2 KVA).

- A Geotronics Model B2 motor generator with an output of 5 KVA at 400 hz.

- A Bison Model 2390 signal enhancement receiver.

- A Geomite Model R401 induced polarization receiver.

The vertical electric sounding data were obtained using a Schlumberger electrode configuration. Soundings were taken in areas where it was possible to obtain a maximum distance from the center to each current electrode ($AB/2$)

of at least 750 feet (229 meters). Some soundings had a maximum AB/2 distance of as much as 2,000 feet (610 meters), but not many such sites were available in the urbanized areas near the geothermal resources. A total of 12 VES soundings were made (Figures 17-27), eleven of which were sited in the South San Bernardino area and one at the Harlem Hot Springs area (Figures 28 and 29). Some of the soundings were affected by cultural features (possibly buried pipelines, etc.). As a result, one profile, VES 2 (not shown), could not be used at all and only a part of other soundings (such as VES 3, Figure 18) provided useful data.

In the use of the dipole-dipole electrode configuration, the receiver was moved away from the transmitter location from a distance of N=1 (400 feet, 122 meters) to N=6 (2,400 feet, 732 meters). This yields a series of 6 progressively deeper resistivity values, and a maximum pseudo-depth of penetration of about 1,400 feet (427 meters). After completion of one such series of readings, the transmitter location was moved along the line about 800 feet (244 meters) and another series of readings was taken until the line was completed. All resistivity data were recorded at a frequency of one Hz. As a check on reading repeatability, two readings usually were taken at each receiver location using different values of current. Values of resistivity were calculated in the field and plotted on a cross section. If the data indicated possible errors, the measurements were repeated.

The locations of the two dipole-dipole electrical resistivity surveys are shown on Figures 28 and 29.

VES-1 SOUTH SAN BERNARDINO GEOTHERMAL AREA

By
G.W. Chase

Figure 17

VES-3 SOUTH SAN BERNARDINO GEOTHERMAL AREA

By
G.W. Chase

Figure 18

VES-4 SOUTH SAN BERNARDINO GEOTHERMAL AREA

By
G.W. Chase

Figure 19

VES-5 SOUTH SAN BERNARDINO GEOTHERMAL AREA

By
G.W. Chase

Figure 20

VES-6 SOUTH SAN BERNARDINO GEOTHERMAL AREA

By
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Figure 21

VES-7 SOUTH SAN BERNARDINO GEOTHERMAL AREA

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Figure 22

VES-8 SOUTH SAN BERNARDINO GEOTHERMAL AREA

By
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Figure 23

VES-9 SOUTH SAN BERNARDINO GEOTHERMAL AREA

By
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Figure 24

By
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Figure 25

By
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Figure 26

VES-12 HARLEM HOT SPRINGS GEOTHERMAL AREA

By
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Figure 27

Figure 28. Location map of electrical resistivity surveys, South San Bernardino geothermal area.

Figure 29. Location map of electrical resistivity surveys, Harlem Hot Springs geothermal areas.

VES Data

The VES field curves were interpreted in terms of horizontally-layered structures by means of theoretical sounding curves (Orellana and Mooney, 1966; Rijkswaterstaat, 1969). The resulting approximate thicknesses and resistivity values obtained by this method were then used to calculate theoretical sounding curves by means of a hand calculator program (Haines and Campbell, 1980). If there was poor agreement between the observed and theoretical sounding curves in any examples, the thickness and resistivity parameters were changed to produce a better fit, if possible. In some examples that exhibit a steeply falling resistivity curve, however, it was not possible to calculate a satisfactory theoretical curve because of limitations of the calculator program (Haines and Campbell, 1980, p. 3). VES 9 (Figure 24) is an example of this problem.

Figures 17-27 show both the observed field curves and the calculated curves for each sounding plotted on a log-log base ($AB/2$ versus apparent resistivity). Also shown on the $AB/2$ axis is a plot of the interpreted layers showing thicknesses and true resistivity values. This type of plot shows a direct comparison between the resistivity curves and the thicknesses and depths of the interpreted layers.

Interpretations of two dipole-dipole resistivity sections (see next section) show fairly large local lateral variations in resistivity in the San Bernardino area. If this is true throughout the area, the assumption of a horizontally-layered resistivity structure used above in the interpretation of the VES curves may not be entirely valid. We believe, however, that such

lateral resistivity variations are confined largely to fault zones and possibly geothermal zones.

Dipole-Dipole Data

Areas suitable for dipole-dipole resistivity surveys in the San Bernardino geothermal area are very limited. Of the two profiles run, the one in the Harlem Hot Springs geothermal area is relatively poor, primarily because it was not possible to obtain good data at some sites on the traverse.

The two dipole-dipole resistivity pseudo sections were sent to the University of Utah Research Institute (UURI) for analysis. The dipole-dipole pseudo sections and the corresponding resistivity models derived from a two-dimensional computer analysis are shown in Figures 30 and 31. The following comments on these data were provided by Claron Mackelsprang (Duncan Foley, written communication, 1981):

"Only line DD1 (south San Bernardino geothermal area) has barely sufficient data to warrant any degree of confidence in the model as shown. Line DD2 (Harlem Springs geothermal area) is very ambiguous due to the paucity of data provided. Three possible models are shown for this line, none of which gives a good fit to the observed data along all the diagonals, but are however included to show the range in ambiguity present."

"The models require intrinsic resistivities that range between 50 and 1,500 ohm-feet in order to closely approximate the observed data. The lower resistivities may be related to the thermal fluids present. The higher resistivities could perhaps be explained by fresh water saturated sands or gravels. This is not intended as an interpretation of the data but rather as a means of explaining the sharp resistivity contrasts required by the models in order to approximate the field data."

SOUTH SAN BERNARDINO GEOTHERMAL AREA

Dipole-Dipole Line DD#1 Pseudo-Section

2 Dimensional Interpretation - Line DD#1

Figure 30

Figure 31

Interpretation of Resistivity Data

South San Bernardino geothermal area. Dipole-dipole line DD1 is 4,800 feet (1463 meters) long and is located along a north-trending line along the west levee of Warm Creek Channel from Central Avenue on the north to past the city sewage disposal facility, on the south (Figure 28). The resistivity model for this profile (Figure 30) shows some features that might be related directly or indirectly to the geothermal resource in the south San Bernardino geothermal area. Along the south half of the line, between stations 36 and 44, there is a zone of low resistance (50 ohm-feet) near the surface. This zone dips steeply toward the north on the section and is bordered on both the north and south by more resistive units (up to 500 ohm-feet). This zone of low resistance might represent clay, warm mineralized water, or both, possibly related to a fault zone.

Farther north on the resistivity model for DD1, near station 18, there is a steep contact between units with resistivities of about 100 ohm-feet, on the north, and about 500 ohm-feet on the south. This resistivity contact is located close to the projected trend of the warmest artesian water wells and also close to the estimated location of the Loma Linda fault (Figure 12). Thus, this resistivity contact could represent the Loma Linda fault (or a parallel fault) that serves as a barrier to localize the hot water (or serve as a conduit). The change in resistivity from 100 ohm-feet to 500 ohm-feet along this possible fault boundary suggests a corresponding change in the geologic section. The 100 ohm-feet section may indicate more clay, warmer water, or possibly less water than in the section with the higher resistivity to the south. It is not possible to be certain whether the warm water is

found in only one of the two sections with differing resistivities or whether it is confined to the contact (fault zone?) between them.

The eleven VES soundings in the south San Bernardino area (Figures 17-26) are in scattered locations throughout the area (Figure 28). The interpreted VES models shown in the above figures were used to construct two resistivity sections (A-A' and B-B') (Figures 32 and 33). These sections provide a relatively broad scale view of the electrical resistivity characteristics within and around the south San Bernardino geothermal area. The sections show the locations of selected drill holes with geologic logs and temperature measurements available. They also show where the well casings have been perforated, presumably where the best aquifers are found.

The VES soundings can be divided into two general types. In the east and northeast sides of the area (VES 1, 5, 7, 8, and 11) the interpreted electrical section usually consists of about four layers that can be summarized as follows:

<u>Layer</u>	<u>Thickness</u>	<u>Range in Resistivity (ohm-feet)</u>
1	0-20 feet (0-6 meters)	400-2,000 (may be 2 layers)
2	100-200 feet (30-61 meters)	75-150
3	400-700 feet (122-213 meters)	300-500
4	very large resistivity (basement)	25-100

A relatively thick layer (400-700 feet, 122-213 meters) of relatively high resistivity (300-500 ohm-feet) between an upper layer of distinctly lower resistivity (75-150 ohm-feet) and a lower layer of much lower resistivity

Figure 32

Figure 33

(25-100 ohm-feet) characterizes these soundings (Figures 32 and 33). Approximate correlations with perforations in nearby well logs suggest that the layer with the relatively high resistivity contains the best aquifers. It is also possible that the warm water produced from well Location Nos. 57, 59, 62, 81, and 82 (Figure 12), is also found in this high resistivity zone.

In the western part of the area, VES 3, 4, and 9 have interpreted electrical sections consisting of three principal layers that can be summarized as follows:

<u>Layer</u>	<u>Thickness</u>	<u>Range in Resistivity (ohm-feet)</u>
1	0-30 feet (0-9 meters)	500-5,000 (may be 2 layers)
2	50-200 feet (15-61 meters)	75-125
3	very large resistivity (basement)	25-60

These soundings do not show the thick layer of higher resistivity (300-500 ohm-feet) that characterizes the soundings of the first group. VES 6 and 10, also in the western part of the area, however, apparently do not fit either of these two groups. The two distinct types of soundings may be separated by a somewhat arbitrarily located fault (Fault F4) that crosses dipole-dipole line (DD1) near station 34, at the location of one of the resistivity anomalies observed previously (Figure 12). As mentioned before, this resistivity anomaly may represent a fault or some other type of contact.

A comparison between the VES data and the more detailed resistivity data from the dipole-dipole line DD1 (Figure 30), however, indicates that in detail the area cannot be divided into the two general types of resistivity soundings

discussed above. Line DD1 shows both a zone of low resistivity on the north end of the profile where the more regional VES data suggest a thick zone of high resistivity, and a zone of relatively high resistivity on the south end of the profile where VES data suggests an area of low resistivity. The zone of relatively high resistivity from near station 34 to station 18 is in agreement with the VES data, however. As mentioned before, the warm water wells might be located either in the zone of high resistivity between stations 34 and 18, in the zone of lower resistivity just to the north, or they might be confined to the possible contact (Loma Linda fault?) between the two zones.

Harlem Hot Springs geothermal area. Dipole-dipole line DD2 located in the Harlem Hot Springs geothermal area (Figure 29), is 4,800 feet (1,463 meters) long and trends west along the south levee of a part of Warm Creek Channel, approximately between Victoria Avenue, on the east, and Sterling Avenue on the west. The interpreted section shown in Figure 31 is one of three alternate sections that differ somewhat in detail, but show the same general features. The east half of the section shows very high values of resistivity (1,000 - 1,500 ohm-feet). The west end of the section shows shallow zones with resistivities of 50, 100, and 200 ohm-feet, overlying a relatively thick zone with a resistivity of about 300 ohm-feet. Separating these zones of relatively high resistivity is a narrow zone with a resistance of about 50 ohm-feet (between stations 20 and 24). This narrow zone of relatively low resistivity has a steep dip toward the west. The zones of relatively high resistivity might represent coarse water-saturated sediments. The narrow zone of low resistivity could represent a fault zone containing abundant clay, and perhaps warm water.

Line DD2 is oriented approximately parallel to and somewhat north of several wells that are reported to produce warm water. Well Location Nos. 15 and 16 (Figure 13), in projection northward, might be within relatively high resistivity zones. However, this is not certain because: 1) the narrow zone of low resistivity near station 22 could possibly project into the vicinity of well Location No. 16, and, 2) we cannot be certain that the zone of high resistivity on the eastern end of the line projects eastward as far as the well Location No. 15.

Vertical electric sounding VES 12 (Figure 27) is located about 3,000 feet (914 meters) northeast of Harlem Springs (Figures 13 and 29), and is not close to any of the warm wells. This was the only sounding completed in the Harlem Hot Springs area because of the few sites available. The interpretation of this sounding shows three layers, two of relatively high resistivity (2,300 and 250 ohm-feet) at shallow depths overlying a thick layer of intermediate resistivity (115 ohm-feet) below a depth of about 20 feet (6 meters). Whether this sounding is representative of the Harlem Hot Springs area as a whole is not known.

Conclusions

Regional gravity data help reveal the structural setting of the San Bernardino Valley, including the major graben and its fault boundaries. A local gravity anomaly trend in the Harlem Hot Springs area can be interpreted as a fault (Fault F1) that offsets basement rocks. The proposed Fault F1 is located close to many of the warm water wells in the Harlem Hot Springs area and it may be related to the occurrence of this resource.

Vertical electric soundings and dipole-dipole resistivity sections indicate that the south San Bernardino and Harlem Hot Springs areas are characterized by contrasting zones of electrical resistivity, ranging from moderate to high in values. The lower resistivity values could represent possible fault zones with a high clay content or perhaps hot water. The zones of higher resistivity might represent coarse water-saturated sediments, but they might also include warm water in some places.

A possible line or zone of hot water wells in the south San Bernardino area is located near a resistivity contact that might represent the Loma Linda fault. Without additional information, it is difficult to judge whether the warm water might be found in the zone of low resistivity, or the zone of high resistivity, or whether it might be confined to the fault zone itself.

Ground magnetic data obtained in San Bernardino area show anomalies that may be related to some of the major faults such as the San Andreas fault. Most other faults in the area, however, apparently are not marked by magnetic anomalies. The magnetic data evidently are of limited value for locating geothermal resources in the San Bernardino area.

SEISMICITY OF THE SAN BERNARDINO AREA, CALIFORNIA

Introduction

A high rate of seismicity is often observed in association with geothermal resource areas. The record of seismicity commonly is utilized as an exploration tool as well as a diagnostic tool for geothermal resource investigations. The distribution of earthquake epicenters (especially microearthquakes) in space and time has been a primary tool for geothermal exploration. Monitoring the character and velocity changes of seismic waves generated by earthquakes (and other energy sources) provides an accurate determination of a variety of diagnostic acoustical properties of rocks in geothermal resource areas. It is evident that the study of earthquakes in a geothermal area can sometimes yield important clues to the nature and character of the geothermal reservoir.

To evaluate the regional pattern of seismic activity around San Bernardino and to ascertain if this pattern bears any relationship to the geothermal resource, all seismic events from 1900-1974 were computer plotted and overlain on a base map. The base map is comprised of the eastern one half San Bernardino, California and the western one half Redlands, California 15 minute topographic quadrangles (Plate 7). Seismic data used for computer plotting were obtained from the California Division of Mines and Geology (CDMG) Earthquake Catalog of California (Real et al., 1978).

Epicenter Locations

In all, 301 seismic events have been recorded in the San Bernardino study area for 1900-1974. Only 226 of the events were computer plotted. The system does not allow "overprints". Therefore, only one of several events (the largest) occurring at the same coordinates, but at different times, is plotted.

Table 2 is a reproduction of the computer listing of all the earthquakes included in the study area. The table provides earthquake data on location, time, depth, magnitude, etc. A magnitude (MAG) 9.99 means that no data were available to determine the actual magnitude of the event.

The California Division of Mines and Geology Earthquake Catalog of California has been compiled from a great many sources of information. The primary source of data in the southern California region since 1932 is the California Institute of Technology. Two other sources are also referenced in Table 2.

Reference (REF)

Number

2	California Institute of Technology (1976). Magnetic tape catalog of earthquakes in southern California, 1932-1975.
7	Topozada, T.R., Parke, D.L. and Higgins, C.T. (1978), Seismicity of California, 1900-1931; California Division of Mines and Geology Special Report 135.
11	Gutenberg, B. and Richter, C.F. (1949). Seismicity of the Earth and Associated Phenomena, Princeton University Press, Princeton, New York, 273 p.

CALIFORNIA DIVISION OF MINES AND GEOLOGY
EARTHQUAKE CATALOG SYSTEM

PROGRAM RETRIEVE
VER. CON109H-128

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DATA RETRIEVAL REQUEST FOR: EARTHQUAKES NEAR SAN BERNARDINO

ID NO.	LATITUDE	LONGITUDE	DATE	TIME	DEPTH	QUAL	REF	MAG	REF	INT	REF	ID NO.
* 1500510	34.000	117.200	6/29/1952	7 6 17.0	0.0	B	2	2.60	2	0		1500510
* 1500444	34.000	117.217	5/10/1950	11 5 50.0	0.0	B	2	2.80	2	0		1500444
1500324	34.000	117.233	3/18/1947	5 41 14.0	0.0	C	2	2.60	2	0		1500324
1500161	34.000	117.233	1/ 7/1938	4 47 0.0	0.0	C	2	2.50	2	0		1500161
* 1500723	34.000	117.233	9/ 4/1959	14 26 0.0	0.0	B	2	2.60	2	0		1500723
1500051	34.000	117.250	11/ 1/1932	4 45 0.0	0.0	E	2	4.00	2	5C	006	1500051
1500650	34.000	117.250	2/25/1958	21 12 27.0	0.0	B	2	2.70	2	0		1500650
1500638	34.000	117.250	8/30/1957	5 57 56.0	0.0	B	2	2.60	2	0		1500638
1500011	34.000	117.250	7/23/1923	7 30 26.0	0.0		11	6.25A	011	7C	003	1500011
* 1500405	34.000	117.267	1/ 8/1949	19 8 47.0	0.0	C	2	2.80	2	0		1500405
1500667	34.000	117.283	8/18/1958	1 20 32.0	0.0	B	2	2.90	2	0		1500667
1500511	34.000	117.283	8/ 9/1952	1 29 7.0	0.0	C	2	2.20	2	0		1500511
* 1500194	34.000	117.283	11/ 7/1939	18 52 8.4	0.0	A	2	4.70	2	0A	006	1500194
1500218	34.000	117.300	5/10/1941	16 59 36.0	0.0	D	2	2.50	2	0		1500218
* 1500458	34.000	117.300	9/21/1950	22 45 12.0	0.0	B	2	3.40	2	0A	006	1500458
* 1500332	34.000	117.333	7/30/1947	4 50 18.0	0.0	C	2	2.70	2	0A	006	1500332
1500264	34.000	117.367	10/ 2/1944	19 41 14.0	0.0	C	2	2.70	2	0		1500264
1500056	34.000	117.367	1/ 3/1934	19 38 0.0	0.0	D	2	2.00	2	0		1500056
1500058	34.000	117.367	1/10/1934	22 47 0.0	0.0	C	2	2.00	2	0		1500058
* 1500226	34.000	117.367	12/ 6/1941	19 0 23.0	0.0	B	2	3.00	2	0		1500226
* 1501058	34.001	117.165	3/17/1972	19 48 8.1	8.0	A	2	3.00	2	0A	006	1501058
* 1501044	34.001	117.236	7/26/1971	15 40 11.0	12.3	A	2	2.40	2	0		1501044
* 1500773	34.002	117.292	9/30/1961	17 46 40.5	15.5	B	2	2.70	2	0		1500773
* 1501225	34.003	117.234	5/18/1973	6 35 12.2	6.0	C	2	1.70	2	0		1501225
* 1501042	34.005	117.234	7/25/1971	17 31 29.9	8.0	A	2	3.10	2	0A	006	1501042
* 1501382	34.006	117.201	3/24/1975	22 2 7.4	15.0	A	2	2.40	2	0		1501382
* 1500873	34.006	117.357	8/14/1966	15 5 2.8	19.3	B	2	2.80	2	0		1500873
* 1501316	34.007	117.265	2/ 4/1974	10 17 54.1	9.1	D	2	2.20	2	0		1501316
* 1500421	34.009	117.206	8/17/1949	5 14 19.9	16.0	A	2	3.40	2	0A	006	1500421
* 1501043	34.009	117.215	7/25/1971	20 32 42.9	8.0	A	2	2.80	2	0		1501043
* 1500518	34.011	117.188	11/16/1952	13 48 23.8	20.2	A	2	3.80	2	4C	006	1500518
* 1501262	34.011	117.217	9/ 8/1973	15 47 8.0	8.5	C	2	1.70	2	0		1501262
* 1500970	34.013	117.133	1/13/1970	9 26 37.6	10.0	A	2	2.80	2	0		1500970
* 1501380	34.014	117.138	3/22/1975	11 13 51.0	14.8	A	2	2.70	2	0		1501380
* 1501292	34.015	117.127	12/ 5/1973	16 7 20.5	6.4	C	2	1.70	2	0		1501292
* 1501298	34.015	117.232	12/18/1973	14 34 27.4	6.6	C	2	2.30	2	0		1501298
* 1500547	34.017	117.167	12/29/1953	10 39 35.0	0.0	B	2	3.10	2	0		1500547
* 1500594	34.017	117.233	4/16/1956	0 10 33.0	0.0	B	2	2.50	2	0		1500594
* 1501341	34.017	117.248	4/12/1974	19 38 21.9	16.0	B	2	2.50	2	0		1501341
* 1500420	34.017	117.250	7/16/1949	15 42 20.0	0.0	B	2	2.70	2	0		1500420
1500158	34.017	117.267	11/22/1937	23 30 0.0	0.0	C	2	3.00	2	0		1500158
1500195	34.017	117.267	1/ 4/1940	7 15 32.0	0.0	C	2	2.50	2	0		1500195
1500164	34.017	117.267	1/15/1938	21 10 0.0	0.0	D	2	2.50	2	0		1500164
1500190	34.017	117.267	7/18/1939	4 58 0.0	0.0	B	2	2.50	2	0A	006	1500190
1500240	34.017	117.267	5/ 8/1943	15 59 17.0	0.0	C	2	2.50	2	0		1500240
1500112	34.017	117.267	12/ 5/1935	7 53 0.0	0.0	B	2	2.00	2	0		1500112
1500132	34.017	117.267	9/20/1936	10 52 0.0	0.0	C	2	2.00	2	0		1500132
* 1500159	34.017	117.267	11/24/1937	21 37 0.0	0.0	B	2	3.00	2	0		1500159
1500409	34.017	117.283	3/10/1949	15 54 17.0	0.0	B	2	2.40	2	0		1500409
1500297	34.017	117.283	6/ 9/1946	21 43 0.0	0.0	C	2	2.30	2	0		1500297
* 1500256	34.017	117.283	6/19/1944	15 42 48.0	0.0	C	2	2.80	2	0A	002	1500256

Table 2. Earthquake data for the San Bernardino Area, California - 1900 - 1974.

CALIFORNIA DIVISION OF MINES AND GEOLOGY
EARTHQUAKE CATALOG SYSTEM

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DATA RETRIEVAL REQUEST FOR: EARTHQUAKES NEAR SAN BERNARDINO

ID NO.	LATITUDE	LONGITUDE	DATE	TIME	DEPTH	QUAL	REF	MAG	REF	INT	REF	ID NO.
* 1500528	34.017	117.300	3/16/1953	5 16 50.0	0.0	B	2	2.10	2	0		1500528
* 1501217	34.018	117.328	4/25/1973	5 1 27.6	5.1	D	2	1.70	2	0		1501217
* 1501390	34.021	117.253	10/29/1975	12 28 35.6	15.7	P	2	2.70	2	0		1501390
* 1501285	34.024	117.143	11/25/1973	20 47 49.1	7.6	C	2	1.80	2	0		1501285
* 1501041	34.025	117.192	7/25/1971	13 36 14.8	8.0	A	2	2.80	2	0		1501041
* 1501040	34.025	117.202	7/25/1971	13 34 31.5	8.0	A	2	2.70	2	0		1501040
* 1501207	34.026	117.292	3/31/1973	3 51 39.2	8.0	A	2	2.50	2	0		1501207
* 1501067	34.028	117.194	6/ 3/1972	9 54 38.3	4.6	A	2	2.60	2	0		1501067
* 1501107	34.029	117.255	10/16/1972	3 32 48.6	8.0	A	2	2.40	2	0		1501107
* 1501236	34.029	117.264	7/ 4/1973	17 2 5.6	6.5	D	2	1.70	2	0		1501236
* 1501226	34.030	117.136	5/18/1973	6 35 19.6	8.0	A	2	3.30	2	0A	006	1501226
* 1501244	34.030	117.267	7/24/1973	3 37 26.1	7.6	C	2	1.70	2	0		1501244
* 1501321	34.031	117.296	2/17/1974	14 28 14.9	7.5	C	2	1.70	2	0		1501321
* 1501325	34.032	117.200	2/24/1974	5 36 3.4	6.5	C	2	1.70	2	0		1501325
* 1500640	34.033	117.183	9/30/1957	2 12 47.0	0.0	B	2	2.50	2	0		1500640
1500558	34.033	117.217	12/ 6/1954	6 1 50.0	0.0	B	2	2.60	2	0		1500558
* 1500564	34.033	117.217	4/ 1/1955	14 53 39.0	0.0	B	2	2.70	2	0		1500564
1500557	34.033	117.267	9/10/1954	21 33 13.0	0.0	B	2	2.60	2	0		1500557
* 1500447	34.033	117.267	5/29/1950	3 3 5.0	0.0	B	2	3.20	2	0		1500447
1500495	34.033	117.283	12/ 3/1951	18 18 46.0	0.0	C	2	2.70	2	0A	006	1500495
1500375	34.033	117.283	5/31/1948	11 30 8.0	0.0	B	2	2.60	2	0		1500375
1500494	34.033	117.283	12/ 3/1951	18 8 54.0	0.0	C	2	2.50	2	0A	002	1500494
* 1500503	34.033	117.283	3/ 3/1952	6 30 10.0	0.0	B	2	2.70	2	0		1500503
1500085	34.033	117.317	4/19/1935	8 39 0.0	0.0	B	2	3.00	2	0		1500085
1500078	34.033	117.317	12/27/1934	13 41 0.0	0.0	C	2	3.00	2	0		1500078
1500077	34.033	117.317	12/ 5/1934	14 21 0.0	0.0	B	2	2.50	2	0		1500077
1500063	34.033	117.317	3/28/1934	16 30 0.0	0.0	B	2	2.00	2	0		1500063
1500064	34.033	117.317	4/22/1934	10 11 0.0	0.0	B	2	2.00	2	0		1500064
1500074	34.033	117.317	8/31/1934	12 54 0.0	0.0	B	2	2.00	2	0A	006	1500074
1500096	34.033	117.317	7/29/1935	21 35 0.0	0.0	C	2	2.00	2	0		1500096
1500082	34.033	117.317	2/15/1935	15 13 0.0	0.0	B	2	1.50	2	0		1500082
1500081	34.033	117.317	2/15/1935	9 23 0.0	0.0	B	2	1.50	2	0		1500081
* 1500101	34.033	117.317	9/ 3/1935	6 47 0.0	0.0	B	2	4.50	2	4C	006	1500101
* 1500398	34.033	117.333	11/30/1948	0 53 3.0	0.0	B	2	2.50	2	0		1500398
1500272	34.033	117.350	2/ 1/1945	22 43 5.0	0.0	C	2	2.50	2	0		1500272
1500273	34.033	117.350	2/ 1/1945	22 47 2.0	0.0	C	2	2.30	2	0		1500273
1500364	34.033	117.350	4/ 2/1948	14 36 18.0	0.0	B	2	2.20	2	0		1500364
* 1500199	34.033	117.350	4/18/1940	18 43 43.9	0.0	A	2	4.40	2	0A	002	1500199
* 1500030	34.033	117.367	4/14/1932	7 52 5.4	0.0	B	2	2.50	2	0		1500030
* 1501252	34.035	117.281	8/10/1973	0 45 48.6	6.1	D	2	1.70	2	0		1501252
* 1501123	34.036	117.210	10/31/1972	11 16 26.9	8.0	A	2	2.60	2	0		1501123
* 1500625	34.037	117.310	2/ 6/1957	9 4 32.5	5.3	A	2	3.60	2	5C	006	1500625
* 1500802	34.038	117.323	7/26/1963	7 33 51.5	18.9	A	2	3.60	2	3C	006	1500802
* 1501205	34.040	117.272	3/30/1973	15 50 21.9	8.0	A	2	3.20	2	3C	006	1501205
* 1501111	34.040	117.313	10/21/1972	12 43 2.7	6.6	C	2	1.70	2	0		1501111
* 1501299	34.040	117.332	12/19/1973	15 22 36.4	8.0	B	2	1.80	2	0		1501299
* 1500880	34.041	117.139	9/11/1966	5 33 19.9	-2.0	B	2	2.60	2	0		1500880
* 1501273	34.041	117.198	10/23/1973	10 37 35.3	8.0	A	2	2.60	2	0		1501273
* 1501059	34.041	117.249	3/22/1972	12 54 3.9	8.0	B	2	2.60	2	0A	006	1501059
* 1501317	34.041	117.278	2/ 4/1974	12 4 55.3	7.9	C	2	2.10	2	0		1501317
* 1501393	34.041	117.279	11/30/1975	0 14 29.9	16.4	P	2	2.50	2	0		1501393

Table 2. Continued.

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ID NO.	LATITUDE	LONGITUDE	DATE	TIME	DEPTH	QUAL	REF	MAG	REF	INT	REF	ID NO.
* 1500935	34.043	117.173	10/20/1968	5 35 31.8	-2.0	B	2	2.70	2	0		1500935
* 1500186	34.043	117.228	4/ 3/1939	2 50 44.7	10.0	A	2	4.00	2	0A	006	1500186
* 1501263	34.044	117.263	9/12/1973	2 0 6.1	8.2	C	2	1.70	2	0		1501263
* 1501239	34.045	117.274	7/10/1973	22 22 48.4	5.8	C	2	1.70	2	0		1501239
* 1500958	34.045	117.289	8/30/1969	4 17 46.3	9.8	B	2	2.50	2	0		1500958
* 1501181	34.045	117.333	1/23/1973	15 19 22.8	5.7	C	2	1.70	2	0		1501181
* 1501245	34.045	117.344	7/27/1973	14 29 1.2	8.0	B	2	1.80	2	0		1501245
* 1501251	34.046	117.344	8/ 8/1973	14 11 18.6	6.0	C	2	1.70	2	0		1501251
* 1500825	34.048	117.174	1/21/1965	21 9 50.5	9.4	B	2	3.00	2	4C	002	1500825
* 1501274	34.049	117.265	10/27/1973	8 6 14.1	7.3	D	2	1.70	2	0		1501274
* 1500668	34.050	117.217	8/28/1958	0 21 38.0	0.0	B	2	2.80	2	0		1500668
* 1500984	34.050	117.222	7/18/1970	3 41 1.9	8.0	A	2	2.90	2	0		1500984
1500439	34.050	117.233	4/ 1/1950	14 16 31.0	0.0	B	2	2.80	2	0		1500439
1500548	34.050	117.233	3/10/1954	18 46 31.0	0.0	B	2	2.70	2	0		1500548
1500620	34.050	117.233	11/11/1956	23 42 16.0	0.0	B	2	2.40	2	0		1500620
1500613	34.050	117.233	8/29/1954	6 21 20.0	0.0	B	2	2.40	2	0		1500613
* 1500566	34.050	117.233	4/ 3/1955	15 1 38.0	0.0	B	2	2.90	2	0		1500566
* 1501220	34.050	117.263	5/ 3/1973	21 22 19.7	6.5	C	2	1.70	2	0		1501220
1500426	34.050	117.267	11/24/1949	14 7 35.0	0.0	B	2	2.10	2	0		1500426
* 1500492	34.050	117.267	11/23/1951	11 40 7.0	0.0	C	2	2.90	2	0		1500492
1500124	34.050	117.283	5/17/1936	4 27 0.0	0.0	C	2	2.00	2	0		1500124
* 1500123	34.050	117.283	5/16/1936	13 37 0.0	0.0	B	2	3.00	2	0A	006	1500123
* 1500428	34.050	117.300	1/ 3/1950	17 26 38.0	0.0	B	2	2.80	2	0		1500428
1500312	34.050	117.333	10/14/1946	22 27 6.0	0.0	C	2	2.40	2	0		1500312
1500446	34.050	117.333	5/20/1950	15 29 14.0	0.0	B	2	2.30	2	0		1500446
* 1500197	34.050	117.333	3/ 5/1940	17 6 4.0	0.0	C	2	2.50	2	0		1500197
* 1501266	34.051	117.333	9/21/1973	14 19 42.3	5.4	C	2	1.70	2	0		1501266
* 1500981	34.053	117.180	6/16/1970	14 24 22.3	8.0	B	2	2.70	2	0		1500981
* 1500561	34.053	117.236	3/12/1955	20 36 23.1	16.0	A	2	2.60	2	0		1500561
* 1500957	34.053	117.292	8/29/1969	17 42 18.1	8.5	B	2	3.00	2	3C	006	1500957
* 1501277	34.053	117.321	11/ 9/1973	15 28 44.6	5.0	C	2	1.70	2	0		1501277
* 1500816	34.055	117.192	5/22/1964	5 6 41.8	13.4	B	2	3.10	2	0A	002	1500816
* 1501275	34.055	117.311	10/30/1973	15 39 29.0	9.9	C	2	1.70	2	0		1501275
* 1501175	34.056	117.312	1/19/1973	15 16 38.8	9.7	D	2	1.70	2	0		1501175
* 1501281	34.056	117.338	11/16/1973	15 20 16.7	8.0	B	2	2.00	2	0		1501281
* 1501265	34.057	117.283	9/19/1973	5 15 56.9	7.4	D	2	1.70	2	0		1501265
* 1501180	34.058	117.310	1/23/1973	15 18 45.5	9.6	D	2	1.70	2	0		1501180
* 1501280	34.058	117.333	11/16/1973	15 19 41.5	8.0	B	2	1.80	2	0		1501280
* 1500865	34.060	117.173	3/14/1966	15 11 2.1	-0.3	B	2	2.50	2	0		1500865
* 1501293	34.060	117.204	12/11/1973	4 55 29.0	8.0	A	2	2.50	2	0		1501293
* 1501297	34.060	117.255	12/17/1973	14 41 19.9	8.0	D	2	1.70	2	0		1501297
* 1500501	34.062	117.221	2/20/1952	0 42 1.6	16.1	A	2	3.40	2	0		1500501
* 1501063	34.062	117.233	5/23/1972	10 19 44.4	8.0	A	2	3.00	2	0		1501063
* 1501336	34.066	117.349	3/12/1974	14 24 34.0	0.2	B	2	1.90	2	0		1501336
* 1500500	34.067	117.133	2/19/1952	9 21 53.0	0.0	B	2	2.60	2	0		1500500
* 1500514	34.067	117.167	9/24/1952	16 45 11.0	0.0	B	2	2.80	2	0		1500514
* 1500515	34.067	117.167	9/28/1952	4 0 10.0	0.0	B	2	3.00	2	0		1500515
1500688	34.067	117.233	5/31/1959	2 36 13.0	0.0	B	2	2.60	2	0		1500688
* 1500755	34.067	117.233	12/ 3/1960	18 7 43.0	0.0	B	2	2.70	2	0		1500755
* 1500177	34.067	117.250	8/ 1/1938	2 29 0.0	0.0	B	2	2.50	2	0		1500177
* 1500531	34.067	117.283	4/13/1953	23 9 40.0	0.0	B	2	2.50	2	0		1500531

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ID NO.	LATITUDE	LONGITUDE	DATE	TIME	DEPTH	QUAL	REF	MAG	REF	INT	REF	ID NO.
* 1500166	34.067	117.300	1/31/1938	4 48 0.0	0.0	B	2	2.50	2	0		1500166
* 1500366	34.067	117.350	4/14/1948	14 29 4.0	0.0	C	2	2.70	2	0		1500366
* 1500684	34.067	117.367	5/ 6/1959	23 23 29.0	0.0	C	2	3.30	2	0A	006	1500684
* 1501268	34.068	117.317	9/28/1973	14 21 33.1	8.0	A	2	2.40	2	0		1501268
* 1501131	34.070	117.282	11/20/1972	6 56 5.6	8.0	B	2	2.30	2	0		1501131
* 1501269	34.078	117.338	10/11/1973	14 15 21.4	8.0	A	2	2.20	2	0		1501269
* 1500836	34.078	117.355	4/ 5/1965	11 9 36.5	16.7	B	2	2.30	2	0		1500836
* 1501108	34.080	117.275	10/17/1972	19 39 36.7	8.0	A	2	2.10	2	0		1501108
* 1501264	34.082	117.266	9/15/1973	2 15 21.0	8.0	A	2	2.60	2	0		1501264
* 1500654	34.083	117.183	3/31/1958	14 33 43.0	0.0	B	2	3.40	2	4C	006	1500654
* 1500653	34.083	117.200	3/24/1958	20 46 17.0	0.0	B	2	2.70	2	0		1500653
* 1500455	34.083	117.200	9/ 1/1950	17 30 46.0	0.0	B	2	2.90	2	0		1500455
* 1500451	34.083	117.250	8/18/1950	14 55 52.0	0.0	B	2	2.30	2	0		1500451
* 1500639	34.083	117.267	9/ 1/1957	13 2 13.0	0.0	B	2	3.30	2	0		1500639
* 1500266	34.083	117.300	10/29/1944	14 5 39.0	0.0	C	2	2.50	2	0		1500266
* 1500681	34.083	117.333	4/13/1959	13 17 25.0	0.0	C	2	2.50	2	0		1500681
* 1500834	34.083	117.348	3/19/1965	3 9 25.5	17.0	B	2	2.50	2	0		1500834
* 1501087	34.085	117.235	9/11/1972	9 40 28.7	8.0	A	2	3.80	2	5C	006	1501087
* 1500419	34.085	117.336	7/ 3/1949	9 50 21.8	20.5	B	2	3.10	2	0		1500419
* 1501352	34.086	117.290	6/30/1974	7 16 57.6	10.2	B	2	2.50	2	0		1501352
* 1500800	34.086	117.344	6/26/1963	12 30 47.8	15.1	B	2	2.60	2	0		1500800
* 1501334	34.087	117.317	3/ 4/1974	20 10 51.2	7.9	D	2	1.80	2	0		1501334
* 1501178	34.087	117.324	1/22/1973	13 28 0.0	5.4	C	2	1.70	2	0		1501178
* 1501381	34.088	117.319	3/23/1975	4 30 22.4	14.5	A	2	3.20	2	0		1501381
* 1501276	34.089	117.305	11/ 4/1973	15 11 2.4	6.2	D	2	1.70	2	0		1501276
* 1501261	34.090	117.306	9/ 6/1973	16 34 6.6	5.8	D	2	1.70	2	0		1501261
* 1501086	34.091	117.341	9/ 8/1972	0 11 51.4	8.0	A	2	2.60	2	0		1501086
* 1501198	34.095	117.240	3/11/1973	9 10 49.0	8.0	A	2	2.40	2	0		1501198
* 1500931	34.098	117.352	8/17/1968	7 44 42.3	18.3	C	2	3.10	2	4C	006	1500931
* 1500657	34.100	117.167	4/15/1958	21 51 52.0	0.0	B	2	3.20	2	0A	006	1500657
* 1500009	34.100	117.200	4/23/1923	21 13 0.0	0.0		7	9.99A		5B	004	1500009
* 1500001	34.100	117.300	12/27/1901	11 0 0.0	0.0		7	9.99A		6B	004	1500001
* 1500005	34.100	117.300	11/22/1911	2 57 0.0	0.0		7	9.99A		5B	004	1500005
* 1500002	34.100	117.300	7/15/1905	20 41 0.0	0.0		7	9.99A		7B	004	1500002
* 1500516	34.100	117.300	10/17/1952	12 48 50.0	0.0	B	2	3.00	2	4C	006	1500516
* 1500517	34.100	117.300	10/17/1952	15 23 22.0	0.0	B	2	2.50	2	4C	006	1500517
* 1500014	34.100	117.300	2/16/1931	13 27 0.0	0.0		7	4.00D	007	5C	006	1500014
* 1500572	34.100	117.317	6/26/1955	3 54 1.0	0.0	B	2	3.00	2	0		1500572
* 1500201	34.100	117.333	7/ 7/1940	1 50 51.0	0.0	D	2	3.50	2	0A	006	1500201
* 1500134	34.100	117.350	9/26/1936	9 10 0.0	0.0	B	2	1.50	2	0		1500134
* 1501209	34.104	117.305	4/ 4/1973	5 32 9.1	5.0	D	2	1.70	2	0		1501209
* 1501036	34.106	117.366	6/23/1971	1 34 0.2	17.2	A	2	3.00	2	0A	006	1501036
* 1500422	34.108	117.312	8/31/1949	10 58 42.2	14.0	A	2	2.90	2	0		1500422
* 1501049	34.112	117.326	9/15/1971	8 23 59.8	10.8	B	2	3.00	2	0		1501049
* 1500829	34.113	117.311	2/27/1965	2 26 8.9	12.5	B	2	3.30	2	5C	006	1500829
* 1500923	34.115	117.357	3/26/1968	8 48 25.5	17.2	B	2	2.30	2	0		1500923
* 1500768	34.117	117.133	5/28/1961	16 25 11.0	0.0	C	2	2.50	2	0		1500768
* 1500577	34.117	117.209	10/13/1955	5 25 31.2	9.3	A	2	3.50	2	4C	006	1500577
* 1500450	34.117	117.217	8/18/1950	1 44 0.0	0.0	C	2	2.20	2	0		1500450
* 1500747	34.117	117.283	9/ 1/1960	7 35 5.0	0.0	B	2	3.50	2	4C	006	1500747
* 1500286	34.117	117.283	11/10/1945	18 32 51.0	0.0	C	2	2.60	2	0		1500286

Table 2. Continued.

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ID NO.	LATITUDE	LONGITUDE	DATE	TIME	DEPTH	QUAL	REF	MAG	REF	INT	REF	ID NO.
* 1500330	34.117	117.283	6/23/1947	16 5 24.0	0.0	C	2	3.80	2	0		1500330
1500341	34.117	117.300	11/22/1947	19 23 19.0	0.0	B	2	2.80	2	0		1500341
1500294	34.117	117.300	3/25/1946	2 43 32.0	0.0	B	2	2.70	2	0		1500294
1500269	34.117	117.300	1/11/1945	13 16 30.0	0.0	B	2	2.50	2	0		1500269
* 1500534	34.117	117.300	5/ 4/1953	2 30 23.0	0.0	B	2	3.40	2	4C	006	1500534
1500487	34.117	117.333	9/22/1951	8 25 16.0	0.0	B	2	2.70	2	0		1500487
* 1500522	34.117	117.333	1/25/1953	12 23 11.0	0.0	B	2	2.70	2	5C	006	1500522
1500587	34.117	117.367	12/23/1955	1 20 20.0	0.0	B	2	2.30	2	0		1500587
* 1500588	34.117	117.367	12/23/1955	8 43 44.0	0.0	B	2	3.30	2	4C	006	1500588
* 1500486	34.118	117.341	9/22/1951	8 22 39.1	11.9	A	2	4.30	2	5C	006	1500486
* 1500118	34.127	117.338	2/23/1936	22 20 42.7	10.0	A	2	4.50	002	5C	006	1500118
* 1500047	34.133	117.233	8/30/1932	5 48 55.3	0.0	B	2	2.00	2	0		1500047
* 1500647	34.133	117.250	12/17/1957	14 22 15.0	0.0	B	2	2.80	2	0		1500647
1500424	34.133	117.267	10/ 1/1949	4 23 5.0	0.0	B	2	2.30	2	0A	006	1500424
* 1500296	34.133	117.267	4/19/1946	22 38 50.0	0.0	C	2	2.70	2	0		1500296
1500536	34.133	117.300	5/13/1953	5 2 46.0	0.0	B	2	2.60	2	0		1500536
1500655	34.133	117.300	4/ 7/1958	12 1 15.0	0.0	B	2	2.50	2	0A	006	1500655
* 1500643	34.133	117.300	10/27/1957	15 25 22.0	0.0	B	2	3.00	2	0		1500643
* 1500535	34.133	117.317	5/ 4/1953	14 13 0.0	0.0	B	2	2.30	2	0		1500535
* 1500310	34.133	117.333	9/10/1946	23 55 21.0	0.0	C	2	2.40	2	0		1500310
* 1500975	34.136	117.272	4/30/1970	7 50 38.8	8.0	B	2	2.50	2	0		1500975
* 1500876	34.136	117.372	9/ 2/1966	11 58 12.9	7.0	B	2	2.20	2	2C	006	1500876
* 1500119	34.140	117.339	2/26/1936	9 33 27.6	10.0	A	2	4.00	2	0A	006	1500119
* 1500457	34.150	117.267	9/21/1950	14 30 58.0	0.0	B	2	2.30	2	0		1500457
* 1500488	34.150	117.333	10/22/1951	1 14 28.0	0.0	A	2	3.20	2	0		1500488
* 1500306	34.150	117.367	7/27/1946	1 31 57.0	0.0	B	2	2.50	2	0		1500306
* 1500986	34.156	117.158	9/ 3/1970	10 12 31.8	8.0	B	2	2.60	2	0		1500986
* 1501204	34.160	117.313	3/28/1973	17 52 26.1	8.0	A	2	3.40	2	5C	006	1501204
* 1501369	34.161	117.336	11/16/1974	6 41 5.3	6.6	B	2	2.40	2	0		1501369
* 1501370	34.162	117.342	11/22/1974	13 58 33.7	8.0	A	2	2.30	2	0		1501370
* 1501017	34.165	117.287	11/ 8/1970	18 19 26.6	8.0	B	2	2.90	2	0		1501017
* 1501241	34.166	117.288	7/16/1973	6 43 53.2	5.7	D	2	1.70	2	0		1501241
* 1500391	34.167	117.217	10/29/1948	23 59 7.0	0.0	C	2	3.10	2	0		1500391
* 1500423	34.167	117.233	9/29/1949	10 53 58.0	0.0	C	2	2.30	2	0A	006	1500423
* 1500169	34.167	117.250	5/17/1938	0 43 0.0	0.0	C	2	3.00	2	0		1500169
* 1500456	34.167	117.267	9/18/1950	4 41 38.0	0.0	B	2	3.20	2	3C	006	1500456
* 1500951	34.168	117.254	7/10/1969	6 38 13.3	-1.5	A	2	2.90	2	0A	002	1500951
* 1500919	34.169	117.276	1/19/1968	6 22 53.7	6.6	B	2	2.60	2	0A	006	1500919
* 1500866	34.169	117.304	3/31/1966	11 49 11.3	6.8	B	2	3.10	2	0A	006	1500866
* 1500783	34.170	117.193	7/26/1962	16 43 30.6	7.9	B	2	2.40	2	0		1500783
* 1501024	34.170	117.299	11/15/1970	14 53 55.2	8.0	B	2	2.30	2	0		1501024
* 1500812	34.171	117.342	2/28/1964	4 13 27.3	10.4	B	2	2.50	2	0		1500812
* 1501021	34.172	117.293	11/12/1970	23 33 50.2	8.0	A	2	3.10	2	0		1501021
* 1501020	34.175	117.299	11/10/1970	15 14 22.7	8.0	A	2	2.70	2	0		1501020
* 1500942	34.181	117.339	3/ 5/1969	13 53 50.6	6.4	A	2	3.40	2	4C	006	1500942
* 1501349	34.182	117.131	6/15/1974	21 41 37.5	6.2	A	2	2.30	2	0		1501349
* 1500496	34.183	117.133	2/14/1952	16 31 16.0	0.0	B	2	3.00	2	0		1500496
* 1500337	34.183	117.167	10/15/1947	10 57 9.0	0.0	B	2	2.50	2	0		1500337
* 1500016	34.183	117.283	1/ 7/1932	5 39 20.0	0.0	B	2	1.00	2	0		1500016
* 1500441	34.183	117.317	4/16/1950	9 0 29.0	0.0	B	2	1.70	2	0		1500441
1500460	34.183	117.317	9/24/1950	6 17 18.0	0.0	B	2	1.40	2	0		1500460

Table 2. Continued.

CALIFORNIA DIVISION OF MINES AND GEOLOGY
EARTHQUAKE CATALOG SYSTEM

PROGRAM RETRIEVE
VER. CON109H-128

DATE: 07/23/81
REQUEST: 1-A
PAGE: 10

DATA RETRIEVAL REQUEST FOR: EARTHQUAKES NEAR SAN BERNARDINO

ID NO.	LATITUDE	LONGITUDE	DATE	TIME	DEPTH	QUAL	REF	MAG	REF	INT	REF	ID NO.
* 1500485	34.183	117.317	9/ 3/1951	21 34 38.0	0.0	C	2	2.60	2	0		1500485
1500204	34.183	117.333	8/28/1940	11 2 54.0	0.0	B	2	3.00	2	0		1500204
1500125	34.183	117.333	6/ 1/1936	16 54 0.0	0.0	B	2	2.50	2	0		1500125
* 1500106	34.183	117.333	10/14/1935	9 36 0.0	0.0	B	2	3.00	2	0A	006	1500106
* 1501328	34.183	117.363	2/26/1974	12 54 36.0	5.2	B	2	1.80	2	0		1501328
* 1501022	34.186	117.226	11/13/1970	16 22 54.3	8.0	A	2	3.50	002	4C	006	1501022
* 1500917	34.188	117.372	12/28/1967	15 19 27.8	11.0	B	2	3.00	2	0		1500917
* 1500943	34.192	117.351	3/17/1969	3 4 51.7	4.5	B	2	3.40	002	5C	006	1500943
* 1500893	34.194	117.275	2/18/1967	18 48 56.1	0.5	B	2	3.60	2	4C	006	1500893
* 1501023	34.198	117.280	11/14/1970	11 58 37.9	8.0	B	2	2.50	2	0		1501023
* 1500915	34.198	117.345	11/17/1967	21 25 10.5	-2.0	B	2	2.90	2	0		1500915
1500275	34.200	117.150	2/16/1945	8 15 9.0	0.0	B	2	3.00	2	0		1500275
1500270	34.200	117.150	1/24/1945	18 1 0.0	0.0	B	2	2.60	2	0		1500270
* 1500271	34.200	117.150	1/26/1945	4 23 56.0	0.0	B	2	3.50	2	5C	006	1500271
* 1500852	34.200	117.265	9/12/1965	1 59 9.9	-2.0	B	2	2.80	2	0A	002	1500852
1500006	34.200	117.300	4/13/1913	10 45 0.0	0.0		7	9.99A		5B	004	1500006
* 1500749	34.200	117.300	10/ 4/1960	9 22 16.0	0.0	B	2	2.70	2	0A	006	1500749
1500075	34.200	117.333	11/26/1934	1 58 0.0	0.0	B	2	2.00	2	0		1500075
* 1500406	34.200	117.333	2/11/1949	12 43 5.0	0.0	C	2	2.50	2	0		1500406
* 1500459	34.200	117.350	9/24/1950	5 41 48.0	0.0	C	2	1.40	2	0		1500459
* 1501247	34.206	117.372	8/ 2/1973	1 3 26.5	8.0	A	2	3.00	2	0		1501247
* 1500777	34.216	117.168	2/ 1/1962	22 4 30.5	-2.0	C	2	2.60	2	0		1500777
1500267	34.217	117.167	11/ 7/1944	14 48 17.0	0.0	C	2	2.80	2	0A	006	1500267
* 1500262	34.217	117.167	9/ 3/1944	11 20 59.0	0.0	C	2	2.90	2	0		1500262
1500182	34.217	117.200	1/ 4/1939	7 41 0.0	0.0	C	2	2.50	2	0		1500182
* 1500183	34.217	117.200	1/ 4/1939	10 49 0.0	0.0	C	2	3.00	2	0A	006	1500183
* 1500555	34.217	117.317	7/22/1954	23 53 2.0	0.0	B	2	2.80	2	0		1500555
* 1500966	34.218	117.305	12/12/1969	19 48 29.6	10.0	B	2	2.50	2	0		1500966
* 1501038	34.226	117.208	7/15/1971	6 34 8.3	-2.0	A	2	2.60	2	0		1501038
* 1500660	34.233	117.133	7/15/1958	18 7 53.0	0.0	B	2	2.90	2	0		1500660
* 1501308	34.233	117.166	1/14/1974	7 16 2.7	5.6	B	2	2.20	2	0		1501308
* 1500187	34.233	117.200	4/ 5/1939	17 42 0.0	0.0	B	2	2.50	2	0		1500187
* 1500234	34.233	117.217	8/24/1942	14 54 19.0	0.0	C	2	1.50	2	0A	006	1500234
* 1501357	34.237	117.161	8/ 4/1974	9 8 6.5	8.0	A	2	3.40	2	0A	006	1501357
* 1501029	34.240	117.351	2/ 4/1971	23 42 2.1	8.0	B	2	2.40	2	0		1501029
* 1501215	34.242	117.178	4/23/1973	7 10 58.3	8.0	A	2	2.70	2	0		1501215
* 1501356	34.243	117.178	8/ 4/1974	9 2 2.7	8.0	A	2	2.90	2	0		1501356
* 1501364	34.246	117.167	10/14/1974	18 11 13.2	2.4	A	2	2.70	2	0		1501364
* 1501363	34.247	117.157	10/14/1974	17 33 0.1	3.4	A	2	3.20	2	2C	006	1501363
* 1501359	34.248	117.207	9/11/1974	10 31 32.2	3.4	B	2	2.00	2	0		1501359
* 1501055	34.249	117.171	12/24/1971	1 59 46.2	8.0	A	2	2.70	2	0		1501055
* 1500595	34.250	117.150	5/17/1956	4 7 7.0	0.0	B	2	3.20	2	0		1500595
1500757	34.250	117.167	1/ 2/1961	6 33 24.0	0.0	C	2	3.00	2	0		1500757
1500756	34.250	117.167	1/ 2/1961	6 33 20.0	0.0	C	2	2.80	2	0		1500756
* 1500303	34.250	117.167	7/ 4/1946	15 55 57.0	0.0	C	2	3.00	2	0		1500303
* 1500480	34.250	117.367	5/27/1951	6 19 52.0	0.0	B	2	3.00	2	0		1500480

----- END OF REQUEST NUMBER 1-A ----- 301 RECORDS SELECTED ----- 226 RECORDS PLOTTED -----

Table 2. Continued.

Only events equal to or greater than magnitude 4.0 or intensity V are accounted for during the period 1900-1931 primarily because of the lack of uniformity in reporting earthquakes and because the accuracy and methodology of seismographic instrumentation were not available until later. In 1932 statewide seismographic coverage was established. Thereafter data have been continuously measured and tabulated.

Quality (QUAL) ratings presented in the Earthquake Catalog of California are somewhat arbitrary and are not directly comparable from one source to another. The following key explains the criteria that the California Institute of Technology uses to assign hypocenter quality judgements. Also, the codes accompanying the magnitude (MAG) and intensity (INT) values in Table 2 are explained.

Key to Record Parameter Codes

I. Quality of Hypocenter (QUAL) as used by Cal Tech (REF 2)

- A. - Epicenter specially investigated
- B. - Epicenter probably within 5 km origin time to nearest second
- C. - Epicenter probably within 15 km origin time to a few seconds
- D. - Epicenter not known within 15 km rough location
- E. - Very rough location

II. Type of Magnitude (MAG)

- A. - Local Richter
- B. - Surface wave
- C. - Body wave
- D. - Local estimated from intensity
- E. - Local estimated from duration

III. Type of Intensity (INT)

- A. - No intensity given but felt
- B. - Rossi-Forel
- C. - Modified Mercalli

Epicenters of all qualities A-E were computer plotted for the San Bernardino study area. However, epicenter locations assigned quality A have been manually hatched in order to more easily visualize these more accurately located events (Plate 7). Also, the boundaries of the geothermal areas in San Bernardino were manually drafted onto the plate.

Discussion

There are no salient structural relationships visible (on Plate 7) when viewing the epicenter location distribution as a whole in the San Bernardino study area. However, noting the quality of hypocenters described in the "Key to Record Parameter Codes" above (especially QUAL A and B), a 10 km wide corridor centered about the San Jacinto fault zone was constructed on Plate 7. The San Jacinto fault zone may be considered to include the Loma Linda fault and other nearby faults. The corridor contains 62% of all the epicenters plotted on Plate 7. This clearly implies seismic activity associated with the San Jacinto fault zone in the San Bernardino Area. A casual observation of the distribution of epicenter locations, considering the 10 km wide corridor concept, suggests the San Jacinto fault zone has been more active from 1900-1974 than the San Andreas fault trace in the San Bernardino area.

Attempts have been made to associate seismic activity with heat generation along strike-slip faults in California (Henyey and Wasserburg, 1971; Lacherbruch and Sass, 1973; and Lee, 1980). The correlation is still not defined. Apparently no such association was found by Henyey and Wasserburg (1971) on the San Andreas or Garlock faults.

Of interest, however, is a local heat flow anomaly reported by Lee (1980) on the San Jacinto fault approximately 50 km or so southeast of San Bernardino at Anza, California (Figure 34). The anomaly based on data from 9 drill holes is nearly symmetrical about the fault trace. It has a peak of $0.8 \mu\text{cal}/\text{cm}^2 \text{ sec.}$ above a background of approximately $1 \mu\text{cal}/\text{cm}^2 \text{ sec.}$ Its halfwidth is approximately 7 km and the mean over a 40 km anomalous zone is approximately $0.20 \mu\text{cal}/\text{cm}^2 \text{ sec.}$

The San Jacinto fault zone is probably the most active fault zone in Southern California (Allen, 1975). That anomalous heat flows may sometimes be caused by active seismicity may be indicated by the fact that almost the complete areal extent of the south San Bernardino geothermal area is contained within the 10 km seismic corridor along the San Jacinto fault zone on Plate 7. However, it should be pointed out that the two other smaller geothermal areas on Plate 7 reside outside the greater seismicity area and one (Arrowhead Hot Springs geothermal area) contains the "hottest" surface water temperatures.

Lee (1980) attributes the local heat flow anomaly on the San Jacinto fault to "favorable conditions for concentrating heat sources rather than higher heat generation rate along the San Jacinto fault."

One other epicenter distributional feature is evident on Plate 7 if the data is viewed in a particular discriminatory way. The central portion of the map wherein lie the south San Bernardino and Harlem Hot Springs geothermal areas is nearly devoid of A quality epicenter locations (the hatched locations). The A quality epicenter locations are distributed in a broad semicircular pattern about these two geothermal areas.

Figure 34. Heat flow anomaly across the San Jacinto Fault near Anza, California. From Lee, 1980.

Comparison of Plates 3, 5, 6, and 7 show the area devoid of A quality epicenter locations can be correlated with gravity anomalies, historic boundaries of artesian activity, and the 1973 ground water table depression. The A quality locations seem to ring the area thought to be a relative deep basin. One conclusion might be that the more precisely located epicenters (A quality) indicate active faulting about the perimeter of the deeper basin and such faulting is the structural control for the basin. Certainly this is the case along the southwest side of the basin along the San Jacinto fault zone.

Summary

The epicenter location map of the San Bernardino study area (Plate 7) shows two distributional features when observed in a particular discriminatory way.

The San Jacinto fault zone appears to be very seismically active from 1900-1974. The activity may have some association with anomalous heat flow known to occur elsewhere on the San Jacinto fault.

A semicircular ring of A quality epicenters about the deeper basin containing the south San Bernardino and Harlem Hot Springs geothermal areas may indicate that the basin perimeter is fault controlled, as is the case on the southwest side of the basin along the San Jacinto fault.

GEOCHEMISTRY

Introduction

Geochemical analyses of fluids from a geothermal resource provide a means for determining many diagnostic properties of the reservoir. The chemical composition of thermal waters provides the only indirect means of quantitatively estimating geothermal reservoir temperature. Analyses of mineral segregation in thermal fluids may indicate structural features or barriers within a geothermal reservoir. Geochemistry may also be able to provide some clues to the type of thermal system being investigated including such parameters as heat source, path of fluids, etc.

Early chemical analyses are recorded for some of the developed hot springs and geothermal wells at San Bernardino by Blake (1857), Mendenhall (1905), Bailey (1910), Waring (1915), Dutcher and Garrett (1963), and Moyle (1974).

Methodology

The California Division of Mines and Geology (CDMG) planned to sample as many geothermal wells and springs as possible to aid in the geothermal resource investigation of the San Bernardino Area. Although Plate 1 shows 97 geothermal well and spring locations, most of these are older wells and can no longer be found. Other wells have been abandoned and a water sample from a stagnant well is not representative. Access to other wells was denied because the well and pumping apparatus were self enclosed. Still other wells have

inoperable pumps. These and some other minor reasons drastically reduced the accessible geochemistry sample population.

CDMG sampled and had analyzed waters from 13 wells during the San Bernardino geothermal investigation. Well owners provided CDMG with an additional eight geochemical analyses from their files. The individual analyses are grouped in Appendix A at the end of this report. They are entered in sequential location numbers as posted on Plate 1. CDMG sampled Location Nos. 2, 3, 6b, 8, 10, 17, 32, 37, 47, 57, 59, 62, and 93. Well owners provided analyses for Location Nos. 7, 13, 25, 27, 28, 59, and 66.

The laboratory techniques utilized to produce the eight analyses provided by well owners is not known. Therefore, only analyses from the CDMG sampled wells are recorded in Table 3. The analyses are grouped according to the geothermal area in which the waters were collected. Within each group the analyses are arranged in increasing order of maximum recorded temperature. The temperatures are as noted in the explanation on Plate 1. A further subdivision of the analyses from the south San Bernardino geothermal area is shown on Table 3. This subdivision divides the waters into two distinct groups based on similarity of elemental concentrations and other geochemistry properties.

Approximately one gallon of fluid sample was obtained at each well. The sample was filtered and divided into bottles for shipment to the University of Utah Research Institute (U.U.R.I.) and the Geochemical Laboratory of the CDMG at San Francisco. Concentrations of chloride (Cl), sulfate (SO_4), sulfide (S), and ammonia (N/NH_3) as well as measurements of alkalinity, salinity, pH, electrical conductivity, and temperature were determined in the field by

LOCATION NUMBER ON PLATE 1	ELEMENTAL CONCENTRATIONS IN PARTS PER MILLION (PPM)																	Salinity ‰	pH	Conductivity at Temp. specified (µmho/cm)/(°C)	Maximum recorded Temp. at depth specified (°C)/(ft.)
	Na	K	Ca	Mg	Fe	Si	Sr	Li	B	Cl	F	S	SO ₄	N(NH ₃)	CO ₂	HCO ₃	TDS				
ARROWHEAD HOT SPRINGS GEOTHERMAL AREA																					
Location No. 2	208	7	11	12	.04	50	.38	.18	1.9	65	5.0	.06	315	X	6.0	56	729	0.7	7.1	1700/34°	81°/0'
Location No. 3	173	7	10	X	X	51	.29	.15	1.7	56	5.5	.02	281	X	5.5	75	644	0.5	7.2	1300/32°	84°/0'
Location No. 6b	204	11	32	1	X	74	.74	.23	2.5	67	4.4	.01	235	X	X	96	700	0.6	6.6	1600/31°	84°/100'
EAST BRANCH HARLEM HOT SPRINGS GEOTHERMAL AREA																					
Location No. 93	35	X	32	11	X	26	.28	X	0.2	16	1.8	X	17	X	X	140	212	0.1	6.5	453/19°	19°/0'
Location No. 8	48	X	37	12	.57	27	.33	X	0.1	21	1.0	X	40	X	X	159	288	.01	6.5	530/26°	25°/0'
Location No. 10	105	X	17	X	X	24	.21	X	0.6	36	4.0	X	103	X	X	95	359	0.3	7.0	850/35°	43°/440'
WEST BRANCH HARLEM HOT SPRINGS GEOTHERMAL AREA																					
Location No. 17	86	X	27	4	X	20	.09	X	X	27	1.2	X	97	X	X	136	352	0.2	6.7	720/30°	28°/0'
SOUTH SAN BERNARDINO GEOTHERMAL AREA																					
Location No. 62	60	X	4	X	X	15	.05	X	0.6	20	2.6	X	17	0.2	X	140	212	0.1	7.6	365/31°	29°/0'
Location No. 59	75	X	8	X	X	21	.10	X	1.5	58	3.6	X	20	0.1	X	124	272	0.1	7.4	520/32°	43°/0'
Location No. 57	96	X	3	X	X	27	.07	X	2.4	96	6.1	X	34	X	11	81	336	0.2	7.8	640/32°	56°/0'
Location No. 37	15	3	57	10	X	17	0.4	X	X	6	0.5	X	26	X	X	230	269	0.1	6.2	440/29°	21°/0'
Location No. 47	25	4	58	9	.25	21	.48	X	X	8	0.6	X	25	0.6	X	236	288	0.1	6.6	483/27°	26°/230'
Location No. 32	27	4	40	7	X	25	0.4	X	X	7	0.6	X	26	X	X	198	255	0.1	6.2	425/31°	31°/0'

Table 3. Geochemistry data for 13 water wells sampled during the CDMG (1980-81) geothermal investigation of the San Bernardino Area, California.

CDMG utilizing their portable geochemistry laboratory facilities. These data are listed under the heading "CDMG Field Analysis" on the individual analyses presented in Appendix A. The cation analyses were performed at U.U.R.I. in Salt Lake City. Cations include sodium (Na) to thorium (Th) on the list of elements under the heading "UURI Analysis" on each individual analysis sheet in Appendix A. The cation concentrations were measured on an Inductively Coupled Plasma Spectrometer. U.U.R.I. also analyzed two anions; chloride (Cl) and fluoride (F). Chloride concentration was measured by the Mohr titration method. Fluoride concentration was determined by a specific ion meter. Silica (SiO_2), carbonate (CO_3), bicarbonate (HCO_3), sulfate (SO_4), and total dissolved solids (T.D.S.) concentrations were determined at the Geochemical Laboratory of the California Division of Mines and Geology (CDMG) at San Francisco by standard geochemical laboratory techniques. These data are posted on each individual geochemical analysis in Appendix A under the heading "CDMG Lab Analysis".

Table 3 is a composite of the data from the individual CDMG geochemistry analysis in Appendix A. Cations whose concentrations were non-existent or less than the lowest detectable limits of U.U.R.I.'s capabilities for all 13 samples are not included in Table 3.

Results

Chemical similarities and differences in waters from the designated geothermal areas are evident in Table 3. Some observations are listed below:

- o Arrowhead Hot Springs geothermal area waters are the only ones that contain lithium (Li) and detectable sulfide (S).

- o Arrowhead Hot Springs waters are one of only two groups in Table 3 that contain potassium (K).
- o Arrowhead Hot Springs waters contain much higher concentrations of sodium (Na), silica (Si), and sulfate (SO₄) as well as higher TDS than any other group in Table 3.
- o Geothermal waters of the East Branch and West Branch of Harlem Hot Springs geothermal areas appear similar in elemental make-up and concentrations except Location No. 17 has less strontium (Sr) and no detectable boron (B) compared to the wells in the East Branch.
- o South San Bernardino geothermal area waters can be divided into two groups based on elemental make-up and concentrations. The upper group in Table 3 (Location Nos. 62, 59, and 57) contains boron(B), but there is no detectable potassium (K) nor magnesium (Mg) as compared with the lower group (Location Nos. 37, 47, 32).
- o Waters of the upper group of the south San Bernardino geothermal area are basic (pH > 7.0) while the lower group waters are acidic (pH < 7.0).
- o Other contrasts are observable in Table 3, but some differences in concentrations are temperature dependent and may not directly indicate differences in chemical properties.

Discussion

Historically water wells drilled in the San Bernardino area have been perforated for a large percentage of their total depth. Also, when warm water was encountered during drilling the wells were backfilled in an attempt to seal the geothermal waters from the well. Therefore, a mixing problem exists in these wells. That is, it is impossible to obtain a sample of water directly from a geothermal aquifer in the wells at San Bernardino. A scan of the geological well logs in Appendix C will provide some examples of the problem. Hence, a sample geochemically analyzed from the wells will be contaminated by waters from fresh water aquifers. (This probably is not a problem in the Arrowhead Hot Springs geothermal area where the geothermal aquifers reach the surface.) This contamination problem must be kept clearly in mind when discussing the results of the geochemical analyses posted in Table 3.

Despite the fresh water contamination of the geothermal wells the data in Table 3 present remarkable similarities in each group and remarkable contrasts between groups. This suggests that geothermal reservoir characteristics such as source of heat, source of fluids, geothermal fluids travel path, etc. may be different for each geothermal area shown on Plate 1.

Barnes (1970) suggests that the presence of boron (B) in geothermal fluids indicates those fluids may have escaped along faults. Boron was detected in all samples of the Arrowhead Hot Springs group, east branch of the Harlem Hot Springs group, and the upper group of the south San Bernardino geothermal area as shown in Table 3. The wells in these groups are located near fault traces as shown on Plate 1. It is believed that these faults are the conduit systems allowing deeply circulated meteoric waters to rise into the alluvial strata of the San Bernardino area.

The subgrouping of the data in Table 3 for the south San Bernardino geothermal area appears to indicate a very important structural feature. Wells with Location Nos. 62, 59, and 57 (Plate 1) have similar elemental compositions that differ from the other 3 wells sampled in the area. These wells are in alignment on a northwest trend. All three of the wells were heavily artesian in the spring of 1981. Again, noting the similarity of the boron concentration in these three wells and regarding geophysical data discussed elsewhere in the report, it is assumed that these three wells are astride a northwest trending fault trace that allows a "plume" of geothermal fluid to rise to near the surface. The fault is the projection of the Loma Linda fault trace in the alluvial section of the San Bernardino area.

GEOTHERMOMETRY

Introduction

The use of chemical geothermometers (geothermometry) is an indirect method of estimating the temperature of a subsurface reservoir where the geothermal fluids are assumed to have equilibrated. Geothermometry methods are based on temperature-dependent, water-rock reactions which determine the chemical and isotopic composition of geothermal fluids. The most common soluble chemical constituents of thermal waters are SiO_2 , Na, K, Ca, Mg, Cl, HCO_3 , and CO_3 . The three most generally used geothermometers are the silica, Na-K-Ca, and sulfate-isotope geothermometers. The validity of the estimated temperatures calculated by utilizing these geothermometry algorithms is based on the following assumptions:

- 1) Temperature-dependent reactions at depth control the concentration of the geothermometer.
- 2) The reservoir contains an adequate supply of the reactants.
- 3) Water-rock equilibrium is established in the reservoir.
- 4) The constituents used in the geothermometer do not reequilibrate with the confining rock as the water flows to the surface.
- 5) Mixing of thermal and nonthermal groundwater does not occur.

Problems and inaccuracies arise with the calculated reservoir temperature when one or more of the above assumptions are violated. The geochemical data utilized for the geothermometry calculations in this report come from wells that were drilled for a fresh or cold water supply. As earlier explained, these wells were typically perforated over a large percentage of their total

depth to maximize water production. Hence, the waters in each well are a mixture of waters from distinct aquifers. If one of these aquifers contained geothermal fluids, those fluids would then be mixed (at unknown proportions) with waters from fresh water aquifers. This is a direct violation of assumption No. 5 above. It is assumed that this contamination problem caused by mixing occurs in all water wells thought to contain geothermal waters in the San Bernardino area. The exception is the Arrowhead Hot Springs geothermal area where the hot water aquifer or aquifers may reach the surface. The geothermometric results presented below should be considered with great care and some skepticism due to the mixing problem.

Methodology

Early in the CDMG geothermal investigation at San Bernardino it was learned that the Institute of Geophysics and Planetary Physics at the University of California, Riverside, was undertaking a geothermometry investigation for the City of Riverside Public Utilities, Water Division. Part of their study area included a large portion of the south San Bernardino geothermal area. A cooperative program was arranged by CDMG and Dr. Wilfred Elders of the University of California, Riverside to share data. Additional geochemistry data gathered by CDMG were added to the University of California, Riverside study. The additional data were comprised of geochemistry analyses from 35 municipally owned water wells supplied by the City of San Bernardino Municipal Water Department and by geochemistry data from 13 water wells analyzed by CDMG during their geothermal investigation.

Carter Hull, a graduate student at the University of California, Riverside, under the supervision of Dr. Willfred Elders, computer programmed the algorithms of the empirical Na-K-Ca geothermometer as devised by Fournier and Truesdell (1973) and Fournier and Potter (1978). Hull (1981) computer processed the geochemistry results from 95 wells supplied by the City of Riverside Public Utilities Water Division and the geochemistry results of the 35 water wells supplied by the City of San Bernardino Municipal Water Department. An approximate temperature of the last water-rock interaction was computer calculated for waters in each well. CDMG manually calculated temperatures using the Na-K-Ca geothermometer for the 13 wells they sampled.

The resulting calculated reservoir temperatures are posted on Plate 8 adjacent to the locations of the wells sampled. CDMG manually contoured the data presented on Plate 8.

Results

Plate 8 includes seventy-five wells for which Na-K-Ca geothermometry calculations were performed. The resulting estimated reservoir temperatures range from 14° - 149°C. The majority of the wells were known to be fresh or cool water wells. The Na-K-Ca geothermometer was applied to the geochemistry data from all wells regardless of well temperatures. The distribution of wells is not uniform making contouring of the estimated reservoir temperatures difficult.

Discussion

The greatest estimated reservoir temperatures and perhaps the most accurate temperatures occur in Arrowhead Hot Springs geothermal area. Reservoir temperatures of 136°C, 142°C, and 149°C were calculated. Taking the average, an estimated reservoir temperature of 142°C is arrived at. Assuming a geothermal gradient of 31°C/km (A.A.P.G. and U.S.G.S., 1975) and a mean annual surface temperature of 17°C, a depth of circulation of approximately 4 km (2.5 miles) is calculated for geothermal fluids for the Arrowhead Hot Springs geothermal area.

Jarzabek (1980) calculated a reservoir temperature of 144°C using the Na-K-Ca geothermometer ($\beta=1/3$) and 138°C using the quartz geothermometer for one sample (SB-1) collected at Arrowhead Hot Springs. The above CDMG calculated average temperature compares favorably with Jarzabek's results.

Utilizing a tritium mixing equation, Jarzabek (1980) shows that water from a hot spring at Arrowhead Hot Springs has a small component of recent local ground water intermixed with geothermal waters. However, analysis of geothermal fluids from a nearby well indicates no mixing of young ground water with geothermal reservoir fluids. The assumption is that the well is cased and this precludes shallow ground water contamination. All three of the estimated reservoir temperatures calculated by CDMG above are for wells in the Arrowhead Hot Springs area. Therefore, the average temperature of 142°C is considered to be a reliable indicator of the geothermal reservoir temperature.

Na-K-Ca geothermometry calculations for wells in the south San Bernardino geothermal area yielded estimated reservoir temperatures ranging from 25° - 63°C. Arbitrarily using the highest temperature of 63°C and the values for the geothermal gradient and mean annual surface temperature cited above, a depth of circulation of approximately 1.5 km (0.9 miles) is calculated for geothermal fluids for the south San Bernardino geothermal area.

The reliability of the geothermometry calculations for the south San Bernardino geothermal area may be questionable. The assumption is made that fresh water and geothermal waters are intermixed in all wells designated as "hot" wells in this geothermal area. The chemical contribution and mixing ratios due to fresh water "contamination" are not known. No attempt is made in this report to determine mixing ratios.

Chemical analyses and subsequent geothermometry calculations performed on samples wholly obtained from geothermal aquifers in this area may indicate higher reservoir temperatures than calculated above.

The contouring on Plate 8 does, however, indicate a "hot spot" that is in alignment along the Loma Linda fault trace in the south San Bernardino geothermal area. Generally, the hottest temperatures calculated using the Na-K-Ca geothermometer for this area fall within two zones aligned with the Loma Linda fault. This is interpreted as indicating a "plume" or zone of upwelling of geothermal fluids from depth along the fracture zone of the fault. There may be other such plumes in the south San Bernardino geothermal area, but the data point distribution is not of an adequate uniform areal density to make definitive interpretations.

There was no potassium (K) in the wells sampled by CDMG in the Harlem Hot Springs geothermal areas. The Na-K-Ca geothermometer could not be applied to this area.

Seven wells southwest of the south San Bernardino geothermal area and the San Jacinto fault zone show Na-K-Ca geothermometry temperatures of 44° - 71°C. This temperature range is qualitatively higher than the temperature range within the geothermal area. The incongruity is obvious, but the explanation or explanations are elusive. Total depth of wells, zones of casing perforation, well water temperature, etc. were not considered for the Na-K-Ca geothermometry calculations. Therefore, wells were not sorted into like categories of physical characteristics. These seven wells are within or very near the Santa Ana River drainage. Some or all of these wells may be deep enough to intersect deeper aquifers that are the subterranean drain for the south San Bernardino geothermal area along the path of the Santa Ana River. This discharge is probably a mixture of waters from one or more geothermal "plumes" in the south San Bernadino geothermal area, geothermal fluids from the Harlem Hot Springs geothermal areas drained into the area along a subterranean route superficially indicated by Warm Creek, and fresh water from various shallower aquifers. The geothermometry temperatures for the south San Bernardino geothermal area may be anomalously low due to mixing or other violations of the basic assumptions required for reliability of geothermetric calculations.

The incongruity between Na-K-Ca geothermometry temperatures within the south San Bernardino geothermal area and those to the southwest points out the inadequacy of relying upon one investigative technique to supply the definitive assessment of a geothermal resource.

DIRECT TEMPERATURE MEASUREMENTS OF THE SAN BERNARDINO GEOTHERMAL AREAS

Introduction

Probably the most important property of a geothermal reservoir is its temperature. Several methods were employed by CDMG to collect direct temperature measurements of the San Bernardino geothermal areas. Wells and springs with temperatures of 20°C and greater are considered to be geothermal.

Methodology

First, locations of geothermal wells and temperatures were researched in the literature. Mendenhall (1905), Bailey (1910), Waring (1915), Dutcher and Garrett (1963), and Moyle (1974) are the sources of historic data. All temperatures reported in these publications were considered to be surface water temperatures unless otherwise recorded.

Secondly, municipal water companies and private water companies were contacted to provide locations and temperatures of geothermal wells and springs known to each of them. Likewise all temperatures reported were considered to be surface water temperatures unless otherwise stated.

And thirdly, CDMG recorded surface temperatures with a standard hand held maximum recording thermometer in many wells and springs. The data were collected in the discharge of artesian and pumping wells as well as in flowing

springs. CDMG also recorded downhole water temperatures. A CDMG crafted, thermistor tipped temperature probe attached to 1200 feet (366 meters) of graduated electrical conducting cable was manually lowered into accessible water wells. Changes in electrical resistance of the thermistor due to water temperature differences were recorded by a standard multi-test meter operated in the resistance measuring mode. Actual temperatures were then deduced from a temperature versus resistance graph that was empirically derived preparatory to field work. Later, temperature logs were drafted depicting curves of water temperature versus depth of probe penetration in each well. Appendix B in this report contains 18 temperature logs. CDMG directly recorded 13 of these, 3 were reconstructed by CDMG from data supplied on the original driller's log, and the remaining 2 temperature logs were recorded by Geothermal Surveys, Inc.

All surface temperature data whether old or newly collected from literature, personal communication, or directly measured by CDMG are presented in the explanation of Plate 1. Maximum recorded temperatures from the temperature logs in Appendix B are also presented in the explanation. In all, there are 97 geothermal wells and springs posted on Plate 1. These occupy Location Nos. 1-92 (some locations are subdivided such as 6a and 6b).

Results

Great care must be observed when discussing the temperatures posted on Plate 1 in a collective way. Temperatures presented in the explanation have been recorded over an approximate 80 year span. It is quite reasonable to assume that surface temperatures of wells recorded say by Mendenhall (1905)

may not be the same temperatures that would be measureable today even if these old wells can be found.

Arrowhead Hot Springs Geothermal Area

CDMG recorded surface temperatures of 29° - 87°C in wells and springs in the Arrowhead Hot Springs geothermal area (Plate 1, Location Nos. 1-7). However, the surface temperature range of Location Nos. 1-6 was 75° - 87°C. Location No. 7 appears anomalously "cooler" than the rest. Note, however, that this location is at a higher altitude than the others and therefore may not be as deep relative to sea level as some of the other wells in this area.

Only one well was temperature probed in this geothermal area, and only one measurement was recorded. Location No. 6b was 84°C at a depth of 100 feet (30 meters).

The greatest temperatures directly measured by CDMG are in the Arrowhead Hot Springs geothermal area. The "hotter" geothermal wells and springs seem to be confined to a narrow band trending northwest by west across the geothermal area.

Harlem Hot Springs Geothermal Areas

CDMG was able to temperature probe six wells in or near the Harlem Hot Springs geothermal areas during the resource investigations. These are wells

with Location Nos. 8, 9, 10 and 93 in the Patton State Hospital area on Plate 1, and Location Nos. 23 and 24 west of the intersection of Base Line Road and Sterling Avenue. There are no longer any natural hot springs in this area.

The temperature logs of these wells are given in Appendix B. The logs have been combined into the Patton State Hospital group on Figure 35 and into those owned by East San Bernardino County Water District on Figure 36.

Some broad interpretations of Figure 36 give clues to the nature of the geothermal resource in the area of Location Nos. 23 and 24. Two pronounced protuberances on the temperature curve of Location No. 24 and one on the temperature curve of Location No. 23 possibly suggest a thin (perhaps 50 feet, 15 meters, thick) hot water aquifer above a cooler water aquifer perhaps 40 feet (12 meters) thick (see Figure 36). These two wells are approximately 1,150 feet (351 meters) apart.

The inference is that the geothermal waters probably are confined to discrete and sometimes thin aquifers. Migration of geothermal fluids between discrete aquifers probably occurs along faults, fracture zones, and older, buried, crosscutting alluvial channels.

Location Nos. 23 and 24 are both abandoned wells. The near vertical gradient for most of the curve of Location No. 23 on Figure 36 is characteristic of an artesian well. However, the well was not flowing at the time of temperature probing and had no known recent history of artesian flow. The vertical gradient may be due to heavy water turbulence within the well and within some of the aquifers it intersects.

Figure 35. Temperature profiles from water wells owned by Patton State Hospital, San Bernardino, California. Location numbers refer to PLATE 1.

Another interpretation is that this curve accurately represents temperature versus depth in this area (i.e., perhaps water of near 40°C temperature is available at approximately 160 feet depth). Nearby well Location Nos. 15a, 15c, 16, and 18 all reported temperatures greater than 40°C at a relative shallow depth. However, these temperature measurements are rather old (see explanation of Plate 1).

Intuition may favor the first interpretation because the hot water table at this site has probably lowered over the years as it has elsewhere in the San Bernardino geothermal areas.

South San Bernardino Geothermal Area

The south San Bernardino geothermal area outlined on Plate 1 contains approximately 60 geothermal well locations. That is approximately two-thirds of the total geothermal locations posted on Plate 1. CDMG surveyed 11 wells in the south San Bernardino geothermal area. These include Location Nos. 32, 37, 47, 48, 50, 52, 57, 58, 59, 62, and 95. The temperature logs and/or surface temperatures are presented in Appendix B and in the explanation of the Plate 1 respectively.

Figure 37 is a compilation of the temperature logs for the central portion of the south San Bernardino geothermal area. Of the wells presented, Location No. 57 has approximately twice the temperature as compared to the rest. Temperature curves of nearly all the rest of the wells fall within the 20° - 30°C range.

Figure 37. Temperature profiles from water wells located in the central portion of the South San Bernardino Geothermal Area. Location numbers refer to PLATE 1.

CDMG (1980-81) recorded the surface temperature of Location Nos. 57, 59, and 32 to be 56°C, 43°C, and 31°C respectively. All were heavily artesian. These were the "hottest" surface temperatures measured by CDMG in the south San Bernardino geothermal area. In fact the surface temperature of the artesian flows of Location Nos. 57 and 59 are much "hotter" than any temperature recorded on all the CDMG temperature logs for the south San Bernardino geothermal area. The implication is that the wells at Location Nos. 57 and 59 are closer to one of the hotter parts of this geothermal resource, and probably are astride an upwelling "plume" of geothermal fluid.

ASSESSMENT OF THE GEOTHERMAL RESOURCES

AT SAN BERNARDINO, CALIFORNIA

Introduction

A geothermal resource assessment, by necessity, must be updated, refined, and reevaluated as more data on a particular resource area become available. Therefore, some of the material presented in this report concerning the low-temperature geothermal resources at San Bernardino, California may be modified in the future. Data from the geothermal development program proposed by the City of San Bernardino Municipal Water Department will add greatly to the refinement of the assessment of the geothermal resources in the area.

Probably since Spanish exploration in the very early 1800's, low-temperature ($<90^{\circ}\text{C}$) surficial geothermal resources have been historically noted in the San Bernardino area, California. Today there are still several geothermally active areas and there is good reason to speculate that geothermal fluids have issued in this very tectonically active area for many millennia. This apparent longevity of the geothermal resources should be encouraging to potential geothermal developers in San Bernardino.

Properties of the Resources Areas

Geothermal springs and drilled water wells that have intersected geothermal aquifers have been located in three general areas at San Bernardino. These areas have been initially delineated and designated as the Arrowhead Hot

Springs geothermal area, the south San Bernardino area, and the Harlem Hot Springs geothermal area (Plate 1). The Harlem Hot Springs area has been temporarily divided into as yet unconnected east and west branches.

The contrasts in geochemical analyses of fluids from each geothermal area (Table 3) suggests separate sources for each area or, at the very least, separate travel paths of the geothermal fluids. Boron found in the samples suggests association of geothermal fluids with faulting. Geological and geophysical surveys have located faults associated with all the designated geothermal areas (Plate 1).

Arrowhead Hot Springs Geothermal Area

The Arrowhead Hot Springs geothermal area comprises 1.2 km² (0.5 mi²) of area. The "hottest" surficial geothermal waters in San Bernardino are found in this area. The maximum recorded surface temperature is 87°C (189°F) (Plate 1, Location No. 5). There has been relatively very little change through recorded literature in the surficial temperatures of the geothermal discharge in this area (i.e. near boiling temperatures seem to have always been available at the Arrowhead Hot Springs geothermal area).

Geothermometry calculations suggest a maximum reservoir temperature of approximately 142°C (288°F) and a depth of circulation for geothermal fluids of 4 km (2.5 miles).

Geothermal wells and springs at the Arrowhead Hot Springs complex naturally flow at approximately 100-200 gpm. The flowing well and springs at Water-

man Hot Springs, also included in the Arrowhead Hot Springs geothermal area, can naturally discharge (with well head open) at approximately 30-50 gpm. Arbitrarily combining the high discharge rates, then perhaps as much as 250 gpm of geothermal fluids flow from the geothermal area. This is about a four-fold increase over early estimates (Waring, 1915). The increase is, in most part, probably due to the drilling of wells in more recent years that are flowing at Arrowhead and Waterman Hot Springs. The speculation is that an appropriately sited system of wells could further increase (by some unknown amount) the geothermal discharge rate and probably (if drilled appropriately deep enough) increase the temperature of the discharge.

There is a very thin stratum of alluvial material within the Arrowhead Hot Springs geothermal area. Hence, only a very minor alluvial pore-filled geothermal reservoir is available. The geothermal fluid production would be in basement rock from the fracture zone of the fault segment that offshoots the San Andreas fault (Plate 1).

The high mineral content (Table 3) of geothermal fluids from the Arrowhead Hot Springs geothermal area is a concern in future geothermal development.

Harlem Hot Springs Geothermal Areas

The total combined area of the east and west branches of the Harlem Hot Springs geothermal areas is 6.5 km^2 (2.5 mi^2). The highest measured temperature in a well from literature is 54°C (130°F) at 194 feet (59 meters) (Plate 1, Location No. 15c). CDMG recorded a temperature of 49.5°C (121°F) at

570 feet (174 meters) in well Location No. 24. Water temperatures in wells have generally lowered over the past one hundred years undoubtedly in response to the lowered geothermal water table. The geothermal water table has lowered perhaps 300-400 feet (91-122 meters) during this time span in the Harlem Hot Springs geothermal areas.

The current production of geothermal fluids from the Harlem hot Springs geothermal areas is unknown, but it must be substantial considering the operating Base Line Laundry (Plate 1, Location No. 17), the Patton State Hospital (Plate 1, Location Nos. 8, 9, and 10), and the Southern California Water Co. (Plate 1, Location Nos. 27 and 28) all of whom are currently pumping from their wells.

The temperature curves of Figure 36 indicate that geothermal waters are confined to discrete and sometimes thin aquifers within the alluvial strata of the valley.

Lack of potassium (K) in the water samples collected within the Harlem Hot Springs geothermal areas (Table 3) precluded calculating geothermometry temperatures of the reservoir.

Geophysical and geological surveys conducted within the Harlem Hot Springs geothermal areas have developed a new faulting fabric as compared to that presented in previous literature. Notable is the generally east-west trending Fault F1 inferred from gravity data (Figure 13 and Plate 1). There is a trend of geothermal wells subparalleling this fault just to the south (Plate 1, well Location Nos. 15a-d, 14, 16, 17, 18, 19, 20, 23, and 24). Fault F1 may

have some adjoining association with the possible structural limitation to geothermal resources shown on Plate 1. Dutcher and Garret's (1963) fault "K" and "L" (Figure 13) have been replaced by new proposed fault alignments, Faults F2 and F3 (Plate 1). These faults are associated with geothermal wells. The juxtaposition relationship of Faults F2 and F3 with Fault F1 is not clear at this time.

Gravity data imply a thickness of alluvial strata of 1,400 feet (427 meters) just south of Fault F1 and 1,100 feet (335 meters) immediately north of the fault. Certainly the geologic log of the well with Location No. 92a (Plate 1) indicates that the alluvial strata in this area is over approximately 650 feet (198 meters) thick (Appendix C). The alluvial strata thins northeastward across the Harlem Hot Springs geothermal areas, but is still over 500 feet (152 meters) thick at well Location No. 8 on Plate 1 as evidenced by the geologic log (Appendix C). What part or parts of this wedge-shaped (in cross-section) alluvial strata are geothermal reservoirs or aquifers could not be determined from the data collected during this investigation.

South San Bernardino Geothermal Area

The south San Bernardino geothermal area is the largest designated geothermal area comprising 16 km² (6.2 mi²). There no longer are any hot springs in this area. The maximum reported historic temperature was 41°C (106°F) from shallow wells drilled at the old Urbita Hot Springs site (Plate 1, Location No. 43). The most recent maximum recorded temperature is 56°C (133°F) in a flowing well (Plate 1, Location No. 57) drilled some 600

feet (183 meters) deeper than the old wells at the Urbita site. It appears that the geothermal water table has lowered several hundreds of feet over the past 100 years in the south San Bernardino geothermal area, but "hotter" temperatures may be found at depth. An increase of geothermal temperatures with depth is also evidenced on Figure 37 from the temperature curves of wells within the geothermal area.

Unreliable geothermometric calculations (due to mixing of fresh water and geothermal waters in wells as well as other problems) yielded a maximum reservoir temperature of 63°C (145°F) and a depth of circulation of approximately 1.5 km (0.9 mi) for geothermal fluids in the south San Bernardino geothermal area.

The total amount of geothermal fluids currently being withdrawn from the south San Bernardino geothermal area is not determinable from data gathered for this report, but perhaps from 1500-2000 gpm of warm water was flowing artesian in toto from wells at Location Nos. 32, 57, 59, 81, and 82 during the early spring of 1981. The fraction of geothermal fluids mixed with fresh ground water was not determined.

The San Jacinto fault is a dominant feature in the south San Bernardino geothermal area. The fault is in part responsible for the downdropped Bunker Hill hydrologic basin and also is a geothermal fluids barrier. A segment of the fault is also probably a conduit for ascending geothermal fluids.

The Loma Linda fault is also a dominant structural feature in the south San Bernardino geothermal area. The fault trace has been more accurately

located slightly to the southwest than previous reports (Dutcher and Garrett, 1963) from data from CDMG geophysical and geological surveys (Plate 1 and Figure 12). The downdropped northeastern side of the Loma Linda fault forms the deepest part of the alluvial basin (Bunker Hill basin) at San Bernardino. The depth of the deepest part of the basin (to basement rock) is at least 2,460 feet (750 meters). The deep basin is inferred from the gravity contours and explicitly demonstrated by the "Del Rosa No. 1" well on Plate 6. The geologic log of "Del Rosa No. 1" in Appendix C shows that basement rocks were not encountered in this well.

Hadley and Smith (1973) calculated an average depth to basement material of 3300 feet (1006 meters) from a seismic refraction profile along the Santa Ana River from Alabama Street southwestward to the Tri-City Airport in San Bernardino. The seismic refraction profile location is immediately south of "Del Rosa No. 1" (Plate 6).

The Loma Linda fault and Fault F4 are probably geothermal fluid barriers at some depth. The "hotter" geothermal wells (Plate 1, Location Nos. 57, 59, 62, 81, and 82) are either astride the Loma Linda fault or just northeast of its trace while a well of comparable depth, Plate 1, Location No. 58, just southwest of Fault F4 has a much lower temperature (see Explanation of Plate 1). Also the geochemistry of the water from wells at Location Nos. 57, 59, and 62, aligned along the Loma Linda fault, are similar, but remarkably different from the other wells sampled in the San Bernardino geothermal area (Table 3). These two facts substantiate that Fault F4 and the Loma Linda fault are at least partially a geothermal water barrier.

A segment of the Loma Linda fault is a major conduit for ascending geothermal fluids. Geothermal wells at Location Nos. 37, 57, 59, 81, and 82 aligned along the fault were heavily artesianing in the Spring of 1981. The chemistry analyses of the waters sampled along this alignment are all very similar, but differ from all other wells sampled in the area as mentioned above. This indicates a separate and distinct geothermal fluids source within the San Bernardino geothermal area. Also, Plate 8 shows a relatively high geothermometric temperature zone centered over this segment of the Loma Linda fault. All of the evidence indicates a major geothermal fluids upwelling or "plume" along this segment of the Loma Linda fault.

Geothermal Resources Model

The geothermal resources at San Bernardino are characteristic of hydrothermal convection systems. Such systems require a heat source, a transmitting fluid, a sufficient vertical permeability for heated, low-density fluids to rise, and, in most systems, a recharging mechanism of descending cooler fluids. Convective circulation of hot fluids is the driving mechanism that transports heat energy from depth to reservoirs near the earth's surface. Hydrothermal convection systems are most likely recognizable in areas of extensive faulting and are often controlled by intersecting geologic structures.

Figure 38 is a diagrammatic representation of the ascending cycles of the major hydrothermal convection systems at San Bernardino. Meteoric water enters the system elsewhere descending to depth along fault and fracture zones

Figure 38. Diagrammatic cross-section (not to scale) of the geothermal reservoirs of the San Bernardino Area, California. The arrows indicate possible paths of geothermal fluids. In recent years, ground water levels in parts of the San Bernardino area have risen dramatically. (By L. G. Youngs, 1981, CDMG.)

where it is heated from the earth's natural heat gradient. (The San Bernardino area is very seismically active and heat may also be supplied via tectonic stresses. (See the "Seismicity of the San Bernardino Area, California" section above.) Heated fluids then ascend along "paths of least resistance" (faults, fractures, geologic contacts, etc.) into overlying alluvial strata forming geothermal reservoirs in permeable aquifers. However, the geothermal fluids within the Arrowhead Hot Springs geothermal area ascend through basement rock to the surface. The geothermal reservoir here must then be confined to the faults and fractures of the segment of the San Andreas fault zone through which the hot fluids rise.

Within the Harlem Hot Springs and south San Bernardino geothermal areas heated fluids ascend fault systems that not only offset basement rocks but offset the overlying alluvial strata as well. Geothermal fluids migrate into contiguous permeable aquifers. However, the intercalated alluvial stratigraphy and the stratigraphic offsets caused by faulting are the controlling factors to lateral migration of the geothermal fluids. Highly permeable alluvial sands and gravels are interbedded with less permeable units that are in turn faulted, creating a complex system of aquifers. The alluvial stratigraphic units are probably not continuous for any great lateral extent, as these lenticular and cut-off beds formed in a fluvial environment, were dissected, and then inundated by subsequent flood plain and channel deposits. Hence, the geothermal reservoirs are composed of discrete and discontinuous aquifers charged by "plumes" of ascending geothermal fluids.

The most easily recognizable geothermal "plumes" are along a segment of the Loma Linda fault in the south San Bernardino geothermal area described

above and the narrow alignment of geothermal Location Nos. 1, 2, 3, 4, 5, and 6a,b in the Arrowhead Hot Springs geothermal area (Plate 1). There appears to be a geothermal fluids "plume" in association with and just south of Fault F1 in the west branch of the Harlem Hot Springs geothermal areas along the alignment of geothermal Location Nos. 15 a-d, 14, 16, 17, 18, 19, 20, 23, and 24 (Plate 1). Another "plume" is suspected in the east branch of the Harlem Hot Springs geothermal areas associated with Fault F2 along the alignment of geothermal well Location Nos. 10, 25, 27, and 28 (Plate 1). Probably there are one or more additional geothermal "plumes" within the south San Bernardino geothermal area as evidenced by the dissimilar geochemical analyses of geothermal samples from this area (Table 3). Likely locales are the old Urbita Hot Springs area and along a tenuous alignment slightly northeast and parallel to the San Jacinto fault composed of geothermal Location Nos. 29, 30, 31, 32, 39, 40, and 41 (Plate 1).

Two other viable locales for future geothermal exploration are indicated in this report. One is the deepest part of the Bunker Hill basin northeast of the Loma Linda fault suggested by the gravity contours near the well "Del Rosa No. 1" on Plate 6. Geothermal fluids may "collect" here along the alluvial-basement rock contact (Figure 38). The other location is southeast of and along the proposed structural limitation to geothermal areas shown on Plate 1.

Conclusions

There are viable low-temperature geothermal resources at San Bernardino, California capable of being developed for utilization. The three active

designated geothermal areas are the most likely sites for geothermal exploration and development of the resources. Within each geothermal area the most likely exploration and development sites are along the geothermal fluids "plumes" described above.

This report includes a wealth of new data and new analyses of older data wholly oriented to assessing the geothermal resources at San Bernardino. This major effort cannot, however, clearly delineate all the properties of the geothermal resources.

The geothermal resources at San Bernardino are classified as low-temperature geothermal resources ($< 90^{\circ}\text{C}$). However, geothermometric calculations applied at the Arrowhead Hot Springs geothermal area suggested reservoir temperatures at depth that would promote that resource into the moderate-temperature geothermal resources range (between 90°C and 150°C). There were no data developed during this investigation that could reliably predict the maximum temperatures that might be produced by deep drilling into the Harlem Hot Springs or the south San Bernardino geothermal areas.

The complex discontinuous system of geothermal aquifers (some probably invaded with migrating fresh ground waters) does not lend itself to an estimation of the volume of geothermal fluids available at either the Harlem Hot Springs or the south San Bernardino geothermal areas. An extensive geothermal exploratory drilling program would have to be initiated to ascertain a reliable volumetric estimation.

The next phase of assessing or developing the geothermal resources of San Bernardino should be an exploratory drilling program or, at the very least, a deep well drilling monitoring program that would collect and analyze data having direct bearing on the geothermal resources from relatively deep drilled wells. These data would include detailed geologic logs, temperature logs, geophysical logs, geochemical analyses of geothermal fluids from discrete aquifers, flow tests, etc. Analysis and interpretation of such data should provide further refinement of the geothermal reservoir's characteristics than was possible from data developed during the preparation of this report.

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APPENDIX A
GEOCHEMISTRY ANALYSIS

EXPLANATION OF WATER WELL ANALYSIS

The following geochemistry analyses show the elemental concentrations that were recorded for the indicated samples. The element names are provided below. The elemental concentrations are measured in parts per million (ppm) of the total. Concentration values preceded by the "less than" symbol (<) indicate the lowest detectable concentration limits.

EXAMPLE:	<u>ELEMENT</u>	<u>CONCENTRATION (PPM)</u>
	Ni	<0.125

The example states that the nickel concentration is less than 0.125 ppm which is the lowest detectable concentration of nickel possible by the methods used in this analysis. In fact the nickel concentration may be zero or non-existent in this sample. A list of the lowest detectable elemental concentration limits for the analyses performed at the Earth Science Laboratory of the University of Utah Research Institute (U.U.R.I.) in Salt Lake City is presented below:

LOWEST DETECTABLE ELEMENTAL CONCENTRATION (PPM)			LOWEST DETECTABLE ELEMENTAL CONCENTRATION (PPM)		
<u>ELEMENT SYMBOL</u>	<u>ELEMENT NAME</u>		<u>ELEMENT SYMBOL</u>	<u>ELEMENT NAME</u>	
Na	Sodium	<2.50	Ag	Silver	<0.050
K	Potassium	<2.50	Au	Gold	<0.100
Ca	Calcium	<0.50	As	Arsenic	<0.625
Mg	Magnesium	<0.500	Sb	Antimony	<0.750
Fe	Iron	<0.025	Bi	Bismuth	<2.50
Al	Aluminum	<0.625	U	Uranium	<6.25
Si	Silicon	<0.250	Te	Tellurium	<1.25
Ti	Titanium	<0.125	Sn	Tin	<0.125
P	Phosphorus	<0.625	W	Tungsten	<0.125
Sr	Strontium	<0.013	Li	Lithium	<0.05
Ba	Barium	<0.625	Be	Beryllium	<0.005
V	Vanadium	<1.25	B	Boron	<0.125
Cr	Chromium	<0.050	Zr	Zirconium	<0.125
Mn	Manganese	<0.250	La	Lanthanum	<0.125
Co	Cobalt	<0.025	Ce	Cerium	<0.250
Ni	Nickel	<0.125	Th	Thorium	<2.50
Cu	Copper	<0.063	Cl	Chloride	<2.00
Mo	Molybdenum	<1.25	F	Fluoride	<0.10
Pb	Lead	<0.250			
Zn	Zinc	<0.125			
Cd	Cadmium	<0.063			

GEOCHEMISTRY ANALYSIS

WELL - Waterman Hot Springs
Sample Date 4/22/81

UURI ANALYSIS

Element	Concentration (ppm)
Na	208
K	7
Ca	11
Mg	12
Fe	0.04
Al	< 0.625
Si (as SiO ₂)	50
Ti	< 0.125
P	< 0.625
Sr	0.38
Ba	< 0.625
V	< 1.25
Cr	< 0.050
Mn	< 0.250
Co	< 0.025
Ni	< 0.125
Cu	< 0.063
Mo	< 1.25
Pb	< 0.250
Zn	< 0.125
Cd	< 0.063
Ag	< 0.050
Au	< 0.100
As	< 0.625
Sb	< 0.750
Bi	< 2.50
U	< 6.25
Te	< 1.25
Sn	< 0.125
W	< 0.125
Li	0.18
Be	< 0.005
B	1.9
Zr	< 0.125
La	< 0.125
Ce	< 0.250
Th	< 2.50
Cl	65
F	5.0

CDMG FIELD ANALYSIS

Chloride (Cl)	< 139	ppm
Sulfate (SO ₄)	330	ppm
Sulfide (S)	0.06	ppm
Ammonia (N(NH ₃))	N.D.	ppm
Alkalinity		
Bicarbonate (HCO ₃)	30	ppm
Carbonate (CO ₃)	20	ppm
Salinity	0.7	%
pH	7.1	
Electrical Conductivity at 34°C	1700	µmho/cm

CDMG LAB ANALYSIS

Silica (SiO ₂)	56	ppm
Carbonate (CO ₃)	6.0	ppm
Bicarbonate (HCO ₃)	56.43	ppm
Sulfate (SO ₄)	314.9	ppm
Corrected TDS	729	ppm

GEOCHEMISTRY ANALYSIS

Well at Arrowhead Hot Springs
Sample date 4/22/81

UURI ANALYSIS	
Element	Concentration (ppm)
Na	173
K	7
Ca	10
Mg	< 0.500
Fe	< 0.025
Al	< 0.625
Si (as SiO ₂)	51
Ti	< 0.125
P	< 0.625
Sr	0.29
Ba	< 0.625
V	< 1.25
Cr	< 0.050
Mn	< 0.250
Co	< 0.025
Ni	< 0.125
Cu	< 0.063
Mo	< 1.25
Pb	< 0.250
Zn	< 0.125
Cd	< 0.063
Ag	< 0.050
Au	< 0.100
As	< 0.625
Sb	< 0.750
Bi	< 2.50
U	< 6.25
Te	< 1.25
Sn	< 0.125
W	< 0.125
Li	0.15
Be	< 0.005
B	1.7
Zr	< 0.125
La	< 0.125
Ce	< 0.250
Th	< 2.50
Cl	56
F	5.5

CDMG FIELD ANALYSIS	
Chloride (Cl)	< 139 ppm
Sulfate (SO ₄)	230 ppm
Sulfide (S)	0.02 ppm
Ammonia (N(NH ₃))	N.D. ppm
Alkalinity	
Bicarbonate (HCO ₃)	40 ppm
Carbonate (CO ₃)	20 ppm
Salinity	0.5 %
pH	7.2
Electrical Conductivity at 32°C	1300 µmho/cm

CDMG LAB ANALYSIS	
Silica (SiO ₂)	59 ppm
Carbonate (CO ₃)	5.5 ppm
Bicarbonate (HCO ₃)	74.73 ppm
Sulfate (SO ₄)	280.65 ppm
Corrected TDS	644 ppm

GEOCHEMISTRY ANALYSIS

Well at Arrowhead Hot Springs
Sample Date 4/22/81

UURI ANALYSIS

Element	Concentration (ppm)
Na	204
K	11
Ca	32
Mg	1
Fe	< 0.025
Al	< 0.625
Si (as SiO ₂)	74
Ti	< 0.125
P	< 0.625
Sr	0.74
Ba	< 0.625
V	< 1.25
Cr	< 0.050
Mn	< 0.250
Co	< 0.025
Ni	< 0.125
Cu	< 0.063
Mo	< 1.25
Pb	< 0.250
Zn	< 0.125
Cd	< 0.063
Ag	< 0.050
Au	< 0.100
As	< 0.625
Sb	< 0.750
Bi	< 2.50
U	< 6.25
Te	< 1.25
Sn	< 0.125
W	< 0.125
Li	0.23
Be	< 0.005
B	2.5
Zr	< 0.125
La	< 0.125
Ce	< 0.250
Th	< 2.50
Cl	67
F	4.4

CDMG FIELD ANALYSIS

Chloride (Cl)	< 139	ppm
Sulfate (SO ₄)	325	ppm
Sulfide (S)	0.01	ppm
Ammonia (N(NH ₄))		
Alkalinity		
Bicarbonate (HCO ₃)	60	ppm
Carbonate (CO ₃)	10	ppm
Salinity	0.6	%
pH	6.6	
Electrical Conductivity		
at 31°C	1600	µmho/cm

CDMG LAB ANALYSIS

Silica (SiO ₂)	85	ppm
Bicarbonate (HCO ₃)	96.08	ppm
Sulfate (SO ₄)	235.15	ppm
Corrected TDS	700	ppm

Location No. 7
on PLATE 1

GEOCHEMISTRY ANALYSIS

"Hot Well" at Arrowhead Hot Springs
Sample Date 7/28/1976
Analysis by Edward S. Babcock and Sons

	<u>CONCENTRATION (ppm)</u>
Calcium (Ca)	42
Magnesium (Mg)	6
Sodium (Na)	36
Potassium (K)	6
Ammonium (NH ₄)	N.D.
Sulfate (SO ₄)	48
Chloride (Cl)	16
Nitrate (NO ₃)	1
Phosphate (PO ₄)	N.D.
Alkalinity as	
Hydroxide (OH)	0
Carbonate (CO ₃)	0
Bicarbonate (HCO ₃)	180
Total Hardness calculated	
as CaCO ₃	130
Total Dissolved Residue (180°C)	245
Fluoride (F)	0.4
Boron (B)	0.0
Iron (Fe)	N.D.
Manganese (Mn)	N.D.

Conductivity, EC x 10 ⁶ @ 25°C	440 µmho/cm
Percent Sodium	36%
Hydrogen-ion activity (pH)	7.6

GEOCHEMISTRY ANALYSIS

WELL - "Patton Hospital #14"
Sample Date 4/21/81

UURI ANALYSIS

Element	Concentration (ppm)
Na	48
K	< 2.50
Ca	37
Mg	12
Fe	0.57
Al	< 0.625
Si (as SiO ₂)	27
Ti	< 0.125
P	< 0.625
Sr	0.33
Ba	< 0.625
V	< 1.25
Cr	< 0.050
Mn	< 0.250
Co	< 0.025
Ni	< 0.125
Cu	< 0.063
Mo	< 1.25
Pb	< 0.250
Zn	< 0.125
Cd	< 0.063
Ag	< 0.050
Au	< 0.100
As	< 0.625
Sb	< 0.750
Bi	< 2.50
U	< 6.25
Te	< 1.25
Sn	< 0.125
W	< 0.125
Li	< 0.050
Be	< 0.005
B	0.1
Zr	< 0.125
La	< 0.125
Ce	< 0.250
Th	< 2.50
Cl	21
F	1.0

CDMG FIELD ANALYSIS

Chloride (Cl)	< 139	ppm
Sulfate (SO ₄)	79	ppm
Sulfide (S)	nil	ppm
Ammonia (N(NH ₃))	N.D.	ppm
Alkalinity		
Bicarbonate (HCO ₃)	110	ppm
Salinity	0.01	%
pH	6.5	
Electrical Conductivity		
at 26°C	530	umho/cm

CDMG LAB ANALYSIS

Silica (SiO ₂)	24	ppm
Bicarbonate (HCO ₃)	158.6	ppm
Sulfate (SO ₄)	40.01	ppm
Corrected TDS	288	ppm

GEOCHEMISTRY ANALYSIS

WELL - "Patton Hospital #11"
Sample Date 4/21/81

UURI ANALYSIS

Element	Concentration (ppm)
Na	105
K	< 2.50
Ca	17
Mg	< 0.500
Fe	< 0.025
Al	< 0.625
Si (as SiO ₂)	24
Ti	< 0.125
P	< 0.625
Sr	0.21
Ba	< 0.625
V	< 1.25
Cr	< 0.050
Mn	< 0.250
Co	< 0.025
Ni	< 0.125
Cu	< 0.063
Mo	< 1.25
Pb	< 0.250
Zn	< 0.125
Cd	< 0.063
Ag	< 0.050
Au	< 0.100
As	< 0.625
Sb	< 0.750
Bi	< 2.50
U	< 6.25
Te	< 1.25
Sn	< 0.125
W	< 0.125
Li	< 0.050
Be	< 0.005
B	0.6
Zr	< 0.125
La	< 0.125
Ce	< 0.250
Th	< 2.50
Cl	36
F	4.0

CDMG FIELD ANALYSIS

Chloride (Cl)	< 139	ppm
Sulfate (SO ₄)	150	ppm
Sulfide (S)	N.D.	ppm
Ammonia (N(NH ₃))	N.D.	ppm
Alkalinity		
Bicarbonate (HCO ₃)	70	ppm
Salinity	0.3	%
pH	7.0	
Electrical Conductivity		
at 35°C	850	µmho/cm

CDMG LAB ANALYSIS

Silica(SiO ₂)	22	ppm
Bicarbonate(HCO ₃)	94.55	ppm
Sulfate (SO ₄)	102.55	ppm
Corrected TDS	359	ppm

Location No. 13
on PLATE 1

GEOCHEMISTRY ANALYSIS

WELL - "Patton Hospital #9"
Sample Date 12/10/71

Analysis by Clinical Laboratory of San Bernardino, Inc.

	<u>CONCENTRATION (ppm)</u>
Calcium	35.2
Magnesium	7.8
Sodium	112.7
Potassium	2.1
Carbonate	nil
Bicarbonate	129.3
Sulfate	146.0
Chloride	57.5
Nitrate (NO ₃)	30.8
Manganese	nil
Fluoride	2.33
Total Hardness as CaCO ₃	120.0
Total Alkalinity as CaCO ₃	N.D.
Total Dissolved Solids	460
Boron	0.10
Iron	0.072
<hr/>	
Hydrogen-ion activity (pH)	7.59
Percent Sodium	66.6%
Specific Conductance (K x 10 ⁻⁶)	725 μ mho/cm

Location No. 13
on PLATE 1

GEOCHEMISTRY ANALYSIS

WELL - "Patton Hospital #9"
Sample Date (?)

Analysis by National Aluminate Corporation

	<u>CONCENTRATION (ppm)</u>
Total Dissolved Solids	37.5
Suspended Solids	X
Total Hardness (as CaCO_3)	90
Calcium Hardness (as CaCO_3)	64
Magnesium Hardness (as CaCO_3)	26
Phenolphthalein Alk. (as CaCO_3)	0
P(BaCl) Alk. (as CaCO_3)	0
Total Alk. (MO)(as CaCO_3)	101
Total Alk. (Calc.) (as CaCO_3)	X
Free Carbon Dioxide (as CaCO_3)	29
Chloride (as NaCl)	56
Sulfate (as Na_2SO_4)	220
Phosphate (as PO_4 in ppm.)	0
Silica (as SiO_2)	32
Iron (as Fe in ppm.)	0.10
Total Oil	X
pH	7.2
Color No.	0

GEOCHEMISTRY ANALYSIS

WELL - "Base Line Laundry"
Sample Date 4/22/81

UURI ANALYSIS

Element	Concentration (ppm)
Na	86
K	< 2.50
Ca	27
Mg	4
Fe	< 0.025
Al	< 0.625
Si (as SiO ₂)	20
Ti	< 0.125
P	< 0.625
Sr	0.09
Ba	< 0.625
V	< 1.25
Cr	< 0.050
Mn	< 0.250
Co	< 0.025
Ni	< 0.125
Cu	< 0.063
Mo	< 1.25
Pb	< 0.250
Zn	< 0.125
Cd	< 0.063
Ag	< 0.050
Au	< 0.100
As	< 0.625
Sb	< 0.750
Bi	< 2.50
U	< 6.25
Te	< 1.25
Sn	< 0.125
W	< 0.125
Li	< 0.050
Be	< 0.005
B	< 0.125
Zr	< 0.125
La	< 0.125
Ce	< 0.250
Th	< 2.50
Cl	27
F	1.2

CDMG FIELD ANALYSIS

Chloride (Cl)	< 139	ppm
Sulfate (SO ₄)	106	ppm
Sulfide (S)	N.D.	ppm
Ammonia (N(NH ₃))	N.D.	ppm
Alkalinity		
Bicarbonate (HCO ₃)	100	ppm
Salinity	0.2	%
pH	6.7	
Electrical Conductivity		
at 30°C	720	µmho/cm

CDMG LAB ANALYSIS

Silica (SiO ₂)	19	ppm
Bicarbonate (HCO ₃)	135.73	ppm
Sulfate (SO ₄)	96.63	ppm
Corrected TDS	352	ppm

Location No. 25
on PLATE 1

GEOCHEMISTRY ANALYSIS

WELL - "Palm Well #1"
Sample Date 1/31/72

Analysis by Clinical Laboratory of San Bernardino, Inc.

	<u>CONCENTRATION (ppm)</u>
Calcium	54.4
Magnesium	7.3
Sodium	71.8
Potassium	2.5
Carbonate	nil
Bicarbonate	168.4
Sulfate	94.0
Chloride	29.0
Nitrate (NO ₃)	69.5
Manganese	nil
Fluoride	1.74
Total Hardness as CaCO ₃	166.0
Total Alkalinity as CaCO ₃	138.0
Total Dissolved Solids	420
Boron	0.50
Iron	Trace
<hr/>	
Hydrogen-ion activity (pH)	8.02
Percent Sodium	48.0%
Specific Conductance (k x 10 ⁻⁶)	655 μ mho/cm

Location No. 27
on PLATE 1

GEOCHEMISTRY ANALYSIS

WELL - Dunkirk #1
Sample Date 1/28/75

Analysis by Clinical Laboratory of San Bernardino, Inc.

	<u>CONCENTRATION (ppm)</u>
Calcium	64.0
Magnesium	16.0
Sodium	37.0
Potassium	1.7
Carbonate	nil
Bicarbonate	185.4
Sulfate	68.0
Chloride	25.00
Nitrate (NO ₃)	66.0
Manganese	<0.01
Fluoride	0.38
Total Hardness as CaCO ₃	225.6
Total Alkalinity as CaCO ₃	152.0
Total Dissolved Solids	372
Iron	0.050

Hydrogen-ion activity (pH)	7.91
Percent Sodium	26.1%
Specific Conductance (k x 10 ⁻⁶)	630 μ mho/cm

Location No. 28
on PLATE 1

GEOCHEMISTRY ANALYSIS

WELL - Dunkirk #2
Sample Date 1/28/75

Analysis by Clinical Laboratory of San Bernardino, Inc.

	<u>CONCENTRATION (ppm)</u>
Calcium	64.5
Magnesium	16.7
Sodium	42.0
Potassium	1.7
Carbonate	nil
Bicarbonate	190.3
Sulfate	72.0
Chloride	27.5
Nitrate (NO ₃)	70.0
Manganese	<0.01
Fluoride	0.34
Total Hardness as CaCO ₃	229.7
Total Alkalinity as CaCO ₃	156.0
Total Dissolved Solids	389
Iron	0.066
<hr/>	
Hydrogen-ion activity (pH)	8.05
Percent Sodium	28.2%
Specific Conductance (k x 10 ⁻⁶)	650

GEOCHEMISTRY ANALYSIS

WELL - Colton #12
Sample Date 4/27/81

UURI ANALYSIS

Element Concentration (ppm)

Na	27
K	4
Ca	40
Mg	7
Fe	< 0.025
Al	< 0.625
Si (as SiO ₂)	25
Ti	< 0.125
P	< 0.625
Sr	< 0.40
Ba	< 0.625
V	< 1.25
Cr	< 0.050
Mn	< 0.250
Co	< 0.025
Ni	< 0.125
Cu	< 0.063
Mo	< 1.25
Pb	< 0.250
Zn	< 0.125
Cd	< 0.063
Ag	< 0.050
Au	< 0.100
As	< 0.625
Sb	< 0.750
Bi	< 2.50
U	< 6.25
Te	< 1.25
Sn	< 0.125
W	< 0.125
Li	< 0.050
Be	< 0.005
B	< 0.125
Zr	< 0.125
La	< 0.125
Ce	< 0.250
Th	< 2.50
Cl	7
F	0.6

CDMG FIELD ANALYSIS

Chloride (Cl)	< 139	ppm
Sulfate (SO ₄)	30	ppm
Sulfide (S)	N.D.	ppm
Ammonia (N(NH ₃))	N.D.	ppm
Alkalinity		
Bicarbonate (HCO ₃)	160	ppm
Salinity	0.1	%
pH	6.2	
Electrical Conductivity		
at 31°C	425	µmho/cm

CDMG LAB ANALYSIS

Silica (SiO ₂)	26	ppm
Bicarbonate (HCO ₃)	198.25	ppm
Sulfate (SO ₄)	26.33	ppm
Corrected TDS	255	ppm

GEOCHEMISTRY ANALYSIS

WELL - "Mill & 'D' Street Well"
Sample Date 4/28/81

UURI ANALYSIS	
Element	Concentration (ppm)
Na	15
K	3
Ca	57
Mg	10
Fe	< 0.025
Al	< 0.625
Si (as SiO ₂)	17
Ti	< 0.125
P	< 0.625
Sr	0.40
Ba	< 0.625
V	< 1.25
Cr	< 0.050
Mn	< 0.250
Co	< 0.025
Ni	< 0.125
Cu	< 0.063
Mo	< 1.25
Pb	< 0.250
Zn	< 0.125
Cd	< 0.063
Ag	< 0.050
Au	< 0.100
As	< 0.625
Sb	< 0.750
Bi	< 2.50
U	< 6.25
Te	< 1.25
Sn	< 0.125
W	< 0.125
Li	< 0.050
Be	< 0.005
B	< 0.125
Zr	< 0.125
La	< 0.125
Ce	< 0.250
Th	< 2.50
Cl	6
F	0.5

CDMG FIELD ANALYSIS	
Chloride (Cl)	< 139 ppm
Sulfate (SO ₄)	18 ppm
Sulfide (S)	N.D. ppm
Ammonia (N(NH ₃))	N.D. ppm
Alkalinity	
Bicarbonate (HCO ₃)	200 ppm
Salinity	0.1 %
pH	6.2
Electrical Conductivity	
at 29°C	440 µmho/cm

CDMG LAB ANALYSIS	
Silica (SiO ₂)	20 ppm
Bicarbonate (HCO ₃)	230.28 ppm
Sulfate (SO ₄)	25.97 ppm
Corrected TDS	269 ppm

GEOCHEMISTRY ANALYSIS

WELL - Meeks & Daly "Coburn Well"
Sample Date 4/24/81

UURI ANALYSIS

Element	Concentration (ppm)
Na	25
K	4
Ca	58
Mg	9
Fe	0.25
Al	< 0.625
Si (as SiO ₂)	21
Ti	< 0.125
P	< 0.625
Sr	0.48
Ba	< 0.625
V	< 1.25
Cr	< 0.050
Mn	< 0.250
Co	< 0.025
Ni	< 0.125
Cu	< 0.063
Mo	< 1.25
Pb	< 0.250
Zn	< 0.125
Cd	< 0.063
Ag	< 0.050
Au	< 0.100
As	< 0.625
Sb	< 0.750
Bi	< 2.50
U	< 6.25
Te	< 1.25
Sn	< 0.125
W	< 0.125
Li	< 0.050
Be	< 0.005
B	< 0.125
Zr	< 0.125
La	< 0.125
Ce	< 0.250
Th	< 2.50
Cl	8
F	0.6

CDMG FIELD ANALYSIS

Chloride (Cl)	< 139	ppm
Sulfate (SO ₄)	47	ppm
Sulfide (S)	N.D.	ppm
Ammonia (N(NH ₃))	0.6	ppm
Alkalinity		
Bicarbonate (HCO ₃)	180	ppm
Salinity	0.1	%
pH	6.6	
Electrical Conductivity		
at 27°C	483	µmho/cm

CDMG LAB ANALYSIS

Silica (SiO ₂)	20	ppm
Bicarbonate (HCO ₃)	236.38	ppm
Sulfate (SO ₄)	25.04	ppm
Corrected TDS	288	ppm

GEOCHEMISTRY ANALYSIS

WELL - Meeks & Daly #66
Sample Date 4/23/81

UURI ANALYSIS

Element	Concentration (ppm)
Na	96
K	< 2.50
Ca	3
Mg	< 0.500
Fe	< 0.025
Al	< 0.625
Si (as SiO ₂)	27
Ti	< 0.125
P	< 0.625
Sr	0.07
Ba	< 0.625
V	< 1.25
Cr	< 0.050
Mn	< 0.250
Co	< 0.025
Ni	< 0.125
Cu	< 0.063
Mo	< 1.25
Pb	< 0.250
Zn	< 0.125
Cd	< 0.063
Ag	< 0.050
Au	< 0.100
As	< 0.625
Sb	< 0.750
Bi	< 2.50
U	< 6.25
Te	< 1.25
Sn	< 0.125
W	< 0.125
Li	< 0.050
Be	< 0.005
B	2.4
Zr	< 0.125
La	< 0.125
Ce	< 0.250
Th	< 2.50
Cl	96
F	6.1

CDMG FIELD ANALYSIS

Chloride (Cl)	< 139 ppm
Sulfate (SO ₄)	34 ppm
Sulfide (S)	N.D. ppm
Ammonia (N(NH ₃))	0.2 ppm
Alkalinity	
Bicarbonate (HCO ₃)	50 ppm
Carbonate (CO ₃)	20 ppm
Salinity	0.2 %
pH	7.8
Electrical Conductivity at 32°C	640 µmho/cm

CDMG LAB ANALYSIS

Silica (SiO ₂)	29 ppm
Bicarbonate (HCO ₃)	80.83 ppm
Carbonate (CO ₃)	10.5 ppm
Sulfate (SO ₄)	34.35 ppm
Corrected TDS	336 ppm

GEOCHEMISTRY ANALYSIS

WELL - Meeks & Daly #59
Sample Date 4/23/81

UURI ANALYSIS

Element Concentration (ppm)

Na	75
K	< 2.50
Ca	8
Mg	< 0.500
Fe	< 0.025
Al	< 0.625
Si (as SiO ₂)	21
Ti	< 0.125
P	< 0.625
Sr	0.10
Ba	< 0.625
V	< 1.25
Cr	< 0.050
Mn	< 0.250
Co	< 0.025
Ni	< 0.125
Cu	< 0.063
Mo	< 1.25
Pb	< 0.250
Zn	< 0.125
Cd	< 0.063
Ag	< 0.050
Au	< 0.100
As	< 0.625
Sb	< 0.750
Bi	< 2.50
U	< 6.25
Te	< 1.25
Sn	< 0.125
W	< 0.125
Li	< 0.050
Be	< 0.005
B	1.5
Zr	< 0.125
La	< 0.125
Ce	< 0.250
Th	< 2.50
Cl	58
F	3.6

CDMG FIELD ANALYSIS

Chloride (Cl)	< 139	ppm
Sulfate (SO ₄)	34	ppm
Sulfide (S)	N.D.	ppm
Ammonia (N(NH ₃))	0.1	ppm
Alkalinity		
Bicarbonate (HCO ₃)	70	ppm
Salinity	0.1	%
pH	7.4	
Electrical Conductivity		
at 32°C	520	µmho/cm

CDMG LAB ANALYSIS

Silica (SiO ₂)	20	ppm
Bicarbonate (HCO ₃)	123.53	ppm
Sulfate (SO ₄)	20.39	ppm
Corrected TDS	272	ppm

Location No. 59
on PLATE 1

GEOCHEMISTRY ANALYSIS

WELL - Meeks and Daly #59
Sample Date 7/22/80

Analysis by Edward S. Babcock and Sons Inc.

	<u>CONCENTRATION (ppm)</u>
Total Hardness as CaCO ₃	28
Calcium (Ca)	11
Magnesium (Mg)	< 1
Total Alkalinity as CaCO ₃	
Hydroxide (OH)	none
Carbonate (CO ₃)	none
Bicarbonate (HCO ₃)	119
Chloride (Cl)	67
Potassium (K)	2
Nitrate (NO ₃)	<1
Fluoride (F)	3.4
Boron (B)	1.6
Iron (Fe)	0.16
MBAS	<0.1
Total Dissolved Residue	220
<hr/>	
Electrical Conductivity EC x 10 ⁻⁶ @ 25°C	495 µmho/cm
pH	7.9

GEOCHEMISTRY ANALYSIS

WELL - 1S/4W-22A1
Sample Date 4/23/81

UURI ANALYSIS

Element Concentration (ppm)

Na	60
K	< 2.50
Ca	4
Mg	< 0.500
Fe	< 0.025
Al	< 0.625
Si (as SiO ₂)	15
Ti	< 0.125
P	< 0.625
Sr	0.05
Ba	< 0.625
V	< 1.25
Cr	< 0.050
Mn	< 0.250
Co	< 0.025
Ni	< 0.125
Cu	< 0.063
Mo	< 1.25
Pb	< 0.250
Zn	< 0.125
Cd	< 0.063
Ag	< 0.050
Au	< 0.100
As	< 0.625
Sb	< 0.750
Bi	< 2.50
U	< 6.25
Te	< 1.25
Sn	< 0.125
W	< 0.125
Li	< 0.050
Be	< 0.005
B	0.6
Zr	< 0.125
La	< 0.125
Ce	< 0.250
Th	< 2.50
Cl	20
F	2.6

CDMG FIELD ANALYSIS

Chloride (Cl)	< 139	ppm
Sulfate (SO ₄)	18	ppm
Sulfide (S)	N.D.	ppm
Ammonia (N(NH ₃))	0.2	ppm
Alkalinity		
Bicarbonate (HCO ₃)	90	ppm
Carbonate (CO ₃)	20	ppm
Salinity	0.1	%
pH	7.6	
Electrical Conductivity		
at 31°C	365	µmho/cm

CDMG LAB ANALYSIS

Silica (SiO ₂)	16	ppm
Bicarbonate (HCO ₃)	140.3	ppm
Sulfate (SO ₄)	16.88	ppm
Corrected TDS	212	ppm

Location No. 66
on PLATE 1

GEOCHEMISTRY ANALYSIS

"Mud Bath Well" at Arrowhead Hot Springs
Sample Date 10:00 a.m. 10/25/1976

Analysis by Edward S. Babcock and Sons

	<u>CONCENTRATION (ppm)</u>
Calcium (Ca)	27
Magnesium (Mg)	1
Sodium (Na)	204
Potassium (K)	11
Ammonium (NH ₄)	N.D.
Sulfate (SO ₄)	390
Chloride (Cl)	51
Nitrate (NO ₃)	1
Phosphate (PO ₄)	N.D.
Alkalinity as	
Hydroxide (OH)	0
Carbonate (CO ₃)	0
Bicarbonate (HCO ₃)	110
Total Hardness calculated	
as CaCO ₃	71
Total Dissolved Residue (180°C)	780
Fluoride (F)	4.6
Boron (B)	2.4
Iron (Fe)	N.D.
Manganese (Mn)	N.D.
Arsenic	0.03

Conductivity, EC x 10⁶ @ 25°C
Percent Sodium
Hydrogen-ion activity (pH)

1050 μ mho/cm
84%
7.6

GEOCHEMISTRY ANALYSIS

WELL - "Patton Hospital #2"
Sample Date 4/22/81

UURI ANALYSIS		CDMG FIELD ANALYSIS	
Element	Concentration (ppm)		
Na	35	Chloride (Cl)	< 139 ppm
K	< 2.50	Sulfate (SO ₄)	47 ppm
Ca	32	Sulfide (S)	N.D. ppm
Mg	11	Ammonia (N(NH ₃))	N.D. ppm
Fe	< 0.025	Alkalinity	
Al	< 0.625	Bicarbonate (HCO ₃)	130 ppm
Si (as SiO ₂)	26	Salinity	0.1 %
Ti	< 0.125	pH	6.5
P	< 0.625	Electrical Conductivity	
Sr	0.28	at 19°C	453 µmho/cm
Ba	< 0.625		
V	< 1.25		
Cr	< 0.050		
Mn	< 0.250		
Co	< 0.025		
Ni	< 0.125		
Cu	< 0.063		
Mo	< 1.25		
Pb	< 0.250		
Zn	< 0.125		
Cd	< 0.063		
Ag	< 0.050		
Au	< 0.100		
As	< 0.625		
Sb	< 0.750		
Bi	< 2.50		
U	< 6.25		
Te	< 1.25		
Sn	< 0.125		
W	< 0.125		
Li	< 0.050		
Be	< 0.005		
B	0.2		
Zr	< 0.125		
La	< 0.125		
Ce	< 0.250		
Th	< 2.50		
Cl	16		
F	1.8		

CDMG LAB ANALYSIS	
Silica (SiO ₂)	29 ppm
Bicarbonate (HCO ₃)	140.3 ppm
Sulfate (SO ₄)	16.88 ppm
Corrected TDS	212 ppm

APPENDIX B
TEMPERATURE LOGS

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

CDMG - PLATE 1, Location No. 8 ("Patton Hospital # 14")

DATE 4/21/81

NOTE: Well unpumped for many weeks, total depth of well approx. 500 ft., Temp. probe apparently blocked at 310 ft.

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

CDMG - PLATE 1, Location No. 9 ("Patton Hospital #10")

DATE 4/21/81

NOTE: Well unpumped for approx. 3 mos., Total depth supposed to be 420 ft., Temp. probe penetrated only 400 ft.

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

CDMG - PLATE 1, Location No. 10 ("Patton Hospital # 11")

DATE 4/22/81

NOTE: Total depth of well unknown, Temp. probe penetrated 440 ft.

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

CDMG - PLATE 1, Location No. 15c. ("State # E-53h")

DATE 1912 Temp. curve constructed from data on driller's log.

NOTE: Total depth of well 194 ft., Temperatures above were encountered when drilled in 1912.

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

CDMG - PLATE 1, Location No. 23 (East San Bernardino County Water
District No. 6)

DATE 4/27/81

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

CDMG - PLATE 1, Location No. 24 (East San Bernardino County Water
District "Bone Yard Well")

DATE 4/27/81

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

CDMG - PLATE 1, Location No. 28 (Dunkirk # 2)

DATE MARCH 1973 Temp. curve constructed from data on driller's log in
Appendix C.

NOTE: Total depth of well 391 ft., Temperatures above were encountered when well drilled in March 1973.

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

CDMG - PLATE 1, Location No. 32 (Colton # 12)

DATE 5/22/80 Temperature curve reconstructed from Geothermal Surveys
Inc., data, May 28, 1980.

NOTE: Well was artesian at time of survey. Well is approx.
900 ft. deep.

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

CDMG - PLATE 1, Location No. 47 (Meeks & Daly "Coburn Well")

DATE 4/24/81

NOTE: Well approx. 700 ft. deep, Temp. probe blocked at 290 ft.

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

CDMG - PLATE 1, Location No. 48 (Meeks & Daly #69)

DATE 4/24/81

NOTE: Well approx. 800-900 ft. deep, Temp. probe blocked at 480 ft.

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

CDMG - PLATE 1, Location No. 50 (Meeks & Daly "New E")

DATE 4/23/81

NOTE: Well approx. 900 ft. deep, Temp. probe blocked at 170 ft.

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

CDMG - PLATE 1, Location No. 52 (Meeks & Daly # 51)

DATE 4/23/81

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

CDMG - PLATE 1, Location No. 57 (Meeks & Daly #66)

DATE 5/22/80 Temp. curve reconstructed from Geothermal Surveys Inc.
data May 28, 1980.

NOTE: Well was artesian at time of survey. Well approx. 975 ft. deep. Temp. probe could not penetrate below 160 ft.

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

CIMG - PLATE 1, Location No. 58 ("Byrne Well")

DATE 4/25/81

CDMG - PLATE 1, Location No. 60 (State # E-98e)

DATE: Oct. 1931 Temp. curve constructed from data on driller's log
in Appendix C.

185

NOTE: Total depth of well 1188 ft. Temperatures above were
encountered when well drilled in Oct. 1931.

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

CDMG - PLATE 1, Location No. 93 ("Patton Hospital # 2")
DATE 4/22/81

NOTE: Total depth of well 551 ft. Temp. probe penetrated only 330 ft.
After pump ran for 10-15 min. temp. of discharge was 19°C.

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

CDMG - PLATE 1, Location No. 94
DATE 4/25/81

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

CDMG - PLATE 1, Location No. 95 ("Hanford Well")
DATE 4/24/81

NOTE: This well may be the same well as Location No. 36 which may be slightly mislocated in the original reference (Ref. 6).
See PLATE

APPENDIX C

GEOLOGIC WELL LOGS

Location No. 8
on PLATE 1

"PATTON HOSPITAL #14"

Depth: 500 ft.
Drilled: Feb. - June 1965
Casing: 16 inch diameter
Perforation from: 360 ft. to 425 ft.
Water first found at 350 ft.

GEOLOGIC LOG

0 ft. to 20 ft.	Soil and Clay.
20 ft. to 60 ft.	Sandy Clay.
60 ft. to 70 ft.	Sand.
70 ft. to 78 ft.	Sand and Rock.
78 ft. to 128 ft.	Clay.
128 ft. to 134 ft.	Rock.
134 ft. to 150 ft.	Clay.
150 ft. to 178 ft.	Silty Sandy Clay 3/16 inch Rocks.
178 ft. to 185 ft.	Rock and Clay.
185 ft. to 208 ft.	Sand Rock Clay.
208 ft. to 245 ft.	Sandy Rocky Clay.
245 ft. to 360 ft.	Sand gravel seams clay (could have had water at one time).
360 ft. to 376 ft.	Gravel up to boulders.
376 ft. to 380 ft.	Rock.
380 ft. to 388 ft.	Sandy Clay.
388 ft. to 420 ft.	Clay and gravel.
420 ft. to 430 ft.	Brown clay.
430 ft. to 458 ft.	Hard sand and seams of clay.
458 ft. to 500 ft.	Clay with small rocks.

Location No. 9
on PLATE 1

"PATTON HOSPITAL #10"

Depth: 420 ft.
Drilled: Sept. - Oct. 1950
Casing: 16 inch diameter to 409 ft.
Perforations from: 235 ft. to 319 ft.
330 ft. to 382 ft.

GEOLOGIC LOG

0 ft. to 2 ft.	Top soil.
2 ft. to 31 ft.	Sand and gravel.
31 ft. to 110 ft.	Sandy yellow clay.
110 ft. to 230 ft.	Sandy yellow clay with boulders.
230 ft. to 290 ft.	Cemented sand, gravel and boulders.
290 ft. to 310 ft.	Sand, gravel, big boulders.
310 ft. to 319 ft.	Cemented sand, gravel and boulders.
319 ft. to 330 ft.	Yellow clay and boulders.
330 ft. to 358 ft.	Cemented sand, gravel and boulders.
358 ft. to 362 ft.	Yellow clay, boulders.
362 ft. to 384 ft.	Cemented sand, gravel and boulders.
384 ft. to 386 ft.	Yellow clay and boulders.
386 ft. to 415 ft.	Cemented sand, gravel and boulders.
415 ft. to 420 ft.	Yellow sandy clay and boulders.

STATE #E-53h
"HARLEM SPRINGS WELL"

100 ft. East of Pepper Ave. and Approximately
600 ft. North of Base Line. Back of
both houses.

Drilled: 1912

Drilled by: H.F. Gansner

GEOLOGIC LOG

0 ft. to 12 ft.	Loamy Soil.
12 ft. to 42 ft.	Sandy Clay.
42 ft. to 60 ft.	Sandy Gravel.
60 ft. to 80 ft.	Sandy Clay.
80 ft. to 120 ft.	Sandy Gravel.
120 ft. to 130 ft.	Gravel.
130 ft. to 150 ft.	Gravel.
150 ft. to 160 ft.	Gravel and Sand.
160 ft. to 180 ft.	Gravel and Sand.
180 ft. to 194 ft.	Gravel.

Temperature at	130 ft. -	90°(F)
	150 ft. -	100°
	180 ft. -	104°
	194 ft. -	130°

Water stood at 7 ft.

Location No. 15d
on PLATE 1

STATE #E-50h

"HARLEM SPRINGS"

50 ft. East of Victoria and 600 ft.
North of Base Line.

Depth: 213 ft.

Diameter: 12 inches

Drilled: 1929

Drilled by: Mecham

GEOLOGIC LOG

0 ft. to	19 ft.	Soil.
19 ft. to	57 ft.	Sand and Rock.
57 ft. to	59 ft.	Clay Soil.
59 ft. to	77 ft.	Coarse Gravel.
77 ft. to	92 ft.	Running Sand.
92 ft. to	98 ft.	Sediment.
98 ft. to	107 ft.	Sandy Gravel.
107 ft. to	128 ft.	Gravel.
128 ft. to	137 ft.	Hard Red Clay Soil.
137 ft. to	184 ft.	Sand and Some Gravel.
184 ft. to	213 ft.	Coarse Gravel.

Well not cut (perforated); continued down
to 290 ft.; hot water at 260 ft.

STATE #E-50m
"BASE LINE LAUNDRY"

1000 ft. West of Victoria and 300 ft.
north of Base Line.
Drilled: 1929
Drilled by: Mecham
Diameter: 12-inch.

GEOLOGIC LOG

0 ft. to	5 ft.	Very Hard Soil
5 ft. to	17 ft.	Sediment and Sand.
17 ft. to	38 ft.	Clay Sediment, Hard Red Clay.
38 ft. to	50 ft.	Sand.
50 ft. to	55 ft.	Sand and Rock.
55 ft. to	66 ft.	Coarse Gravel.
66 ft. to	74 ft.	Sand and Gravel.
74 ft. to	86 ft.	Sand.
86 ft. to	89 ft.	Clay.
89 ft. to	94 ft.	Gravel.
94 ft. to	101 ft.	Sand.
101 ft. to	107 ft.	Clay.
107 ft. to	140 ft.	Sand.
140 ft. to	169 ft.	Gravel
169 ft. to	171 ft.	Clay Sediment.
171 ft. to	201 ft.	Sandy Gravel.

Perforation from: 90 ft. to 93 ft.
145 ft. to 152 ft.
179 ft. to 185 ft.

S.W.L. - Sept. 1929 - 10 ft.
Hot Water - 126° (F)

"PALM WELL #1"

Depth: 500 ft.
Drilled: Aug. - Sept. 1948
Casing: 20 inch diameter
Perforations from: 182 ft. to 238 ft.
 266 ft. to 318 ft.
 392 ft. to 448 ft.

Water first encountered at 162 ft.

GEOLOGIC LOG

0 ft. to 10 ft.	Top soil.
10 ft. to 13 ft.	Clay and gravel.
13 ft. to 100 ft.	Boulders.
100 ft. to 180 ft.	Clay and boulders.
180 ft. to 240 ft.	Sand and boulders.
240 ft. to 263 ft.	Clay some gravel.
263 ft. to 320 ft.	Sand and boulders.
320 ft. to 388 ft.	Clay some gravel.
388 ft. to 450 ft.	Sand and boulders.
450 ft. to 472 ft.	Packed sand.
472 ft. to 500 ft.	Sand, gravel 1 inch, clay streaks.

On August 13, 1949, a plug was placed at approximately 380 ft. to seal off lowest set of perforations. Plug reduced temperature from 110° (F) to 90° (F).

"DUNKIRK #1"

Depth: 406 ft.
Drilled: Feb. - Mar. 1959
Casing: 16 inch diameter
Perforations from: 297 ft. to 322 ft.
330 ft. to 390 ft.

Water first encountered at 90 ft.

GEOLOGIC LOG

0 ft. to	5 ft.	Top soil.
5 ft. to	15 ft.	Clay and boulders.
15 ft. to	55 ft.	Sand, gravel and boulders (10 inches).
55 ft. to	125 ft.	Gravel and boulders, some clay.
125 ft. to	150 ft.	Sandy clay.
150 ft. to	170 ft.	Clay and gravel 6 inches.
170 ft. to	205 ft.	Sandy clay and gravel 1 inch.
205 ft. to	240 ft.	Sandy clay (hard).
240 ft. to	270 ft.	Sandy clay and gravel 1 inch.
270 ft. to	290 ft.	Brown clay.
290 ft. to	305 ft.	Sand and gravel 3 inches.
305 ft. to	324 ft.	Sand and gravel 6 inches.
324 ft. to	328 ft.	Brown clay.
328 ft. to	401 ft.	Sand and gravel 10 inches, some clay.
401 ft. to	406 ft.	Blue sandy clay.

"DUNKIRK #2"

Depth: 391 ft.

Drilled: Feb. - May 1973

Casing: 16 inch diameter

Perforations from: 260 ft. to 270 ft.
297 ft. to 318 ft.
333 ft. to 338 ft.
342 ft. to 347 ft.
357 ft. to 363 ft.
368 ft. to 379 ft.

GEOLOGIC LOG

0 ft. to 2 ft.	Top soil.
2 ft. to 15 ft.	Clay, sand, gravel and boulders up to 3 ft.
15 ft. to 20 ft.	Sand, gravel and boulders.
20 ft. to 30 ft.	Sand, clay, gravel and some boulders.
30 ft. to 55 ft.	Sand, gravel, boulders and some clay.
55 ft. to 77 ft.	Brown clay, gravel and sand.
77 ft. to 91 ft.	Brown sandy clay and gravel.
91 ft. to 103 ft.	Sand, gravel, some boulders and red clay.
103 ft. to 122 ft.	Sand, gravel, boulders and some brown clay.
122 ft. to 135 ft.	Sandy clay and gravel.
135 ft. to 167 ft.	Sand, gravel, boulders and a little clay (hard).
167 ft. to 191 ft.	Hard, sandy, clay and gravel to 2 inches.
191 ft. to 201 ft.	Sticky sandy brown clay and gravel.
201 ft. to 211 ft.	Sandy brown clay, some gravel.
211 ft. to 221 ft.	Sandy clay and gravel (hard).
221 ft. to 228 ft.	Sand, gravel, some clay (hard).
228 ft. to 258 ft.	Sandy clay and gravel.
258 ft. to 271 ft.	Sand, gravel and boulders up to 10 inches (tight).
271 ft. to 275 ft.	Hard brown clay and gravel.
275 ft. to 287 ft.	Hard, sandy clay and gravel (up to) 3 inches.
287 ft. to 295 ft.	Hard, sandy clay.
295 ft. to 319 ft.	Sand, gravel, to 6 inches, some clay.
319 ft. to 323 ft.	Clay, sand and gravel - 1 inch
323 ft. to 327 ft.	Sandy clay
327 ft. to 331 ft.	Clay, sand and gravel to 8 inches.

GEOLOGIC LOG

331 ft. to 339 ft. Sand, gravel to 8 inches.
339 ft. to 343 ft. Clay, sand and gravel - 3 inches.
343 ft. to 347 ft. Sand and gravel to 10 inches.
347 ft. to 355 ft. Clay, sand and gravel - 3 inches.
355 ft. to 363 ft. Sand, gravel, to 6 inches, some
clay.
363 ft. to 367 ft. Sand, clay and gravel to 4 inches
(hard).
367 ft. to 379 ft. Sand and gravel to 6 inches.
379 ft. to 391 ft. Sand, gravel to 1 inch - clay.

WATER TEMPERATURE (taken every 5 ft. from 350 ft.)

350 ft.	84°(F)
355 ft.	88°
360 ft.	90°
365 ft.	96°
370 ft.	96°
375 ft.	98°
380 ft.	100°
385 ft.	105°
390 ft.	115°

STATE #E-85c
CITY OF COLTON WELL

Northeast corner of Mill Street and Mt. Vernon
Avenue, San Bernardino.

GEOLOGIC LOG

0 ft. to 30 ft.	Soil.
30 ft. to 40 ft.	Clay.
40 ft. to 50 ft.	Water gravel.
50 ft. to 60 ft.	Clay.
60 ft. to 92 ft.	Water gravel.
92 ft. to 130 ft.	Blue clay.
130 ft. to 132 ft.	Gravel.
132 ft. to 186 ft.	Clay and sand.
186 ft. to 220 ft.	Water gravel.
220 ft. to 240 ft.	Hard clay.
240 ft. to 272 ft.	Sand and clay.
272 ft. to 294 ft.	Water gravel.
294 ft. to 326 ft.	Clay.
326 ft. to 334 ft.	Cemented gravel.
334 ft. to 344 ft.	Clay.
344 ft. to 388 ft.	Slummy clay and sand.
388 ft. to 538 ft.	Hard slummy clay.
538 ft. to 608 ft.	Warm water, gravel, flowed 30 miner inches.
608 ft. to 624 ft.	Soft clay.
624 ft. to 628 ft.	Blue sand.
628 ft. to 632 ft.	Fine gravel, warm.
632 ft. to 660 ft.	Clay.
660 ft. to 702 ft.	Hard clay.
702 ft. to 704 ft.	Sand.
704 ft. to 722 ft.	Clay.
722 ft. to 744 ft.	Sand.
744 ft. to 802 ft.	Clay.
802 ft. to 812 ft.	Gravel hot.
812 ft. to 904 ft.	Clay blue.

Finished drilling: May 9, 1929.

STATE #E-92y
STODDARD STREET WELL

285 ft. East of Stoddard Street - 170 ft. South
of A.T. & S.F.R.R.

Diameter: 16 inches, 8 gage casing

Depth: 792 ft.

Drilled: August, 1951

Drilled by: Barber-Bridge

GEOLOGIC LOG

0 ft. to	5 ft.	Top soil.
5 ft. to	11 ft.	Clay brown sandy.
11 ft. to	26 ft.	Fine sand.
26 ft. to	46 ft.	Sand and gravel 4 inches.
46 ft. to	66 ft.	Sand and gravel, streaks clay.
66 ft. to	74 ft.	Clay blue.
74 ft. to	77 ft.	Gravel 2 inches.
77 ft. to	79 ft.	Clay blue.
79 ft. to	92 ft.	Gravel to 3 inches.
92 ft. to	108 ft.	Clay blue.
108 ft. to	114 ft.	Gravel 3 inches.
114 ft. to	133 ft.	Clay streaks gravel.
133 ft. to	170 ft.	Gravel 3 inches.
170 ft. to	174 ft.	Clay blue.
174 ft. to	193 ft.	Gravel 3 inches.
193 ft. to	197 ft.	Clay yellow.
197 ft. to	243 ft.	Clay blue.
243 ft. to	267 ft.	Gravel 4 inches.
267 ft. to	280 ft.	Clay yellow sandy.
280 ft. to	297 ft.	Gravel 3 inches.
297 ft. to	316 ft.	Clay yellow sandy.
316 ft. to	322 ft.	Gravel 2 inches.
322 ft. to	328 ft.	Cemented gravel.
328 ft. to	365 ft.	Clay yellow.
365 ft. to	414 ft.	Clay blue.
414 ft. to	417 ft.	Clay yellow sandy.
417 ft. to	422 ft.	Clay blue.
422 ft. to	424 ft.	Sand and gravel one half dirty.
424 ft. to	490 ft.	Clay yellow sandy.

GEOLOGIC LOG

490 ft. to 618 ft. Clay blue.
618 ft. to 630 ft. Clay yellow sticky.
630 ft. to 685 ft. Clay yellow sandy.
685 ft. to 774 ft. Gravel 4 inches.
774 ft. to 792 ft. Clay yellow.

July 9, 1951 - Well flowed 175 M.I. after
Perforating and Sand pumping - Water
Temperature 85° (F).

July 30, 1951 - 2,700 G.P.M. - Pumping level
39 ft. Water Temperature 86° (F).

Perforated from: 133 ft. to 170 ft.
174 ft. to 193 ft.
243 ft. to 267 ft.
280 ft. to 297 ft.
316 ft. to 328 ft.
700 ft. to 774 ft.

For Details of Total Depth of Well and the results
of an attempt to decrease the water temperature and
fluoride contents - See Field Book No. 53, page
65 to 73.

STATE #E-29a
WATER DEPT. #83

SAN BERNARDINO WATER DEPT. - "HANFORD WELL NO. 2"

Southeast corner of 2nd. and "D" Street (South Well).
Drilled: 1929-1930
12-inch - 8 Gage
12-inch Diameter, to ground surface
16 inches to 627 ft. reduced to 12 inches
12 inches not removed inside 16 inch casing

GEOLOGIC LOG

0 ft. to 28 ft.	Sandy clay.
28 ft. to 89 ft.	Blue clay.
89 ft. to 97 ft.	Coarse water gravel.
97 ft. to 114 ft.	Blue sandy clay.
114 ft. to 130 ft.	Coarse water gravel.
130 ft. to 153 ft.	Hard blue clay.
153 ft. to 187 ft.	Coarse water gravel and boulders.
187 ft. to 200 ft.	Blue clay.
200 ft. to 211 ft.	Coarse water gravel.
211 ft. to 265 ft.	Hard blue clay.
265 ft. to 293 ft.	Blue clay and mud.
293 ft. to 315 ft.	Coarse water gravel and boulders.
315 ft. to 327 ft.	Hard blue clay.
327 ft. to 343 ft.	Coarse water gravel and boulders.
343 ft. to 347 ft.	Yellow clay.
347 ft. to 353 ft.	Blue clay.
353 ft. to 355 ft.	Yellow clay.
355 ft. to 369 ft.	Sand and gravel.
369 ft. to 414 ft.	Blue sticky clay.
414 ft. to 420 ft.	Yellow sandy clay.
420 ft. to 433 ft.	Fine sand with flow.
433 ft. to 438 ft.	Yellow sandy clay.
438 ft. to 458 ft.	Yellow clay.
458 ft. to 485 ft.	Hard red clay.
485 ft. to 525 ft.	Hard blue clay.
525 ft. to 539 ft.	Fine sand with flow.
539 ft. to 553 ft.	Hard blue clay.
553 ft. to 561 ft.	Pea gravel.
561 ft. to 570 ft.	Hard blue clay.
570 ft. to 575 ft.	Hard yellow clay.
575 ft. to 585 ft.	Sand and gravel with flow.
585 ft. to 607 ft.	Boulders with flow.
607 ft. to 611 ft.	Blue clay and mud.
611 ft. to 617 ft.	Sandy blue clay.

GEOLOGIC LOG

617 ft. to 619 ft. Soft yellow clay.
619 ft. to 623 ft. Fine sand with flow.
623 ft. to 645 ft. Hard blue clay.
645 ft. to 680 ft. Gray quicksand.
680 ft. to 695 ft. Sand.
695 ft. to 775 ft. Boulders - heavy flow, artesian.
775 ft. to 790 ft. Yellow sandy clay.
790 ft. to 800 ft. Gravel and boulders, flow.
800 ft. to 816 ft. Yellow sandy clay.
816 ft. to 836 ft. Gravel and boulders, flow.
836 ft. to 850 ft. Cemented gravel.
850 ft. to 872 ft. Blue clay.
872 ft. to 878 ft. Yellow clay conglomerate.
878 ft. to 890 ft. Boulders, flow.
890 ft. to 902 ft. Blue clay.
902 ft. to 904 ft. Gravel, flow.
904 ft. to 930 ft. Cement boulders.
930 ft. to 946 ft. Yellow clay conglomerate.
946 ft. to 963 ft. Cement boulders.
963 ft. to 969 ft. Sand and gravel.
969 ft. to 974 ft. Boulders, flow.
974 ft. to 990 ft. White cement.
990 ft. to 994 ft. Fine sand.
994 ft. to 1014 ft. Yellow sandy clay.
1014 ft. to 1020 ft. Fine sand, flow.
1020 ft. to 1038 ft. Sand and gravel.
1038 ft. to 1070 ft. Yellow sand and clay.
1070 ft. to 1078 ft. Cemented gravel.
1078 ft. to 1085 ft. Fine sand.
1085 ft. to 1097 ft. Boulders, heavy flow.
1097 ft. to 1128 ft. Hard sand.
1128 ft. to 1150 ft. Boulders and clay, no flow.
1150 ft. to 1188 ft. Coarse water gravel.
1188 ft. to 1202 ft. Cemented boulders and sand rock.
1202 ft. to 1208 ft. Coarse water gravel and sand.
1212 ft. to 1235 ft. Cemented gravel.
Open hole below 1212 ft.

Well flowed 153 M.I. - April 8, 1930 - 90° (F) Temperature
25 - pound pressure.

March 1934. To reduce temperature well sealed off at
1065 ft. Flow 82 M.I. 80° (F) Temperature.

Loss of 17.5 M.I.

Well perforated from: 698 ft. to 778 ft.
793 ft. to 803 ft.
819 ft. to 853 ft.
881 ft. to 893 ft.
905 ft. to 933 ft.
949 ft. to 977 ft.
1025 ft. to 1041 ft.

Location No. 37
on PLATE 1

STATE #E-93r
WATER DEPT. #182

SAN BERNARDINO WATER DEPT. - MILL & "D" STREET WELL.

Northwest Corner of Mill and "D" St.,
San Bernardino.

Drilled: October, 1933

Diameter: 16-inch

GEOLOGIC LOG

0 ft. to	4 ft.	Sand.
4 ft. to	10 ft.	Sandy clay (soft).
10 ft. to	19 ft.	Blue clay.
19 ft. to	23 ft.	Sand and $\frac{1}{2}$ inch gravel.
23 ft. to	28 ft.	Gravel $\frac{1}{2}$ inch to 4 inches.
28 ft. to	29 ft.	Clay.
29 ft. to	46 ft.	Sand and gravel to 4 inches.
46 ft. to	58 ft.	Cemented clay and gravel.
58 ft. to	70 ft.	Sand and gravel to 2 inches.
70 ft. to	75 ft.	Blue clay.
75 ft. to	91 ft.	Yellow clay.
91 ft. to	112 ft.	Blue clay and silt.
112 ft. to	127 ft.	Sand and gravel to 4 inches.
127 ft. to	144 ft.	Blue sandy clay.
144 ft. to	172 ft.	Sand and gravel to 4 inches - perforated.
172 ft. to	180 ft.	Tight blue sand and gravel to $\frac{1}{2}$ inch.
180 ft. to	188 ft.	Blue clay.
188 ft. to	202 ft.	Sand and gravel - perforated.
202 ft. to	212 ft.	Sand.
212 ft. to	217 ft.	Gravel to 2 inches - perforated.
217 ft. to	258 ft.	Clay.
258 ft. to	272 ft.	Gravel to 5 inches - perforated.
272 ft. to	288 ft.	Clay.
288 ft. to	305 ft.	Gravel, sand and clay streaks - perforated.
305 ft. to	317 ft.	Clay and sand streaks.
317 ft. to	323 ft.	Gravel to 6 inches - perforated.
323 ft. to	410 ft.	Clay (hard).
410 ft. to	414 ft.	Sand.
414 ft. to	417 ft.	Gravel to 1 inch - perforated.
417 ft. to	420 ft.	Yellow silty clay.
420 ft. to	424 ft.	Blue clay.
424 ft. to	485 ft.	Gray clay (hard).
485 ft. to	497 ft.	Sandy clay and light gravel.
497 ft. to	506 ft.	Sand and light gravel with clay streaks.
506 ft. to	513 ft.	Muddy sand.
513 ft. to	545 ft.	Blue clay with some sand.
545 ft. to	552 ft.	Sand and gravel to 1 inch.
552 ft. to	557 ft.	Blue clay.

Water is bad and hot below 500 ft.

STATE #E-89b

"DE SIENNA HOT SPRING WELL"

310 ft. South & 20 ft. West of center line of
private road extending to Colton Ave. from
Junction of "K" St. & Hillcrest Ave.,
San Bernardino.

Drilled: 1926.

Drilled by: W.A. Rice.

Diameter: 12 inch.

GEOLOGIC LOG

0 ft. to 24 ft.	Gravel.
24 ft. to 65 ft.	Blue clay.
65 ft. to 71 ft.	Gravel.
71 ft. to 160 ft.	Blue clay.
160 ft. to 168 ft.	Yellow.
168 ft. to 191 ft.	Gravel.
191 ft. to 203 ft.	Blue clay.
203 ft. to 222 ft.	Gravel.
222 ft. to 225 ft.	Blue clay - some wood.
225 ft. to 257 ft.	Gravel.
257 ft. to 268 ft.	Blue clay.
268 ft. to 296 ft.	Gravel.
296 ft. to 304 ft.	Blue clay - some wood.
304 ft. to 318 ft.	Gravel - perforated.
318 ft. to 376 ft.	Blue clay.
376 ft. to 386 ft.	Hot gravel 86° (F) perforated.
386 ft. to 462 ft.	Blue clay (lost flow).
462 ft. to 470 ft.	Sand and gravel.
470 ft. to 485 ft.	Hot gravel 99° (F) perforated.
485 ft. to 494 ft.	Blue clay.
494 ft. to 502 ft.	Blue clay.
502 ft. to 520 ft.	Gravel - perforated.
520 ft. to 522 ft.	Clay.
522 ft. to 544 ft.	Gravel.
544 ft. to 547 ft.	Clay - perforated.?

STATE #E-93j
"URBITA SPRINGS WELL"

50 ft. Easterly from Colton Ave., 1200 ft.
West to South "E" St. and 1700 ft.
South of Mill St.

GEOLOGIC LOG

0 ft. to 48 ft.	Sand and gravel.
48 ft. to 65 ft.	Gravel.
65 ft. to 90 ft.	Clay.
90 ft. to 152 ft.	Gravel.
152 ft. to 174 ft.	Clay.
174 ft. to 183 ft.	Sandy clay.
183 ft. to 230 ft.	Cemented gravel - warm water.
230 ft. to 250 ft.	Cemented gravel - warm water.
250 ft. to 266 ft.	Sand and gravel.
266 ft. to 276 ft.	Clay.
276 ft. to 302 ft.	Gravel.
302 ft. to 330 ft.	Blue clay - warm water.
330 ft. to 356 ft.	Blue clay.
356 ft. to 368 ft.	Blue sandy clay.

Location No. 45
on PLATE 1

STATE #E-93k 1
RIVERSIDE WATER COMPANY

On Coburn Tract - Center line of tract approximately
300 ft. North of Warm Creek and 1,300 ft. West
of "E" Street.

Depth: 225 ft.
Diameter: 9 inches
Drilled: 1889
Drilled by: Rice

GEOLOGIC LOG

0 ft. to 15 ft.	Sand.
15 ft. to 63 ft.	Clay.
63 ft. to 81 ft.	Sand, water, light flow.
81 ft. to 127 ft.	Clay.
127 ft. to 132 ft.	Sand, water, light flow.
132 ft. to 211 ft.	Clay.
211 ft. to 215 ft.	Sand.
215 ft. to 218 ft.	Gravel.
218 ft. to 225 ft.	Boulders.

Struck warm water at 211 ft.
Cut 215 ft. - 224 ft.
Well flow: 1½ inch over casing

Location No. 46
on PLATE 1

STATE #E-93k 3
RIVERSIDE WATER COMPANY

On Coburn Tract - Center line of tract approximately
300 ft. North of Warm Creek and 1,300 ft. West
of "E" Street.

Depth: 175 ft.
Diameter: 7 inches
Drilled: 1889
Drilled by: Rice

GEOLOGIC LOG

0 ft. to 10 ft.	Sand.
10 ft. to 65 ft.	Clay.
65 ft. to 75 ft.	Sand - slight flow.
75 ft. to 127 ft.	Clay.
127 ft. to 132 ft.	Sand - slight flow.
132 ft. to 162 ft.	Clay.
162 ft. to 164 ft.	Sand.
164 ft. to 175 ft.	Boulders - slight flow.

Cut - 127 ft. to 132 ft.
164 ft. to 174 ft.
Warm water 105°(F)
Flowed 3/4 inches above casing.

STATE #E-39v

CITY OF RIVERSIDE, COOLEY "I" WELL

150 ft. North of 3rd, Street and 60 ft. East of
Waterman Avenue. (240 ft. West of E-39q).

Depth: 1146 ft.

Drilled: January 1947

Drilled by: Barber-Bridge
Drilling Corp.

GEOLOGIC LOG

0 ft. to	8 ft.	Soil.
8 ft. to	32 ft.	Gravel - 3 inches.
32 ft. to	44 ft.	Yellow clay.
44 ft. to	46 ft.	Gravel - 4 inches.
46 ft. to	48 ft.	Blue clay.
48 ft. to	72 ft.	Gravel - 2 inches.
72 ft. to	128 ft.	Blue clay.
128 ft. to	184 ft.	Sandy yellow clay.
184 ft. to	188 ft.	1 inch gravel.
188 ft. to	197 ft.	Sandy yellow clay.
197 ft. to	222 ft.	Gravel - 6 inches, dirty.
222 ft. to	234 ft.	Sandy yellow clay.
234 ft. to	270 ft.	Sandy blue clay.
270 ft. to	292 ft.	Yellow clay.
292 ft. to	322 ft.	Gravel - 3 inches.
322 ft. to	354 ft.	Yellow clay.
354 ft. to	390 ft.	Blue clay.
390 ft. to	410 ft.	Clay and rocks.
410 ft. to	496 ft.	Yellow clay.
496 ft. to	518 ft.	Fine sand - dirty.
518 ft. to	548 ft.	Yellow clay - dirty.
548 ft. to	580 ft.	Yellow clay.
580 ft. to	590 ft.	Clay and rocks.
590 ft. to	599 ft.	Gravel - 2 inches - $\frac{1}{2}$ inch flow.
599 ft. to	605 ft.	Cemented gravel.
605 ft. to	628 ft.	Gravel - 1 inch - 1 inch flow.
628 ft. to	663 ft.	Sandy yellow clay.
663 ft. to	698 ft.	Gravel - 3 inches - $1\frac{1}{2}$ inch flow.
698 ft. to	725 ft.	Sandy yellow clay.
725 ft. to	772 ft.	Gravel - 3 inches - 2 inches flow.
772 ft. to	792 ft.	Yellow clay.
792 ft. to	802 ft.	Cemented clay.
802 ft. to	810 ft.	Yellow clay.
810 ft. to	830 ft.	Clay and boulders.

GEOLOGIC LOG

830 ft. to 842 ft. Cemented gravel.
842 ft. to 857 ft. Clay and boulders.
857 ft. to 861 ft. Gravel - 1 inch.
861 ft. to 878 ft. Clay and boulders.
878 ft. to 914 ft. Gravel - 2 inches (dirty no flow).
914 ft. to 924 ft. Gravel - 2 inches (2 inches flow).
924 ft. to 1048 ft. Gravel and boulders.
1048 ft. to 1063 ft. Yellow clay.
1063 ft. to 1068 ft. Cemented gravel.
1068 ft. to 1110 ft. Clay and gravel.
1110 ft. to 1118 ft. Gravel and boulders (no flow).
1118 ft. to 1132 ft. Yellow clay.
1132 ft. to 1146 ft. Yellow clay (showing wood).

Perforated from: 595 ft. to 625 ft.
670 ft. to 697 ft.
730 ft. to 770 ft.
920 ft. to 1040 ft.

500 M.I. flow.
74°(F) temperature.

Location No. 57
on PLATE 1

STATE #E-96bb
"MEEKS AND DALEY #66"

60. ft. West of Arrowhead Avenue - 90 ft.

North of Central Avenue.

Diameter: 20 inches

6 Gage casing - double

Depth: 975 ft.

Drilled: May, 1966

Drilled by: R. & W. Drilling Inc.

GEOLOGIC LOG

0 ft. to 60 ft.	Sand and gravel.
60 ft. to 64 ft.	Clay.
64 ft. to 210 ft.	Blue silt and sand.
210 ft. to 220 ft.	Gravel and rock - up to 4 inches.
220 ft. to 244 ft.	Blue clay and gravel.
244 ft. to 255 ft.	Gravel and rock - up to 4 inches.
255 ft. to 262 ft.	Brown clay and gravel.
262 ft. to 280 ft.	Brown clay.
280 ft. to 290 ft.	Small gravel.
290 ft. to 310 ft.	Brown clay and gravel.
310 ft. to 315 ft.	Sand and gravel.
315 ft. to 351 ft.	Brown clay and gravel.
351 ft. to 379 ft.	Blue clay and sand with streaks.
379 ft. to 385 ft.	Blue clay.
385 ft. to 387 ft.	Brown sand, fine.
387 ft. to 398 ft.	Blue fine sand, tight.
398 ft. to 415 ft.	Blue clay with gravel streaks.
415 ft. to 450 ft.	Blue sandy clay.
450 ft. to 461 ft.	Cemented sand and gravel.
461 ft. to 467 ft.	Blue sandy clay.
467 ft. to 503 ft.	Blue sandy clay with gravel.
503 ft. to 570 ft.	Brown sand and gravel.
570 ft. to 575 ft.	Brown sand and gravel to 4 inches.
575 ft. to 612 ft.	Brown sandy clay.
612 ft. to 617 ft.	Black sticky clay.
617 ft. to 635 ft.	Brown clay.
635 ft. to 695 ft.	Grey sand and gravel, to 4 inches.
695 ft. to 703 ft.	Tight sand, small gravel brown clay.
703 ft. to 745 ft.	Tight sand and small gravel.
745 ft. to 791 ft.	Silt, fine sand with blue clay.
791 ft. to 801 ft.	Cemented sand and pea gravel.
801 ft. to 809 ft.	Tight sand and small gravel.
809 ft. to 867 ft.	Sand and gravel - up to 4 inches.
867 ft. to 885 ft.	Sand and gravel - tight clean.
885 ft. to 930 ft.	Sand, pea gravel - tight with clay.
930 ft. to 939 ft.	Sand and gravel, small.
939 ft. to 955 ft.	Sand and gravel and rocks.
955 ft. to 967 ft.	Sand, silt with streaks of clay.

GEOLOGIC LOG

967 ft. to 975 ft. Brown and blue clay.

Static Water Level - May 24, 1966 - 69 ft.

Temperature: 120°(F)

Perforations from: 503 ft. 955 ft.

Location No. 60
on PLATE 1

STATE #E-98e
CITY OF RIVERSIDE

0.67 miles South and 0.29 miles East (West?)
from intersection of Central and
Waterman Avenues.

Drilled: October, 1931.

Drilled by: D.A. Beck and Sons (Mueller and Harris)

Diameter: 20 inch

GEOLOGIC LOG			<u>TEMP.</u>
10 ft. to	44 ft.	Blue clay.	
44 ft. to	62 ft.	Yellow sandy clay.	78°F
62 ft. to	78 ft.	Small gravel.	84°F
78 ft. to	102 ft.	Clay and gravel.	
102 ft. to	138 ft.	Good gravel.	74°F
138 ft. to	142 ft.	Clay and gravel.	
142 ft. to	163 ft.	Good gravel.	69°F
163 ft. to	169 ft.	Clay and gravel.	
169 ft. to	181 ft.	Gravel.	72°F
181 ft. to	194 ft.	Sandy clay.	
194 ft. to	206 ft.	Good gravel.	70°F
206 ft. to	218 ft.	Clay and gravel.	
218 ft. to	236 ft.	Gravel and boulders	68°F
236 ft. to	240 ft.	Blue clay.	
240 ft. to	251 ft.	Gravel and fine sand.	67°F
251 ft. to	262 ft.	Clay and gravel.	
262 ft. to	340 ft.	Good gravel.	67°F
340 ft. to	352 ft.	Sandy clay.	
352 ft. to	382 ft.	Blue clay.	
382 ft. to	401 ft.	Small gravel.	69°F
401 ft. to	413 ft.	Clay and gravel.	
413 ft. to	421 ft.	Blue clay.	
421 ft. to	433 ft.	Gravel.	68°F
433 ft. to	452 ft.	Blue clay.	
452 ft. to	458 ft.	Good gravel (small flow).	68°F
458 ft. to	470 ft.	Quicksand.	
470 ft. to	483 ft.	Sandy clay.	
483 ft. to	498 ft.	Blue clay.	
498 ft. to	519 ft.	Sandy clay.	
519 ft. to	536 ft.	Small gravel.	69°F
536 ft. to	592 ft.	Good gravel some boulders.	69°F
592 ft. to	612 ft.	Gravel.	69°F
612 ft. to	620 ft.	Fine sand and gravel.	
620 ft. to	632 ft.	Silt.	
632 ft. to	664 ft.	Sandy clay.	
664 ft. to	668 ft.	Gravel and clay.	
668 ft. to	696 ft.	Gravel and boulders (flow).	69°F
696 ft. to	720 ft.	Gravel and sand.	69°F
720 ft. to	728 ft.	Sandy clay.	
728 ft. to	738 ft.	Good gravel (flow).	70°F
738 ft. to	744 ft.	Sandy clay.	
744 ft. to	758 ft.	Good gravel (flow).	73°F

GEOLOGIC LOG			<u>TEMP.</u>
758 ft. to	822 ft.	Clay and silt.	
822 ft. to	826 ft.	Cemented gravel.	70°F
826 ft. to	856 ft.	Clay and cement.	
856 ft. to	876 ft.	Clay and gravel.	
876 ft. to	882 ft.	Gravel (no flow).	72°F
882 ft. to	890 ft.	Clay and gravel.	
890 ft. to	892 ft.	Sandy clay.	
892 ft. to	908 ft.	Gravel (flow).	70°F
908 ft. to	918 ft.	Sand and clay.	
918 ft. to	950 ft.	Gravel (flow).	74°F
950 ft. to	954 ft.	Sandy clay.	
954 ft. to	960 ft.	Gravel (flow).	76°F
960 ft. to	970 ft.	Yellow clay.	
970 ft. to	992 ft.	Gravel and sand.	
992 ft. to	1014 ft.	Gravel (flow).	72°F
1014 ft. to	1042 ft.	Sand and clay.	
1042 ft. to	1055 ft.	Clay and water gravel.	
1055 ft. to	1072 ft.	Blue clay.	
1072 ft. to	1079 ft.	Tight gravel.	72°F
1079 ft. to	1090 ft.	Sandy clay.	
1090 ft. to	1100 ft.	Gravel and sand.	74°F
1100 ft. to	1137 ft.	Blue clay.	
1137 ft. to	1145 ft.	Clay and gravel.	
1145 ft. to	1166 ft.	Gravel (flow).	72°F
1166 ft. to	1188 ft.	Blue clay.	

Location No. 61
on PLATE 1

STATE #E-130h

MEADOWBROOK DAIRY

459 ft. South of Dumas Street - 1,042 ft. East (West?)
of Waterman Avenue - 3,600 ft. South of Central.

Diameter: 14 inches

Depth: 744 ft.

Drilled: August, 1950

Drilled by: Barber-Bridge

GEOLOGIC LOG

0 ft. to 22 ft.	Sand fine.
22 ft. to 86 ft.	Clay blue.
86 ft. to 95 ft.	Clay brown sandy.
95 ft. to 104 ft.	Sand gravel and clay.
104 ft. to 128 ft.	Sandy and gravel 4 inches.
128 ft. to 132 ft.	Clay yellow.
132 ft. to 140 ft.	Sand and gravel dirty.
140 ft. to 158 ft.	Gravel 4 inches.
158 ft. to 176 ft.	Clay yellow sandy.
176 ft. to 204 ft.	Clay blue.
204 ft. to 222 ft.	Clay yellow.
222 ft. to 237 ft.	Gravel and boulders.
237 ft. to 245 ft.	Clay yellow sandy.
245 ft. to 262 ft.	Gravel and boulders.
262 ft. to 264 ft.	Gravel dirty.
264 ft. to 272 ft.	Clay yellow sandy.
272 ft. to 283 ft.	Sand gravel and clay.
283 ft. to 326 ft.	Gravel 2 inches.
326 ft. to 339 ft.	Sand and gravel 1 inch to 4 inches.
339 ft. to 343 ft.	Clay yellow sandy.
343 ft. to 356 ft.	Gravel 2 inches streaks, clay.
356 ft. to 372 ft.	Clay yellow sandy.
372 ft. to 378 ft.	Clay blue.
378 ft. to 418 ft.	Clay yellow.
418 ft. to 423 ft.	Clay blue.
423 ft. to 440 ft.	Clay yellow.
440 ft. to 468 ft.	Clay blue showing.
468 ft. to 476 ft.	Clay brown sandy.
476 ft. to 515 ft.	Clay blue.
515 ft. to 538 ft.	Clay yellow sandy.
538 ft. to 578 ft.	Clay yellow and gravel.

GEOLOGIC LOG

578 ft. to 595 ft.	Fine sand and gravel 2 inches.
595 ft. to 618 ft.	Gravel and boulders.
618 ft. to 630 ft.	Clay yellow.
630 ft. to 636 ft.	Gravel 1 inch.
636 ft. to 638 ft.	Clay yellow.
638 ft. to 651 ft.	Gravel.
651 ft. to 662 ft.	Clay yellow.
662 ft. to 702 ft.	Clay yellow and gravel.
702 ft. to 708 ft.	Gravel and boulders dirty.
708 ft. to 744 ft.	Gravel and boulders.

Well flowed approximately 25 M.I. after perforating.

August 2, 1950 - 1,400 G.P.M. - Pumping level 82 ft.

Water temperature - 72°(F)

Pipe rolled in from 717 ft. to 722 ft. trapping mud scow. Mud scow left in well and cemented off to 716 ft.

Perforated from: 595 ft. to 618 ft.
630 ft. to 636 ft.
638 ft. to 651 ft.
702 ft. to 714 ft.

Location No. 63
on PLATE 1

THORN (THORNE) No. 12

Drilled: Feb. - Aug. 1960

Diameter: 14 inches

Depth: 654 ft.

Perforations: 5/16 inch x 2¼ inches - 9 cuts every
12 inches from 240 ft. to 462 ft.

Water temperature when test pumping was 76°F

GEOLOGIC LOG

0 ft. to 6 ft.	Top soil.
6 ft. to 13 ft.	Brown sandy clay.
13 ft. to 23 ft.	Black and brown sandy clay.
23 ft. to 70 ft.	Hard gray clay.
70 ft. to 78 ft.	Gray loose sand.
78 ft. to 104 ft.	Loose 3 inch gravel.
104 ft. to 114 ft.	Gray clay.
114 ft. to 176 ft.	Loose 3 inch gravel.
176 ft. to 202 ft.	Brown sandy clay.
202 ft. to 212 ft.	Brown clay and sand.
212 ft. to 239 ft.	Loose 3 inch gravel with lots of sand.
239 ft. to 241 ft.	Red clay.
241 ft. to 255 ft.	3 inch gravel.
255 ft. to 276 ft.	Blue sandy clay.
276 ft. to 286 ft.	Loose 2 inch gravel.
286 ft. to 296 ft.	Blue sandy clay.
296 ft. to 303 ft.	Gravel (with) 2 ft. of brown clay.
303 ft. to 412 ft.	Loose 4 inch gravel.
412 ft. to 416 ft.	Brown silty clay.
416 ft. to 440 ft.	Loose 4 inch gravel.
440 ft. to 448 ft.	Blue clay (and) gravel.
448 ft. to 460 ft.	Loose 3 inch gravel.
460 ft. to 484 ft.	Blue clay.
484 ft. to 492 ft.	Blue clay.
492 ft. to 532 ft.	Yellow sandy clay.
532 ft. to 552 ft.	Yellow clay and sand.
552 ft. to 604 ft.	Blue sandy clay.
604 ft. to 606 ft.	Loose 3/4 inch gravel.
606 ft. to 616 ft.	Brown sandy clay.
616 ft. to 624 ft.	Blue sandy clay.
624 ft. to 632 ft.	Blue and brown clay.
632 ft. to 648 ft.	Sand and blue clay - warm.
648 ft. to 654 ft.	Blue sandy clay - warm.

Location No. 82
on PLATE 1

WELL 1S/4W-22H4

Depth: 965 ft.

Geologic log interpreted from diagrammatic geologic column of well 1S/4W-22H4 from Dutcher and Garrett, 1963, Plate 7.

GEOLOGIC LOG

0 ft. to 10 ft.	Sandy clay.
10 ft. to 68 ft.	Clay.
68 ft. to 86 ft.	Clay and gravel.
86 ft. to 136 ft.	Gravel and boulders.
136 ft. to 151 ft.	Clay.
151 ft. to 176 ft.	Gravel and boulders.
176 ft. to 219 ft.	Clay.
219 ft. to 319 ft.	Gravel and boulders.
319 ft. to 519 ft.	Clay.
519 ft. to 524 ft.	Sandy clay.
524 ft. to 559 ft.	Clay.
559 ft. to 639 ft.	Gravel and boulders.
639 ft. to 649 ft.	Sand or sandy clay.
649 ft. to 659 ft.	Gravel and boulders.
659 ft. to 709 ft.	Sandy clay.
709 ft. to 930 ft.	Gravel with some clay.
930 ft. to 954 ft.	Sandy clay and sand.

Location No. 92a
on PLATE 1

"ARROYO VERDE WELL"

Drilled: 1898

Depth: 648 ft.

Geologic log interpreted from diagrammatic geologic column
from Mendenhall, 1905, Figure 6, p. 44.

GEOLOGIC LOG

0 ft. to 198 ft.	Clay.
198 ft. to 238 ft.	Gravel.
238 ft. to 360 ft.	Clay.
360 ft. to 391 ft.	Sand.
391 ft. to 397 ft.	Clay.
397 ft. to 443 ft.	Gravel or sandy gravel.
443 ft. to 489 ft.	Clay.
489 ft. to 523 ft.	Sand.
523 ft. to 587 ft.	Clay.
587 ft. to 627 ft.	Gravel or sandy gravel.
627 ft. to 633 ft.	Clay.
633 ft. to 648 ft.	Gravel or sandy gravel.

Location No. 93
on PLATE 1

"PATTON HOSPITAL #2"

Drilled: March, 1964

GEOLOGIC LOG

0 ft. to	3 ft.	Top soil.
3 ft. to	92 ft.	Sandy clay.
92 ft. to	170 ft.	Dirty sand.
170 ft. to	224 ft.	Sandy clay.
224 ft. to	323 ft.	Sand and gravel up to 12 inches.
323 ft. to	335 ft.	Boulders.
335 ft. to	423 ft.	Sand and gravel.
423 ft. to	483 ft.	Clay and gravel.
483 ft. to	501 ft.	Sticky clay.
501 ft. to	551 ft.	Clay (open hole).

501 ft. of casing.

Bottom 50 ft. drilled, not cased, back filled with
gravel back to shoe.

Perforated from 370 ft. to 483 ft.

Location No. ONO No. 1
on PLATE 6

"ONO NO. 1"

Drilled: 1950
Depth: 1712 ft.

(A geologic log of this well was not available. A broad interpretation of the electric log (not presented) for this well may suggest an alluvial thickness of only approximately 500 feet at this location).

"HIGGS NO. 1"

1S/4W Sec. 18

Depth: 4015 ft.
Start Drilling on November 1, 1930.
Apparently abandoned in April, 1942.

GEOLOGIC LOG

1 ft. to	18 ft.	Surface sand.
18 ft. to	25 ft.	Red hard-pan.
25 ft. to	164 ft.	Clay, containing boulders and some gravel.
164 ft. to	186 ft.	Brown clay.
186 ft. to	211 ft.	Water gravel, very coarse.
211 ft. to	220 ft.	Clay.
220 ft. to	224 ft.	Shell.
224 ft. to	240 ft.	Clay.
240 ft. to	243 ft.	Water gravel, fine.
243 ft. to	268 ft.	Cemented sand and gravel.
268 ft. to	332 ft.	Alternating strata of clay and sand.
332 ft. to	352 ft.	Brown, sticky clay.
352 ft. to	361 ft.	Sand.
361 ft. to	363 ft.	Clay.
363 ft. to	442½ft.	Sand and a little clay, hard.
442½ft. to	447½ft.	Pure brown, sticky clay soft.
447½ft. to	460 ft.	Light brown, shaley sand, hard.
460 ft. to	469 ft.	Brown sticky shale, soft.
469 ft. to	478 ft.	Light brown, sandy shale.
478 ft. to	485 ft.	Brown shale, very sticky.
485 ft. to	487 ft.	Light brown, sandy shale, hard.
487 ft. to	492 ft.	Brown shale, soft and sticky.
492 ft. to	505 ft.	Brown shale, sticky.
505 ft. to	519 ft.	Brown clay, sticky.
519 ft. to	522 ft.	Light brown, sandy shale, hard.
522 ft. to	529 ft.	Clay.
529 ft. to	535 ft.	Sand.
535 ft. to	542½ft.	Red, sticky clay.
542½ft. to	634 ft.	Sand and shale, hard.
634 ft. to	651 ft.	Brown sticky clay.
651 ft. to	727 ft.	Mostly brown sticky shale, some gray sand, hard.
727 ft. to	730 ft.	Red, sand, coarse.
730 ft. to	760 ft.	Sticky brown clay.
760 ft. to	850 ft.	Conglomerate, light brown sand, much red mica, hard.
850 ft. to	955 ft.	Black mica sand, hard.

GEOLOGIC LOG

955 ft. to 1090 ft.	Hard rock, bluish fine sand.
1090 ft. to 1100 ft.	Water sand, fine.
1100 ft. to 1240 ft.	Hard rock, gray sand.
1240 ft. to 4015 ft.	"The only formation encountered below 1240 ft. was granite which varied in color from a dark micaceous to a light grey with depth. Hardness varied and many fractures were encountered".

U.S.G.S. 1S/4W-10B1
"MEADOWBROOK PARK TEST HOLE"

Depth: 875 ft.
Drilled: Feb. - Mar. 1977
Three casings set in hole for various test purposes.

GEOLOGIC LOG

0 ft. to 10 ft.	Sand, brown coarse to very coarse.
10 ft. to 16 ft.	Gravel and cobbles.
16 ft. to 29 ft.	Sand and gravel, occasional cobble (wood at 28 ft.).
29 ft. to 31 ft.	Sand.
31 ft. to 37 ft.	Sand and cobble.
37 ft. to 55 ft.	Sand.
55 ft. to 56 ft.	Sand, some clay.
56 ft. to 70 ft.	Sand.
70 ft. to 81 ft.	Gravel (wood from 79 to 81 ft.).
81 ft. to 85 ft.	Gravel and sand, some silty clay.
85 ft. to 94 ft.	Sand, some silty clay (wood from 87 to 90 ft.).
94 ft. to 97 ft.	Gravel and cobbles.
97 ft. to 100 ft.	Sand and gravel, occasional cobble.
100 ft. to 105 ft.	Gravel and sand, occasional cobble.
105 ft. to 112 ft.	Gravel and cobbles.
112 ft. to 117 ft.	Sand and gravel.
117 ft. to 119 ft.	Sand, occasional cobble.
119 ft. to 141 ft.	Sand.
141 ft. to 143 ft.	Sand, some silty clay.
143 ft. to 150 ft.	Sand, some silty clay and cobbles.
150 ft. to 180 ft.	Sand and cobbles.
180 ft. to 205 ft.	Gravel.
205 ft. to 212 ft.	Sand and gravel.
212 ft. to 221 ft.	Sand and silty clay.
221 ft. to 265 ft.	Sand and gravel, some silty clay.
265 ft. to 283 ft.	Sand with streaks of clay.
283 ft. to 295 ft.	Sand, fine; with streaks of clay.
295 ft. to 301 ft.	Sand, fine; and cobbles.
301 ft. to 315 ft.	Sand, brown; occasional cobble.
315 ft. to 330 ft.	Sand and cobbles.
330 ft. to 335 ft.	Sand; occasional cobble.
335 ft. to 344 ft.	Sand; some small gravel.
344 ft. to 350 ft.	Clay and sand.
350 ft. to 370 ft.	Sand; some clay and cobbles.
370 ft. to 385 ft.	Sand; clay and cobbles.
385 ft. to 395 ft.	Sand; some clay.

GEOLOGIC LOG

395 ft. to 410 ft.	Clay, sandy.
410 ft. to 440 ft.	Clay, silty; occasional cobble.
440 ft. to 455 ft.	Clay, silty; some sand and cobbles.
455 ft. to 460 ft.	Sand; some clay and cobbles.
460 ft. to 465 ft.	Sand, silty.
465 ft. to 470 ft.	Clay, sandy; occasional cobble.
470 ft. to 477 ft.	Sand; streaks of clay with occasional cobble.
477 ft. to 488 ft.	Clay, silty; streaks of sand.
488 ft. to 491 ft.	Sand; streaks of silty clay.
491 ft. to 541 ft.	Clay, silty; occasional cobble and small streaks of sand.
541 ft. to 561 ft.	Clay, silty; some small gravel and sand.
561 ft. to 577 ft.	Silt and very fine sand; some clay.
577 ft. to 590 ft.	Silt and very fine sand; some clay and cobbles.
590 ft. to 595 ft.	Sand and clay.
595 ft. to 612 ft.	Clay with streaks of sand.
612 ft. to 616 ft.	Sand and clay.
616 ft. to 635 ft.	Gravel; sand; and cobbles.
635 ft. to 650 ft.	Sand; gravel; and cobbles.
650 ft. to 653 ft.	Sand, fine.
653 ft. to 660 ft.	Sand, fine; some cobbles.
660 ft. to 677 ft.	Sand, coarse; and fine gravel.
677 ft. to 690 ft.	Sand, fine to medium.
690 ft. to 699 ft.	Sand, fine to medium; occasional cobble and streaks of gravel.
699 ft. to 733 ft.	Sand, very fine; and silt; occasional cobble.
733 ft. to 737 ft.	Sand, very coarse; and small gravel.
737 ft. to 742 ft.	Sand, medium.
742 ft. to 750 ft.	Sand, fine to medium; occasional cobble and streaks of coarse sand.
750 ft. to 760 ft.	Sand, fine; and cobbles.
760 ft. to 775 ft.	Sand, fine; and some cobbles.
775 ft. to 785 ft.	Sand; some small streaks of brown clay; occasional cobble.
785 ft. to 790 ft.	Sand and brown clay; some cobbles.
790 ft. to 798 ft.	Clay, brown; and sand; some cobbles.
798 ft. to 805 ft.	Sand and clay; some cobbles.
805 ft. to 810 ft.	Clay and sand; some cobbles.
810 ft. to 825 ft.	Clay, brown; and sand; occasional cobble.
825 ft. to 875 ft.	Rock, granitic, hard drilling.

"DEL ROSA NO. 1"

1S/4W Sec. 13

Drilled: (?)

Depth: 2460 ft.

GEOLOGIC LOG

0 ft. to	46 ft.	Soil.
46 ft. to	51 ft.	Gravel.
51 ft. to	80 ft.	Decomposed granite washed.
80 ft. to	116 ft.	Sand and gravel.
116 ft. to	156 ft.	Decomposed Red granite wash.
156 ft. to	294 ft.	Conglomerate.
294 ft. to	430 ft.	Hard formation, mostly lime.
430 ft. to	440 ft.	Red shale, showing gas and oil.
440 ft. to	450 ft.	Good showing, live oil.
450 ft. to	460 ft.	Change showing lime formation.
460 ft. to	471 ft.	Hard sandy shale.
471 ft. to	480 ft.	Light oil showing.
480 ft. to	510 ft.	Light oil showing.
510 ft. to	525 ft.	Trifle hard.
525 ft. to	535 ft.	Sandy shale.
535 ft. to	580 ft.	Sand, fine showing of live oil.
580 ft. to	625 ft.	Fernando oil sand, good showing of oil.
625 ft. to	745 ft.	Good gas pressure, showing oil.
745 ft. to	760 ft.	Hard sand shale.
760 ft. to	790 ft.	Hard sand shale.
790 ft. to	825 ft.	Sticky blue clay.
825 ft. to	845 ft.	Blue shale.
845 ft. to	900 ft.	Sticky blue shale, showing oil and gas.
900 ft. to	1000 ft.	Blue, brown and black shale showing.
1000 ft. to	1020 ft.	Blue shale.
1020 ft. to	1300 ft.	Blue shale.
1300 ft. to	1640 ft.	Blue sand shale.
1640 ft. to	1885 ft.	Coarse sand, blue and white.
1885 ft. to	1900 ft.	Sand fine.
1900 ft. to	1925 ft.	Oil sand.
1925 ft. to	1975 ft.	Sand shale.
1975 ft. to	2000 ft.	Hard sand shale.
2000 ft. to	2035 ft.	Coarse sand with conglomerate showing.
2035 ft. to	2045 ft.	Sandy blue shale.
2045 ft. to	2078 ft.	Hard blue shale.
2078 ft. to	2148 ft.	Sand and blue shale.
2148 ft. to	2180 ft.	Oil sand.
2180 ft. to	2207 ft.	Blue sand shale.
2207 ft. to	2235 ft.	Fine blue sand.

GEOLOGIC LOG

2235 ft. to 2265 ft. Sandy blue shale.
2265 ft. to 2355 ft. Light blue shale.
2355 ft. to 2380 ft. Gray sand shale showing oil.
2380 ft. to 2460 ft. Sandy shale.

"INLAND NO. 1"

1N/4W Sec. 18

Depth: 802 ft.

Drilled: 1949

GEOLOGIC LOG

0 ft. to 18 ft.	Soil.
18 ft. to 80 ft.	Sand and gravel with boulders.
80 ft. to 100 ft.	Coarse gravel.
100 ft. to 115 ft.	Coarse gravel with thin streaks of clay.
115 ft. to 127 ft.	Coarse gravel.
127 ft. to 162 ft.	Sand and gravel.
162 ft. to 186 ft.	Redish-brown clay.
186 ft. to 400 ft.	Coarse sandy gravel.
400 ft. to 491 ft.	Hard sandy gravel.
491 ft. to 525 ft.	Hard sandy gravel.
525 ft. to 561 ft.	Hard blue shale.
561 ft. to 564 ft.	Lime.
564 ft. to 595 ft.	Hard greenish sandy siltstone.
595 ft. to 600 ft.	Sandy shale, Lignite and gas shows.
600 ft. to 603 ft.	Blue shale, Lignite and gas shows.
603 ft. to 606 ft.	Limey shale, Lignite and gas shows.
606 ft. to 636 ft.	Greenish grayish hard Sandstone, Lignite and gas shows with soft streaks.
636 ft. to 651 ft.	CORE #1 1 ft. 0 inches Greenish sandy shale (fault gouge). 9 ft. 0 inches Blue gray shale with a slickensides and fault gouge.
651 ft. to 671 ft.	CORE #2 Fault gouge and Breccia Blue-black Shale. Matrix with mica schist pebbles.
671 ft. to 691 ft.	CORE #3 -----
691 ft. to 702 ft.	CORE #4 Fault gouge with 0 ft. 2 inches granite boulder(?).
702 ft. to 722 ft.	CORE #5 ----- Lignite and Gas shows at 720 ft.
722 ft. to 742 ft.	CORE #6 0 ft. 6 inches white Fault gouge. 0 ft. 6 inches Green igneous boulder(?). 2 ft. 0 inches Fault gouge (blue-black shale).

GEOLOGIC LOG

742 ft. to 746 ft. CORE #7 -----
746 ft. to 784 ft. Drilled Hard re-cemented granite wash.
784 ft. to 802 ft. CORE #8 Granodiorite consolidated into
schist (Microscopic analysis).

(Though the above geologic log does not so indicate, a broad interpretation of the electric log (not present) of this well may suggest an alluvial thickness of only approximately 470 ft. at this site.)

NOTE: Electrical log for this well records a maximum temperature of 100°F (assumed to be bottom hole temperature encountered when drilling?).

"DANA #1"

1S/5W-Sec. 26

Depth: 3290 ft.

Drilled: Jan. 1950 - Mar. 1954

Junk in hole - 168 ft. drill pipe, collars,
and bit with top at 3009 ft.

GEOLOGIC LOG

0 ft. to	80 ft.	Sand and boulders.
80 ft. to	85 ft.	Shale gray.
85 ft. to	176 ft.	Sand - gray, med. hard.
176 ft. to	180 ft.	Sand - brown, show of oil and gas.
180 ft. to	208 ft.	Sand - gray, med. hard.
208 ft. to	215 ft.	Sand - brown, soft micaceous.
215 ft. to	228 ft.	Sand - gray, med. hard.
228 ft. to	324 ft.	Conglomerate - med.(?) soft fine gravel.
324 ft. to	330 ft.	Sand - brown, med. hard, oil show.
330 ft. to	373 ft.	Conglomerate - med.(?) soft.
373 ft. to	378 ft.	Sand - hard.
378 ft. to	434 ft.	Conglomerate - med. soft.
434 ft. to	436 ft.	Sand - brown, show of oil.
436 ft. to	496 ft.	Sand - gray, med. soft, water.
496 ft. to	512 ft.	Sandy lime-gray, med. hard.
512 ft. to	514 ft.	Sandy lime-gray, hard.
514 ft. to	662 ft.	Conglomerate and clay - brown and blue.
662 ft. to	665 ft.	Sand - brown, show of gas.
665 ft. to	700 ft.	Sand - brown, hard.
700 ft. to	742 ft.	Lime - brown, sandy shale.
742 ft. to	745 ft.	Granite - gray.
745 ft. to	815 ft.	Granite - mica and quartz, (?).
815 ft. to	816 ft.	Brown sand - oil show, (?).
816 ft. to	931 ft.	Granite - blue grey.
931 ft. to	933 ft.	Shale - brown.
933 ft. to	1546 ft.	Granite - oil show at 944 ft.
1546 ft. to	1580 ft.	Granite dirite.
1580 ft. to	1660 ft.	Granite dirite and gray lime hole making (?).
1660 ft. to	1674 ft.	Granite dirite - black gray.
1674 ft. to	1714 ft.	Tough brown shale.
1714 ft. to	1724 ft.	Shale - soft.
1724 ft. to	1728 ft.	Shale - soft, show of oil.
1728 ft. to	1780 ft.	Granite dirite - black and gray.
1780 ft. to	1807 ft.	Limestone quartz and dirite.
1807 ft. to	1890 ft.	Sandy limestone - hard.
1890 ft. to	1933 ft.	Green shale - carrying oil.
1933 ft. to	1937 ft.	Green granite.
1937 ft. to	1947 ft.	Limestone quartz.
1947 ft. to	1986 ft.	Shale - brown, carrying oil.
1986 ft. to	1988 ft.	Sand - brown, carrying oil.

GEOLOGIC LOG

1988 ft. to 2221 ft.	Granite dirite - blue gray.
2221 ft. to 2224 ft.	Green sand - carrying oil.
2224 ft. to 2587 ft.	Green granite dirite.
2587 ft. to 2646 ft.	Limestone - oil show.
2646 ft. to 2650 ft.	Wash (?) - boulders and rock.
2650 ft. to 2780 ft.	Limestone - oil show.
2780 ft. to 2794 ft.	Limestone quartz.
2794 ft. to 2870 ft.	Green granite - brown, show (?).
2870 ft. to 2886 ft.	"Course" green sand carrying oil.
2886 ft. to 3080 ft.	Limestone quartz dirite.
3080 ft. to 3090 ft.	Green sticky shale carrying oil.
3090 ft. to 3144 ft.	Green granite dirite.
3144 ft. to 3170 ft.	Limestone quartz.
3170 ft. to 3287 ft.	Limestone quartz hard.
3287 ft. to 3290 ft.	Oil sand - brown.

(A broad interpretation derived from the correlation of the above non-technical geologic log and the electrical log (not presented) for this well suggests that basement complex materials were encountered in this well at approximately 740 ft.).

SELECTED REFERENCES FOR THE SAN BERNARDINO AREA, CALIFORNIA,
GEOTHERMAL RESOURCE AREAS

By

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1981

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WATER TABLE ELEVATION AND HISTORIC LIMITS OF ARTESIAN ZONE IN THE SAN BERNARDINO AREA, CALIFORNIA

1981
Compiled by L.G. Youngs

EXPLANATION

- Water table elevation contour (relative to mean sea level). Dashed where estimated. After Laverly (1973) with slight modification.
- Limits of artesian zone. Each boundary labeled with date and reference. The San Bernardino Municipal Water Department, 1981, 0-15 feet depth to water (boundary) has been slightly modified.
- Designated geothermal resource area (this study).

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INDEX MAP

(Compiled from the above
7.5 minute topographic quadrangles.)

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

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF CONSERVATION

SAN BERNARDINO
GEOTHERMAL STUDY
PLATE 4

LOCATION MAP OF MAGNETIC TRAVERSES IN THE SAN BERNARDINO AREA, CALIFORNIA

Compiled by
L.G. YOUNGS

1981

SCALE - 1:62,500

CONTOUR INTERVAL 80 FEET

EXPLANATION

FOR ALL THE MAGNETIC TRAVERSES SHOWN ON THE MAP, A MAGNETOMETER READING WAS RECORDED GENERALLY EVERY 100 FEET (30.5 METERS) PACED ALONG THE TRAVERSE. PACED DISTANCE BETWEEN THE CROSS-BARS IS 1000 FEET (305 METERS). TRAVERSES LABELED WITH AN "M" ARE FROM FIFE, D.L., AND OTHERS, 1976, PLATE 8. TRAVERSES LABELED WITH "SBM" WERE MADE DURING THE CDMG 1980-81 SAN BERNARDINO GEOTHERMAL INVESTIGATION (THIS REPORT). TRAVERSE SBM - 2 WAS MADE PARALLEL TO AND APPROXIMATELY 50 FEET (15 METERS) EAST OF TRAVERSE SBM - 3. FOR MAP CLARITY THE PRECISE LOCATION OF TRAVERSE SBM - 2 IS NOT SHOWN.

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

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF CONSERVATION

SAN BERNARDINO
GEOTHERMAL STUDY
PLATE 5

COMPLETE BOUGUER GRAVITY MAP EASTERN ONE HALF SAN BERNARDINO, CALIFORNIA AND WESTERN ONE HALF REDLANDS, CALIFORNIA 15 MINUTE QUADRANGLES

By
L.G. YOUNGS, G.W. CHASE, R.H. CHAPMAN, and E.H. KISHI

1981

EXPLANATION

GRAVITY CONTOUR INTERVAL - 2 mgal

REDUCTION DENSITY - 2.67 g/cm³

● GRAVITY STATION LOCATION AND
BOUGUER GRAVITY ANOMALY VALUE

--- GRAVITY CONTOUR LINES, DASHED WHERE INFERRED

WITH ADDITIONAL DATA FROM THE FOLLOWING SOURCES:

McWhirter, J.L., 1979, Gravity survey of the San Jacinto Fault Zone through the San Bernardino Valley, San Bernardino, California: University of Redlands, California, Unpublished senior paper, 17 p.

Willingham, C.R., 1968, A gravity survey of the San Bernardino Valley, Southern California: University of California, Riverside, Unpublished M.A. thesis, 96 p.

MAP LOCATION

AREA MAPPED

MAGNETIC NORTH
AND DECLINATION

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

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF CONSERVATION

SAN BERNARDINO
GEOTHERMAL STUDY
PLATE 5

MAP OF HYDROLOGICAL FEATURES AND SELECTED WELLS WITH GRAVITY CONTOURS FOR THE SAN BERNARDINO AREA, CALIFORNIA

Compiled by
L.G. YOUNGS

1981

SCALE - 1:62,500

CONTOUR INTERVAL 80 FEET

EXPLANATION

GRAVITY CONTOUR INTERVAL - 2mgal

REDUCTION DENSITY - 2.67 g/cm³

GRAVITY CONTOUR LINES, DASHED WHERE INFERRED

LOCATION AND NAME OF WELL THAT ENCOUNTERED BASEMENT ROCKS. T.D. - TOTAL DEPTH, D.B. - DEPTH TO BASEMENT ROCKS. THE GEOLOGIC LOGS OF THESE WELLS ARE AT THE END OF APPENDIX C.

DESIGNATED GEOTHERMAL RESOURCE AREAS (THIS REPORT).

HACHURED AND STIPPLED AREAS ARE LIMITS OF OLD ARTESIAN ZONES (AFTER MENDENHALL, 1905).

FAULT TRACE (AFTER FIFE, AND OTHERS, 1976)

WITH ADDITIONAL DATA FROM THE FOLLOWING SOURCES:

McWhirter, J.L., 1979, Gravity survey of the San Jacinto Fault Zone through the San Bernardino Valley, San Bernardino, California: University of Redlands, California, Unpublished senior paper, 17p.

Willingham, C.R., 1968, A gravity survey of the San Bernardino Valley, Southern California: University of California, Riverside, Unpublished M.A. thesis, 96p.

MAP LOCATION

San Bernardino Quad. Redlands Quad.

AREA MAPPED

MAGNETIC NORTH
AND DECLINATION

NA-K-Ca GEOTHERMOMETRY MAP FOR THE SAN BERNARDINO AREA, CALIFORNIA

1981

Showing data developed by:
C. HULL and W. A. ELDERS
University of California, Riverside

With additional data and contouring by:
L. G. YOUNGS
California Division of Mines and Geology

EXPLANATION

● 31°

Well location and Na-K-Ca geothermometry temperature in degrees Celsius (C°).

--- 30°

Approximately located Na-K-Ca geothermometry temperature (C°) contour line. Contour interval 10°C.

INDEX MAP
(Compiled from the above
7.5 minute topographic quadrangles.)