D Foley

DRILLING ADDENDUM

to

RESOURCE ASSESSMENT OF LOW- AND MODERATE-TEMPERATURE GEOTHERMAL WATERS IN CALISTOGA, NAPA COUNTY, CALIFORNIA

Report of the Second-year, 1979-80 of the
U.S. Department of Energy-California State Coupled Program
for
Reservoir Assessment and Confirmation

by

Gary C. Taylor 1/
C. Forrest Bacon 1/
Rodger H. Chapman 2/
Gordon W. Chase 2/
Hasmukhrai H. Majmundar 3/

May 1981

This work was performed under Grant No. DE-FG03-79ET27035
for the U.S. Department of Energy, Division of Geothermal Energy,
by the California Department of Conservation
Division of Mines and Geology
Addendum to OFR 81-13 SAC

1/ Geologist, California Division of Mines and Geology
2/ Geophysicist, California Division of Mines and Geology
3/ Geochemist, California Division of Mines and Geology

DISCLAIMER

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

X 1/25

STATE OF CALIFORNIA—THE RESOURCES AGENCY

EDMUND G. BROWN JR., *Governor*

DEPARTMENT OF CONSERVATION
DIVISION OF MINES AND GEOLOGY
SACRAMENTO OFFICE
610 BERCUT DRIVE
SACRAMENTO, CA 95814
(Phone 916—323-8554)

January 15, 1982

Gerald Katz
Program Manager
Geothermal Energy Division
Department of Energy SAN
1333 Broadway
Oakland, CA 94612

Dear Mr. Katz:

As a follow up to my April 16, 1981, letter of Transmittal for our final second year report (1979-80) titled "Resource Assessment of Low-and Moderate-Temperature Geothermal Waters in Calistoga, Napa County, California", I am sending herewith ten copies of the addendum for that report. The title is "Drilling Addendum to Resource Assessment of Low-and Moderate-Temperature Geothermal Waters in Calistoga, Napa County, California", and it describes the results of our Calistoga drilling operations that were conducted by California Division of Mines and Geology after preparation of the final report. This completes our submittal of reports under terms of Grant Number DE-FG03-79ET27035 and you should now have received all products called for under the terms of that grant.

The drilling addendum has previously received patent clearance from your office following submittal of a preliminary copy for that purpose.

Sincerely,

C. Forrest Bacon

C. Forrest Bacon
Geothermal Officer

Enclosures

cc: Bob Gray (5 cys)
Federal Building, MS: 3344
12th and Penn Avenue, N.W.
Washington, D.C. 20461

✓Duncan Foley (1 cy)
University of Utah Research Institute
420 Chipeta Way, Suite 120
Salt Lake City, Utah 84108

W.A. Duffield (1 cy)
Geothermal Coordinator
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025

DRILLING ADDENDUM

to

RESOURCE ASSESSMENT OF LOW- AND MODERATE-TEMPERATURE GEOTHERMAL WATERS IN CALISTOGA, NAPA COUNTY, CALIFORNIA

Report of the Second-year, 1979-80 of the
U.S. Department of Energy-California State Coupled Program
for
Reservoir Assessment and Confirmation

by
Gary C. Taylor 1/
C. Forrest Bacon 1/
Rodger H. Chapman 2/
Gordon W. Chase 2/
Hasmukhrai H. Majmundar 3/

May 1981

This work was performed under Grant No. DE-FG03-79ET27035
for the U.S. Department of Energy, Division of Geothermal Energy,
by the California Department of Conservation
Division of Mines and Geology
Addendum to OFR 81-13 SAC

1/ Geologist, California Division of Mines and Geology
2/ Geophysicist, California Division of Mines and Geology
3/ Geochemist, California Division of Mines and Geology

CONTENTS

PREFACE

This addendum report presents the results of the California Division of Mines and Geology (CDMG) drilling program at Calistoga, California, which was the final geothermal-resource assessment investigation performed under terms of the second year contract (1979-80) between the U.S. Department of Energy (DOE) and the CDMG under the State Coupled Program. This report is intended to supplement information presented in CDMG's technical report for the project year, "Resource Assessment of Low-and Moderate-Temperature Geothermal Waters in Calistoga, Napa County, California."

During the investigative phase of the CDMG's Geothermal Project, over 200 well-driller's reports were obtained from the Department of Water Resources (DWR). It was hoped that the interpretation and correlation of these logs would reveal the subsurface geology of the Upper Napa Valley and also provide a check for the various geophysical surveys that were performed in the course of the study. However, these DWR driller logs proved to be inadequate due to the brief, non-technical, and erroneous descriptions contained on the logs. As a result of the lack of useable drill-hole data, and because information was desired from deeper horizons, it became evident that drilling some exploratory holes would be necessary in order to obtain physical evidence of the stratigraphy and aquifers in the immediate Calistoga area.

Pursuant to this objective, a total of twelve sites were selected--four under jurisdiction of Napa County and eight under jurisdiction of the City of Calistoga. A moratorium is currently in existence within Napa County on most geothermal drilling, and environmental and time constraints precluded CDMG from obtaining the ncessary site permits within the county. However, a variance was applied for and obtained from the City of Calistoga to allow CDMG to drill within the city limits. With this areal constraint and also funding limits in mind, six drilling sites were selected on the basis of (1) proximity to areas where geophysical surveys had been performed, (2) accessibility of the site for drill rig setup, and (3) favorability for obtaining the maximum information possible concerning the geology and the resources. Necessary landowner permission and permits were secured for these sites, and actual drilling began on December 17, 1980.

Drilling was terminated on February 4, 1981, with the completion of three holes that ranged in depth from 205 to 885 feet. Use of a relatively new drilling technique called the Dual Tube Method enabled the collection of precise subsurface data of a level of detail never before obtained in the Calistoga area. As a result, a totally new and unexpected picture of the geothermal reservoir conditions there has been obtained, and is outlined in this addendum report.

DRILLING ADDENDUM

SUMMARY AND CONCLUSIONS

The Calistoga test drilling program, which was conducted as the final phase of the CDMG resource assessment of low and moderate temperature geothermal waters in the Calistoga area, has revealed a new and unexpected picture of subsurface conditions and has greatly influenced the results of the resource assessment. Of greatest importance was the discovery that as many as seven aquifers are present in the vertical section and that the aquifers are separated by thin to very thick layers of moist to dry volcanic ash, partly altered to clay. Also of great importance was the finding that basement rocks in many parts of the valley are much deeper than expected and that the configuration of the bedrock surface is apparently highly irregular. A hot water bearing zone of scoriaceous-material underlying a dacitic-tuff unit was encountered in the bottom of two of the three drill holes and may provide an as yet untapped deep geothermal resource along the southwestern margin of the valley.

Evidence obtained from the drilling program has shown that the thickness of the vertical section of sediments that contain, or may contain, the geothermal resource may be approximately double the conservative estimate made in the main volume of the Calistoga report, with an actual aquifer yield of >25°C water estimated at 13,500 - 20,000 acre feet. This estimate has resulted from the development of accurate information on location and thickness of geothermal aquifers in the vertical geologic section, a process that can be accomplished only through drilling.

Geochemistry from the drilling program has largely corroborated evidence obtained previously. It has shown that waters above the geothermal zone, that begins at approximately 120 feet below the ground surface, are fresh, potable, and contain almost no deleterious substances. Waters in the geothermal zone, below 120 feet, on the other hand, contain relatively high concentrations of minerals, including boron, that are deleterious to plant growth and may cause scaling and other problems. Although too few holes were drilled to make it possible to prove the usefulness of water chemistry in determining geologic structure, the evidence obtained appeared favorable and tended to corroborate earlier conclusions discussed in the main Calistoga report volume.

Finally the drilling program has shown that geothermometric temperatures are an accurate means of predicting maximum temperatures and that measured temperatures compare favorably with geothermometric temperatures in the Calistoga area.

The geothermal test drilling program has proven a great asset to the Calistoga resource assessment program and has made possible a far more accurate assessment than would otherwise have been possible. The statement that "you can't prove the resource until you drill" has once again been proven to be accurate.

DRILLING PROGRAM OBJECTIVES, RATIONALE

It has long been a recognized fact that in geothermal resource assessment, as in other types of subsurface exploration, the only way to finally test the presence, quality, and quantity of the resource is to drill a hole or holes to prove it is there. Although the Calistoga area is not "unproven" with respect to geothermal resources (there are many geothermal wells located throughout the area), it was apparent at the onset of CDMG's studies that too little was known about the subsurface conditions that control the geothermal resource in the Calistoga area. Evidence for this was seen in the unexplained relatively close proximity of hot and merely warm wells, and in wide variations of flow from closely spaced adjacent wells.

In order to assure the best possible assessment of the Calistoga geothermal resource within the funding available, CDMG undertook a drilling program designed to gain the maximum information, per dollar spent, about the reservoir, the reservoir conditions, and the resource itself. Some of the information that was expected to be obtained from the drilling program included the following:

- A detailed and accurate lithologic description of the vertical geologic section in the reservoir area (logs for previously drilled holes were unobtainable or inaccurate).
- Correlation of geologic units between holes to obtain a good geologic cross section of the reservoir area.
- Correlation of previously obtained geophysical data with observed data from the wells.
- Thickness of the reservoir sediments and the number, thickness, continuity, and quality of the contained aquifers.
- Water quality, temperature, and geothermometry for individual aquifers.
- Flow data for the aquifers.

- Geochemical correlations that could help unravel the subsurface geologic structural picture.
- Overall, information that could be used to help make the final assessment of the geothermal resource at Calistoga.

In order to obtain the best possible results from up to six holes that could be completed in the drilling program, sites for 12 drill holes were selected at strategic locations throughout the resource area, including six preferred sites and six alternate sites. These sites were selected to provide the best possible cross section of the valley and reservoir area and, for correlation purposes, were located immediately adjacent to previously completed CDMG geophysical study alignments. One hole was chosen to provide information on the maximum thickness of the alluvial section of the valley while others were located to test the areas of higher temperature and maximum geothermal fluid flow. The complete list of hole sites chosen, together with the rationale for the selection of each site, is contained in the main Calistoga report volume.

The sites were chosen without consideration for political boundaries; some within the Napa County jurisdictional area and some within the city limits of Calistoga. Unfortunately, environmental reporting and permitting requirements, for the sites located in the county jurisdictional area, could not be completed within the time frame required to allow for completion of the drilling program on schedule. A variance was applied for and obtained from the City of Calistoga to drill six holes located within the city limits (Figure 1). Although some of these were alternates to the preferred holes, it was expected that they would still provide the maximum desired information.

During the course of setting up the program to obtain bids from drilling contractors for completion of the work at Calistoga, CDMG investigated the merits of the dual tube drilling technique, in which reverse circulation is used and the casing advances with the drill bit. It was decided that the advantages of the technique--providing uncontaminated water and lithologic samples--could be beneficial to the CDMG program (see Appendix A). The contractor who submitted the low bid based his bid on the use of dual tube equipment. His bid was accepted by CDMG, and he was given the order to proceed with the drilling.

The decision was made first to drill the hole that would penetrate the thickest sedimentary section in the valley (Arroyo #1) and thus to obtain information that would be used for correlation purposes with all other drill holes drilled in the program. Following that, holes were to be drilled to provide information for a cross section paralleling the geophysical section that crosses the valley in a northeast-southwest direction (Moore #1, LES 9). The other holes (LES 4-6) were designed to provide a section normal to the first and to be used for possible flow tests. These holes were sited to provide additional information adjacent to one of the two hottest areas in the valley.

Drilling of up to six holes within the funding availalbe was predicated upon "best of all possible worlds" drilling conditions, and based on information provided by the drilling contractor as to what might be expected regarding drilling speeds. As is almost universally the case in drilling operations, the best of all possible worlds conditions did not prevail, and drilling, which was done on a time and materials basis, was limited to three holes in order to stay within available funding. A complete account of the relative merits of the drilling system together with an analysis of some of the problems encountered is included in Appendix A.

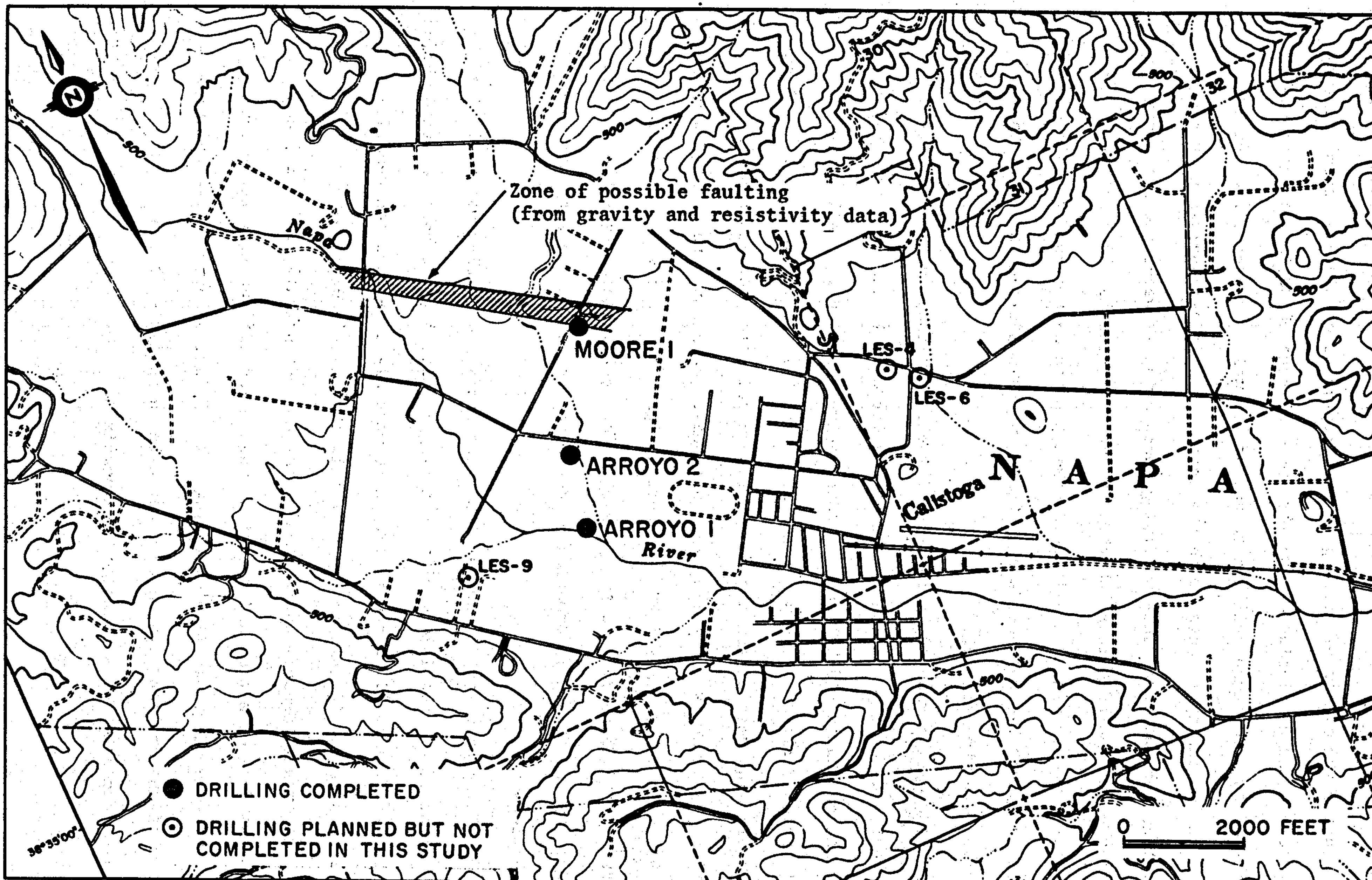


Figure 1. Drilling Addendum for Second Year Report "Resource Assessment of Low-and Moderate-Temperature Geothermal Waters in Calistoga, Napa County, California", drill hole location map.

DRILL-HOLE-SITE SELECTION AND SITE DESCRIPTIONS

Three holes were drilled by the Division of Mines and Geology in the Calistoga drilling program: These included Arroyo #1, 205 feet; Arroyo #2, 885 feet; and Moore #1, 562 feet. The locations for the holes are shown on Figure 1. All three are sited on the alluvium of the flat valley floor.

Arroyo #1

This site was located approximately 100 feet east of the Napa River on a farm road on the Arroyo property, a 37 acre vineyard. Important considerations in selecting this site were: (1) the site was near the projected deepest part of the Upper Napa Valley basin and would provide a deep alluvial section before encountering Franciscan Basement; (2) the site was to the west of a major trend of known hot water wells and would provide lateral control in that direction for known hot water; and (3) it was expected that a hole having a depth of about 1,000 feet (a limit imposed by State Division of Oil and Gas restrictions) would provide a maximum amount of useful correlative information.

This was the first site drilled. Drilling commenced on December 18, 1980, with the drilling of 50 feet and the setting of 50 feet of 8½ inch I.D. conductor pipe. This pipe was necessary due to the landowner's request and a regulatory stipulation from the California Division of Oil and Gas (CDOG) that a blow-out preventor be installed. This stipulation from CDOG was subsequently rescinded upon field inspection by DOG personnel of the dual-tube rig, and was not required for other drill holes. Unfortunately, this conductor pipe, in conjunction with a near surface standing water level, proved to be a detriment to completion of this hole. Each time a rod change was made, the conductor pipe would immediately fill with water, and, upon restart of drilling, large volumes of water would be blown out of the hole and onto the area around the rig. Because this water was suspected of having high boron content and because, with the onset of the winter rains, it would not be possible to control its flow on the surface, the hole was abandoned at a total depth of 205 feet on December 24, 1980.

Arroyo #2

This site is located upon the same piece of property as Arroyo #1 but was sited on firm ground adjacent to Grant Street. Arroyo #2 is 1200 feet east of Arroyo #1 and was intended to substitute for the premature abandonment of that site.

Drilling commenced on December 29, 1980. The hole was abandoned on January 23, 1981, at a depth of 885 feet. The drilling of this hole was very slow and time consuming due to the continual plugging of the tools by very plastic clays (altered volcanic ash). The tools were plugged a total of eight times at respective depths of 242, 442, 445, 622, 742, 802, 863, feet. The hole was abandoned at 885 feet due to very rapid increase in rod torque which signaled certain rotational freeze-up of the drill pipe, had drilling been continued. A wealth of new and unexpected information was obtained from this hole.

Moore #1

This site is located at 2150 Greenwood Avenue within a 5 acre parcel owned by Mr. Tex Moore. The site was adjacent to a traverse along which gravity, magnetic, and resistivity geophysical surveys had been performed. The hole was planned in order to provide stratigraphic control for the geophysical surveys and to provide a correlative section that could be used in conjunction with the Arroyo #2 geologic log in an attempt to produce a geologic cross-section of the Upper Napa Valley.

Drilling commenced on January 27, 1981. The hole was abandoned on February 4, 1981, at a depth of 562 feet. The same problems encountered in drilling Arroyo #2 were also present in the Moore #1 hole; namely, the continual plugging of the tools by very plastic clay (altered volcanic ash). Unfortunately, termination of this hole, because of a funding shortfall, resulted in abandonment of the hole before it intersected Franciscan basement rocks. However, much very useful information was obtained from this hole, particularly with respect to stratigraphy and probable attitude of beds and with regard to confirmation of geothermal resource projections.

INTERPRETATION OF RESULTS

Ground-Water Geochemistry

As was previously mentioned, all aquifers encountered in the Arroyo #1 and #2 and the Moore #1 drill holes were sampled. The chemical analysis of 26 water samples taken at various depths from the 3 drill holes are shown in Table C-1, Appendix C. With only two exceptions, all of the water samples are classified as being of sodium chloride water type, based upon the relative abundance of chemical constituents.

The two exceptions, samples M-016-81 and M-017-81, which were classified as being of calcium-bicarbonate water type, were produced from two shallow, hand dug wells immediately adjacent to the Moore #1 drill site. These samples were taken due to problems encountered upon the initiation of drilling and the inability to produce an uncontaminated shallow water sample from the Moore drill hole (refer to Drill Hole Log in Appendix B). The log shows that these two samples came from a shallow (perched?), surficial stream channel deposit that is probably easily recharged by precipation and the resultant ephemeral runoff. In addition to being of a calcium-bicarbonate water type, both samples had almost non-existant boron content (.2 and .4 ppm) and a low temperature 12-13°C. These temperatures, which are anomalous in themselves, would tend to indicate a recent meteoric source for this water.

The remaining 24 water samples are of a sodium chloride water type. Inherent with this water type, boron concentration, and SAR (sodium adsorption ratio) values are characteristically high, RSC (residual sodium carbonate) values are above 2.00 meq/lt. and high iron values were noted. The delineation of sodium chloride water bearing aquifers with depth tends to support several of the preliminary interpretations given in the first report, to note:

(1) The existance of sodium chloride water types with depth probably indicates a hot-water dominated hydrothermal system of volcanic origin, whereby deep-percolating meteoric water and possibly water of other origins becomes involved in a hydrothermal system of high terrestrial heat flow associated with a deep magmatic source (White, 1957). This water is heated to steam containing alkali halides in solution;

is subsequently circulated within the hydrothermal, ground-water system; and, upon condensation at or near the surface ofthe earth, yields sodium chloride water (Faye 1971).

(2) There appeared to be a minor relationship between water quality and depth. Overall, all of the aquifers sampled were of poor water quality, but water quality (measured as TDS) appeared to deteriorate with depth, although the highest boron reading recorded, 17.3 ppm, occurred at a depth of 664 feet in the Arroyo #2 drill hole; the range of boron content for all of the geothermal water samples was from 10-17 ppm. This high range of boron would preclude the use of any of these aquifers for commerical irrigation and the high sodium concentrations may be above the limits (270mg/1) recommended by the Environmental Protection Agency for public water supplies.

(3) Water temperatures (refer to Plate 1) show an overall increase in relation to depth. However, several interesting temperature anomalies were delineated. In particular, temperature regressions were noted at depths of 130-170 feet, 475-485 feet, and 620-625 feet in the Arroyo #2 hole, and at a depth of 325-515 feet in the Moore #1 hole. All these temperature gradient regressions, with one exception, occur at the boundaries of dry zones and provide supportive physical evidence of the fact that stratiform aquifer barriers exist in the subsurface of the Upper Napa Valley. However, a temperature "spike" recorded at a depth of 622 feet in the Arroyo #2 hole, is not readily explainable by a confining lithologic unit, for it occurred within a high volume water-producing zone.

The following is a brief enumeration of the interpretations and conclusions that were reached from the Calistoga geochemical investigations, including those that are described in the main volume of the Calistoga report and those that have resulted from the drilling program. An independently funded report on the water chemistry of the Calistoga area (Majmundar, in preparation) will describe in detail the findings that lead to these conclusions.

1. The main structural break is interpreted as a fault parallel to the axis of the valley floor, with other smaller faults perpendicular to this main break

2. Geothermal waters in each of the three wells, Arroyo #1, Arroyo #2, and Moore #1, are rich in chloride, which implies a hot-water system rather than a vapor-dominated system.
3. The presence of high chloride concentration and higher SAR and RSC values make these waters unfit for irrigation of most crops and for other domestic uses.
4. The maximum subsurface temperature for the geothermal reservoir at Calistoga seems to be on the order of 140°C.
5. Deleterious subtances such as boron are associated only with the sodium-chloride type of waters in the Calistoga area.
6. As a whole, sodium-chloride type waters in Calistoga have the highest temperatures, maximum SAR, RSC, and TDS. Moreover, they represent the deep water reservoir of Calistoga.

Stratigraphy and Structure

As shown on the three lithologic drill-hole logs and depicted on the interpretive cross section (Plate 1), excellent stratigraphic correlation between the drill holes was made possible by the recovery of distinctive, uncontaminated samples via the dual tube drilling method. The geologic cross section (Plate 1) is projected along a northeast-southwest plane approximately perpendicular to the axis of northwest trending Upper Napa Valley. Horizontal scale is 1"=100' and vertical scale is 1"=25'.

The Upper Napa Valley is a shallow basin, underlain by a thick section of Quaternary alluvial sediments and Plio-Pleistocene pyroclastic stratified rocks (Sonoma Volcanic) that dip at 9° southwest. Lower units of Sonoma Volcanic rocks are comprised of dacitic ash flow tuffs that typically vary only in degree of induration. These ash flow tuffs are intercalated with volcanic ash units of aerial deposition and minor sedimentary facies of volcanic debris.

The upper dacitic ash flow tuff is overlain by a small sedimentary gravel unit that was correlative between the drill holes and is overlain in turn by volcanic ash. This gravel horizon indicates a minor hiatus in volcanic activity with resultant development of a brief depositional alluvial surface. In turn, the pyroclastic units are overlain by an alluvial section of flood plain and channel deposits that are intercalated with minor aerial deposits of volcanic ash.

The underlying pyroclastic ash flow tuffs and volcanic ash deposits all show a very consistent 9° dip to the southwest. Plate 1 shows a selection of 8 individually identified pyroclastic units that were found to be correlative between the Arroyo #2 and Moore #1 drill holes. Variability of thickness for these 8 pyroclastic units, ranged from 292 feet at the Moore #1 site decreasing to 225 feet at the Arroyo #2 site. This variability is almost wholly accounted for by the dacitic ash flow tuffs in the lower section, for the overlying ash falls are very consistent in total thickness. This east to west decrease in ash flow tuff section is interpretated as follows: (1) these ash flow tuffs originated from an eruptive center to the north or east, and (2) these ignimbritric flows were deposited on a nearly level ground surface, with vertical thickness and sorting a function of distance from this eruptive source.

As mentioned earlier, drilling was terminated before Mesozoic rocks were encountered in either drill hole, but based on surficial outcrops of Franciscan rocks along the Upper Napa Valley eastern margin, and the failure of a nearby deep (+2000 feet) geothermal exploration hole to hit Mesozoic Rocks, it is interpretated that the pre - Sonoma Volcanic basement surface was one of highly variable relief. If this summation is correct, then the consistancy of the pyroclastic depositional surface would tend to indicate either (1) that an extensive section of underlying pyroclastric and/or alluvial sediments had established a stable depositional baseline prior to the eruption of the dacitic ash flow tuffs, or (2) that the eastern valley margin is coincident with a major fault and the valley is a downdropped graben block. Geophysical data does not indicate the latter, but does tend to support a deepening structural basin plunging to the southwest.

Radiometric ages of the youngest tuffs and flows that erupted in the Sonoma Volcanic field cluster in the range 3.0 to 4.0 million years (Sarna-Wojoicki, 1976). This cluster of dates defines a maximum age for a late Plio-cene to early Pleistocene orogeny that deformed and uplifted the formations containing the volcanic units. This Plio-Pleistocene structural deformation is believed to be responsible for the 9° dip of the Sonoma Volcanics pyroclastic units of the southwest.

Development of this deformation and uplift led to massive erosion of the volcanic units comprising the highlands and deposition of thick sections of alluvial sediments in structural depressions. The eastward shift of progressively younger eruptive units from the Sonoma Volcanics field at the western margin of the Great Valley suggest that uplift and volcanism were proceeding simultaneously (Sarna-Wojoicki, 1976).

Thus the thick section of alluvial sediments shown on the logs as being comprised wholly of volcanic detritus may well represent this subsequent period of mass wasting and depositional adjustment. As shown on the geologic cross-section, major alluvial units are intercalated with altered volcanic ash units of probable aerial origin. These distinctive ash falls may well represent the volcanic fallout of material originating from eruptive centers outside of the immediate Napa Valley area.

The thick section (30 feet) of silty blue clay logged in the Arroyo #2 drill hole between the depths of 290 and 300 feet probably represents an alluvial accumulation of reworked volcanic ash that was deposited as a flood plain and/or channel deposit. Ommission of this thick correlative unit in the Moore drill hole can best be explained by the striping of this volcanic material from an active erosional surface at the Moore site and deposition of this volcanic ash in a structual depression lying to the west.

A stabilization of base level is represented by the two correlative silty clays (altered volcanic ash) found in the upper 200 feet of the three drill holes. The respective depths of these ash fall layers are very consistent, and represent deposition on a land surface similar to that present under current geomorphologic conditions in the Upper Napa Valley. These uppermost volcanic ash units may well represent Quaternary volcanism in the Clear Lake Volcanic field. The Clear Lake Volcanic field (Anderson, 1936; Brice, 1953; Sarna-Wojoicki, 1976; Hern, Donnelly and Goff, 1975; Sims and Rymer 1975) northeast of the Sonoma Volcanic field was active during Pliocene and Quaternary time and continued up to Holocene time. The Clear Lake Volcanics consist of basalt, andesite, dacite, and rhyolite; they occur as domes, flows, and pyroclastic deposits in a structurally and chronologically complex sequence (Hearn, Donnelly and Goff, 1975). The youngest ash recognized in a core from Clear Lake is about 10,000 years old (core 7, Sims and Rymer, 1975). Thus, the fine-grained ash falls preserved in the upper alluvial section may represent Late Holocene Clear Lake Volcanic activity.

Hydrology

The alluvial and pyroclastic units comprising the stratigraphy of the Upper Napa Valley are the primary factors controlling the movement of groundwater through the subsurface.

Highly permeable alluvial sands and gravels are interbedded with less permeable to impervious volcanic units, thus causing groundwater to migrate through a complex system of aquifers. The alluvial units of gravels and sands are probably not continuous for any great lateral extent, for these lenticular and cutoff beds formed in a fluvial environment, were dissected, and then inundated by subsequent floodplain and channel deposits. Within a specific vertical section, development of water would be dependent upon the transmissibility coefficient of the adjacent beds. This fact is exemplified by the water content shown on the logs (Plate 1), where dry zones are shown to occur within facies of highly permeable sands and gravels. Thus, wells located in close proximity to one another and drilled to the same depth could produce highly variable rates of water discharge.

The hydrology picture of the Calistoga area is made more complex by the aforementioned silty clays of altered volcanic ash origin. This pyroclastic material, primarily quartzo-feldspathic glass shards that was aerially deposited, has undergone almost complete alteration to smectite clay materials. The resultant formation of these expansive clays has generated distinct and effective stratiform barriers to vertical migration of groundwater. The expansive and self-sealing properties of this altered pyroclastic debris are proven by the retrieval of completely dry and dusty ash from depths exceeding 850 feet and the abrupt cutoff of water-bearing zones by thinly bedded ash beds less than 6 inches thick.

The drill logs indicate that the effectiveness of these volcanic ash beds as vertical barriers to groundwater movement is dependent upon (1) clay mineralogy, (2) thickness of the ash fall or ash flow tuff units, and (3) lateral continuity of these units. At the least, all altered volcanic ash units are aquitards and several of the thicker units are proven aquicludes.

As has been noted, flowing wells in the Calistoga area are, with few exceptions, hydrothermal and yield sodium chloride water. Noting the relation of silica solubility to water temperature Fournier and Rowe (1966) suggested the possibility that hot sodium chloride water rising from depth, along faults, mixes with downward-percolating cooler water causing the precipitation of silica and the subsequent cementaton of material at the mixing interface. White, Muffler, and Truesdell (1971) indicate that such "self-sealing" phenomena are common in hot-water dominated hydrothermal systems with temperatures in excess of 150°C (302°F). Such activity, taking place over an area of several square miles, could produce a zone of relatively impermeable material that would confine sodium chloride water under a potentiometric head.

Discovery of the subsurface pyroclastic aquitards and/or aquicludes suggests an alternative explanation to the artesian or free flowing properties of numerous hot water wells delineated in the well study of the Calistoga area. The development of a potentiometric surface is dependent upon: (1) the intake or recharge area being at a higher elevation and (2) the existence of confining beds between the recharge and discharge area. Both of these conditions are satisfied by the existence of the pyroclastic units and their expansive clay horizons. Thus, the presence of flowing wells that are discharging hydrothermal water in the Calistoga Study Area is probably due to the combined influence of local confining zones and the geothermally induced density differences of groundwater.

REASSESSMENT OF EARLIER CONCLUSIONS

Results of the drilling program at Calistoga have shown some major discrepancies when compared with the interpretations made from the geophysical data developed during CDMG's pre-drilling program studies. Of particular importance are the estimates of depths to probable basement rocks that were developed during the seismic refraction survey, and of subsurface hot water occurrence based on low resistivity values measured during the electrical resistivity surveys. A discussion of the problems encountered together with a reevaluation and explanation for the discrepancies is given below. Page numbers given in the discussion refer to the appropriate pages in the main annual report volume on the Calistoga geothermal assessment studies.

Seismic Refraction Survey
(p. 67-76, 91-94)

The results of the seismic refraction survey indicated four basic velocity ranges that probably represent different rock units (p. 68). Of these, layer 4 (velocity range, 12,000-14,500 feet per second) was attributed to "probable Franciscan basement rocks" (p. 72), although this velocity range could also represent volcanic flows. The seismic refraction section along Greenwood Avenue (Plate 7, Part C) shows that this relatively high velocity layer is at a shallow depth from the northeastern end of the line at least as far as the 1600 foot mark. From station 1600 to the southwest, the contact between the upper layers and layer 4 (dashed line) is shown to dip generally to the southwest, but this contact is based on data of poor quality.

Moore #1 drill hole, which is located at about station 1800 (Plate 7), was drilled to a total depth of 562 feet. The projection of the Arroyo #2 drill hole, which is at about the 4200 foot mark on this line, was drilled to a total depth of 885 feet. Neither of these drill holes encountered rock that is likely to have a seismic velocity in the range of 12,000 to 14,500 feet per second, with the possible exception of two thin zones of welded tuff found in the lower parts of both holes. However, these welded tuff zones are at much greater depths than the top of layer 4 on the seismic section. Thus, it appears that the dashed line representing layer 4 southwest of the 1600 foot mark (Plate 7, Part C) is not an accurate representation of this layer. However, the apparent dip of this layer in the seismic section is similar to that suggested by geologic units shown in the drill hole logs.

The seismic evidence for the presence of layer 4 on the Greenwood Avenue line is better northeast of the 1600 foot mark (solid line, Plate 7, Part C). The top of layer 4 in this part of the line also has a southwestward component of dip, but this dip is not large enough to account for the failure to find the layer in the Moore #1 drill hole. However, a relatively steep gravity gradient and a resistivity boundary near the location of this drill hole (Plate 7, Parts C and D) may represent a fault or faults in this general area (p. 92). The gravity profile also indicates that if a fault (or faults) is present, the southwestern side has moved downward. If such a fault is located northeast of the drill hole, layer 4 may be offset downward to a depth greater than the total depth of this hole (562 feet).

Electrical Resistivity Survey
(p. 77-94)

In the main Calistoga report, the cause of the low values of electrical resistivity measured in parts of the area near Calistoga was attributed primarily to hot water (p. 77). However, the drilling program has revealed unexpectedly large amounts of clay (altered volcanic tuffs) in the valley. Therefore, it is likely that the observed low-resistivity anomalies are caused by the clay, as well as by the hot water, because clay also is characterized by low values of electrical resistivity.

Hot water may have been the agent responsible for the alteration of the volcanic tuffs to clay. If so, there may be a close association between clay zones and hot water--that is, unless the circulation pattern within the reservoir has changed. However, if clay zones and hot water are not necessarily associated, some low-resistivity anomalies may represent only clay zones.

According to the logs for the Moore #1 and Arroyo #2 drill holes, the geologic units in the upper parts of the holes are relatively flat-lying; however, in the lower sections of the holes, units have a southwestward component of dip. This is generally similar to the pattern of resistivity contours in Plate 7, Part A. Furthermore, the maximum temperatures recorded in the lower parts of these drill holes (159°F at 562 feet in Moore #1, 146°F at 620 feet in Arroyo #2) are close to or within the 20 ohm-feet contours shown in Plate 7, Part A. Thus, there also appears to be a close relationship between the temperature and the resistivity data.

RESOURCE ASSESSMENT

A geothermal resource assessment, by necessity, must be updated, refined, and reevaluated as more data on a particular resource area become available. Hence, some of the material presented below will undoubtedly undergo modification and revision as the low- to moderate-temperature geothermal resource within the Calistoga area undergoes future development and study.

Reservoir Model

The geothermal resource at Calistoga is a hydrothermal convection system, or possibly, a combination of two or more hydrothermal convection systems. Such systems require a heat source, a fluid, and sufficient vertical permeability for hot, low-density fluids to rise and, in most systems, be recharged by descending cooler fluids. Convective circulation of hot fluids is the mechanism that transports energy from the depth to reservoirs near the earth's surface. Hydrothermal convective systems are most likely to develop in areas where there is a residual heat supply related to relatively young volcanics. Lying immediately southwest of the Clear Lake Volcanic field, which had activity into Holocene time, the Upper Napa Valley is bounded by and underlain by Tertiary Sonoma Volcanic pyroclastic deposits that range in age from 3.0 to 4.0 million years (Sarna-Wojcicki, 1976). Thus, the heat source or "driving" mechanism for hydrothermal convection systems at Calistoga is probably the residual heat from the magma chamber or chambers that were the source of these late Pliocene-Pleistocene volcanic extrusives.

The second requirement for a hydrothermal convection system, a fluid, is provided by water, probably of principally meteoric origin, coming into contact with this residual heat source and then ascending along fault or fracture zones in the Calistoga vicinity.

Waring (1915, p. 109) early suggested that faulting was responsible for the hot water seepage at the original hot springs at Calistoga. Faye (1975) inferred the existence of a fault aligned with the topographic axis of the Upper Napa Valley at Calistoga. Others have, at various times, speculated on the existence and location of faulting in the subsurface of the Upper Napa Valley. The geophysical studies conducted by CDMG at Calistoga (reported in the main volume of the Calistoga report) indicated several areas of inconclusive, but possible evidence of faulting associated with areas of known geothermal waters. The physical evidence developed during the drilling program study tends to support this hypothesis with some modification. It now appears that heated meteoric water is ascending fault or fracture zones to near-surface depths. The location of the two areas with the hottest surficial waters, the California Geyser at 135°C, and Pacheteau's at 121°C, are coincident with the projected traces of faults mapped to the east. Both of these areas produce water from drilled wells at shallow depths of 192 feet and 201 feet respectively. Deeper drill holes exist in close proximity to both of these sites, yet only minor temperature increases with depth have been noted. Specifically, two test wells drilled at the Geysers to depths of 787 and 836 feet and located at horizontal distances of 360 and 630 feet, respectively, from the Geyser well, recorded bottom-hole temperatures of 124°C and 118°C. Although the temperature logs of these holes show a continuous increase in temperature with depth, the lower maximum bottom-hole temperature tends to indicate that the hotter water (>135°C) must be confined and has little downslope lateral migration.

Analogously, a well 1890 feet in depth has been drilled near Pacheteau's and again the temperature log shows a continuous increase with depth to a maximum bottom-hole temperature of 134°C. Numerous wells within a quarter mile radius of this well produce waters in the 94°C to 121°C range from shallow depths up to 200 feet. Water temperature shows a rapid falloff to the southwest from the source; this rapid falloff would suggest a cooling phenomenon with lateral migration from a point source.

The localization of hot surficial water at the Geyser and at Pacheteau's may be explained by water from a deep seated convection system coming up along a fault conduit and then outwelling upward along the basal contact between alluvial sediments and pyroclastic debris flows. The geomorphology of the Upper Napa Valley shows a valley undergoing active alluviation, with erosional surfaces protruding through the Quaternary alluvial cover. Both the Geysers wells and Pacheteau's wells are located at the distal ends of erosional ridge structures that are coincident with the current erosional-alluvial interface. The basal contact may provide an avenue for the upward migration of hotter, less dense geothermal fluids, especially in consideration of the expansive and self-sealing properties of the altered volcanic ash fall material (clays) preserved within the alluvial sedimentary section.

Reservoir Volume Analysis

A geothermal reservoir is a complex, heterogeneous volume of rock and water, but most of the thermal energy is contained in the rock. Most volumetric estimates consider the reservoir as a volume of rock and water regardless of permeability and porosity. That is, typically, no attempt is made to distinguish those parts of a reservoir that are permeable and porous from those that are not. However, because of the information developed from the drilling program showing a thick section of impermeable volcanic rocks sandwiched between two water bearing alluvial zones, a zonation of the Calistoga geothermal reservoir was performed.

Area: Plate 12 of the main Calistoga report is a compilation of 133 "hot" water wells located near Calistoga. It is assumed that all of these wells have temperatures greater than or equal to 25°C. An approximate boundary line enclosing the wells was drawn and then modified to fit geophysical and other evidence as appropriate. This boundary serves as an estimate of the lateral extent of the geothermal aquifer pending revisions based on future drill holes. The enclosed area is approximately 5.79 square miles.

Volume: The Upper Napa Valley was divided vertically into four subsurface zones. From top to bottom these are: (1) that volume of alluvial sediments from the surface down to 120 feet in depth, (2) residual volume of alluvial sediments lying below 120 feet and extending to the top of the underlying southwest dipping pyroclastic beds, (3) volume of impermeable pyroclastic material composed wholly of volcanic ash and ash flow tuff and (4) volume of saturated pyroclastic material and/or alluvial sediments underlying Zone 3.

Zone 1 - Based upon information collected during the Calistoga well canvass and the drilling program the top 120 feet of alluvial sediments has been withdrawn from the geothermal reservoir assessment on the basis of water temperature. Although saturated, only very isolated wells produce waters in excess of 25°C from a depth of less than 120 feet in the Calistoga area. Additionally, this depth coincides with the average at which 13 temperature logs (Appendix B) show a markedly high increase in temperature versus depth.

Zone 2 - On the basis of geophysical work and the drilling program, the thickness of alluvium has been shown to progressively increase in a southwesterly direction at an assumed dip of approximately 9°. This dip has been projected to the western margin of the valley, with a resultant maximum section of approximately 1400 feet of alluvial sediments. Thus, the average section for this prism yields an approximate volume of sediments 640 feet deep by the 5.79 square miles of area that probably contains interstitial waters with a temperature greater than 25°C. This gives a tentative mean reservoir thermal energy of 0.52×10^{18} Joules. Kunkel and Upson (1960) used specific-yield values that ranged from 5 to 8 percent to estimate the volume of water in the alluvial aquifer, and Faye (1974) used a specific-yield value of 6 percent for the alluvial aquifer. A current hydrologic study in the Sonoma Valley by the

Department of Water Resources utilized a specific yield value of 6.95 percent (C. Herbst, 1981 personal communication) for the alluvium. Because the alluvial section and the large data base used by DWR in the Sonoma study are similar to those of the Upper Napa Valley; a specific-yield factor of 6.95 percent was utilized for the Upper Napa Valley. Thus, using a specific-yield value of 6.95 percent and assuming peripheral vertical barriers, an estimate of the total quantity of geothermal water in storage in the upper alluvial aquifer of the Upper Napa Valley is 135,000 acre-feet. However, based upon the DWR Sonoma Study, perhaps only 10-15 percent of this water can realistically be withdrawn (C. Herbst, personal communication), which consideration reduces the upper aquifer yield of geothermal water to the range of 13,500-20,250 feet.

Zone 3 - Both drill holes encountered a thick section of volcanic ash and ash flow tuffs that contained no interstitial water and were impermeable barriers to vertical groundwater migration. This unit is considered to have no storage capacity.

Zone 4 - The Arroyo #2 and Moore #1 drill holes were both terminated in a dacitic ash flow tuff unit. Although the upper part of this unit appeared to be welded and virtually impermeable, the underlying scoriaceous material produced a large volume of hot water. As shown on the drill logs, a very rapid increase in temperature in conjunction with a large volume of water was produced upon penetration of the permeable scoriaceous volcanic material. Both of these physical parameters were previously unknown, and this underlying aquifer may represent a major addition to the geothermal resource in the Upper Napa Valley. Three major problems arise with trying to model this underlying aquifer: (1) the actual vertical thickness of this unit are unknown, for neither drill hole hit Mesozoic basement rocks; (2) the actual hydrologic properties (that is permeability, hydraulic conductivity) of this underlying unit are unknown because the actual physical composition of the unit (whether alluvial sediments or pyroclastic debris flows) is unknown; and (3) the lateral extent to the West of this underlying aquifer basin is unknown.

The Arroyo #2 drill hole, which had a total depth of 885 feet, is the westernmost deep (>600 feet) drill hole in the Upper Napa Valley area. As shown on Plate 1, this drill hole just barely penetrated into the saturated dacitic scoriaceous material, with a resultant increase in water.

The gravity profile (Figure 4, main Calistoga report) shows a thickening of sediments to the southwest, although the largest gravity anomaly is located well west of the currently projected structural discontinuity coincident with Highway 129. Thus, if the Zone 3 pyroclastic beds are continuous to the west and maitain a dip of 9°, the underlying Zone 4 geothermal waters would be very deep at the western margin of the Valley. This fact could explain why geothermal waters have not been delineated in this area; it would not be because the resource doesn't exist but rather because wells have not been drilled to depths adequate to encounter the resource.

COMMENTS ON THE RELATIVE SUCCESS OF TECHNIQUES USED THROUGHOUT THE PROJECT

It is difficult to rate each of the techniques used in the Calistoga project as to its relative successfulness compared to other techniques. Each technique used by CDMG has provided additional insight into the resource, and it is the sum of results from all the techniques that has provided the picture that we now have of the geothermal resource at Calistoga.

Overall, the drilling program has provided the most dramatic results in changing our thinking about many aspects of the resource. However, it was information developed in other parts of the program that enabled the selection of drill sites to best display the important aspects ofthe reservoir and resource confirmation. It should be pointed out that without use of the dual tube technique the drilling program would not have been nearly as effective as it was in providing data for resource assessment.

Geophysical techniques, particularly gravity and resistivity, have provided significant information. Gravity has shown an as yet unproven possible extension of the resource, or possibly a heat source, beneath the hills that border the Calistoga valley area on the southwest. Resistivity, although subject to some minor misinterpretation before drilling because of lack of knowledge of clay beds in the section, has proven a very valuable tool in locating high heat areas. The seismic technique, although not a direct indicator of subsurface geothermal-related phenomena, is a very useful tool in developing a picture of subsurface geologic structure that may in turn explain many aspects of the geothermal reservoir and the occurrence of themal waters.

The shallow-temperature-probe technique, although not utilized to the fullest extent, provided excellent corroborative results for known areas of higher heat and for areas where resistivity indicated higher subsurface temperatures. The companion microacoustic study, on the other hand, because of escaping gas and a near surface water table which caused masking noises, did not prove an effective technique for study in the Calistoga area.

Geochemistry has proven a valuable tool with respect to geothermometric studies, and results obtained using the technique very closely paralleled the results that were measured using a down-hole temperature logger. A separately funded study detailing the use of geochemistry in helping to develop a subsurface geologic structural picture is in progress (Majmundar, in preparation).

One very important technique that was used to gain an early picture of the locations of the highest heat areas was the canvass of the local area wells, including temperature probe and chemical water sampling. Such a technique is, of course, not applicable where only one or two wells may be available, but in Calistoga it was possible to develop an early version of the temperature contour map (Plate 13 of the main volume of the Calistoga report) with which to further refine our study area and to make more effective use of proposed study techniques.

In general, each of the techniques reported in the main volume and drilling addendum of the Calistoga report has provided useful information. The degree of usefulness of one technique over the other may vary from one locality to another. Experience using a given technique in a given geologic setting may improve the usefulness of the technique and thereby enhance the returns that may be expected for its use.

SELECTED REFERENCES

Bader, J.S., and Svitek, J.F., 1973, Data for selected wells - Napa Quadrangle, Yountville Quadrangle, Rutherford Quadrangle, St. Helena Quadrangle, and Calistoga Quadrangle (5 reports): U.S. Geological Survey open-file reports.

Bailey, E.E., Irwin, W.P., and Jones, D.L., 1964, Franciscan and related rocks and their significance in the geology of western California: California Division of Mines and Geology Bulletin 183, 165 p.

Blake, M.C., Jr., Smith, J.T., Wentworth, C.M., and Wright, R.H., 1971, Preliminary geologic map of western Sonoma County and northernmost Marin County California: U.S. Geological Survey-Department of Housing and Urban Development Basic Data Contribution 12.

Barnes, Ivan, 1970, Metamorphic waters from the Pacific Tectonic belt of the west coast of the United States: Science, v. 168, May 22, p. 973-975.

Barnes, Ivan, and O'Neil, J.R., 1969, The relationship between fluids in some fresh alpine-type ultramafics and possible modern serpentinization, western United States: Geological Society of America Bulletin, v. 80, p. 1947-1960.

Berkstresser, C.F., Jr., 1968, Data for springs in the northern Coast Ranges and Klamath Mountains of California: U.S. Geological Survey open-file report, 49 p.

Brice, J.C., 1953, Geology of Lower Lake Quadrangle, California: California Division of Mines and Geology Bulletin 166, 72 pp.

Crutchfield, W.H., Jr., 1953, The geology and silver mineralization of the Calistoga district, Napa County, California: California University, Berkeley, unpublished MS. thesis, 71 p.

Dickerson, R.E., 1922, Tertiary and Quaternary history of the Petaluma, Point Reyes, and Santa Rosa Quadrangles: California Academy of Science Procedures, 4th series, v. 11, no. 19. p. 527-601.

Faye, R.E., 1973, Ground-water hydrology of northern Napa Valley, California: U.S. Geological Survey Water-Resources Investigation 13-73, 64 p.

Fournier, R.O., and Rowe, J.J., 1966, Estimation of underground temperatures from the silica content of water from hot springs and wet-steam wells: American Journal of Science, v. 264, p. 685-697.

Fournier, R.O., 1979, A revised equation for the Na/K geothermometer: Transactions, Geothermal Resources Council, v. 3, pp. 221-224.

Fournier, R.O., and Potter II, R.W., 1979, Magnesium correction to the Na-K-Ca chemical geothermometer: Geochemicalet Cosmochimica Acta, v. 43, pp. 1543-1550.

Fournier, R.O., and Truesdell, A.H., 1973, An empirical Na-K-Ca geothermometer for natural waters: Geochemicalet Cosmochimica Acta, v. 37, pp. 1255-1275

Fournier, R.O., and Truesdell, A.H., 1974, Geochemical indicators of Subsurface temperature, part II: Estimation of temperature and fraction of hot water mixed with cold water: U.S. Geological Survey Journal of Resources, v. 2, no. 3, pp. 263-270.

Fox, K.F., Sims, J.D., Bartow, J.A., and Helley, E.J., 1973, Preliminary Geologic Map of Eastern Sonoma County and Western Napa County, California: U.S. Geological Survey Basic Data Contribution, no. 561.

Gealey, W.K., 1951, Geology of the Healdsburg quadrangle, California: California Division of Mines and Geology Bulletin 161, 75 p.

Hearn, B.C., Donnelly, J.M., and Goff, F.E., 1975, Geology and Geochronology of the Clear Lake Volcanics, California: U.S. Geological Survey, open-file report 75-296, 18 pp.

Johnston, Stedwell, 1948, The geology of a portion of the Calistoga quadrangle: California Division of Mines and Geology, scale 1:250,000.

Koenig, J.B., 1963, Geologic map of California, Olaf P. Jenkins edition, Santa Rosa sheet: California Division of Mines and Geology, scale 1:250,000.

Kunkel, Fred, and Upson, J.E., 1960, Geology and ground water in Napa and Sonoma Valleys, Napa and Sonoma Counties, California: U.S. Geological Survey Water Supply Paper 1498, 252 p.

Majmundar, H.H. (In Preparation), Geochemical investigations of geothermal waters from Calistoga, Napa County, California: California Division of Mines and Geology report.

McNitt, J.R., 1968a, Geology of the Kelseyville quadrangle, Sonoma Lake, and Mendocino Counties, California: California Division of Mines and Geology Map Sheet 9, scale 1:62,500.

Muffler, L.J.P., 1979, Assessment of geothermal resources of the United States - 1978: U.S. Geological Survey Circular 790.

Palmer, C., 1911, The geochemical interpretation of water analyses: U.S. Geological Survey Bulletin 479, 31 pp.

Piper, A.M., 1944, A graphic procedure in the geochemical interpretation of water-analysis: A.G.U. Transactions, 25th Annual Meeting, Section in hydrology.

Sarna-Wojcicki, A.M., 1976, Correlation of late Cenozoic tuffs in the Central Coast Ranges of California by means of trace and minor element chemistry: U.S. Geological Survey Professional Paper 972, 29 pp.

Sims, J.D., and Rymer, M.J., 1975, Preliminary Description and Interpretation of Core and Radiographs from Clear Lake, California: U.S. Geological Survey, open-file report 75-144, 21 pp.

Swe, Win, and Dickinson, W.R., 1970, Sedimentation and thrusting of late Mesozoic rocks in the Coast Ranges near Clear Lake, California: Geological Society of America Bulletin, v. 81, no. 1, p. 165-188.

Todd, D.K., 1964, Ground water hydrology: John Wiley and Sons, Inc., New York.

Waring, G.A., 1915 Springs of California: U.S. Geological Survey Water-Supply Paper 338, 410 p.

Weaver, C.E., 1949, Geology of the Coast Ranges immediately north of the San Francisco Bay region, California: Geological Society of America Memoir 35, 242 p.

Weaver, C.E., 1957, Thermal waters of volcanic origin: Geological Society of America Bulletin, v. 68, p. 1637-1658.

White, D.E., Barnes, I., and O'Neil, J.R., 1973, Thermal and mineral waters of nonmeteoric origin, California Coast Ranges: Geological Society of America Bulletin, v. 84, p. 547-560.

White, D.E., Muffler, L.J.P., and Truesdell, A.H., 1971, Vapor-dominated hydrothermal systems compared with hot-water systems: Economic Geology, v. 66, p. 75-97.

White, D.E., and Ellis, A.J., cf. Truesdell, A.H., 1976, Summary of Section III: Geochemical techniques in exploration: Proceedings, 2nd U.N. Symposium on the development and use of geothermal resources, San Francisco, v. 1, U.S. Government Printing Office.

Wilcox, L.V., 1955, The classification and use of irrigation waters: U.S. Department of Agriculture, Agricultural Research Service Circular, 969, 19 p.

Youngs, L.G., Bacon, C.F., Chapman, R.C., Higgins, C.T., Majmundar, H.H., and Taylor, G.C., 1980, Resource Assessment of Low-and Moderate-Temperature Geothermal Waters in Calistoga, Napa County, California: Report of the Second year, 1979-1980 of the U.S. Department of Energy - California State Coupled Program.

APPENDICES A-C

APPENDIX A
DRILLING METHODS, EQUIPMENT AND PROCEDURES

Drilling Equipment

The drilling was performed by the Water Development Corp. of Woodland, California using a DrillTEK D40K Top Head Hydraulic Drive Rotary Rig equipped with a 750 CFM/250 psi air compressor and utilizing flush-jointed dual tube drill pipe 5-1/8 inches in diameter. Dual -tube drilling, as the name indicates, is based on the use of double-walled or concentric drill pipe. The hole cleaning air (or fluid) is circulated down the annulus between the inner and outer pipes to the drill bit (refer to Figure A-1) where it flushes the cuttings up through the center tube at high velocity (nominal is 7000 feet/per minute). The rapid flow of chips and formational water is passed into a cyclone mounted on the rig from which samples can be easily collected.

Because the outer tube supports the hole and circulation is maintained internally, surface casing can be eliminated. This results in one of the system's prime advantages - the ability to maintain circulation even while drilling in caving or unconsolidated strata, voids, or highly fractured ground. Using proper drilling and sampling techniques, chip and water samples from dual-tube drilling are in little danger of contamination from wall erosion, are free of foreign matter, and therefore are highly representative of the strata encountered. In addition, because the casing is carried down with the drill bit and in effect "seals off" each successive interval, it is possible to obtain uncontaminated water samples from each aquifer encountered while drilling with air.

Analysis of Dual-Tube Drilling Method

The test holes that were drilled by CDMG provided physical data on the stratigraphy and aquifers that would never have been recoverable by other drilling methods. The following are some of the outstanding results obtained in this project using the dual tube equipment.

- The identification of aquifers separated by only inches of altered volcanic ash (smectitic clays).

- The ability to extract uncontaminated water samples from these aquifers.

- Identification of yield, chemical composition, and temperature of individual aquifers.

- Delineation of distinict, very thin, aerially deposited volcanic ash beds and delineation of cooling units within volcanic ash flow tuffs.

- Sampling and retrieval of dry altered volcanic ash from depths ranging to 870 feet.

Problems Encountered

Within alluvial sections comprised principally of saturated sands and gravels, drilling advance was fast (40-60 ft/hr) and problem free. However, when transition zones containing clay (wet to dry to dry to wet) were encountered, tools became plugged very easily. As shown on the logs, dry zones were principally composed of altered volcanic ash that had, upon alteration, formed relatively impermeable clays that were very plastic. Because of the high degree of plasticity, the tri-cone bit merely deformed or remolded this clay without breaking it up enough to free it for discharge up the inner barrel. When this happened, either the clay was forced into the eight ½-inch diameter air holes between the sub and tri-cone bit or was extruded up into the inner barrel. In either case this resulted in plugged tools and necessitated pulling the tools out of the hole for cleaning. At depths below 400 feet, with caving conditions in the hole, it took as mcuh as a two-day turnaround, in some instances, to reoccupy the hole. On the Arroyo #2 hole, for example, tools were plugged seven times below 400 feet. This is the major reason why total footage of only 1652 feet was drilled under the contract which specified a basis of time and material payment to the drilling contractor. As experience was gained in drilling in the somewhat unique Calistoga geologic conditions, it became possible, through careful teamwork between the geologist and driller, to avoid some tool plugging by immediately removing downward drilling pressure when a clay bed was encountered. The geologist quickly notified the driller at the first sign of clay in the cuttings, and the driller then either removed down pressure or applied a lifting force to counter the weight of the drill rods and tools.

Sampling Procedure

In the dual tube air drilling method, because the outer tube supports the hole, with circulation being maintained internally, a 100 percent representative sample of materials being penetrated by the bit is continuously delivered to the surface as long as the drill is operating. This proved to be extremely advantageous in retrieving not only lithologic samples, but also uncontaminated water samples from various discrete formational aquifers.

Water Sampling:

Water samples were taken from all formational aquifers encountered in each drill hole. Because air was used as the drilling medium and because the dual tube pipe served to seal off and isolate intervals, it was possible to monitor the exact water content of the intervals of differing lithologies that were encountered, as shown on the logs (Plate 1). Typically, when a water-bearing zone was encountered, drill rotation and advance were shut off and air circulation was maintained for five to fifteen minutes. This procedure allowed the drill return water to partially clarify and reduced the time necessary to filter the water samples. Water samples were filtered using a vacuum pump and a 0.45mm (micrometer) membrane filter. The filter was rinsed with distilled deionized water immediately prior to use. The plastic bottles were rinsed first with the filtered sample, and then the filtered sample was collected.

The water sample collected from each aquifer was subdivided into four separate bottles: one 125 ml filtered non-acidified for chlorine and fluoride determination; one 125 ml filtered non-acidified for chlorine and fluoride determination; one 250 ml filtered non acidified sample for carbonate, bicarbonate, and total dissolved solids (T.D.S.) determination; one 60 ml filtered acidified (10% HNO_3) for all cation determination; and one 125 ml filtered acidified (1 ml HCl in 125 ml sample) for sulfate determination.

Details of sampling techniques, use of the air pressured filtration equipment, and methods used in laboratory analyses are given in the main volume of the 1979-80 report to DOE on the Calistoga studies, and in a separately funded geochemical report on Calistoga (Majmundar, in preparation).

The first site, Arroyo #1, was located on a farm road in the middle of a vineyard. For this reason, the first 60-70 feet of the well was to be cased and cemented with steel pipe and bentonite mud was used to drill the first 70 feet. Because of the usage of bentonite, the waters sampled contained bentonitic mud to the extent that filtration was impossible. Therefore, all the collected water samples in the upper part of the hole was discarded down to about 150 feet in depth.

Only two water samples (M-001-80, M-002-80) were collected at depths of 155 and 180 feet, respectively, from the Arroyo #1 site while drilling. The third water sample (WR #1) was collected from the drill-site, using a downhole sampler, two days after the drilling operation had ceased.

Fifteen water samples (M-003-80 through M-015-81) were collected at various depths, while drilling the second well site, Arroyo #2. Though bentonite mud was not used in drilling the second and third wells, clay-sized particles of volcanic ash were in colloidal suspension in the water samples making them impossible to filter. Therefore a new vacuum filtration technique was adapted from labortary procedures for field-filtration. This vacuum filtration system was used for all samples collected following sample M-028-81.

However, even using this procedure it was necessary to filter each sample several times until the sample water cleared.

Eight samples (M_016-81 through M-023-81) were collected during drilling of the third well, Moore #1. Two of these samples were from the fresh water zone, and were collected from a seperate, previously drilled well, 65 feet deep, located 50 feet away from the Moore #1 well-site. Sample M-016-81 is from this well collected at 12 feet depth, and sample M-017-81 is from 65 feet. The rest of the six water samples (M-018-81 through M-023-81) were collected at various depths during the drilling operation. The water logs of the three wells are given with the geological logs on Plate 1.

Lithologic sampling:

To facilitate lithologic sampling, the mixture of air rock particles, and water coming from the return line is fed to a centrifugal separator or "cyclone" where solid material is removed and discharged into sample splitter. Chip samples were collected by inserting Gilsen screens into the discharge outflow, typically a 40 to 100 mesh stack, and by visually estimating the lithologic classification of the split material. Standard core boxes were used to preserve bulk samples of the materials encountered throughout the drilling process, and special small samples, representative of a given interval, were retained in water-tight plastic bags.

Field Analysis

A continuous temperature log was maintained by utilizing a digital resistance temperature probe manufactured by Gisco-Keck Geophysical instruments (#DR-787 digital temperature meter). This temperature probe was attached to a float, which in turn was positioned immediately to the side of the direct flow discharge out of the cyclone into a large metal barrel. This method facilitated accurate and continuous temperature measurements of encountered aquifers without exposing the probe to abrasive wear from rock particles within the discharge. In areas where damp or wet slurries were being produced, samples of the discharge material were collected, and a temperature was taken with a hand-held conventional mercury-in-glass thermometer. In addition to temperature, the pH, salinity, specific conductance, and semi-quantitative chloride content for water samples were determined in the field along with various acidifications and dilutions of filtered samples.

Actual water content of encountered aquifers was monitored by measuring the discharge at the cyclone in gallons per minute, and recorded as a range of volume on the drill log. These gallonage figures do not indicate total yield of the encountered aquifer; they are only relative volumetric measurements. As shown in the schematic of the dual tube pipe (Figure A-1), the area available for actual aquifer transmissibility is the residual volume lying between the roller bits on the tri-cone. Thus, a gallonage figure of 10-15 gpm on the log would in all probability be equivalent to a yield considerably in excess of that amount if that aquifer section were developed with a conventional, larger diameter, perforated well casing or with well screens.

Chip samples were continuously monitored at the cyclone discharge and bagged samples, for later analysis, were collected at 5-foot intervals and/or at lithologic changes, whichever came first. Sample classification was based on the United Soil Classification criteria except where rock (volcanic ash and welded tuff) was encountered. The logs (Plate 1), except in those instances, show standard soil classification symbols. One special symbol was added for a clay apparently derived from in-situ alteration of volcanic ash.

Physical and mineralogical composition of the sand and gravel fraction was noted on the log. The clay and silt fractions of the sample were color coded by using Munsell soil color charts immediately after sample collection.

This immediate color coding was necessary in order to standardize descriptive clay colors, for it was found that radical color changes occurred upon exposure of the sample to air. This fact is exemplified by a dark bluish-grey altered volcanic ash (clay) that immediately oxidized to a light olive-brown color.

APPENDIX B
LITHOLOGY OF UNITS AND DRILL-HOLE DATA

Lithologic Description of Units

Alluvium

In this report, lithologies described as alluvium include the older alluvium, terrace deposits, older-alluvial fan deposits, and younger alluvium as mapped and described by Kunkel and Upson (1960), and Fox, Sims, Bartow and Helly (1973). Subsurface stratigraphic correlation to these surficial deposits has not been attempted, although a discussion of erosional surfaces is presented in another section.

As shown in the logs 1-3, the alluvium consists of interbedded unconsolidated gravels, clayey gravels, silty gravels, sands and clays probably comprising channel, floodplain and alluvial fan deposits. For the most part, these alluvial deposits are poorly sorted and composed of sub-angular volcanic material. The gravel and sand fraction principally falls within the dark colored basalt-andesite-dacite compositional range with minor lighter colored rhyolitic material. The silt fraction within these alluvial sediments consists of fine grained pyroclastic-derived material and a large percentage of clays probably derived from highly altered volcanic ash. Thickness of individual facies is highly variable, ranging from less than 1 foot to a maximum of 50 feet.

Silty Clays

This specific unit has been split out of the alluvial section because of its importance to the stratigraphy and because it serves as a groundwater barrier within the Upper Napa Valley. Units shown as silty clays on logs 1-3 are typically composed of highly altered volcanic ash, which exhibits a very high degree of plasticity. Undoubtedly some of these clays are derived from re-worked pyroclastic material, but some of them are the result of in-situ alteration of direct ash fall material that has not been reworked. This fact is discussed further in this report in the Stratigraphy and Structure section in the body of this addendum.

These silty clays typically exhibit a dark bluish grey color (5B5/1 to 5B4/1) (see Munsell soil color chart), and are composed of expansive clay minerals of the smectite group (formerly the montmorillonite group), very minor residual lithic fragments, mafic mineral assemblages of hornblende and/or hypensthene and diagenetic pyrite crystals. Although the bluish-grey color is typical of these clays, being within a reducing environment, some units do exhibit a dark reddish-brown color probably indicative of an advanced stage of oxidation. Laboratory analyses of these clays by James Post, Sacramento State University, has confirmed that most fall within the smectite group. However, one sample, A-100, was described as an ordered layer clinochlore.

These silty clays (altered volcanic ash, probable aerial deposition) exhibit the characteristics of being aquitards and/or aquicludes; but because of their limited stratigraphic thickness (0.5 to 5 feet) they have assimilated moisture due to contact with hydrothermal water-bearing alluvial sediments. This fact, has resulted in a higher degree of alteration (that is, a greater percentage and/or variability of smectite minerals) than material logged as altered volcanic ash.

<u>Altered Volcanic Ash</u>

This material has been differentiated from the above silty clays principally on the basis of moisture content, degree of alteration, and color. Mineralogically, this altered volcanic ash -- composed of devitrfied glass shards, mafic mineral assemblages of hornblende, hypersthene and augite, and clays (probably of the smectite group) -- is almost identical to the units that were logged as silty clays. However, because of two physical facts -- namely, (1) formation of expansive clay minerals (smectite) with resultant self-sealing properties, and (2) stratigraphic thicknesses measured in the tens of feet -- this volcanic pyroclastic material has remained dry. Extracted from depths in excess of 750 feet, this volcanic ash was discharged from the cyclone in the form of clouds of dust.

Colors varied from a very dark greyish-black through dark to light greys, and reddish tans to a light greyish white. Color changes typically were accompanied by a change in particle size distribution and were interpreted as being volcanic ash falls intercalcated with pyroclastic ash flow tuffs. Particle size distribution is within the clay-silt range (.063mm to less than .002mm) for the air fall material. Thickness ranges upward to welded pyroclastic ash flow tuffs that measure tens of feet thick and show remmant pumice fragments, > 1cm. in length.

Ash-Flow Tuffs

Several discrete ash-flow tuffs, ranging from semi-unconsolidated pyroclastic debri to highly siliceous welded dacite tuff were encountered in both the Arroyo #2 and Moore #1 drill holes.

Both drill holes bottomed in a black dacitic tuff characterized by diagenetic euhedral pyrite crystals and minor in-filling of voids of silica. Thickness exceeded ten feet, but in both cases drilling had to be terminated within this unit; so actual stratigraphic thickness is unknown.

This black dacitic tuff is overlain by approximately five feet of a light greenish-grey colored dacitic vitric tuff that exhibits an advanced degree of induration. Glass shards appear welded and fused, and the unit appears to represent the upper surface of an ash flow cooling unit.

The above group of beds is overlain by approximate 25 feet of altered volcanic ash that in turn is overlain by 20 feet of greyish-black dacitic tuff. The tuff appears to be composed of lightly indurated ash flow material that locally has been resilicified. Interstices between lithic fragments are often filled with a soft opaline(?) material.

The uppermost ash flow tuff encountered is a greyish-white to greenish-grey colored dacitic vitric tuff. This unit exhibits a highly siliceous welded matrix, with individual lithic fragments almost indistinguishable. This tuff is a hard, very dense material, and exhibits characteristics of a cooling rind. This highly siliceous unit, grades downward into a greyish-black tuff that consists of pyroclastic lapilli with accessory opaline(?) silica filling natural voids. Sulfides are present as pyrite (Fes), and are probably of diagenetic origin; pyrite typically consists of fracture filling and surficial coatings on vitric (pumice) fragments.

Lithologic and Hydrologic Logs

Water Content Definition

1 gpm	
1-5 gpm	Actual water yield measured at the discharge with drill rotation and rod advance shutoff and air circulation being maintained through dual-tube rods.
5-10 gpm	
10-15 gpm	
WET SLURRY	- Material produced from discharge has enough free water to suspend particulate matter but impossible to filter for a water sample. Behaves as a fluid but has a high percentage of solids.
WET	- Material has enough free water that water can be extruded upon hand squeezing but a water sample could not be attained.
DAMP	- Material will not produce water upon squeezing but contains minor interstitial water such that it can be molded and remains as a coherant mass.
DRY	- Material cannot be molded, is non-cohesive, and was discharged accompanied by minor clouds of dust.
VERY DRY	- As above except material was discharged wholly as dust.

State of California
The Resources Agency

DIVISION OF MINES AND GEOLOGY

DRILL HOLE LOG

HOLE NO. Moore #1

PROJECT Calistoga Low Temperature Geothermal

ELEV.

FEATURE

DEPTH 562' TD

LOCATION Greenwood Ave. DATE DRILLED 1/27/81

ATTITUDE

LOGGED BY Gary Taylor CONTR. Water Development DRILL RIG D40K

WATER TABLE 2'

* Water Content - is amount of water produced at the discharge by only air circulation and is a minor fraction of the yield that could be produced if that aquifer was developed by standard well methods.

DEPTH	WATER CONTENT	LOG	CLASSIFICATION AND DESCRIPTION	SAMPLE NO.	MODE	REMARKS
2' Sub	W.L.		0.0-3.5 Topsoil - Roadbase & Dump Material			Drilling with 5 1/8" Tri-Cone Rotary Bit and Dual-tube rod
			2.5- Water Level			
22'	Surface Water	GP	3 5-30.0 Gravel: Saturated, poorly sorted, var. colored volcanics, sub-angular			No cutting in cyclone return as cuttings are being blown around outside of tools
		CC	30.0-40.0 Clayey Gravels: damp, poorly graded, sub-rounded var. colored volcanics pred. basalts & andesite w/minor rhyolite. 10% silty-clay: yellowish-brown, plastic. 10 YR 4/4	*T-1	C.S.	*All samples are cuttings recovered from cyclone
42'		SC	40.0-45.0? Clayey Sand: damp, poorly sorted, med. plasticity, dark yellowish brown 10 YR 4/4	T-2		
62'	Dry	GP	45.0-75.0 Gravel: dry, poorly sorted, 80% coarse grained var. colored sub-angular volcanics, 10% sand and 10% silty clay	T-3		Washout of water around tools no cutting coming out of return shutdown on 1/27/81

SHEET 1 OF 6

State of California
The Resources Agency
DIVISION OF MINES AND GEOLOGY
DRILL HOLE LOG

HOLE NO. ____________

PROJECT & FEATURE ____________

DEPTH	WATER CONTENT	LOG	CLASSIFICATION AND DESCRIPTION	SAMPLE NO.	MODE	REMARKS
		GR	Same as 45.0-75.0 except sand fraction increases to 15-20%.	T-4		Dusty Drilling
82'	Dry	SC	81.0-95.0 Clayey-Sand: Damp, poorly graded w/minor gravel, clay: lt. olive color plastic, 2.5 Y 5/4	T-5		
	Damp	CL	95.0-98.0 Sandy Clay; damp, 70% fines, low plasticity, dk. gry-brn color 2.5 Y 4/2	T-6		
102'		GM	98.0-115.0 Silty Gravel: Wet, 80% gravel, sub-angular, hard var. colored volcanic rocks; 20% fine, non-plastic, olive brown 2.5 Y 4/4 Silt.	T-7 T-8		Mud Slurry has temp. of 15°C (59°F)
		ML	115.0-122.0 Sandy Silt; saturated, non plastic, quick dilatency; 10% fine-grained, dark-colored volcanic sand, lt. olive brn 2.5 Y 5/4			
122' 142'	Wet Minor Water <1gpm	GM	122.0-159.0 Silty Gravel: saturated, 75-80% gravel, sub-angular, hard variable colored volcanic rocks, poorly sorted; 20-25% fine, med-plastic, lt. olive brown color, 2.5 Y 5/4	T-9 T-10 T-11 T-12		Mud slurry temp. at 30°C (86°F) not enough H_2O to take a sample
	Dry	CL	159.0-161.0 Silty Clay: saturated, low-plastic, quick dilatency; 10-15% dark colored volcanic sand. lt. bluish grey color.	T-13		
162'	Wet	GM	161.0-173.0 Silty Gravel; saturated, 80% gravel same as 122.0-159.0	T-14		
	Dry	CL	173.0-175.0 Silty clay (altered volcanic ash), wet, plastic, bluish-grey color 5B 5/1	T-15		

The Resources Agency

DIVISION OF MINES AND GEOLOGY

DRILL HOLE LOG

HOLE NO. ______

PROJECT & FEATURE ______

DEPTH	WATER CONTENT	LOG	CLASSIFICATION AND DESCRIPTION	SAMPLE NO.	MODE	REMARKS
	Wet Slurry	GM	175.0-179.0 Silty Gravel: same as 122.0-159.0			
		CL	179.0-180. Silty Clay 5B 6/1			
182		GM	180.0-183.0 Silty Gravel: wet, lt. tan color			
		CL	183.0-184.0 Silty Clay: 5 B 6/1			
		GM	184.0-199.0 Silty Gravel: wet, 80% gravel sub-angular, pred. dark colored volcanic rocks; 20% fine, plastic olive gry silt 5 Y 4/2	T-16		H_2O temp at 32°C (89°F)
202	Minor Water 1-3gpm	CL	199.0-200.5 Silty Clay bluish-grey 5B5/1	T-17		H_2O Temp at 36°C
		GM	200.5-210.0 Silty Gravel: same as 184.0-199.0			
		SM	210.0-216.0 Silty Sand: saturated, 80% sub angular var. colored volcanic sand; 20% fine, non-plastic, gry-brn color 2.5 Y 4/2	T-18		H_2O Sample taken at 210' and 36°C
		SM	216.0-220.0 Silty Sand: Same as above except lt. reddish-brn color			Reddish-Brown color appears to be oxidized sulfides within andesite probably F_eS
222		GM	220.0-230.5 Silty Gravel: Saturated, 90% sand and gravel, var. colored volcanics with red Fe oxide coating; 10% fine silt, lt. reddish-brown color 5 YR 4/4	T-19		
		GM	230.0-233.0 Silty Gravel: same as above but with lt. tan color to silt.	T-20		
242	Water 5-10gpm	GM	233.0-264.5 Silty Gravel: saturated, 90% pred. dark colored volcanics prin. andesite with minor wht. rhyolite clasts; 10% fine, olive-gry silt 5 Y 4/2	T-21		H_2O Sample taken at 242' 45°C
262				T-22		
	DRY	CL	264.5-267.0 Silty Clay: 5 B 4/1	T-23		
	Water 5-10gpm	GM	267.0-292.0 Silty Gravel: saturated, poorly sorted, var. colored volcanics 5 Y 4/2 color.	T-24		

SHEET 3 OF 6

The Resources Agency
DIVISION OF MINES AND GEOLOGY
DRILL HOLE LOG

HOLE NO. ____________

PROJECT & FEATURE ____________

DEPTH	WATER CONTENT	LOG	CLASSIFICATION AND DESCRIPTION	SAMPLE NO.	MODE	REMARKS
282'		GM		T-25		H_2O sample taken at 282' 46°C.
		SM	292.0-294.5 Silty Sand: saturated, 85% Sub-angular volcanic sand; 5% gravel; 10% fine, non-plastic silt, olive-gry color, 5 Y 4/2	T-26		
302'	WATER 5-10 gpm	GM	294.5-311.5 Silty Gravel: saturated, 90% sand & gravel, poorly sorted, var. colored volcanics princ. dk. grn-black andesite & basalt. w/ minor unaltered sulfides F_eS. 10% Silt, non-plastic, 5 Y 4/2	T-27		Rig shutdown on 1/29/81. Tools plugged
				T-28		
		CL	311.5-312.0 Silty Clay: Bluish-grey 5 B 4/1	T-29		
322'		GM	312.0-325.0 Silty Gravel: same as 294.5-311.5 except 10-15% wht. rhyolite gravels.	T-30		H_2O Temp 113°F.
	DRY	CL	325.0-327.0 Silty Clay: damp, dk. bluish-grey color 5B 4/1.	T-31		H_2O Sample at 322' 46°C.
	WATER 1 gpm	GM	327.0-335.5 Silty Gravel: saturated, 90% volcanic sand & gravel, poorly sorted; 10% silt 5Y 4/2			
342'	DAMP	CL	335.5-342.0 Silty Clay: damp, highly plastic, dk. bluish-gry color 5B 4/1. Altered volcanic ash.	T-32		
	DRY	CL	342.0-350.0 Silty Clay: damp, highly plastic, small amount of silt, dark reddish brown 2.5YR 3/4 (oxidized volcanic ash)	T-33		
		CL	350.0-356.0 Silty Clay: Damp, highly plastic, small amount of silt olive grey color 5Y 5/2	T-34		
362'		CL	356.0-370.0 Silty Clay: damp, highly plastic, small amount of silt, grey color 5Y 5/1 Remmant mafic crystals (horn-blende and/or augite?)	T-35 T-36		Welded tuff chips filtered out of slurry
		CL	370.0-375.0 Silty Clay: damp, highly plastic, minor silt, greenish-grey color 5GY 5/1	T-37		

SHEET 4 OF ____

State of California
The Resources Agency
DIVISION OF MINES AND GEOLOGY
DRILL HOLE LOG

HOLE NO. ____________

PROJECT & FEATURE ____________

DEPTH	WATER CONTENT	LOG	CLASSIFICATION AND DESCRIPTION	SAMPLE NO.	MODE	REMARKS
		CL	375.0-382.0 Silty Clay: (altered volcanic ash) Damp, very plastic, minor silt, bluish-grey color 5B 6/1.	T-38		
382'		GC SC	382.0-385.0 Clayey Gravel: dry, poorly sorted, dk colored volcanics 90%; silty clay 10%, greenish-gry color 5GY 5/1	T-39 T-40		Dusty Drilling Rig Shutdown on 1/30/81
402'		CL	395.5-403.5 Silty Clay: damp, very plastic, bluish-grey color 5B 5/1. appears to be altered tuff with transition zone going into hard silicous tuff.			Drillers "Bone"
	DRY		403.5-409.0 Welded Tuff; varigated color white to greyish-green, highly siliceous, minor sulfides (iron pyrite FeS). Feldspar altered to clays	T-41		
		CL	409.0-411.5 Silty Clay: (altered tuff) plastic, greenish-gry color 5GY 5/1			
422'			411.5-424.5 Welded tuff with altered volcanic ash: greyish-black color, highly siliceous tuff with minor FeS sulfides; altered ash, lt. grey color 5Y 6/1, mottled chlorite alteration.	T-42 T-43		Dusty Drilling
			424.5-439.0 Altered Volcanic Ash with minor tuff fragments 5Y 6/1 lt. grey color. Tuff fragments decrease in quantity and size downward in section.	T-44		
442			439.0-450.0 Altered Volcanic Ash: dk. greenish-grey color, 5G 4/1 very plastic when wetted, minor digenetic iron pyrite (FeS)	T-45 T-46		
	VERY DRY		450.0-460.0 Altered Volcanic Ash: same as above and below but color lt. greyish. 5Y 5/1	T-47		
462'			460.0-462.5 Altered Volcanic Ash: very fine grained, lt. greenish-grey color, 5Y 6/1, dry.	T-48		
	DAMP		462.5-464.0 Altered Volcanic Ash, damp complete altered to clay	T-49		
	DRY		464.0-475.0 Altered volcanic ash, dry grn-grey color 5Y 6/1	T-50		

The Resources Agency
DIVISION OF MINES AND GEOLOGY
DRILL HOLE LOG

HOLE NO. ____________

PROJECT & FEATURE ____________

DEPTH	WATER CONTENT	LOG	CLASSIFICATION AND DESCRIPTION	SAMPLE NO.	MODE	REMARKS
482	Very Dry		475.0-487.5 Altered volcanic ash: dry, lt. grey color, NG/	T-51		
			487.5-490.5 Altered volcanic ash: dry, very fine grained, very light-whitish grey color 5 Y 7/1	T-52		Tools plugged at 490' on 2/4/81
			490.5-500.0 Altered volcanic ash: dry, grey color, 5Y 5/1.	T-53		
502	Damp		500.0-515.0 Silty Clay: saturated, very plastic, dk. bluish-grey color 5B 4/1. minor tuff fragments within matrix. Saturated and altered volcanic ash.	T-54 T-55		
	Wet Slurry		515.0-523.0 Ash flow tuff: saturated, greyish-black color, highly altered	T-56		Drilling hard
522			523.0-530.5 Silty Clay: saturated, very plastic, lt. grey color, 5Y 6/1 saturated and altered tuff and volcanic ash.	T-57		Mud temp 40°C
			530.5-539.0 Silty Clay: saturated, very plastic, olive color, 5Y 5/3 black Mg "Scum" showing in cutting	T-58		
542	Water 1-5gpm		539.0-541.5 Silty Clay: saturated, very plastic, dark grey color, 5Y 3/1 black "Scum" on drill H_2O return (Mg)	T-59		H_2O Sample taken at 542' 61°C
			541.5-551.0 Ash flow tuff: saturated, black color, minor FeS, voids appear resilified, feldspar. Altered to clay. Rock dacite-andesite in composition, with manganese staining.	T-60 T-61		Drill H_2O black with Mg_2 "Scum"
	Water 5-10gpm		551.0-556.0 Welded Tuff: saturated, lt. greenish grey color, glassy matrix (vitric tuff), probably represents an upper cooling unit. Rock is of dacite-andesite composition.	T-62 T-63		H_2O sample taken at 562' 71°C
562'			556.0-562.0 Ash flow tuff: same as 541.5-551.0. Dacite-andesite composition, minor calcite infilling of small fractures.			Hole abandoned on 2/4/81 at 562'

SHEET 6 OF 6

State of California
The Resources Agency

DIVISION OF MINES AND GEOLOGY

DRILL HOLE LOG

HOLE NO. Arroyo #1

PROJECT Calistoga Geothermal Project

ELEV.

FEATURE

DEPTH

LOCATION 2565 Grant St. Calistoga DATE DRILLED 12/18/80

ATTITUDE

LOGGED BY Taylor & Youngs CONTR. Water Development DRILL RIG D40K

WATER TABLE

* Water Content - is amount of water produced at the discharge by only air circulation and is a minor fraction of the yield that could be produced if that aquifer was developed by standard well methods.

*CS-Sample of cuttings

DEPTH	WATER CONTENT	LOG	CLASSIFICATION AND DESCRIPTION	SAMPLE NO.	* MODE	REMARKS
5' Sub	Conductor Casing Set & Cemented		0-5.0 Topsoil			Start with 12 1/4" steel tipped tri-cone bit with mud
		CL	5.0-18.0 Silty Clay: damp, low plasticity, dk. reddish-grey mottled color, 5YR 4/2	A-3		Sample A#3 taken from cutting pile exact hole position unknown.
				A-1		Drillers "Bone"
		SC	18.0-23.0 Clayey Sand; damp, med. sorting, dk. yellowish-brown color, 10 YR 4/4.	A-2		
25		GM	23.0-73.0 Silty Gravel; wet, 75-80% gravel, var. colored volcanics, princ. dk. basalts and	A-4		slowed drilling rate
	W.L.		Water Table andesites, poorly sorted; 20-25% silt, plastic, lt. olive brown color 2.5Y 5/4.	A-5		12/20/80 66°F Temp. recorded in morning before drilling began mud on bottom air temp. at 47°F.
	50' of 8½" I.D.			A-6		
45				A-7		
				A-8		12/18/80 Set 8 1/2" ID casing drill ahead w/5 1/8" down hole hammer bit. Air return with dual tube.
	Water 1-5 gpm		Silty Gravels (As Above) Sub. rounded, var. colored, stream gravels. very minor qtz. pebbles to 2-2½" showing in return.	A-9		
65				A-10		
				A-11		

SHEET 1 OF 3

State of California
The Resources Agency
DIVISION OF MINES AND GEOLOGY
DRILL HOLE LOG

HOLE NO. ____________

PROJECT & FEATURE ____________

DEPTH	WATER CONTENT	LOG	CLASSIFICATION AND DESCRIPTION	SAMPLE NO.	MODE	REMARKS
85'		GP	75.0-100.0 Gravel: saturated, poorly sorted, large sized 1"-3", dk. colored volcanic rock, sub-angular; 10% silt, lt. olive color 5Y 4/2.	A-12, A-13, A-14, A-15		
		CL	100.0-103.0 Silty Clay: Saturated, very plastic, bluish-grey color 5B 5/1			H_2O Temp 72.8°F
105'		GP	103.0-130.0 Gravel: saturated, same as 75.0-100.0 except silt content increases to 15-20% plastic, lt. olive-brown color, 2.5Y 4/4.	A-16, A-17, A-18		
125'	WATER 5-15 9PM	GM		A-19		
		SP	130.0-133.0 Sand: saturated, poorly sorted with minor gravel. Dk. volcanic sub-angular fragments.	A-20		H_2O Temp 74.5°F
145'		GM	133.0-156.0 Silty Gravel: saturated, 80% gravel, sub-angular dk. colored volcanics; 20% silt, med. plastic, lt. olive-brown color 2.5 Y 5/4	A-21, A-22, A-23, A-24, A-25		H_2O Temp 75.1°F
		GC	156.0-161.0 Gravely Clay, saturated, high plasticity, blue-grey color, 5B 4/1, 60% gravel, sub-angular dk. volcanics	A-26		H_2O Sample taken 12/23/80 with well having set two days H_2O Temp. 78.2°F
165'		GM	161.0-202.0 Silty Gravel: saturated, 80-85% poorly sorted, volcanic gravel, sub-angular; 15% silt, med-plasitc, olive-brown color 2.5Y 5/4	A-27, A-28, A-29		H_2O Temp 81.5°F H_2O Temp 87.5°F

The Resources Agency

DIVISION OF MINES AND GEOLOGY

DRILL HOLE LOG

HOLE NO. ______

PROJECT & FEATURE ______

DEPTH	WATER CONTENT	LOG	CLASSIFICATION AND DESCRIPTION	SAMPLE NO.	MODE	REMARKS
			Silty Gravel. cont.			H_2O Sample taken at 180' 88°F.
				A-30		
185	WATER 5-15 gpm	GM		A-31		
				A-32		
				A-33		H_2O Temp 88.6°F
				A-34		
		GC	202.0-205.0 Clayey Gravel: saturated, 80% volcanic gravel, sub-angular; 20% silty clay, med. plastic, lt. bluish-grey color 5B 5/1.			
205				A-35		Tools pulled to change downhole hammer to tri-cone H_2O Temp. 89.5°F.
						Hole caved on reentry at 105' and was abandoned 12/24/80.

DIVISION OF MINES AND GEOLOGY
DRILL HOLE LOG

HOLE NO. Arroyo #2

PROJECT Calistoga Low Temperature Geothermal Project

ELEV.

FEATURE

DEPTH 885'

LOCATION 2565 Grant St.   DATE DRILLED 12/29/80

ATTITUDE Vertical

LOGGED BY G. Taylor   CONTR. Water Development   DRILL RIG D-40-K

WATER TABLE 42.5'

* Water Content - is amount of water produced at the discharge by only air circulation and is a minor fraction of the yield that could be produced if that aquifer was developed by standard well methods.

DEPTH	* WATER CONTENT	LOG	CLASSIFICATION AND DESCRIPTION	SAMPLE NO.	MODE	REMARKS
2' 308			0-3.5 Topsoil: damp, weathered alluvium w/development of A-C soil horizons			drilling with a $5^{1}/_{8}$" rotary tri-cone bit using a dual-tube drill tek D40K rig
		GP	3.5-18.0 Gravel: dry, poorly sorted, var. colored volcanic rocks, sub-angular. Minor sand and silt fraction			samples were not available for collection due to blow-out of material around outside of the hole.
		CL	18.0-19.0 Silty Clay: damp, med-plastic, lt. olive-grey color 5Y 4/2			
22'	Dry	GP	19.0-31.0 Gravel: dry, poorly sorted same as 3.5-18.0			
		SW	31.0-32.0 Sand: dry, med sorted, sub-angular.			
		GP	32.0-36.0 Gravel: dry, poorly sorted	A-1		
		GC	36.0-37.5 Clayey-Gravel: dry, poorly graded, sub-rounded, low plasticity, DK-Greyish brown 2.5Y 4/4	A-2		
42'	W. L.		Water Level at 42.5'	A-3		H_2O Temp 86.0°F.
		GM	37.5-76.0 Silty Gravel: saturated, poorly sorted, sub-angular, DK. colored volcanic rocks; 15% silt med-plastic, lt olive brown color, 2.5Y 5/4			H_2O Sample taken at 45' and 86°F.
	Minor Water 1-5gpm			A-4		H_2O Temp at 87°F.
62'				A-5		
				A-6		Drillers "Bone"
						H_2O Temp. 88.8°F

SHEET 1 OF 10

....g...y

DIVISION OF MINES AND GEOLOGY

HOLE NO. ____________

DRILL HOLE LOG

PROJECT & FEATURE ____________

DEPTH	WATER CONTENT	LOG	CLASSIFICATION AND DESCRIPTION	SAMPLE NO.	MODE	REMARKS
		SC	76.0-77.0 Clayey Sand: dry, poorly sorted lt. olive brown, 2.5Y 5/4.			
		GP	77.0-79.5 Gravel:	A-7		
82'		CL	79.5-80.0 Clayey Gravel: dry, 2.5Y 4/4			
		GP	80.0-83.0 Gravel:	A-8		
		SC	83.0-85.5 Clayey Sand: dry, 70% fines, low plasticity, lt. olive brown 2.5Y 5/6			
		GP	85.5-92.0 Gravel: dry, poorly sorted, dk. colored volcanics w/minor wht. rhyolite clasts	A-9		
		CL	92.0-93.5 Silty Clay: damp, very plastic, lt. olive brown color, 2.5Y 5/4	A-10		
		GP	93.5-97.0 Gravel:			
		CL	97.0-98.0 Silty Clay: damp, med. plastic, dk. bluish-grey 5B 6/1.	A-11		
102'		GM	98.0-128.0 Silty Gravel: saturated, 85% poorly sorted, pred. dk. colored volcanic rocks w/minor white rhyolite; 15% silt, non-plastic, lt. olive brown color, 2.5Y 5/4	A-12		
				A-13		
				A-14		H_2O Temp at 87.5°F.
				A-15		Drillers bone at 119'
122'				A-16		H_2O Sample taken at 121' 88°F.
		GC	128.0-130.0 Clayey Gravel: dry, 70% dk. volcanics; 30% clayey silt, med. plastic, lt. bluish-grey, 5B 5/1	A-17		
		GM	130.0-142.0 Silty Gravel: dry, same as 98.0-128.0	A-18		Hard and slow drilling
				A-19		
142'		GC	142.0-144.0 Clayey Gravel: dry, 25% med-plastic clay, bluish-grey 5B 6/1	A-20		
		GM	144.0-148.5 Silty Gravel			
		CL	148.5-158.0 Silty Clay: dry, low plasticity, bluish grey color, 5B 5/1	A-21		
				A-22		
		GM	158.0-179.0 Silty Gravel: dry, 75% poorly sorted, dk. colored volcanics, 25% silt, olive grey color, 5Y 4/2 Increase in sand fraction from 172'-179.	A-23		
162'				A-24		Drilling shutdown on 12/29/80
				A-25		H_2O Temp 75.0°F.
				A-26		

SHEET 3 OF 10

The Resources Agency
DIVISION OF MINES AND GEOLOGY
DRILL HOLE LOG

HOLE NO.

PROJECT & FEATURE

DEPTH	WATER CONTENT	LOG	CLASSIFICATION AND DESCRIPTION	SAMPLE NO.	MODE	REMARKS
	<1gpm	GM				
182'		CL	179.0-180.0 Silty Clay: wet, lt. bluish grey color 5B 7/1	A-27		
	Major Water 10-15gpm	GM	180.0-202.0 Silty Gravel: saturated, 85% dk. colored volcanics; 15% silt, low plasticity, olive color 5Y 5/4	A-28		H_2O Temp. 88°F
				A-29		H_2O Sample taken at 185'
				A-30		
				A-31		H_2O Temp 89.6°F
202'	DRY	CL	202.0-204.0 Silty Clay: damp, very plastic, bluish grey color 5B 5/1			H_2O Sample taken at 201'
	Water 5-10gpm	GM	204.0-262.5 Silty Gravel: saturated, 85% dk. colored, poorly sorted volcanic gravel, prin. basalts and black-greenish grey andesites. 15% silt, low plasticity, lt. olive color, 5Y 5/4. Increase in sand % downward.	A-32		
				A-33		
				A-34		
				A-35		H_2O Temp 91.5°F
222'				A-36		H_2O Temp 92.0°F
				A-37		
242'				A-38		H_2O Sample taken at 240' 93.0°F.
				A-39		
				A-40		H_2O Temp. 94.0°F
262'	Damp	SC	262.5-264.5 Clayey Gravel: wet, 60% volcanics, poorly sorted; 40% silty clay, plastic, lt. bluish-grey 5B 7/1	A-41		
	Dry	GP	264.5-279.0 Gravel: dry	A-42		Rig shutdown on 12/30/80 H_2O Temp on startup 94.5°F

SHEET 3 OF 10

The Resources Agency
DIVISION OF MINES AND GEOLOGY
DRILL HOLE LOG

HOLE NO.

PROJECT & FEATURE

DEPTH	WATER CONTENT	LOG	CLASSIFICATION AND DESCRIPTION	SAMPLE NO.	MODE	REMARKS
	Dry	GP	279.0-281.5 Clayey Gravel: damp, 30% clayey silt, med. plastic, bluish-grey color, 5B 6/1.			
282'	Damp	GC		A-43		H_2O Temp 98.4°F
	Water <1gpm	GM	281.5-290.0 Silty Gravel: saturated, 20% poorly sorted, olive color silt, 5Y 4/4			
			290.0-292.0 Silty Clay: dry, very plastic, dk. olive color, 5Y 2.512	A-44		
		CL	292.0-321.0 Silty Clay: damp, very plastic, dense dk. bluish grey color 5B 4/1. Altered volcanic ash (air fall) color changes on oxidation to olive-olive gray color 5Y 4/2.	A-45		Very slow drilling to prevent plugup of hoses and cyclone with clay.
302'	Dry	CL				
				A-46		
	Damp					
322'		GC	321.0-322.0 Clayey Gravel:			
			322.0-343.0 Silty Gravel: saturated, poorly sorted, 85% coarse volcanic gravel 1 1/4, 15% silt-low plastic, lt. olive grey color, 5Y 5/2.	A-47		H_2O Temp 97.0°F.
		GM		A-48		
				A-49		H_2O Sample taken at 342' 98.3°F.
342'		CL	343.0 - 344.0 Silty Clay: saturated, dk. bluish grey color, 5B 4/1			
	Water 1-5gpm		344.0 - 360.5 Silty Gravel: saturated same as 322.0-343.0			
		GM		A-50		
				A-51		
362'		CL	360.5-362.0 Silty Clay: saturated, plastic, dk. bluish-grey color 5B 4/1			
		GM	362.0-375.0 Silty Gravel: saturated 60% gravel, 25% sand fraction, 15% non plastic silt.	A-52		H_2O Temp 98.3°F Drillers "Bone" probably oversize cobble

SHEET 4 OF 10

DIVISION OF MINES AND GEOLOGY

DRILL HOLE LOG

HOLE NO. ____________

PROJECT & FEATURE ____________

DEPTH	WATER CONTENT	LOG	CLASSIFICATION AND DESCRIPTION	SAMPLE NO.	MODE	REMARKS
		CL	375.0-376.0 Silty Clay: saturated, bluish-grey color, 5B 5/1			
382'		GM	376.0-391.0 Silty Gravel: saturated, 80% black-greenish colored basaltic to dacitic volcanic rocks, minor coating of red ocher limonite on fracture surfaces, 20% silt, non-plastic, olive color, 5Y 4/2	A-53		H_2O Temp 110°F Rig Setting for 1 Hr.
				A-54		
	WATER 1-5 gpm	CL	391.0-392.0 Silty Clay: saturated, bluish-grey color, 5B 5/1.			
		GM	392.0-398.0 Silty Gravel: saturated			
		CL	398.0-399.0 Silty Clay: saturated, lt. bluish grey color, 5B 5/1	A-55		
402'		GM	399.0-416.0 Silty Gravel: saturated, dk volcanic rocks, 20% silt, low-plastic, lt. olive color			
				A-56		
		CL	416.0-417.0 Silty Clay: saturated, lt. bluish-grey color 5B 5/1			
422'		GM	417.0-423.0 Silty Gravel	A-57		Shutdown on 12/31/80 at 422: Tools pulled to change tri-cone.
		SM	423.0-427.0 Silty Sand:			
		GM	427.0-429.0 Silty Gravel: saturated, minor sht. rhyolite showing in gravel.	A-58		H_2O temp 114°F when hole blown.
		SM	429.0-438.0 Silty Sand: saturated, poorly sorted volcanic sands, 30% silt, lt. olive color, 5Y 5/4			
		GM	438.0-441.0 Silty Gravel	A-59		H_2O sample taken
442'		SM	441.0-444.0 Silty Sand:			Tools plugged at 445' shutdown on 1/12/81
	WATER 5-10 gpm	GM	444.0-461.0 Silty Gravel: saturated, 85% gravels, 15% silt, low plasticity olive color, 5Y 4/2	A-60		Tools pulled and sub changed restart on 1/15/81
				A-61		
462'		CL	461.0-462.0 Silty Clay: saturated, bluish-grey color, 5B 411			
		GM	462.0-470.0 Silty Gravel			H_2O Sample taken
				A-62		
		SM	470.0-478.0 Silty Sand: saturated olive color, 5Y 4/2			

SHEET 5 OF 10

DIVISION OF MINES AND GEOLOGY HOLE NO. ____

DRILL HOLE LOG .

PROJECT & FEATURE ____

DEPTH	WATER CONTENT	LOG	CLASSIFICATION AND DESCRIPTION	SAMPLE NO.	MODE	REMARKS
	5-10 gpm	SM	478.0-483.5 Sandy Clay: damp, med. sorted sand; 70% silty clay, dk. yellowish-brown color, 10YR 5/4	A-63		
482'	DRY	SC				
		SM	483.5-487.0 Silty Sand: saturated, poorly sorted, lt. olive color 5Y 5/4.			H_2O Temp 105°F
		SM	487.0-501.0 Silty Sand: saturated, med sorting, lt reddish brown color, 5YR 6/3.	A-64		
502'		GM	501.0-505.0 Silty Gravel: saturated, with lt. reddish-brown silt, 5YR 6/3	A-65		H_2O Temp 106.1°F
		SM	505.0-512.0 Silty Sand: saturated, med sorting, volcanic sand; silt, dk reddish borwn, 5YR 3/3. (oxidize fes to limonite feo)	A-66		Drill water "Red" color
		GM	512.0-514.0 Silty Gravel			
522'	Minor Water < 1gpm	SM	514.0-542.0 Silty Sand: saturated poorly sorted volcanic sand, pred. dk colored volcanics w/minor wht. rhyolite; 25% silt, low plasticity, lt. reddish-brown color 5YR 6/3	A-67, A-68, A-69		H_2O Temp 108°F H_2O Sample taken at 522'
542'		GM	542.0-564.0 Silty Gravels: saturated, 20-30% silt, low plasticity, lt. yellowish-brown color, 10YR 5/6	A-70, A-71		H_2O Temp 109.7°F
562'		GM	564.0-567.0 Same as above but gravels exhibit med. sorting			
		GM	567.0-578.0 Silty Gravel	A-72		H_2O Temp 109.7°F

SHEET 6 OF 10

The Resources Agency

DIVISION OF MINES AND GEOLOGY

DRILL HOLE LOG

HOLE NO. ______

PROJECT & FEATURE ______

DEPTH	WATER CONTENT	LOG	CLASSIFICATION AND DESCRIPTION	SAMPLE NO.	MODE	REMARKS
582	Water <1gpm	GM	578.0-580.0 Silty Sand: saturated, well sorted, sub-angular; 20% silt, low plasticity, lt. olive color 5Y 5/4			Fast Drilling
		SM		A-73		
		GM	580.0-587.0 Silty Gravel:			H_2O Temp 107.7°F
		CL	587.0-588.0 Silty Clay: lt. bluish-grey color 5B 4/1.	A-74		
	More Water 10-15gpm	GM	588.0-600.0 Silty Gravel: saturated, 80% volcanic sand and gravel; 20% silt, lt. olive color 5Y 5/4, low plasticity.			H_2O Temp 110°F
602		SM	600.0-603.0 Silty Sand	A-75		
		GM	603.0-612.0 Silty Gravel:	A-76		Drillers "Bone", probably bit rolling on oversize cobble.
		CL	612.0-613.0 Sandy Clay: saturated, poorly sorted, low plasticity, bluish-grey color 5B 6/1			H_2O Temp 116°F
622		GM	613.0-659.5 Silty Gravel: saturated, poorly sorted dk. colored volcanic rocks with minor sand lenses; silt, low plasticity, olive color, 5Y 5/4. Reddish-Brown color 5YR 6/3 in cuttings at 621'. Probably digenetic pyrite (FeS) oxidizing to limonite (FeO)	A-77		Rapid increase to 145° in H_2O temp then falloff to 121°F with Rotation shutdown 1/15/81 at 622'
				A-78		
	Water 1-5gpm	GM				H_2O Temp 119°F on restart on 1/16/81
642				A-79		
				A-80		H_2O Temp 115.4°F
662	Dry	CL	659.5-662.0 Silty Clay: Dry, med. Plastic, brown color, 10 YR 5/3. This zone was also dry on redrill	A-81		H_2O Temp 116°F H_2O Sample taken
	Water 1-5gpm	GM	662.0-698.0 Silty Gravel	A-82		H_2O Temp 115°F

SHEET 7 OF 10

DEPTH	WATER CONTENT	LOG	CLASSIFICATION AND DESCRIPTION	SAMPLE NO.	MODE	REMARKS
682'	Water 1-5 gpm	GM	Silty Gravel: saturated, poorly sorted, 20-25% silt, low plasticity, lt. olive color 5Y 5/4.	A-83 A-84		H_2O Temp 111°F
		CL	698.5-701.0 Sandy Clay: saturated low plasticity, lt. reddish brown color 2.5YR 4/4	A-85		
702'		SM	701.0-706.0 Silty Sand: saturated, med. sorted, lt. olive color 5Y 5/4			
		GM	706.0-718.0 Silty Gravel:	A-86		
	Wet (Cuttings Are Wet But No Free Water)	CL	718.0-720.0 Sandy Clay: wet, med. sorted sand w/ dk. reddish-grey clay 5YR 4/2 med. plastic.	A-87		
722		SM	720.0-738.5 Silty Sand: wet, med. sorting, princ. dk color volcanic sand; clayey silt, reddish-grey color 5YR 4/2. Clay appears to be insitu alteration of lt. reddish-brown andesite clasts.	A-88		H_2O Temp 119.4°F H_2O Sample taken at 740
		SM	738.5-742.0 Silty Sand: same as above but without altered clasts.	A-89		
742	Damp	CL	742.0-759.0 Silty Clay: damp, very plastic, reddish-brown color, 5YR 5/3. This unit is an oxidized, altered volcanic ash, probably of aerial origin (air fall) glass shards almost completely divitrified w/remnant crystals of mafics (hornblende, augite)	A-90		Rig shutdown on 1/16/81 at 742' H_2O Temp 146°F on startup 1/17/81 & on 1/21/81
762	Water 2.5gpm	SM	759.0-764.5 Silty Sand: wet, pred. dk. colored volcanic sand, med. sorting; 30% silt, non-plastic, olive brown color, 2.5 Y 4/4	A-91		H_2O Sample taken at 762'
	Damp	CL	764.5-777.0 Silty Clay: damp, very plastic, dk. yellowish brown color, 10YR 4/4. Altered volcanic ash of probable aerial origin. Same as 742.0-759.0 except lesser degree of oxidation.	A-92		

The Resources Agency

DIVISION OF MINES AND GEOLOGY

DRILL HOLE LOG

HOLE NO. ______________

PROJECT & FEATURE ______________

DEPTH	WATER CONTENT	LOG	CLASSIFICATION AND DESCRIPTION	SAMPLE NO.	MODE	REMARKS
782'	Damp	CL / GC	777.0-782.0 Clayey-Gravel: dry, poorly sorted volcanic tuff, sub-rounded, greenish-grey color, 56Y 5/1	A-93		Dusty Drilling
	Dry		782.0-786.0 Altered volcanic ash: dry, dk. greyish-brown color, 10YR 4/2.	A-94		
			786.0-794.0 Altered volcanic ash flow tuff: dry, lt. brownish-grey color, 10YR 6/2. Unit. grades downward into a hard unaltered tuff.	A-95		
802'			794.0-804.0 Welded Tuff:varigated color whitish-grey to greenish-grey highly siliceous, with minor pyrite and minor chlorite alteration.	A-96 A-97		Slow drilling Minor cuttings in return due to clays packing up in inner barrel
	Damp	CL	804.0-814.5 Silty Clay: damp, tuff fragments with altered volcanic ash, dk. yellowish brown color, 10 YR 4/4. Low plasticity.	A-98		Tools plugged at 802' on 1/20/81
822'			814.5-834.0 Altered volcanic ash: dry, dk. greyish-black color, 2.5YR n/3 minor euhedral crystals of pyrite (FeS), probably diagenetic in origin.	A-99 A-100 A-101 A-102		Rods getting difficult To rotate almost stuck on rod change. Water and oil injected into hole in an attempt to decrease torque.
842'			834.0-849.0 Altered volcanic ash: dry, same as above except color changes to a grey color 2.5YR 5/2.	A-103 A-104		
	Very Dry		849.0-854.0 Altered volcanic ash flow tuff: dry, greyish-black color, 2.5YR N/3 Dacitic-andesite in composition. Residual indurated zone at 851.5-852.5. Disseminated pyrite 1-2%.	A-105 A-106		
			854.0-856.5 Altered volcanic Ash: dry, very fine grained, lt. whitish-grey color, 5Y 7/1.	A-107 A-108		
862'			856.6-869.0 Altered volcanic ash: dry olive grey color, 5Y 6/1.	A-109 A-110		
	Damp		869.0-874.0 Altered volcanic ash: dry olive grey color, 5Y 5/1.	A-111		
	7-5 gpm		874.0-878.0 Ash flow tuff	A-112		

SHEET 9 OF 10

The Resources Agency

DIVISION OF MINES AND GEOLOGY

DRILL HOLE LOG

HOLE NO. ______

PROJECT & FEATURE ______

DEPTH	WATER CONTENT	LOG	CLASSIFICATION AND DESCRIPTION	SAMPLE NO.	MODE	REMARKS
882		SM	Welded tuff: highly siliceous, greyish-black color. Manganese along fracture surfaces. 878.0-880.0 Silty Sand: saturated 880.0-885.0 Welded tuff: lt. greenish-grey color, vesicular and glassy, 56Y 5/1 probably represents upper part of an ash flow tuff cooling unit . Rock is andesitic-dacite in composition. 885.0 Welded tuff: as above except color is black 2.5Y N/2. Pyrite 1% ≠ confined to fracture filling. manganese concentrations along fractures & rarely replaces feldspar. Very minor <1% calcite coating. Voids have been resilified with opaline (?)	A-113 A-114 A-115 A-116		Black "scum" on return water (Mg?) H_2O Temp 132.6^{o}F H_2O Sample taken Drilling very slow Hole abandoned at 885' on 1/23/81

SHEET 10 OF 10

APPENDIX C

WATER CHEMISTRY ANALYSES AND RESULTS

Chemical analyses of waters collected from the three wells are shown in Table C-1, along with dates of sample collection, sampling temperature, depth at which samples were collected, pH, specific conductance, salinity, calculated and corrected total dissolved solids, calculations of sodium adsorption ratios (SAR) and residual sodium carbonate (RSC) and chemical charactertics. An explanation of some of the methods used in the collection of the data presented in the columns shown on the table, together with comments on their meanings, is presented following the table.

The geothermal waters in all three wells drilled during this investigation are rich in chloride, implying a hot water system rather than a vapor dominated system.

As has been mentioned elsewhere in this addendum and also in the main volume of the Calistoga report, there are two principal water regimes in the vertical section at Calistoga: a shallow low temperature fresh water zone <120 ft) and a deeper higher temperature geothermal water zone (>120 ft). It is clear from an examination of the water analyses results given in Table C-1 that samples from the fresh water zone are mainly bicarbonate in anion character, with characteristically lower amounts of chloride, sulfate, and carbonate. The samples are mainly calcic in cation character, with relatively lower amounts of sodium, potassium, and magnesium, the other three major cations.

In contrast, the samples from the the geothermal water zone are mainly chloride in anion characteristic with lesser bicarbonate, carbonate, and fluoride content. They are sodic with respect to cation characteristic and have relatively lower calcium, magnesium, and potassium contents.

In general, the calcium bicarbonate fresh water is potable and non-injurious to plant growth. The geothermal waters, on the other hand, are high in sodium chloride and usually contain relatively high amounts of borNn, making them deleterious for many domestic and agricultural uses. Other important parameters in this regard include, but are not limited to, pH, total dissolved solids, SAR, and RSC, as suggested in the preceding explanatory notes for Table C-1.

The results of the drilling program at Calistoga as well as the study of water chemistry for 208 water wells surveyed in and around Calistoga (see the main Calistoga report volume) show that the sodium chloride water type displays the highest temperature and maximum SAR, RSC, and TDS. Moreover, they appear to represent the waters coming from deep-seated water zones.

EXPLANATION FOR TABLE 1

1. Sampling Temperature

Sampling temperature is the surface temperature for a spring or a non-boiling well discharge, the temperature of steam separation for well discharges above boiling, or the down-hole tmeperatures if a down-hole sampler is used. The average temperature for the geothermal waters is 41.5°C while that for the fresh water, is 12.5°C.

2. pH

This is an expression of the intensity of the acidity or alkalinity in water. The scale ranges from 0 (strongly acidic) to 14 (strongly alkaline) with neutral water at 7. Most Western U.S. irrigation waters fall in the mildy alkaline range, 7 to 8.5. The range of pH in the geothermal waters is 6.85 to 9.03 and that for the fresh water is 7.75 to 8.05. The waters of Arroyo #1 well are very mildly acidic to neutral, and those of Arroyo #2 and Moore #1 are neutral to very very slightly alkaline and mildly alkaline to strongly alkaline in nature, respectively.

3. Specific Conductivity

This is the reciprocal of resistivity. The resisitivity is the resistance in ohms of a conductor. Hence, specific conductivity is expressed in reciprocal ohms per centimeter, or mhos per centimeter (Todd, 1964). The range and mean specific conductance for geothermal waters in Arroyo #1, Arroyo #2, and Moore #1, respectively, are 500-900 and 750; 740-960 and 812; and 710-1120 and 911 micro mhos/cm. This shows a similar distinctive progression from west to east as was shown with pH determinations.

4. Cations

The basic cation constituents present in significant concentrations in the water are calcium, magnesium, sodium, and potassium. Calcium, magnesium, and potassium are essential plant foods.

Sodium is taken up by plants, but probably it is not an essential nutrient and may be toxic to plants if taken in heavy quantities. When the sodium concentration is higher, the alkali hazard is higher. Conversely, when calcium and magnesium predominate, the alkali hazard is lower. This hazard can be determined by calculating the Sodium-Adsorption-Ration (SAR).

5. Anions

Carbonate - bicarbonate, sulfate, chloride, and nitrate are the more important anions in water. Sulfate and nitrate are essential plant nutrients and are needed in reasonable concentrations. Chloride in higher concentrations is undesirable and is toxic to some plants. Carbonate water is strongly alkaline, but bicarbonate water is only mildly alkaline. The combined quantity and relative proportions of both determine the alkalinity and pH in a water. With high concentrations of these two anions, calcium and/or magnesium precipitate as carbonates and water becomes relatively concentrated in sodium, which increases the possibility of sodium (alkali) hazard. This hazard can be determined by calculating the Residual Sodium Carbonate (RSC).

6. Salinity (Alkali) Hazard

Salinity hazard is evaluated by using conductivity (that is, total dissolved solids). The growth of plants is hindered or prevented by this kind of hazard. Therefore, total dissolved solids or specific conductance becomes a good measure of the salinity hazard involved in the use of water for irrigation purposes. Total dissolved solids is a measure of the total quantity of dissolved matter in water. It can be determined by the gravimetric method or by calculations. It can also be estimated from the specific conductance. The range and mean corrected total dissolved solids for geothermal water in Arroyo #1; Arroyo #2, and Moore #1 are, respectively, 556-647 and 587; 563-733 and 600; and 549-622 and 580 mg/l. In fresh waters, it is quite low, the range being 145-201 and the mean 173 mg/l.

7. Sodium Hazard or Sodium-Adsorption-Ratio (SAR)

SAR is defined by the equation:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

in which the concentrations are expressed in milliequivalents per liter (meq/l). It is a calculated value. This sodium-adsorption-ratio is used to consider the sodium hazard. SAR is based on the absolute and relative concentrations of positively charged major ions in water. The range and mean of the sodium adsorption-ratios for geothermal waters in Arroyo #1, Arroyo #2, and Moore #1 are, respectively, 9.15 - 10.13 and 9.27, 5.10 - 18.10 and 10.97; and 5.75 - 16.33 and 11.30 meq/l. The range and mean in fresh waters are very low, being 0.67 - 0.71 and 0.69 meq/l, respectively.

8. Bicarbonate Hazard or Residual Sodium Carbonate (RSC)

RSC is used in considering the bicarbonate hazard of water, which is defined by the equation:

$$RSC = (CO_3^{=} + HCO_3^{-}) - (Ca^{\pm\pm} + Mg^{\pm\pm}).$$

in which the concentrations are also expressed in meq/l. It is also a calculated value. Past researchers (Wilcox, L.V., 1955) have shown that waters with more than 2.50 meq/l are marginal, and those containing less than 1.25 meq/l RSC are probably safe. In the present study, the range and mean of residual sodium carbonate ratios for geothermal waters in Arroyo #1, Arroyo #2, and Moore #1 are, respectively, 2.34 - 2.63 and 2.45; 0.03 - 3.77 and 2.42; and 0.00 - 2.86 and 1.81 meq/lRSC. The value for the fresh waters is 0.00 meq/lRSC.

9. Boron Hazard

Boron is found in all natural waters. The concentrations range from traces to several milligrams per liter. Boron is essential to plant growth but is exceedingly toxic at levels only slightly above optimum. Plants may tolerate boron up to 0.5 mg/1B. Injury in senitive plants may develop when irrigated with water containing 0.5 or more mg/1 of boron. In the present study, boron seems to be associated with the sodium-chloride type of water. The range and mean of the boron concentrations for geothermal waters in Arryo #1, Arroyo #2, and Moore #1 are, respectively, 10.4 - 10.7 and 10.5; 10.2 - 17.3 and 11.5; and 10.5 - 12.0 and 11.1 mg/1 B. In the fresh waters, they are 0.2 - 0.4 and 0.3 mg/1 B.

10. Chemical Characteristics of Geothermal Waters

A cation or anion is said to be dominant when its weight in milliequivalents comprises 50% or more of the cation or anion group. In the cases where no cation or anion dominates, the term "mixed" is used to describe the characteristic of the water. On this basis, two kinds of chemical characteristics are found in the present study:

(i) Sodium-Chloride and

(ii) Calcium-Bicarbonate waters.

Water samples M-016-81 and M-017-81 from the fresh water zone are of the calcium-bicarbonate class, and all the other water samples are of the sodium-chloride class. Chemical characteristics were calculated by converting mg/1 values to equivalent parts per million (epm) and then comparing individual cations and anions among their groups. Chemical characteristics are given along with the chemical analyses and other parameters in Table C-1.

Table 1. <u>WATER CHEMISTRY</u> Chemical Analyses and other Parameters for the Well Waters from Calistoga, Napa County, California.

SAMPLE #s	DATE COLLECTED	SAMPLING F	TEMP C	DEPTH FEET	DEPTH METERS	PH	SPECIFIC COND. umho/cm	SALINITY %	Na mg/l	K mg/l	Ca mg/l	Mg mg/l	Fe mg/l	Al mg/l	SiO mg/l	Ti mg/l	Sr mg/l	Ba mg/l	Mn mg/l	Cu mg/l	Zn mg/l	W mg/l	Li mg/l	B mg/l	Cl⁻ mg/l	F⁻ mg/l	CO⁻ mg/l	HCO⁻ mg/l	Bo mg/l	TOTAL DISSOLVED SOLIDS CALCULATED mg/l	TOTAL DISSOLVED SOLIDS CORRECTED mg/l	SAR meq/l	RSC meq/l	CHEMICAL CHARACTERISTIC
ARROYO#1																																		
M-001-80	12-23-80	77	25	155	47.3	6.85	550	0.2	168	9	11	7	0.21	L	26	L	0.08	L	0.6	L	L	L	0.77	10.4	191	7.5	0	212	L	660	556	9.74	2.34	Sodium-Chloride
M-002-80	12-23-80	79	26	180	54.9	7.05	900	0.4	176	16	13	6	18.94	8.4	36	0.5	0.07	L	6.3	L	L	L	1.12	10.5	193	8.9	0	230	L	761	647	10.13	2.63	Sodium-Chloride
WR-1	12-31-80	68	20	30	9.1	7.00	800	0.3	168	8	14	7	2.59	L	18	L	0.11	L	0.5	L	L	L	0.80	10.7	190	6.6	0	227	L	670	558	9.15	2.45	Sodium-Chloride
ARROYO#2																																		
M-003-80	12-30-80	89.5	32	180	54.9	7.10	800	0.3	173	10	15	7	5.74	6.1	12	0.4	0.08	L	L	L	L	L	0.71	10.2	179	6.8	24	195	L	692	596	9.24	2.67	Sodium-Chloride
M-004-80	12-30-80	91	33	200	61.0	7.10	790	0.3	174	8	16	6	2.79	3.9	15	0.3	0.08	L	L	L	L	L	0.50	10.2	183	6.5	17	200	L	678	580	9.42	2.53	Sodium-Chloride
M-005-80	12-30-80	91	33	235	71.6	7.10	830	0.9	166	7	15	7	3.05	3.3	13	0.2	0.08	L	0.3	L	L	L	0.54	10.3	175	5.5	14	212	L	668	563	9.84	2.84	Sodium-Chloride
M-006-80	12-31-80	97	36	280	85.4	7.20	960	0.4	181	9	12	4	2.61	3.7	13	0.2	0.07	L	L	L	L	L	0.84	10.8	190	6.7	18	189	L	677	584	11.56	2.67	Sodium-Chloride
M-007-81	1-15-81	113	45	400	122.0	7.40	810	0.2	190	7	7	3	14.71	2.8	20	0.2	0.04	L	0.3	L	L	L	1.39	11.1	190	7.2	12	211	L	708	605	15.13	3.25	Sodium-Chloride
M-008-81	1-15-81	122	50	462	141.0	7.40	790	0.3	181	7	11	4	6.87	3.1	19	0.2	0.05	L	L	L	0.1	L	1.17	10.8	189	7.2	9	214	L	693	588	11.87	2.92	Sodium-Chloride
M-009-81	1-15-81	122	50	520	159.0	7.70	800	0.3	194	6	8	2	11.55	1.9	26	L	0.06	L	L	L	L	L	1.23	11.3	188	7.2	26	183	L	690	600	15.92	3.28	Sodium-Chloride
M-010-81	1-16-81	124	51	620	189.0	7.90	820	0.3	204	6	8	1	8.78	1.6	36	L	0.07	L	L	L	0.3	L	1.18	12.5	189	7.3	21	217	L	730	623	18.10	3.77	Sodium-Chloride
M-011-81	1-17-81	131	55	740	225.6	7.70	740	0.05	188	7	60	4	2.87	1.2	25	L	0.08	0.9	L	L	6.4	L	1.23	11.0	190	8.3	9	192	L	723	628	6.35	0.13	Sodium-Chloride
M-012-81	1-21-81	116.5	47	762	232.3	7.40	825	0.0	166	5	10	4	14.55	8.9	19	0.3	0.06	L	0.3	L	0.1	L	0.78	10.7	188	7.1	9	156	L	644	568	5.10	2.02	Sodium-Chloride
M-013-81[1/]	1-20-81	100	38	320	97.6	7.65	800	0.4	179	6	60	4	5.24	1.9	54	0.2	0.13	L	0.3	L	3.0	L	1.35	11.3	190	9.0	6	189	L	737	644	6.04	0.03	Sodium-Chloride
M-014-81	1-20-81	107.5	42	664	202.4	7.70	800	0.2	234	5	53	4	11.53	4.4	25	0.2	0.09	L	0.3	L	3.5	L	0.61	17.3	175	6.0	50	235	L	849	733	8.35	2.55	Sodium-Chloride
M-015-81	1-20-81	100	38	320	97.6	7.65	800	0.4	183	5	7	2	5.01	0.7	54	0.1	0.05	L	L	L	L	L	1.39	11.5	188	9.0	8	189	L	680	587	15.73	2.83	Sodium-Chloride
MOORE#1																																		
M-016-81[2/]	1-29-81	53.5	12	12	3.7	7.75	122	0.0	13	L	22	4	0.11	L	36	L	0.07	L	L	L	2.2	L	L	0.2	7	L	0	75	11	182	145	0.67	0.0	Calcium-Bicarbonate
M-017-81[3/]	1-29-81	55	13	65	19.8	8.05	220	0.1	18	L	34	9	L	L	36	L	0.13	L	L	0.1	1.2	L	L	0.4	9	L	0	142	L	270	201	0.71	0.0	Calcium-Bicarbonate
M-018-81	1-29-81	97	36	210	64.0	8.36	890	0.2	170	4	14	4	0.32	L	30	L	0.08	L	L	L	0.1	L	0.60	11.2	188	4.3	0	207	L	651	549	10.31	2.37	Sodium-Chloride
M-019-81	1-29-81	113	45	242	73.8	8.40	950	0.1	178	5	66	4	1.48	0.6	37	0.1	0.15	1.0	0.3	0.1	3.2	0.1	0.88	12.0	189	6.2	9	182	L	711	622	5.75	0.0	Sodium-Chloride
M-020-81	1-29-81	115	46	282	86.0	8.42	850	0.2	174	5	23	3	2.05	1.0	34	0.2	0.08	L	L	L	1.0	L	0.88	10.9	183	6.6	9	179	L	652	564	9.06	1.83	Sodium-Chloride
M-021-81	1-30-81	115	46	322	98.2	8.45	710	0.8	189	5	10	2	1.50	1.5	23	0.2	0.07	L	L	L	0.3	L	0.68	11.3	186	5.9	14	188	L	654	562	14.27	2.86	Sodium-Chloride
M-022-81	2-04-81	142	61	542	165.2	9.03	1120	0.4	185	7	16	1	22.52	L	36	L	0.04	L	0.3	L	1.5	L	1.72	10.7	195	10.2	23	133	L	660	595	12.13	2.04	Sodium-Chloride
M-023-81	2-04-81	142	61	562	171.3	8.42	950	0.5	184	7	8	1	2.31	L	34	L	0.06	L	L	L	0.3	L	1.68	10.5	260	11.2	8	122	L	668	608	16.33	1.77	Sodium-Chloride

1/ Contaminated with tap water while filtering. M-015-81 is duplicate Sample of M-013-81.

2/ This is a fresh water sample from the hand-dug well along side of the drill-site (7 ft. away).

3/ This is a fresh water sample from the well about 50 feet away from the drill-site.

GEOTHERMOMETRY

Geothermometry is an indirect and unique method of calculating the subsurface temperature of a geothermal reservoir. Geothermometry makes use of certain chemical indicators as geothermometers. The summary of the geothermometrical methods and calculations is given in the main volume of the report for Calistoga.

Muffler (1979, p. 64), utilizing the Na-K-CA geothermometric method, calculated a temperature of 141°C for the geothermal reservoir at Calistoga. Majmundar (in preparation) calculated a temperature of 139°C for the same Calistoga reservoir.

In the present drilling investigation, the geothermometrical calculations for the reservoir temperature have been compiled in Table C-2. The averages for each method used are given at the end of the table. Water types for each of the samples have been calculated and are given at the right side of the table.

EXPLANATION FOR TABLE C-2

1. Conductive Temperature (Chalcedony)

   This is the chalcedony saturation geothermometric temperature (°C) with conductive cooling.

2. Conductive Temperature (Quartz)

   This is the quartz saturation geothermometric temperature (°C) assuming no steam loss during conductive cooling.

3. Adiabatic Temperature (Quartz)

   This is the quartz saturation geothermometric temperature (°C) assuming steam loss during adiabatic cooling.

4. Feldspar Temperature

   This is the temperature (°C) calculated from the ratios of Na to K using the White-Ellis curve (cf Truesdell, 1975) Fournier-Truesdell (1973, 1974) equation or revised Fournier (1979) equation.

5. Cation Temperature

   This is also known as the empirical temperature (°C) calculated from the Na to K to Ca using Fournier and Truesdell's (1973, 1974) equation. Fournier and Potter (1979) have published a method of correcting this empirical temperature on the basis of sample's magnesium content.

6. Calculations for classification of water were performed using "weight" as a basis. Equivalent parts per million (epm) values have been used in determining the various water types. The symbols used in this column have the following meanings:

   = when one cation/anion is approximately equal to another cation/anion in concentration.

   $\geq$ when one cation/anion is 1 to 1.2 times the concentration of another cation/anion.

> when one cation/anion is 1.2 to 3 times the concentration of another cation/anion;

>> when one cation/anion is 3 to ten times the concentration of another cation/anion;

>>> when one cation/anion is more than 10 times the concentration of another cation/anion.

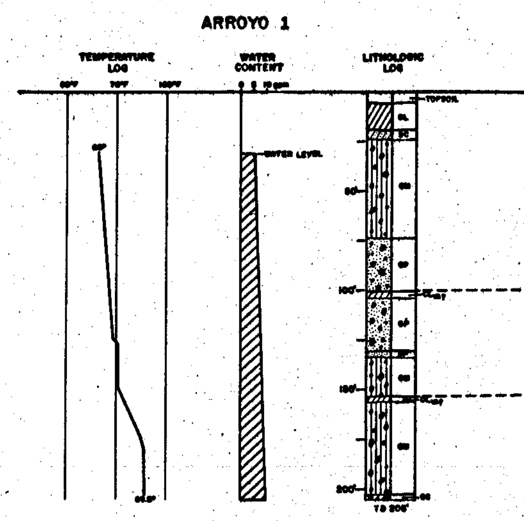
Water type for each water sample in the present investigation is calculated and tabulated at the right hand column on Table C-2 for comparison with subsurface temperature data.

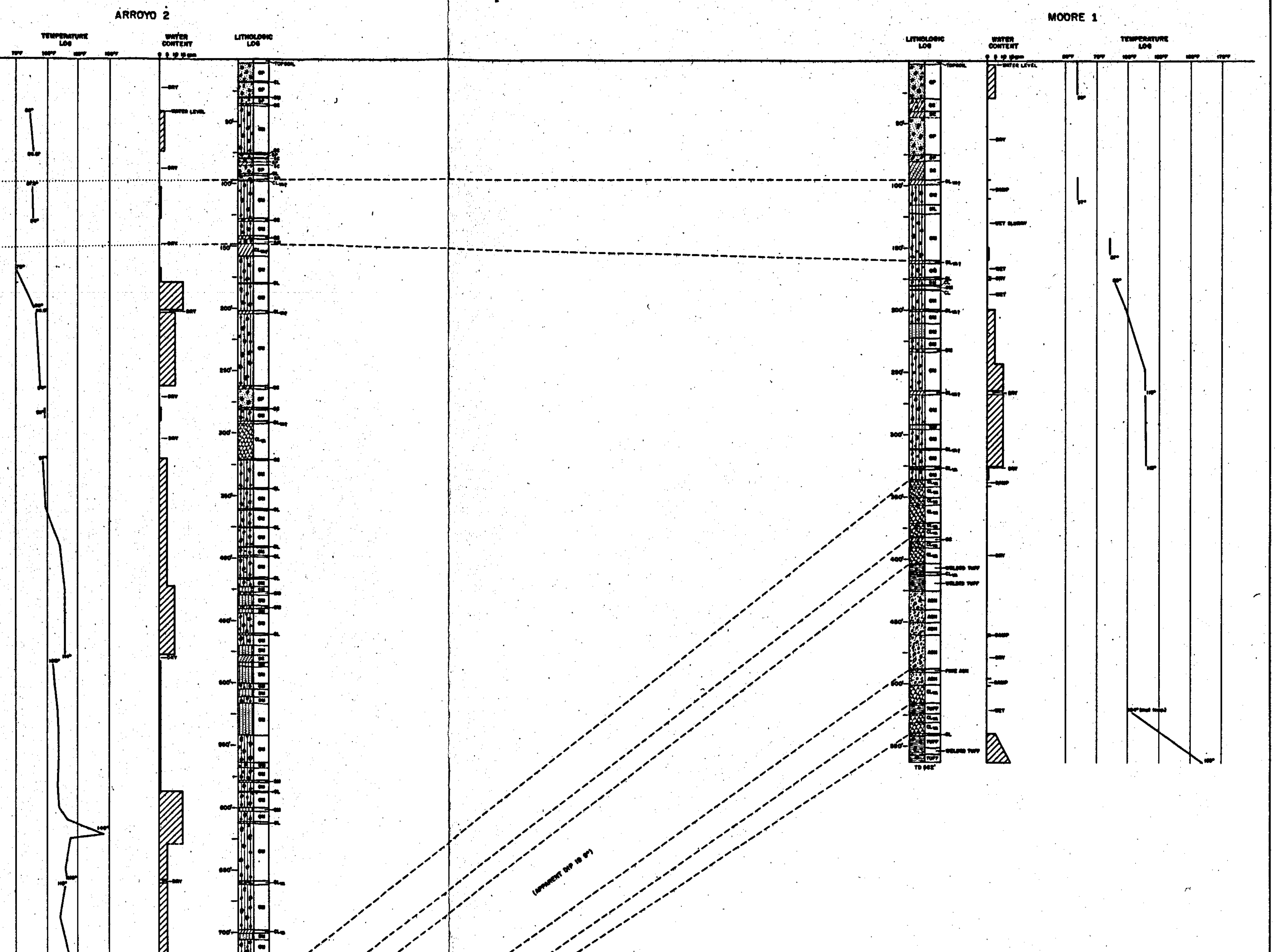
Table 2. GEOTHERMOMETRY Subsurface geothermometric temperatures and water types calculated from the chemical indicators in well waters tabulated in Table 1.

	SILICA TEMPERATURES C°					FELDSPAR C°		CATION TEMPERATURES C° EMPERICAL Na, K, Ca		Mg CORRECTED CATION TEMP. C°	WATER TYPE
								FOURNIER & TRUESDELL, 1973			
SAMPLE #s	SAMPL. TEMP. C°	CHALCEDONY (Conductive)	QUARTZ (Conductive)	QUARTZ (Adiabatic)	WHITE & ELLIS cf TRUESDELL, 1975	FOURNIER & TRUESDELL, 1973, 1974	FOURNIER 1979	β=1/3	β=4/3	FOURNIER & POTTER, 1979	
ARROYO #1											
M-001-80	25	40.2	73.8	79.1	128.8	121.1	168.7	154.0	118.0	28.0	Na >>> Ca ≥ Mg > K Cl > HCO_3 >>> F
M-002-80	26	54.3	87.1	90.8	177.5	173.0	209.0	180.0	138.0	50.0	Na >>> Ca ≥ Mg ≥ K Cl > HCO_3 >> F
WR-1	20	25.4	59.8	66.7	119.4	111.1	160.7	146.0	107.0	34.0	Na >>> Ca ≥ Mg > K Cl > HCO_3 >>> F
ARROYO #2											
M-003-80	32	11.7	46.5	54.7	135.2	127.8	174.1	155.0	114.0	39.0	Na >>> Ca ≥ Mg > K Cl > HCO_3 >> CO_3 > F
M-004-80	33	17.8	52.4	60.0	116.7	108.2	158.4	144.0	104.0	47.0	Na >>> Ca ≥ Mg > K Cl > HCO_3 >> CO_3 > F
M-005-80	33	12.2	47.0	55.2	110.2	101.3	152.7	140.0	100.0	36.0	Na >>> Ca ≥ Mg >> K Cl > HCO_3 >> CO_3 > F
M-006-80	36	12.6	47.4	55.6	122.8	114.7	163.7	151.0	116.0	58.0	Na >>> Ca > Mg ≥ K Cl > HCO_3 >> CO_3 > F
M-007-81	45	30.0	63.9	70.5	100.3	91.0	144.1	141.0	121.0	50.0	Na >>> Ca > Mg ≥ K Cl > HCO_3 >> CO_3 = F
M-008-81	50	28.0	62.2	68.8	103.9	94.6	147.1	140.0	109.0	51.0	Na >>> Ca > Mg ≥ K Cl > HCO_3 >> F ≥ CO_3
M-009-81	50	40.2	73.8	79.1	88.3	78.5	133.5	133.0	112.0	74.0	Na >>> Ca > Mg = K Cl > HCO_3 >> CO_3 > F
M-010-81	51	54.4	87.2	90.9	85.0	75.1	130.6	132.0	113.0	108.0	Na >>> Ca > K > Mg Cl > HCO_3 >> CO_3 > F
M-011-81	55	38.5	72.3	77.7	101.1	75.4	144.8	---	70.0	---	Na > Ca >> Mg ≥ K Cl > HCO_3 >> F ≥ CO_3
M-012-81	47	26.5	60.8	67.6	86.7	76.7	132.0	---	97.0	53.0	Na >>> Ca ≥ Mg > K Cl > HCO_3 >> F ≥ CO_3
M-013-81	38	74.2	105.5	106.8	93.8	84.1	138.3	---	65.0	---	Na > Ca >> Mg > K Cl > HCO_3 >> F > CO_3
M-014-81	42	39.0	72.7	78.2	65.4	54.7	112.8	---	65.0	---	Na >> Ca >> Mg > K Cl > HCO_3 > CO_3 >> F
M-015-81	38	74.2	105.5	106.8	80.3	70.1	126.3	128.0	108.0	67.0	Na >>> Ca > Mg ≥ K Cl > HCO_3 >> F > CO_3
MOORE #1											
M-016-81	12	---	---	---	---	---	---	---	---	---	Ca > Na > Mg HCO_3 >>> SO_4 ≥ Cl
M-017-81	13	---	---	---	---	---	---	---	---	---	Ca > Na > Mg HCO_3 >>> Cl
M-018-81	36	46.3	79.6	84.2	71.1	60.6	118.0	---	82.0	69.0	Na >>> Ca > Mg >> K Cl > HCO_3 >>> F
M-019-81	45	55.7	88.4	92.0	82.0	72.0	127.9	---	57.5	---	Na > Ca >> Mg > K Cl > HCO_3 >> F ≥ CO_3
M-020-81	46	52.2	85.2	89.1	83.5	73.5	129.2	---	79.0	79.0	Na >> Ca >> Mg > K Cl > HCO_3 >> F ≥ CO_3
M-021-81	46	35.1	69.0	74.9	78.2	68.0	124.4	---	99.0	84.0	Na >>> Ca > Mg ≥ K Cl > HCO_3 >> CO_3
M-022-81	61	54.4	87.2	90.9	102.2	93.0	145.6	---	100.0	100.0	Na >>> Ca >> K > Mg Cl > HCO_3 >> CO_3 > F
M-023-81	61	51.8	84.8	88.8	102.6	93.4	146.1	142.0	117.0	112.0	Na >>> Ca > K > Mg Cl > HCO_3 >> F > CO_3

STATISTICS

ARROYO #1										
No/samples	3	3	3	3	3	3	3	3	3	3
Range	20-26	25.4-54.3	59.8-87.1	66.7-90.8	119.4-177.5	111.1-173.0	160.7-209.0	146.0-180.0	170.0-138.0	28.0-50.0
Mean	23.7	40.0	73.6	78.9	141.9	135.1	179.5	160.0	121.0	37.3
Median	25.0	40.2	73.8	79.1	128.8	121.1	168.7	154.0	118.0	34.0
ARROYO #2										
No/Samples	13	13	13	13	13	13	13	9	13	10
Range	32-55	11.7-74.2	46.5-105.5	78.2-135.2	65.4-135.2	54.7-127.8	112.8-174.1	128.0-155.0	65.0-121.0	36.0-108.0
Mean	42.3	35.3	69.0	103.9	99.2	88.6	143.0	140.4	99.5	58.3
Median	42.0	30.0	63.9	101.6	93.8	91.0	144.1	140.0	108.0	52.0
MOORE #1										
No/Samples	6	6	6	6	6	6	6	1	6	5
Range	36-61	35.1-55.7	69.0-88.4	74.9-92.0	71.1-102.6	60.6-93.4	118.0-146.1	142.0	57.5-117.0	69.0-112.0
Mean	49.1	49.3	82.4	86.7	86.6	76.8	132.0	142.0	89.1	88.8
Median	46.0	52.0	85.0	89.0	82.8	70.8	128.6	142.0	91.0	84.0





WATER CONTENT DEFINITIONS

1 gpm 1-5 gpm 5-10 gpm	Actual water yield measured at the discharge with drill rotation and rod advance shutoff and air circulation being maintained through dual-tube rods. Recorded gallonage does not indicate total aquifer yield, as an aquifer showing 10-15 gpm would, if developed by standard well techniques, produce several times this amount of water with minimal drawdown.
WET SLURRY -	Material produced from discharge has enough free water to suspend particulate matter, but almost impossible to filter for a water sample. Behaves as a fluid but has a high percentage of solids.
WET -	Material has enough free water that water can be extruded upon hand squeezing but a water sample could not be attained.
DAMP -	Material will not produce water upon squeezing but contains minor interstitial water such that it can be molded and remains as a coherent mass.
DRY -	Material cannot be molded, is non cohesive and was discharged accompained by minor clouds of dust.
VERY DRY -	As above except material was discharge wholly as a dust.

LITHOLOGIC DESCRIPTIONS

- GP - Gravel -	Poorly sorted, well graded gravels, typically composed of sub-rounded to sub-angular volcanic gravel and sand fraction with minor (< 15 %) per cent silt fraction.
- GM - Silty Gravel -	Poorly sorted, well graded gravels, sub-rounded to sub-angular volcanic gravel and sand fraction, silt fraction 15 %, inorganic and minor plasticity, light olive-brown color 2.5 Y 5/4, forms collodial suspension easily, probably derived from volcanic ash and/or ash-flow tuff.
- GC - Clayey Gravel -	Poorly sorted, well graded gravel, sub-rounded to sub-angular gravel and sand fraction, 10-25 per cent clay, moderate plasticity.
- SC - Clayey Sand -	10-25 per cent clay, sub-rounded to sub-angular volcanic sand; clay moderate plasticity, hard when dry.
- SM - Silty Sand -	Poorly sorted to well sorted volcanic sands, 15-40 per cent silt fraction, inorganic, low plasticity, typically light olive-brown 2.5 Y 5/4 color, forms collodial suspension easily, probably derived from volcanic ash and/or ash flow tuffs.
- CL - Clay -	Moderate to high plasticity, olive-grey 5 Y 4/2 to dark greyish-brown 2.5 Y 4/2 color, hard when dry, typically contains volcanic clast saprolites.
- CL_{VA} - Clay - Damp -	Appears to be an in-situ altered volcanic ash of probable aerial origin, high degree of plasticity, expansive, typically bluish-grey color 5 Y 4/2 but may range to reddish-brown 5 YR 5/3 if oxidized, completely devitrified glass shards with remnant crystals of mafics (Hornblende, Augite).
- Altered Volcanic Ash - or Ash Flow Tuff	Dry, unconsolidated pyroclastic ash of aerial origin or non-indurated ash flow tuff. Olive grey 5 Y 5/1 to greyish-black 2.5 YR N/3 color range. Glass shards have been altered to smectites but degree of alteration is not as advanced as the above clay $unit_{VA}$. Very plastic when wetted, expansive.
- Welded Ash Flow Tuff -	Variability in degree of induration from slightly elliptical glass shards to completely re-silicified glassy matrix. Typically contains 1-2 per cent pyrite (diagenetic?) and manganese coating along fracture surfaces. Dacitic-andesitic in composition.
- ML - Silt -	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.

CALISTOGA GEOTHERMAL TEST HOLE LOGS AND CORRELATIONS

LITHOLOGIC, WATER CONTENT, AND TEMPERATURE LOGS OF ARROYO 1, ARROYO 2 AND MOORE 1 DRILLHOLES CALISTOGA, NAPA COUNTY, CALIFORNIA

BY
GARY TAYLOR

HORIZONTAL SCALE (Approximate) - 1" = 100'
VERTICAL SCALE - 1" = 25'