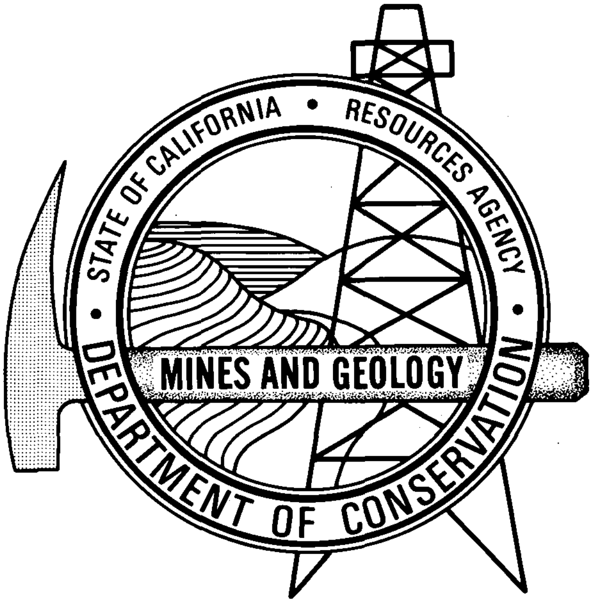
CALIFORNIA DEPARTMENT OF CONSERVATION
DIVISION OF MINES AND GEOLOGY

DMG OPEN-FILE REPORT 83-27

GEOTHERMAL RESOURCES OF THE NORTHERN SONOMA VALLEY AREA, SONOMA COUNTY, CALIFORNIA

1983



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GEOTHERMAL RESOURCES OF THE NORTHERN SONOMA VALLEY AREA, CALIFORNIA

1983

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EXECUTIVE SUMMARY

This report presents the results of an investigation, by the California Division of Mines and Geology, of the geothermal resources of the northern Sonoma Valley area, California. A report on the geothermal resources of the southern Sonoma Valley area, (Youngs and others, 1983) indicated several patterns, trends, and anomalies that appeared to extend north and northwest in the valley. Study of the northern valley area was conducted to attempt to follow these trends and to determine whether significant geothermal resources exist in the area.

A low-temperature geothermal resource has been delineated in the northern Sonoma Valley which is highly localized and of modest temperature. Some specific characteristics of the resource are presented below:

- All evidence suggests the low-temperature geothermal resources in the Sonoma Valley are characteristic of liquid-dominated hydrothermal convection systems. Deep circulating fluids are warmed from the earth's natural heat gradient and then ascend along faults or fracture zones into permeable aquifers underlying the Sonoma Valley.

- The geothermal fluids, underlying portions of the Sonoma Valley, are primarily found in permeable units of Sonoma Volcanics.

- There are three main areas that contain a potential geothermal resource. Included are a northwestward-trending zone, subparallel to the Healdsburg-Rodgers Creek fault zone, that extends from the City of Santa Rosa to the Bennett Valley area; the Spring Lake-Melita area; and an area south of Kenwood that includes Morton's Warm Springs and the McEwan Ranch warm spring.

- Fourteen warm water (temperature $\geq$20°C, 68°F) wells and springs occur within the study area.

- The highest directly measured temperature of geothermal fluids found in the study area is 31.7°C (89.1°F) at the MacDonald Well. However, geothermometry calculations suggest maximum temperatures could be as high as 110°C (230°F) in the deeper subsurface near Morton's Warm Springs. In addition, an overall average geothermometry temperature of 70°C (158°F) was obtained for all of the geothermal occurrences in northern Sonoma Valley for which geochemical data were available (temperature based on the Na-K-Ca ($\beta = 4/3$) geothermometer).

- Water quality, for the termal waters tested, is for the most part good, and disposal of the effluent, after utilization, is not expected to present any major problems.

- Maximum volume of the geothermal fluids available for production was not determined because of lack of pump test data, but artesian flow, which has continued in historic time, suggests that significant geothermal resources exist in the three main areas discussed.

Recommendation:

- Utilization of the resource appears to be feasible for a variety of low-temperature direct uses at this time, and is recommended.

Recommended Further Work Includes the Following:

- A shallow-hole temperature probe survey may greatly refine the understanding of the distribution of heated fluids in the three main areas described and in the "Most Likely Geothermal Production Zone" that extends from the southern valley area into the northern area along the east side of the Sonoma Valley; this type of survey is recommended for any additional study.
- Drilling of deeper (300 meter) test holes in each of the three aforementioned areas can provide confirmation of the geothermal gradient and of the higher resource temperatures that are suggested for the deeper subsurface by geothermometry data. It can also isolate and test individual geothermal aquifers and thus provide temperature measurements (which may be much higher) for unmixed waters. Only by drilling to the resource and pump testing can the volume, temperature, and quality of the geothermal fluids and thus the final proof of the resource be obtained. Test drilling is strongly recommended for any additional study.

ABSTRACT

The northern Sonoma Valley area contains low-temperature geothermal resources near the lower part of the categorized temperature range (20°-90°C) (68°-194°F) that may have the potential for useful development. Although the geothermal resources in the northern Sonoma Valley area appear to be more modest than those in the central portion of Sonoma Valley, as described by Youngs and others (1983), local governments and institutions, private developers, and manufacturers in the northern area may be able to utilize the geothermal resources. This report and the previous California Division of Mines and Geology (CDMG) report on the geothermal resources in the central and southern portions of Sonoma Valley (Youngs and others, 1983) provide a preliminary overall evaluation of the geothermal resources for the entire Sonoma Valley area.

Historically, there have been at least four geothermal springs known in the northern part of Sonoma Valley; all of these are still producing warm water. These include Morton's Warm Springs (formerly known as Los Guilicos Hot Springs), The McEwan Ranch spring, an unnamed spring at Spring Lake, and the MacDonald Warm Spring site. A linear trend of historically known warm water sites in the central portion of the Sonoma Valley may possibly continue into the northern portion of Sonoma Valley to include Morton's Warm Springs. Detailed geophysical, geothermal, and geological surveys conducted in the northern study area were not able to delineate a northern extension of the "east side" fault as described in Youngs and others (1983).

The highest recorded water temperature in the northern Sonoma Valley appears to be 31.7°C (89.1°F) in the artesian discharge from the MacDonald Well (Plate 1, Location No. 13). A similar temperature of 31°C (88°F) was recorded at a depth of 6.1 meters (20 feet) in the Morton's Warm Springs well. Three wells, located along the northwest alinement of warm water wells in association with the Healdsburg-Rodgers Creek fault zone, also gave recorded temperatures of approximately 30°C (86°F).

Interpretation of geophysical, geochemical, and geologic data indicates that geothermal resources located in the northern Sonoma Valley, as well as the entire Sonoma Valley area, are indicative of water-dominated hydrothermal convection systems. Such systems allow warmed meteoric water, heated by the earth's natural thermal gradient, to ascend to the surface or into permeable aquifers near the surface along permeable fracture zones or faults. In the northern Sonoma Valley study area, such a geothermal "plume" is proposed as the source of geothermal fluids encountered in wells and springs in the northwest alinement in the western portion of the study area along the Healdsburg-Rodgers Creek fault zone. More localized "plumes" are thought to exist in the Spring Lake-Melita area and at Morton's Warm Springs and the McEwan Ranch warm spring area. Of greater potential significance, however, in the entire Sonoma Valley, is a zone of known geothermal resources in association with the "east side" fault in the central portion of the valley.

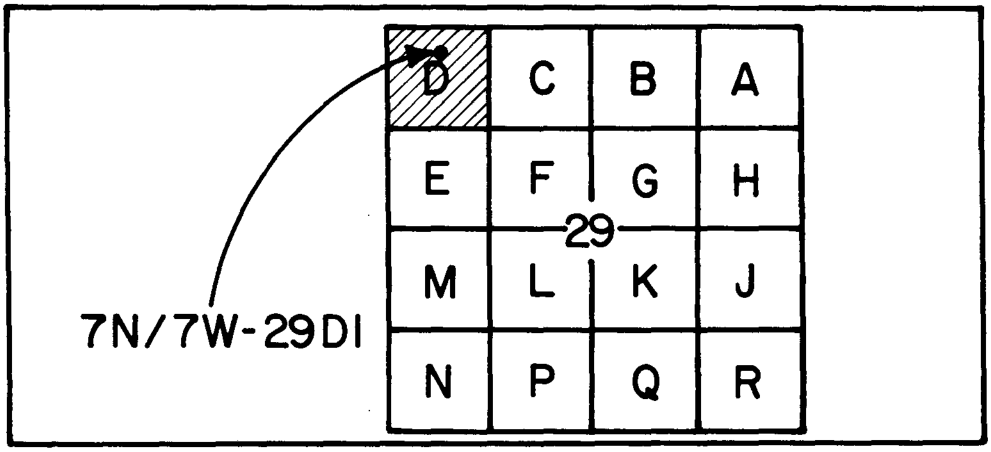
Exploration drilling is recommended in the three suggested areas of northern Sonoma Valley to better define the size and extent of these low-temperature geothermal resources of the Sonoma Valley and evaluate their potential for development.

INTRODUCTION

In 1983, the California Division of Mines and Geology (CDMG), under a grant from the U.S. Department of Energy (DOE), investigated the low-temperature (20°-90°C) (68-194°F) geothermal resources of the central and southern portions of the Sonoma Valley, California. The resulting report presented a summary of historical development of the geothermal resources and the results of geological investigations, detailed geophysical surveys, a study of regional seismicity, geothermometric calculations, geochemical analysis of water samples, and direct temperature measurements, as well as conclusions drawn from these results. Those preliminary results indicated several patterns, trends, and anomalies that appeared to extend north and northwest into the northern reaches of the Sonoma Valley area. This study was conducted by CDMG in an attempt to delineate those anomalies in the northern Sonoma Valley area and to provide an overview of the known low-temperature geothermal resources in the northern area. In recent years, there has been an increased interest in alternate energy sources. As a result, the potential of low- to moderate-temperature geothermal resources is coming under study throughout California. The two CDMG reports presenting the basic geoscientific aspects of the geothermal resources in the Sonoma Valley area should be used as a starting point for all those with an interest in the geothermal resources in this area. Data provided in these two reports should be helpful for local residents, local governments, private developers, and manufacturers in the Sonoma Valley area to ascertain if they are located in a favorable area for geothermal development. These two reports may then be used as a basis for a more detailed or localized exploration program. These reports may be useful in support of financial requests to State and Federal government geothermal development aid programs. The data and conclusions presented in these reports identify the types of uses to which the geothermal resources of Sonoma Valley may be applied, the type of equipment necessary to utilize the resources, and the total cost-effectiveness of potential utilization of the resources.

The well data compiled for this report come from a variety of sources. Because of the varied sources of data, the location of each well or spring shown on Plate 5 and Table 3 is given in one of two locating systems. One system is the simple latitude and longitude to the nearest hundredth of a minute of each site in the area. The second system is more complex and is known as the State Well Numbering System. This system has two basic parts: its township and range and its section location. For example, Well Location No. 15 on Plate 1 is located by 7N/7W, 29D1. The well is located in Township 7 North, Range 7 West, and Section 29. Each section is subdivided into 16 quarter-quarter sections of 16 hectare (40 acres) each; each 16-hectare tract is identified by a letter. Letters A-R are used, with letters I and 0 omitted to avoid confusion with similar appearing numbers. This particular well is in tract "D". Figure 1 shows the lettering system. The final part of the well number is the sequential number of the well within that particular tract.

In the early days of settlement in California, certain areas were set aside as Land Grant Ranchos -- a large proportion of the Sonoma Valley was land grant areas. These areas were not surveyed into township and range subdivisions. However, the surveyed township, range, and section lines surrounding the Sonoma Valley were projected into the valley for the purpose of numbering some of the water wells listed on Plate 5 and Table 3.



STATE WELL NUMBERING SYSTEM

Figure 1.

WARM SPRINGS IN THE NORTHERN SONOMA VALLEY AREA

The earliest and the most commercially developed warm springs areas in the Sonoma Valley were located in the central portion of the valley in a "warm water belt" (Bradley, 1915) that extends north-northwest from the City of Sonoma. Included within this belt are Boyes Hot Springs, Fetters Hot Springs, and Agua Caliente Springs. These sites are Location Nos. 54, 53, and 52 respectively on Plate 1. The historic records of these sites as well as some others are documented in Youngs and others, 1983.

There are at least four known warm springs in the northern study area. Historically, these springs were less commercially developed than those in the central portion of the valley and hence the literature is somewhat sparse. However, the following accounts should provide some insight into the historic nature of these warm springs:

Morton's Warm Springs (Los Guilicos Warm Springs)

The Morton's Warm Springs recreational site (in the past known as Los Guilicos Warm Springs) is located approximately 2.4 kilometers (1.5 miles) south of the City of Kenwood on the east bank of Sonoma Creek and adjacent to Warm Springs Road (Plate 1, Location No. 29.)

It is interesting to note that "...in the early 1800's, the land (northern Sonoma Valley) was swampy and covered with heavy growths of willows, alders, bay and oak; the site of Kenwood being entirely underwater." (Cook, 197?, p. 46). In 1887, the land was drained, and the town, later to be named Kenwood, was laid out. The next year a plot of land was set aside at the natural warm springs, previously a favorite camping ground of the Wappo Indians of the northern Sonoma Valley. The marshy, tide water lands of the southern Sonoma Valley were origianlly occupied by the Coast Miwok Indians (Beard, 1979).

Waring (1915) described two springs at the Los Guilicos Warm Springs site each of which yielded about two to three gallons per minute at water temperatures 25.6°C (78°F) and 27.8°C (82°F) respectively:

> "In 1909 there was a small bathing pool and an old hall or pavilion at the spring near the eastern bank of the creek; at the other spring, on the opposite bank, there was a small pool enclosed by an old bathhouse. The place was used as a camping resort, and several cottages had been erected among the trees nearby."

Berkstresser (1968) lists three geothermal features at the Morton's Warm Springs site; the first two listed are probably wells and the third is listed as a shelter-covered spring. The temperatures respectively are 30.6°C (87°F) measured on November 1, 1956, 28.9°C (84°F) measured on November 1, 1956, and 30.6°C (87°F) measured on October 1, 1966.

Currently at this site, a well about 55 meters (180 feet) deep and 31.8 cm (12.5 inches) in diameter supplies warm water for filling two swimming pools, irrigating the picnic grounds, space-heating the structure on the premises, and supplying the domestic water to 20 nearby residences under the auspices of the Los Guilicos Water Works. Figure 27 is the downhole temperature log of this well. The well, despite this heavy load usage, flows artesian during the winter months. The temperature of the surface discharge water, measured on February 24, 1982, was 30°C (89°F). Natural warm water seepage is still sometimes evident in the bottom of Sonoma Creek behind the swimming and picnic facilities.

The McEwan Ranch Warm Spring

According to Waring (1915), the McEwan Ranch warm spring was located about 2.4 kilometers (1.5 miles) west of Los Guilicos Warm Springs. Waring claims the spring was used partly for irrigation, but that the spring had not been efficiently developed or improved.

It is assumed that an undeveloped warm spring on the property, currently known as the Kiezer Ranch on Bennett Valley Road, is the same spring in Waring's 1915 account. (Plate 1, Location No. 28). The spring surfaces very near the ranch house at a temperature of 23.3°C (74°F) and flows through a narrow ditch to the Yulupa Creek. The temperature reportedly remains constant year round. The spring was discharging at approximately 25 gpm on February 23, 1982. It appears that this spring was never commercially developed. A well of unknown depth has been drilled about 2 meters or so from the spring. This well supplies the entire water requirements of the residents at the ranch.

McDonald Well (Spring ?)

There is a warm water artesian well located approximately 4.8 kilometers (3 miles) east of the City of Santa Rosa on Channel Drive in the Melita area. The well is located in the backyard of a small home on the west bank of a tributary to Santa Rosa Creek. Historically, this well has been called the McDonald Well (Plate 1, Location No. 13).

The McDonald Well is 37.8 meters (128 feet) deep and was drilled in 1955. On December 30, 1982, the well was flowing at approximately 70 gpm at 31.7°C (89.1°F). A chemical analysis of the water from the McDonald Well is shown on Plate 5. A few of the residences near the McDonald Well site also have wells that contain warm water, however, none are as warm, nor produce as much water as the McDonald Well. It is believed that a warm water spring existed at this site sometime in the past. On March 31, 1898, the Sonoma Valley was shaken by an earthquake of magnitude 6.2, whose epicenter was located in the extreme southern part of the valley. A few days later, the Santa Rosa Press-Democrat (April 6, 1898, p. 3) published the following in the "Locals" column:

> "The water in the McDonald Warm Spring east of town was raised 2 feet by the earthquake".

Spring Lake Park Unnamed Spring

In Spring Lake Park, approximately 1 kilometer (0.6 miles) west of the McDonald well, is a warm water spring issuing from the opening of what appears to be a mine adit (Plate 1, Location No. 12). The warm water flows into a small swimming lagoon constructed next to Spring Lake. Little historic data on this spring can be found. However, Park Headquarters personnel thought that the adit was dug a long time ago to improve and clear the flow of the spring. On December 13, 1982, CDMG staff recorded 27°C (81°F) in the discharge of the spring and estimated a 10-20 gpm flow rate. However, on January 6, 1983, other CDMG staff recorded a temperature of 22°C (72°F) in the unnamed spring discharge. This apparent 5°C decrease in temperature over a three week period may reflect differences in measurement techniques. A chemical analysis of the spring water is shown on Plate 5.

Conclusions

The warmest-recorded spring temperature in the study area is 31.7°C (89.1°F) from the well at the McDonald Spring site, followed closely by the 30°C (86°F) measured in the well at Morton's Warm Springs.

The water temperature of Morton's Warm Springs (Plate 1, Location No. 29) may have increased a few degrees over the years since the early 1900's as the accounts above indicate. However, the apparent temperature increase may be the result of inaccuracies in thermometers, inconsistent measurement techniques, or time of year of measurement. At any rate, the flow of the geothermal resource at Morton's Warm Springs has certainly increased since the early 1900's with the drilling of wells at the site. The four historically known warm springs are grouped into two areas. One area south of Kenwood includes Morton's Warm Springs and the McEwan Ranch warm spring. The other area is approximately 4.8 kilometers (3 miles) east of the City of Santa Rosa in the Melita area and includes the unnamed warm spring at Spring Lake Park and the McDonald Warm Spring site (Plate 1). It is interesting to note that, unlike the southern portion of Sonoma Valley where the majority of the known geothermal springs and wells are located in the valley floor proper, in the northern Sonoma Valley area, the historical-known warm springs are located south and southwest of the valley floor in the lower portions of the Sonoma Mountains. This suggests that the natural warm springs in the study area may have some relation to the volcanic rocks that comprise the Sonoma Mountains. The small number of natural warm springs and the modest temperatures recorded in those that do exist imply limited volume, distribution, and temperature of the geothermal resources in the northern Sonoma Valley area.

GEOLOGY OF NORTHERN SONOMA VALLEY AND VICINITY, SONOMA COUNTY, CALIFORNIA

Introduction

The northern Sonoma Valley lies within the Coast Ranges geomorphic province. The tectonics of the province in this area are to a large extent controlled by the right-lateral northwest-trending San Andreas fault system of which the Rodgers Creek, Healdsburg, and Maacama faults are a part. The orientation of northwest-trending mountains and intervening valleys is also to a large part controlled by this fault system. The Santa Rosa and northern Sonoma Valley areas are at the focus of this en echelon system of right-lateral strike-slip faulting.

Purpose

Geologic mapping for this project was undertaken to obtain a better understanding of the stratigraphy and structure of the northern Sonoma Valley. Because the Sonoma Volcanics are known to contain thermal fluids in other areas (Taylor and others, 1981; Chapman and Chase, 1982; and Chapman and others, 1983), this understanding is important to help assess the geothermal resources of the valley.

Previous Studies

The geology of the region has been described by Osmont (1905), Dickerson (1922), Morse and Bailey (1935), and Weaver (1949). Cardwell (1958) and Kunkel and Upson (1960) discussed the water-bearing characteristics of the Sonoma Volcanics in the Sonoma and Napa Valleys. Recent regional studies of this area include Fox and others (1973), Fox (in press), and Huffman and Armstrong (1980), the last being a compilation of previous work. Sickles (1974) mapped geology and geologic hazards in the Kenwood/Glen Ellen area.

Present Study

The geologic map (Plate 1) in this report was compiled at a scale of 1:24,000 from new field observations, from interpretation of black and white aerial photographs at an approximate scale of 1:24,000, and from previous mapping by Fox and others (1973), Cardwell (1958), Sickles (1974), and Weaver (1949).

Variations from previous mapping principally involved some redesignation of unit names, a larger number of mapped faults, and relocation of contacts. Because of difficulties in correlation of rock types across the valley, the geology of each side of the northern Sonoma Valley is discussed separately. The geologic study was confined to, but not inclusive of, the zone labeled "Area Of The Northern Sonoma Valley Geothermal Resource Investigation" shown on Plate 1.

General Geologic Setting

Rock types mapped in the northern Sonoma Valley and vicinity include, from the oldest to youngest, Franciscan Complex and related basement rocks, Petaluma Formation, Sonoma Volcanics, Glen Ellen Formation, and surficial deposits of Quaternary age.

The Jurassic-Cretaceous Franciscan Complex is exposed only in the northeastern part of the area. The Miocene Petaluma Formation is exposed only in the southern-most part of the area. The Mio-Pliocene Sonoma Volcanics is the most extensive rock unit and is deposited unconformably upon the Franciscan Complex in some areas and thrust over Franciscan rocks in other areas. The Sonoma Volcanics are here considered to be mostly younger than the Petaluma Formation, except for the lower portion of the Sonoma Volcanics, which in places interfingers with rocks of the upper Petaluma Formation (Fox, in press). In the study area, the contact was not observed and it is not known if the contact between the two units is gradational or unconformable. Unconformably (?) overlying the Sonoma Volcanics is the Plio-Pleistocene Glen Ellen Formation, which is in turn overlain by Pleistocene and Holocene alluvium and fan deposits.

The northeastern side of Sonoma Valley is characterized by a greater variety of rock types, fewer warm water occurrences, limited hydrothermal alteration of rocks, and moderate to steep dips in the Sonoma Volcanics. In the southwest side of the valley, rocks generally have gentler dips, there are several occurrences of warm water, and faulting apparently is more extensive than previously recognized.

Geology of Northeast Side of Northern Sonoma Valley

Franciscan Complex and Serpentinite

The Jurassic and Cretaceous Franciscan Complex as mapped by Fox and others (1973), underlies major portions of the Mayacmas Mountains. On the northeast side of Sonoma Valley, it forms an uplifted core upon which the Sonoma Volcanics and other Tertiary rock units were deposited. On some places, the Sonoma Volcanics were thrust over this core of Franciscan Complex rocks.

The Franciscan Complex consists of abundant sheared shale and sandstone units (KJfs), which contain resistant masses of hard rocks of several lithologic types including graywacke, shale, greenstone, limestone, chert, some lenses of conglomerate, and metamorphic rock. The metamorphic rock consists principally of metagraywacke with lesser amounts of metachert; silica-carbonate rock is derived from the hydrothermal alteration of serpentinite. For the purpose of this study, serpentinite is generally lumped with the Franciscan Complex.

Where Serpentinite (Sp) is mapped separately, it includes relatively fresh ultra-mafic masses that occur as sheets, lenses, and irregularly shaped bodies, both within and along the boundaries of the Franciscan Complex north and east of Mt. Hood. The base of the Franciscan Complex has not been recognized. For more information on the Franciscan Complex, see Bailey and others (1964), Hsu (1968), and Berkland and others (1972).

Sonoma Volcanics

The Mio-Pliocene Sonoma Volcanics (Fox, in press) is a complex sequence of intercalated volcanic rocks composed of ash-flow and ash-fall tuffs of silicic to intermediate composition, lavas of varying compositions ranging from rhyolite to basalt, agglomerates, volcanic breccias, water-laid tuffs, and sedimentary deposits derived from the Sonoma Volcanics.

Average thickness of the Sonoma Volcanics in northern Sonoma Valley has been estimated at 183 meters (600 feet) by Sickles (1974) for the area northeast of Glen Ellen. Cardwell (1958) estimated 305-366 meters (1,000-1,200 feet) for the Sonoma Volcanics northeast of Kenwood and suggested that the thickness may be greater than 610 meters (2,000 feet). Estimates of thickness are speculative due to complications imposed by extensive faulting, major folding that forms broad synclinal valleys and anticlinal mountain ranges, and by minor folding on the limbs of the larger synclinal structure.

Each of the units depicted as part of the Sonoma Volcanics (Plate 1) typically contains more than one of the rock types mentioned above, thus each unit was assigned a name based on the perceived predominance of a particular rock type. Nomenclature loosely follows that of Fox and others (1973), although there are several areas where the unit names were redesignated.

Glen Ellen Formation and Overlying Surficial Deposits

In the Sonoma Valley area, the Plio-Pleistocene Glen Ellen Formation and its equivalents are mostly conglomerates and fine grained tuffaceous sands and silts with some interbedded silicic tuffs from the upper Sonoma Volcanics. Clasts of obsidian are diagnostic of conglomerates in the Glen Ellen Formation (Fox, in press) and helped to differentiate the Glen Ellen from the Pliocene Huichica Formation. Surficial deposits consist of Quaternary older and younger alluvial fan deposits, composed mostly of sand and gravel, and older alluvium, which contains silt, sand, clay, and gravel.

Structure

The structure of the northeast side of Sonoma Valley is characterized by a generally southwestward dip of the bedding and foliation of Tertiary rock units, with generally north to northwest strikes. The Franciscan Complex is interpreted to form the core of the Mayacmas Mountains which have been uplifted relative to Sonoma Valley.

In the area of Buzzard Peak (Plate 1, 7N/7W, Sections 11 and 12) attitudes and observation of the rocks suggest the presence of a northwest plunging anticline. Weaver (1949, p. 152) noted the existence of minor folds on the northeastern limb of the Kenwood-Sonoma syncline, which forms the southwest facing slope of the Mayacmas Mountains. The presence of these minor folds makes estimates of the stratigraphic thickness of the Sonoma Volcanics speculative.

Other minor folding was only distinctly observed in two places: a tight syncline in Adobe Canyon (near the 5.4 m.y. age-date locality shown on Plate 1), and in the Tst unit in the canyon northeast of Kenwood (Plate 1, 7N/6W, Section 28). Folding in Adobe Canyon was observed in a laminar, white, rhyolite unit. This could be merely contortions within the rhyolite unit, or may be a reflection of the larger tectonic picture involving possible thrust faulting in this area. Synclinal folding in the canyon northeast of Kenwood, within the Tst unit exposed on the north facing slope, is evident from the outcrop of a thick ash-flow tuff. The fold appears to be overlain by a Tsa unit which has not been similarly folded.

In the Sugar Loaf Ridge area and on the east side of Mt. Hood, the contact between the Franciscan Complex and the Sonoma Volcanics is shown as a fault. The type of movement is not clear, but it may be a thrust fault. For this area, Sickles (1974) suggested that the Sonoma Volcanics have been thrust eastward, over other members of this unit and over Franciscan and serpentine rocks as well. North and west-northwest of Mt. Hood, the Sonoma Volcanics-Franciscan Complex contact is shown as depositional (compiled from Fox and others, 1973). In the area between Mt. Hood and the campground area in Sugar Loaf Ridge State Park (Plate 1, 7N/6W, Section 22), the Franciscan Complex-Sonoma Volcanics contact has been obscured by extensive landsliding.

A strike-fault between Tst and Tsa is mapped east of Calistoga Road in Township 7 North, Range 7 West, Sections 4 and 5 and trending to the southeast. As discussed later, the fault is interpreted from geophysical evidence to be of normal displacement with the southwest side down relative to the northeast side. In the central portion of the Kenwood quadrangle, this fault may be buried by pyroclastic flow deposits. It also projects toward a group of three volcanic domes or dikes to the east of Adobe Canyon Road. An alternate explanation is that this is a depositional contact, the strike of which coincides with the location of the domes or dikes.

Several faults are shown due east of Kenwood. Most were mapped on the basis of tonal differences observed on aerial photos. The faults in this area are not known to offset Quaternary materials in the valley, although extensive cultivation of top soils could have destroyed evidence of offset.

A north-trending fault is mapped in the canyon at the upper end of Pythian Road; volcanic rocks observed in the canyon walls are highly fractured and weathered. The fault probably does not offset the welded tuff along the northeastern margin of Sonoma Valley. The sense of offset is not known.

In summary, the northeast side of northern Sonoma Valley has been moderately folded and faulted at least into the Pleistocene. The dominant strike of the rock units is northwest. The major faults within the Sonoma Volcanics are interpreted to be steeply dipping with at least a vertical component of movement. The extent of horizontal components of movement is not known. Thrust faulting in the area probably involves Sonoma Volcanics thrust over Franciscan Complex rocks and perhaps some thrust faults wholly within the Sonoma Volcanics.

Geology of Southwest Side of Northern Sonoma Valley

In contrast to the northeast side of the valley, the rocks on the southwest side are less severely deformed, which is reflected by the more-subdued upland topography. Surface exposure of the Franciscan Complex is absent; present are the Petaluma Formation, Sonoma Volcanics, Glen Ellen Formation (and possibly Huichica Formation), and various young alluvial fan deposits.

Petaluma Formation

The Miocene Petaluma Formation consists of poorly consolidated fluvial, lacustrine, and brackish-water sediments; fine-grained deposits, mainly clay and clay shale, are the most common (Fox, in press). It is exposed only in the area southwest of Morton's Warm Springs where, along Bennett Valley Road, the formation comprises sandy and silty clay with small interbeds of coarse sand and pebble conglomerate. The conglomerate contains clasts of quartz, red chert, black chert, and a distinctive, banded siliceous rock. The thickness of the Petaluma Formation here is unknown.

Sonoma Volcanics

The Mio-Pliocene Sonoma Volcanics covers most of the upland area on the southwest side of northern Sonoma Valley. It is composed mainly of complexly interbedded massive flows and flow breccias of intermediate to mafic composition, tuffs and agglomerates of intermediate to silicic composition, and lesser amounts of massive flows, flow breccias and possibly shallow intrusions of silicic composition; the maximum thickness of these deposits is unknown. Except for local sections, the general stratigraphy within the Sonoma Volcanics here is still not conclusively established. It is complicated by irregular interbedding of commonly indistinguishable petrologic units and by folding and faulting. Fox (in press) lumped all of the Sonoma Volcanics in this area as part of a "lower member", which in the Sonoma Mountains ranges in age from about 5.5 m.y. to at least 7.1 m.y. based on potassium-argon dates.

Lavas of mafic to intermediate composition in most of the area have been differentiated into two units. One unit, distinguished by the presence of phenocrysts of olivine and augite, covers much of the northwestern third of the area. Although it probably includes interbeds of tuff, the unit is dominantly a sequence of flows of olivine-augite basaltic andesite. The second unit, whose stratigraphic position relative to the first unit is not known at this time, covers much of the central third of the area east of Bennett Mountain and is more silicic than the rocks of the first unit. It is composed mostly of dark gray to black lavas of hypersthene andesite.

South of Melita, stratigraphically beneath and interbedded locally with members of the basaltic andesite unit is a thick sequence of tuff and agglomerate of mostly intermediate composition. Some of these pyroclastic deposits may be genetically related to the basaltic andesite lavas. Small exposures of similar although not necessarily correlative deposits are on the southeast flank of Bennett Mountain.

In and near Schultz Canyon, the large canyon west of Schultz Road, a large thickness of silicic tuff with a thin interbed of rhyolite-perlite is stratigraphically beneath flows of the hypersthene anedsite unit described above. These tuffs are exposed over a large part of the area around Schultz, Lawndale, and Bennett Valley Roads. Silicic tuff, is also exposed extensively northwest of Bennett Mountain. This area was mapped as "andesitic to basaltic lava flows" by Fox and others (1973), but the abundance of tuffs requires that the map unit be redefined. Because of insufficient time to map the tuffs separately, the unit is newly mapped as undifferentiated Sonoma Volcanics.

North and east of Bennett Mountain, lavas and possibly shallow intrusions of pink to gray banded rhyolite with zones of perlite are exposed in several places. None are sufficiently distinct in hand specimen to differentiate them. They are known to both overlie and underlie flows of the hypersthene andesite unit and are commonly interbedded with silicic tuffs.

Glen Ellen Formation

The Plio-Pleistocene Glen Ellen Formation consists of fluvial deposits, predominantly conglomerate and tuffaceous sand and silt with lesser amounts of tuff. It is composed mostly of detritus from the Sonoma Volcanics and the Franciscan Complex. The formation onlaps Sonoma Volcanics along the low elevations of northern Sonoma Valley's flanks and is present in the vicinity of Morton's Warm Springs (Plate 1, Location No. 29). In the Sonoma Valley, its thickness is probably at least about 200 meters (656 feet). In the Morton's Warm Springs area, some rocks mapped as Glen Ellen Formation may actually be part of the Pliocene Huichica Formation, which is a sequence of fluvial and lacustrine sediments (Fox, in press). Thicknesses of the Glen Ellen Formation in this area are unknown.

Alluvial Deposits

Quaternary alluvial fan deposits cover most of the floor of Sonoma Valley and are present in a few upland valleys and along stream courses in the Morton's Warm Springs area. The maximum thickness of the deposits may be about 30-50 meters (98-164 feet) in the main Sonoma Valley. The deposits consist largely of detritus derived from the Sonoma Volcanics, the Franciscan Complex, and the Glen Ellen Formation, all exposed in the surrounding highlands.

Structure

The detailed structure of the southwest side of the northern Sonoma Valley cannot be determined until the stratigraphy of the Sonoma Volcanics is established. Nevertheless, there are several localities where the general structure can be discerned. Attitudes and displacements of bedding in volcaniclastic and alluvial deposits is the best evidence of deformation; flow banding and contacts in lava flows are sometimes useful but must be cautiously evaluated.

Gentle to moderate folding is evident in the Glen Ellen Formation along the main valley's margin. Dips are generally 15°-30° to the north or northeast. Near Morton's Warm Springs, the Glen Ellen Formation (or Huichica Formation) is gently folded into a series of small alternating anticlines and synclines (see Cardwell, 1958). West of here, in Schultz Canyon, silicic tuffs and the contact between the silicic tuffs and overlying hypersthene andesite flows all dip very gently to the southeast. The gentle dip indicates either little or no folding in this general area or proximity to the axis of a large broad fold.

In the area south of Melita, shallow dips (10°-30°) in different directions were noted in tuffs and agglomerates, which suggest gentle irregular folding or, in some cases, initial depositional angles. Locally steep dips are probably evidence of drag along faults.

Fox and others (1973) mapped a major fault zone and several smaller faults along the southern fringes of the study area. The Bennett Valley fault zone trends nearly north-south at Spring Lake then curves to the southeast as it cuts the southwest flank of Bennett Mountain and continues along the floor of Bennett Valley. Judged by its trace across the topography, the fault zone appears to dip very steeply in the study area. Its sense of displacement is not known, although Fox (in press) reported a probable vertical component of movement of at least 300 meters (984 feet), southeast of Bennett Mountain. The movement has upthrown the Bennett Mountain (NE) side of the fault relative to the Bennett Valley (SW) side. Gravity data, discussed in the subsequent section, may indicate, however, that the depth to Franciscan rocks is less on the Bennett Valley side than on the Bennett Mountain side. The youngest known movement on the fault zone is late Pliocene (Fox, in press).

Southwest of Morton's Warm Springs, Fox and others (1973) mapped a northwest-trending fault that juxtaposes Glen Ellen Formation with what is interpreted as Petaluma Formation. This fault may be associated with a postulated fault that continues to the northwest to the head of Frey Canyon which is north of the unnamed reservoir.

Several faults, some definite, others postulated, were mapped during the present study in the vicinity of Frey Canyon and northwest of there. Most trend northwest or northeast, although one southwest of Schultz Canyon, mapped from aerial photographs, trends north-south. Some are inferred to cut the Glen Ellen Formation which indicates activity as young as Pleistocene. Most of the newly mapped faults are queried; some may be depositional contacts whose apparent abruptness and geometry resulted from irregular topographic surfaces. It is possible, however, that some represent a northwest-trending zone of faults that cuts Frey Canyon and continues toward Melita.

In summary, the southwest side of northern Sonoma Valley has been folded and faulted, at least into the Pleistocene. Folding has been relatively mild and irregular; the dominant trend of fold axes appears to be northwest. Faulting is prominent between Bennett Valley and the upland crowned by Bennett Mountain. A northwest-trending zone of faults is inferred to extend from west of Morton's Warm Springs through Frey Canyon, possibly as far as Melita. North- and northeast-trending faults may also be extensive. Observed faults have steep dips and vertical components of displacement; the extent of horizontal components of displacement on faults in the area is unknown.

Summary of General Structure of the Main Valley

The northern Sonoma Valley is a conspicuous topographic feature that includes most of the study area. The patterns of folding and faulting in the uplands on each side of the valley indicate that the valley is largely of structural rather than erosional origin. How the rocks and structure on each side are related beneath the valley's bottom is still conjectural, however. The presence or absence of major faulting and, where present, the type of faulting under the valley, likely influence the extent of geothermal resources in the valley more than any other factor.

The only rock unit that can be correlated from one side of the valley to the other with any confidence is the Glen Ellen Formation. Its gentle to moderate inclinations toward the valley's axis indicate that the valley is underlain by a large syncline whose axis is both under and parallel to the length of the valley's floor. The thickness of the Glen Ellen Formation near the synclinal axis can be estimated from a log of a deep (about 350 meters/1150 feet) water well, reported by Cardwell (1958), about 3 kilometers (1.9 miles) directly south of Buzzard Peak. Here, the Glen Ellen Formation and the Quaternary fan deposits together are interpreted as 277 meters (909 feet) thick, which is consistent with the estimated thickness of the Glen Ellen Formation along the valley flanks. The bottom 73 meters (240 feet) of the well is reportedly in Sonoma Volcanics.

The interpretation of a syncline is also supported by the presence on the northeast side of the valley of moderately inclined deposits of the Sonoma Volcanics, which generally dip to the southwest and onlap a core of Franciscan Complex rocks to the northeast; this inclination may be complicated locally by minor folds (some overturned) and faults. Attempts to correlate these rocks with the Sonoma Volcanics on the southwest side of the valley have been unsuccessful in this and previous studies. The rocks on each side may truly be from different episodes of volcanism within the general unit defined as the Sonoma Volcanics. This difference is suggested by both lithologic contrasts and by potassium-argon ages (Kenneth F. Fox, Jr., unpublished data), which indicate the Sonoma Volcanics is progressively older in a south-southwest direction. On the other hand, more-detailed field and laboratory work may recognize correlative units present on both sides of the valley.

The less intense deformation of the southwest side of the valley is reflected by the more subdued topography, the more gentle and irregular folding of the rocks, and the absence of exposed rocks of the Franciscan Complex; more intense deformation of the area would likely have uplifted the Franciscan Complex in a manner similar to that on the northeast side of northern Sonoma Valley. These characteristics indicate that the syncline is asymmetric; a simplified diagram of this interpretation is shown in Figure 2. The syncline appears to be truncated on the northwest by several strike-slip fault zones in the vicinity of Santa Rosa. On the southeast, the main fold continues, with complications, into southern Sonoma Valley.

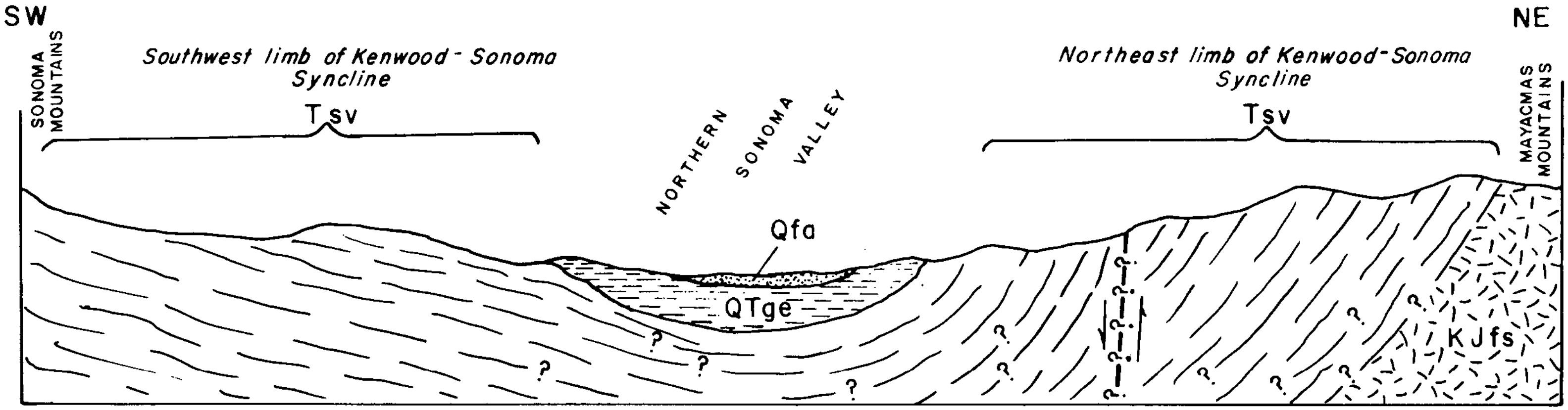


Figure 2. Diagrammatic section across northern Sonoma Valley. An open, asymmetric syncline underlying the valley is depicted. Correlation of individual units within Sonoma Volcanics from one side of valley to the other is not yet established (depicted by question marks). Queried fault in northeast limb may have repeated part of the section of volcanic rocks. Sense of displacement of fault determined from geophysical data. A large concealed fault (not shown) may also underlie center of valley and may explain the change in deformation from one side of valley to the other. Thickness of Sonoma Volcanics is not known. Qfa - Surficial fan and alluvial deposits, QTge - Glen Ellen Formation, Tsv - Sonoma Volcanics, KJfs - Franciscan Complex and serpentine.

The general change in attitudes and composition of beds of the Sonoma Volcanics from one side of the main valley to the other could also be explained by a large, concealed fault under the valley bottom parallel to the major synclinal axis. As discussed earlier, the Sonoma Volcanics on the northeast side of the valley may also be disrupted by a large, northwest- trending fault parallel to the general strike of the bedded deposits (Figure 2 and Plate 1); this fault corresponds approximately with a geophysical anomaly (Plate 2) and may have caused repetition of some of the stratigraphic section. Generally consistent attitudes and thicknesses of the Glen Ellen Formation on both sides of the valley suggest that the Glen Ellen Formation is not offset by major faulting.

Cross faults in the adjacent uplands appear to have little or no effect on the overall synclincal structure of the valley.

Influence of Geology on Locations of Thermal Water in Northern Sonoma Valley

Known locations of thermal water in northern Sonoma Valley are relatively few and of modest temperature. The water is evident in a few springs and several water wells along valley floors; evidence of past or present hydrothermal activity in the highlands that surround the valley floor is largely absent. The only known location of definite hydrothermal alteration in the northern Sonoma Valley is at some of the rhyolite quarries in Nunns Canyon, north of Glen Ellen. Rocks in the quarry in Township 7 North, Range 7 West, Section 10 on Los Alamos Road may also be hydrothermally altered.

The warmest thermal water occurrences are in the Spring Lake-Melita area and in the Morton's Warm Springs area. Two other possible resource areas are just east of Kenwood and at Oakmont Golf Course.

On the east side of Spring Lake, a small warm spring (Plate 1, Location No. 12) is at the base of a steep escarpment. The spring likely rises along the Bennett Valley fault zone, which is probably responsible for the escarpment. About 1 kilometer (0.6 miles) northeast of this spring, along the road to Annadel State Park, are a few shallow warm water wells (Plate 1, Location No. 13) about 20-40 meters (66-131 feet) deep. The wells are drilled into Quaternary alluvium and Sonoma Volcanics; they are immediately adjacent to a ridge underlain by non-welded tuffs of intermediate to silicic composition, which may serve as an aquifer for the thermal water. It is also possible that a northwest-trending fault parallels the base of this ridge in line with the water wells.

Of possible significance is the approximate coincidence of the thermal water at Spring Lake-Melita with a zone of concentrated stress postulated by Fox (in press) where Bennett Valley merges into Rincon Valley. Here, several major right-lateral strike-slip fault zones meet in en echelon pattern with their traces abruptly bent. This area could be the site of an incipient "pull-apart" zone, characterized by thinning of the crust and thus a possible geothermal anomaly. The zone may not be sufficiently mature, however, to produce more than mildly warm water at shallow depth (500 meters/1640 feet).

Warm water is produced by a few artesian wells (about 30-50 meters/98-164 feet depth) and small springs at Morton's Warm Springs (Plate 1, Location No. 29). The area is underlain by the Glen Ellen Formation (Huichica Formation according to Fox, in press), which is gently folded. Cardwell (1958) mapped a small northwest-trending anticline whose axis is directly southeast of the wells and springs. Faults have not been recognized here, but perhaps such structures are conduits for the thermal water, which then migrates into confined permeable layers in the Glen Ellen Formation (Huichica?).

About 1 1/2 kilometers (0.9 miles) southwest of Morton's Warm Springs is McEwan Ranch spring (Plate 1, Location No. 28), which discharges from what is interpreted as Petaluma Formation. The spring probably rises from an unrecognized fracture associated with the nearby northwest-trending fault discussed earlier.

The well at Oakmont Golf Course (Plate 1, Location No. 23) is not exceptionally warm, and its temperature could be a result of conductive geothermal gradient alone (Figure 26). Similarly, the two reportedly warm wells (temperature unknown but probably low) east of Kenwood (Plate 1, Location Nos. 25 and 26) could be explained by conductive geothermal gradient, although nearby east-west-trending faults project into the vicinity of these wells and may influence the wells' thermal character. Alternatively, a concealed north-northwest-trending fault zone may extend through the site of the wells.

A Comparison of Northern and Southern Sonoma Valley Geology

Geography

The geologic units and structural trends of the northern and the southern Sonoma Valley areas are basically similar. Like the northern Sonoma Valley, the southern Sonoma Valley is separated into two marginal hilly areas by the alluvial fill of the valley floor. The Mayacmas Mountains, which form the northeast side of the northern Sonoma Valley, extend to the south to form the east side of the southern Sonoma Valley. The Sonoma Mountains, which form the west side of the southern Sonoma Valley, extend northward into the southwestern portion of the northern Sonoma Valley. The northern and southern valley areas are similar in that the deformation on the east side is more intense than that of the west side, with moderate to steep dips on the east side and generally gentler dips on the west side.

Stratigraphy

Rocks of the Franciscan Complex, which are exposed in the northeastern portion of the northern Sonoma Valley area, are not exposed in the southern Sonoma Valley area even though they and the contemporaneous Great Valley Sequence form the basement on which the late Tertiary sedimentary and volcanic rocks were deposited in both the northern and southern parts of the Sonoma Valley. The Petaluma Formation, which crops out extensively on the west side of the southern Sonoma Valley, extends into the southwestern portion of the northern

Sonoma Valley. While the Petaluma Formation is observed to underlie the Sonoma Volcanics along the Aqua Caliente Creek on the east side of the southern Sonoma Valley, it is not exposed and may not be present on the northeastern side of the northern Sonoma Valley beneath the Sonoma Volcanics in that area.

At Sonoma State Hospital, a geothermal exploration well was drilled to a depth of 436 meters (1430 feet, Plate 1, Location No. 44). The well, which was spudded in Glen Ellen Formation, was drilled through clayey silts and silty sands, presumably Petaluma Formation, to a depth of 305 meters (1000 feet) (213 meters/700 feet below sea level). Below 305 meters (1000 feet), increasing amounts of tuff and volcanic detritus occurred in the sedimentary rocks, and volcanic rocks were encountered below 354 meters (1160 feet) (262 meters/860 feet below sea level).

In mapping the southern Sonoma Valley (Youngs and others, 1983), the rock classification of Fox and others (1973) for the Sonoma Volcanics was not used. Instead, the Sonoma Volcanics were divided into two units, a lower Undifferentiated Sonoma Volcanics overlain by the St. Helena Rhyolites. This is essentially the classification used by Weaver (1949).

The base of the Sonoma Volcanics in the southern Sonoma Valley is a volcanic agglomerate overlain by an olivine-bearing andesite. Most of the area mapped as Lower Undifferentiated Sonoma Volcanics in the southern Sonoma Valley is underlain by these two rock types. On the east side of the southern Sonoma Valley, the rocks overlying the basal agglomerate and andesite are interbedded pumiceous tuffs, andesite mudflow breccias, and flows of basalt and andesite.

The St. Helena Rhyolite comprises primarily welded rhyolitic ashflow tuffs. The unit unconformably overlies the Lower Undifferentiated Sonoma Volcanics. Extensive exposures of this rock type occur on the east side of the southern Sonoma Valley. The unit correlates with Tsr unit in part in the eastern portion of the northern Sonoma Valley (Plate 1). The unit is not exposed on the west side of the southern Sonoma Valley nor in the southwestern side of the northern Sonoma Valley.

Structure

The most significant structural feature in the southern Sonoma Valley, in terms of the geothermal resource, is the "east side" fault. The fault, which is covered by alluvium for most of its length in the Sonoma Valley, has Glen Ellen Formation on the west side, downdropped against Sonoma Volcanics on the east side. The fault forms the western boundary of the "Most Likely Geothermal Production Zone" for the southern valley area, and the highest recorded temperature of geothermal fluids found in the Sonoma Valley occurs along this fault at Boyes Hot Springs (Youngs and others, 1983). This fault, although it extends into the northern Sonoma Valley, does not appear to be a major feature associated with the geothermal resources in that area.

GEOPHYSICAL INVESTIGATIONS

Introduction

Geophysical surveys play a leading role in any complete geothermal resource assessment study. As a part of the northern Sonoma Valley area geothermal investigation, geophysical surveys were undertaken by the California Division of Mines and Geology (CDMG) to provide information needed to evaluate the geothermal resources of the area. A regional gravity map (Chapman and Bishop, 1974), aeromagnetic maps (U.S. Geological Survey, 1974a; 1974b), and geophysical studies consisting of ground magnetic, gravity, electrical resistivity, and seismic refraction surveys (Chapman and others, 1983; Youngs and others, 1983) were already available for all or parts of the area. CDMG's new geophysical work was focused mainly on detailed ground magnetic, gravity, and electrical resistivity surveys. These surveys, their interpretations, and relationships to the geothermal resources are discussed below.

Gravity Survey

Purpose

Gravity measurements provide information both on the regional geology and on local geologic features that might be related to geothermal resources. Rocks of the Franciscan Complex and some units of the Sonoma Volcanics are associated with geothermal occurrences in nearby northern Coast Range areas. In many instances they have relatively high densities in comparison with alluvium and other sediments and sedimentary rocks in this area (Chapman and Bishop, 1974, p. 3). These dense rocks can be mapped by gravity methods and may provide indirect evidence of the possible location of geothermal resources. Additional gravity measurements were made during this investigation to supplement those available from earlier studies and to provide both better regional coverage and more detail in the study area.

Equipment and Field Procedure

Gravity measurements were made in the northern Sonoma Valley area using LaCoste and Romberg geodetic gravity meter G129. Elevations were obtained on detailed lines by surveying. Most regional stations were established at spot elevations on U.S. Geological Survey 7-1/2 minute topographic maps. Elevations for some regional stations were obtained by contour interpolation. All gravity stations were referenced to a gravity base established at a bench mark near Sonoma State Hospital, which was referenced, in turn, to stations of the California Division of Mines and Geology gravity base station network (Chapman, 1966). Seven new lines of gravity traverses totalling about 18 kilometers (11 miles) in length were obtained at a station spacing of 122 meters (400 feet) (Plate 2). In addition, about 80 new stations were established at spot elevations in the area for regional coverage. These gravity traverses and stations are in addition to traverses totalling 54 kilometers (33.5 miles) in length and about 100 regional stations obtained during earlier studies (Chapman and others, 1983; Youngs and others, 1983). All of these stations are shown on Plate 2.

Gravity Data

All gravity data were reduced to complete Bouguer anomalies for a density of 2.67 g/cm^3 and referenced to the International Ellipsoid of 1930. Terrain corrections were made manually out to a radius of 2.29 kilometers (from each station, and to a radius of 166.7 kilometers (approximately 100 miles) by means of a U.S. Geological Survey computer program (Plouff, 1977). Plate 2 is the Bouguer gravity map of the area contoured at an interval of one milligal (mgal). This map includes all of the gravity data available in the area. Profiles of the detailed gravity traverses that are within the boundaries of the northern Sonoma Valley area are shown in Figures 3-12.

The most prominent features of the gravity field shown on Plate 2 and on the regional gravity map by Chapman and Bishop (1974) in the northern Sonoma Valley area are a northwest regional trend, a gravity low in Sonoma Valley proper, and gravity highs in Bennett Valley and in the Mayacmas Mountains east of Sonoma Valley. The pronounced northwest-trending gravity low centered over the northern part of Sonoma Valley is separated from a similar low in Sonoma Valley to the southeast by a gravity ridge near Glen Ellen. The prominent northwest-trending gravity high centered in Bennett Valley extends northwestward into the city of Santa Rosa, but the amplitude of the anomaly decreases in this direction. The gravity high in the Mayacmas Mountains northeast of Sonoma Valley is not well defined on Plate 2, but it is shown more completely on the regional gravity map by Chapman and Bishop (1974).

Interpretation of Gravity Data

The negative gravity anomaly associated with northern Sonoma Valley apparently represents a basin, possibly a syncline or a graben. This basin may be partly separated from the basin in Sonoma Valley to the southeast by a northeast-trending buried ridge near Glen Ellen. This possible ridge may be Franciscan basement rocks or possibly dense units of the Sonoma Volcanics. A positive aeromagnetic anomaly, that corresponds in location approximately with the gravity anomaly in this area, suggests that this ridge may consist, at least in part, of Sonoma Volcanics which are commonly magnetic (Plate 3). A recent drill hole located on the Sonoma State Hospital grounds (Plate 1, Location No. 44) on the south flank of the magnetic anomaly is reported to have encountered possible Sonoma Volcanics (basalt or andesite) at a depth of about 335 meters (1,100 feet) (Figure 14).

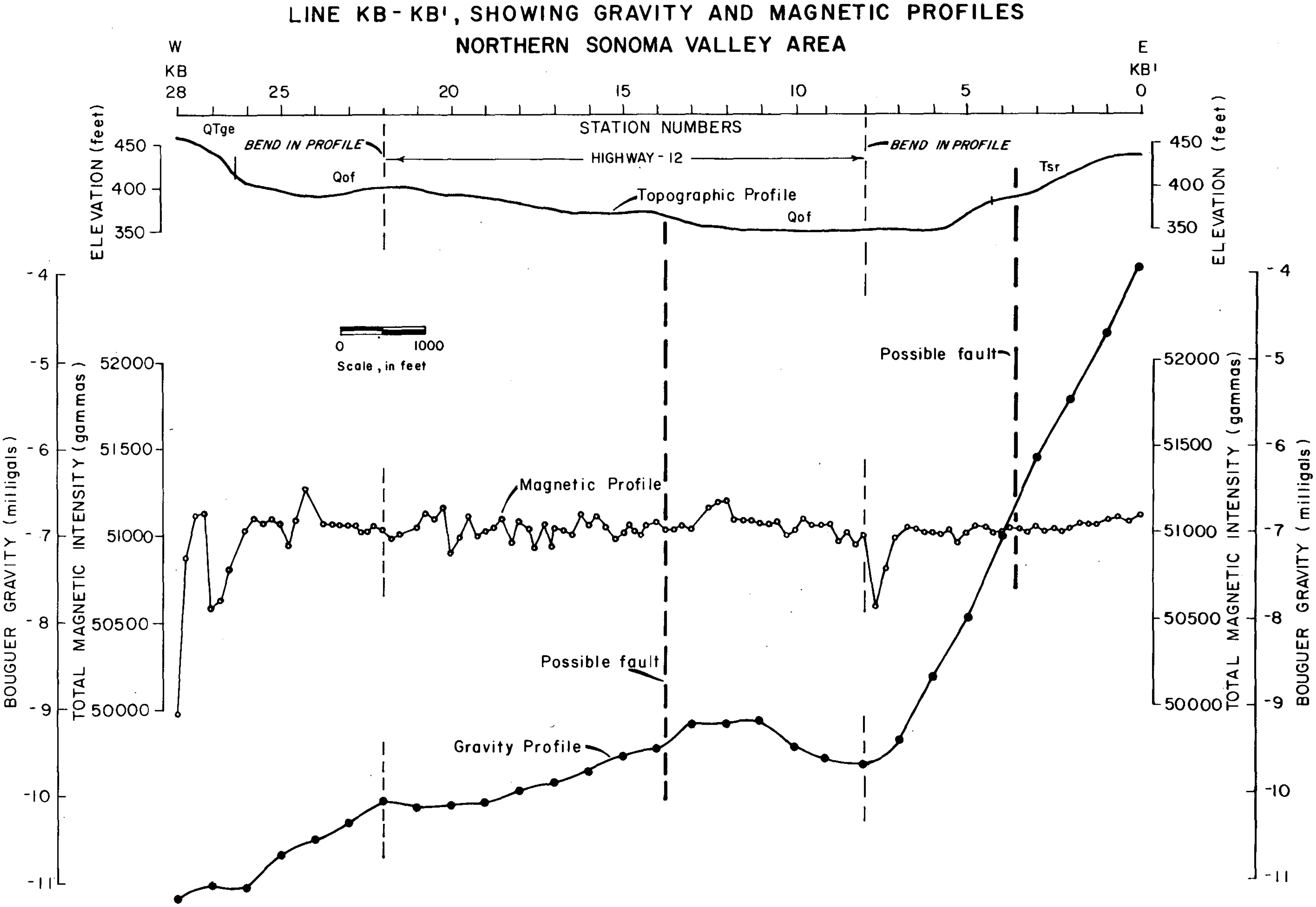

LINE KB-KB', SHOWING GRAVITY AND MAGNETIC PROFILES
NORTHERN SONOMA VALLEY AREA
W
KB
E
KB'
28
25
20
15
10
5
0
STATION NUMBERS
QTge
BEND IN PROFILE
BEND IN PROFILE
HIGHWAY - 12
Qof
Topographic Profile
Qof
Tsr
ELEVATION (feet)
450
400
350
Scale, in feet
0
1000
Possible fault
Magnetic Profile
Possible fault
Gravity Profile
BOUGUER GRAVITY (milligals)
TOTAL MAGNETIC INTENSITY (gammas)
-4
-5
-6
-7
-8
-9
-10
-11
52000
51500
51000
50500
50000

Figure 3.

LINE KC-KC'-KC'', SHOWING GRAVITY AND MAGNETIC PROFILES

NORTHERN SONOMA VALLEY AREA

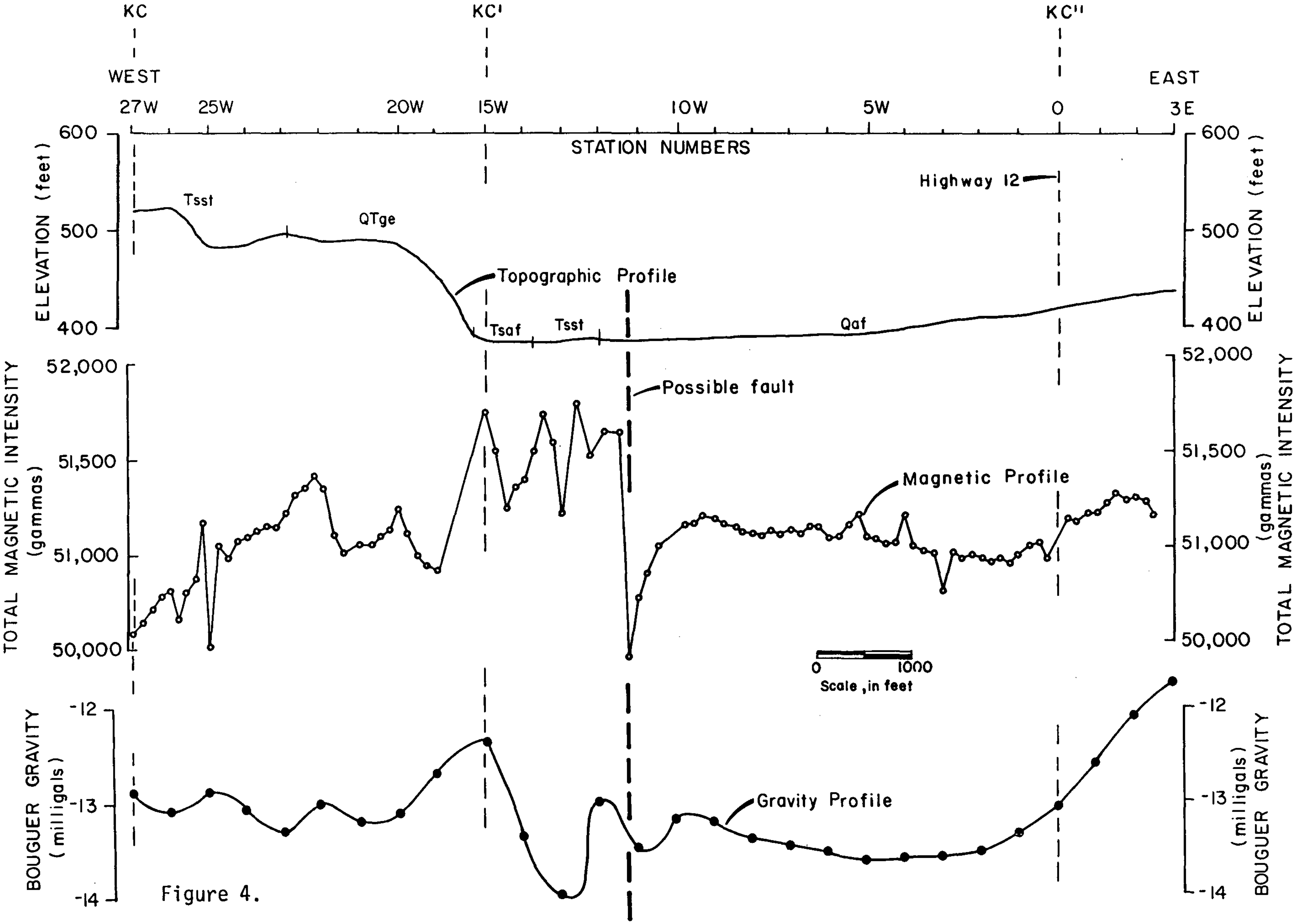


Figure 4.

LINES KG-KG' AND KC'-KC'' SHOWING GRAVITY PROFILE
NORTHERN SONOMA VALLEY AREA

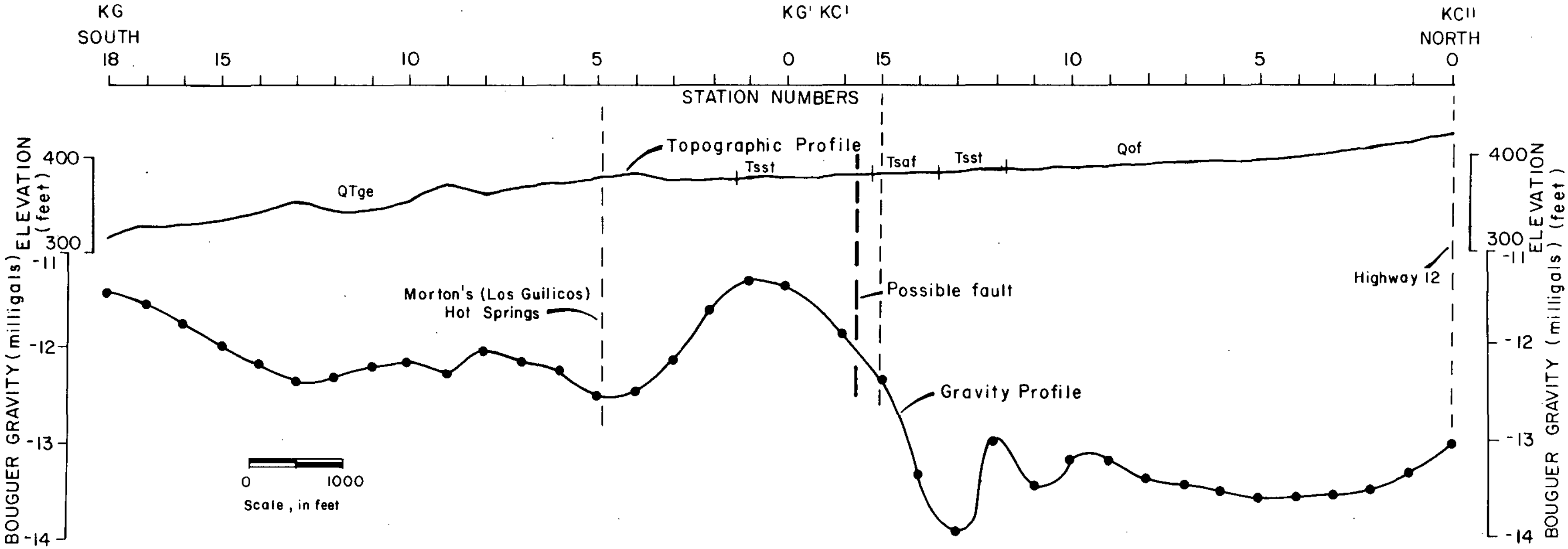


Figure 5.

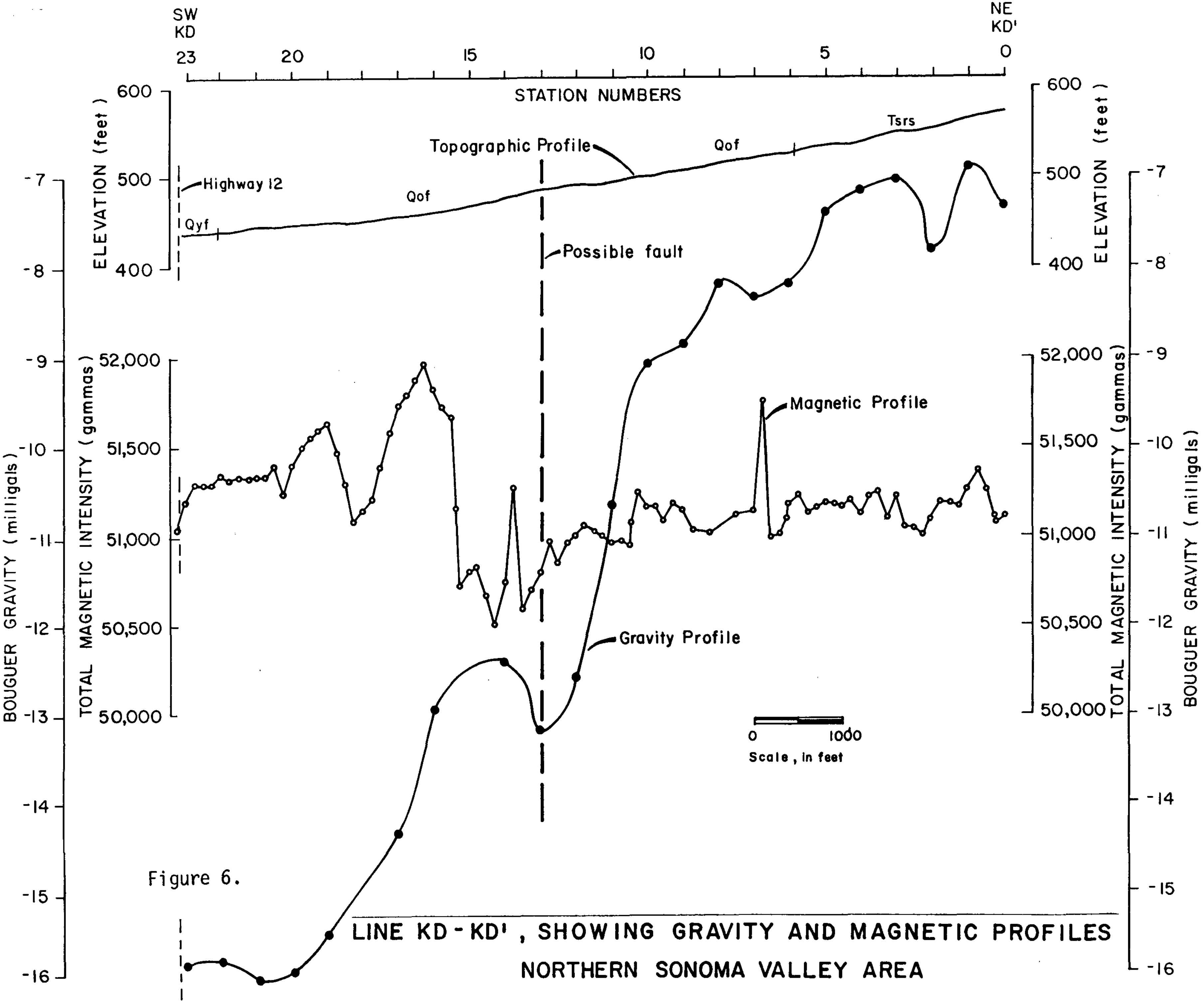


Figure 6.

LINE KD - KD', SHOWING GRAVITY AND MAGNETIC PROFILES NORTHERN SONOMA VALLEY AREA

LINE KE-KE' SHOWING GRAVITY AND MAGNETIC PROFILES
NORTHERN SONOMA VALLEY AREA

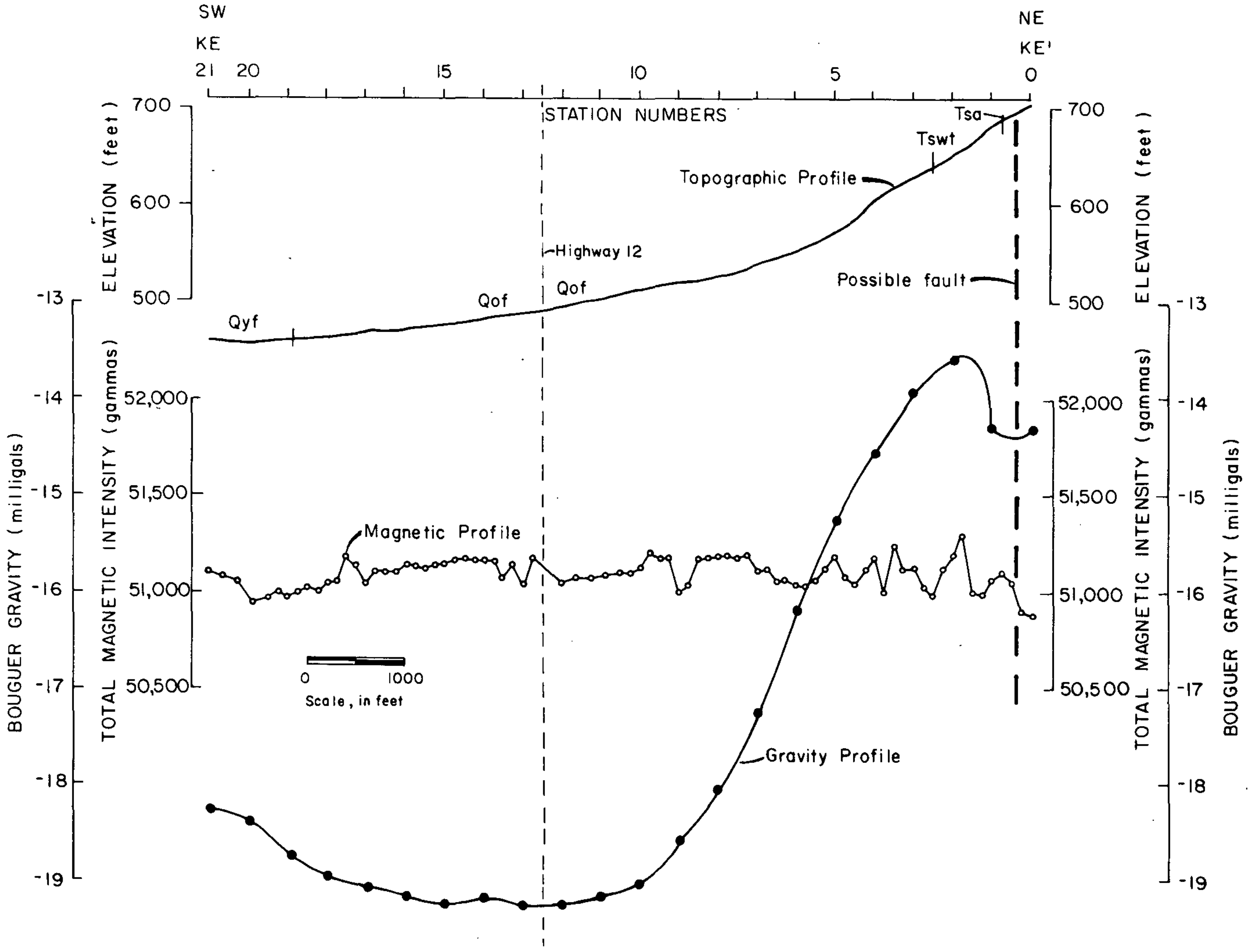
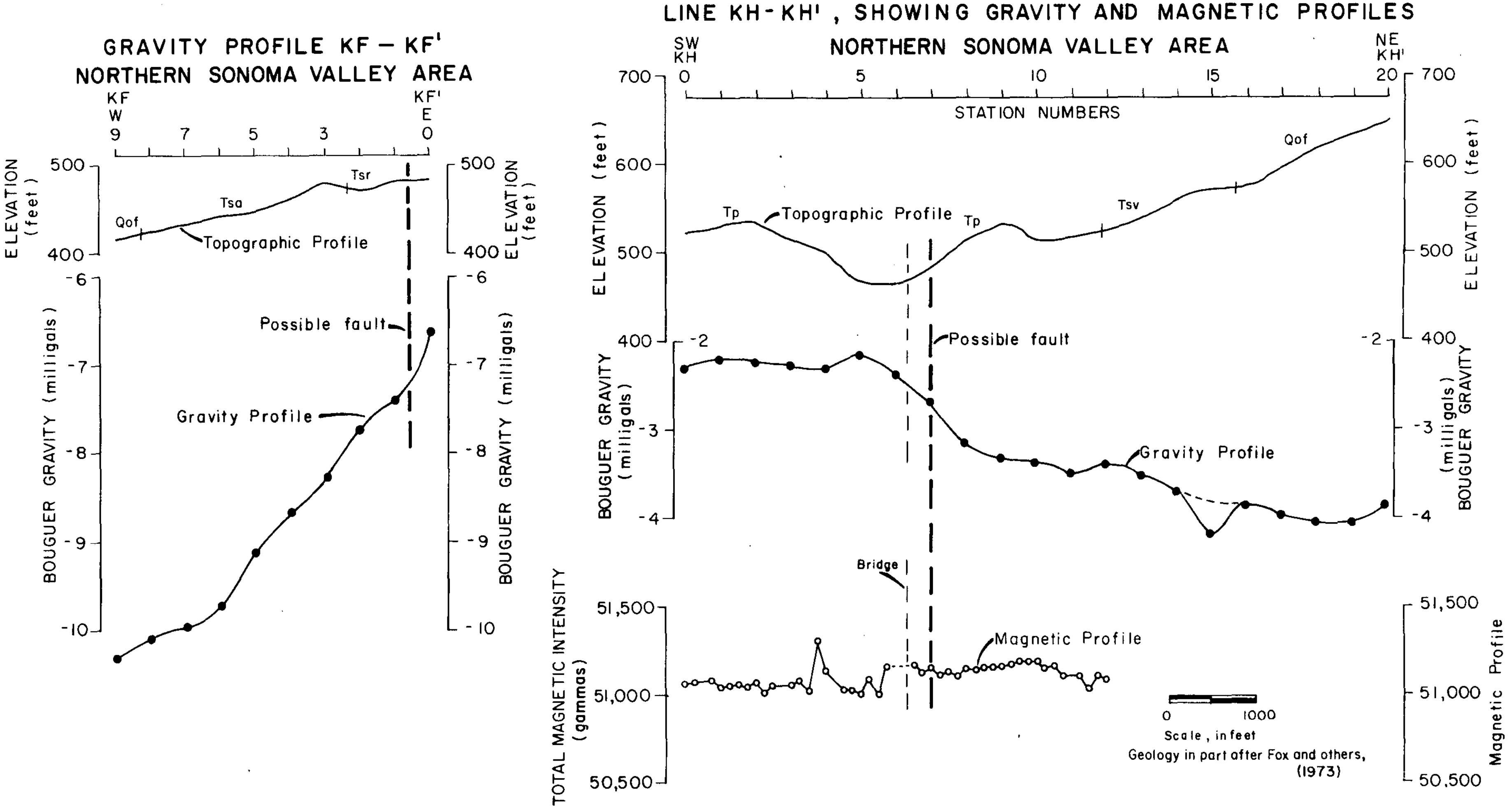


Figure 7.



GRAVITY PROFILE KF — KF'
NORTHERN SONOMA VALLEY AREA

LINE KH-KH', SHOWING GRAVITY AND MAGNETIC PROFILES
NORTHERN SONOMA VALLEY AREA

Geology in part after Fox and others, (1973)

Figure 8.

GRAVITY PROFILE SA2 - SA2', NORTHERN SONOMA VALLEY AREA
SONOMA AVENUE

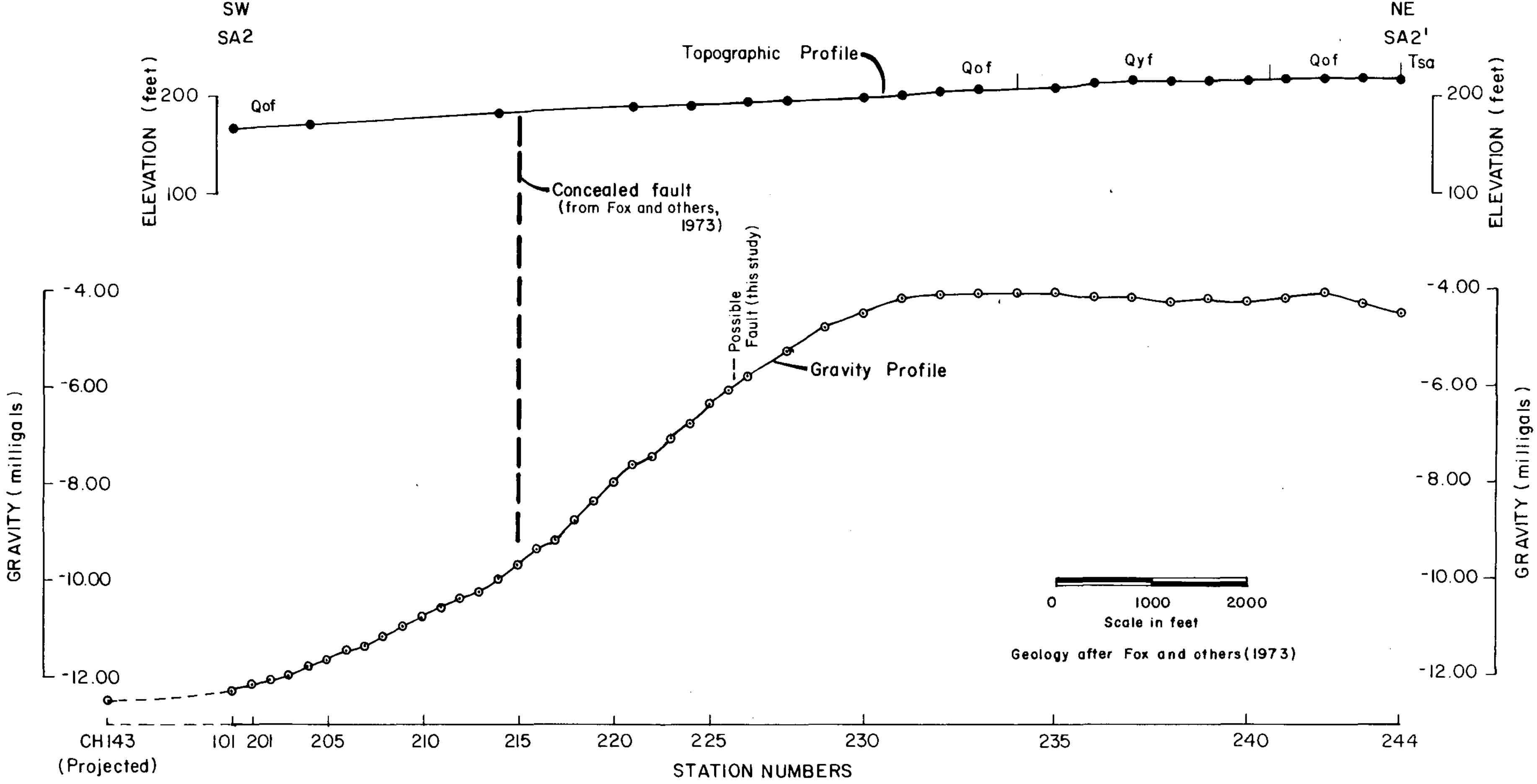


Figure 9.

GRAVITY PROFILE SA3-SA3', NORTHERN SONOMA VALLEY AREA

HOEN AVENUE

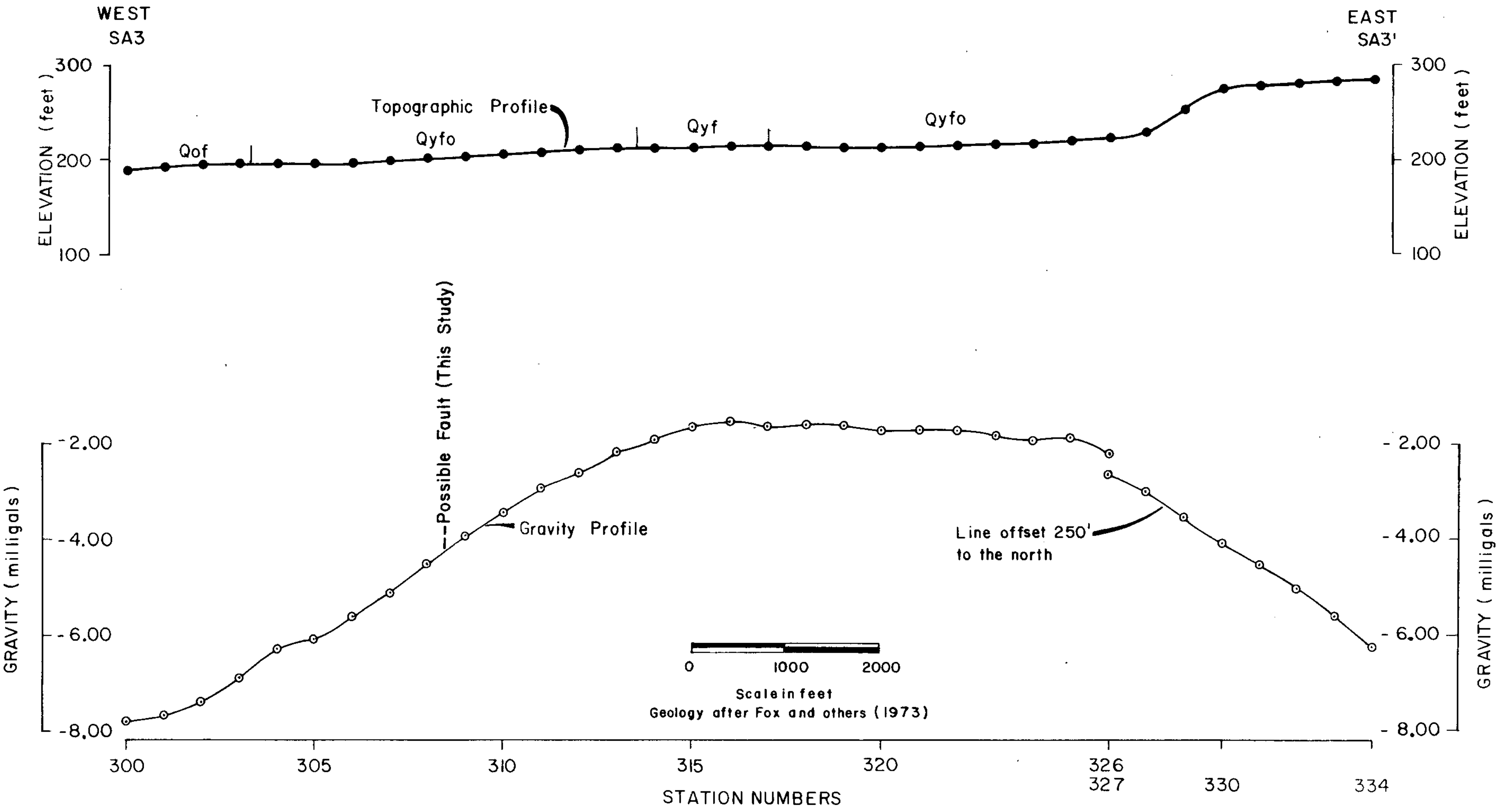


Figure 10.

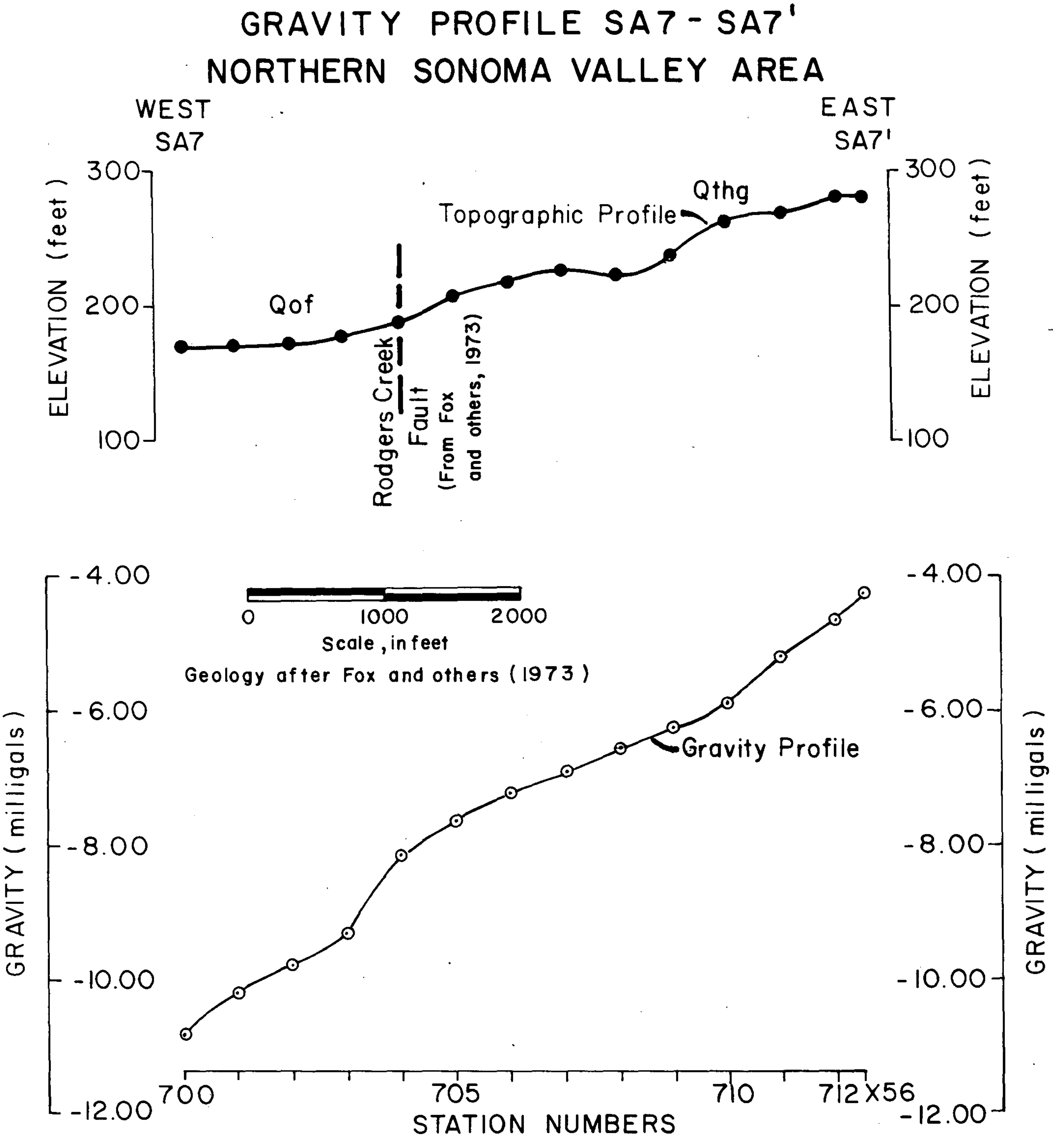
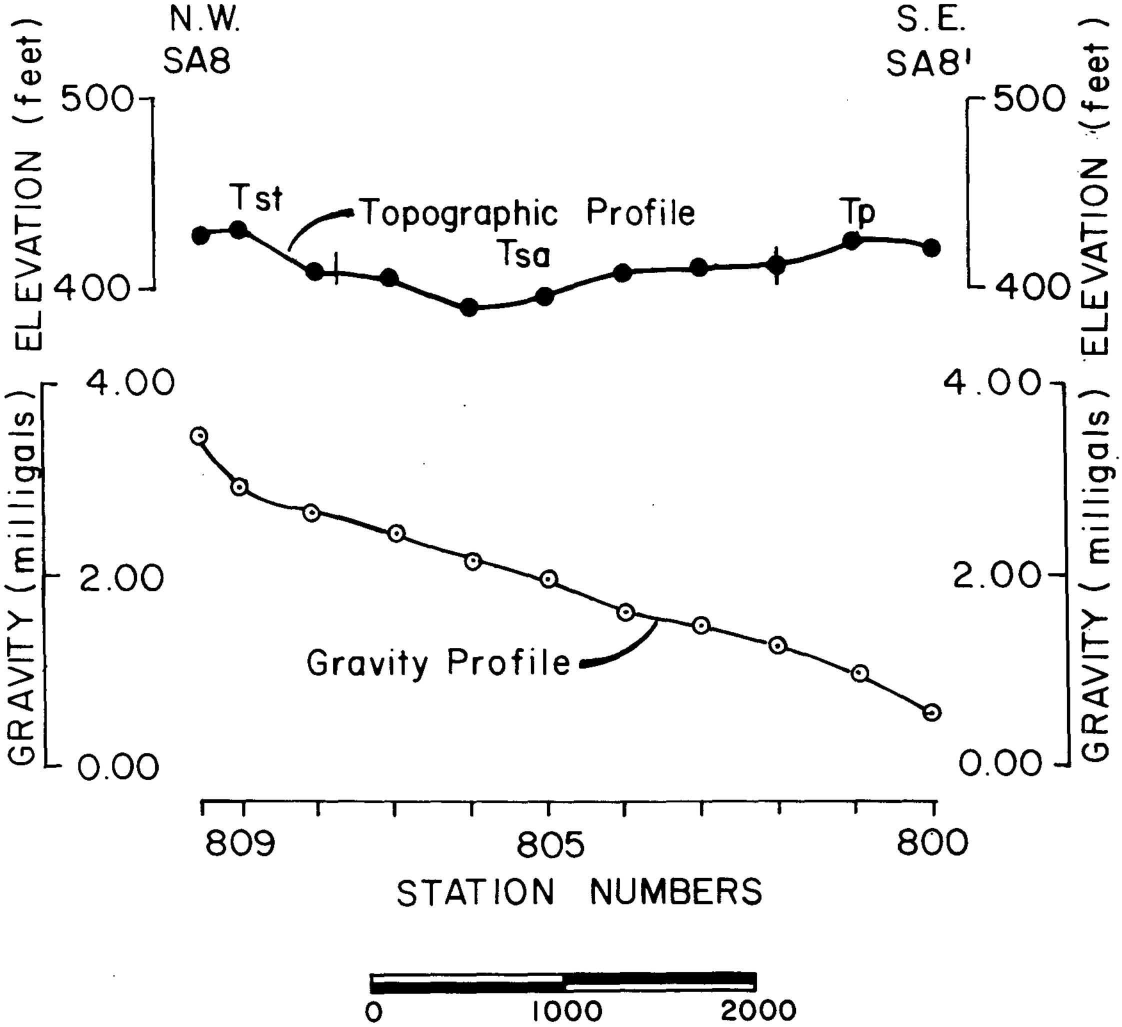

GRAVITY PROFILE SA7 - SA7'
NORTHERN SONOMA VALLEY AREA
WEST
SA7
EAST
SA7'
300
200
100
ELEVATION (feet)
Qof
Qthg
Topographic Profile
Rodgers Creek Fault
(From Fox and others, 1973)
-4.00
-6.00
-8.00
-10.00
-12.00
GRAVITY (milligals)
0
1000
2000
Scale, in feet
Geology after Fox and others (1973)
Gravity Profile
700
705
710
712
X56
STATION NUMBERS

Figure 11.

GRAVITY PROFILE SA8 - SA8'
NORTHERN SONOMA VALLEY AREA



Geology after Fox and others (1973)

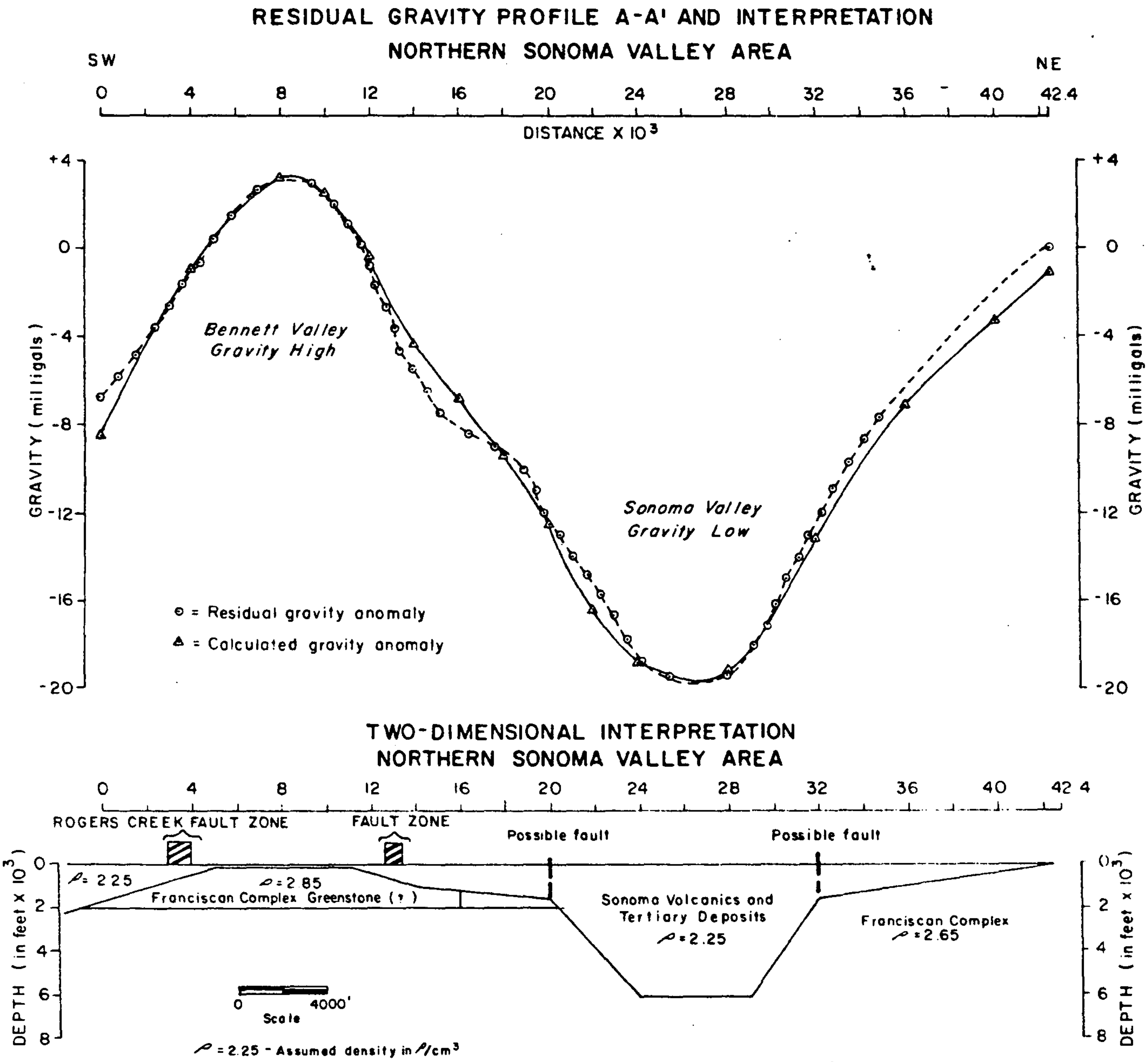
Figure 12.

The positive gravity anomaly centered in Bennett Valley (+4 mgal contour) may be caused either by Franciscan rocks (possibly greenstone) or dense units of the Sonoma Volcanics. Because there is no apparent magnetic anomaly associated with this gravity anomaly (Plate 3, Figure 17), it appears more likely that the cause is Franciscan rocks. If these rocks are Sonoma Volcanics, however, there is a better possibility of the presence of geothermal reservoirs in this area as geothermal reservoirs are known in these rocks in other nearby areas. The dense rocks must be at a relatively shallow depth beneath Bennett Valley to produce the observed steep gravity gradients, but there are no known outcrops nor are there known drill holes that have penetrated them.

The gravity data shown on Plate 2, and gravity profiles SA2-SA2' (Figure 9) and SA3-SA3' (Figure 10) in Santa Rosa suggest possible northwest-trending faults or steep contacts that may bound the dense rocks on both the northeast and southwest sides of Bennett Valley. Fox and others (1973) originally mapped a northwest-trending fault (the Bennett Valley fault zone) located just west of Bennett Mountain, shown on Plate 1, that corresponds to the northeasternmost of these proposed faults. No faults have been mapped on the southwestern side of Bennett Valley, but a fault can often provide an avenue along which geothermal fluids may rise and thus a fault may be inferred by an alignment of warm wells in this area (Plate 1).

Northeast of Bennett Valley and east of the Bennett Valley fault zone, decreasing gravity values suggest that the Sonoma Volcanics and possibly other Tertiary and Quaternary rocks thicken toward Sonoma Valley where the gravity values culminate in a low (-20 mgal contour) that may represent the deepest part of the basin discussed earlier. Gravity values rise northeast of Sonoma Valley in the direction of exposures of Franciscan Complex rocks in the Mayacmas Mountains. The gravity gradient northeast of Sonoma Valley is steep and could represent one or more faults or possibly a steeply-dipping depositional contact between Sonoma Volcanics and Franciscan Complex rocks (Plate 2, Figures 3, 6, 7 and 8).

Figure 13 is a gravity profile (A-A') that extends from west of Bennett Valley, on the southwest, to the Mayacmas Mountains, on the northeast, a total length of 13.8 kilometers (8.3 miles). It was drawn from the contours of Plate 2, after the removal of an assumed regional trend. Figure 13 also shows a possible model of the geologic structure based on the gravity data. For interpretation purposes, a density of 2.65 g/cm^3 was assumed for Franciscan Complex rocks, except in the vicinity of Bennett Valley where it was necessary to add a block having a higher density (2.85 g/cm^3) in order to fully account for the gravity high in this part of the area. Rocks having this density could be Franciscan greenstone, other Franciscan metamorphic rocks, or andesite or basalt flow rocks of the Sonoma Volcanics. The average density of the remaining Sonoma Volcanics and the other Tertiary and Quaternary sedimentary rocks in the section was assumed to be 2.25 g/cm^3.


RESIDUAL GRAVITY PROFILE A-A' AND INTERPRETATION
NORTHERN SONOMA VALLEY AREA

TWO-DIMENSIONAL INTERPRETATION
NORTHERN SONOMA VALLEY AREA

Figure 13.

The model section in Figure 13 was prepared using a two-dimensional hand calculator program (Haines and Campbell, 1979). The results of this analysis are not unique, and other sections could be evised that would fit the observed data equally well, but the main features of this model probably are approximately correct. The most important features of the section include a near-surface mass having a relatively high density beneath the vicinity of Bennett Valley and a synclinal trough, or graben, possibly as deep as 2000 meters (approximately 6000 feet) beneath the main Sonoma Valley. The high-density mass beneath Bennett Valley may be bounded, in part, by the Rodgers Creek fault zone and possibly another fault, on the southwest and by the fault near Bennett Mountain, on the northeast. The trough in the vicinity of Sonoma Valley may also be bounded in part by faults, or at least by steeply dipping contacts, as shown in Figure 13 and Plate 2.

Gravity profile F-F' (Plate 2), located in the southeastern part of the northern Sonoma Valley area near the town of Glen Ellen, shows anomalies that are believed to represent the "east side" fault and a parallel fault, located about 500 meters (approximately 1500 feet) to the west (Youngs and others, 1983, p. 24). The "east side" fault is important because it is associated with geothermal resources in the Sonoma Valley area to the south. However, these faults could not easily be traced further northward by means of the gravity and magnetic data obtained in the northern Sonoma Valley area. The "east side" fault might be represented on profile KB-KB' (Plate 2, Figure 3) by one of the small anomalies on this line, but this is uncertain. Geothermal resources might possibly be found, however, at a relatively shallow depth just east of the "east side" fault near Glen Ellen (Youngs and others, 1983, p. 57).

Gravity profile SA7-SA7' (Plate 2, Figure 11), located just southeast of Santa Rosa, shows a steep gradient over a mapped branch of the Rodgers Creek fault. This and other possible faults suggested by the gravity and magnetic data are shown on Plates 2 and 3.

Magnetic Surveys

Purpose

Measurements of the earth's magnetic field are often useful in studies of the geology of areas that have relatively magnetic rock units. Units of the Sonoma Volcanics, some of which are known to be magnetic, are exposed in extensive areas within the northern Sonoma Valley area. Therefore, it is possible that some of these units can be mapped by magnetic geophysical methods. Because these rocks, when in the proper structural-stratigraphic relationship, can be associated with geothermal fluids, it is important to understand their subsurface extent and relationships.

Published aeromagnetic maps (U.S. Geological Survey, 1974a, 1974b) include the northern Sonoma Valley area. These maps provide an overall view of the magnetic anomalies in the vicinity. Ground magnetic data were also obtained during this study in order to provide more detailed information.

Aeromagnetic Data

The aeromagnetic maps (U.S. Geological Survey, 1974a, 1974b, and Plate 2) indicate that there are large, generally northwest-trending, aeromagnetic anomalies in the northern Sonoma Valley area that reflect both rock types and regional structure. Individual anomalies and anomaly trends in the northern Sonoma Valley area include a positive magnetic anomaly that trends southeastward from near Bennett Mountain to the vicinity of Glen Ellen. This anomaly also extends across Sonoma Valley, where there is a small gap, into the Mayacmas Mountains east of Sonoma State Hospital. It probably represents relatively magnetic units in the Sonoma Volcanics.

The drill hole on the Sonoma State Hospital property mentioned above in the discussion of the gravity data is on the south flank of the magnetic anomaly near Glen Ellen. Measurements of magnetic susceptibility made on samples of rock obtained from this drill hole are shown graphically in Figure 14. As indicated in the figure, the samples of basalt or andesite from depths of 335 meters (1100 feet) to 442 meters (1450 feet) in this drill hole yielded values of magnetic susceptibility between 1200 x 10^{-6} cgs units and 3800 x 10^{-6} cgs units which indicates that these rocks are strongly magnetic.

Another northwest-trending positive anomaly is associated with the Mayacmas Mountains northeast of northern Sonoma Valley. This anomaly evidently is associated with exposures of serpentinite (Koenig, 1963; Fox and others, 1973). Serpentinite usually is a very magnetic rock.

A line of negative magnetic anomalies trends southeastward from the vicinity of Rincon Valley, on the northwest, generally along Sonoma Valley, and into the Mayacmas Mountains northeast of Glen Ellen. These negative anomalies are located generally between the two positive anomalies discussed above. The negative anomalies probably indicate a lack of major units of magnetic rocks in Rincon Valley and northern Sonoma Valley. This trend is interrupted near Melita by a small circular positive anomaly (920 gamma contour) probably caused by surface exposures of andesite (Plate 3).

Equipment and Procedure for Ground Survey

Approximately 23 kilometers (14 miles) (9 profiles) of total-intensity ground magnetic traverses were obtained by CDMG in the northern Sonoma Valley area during this study. This is in addition to 1.9 kilometers (1.1 miles) (2 profiles) of similar data obtained in this area during an earlier survey (Chapman and others, 1983). Many of these profiles correspond in location to the gravity profiles discussed above. All of the ground magnetic data were obtained with a Geometrics model 816 proton-precession magnetometer, which has a reading sensitivity of one gamma. Stations along lines were spaced at intervals of 30 meters or 61 meters (100 or 200 feet), estimated by pacing.

Interpretation of Ground Magnetic Data

The ground magnetic data were plotted in profile form, and the locations of the lines are shown on Plate 3. Most of the profiles follow roads and trails and were run in order to help locate possible faults and other geologic structures that might be related to geothermal resources.

CALIFORNIA DIVISION OF MINES AND GEOLOGY

MAGNETIC SUSCEPTIBILITY OF DRILL CUTTINGS FROM SONOMA STATE (HOSPITAL) WELL NO. 3

by

Kenneth C. Aldridge

JANUARY, 1983

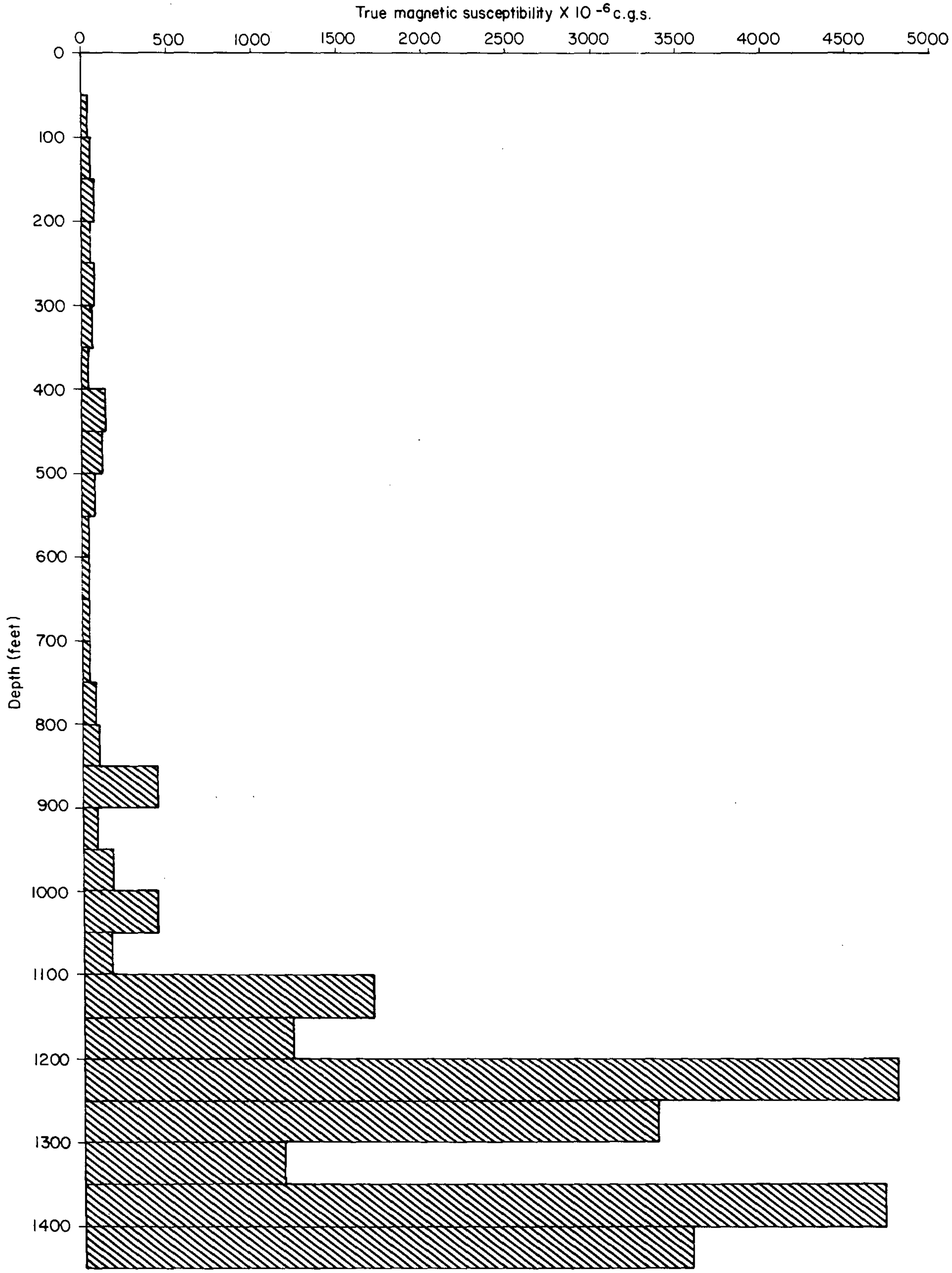


Figure 14.

Profiles KB-KB' (Figure 3), KC-KC'-KC" (Figure 4), KD-KD' (Figure 6), and KE-KE' (Figure 7) are located in northern Sonoma Valley. Most of these profiles indicate a fairly uniform magnetic field, as suggested also by the aeromagnetic map in this area (Plate 3), except for some local anomalies probably caused by cultural features. Profile KC-KC'-KC" (Figure 4) shows a change in character that indicates relatively magnetic rocks southwest of station 11W. The anomaly near station 11W probably indicates a fault or a contact. Similarly, profile KD-KD' (Figure 6) suggests a fault or contact near stations 13 or 14. Both of these magnetic anomalies are close to gravity anomalies that also suggest possible faults or contacts.

Magnetic profiles M2-M2' (Figure 15), M3-M3' (Figure 15), MF-MF' (Figure 16), and KH-KH' (Figure 8) are located near the southwestern side of Bennett Valley (Plate 3), and were run to help locate any possible faults that might be associated with the geothermal resources in this part of the area (Plate 1). These profiles apparently do not show any prominent anomalies that might represent faults. Small anomalies that might be significant are difficult to recognize in the data because of background "noise" probably caused by near-surface volcanic rocks.

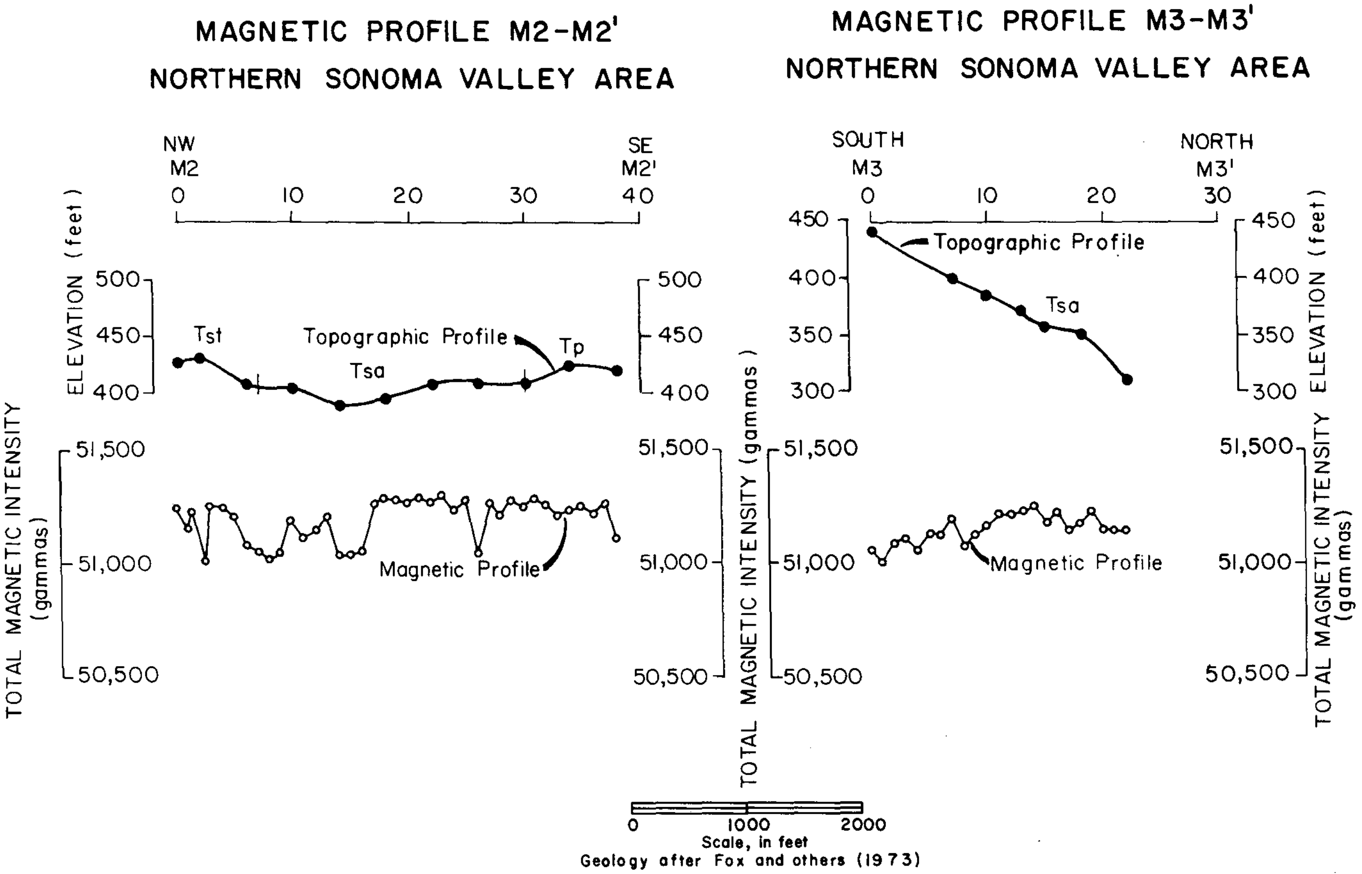
Magnetic profiles ME-ME' (Figure 16) and MG-MG' (Figure 17) were located in the vicinity of the large gravity anomaly in Bennett Valley. These profiles were run in order to determine whether or not there is a magnetic anomaly that corresponds with the gravity anomaly in this area. The profiles are characterized by somewhat irregular values that might be caused by moderately magnetic volcanic rocks, but show no apparent major anomalies that might represent a thick magnetic unit of the Sonoma Volcanics.

Magnetic profile MI-MI' (Figure 17) is located on the Sonoma Mountain road, west of Glen Ellen. This profile crosses the southern end of the Bennett Valley fault that passes near Bennett Mountain to the north. This profile shows no clear evidence of the fault.

Electrical Resistivity Surveys

Purpose

Hot geothermal waters and possible related hyrothermal rock alteration frequently cause geothermal reservoirs to be characterized by low values of electrical resistivity. The known geothermal resources in the northern Sonoma Valley area, however, may not have a temperature high enough to cause a distinct resistivity anomaly. Electrical resistivity data might also help delineate possible geothermal reservoirs in the area either by locating the volcanic rocks that may be the reservoirs, or by locating possible alteration zones that may be associated with the reservoirs. However, the use of this method in the Sonoma Valley area to the south was not encouraging (Youngs and others, 1983, p. 57), so only limited work was done during the present study.


MAGNETIC PROFILE M2-M2' NORTHERN SONOMA VALLEY AREA

MAGNETIC PROFILE M3-M3' NORTHERN SONOMA VALLEY AREA

Geology after Fox and others (1973)

Figure 15.

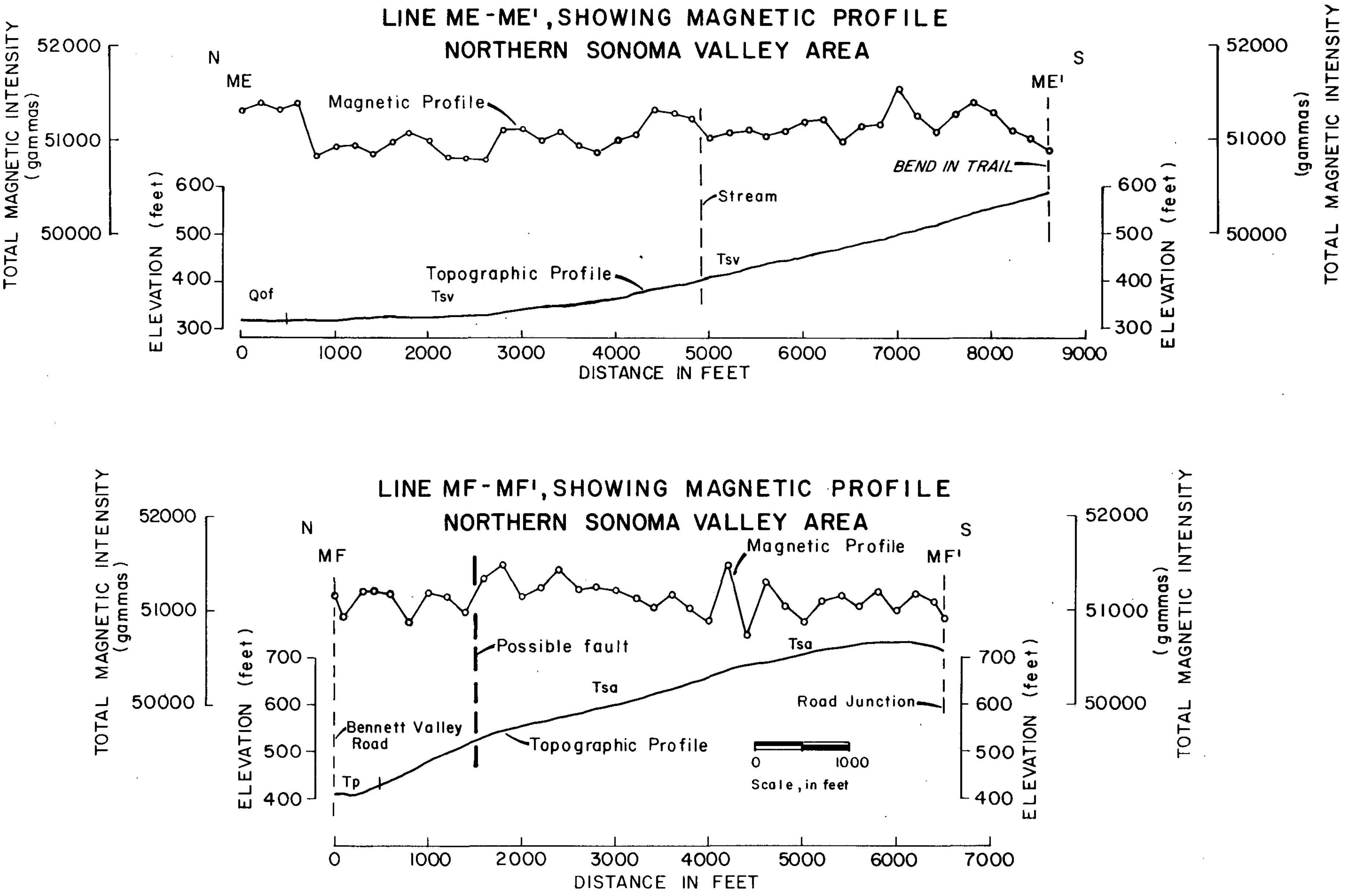

LINE ME-ME', SHOWING MAGNETIC PROFILE
NORTHERN SONOMA VALLEY AREA
N
S
ME
ME'
Magnetic Profile
BEND IN TRAIL
Stream
Topographic Profile
Qof
Tsv
Tsv
TOTAL MAGNETIC INTENSITY (gammas)
52000
51000
50000
ELEVATION (feet)
600
500
400
300
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
DISTANCE IN FEET
LINE MF-MF', SHOWING MAGNETIC PROFILE
NORTHERN SONOMA VALLEY AREA
N
S
MF
MF'
Magnetic Profile
Possible fault
Tsa
Tsa
Road Junction
Bennett Valley Road
Topographic Profile
Tp
0
1000
Scale, in feet
TOTAL MAGNETIC INTENSITY (gammas)
52000
51000
50000
ELEVATION (feet)
700
600
500
400
0
1000
2000
3000
4000
5000
6000
7000
DISTANCE IN FEET

Figure 16.

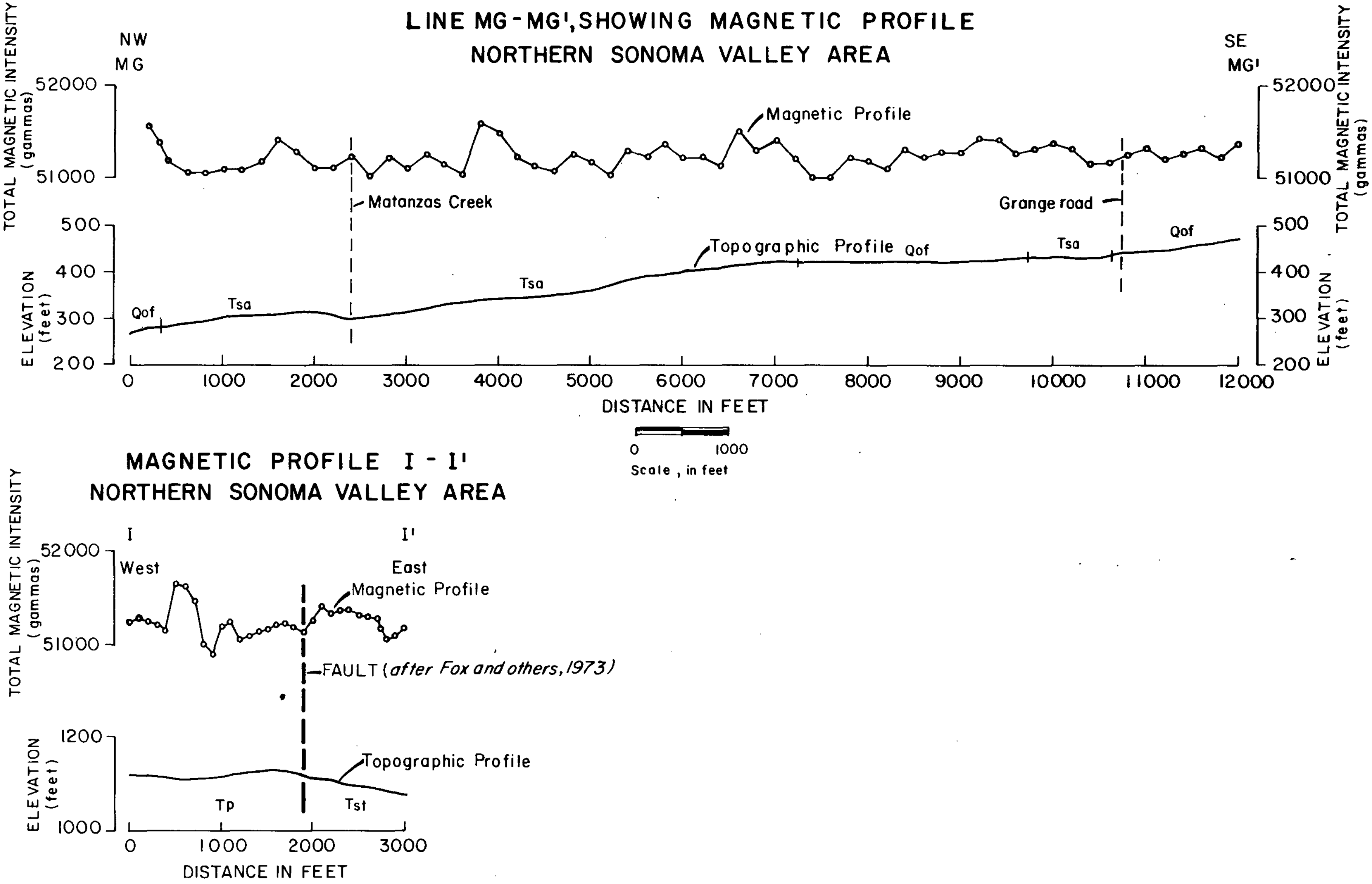

LINE MG-MG', SHOWING MAGNETIC PROFILE
NORTHERN SONOMA VALLEY AREA
NW
MG
SE
MG'
TOTAL MAGNETIC INTENSITY (gammas)
52000
51000
Magnetic Profile
Matanzas Creek
Grange road
ELEVATION (feet)
500
400
300
200
Topographic Profile
Qof
Tsa
Tsa
Tsa
Qof
Tsa
Qof
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
DISTANCE IN FEET
0
1000
Scale, in feet
MAGNETIC PROFILE I - I'
NORTHERN SONOMA VALLEY AREA
I
I'
West
East
TOTAL MAGNETIC INTENSITY (gammas)
52000
51000
Magnetic Profile
FAULT (after Fox and others, 1973)
ELEVATION (feet)
1200
1000
Topographic Profile
Tp
Tst
0
1000
2000
3000
DISTANCE IN FEET

Figure 17.

Equipment and Field Procedure

The equipment used for the electrical resistivity survey consisted of a Geotronics model FT-4 transmitter with an output rated at 4 amps and 800 volts (3.2 KVA). The power supply was a Geotronics model B-2 engine generator with an output of 5KVA at 400 Hz. A Bison signal enhancement receiver was also used. All resistivity measurements were made at a frequency of one Hz.

Resistivity surveys consisting of two dipole-dipole lines and three Schlumberger soundings were done in the Sonoma Valley area southeast of the current study (Youngs and others, 1983, p. 51). In addition, during the current study, three test soundings were done in the southern Sonoma Valley area near known warm wells to help determine the value of the method for use in the northern Sonoma Valley area. Three Schlumberger soundings also were done in a recent CDMG study in the vicinity of Santa Rosa, an area that includes a part of the present study area (Chapman and others, 1983, p. 26).

The Schlumberger vertical electric sounding technique (VES) was the only resistivity method used during the current study. In the use of this method, an electrode configuration is expanded about a central point in order to measure progressively deeper values of electrical resistivity. The results are plotted as a curve showing resistivity as a function of electrode spacing (AB/2) or depth.

Interpretation of Resistivity Data

Interpretation of the resistivity data obtained in adjacent study areas near Sonoma and Santa Rosa is discussed in the reports by Youngs and others (1983) and Chapman and others (1983). The dipole-dipole lines and the soundings both show generally low values of electrical resistivity in these areas, and this is true not only near known geothermal resources but also in most of the areas tested. Additional test resistivity soundings obtained during the current study tend to confirm these observations. Therefore, the resistivity data apparently are not very useful for identification of geothermal resources, at least in most of the areas tested in the vicinity of Sonoma Valley.

One resistivity sounding (VES 3) located near Bennett Valley in the northern Sonoma Valley area (Plate 2, Figure 18) may show evidence for the warm water believed to be present in this part of the study area. The center of this sounding is about 0.5 kilometers (approximately 1500 feet) east of the geothermal well location No. 19, (Plate 1) in the foothills west of Bennett Valley along a private road. The maximum electrode spacing for this sounding was 305 meters (1000 feet). The sounding curve was interpreted in terms of a horizontally layered structure by an automatic interpretation program (Zohdy, 1974).

Interpretation of the data of Figure 18 indicates about four layers from the surface to a depth of 9 meters (30 feet) with resistivities in the intermediate range (35 to 87 ohm-feet). Based on experience in other nearby areas and known geology, this may indicate alluvium or volcanic tuffs. Below 9 meters (30 feet) to a total depth of 143 meters (470 feet), resistivity values are relatively low,

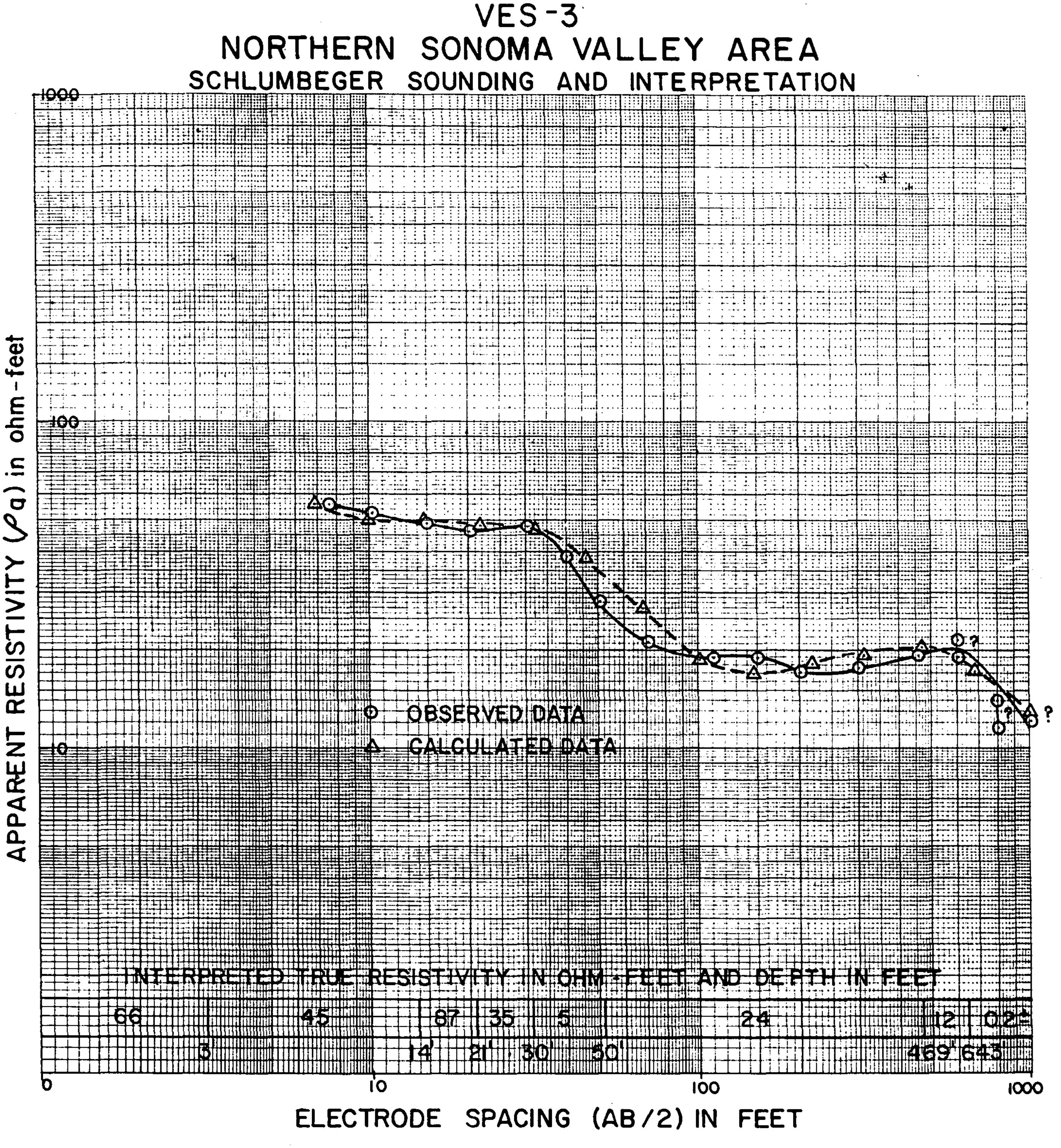

VES-3
NORTHERN SONOMA VALLEY AREA
SCHLUMBEGER SOUNDING AND INTERPRETATION
APPARENT RESISTIVITY (ρa) in ohm-feet
1000
100
10
OBSERVED DATA
CALCULATED DATA
?
INTERPRETED TRUE RESISTIVITY IN OHM-FEET AND DEPTH IN FEET
66
45
87
35
5
24
12
0.2±
3'
14'
21'
30'
50'
469'
643'
0
10
100
1000
ELECTRODE SPACING (AB/2) IN FEET

Figure 18.

mostly about 24 ohm-feet. This layer could be the one from which the Nostrant well (Plate 1, Location No. 19) produces warm water. Below a depth of 143 meters (470 feet), resistivity values apparently decrease and may be less than one ohm-foot to a depth greater than 305 meters (1000 feet). This very low value of resistivity could represent hot water or a thick clay zone. However, measurements at some of the larger electrode spacings on this sounding were difficult to repeat accurately, so there is a possibility of some error in the interpretation of the deeper layers.

The sounding at VES 3 is located close to the gravity anomaly centered in Bennett Valley, but it shows no evidence for a possible high resistivity at depth. A high resistivity might be expected if the area is underlain at a relatively shallow depth by Franciscan Complex rocks or possibly by thick dense units of the Sonoma Volcanics. Thus, the low resistivity values measured may indicate permeable units of the Sonoma Volcanics that may contain warm water.

Conclusions and Recommendations

Geophysical studies in the northern Sonoma Valley area have provided information that is useful in the search for additional geothermal resources. This information includes the identification of possible faults, and other geologic structures as well as certain types of rocks, some of which may be related to geothermal resources.

Possible faults in the northern Sonoma Valley area were located by means of gravity and ground magnetic data. Some of these possible faults, such as one tentatively located near the southwestern side of Bennett Valley, may be associated with known geothermal resources. Others apparently are not associated with any known geothermal resources. The "east side" fault, which is closely associated with geothermal resources in Sonoma Valley southeast of the current study area, could not be positively identified in the northern Sonoma Valley area north of a point near Glen Ellen. However, geothermal resources might be found at a relatively shallow depth east of the fault in this area. Drilling in this location could prove this possibility.

Electrical resistivity data, most of which was obtained in the Sonoma Valley area southeast of the current study area, and in Santa Rosa, northwest of this area, did not prove generally useful for identification of either geothermal reservoirs or geologic structure. This is mainly because the temperature of the thermal water probably is too low, and because sediments containing clay and either weathered or hydrothermally altered volcanic rocks with low values of resistivity may be present in these areas. One electrical sounding, located near a known geothermal reservoir on the southwestern side of Bennett Valley, does show a possible indication of the reservoir, but this is not certain.

The known geothermal resources in the northern Sonoma Valley area are found in wells or springs many of which are believed to be in units of the Sonoma Volcanics. Dense and magnetic units of the Sonoma Volcanics, indicated by positive aeromagnetic and ground magnetic anomalies and positive gravity anomalies, appear to be particularly favorable areas for these resources, especially when the volcanic units are within or near the valleys. For example, magnetic and/or gravity anomalies in Bennett Valley, Santa Rosa, and near Glen Ellen suggest the presence of units of the Sonoma Volcanics which may represent areas where new geothermal resources could be found. It is recommended that additional gravity, magnetic, and possibly electrical resistivity data be obtained and test drilling be performed in these areas to provide more information on the location of the volcanic rocks and on possible structural control.

SEISMICITY OF THE NORTHERN SONOMA VALLEY AREA

Elevated seismic activity is often observed in areas of geothermal occurrences. Therefore, seismic and especially microseismic surveys are commonly used as both a diagnostic and exploration tool in examining geothermal resource areas. (Microseismic surveys are generally concerned with earthquakes of magnitude 2 or less.) The primary information examined in such studies is the distribution of earthquake epicenters in space and time. Some studies analyze the character and velocity changes of seismic waves generated by earthquakes. This often provides information on the subsurface geology in geothermal resource areas. However, a microseismic survey in the northern Sonoma Valley area was not within the scope of this report. Instead, the regional pattern of larger earthquake activity in the northern Sonoma Valley area was investigated to ascertain if the seismic activity bore any relationship to the low-temperature geothermal resources. Seismic events from 1800-1974 were computer-plotted and then manually transferred to a base map of the study area (Plate 4). The seismic data were obtained from the California Division of Mines and Geology (CDMG) Earthquake Catalog System. A comprehensive discussion of the CDMG Earthquake Catalog System can be found in Real and others (1978) and augmented with Toppozada and others (1981).

In all, 124 seismic events have been recorded for the area encompassed on Plate 4. The computer plotting program does not allow for overprints, therefore, only the largest of several events, occurring at the same coordinates, is represented on Plate 4. Table 1 is a copy of the computer listing of all the earthquakes pertinent to the study. A magnitude (MAG) of 9.99 indicates that no data were available to determine the actual magnitude of the event.

In general, the distribution of epicenters shown on Plate 4 in the southern and central portions of the Sonoma Valley is sparse. However, in the northern study area shown on Plate 4, there is a much denser distribution of epicenters. A general, northwest-trending zone of epicenters can be seen centered over the Sonoma Mountains and extending northwestward into the City of Santa Rosa. The majority of the epicenter locations are contained in a zone bordered on the east and northeast by Sonoma Valley proper and bordered on the southwest by the Healdsburg and Rodgers Creek faults. The parallel alignment of this zone of epicenters with the Healdsburg and Rodgers Creek faults and an alignment with a zone of warm water wells and springs shown on Plate 4 is quite conspicuous. An inference can be made that the low-temperature geothermal resources in this localized area, as manifested by the warm water wells and springs, have some association with the active Healdsburg-Rodgers Creek fault system.

On October 1, 1969, the Santa Rosa area experienced a magnitude 5.6 earthquake (Steinbrugge and others, 1970). It is interesting to note that geothermal Locations Nos. 7, 8, 9, 10, and 11 (Plate 4) are located in areas that experienced broken curbing, pavements, and sidewalks from this earthquake. In addition, at geothermal Locations Nos. 10 and 11, there were reported broken water mains, water lines, and there was a fire department call. These

Table 1. Earthquakes in the Sonoma Valley area from 1800-1974.

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     CALIFORNIA DIVISION OF MINES AND GEOLOGY                            PROGRAM RETRIEVE                            DATE: 01/07/83
     EARTHQUAKE CATALOG SYSTEM                                           VER. CON109H-128                         REQUEST:  1-A
                                                                                                                     PAGE:     5
     DATA RETRIEVAL REQUEST FOR: SONOMA VALLEY SEISMICITY
     -------------------------------------------------------------------------------------------------------------------------------

      ID NO.    LATITUDE   LONGITUDE      DATE          TIME       DEPTH  QUAL   REF  MAG    REF   INT   REF        ID NO.
 •   4400336     38.270    122.339    12/ 2/1970    1 36 32.1     12.4    C      9  1.92   009    0              4400336
 •   4400130     38.270    122.400    11/ 2/1953    3  2 56.0      0.0    C      1  2.50     1    0              4400130
 •   4400177     38.290    122.520     6/19/1956   18 32 57.0      0.0    A      1  2.30     1    0              4400177
 •   4400384     38.294    122.375    12/30/1971   17 48 16.4      7.9    B      9  1.26     9    0              4400384
 •   4400546     38.300    122.400    10/12/1891    6 28  0.0      0.0         008  5.500  008    8C   008       4400546
 •   4400174     38.320    122.390     4/25/1956   23 57 54.0      0.0    B      1  1.90     1    0              4400174
 •   4400004     38.330    122.500     2/25/1919   22 39  0.0      0.0           1  4.500  007    6B   004       4400004
 •   4400403     38.330    122.564     5/14/1972    3 25 12.5     11.4    A      9  1.74     9    0              4400403
 •   4400067     38.330    122.580     9/ 1/1948   21 27 47.0      0.0    A      1  3.30     1    0A   006       4400067
 •   4400466     38.334    122.552     4/ 9/1973   19 59 44.1      5.8    B      9  1.36     9    0              4400466
 •   4400517     38.340    122.566    10/ 5/1973    6 43 24.9      3.6    B      9  0.71     9    0              4400517
 •   4400279     38.350    122.600     4/14/1962   19 37 37.0     13.0    B      1  3.00     1    0              4400279
 •   4400432     38.355    122.603    11/16/1972    4 18  1.9      5.3    B      9  1.31     9    0              4400432
 •   4400369     38.359    122.571     9/20/1971    7  5 17.6      8.1    B      9  1.58     9    0              4400369
 •   4400366     38.362    122.572     8/26/1971   14 12 19.6      8.2    A      9  1.85     9    0              4400366
 •   4400443     38.364    122.572    12/29/1972    1 33  5.8      9.2    B      9  0.53     9    0              4400443
 •   4400380     38.365    122.582    12/ 8/1971    9 25 13.9      8.7    B      9  1.01     9    0              4400380
 •   4400508     38.367    122.549     9/20/1973    6 41 56.1     11.0    B      9  1.11     9    0              4400508
 •   4400355     38.371    122.376     6/ 7/1971    4 56 59.5      4.2    C      9  1.38   009    0              4400355
 •   4400441     38.375    122.403    12/24/1972   11 47 10.1      7.7    B      9  1.23     9    0              4400441
 •   4400558     38.380    122.630     6/ 6/1974   12 13 51.1      0.0           1  3.10     1    4C   006       4400558
 •   4400426     38.385    122.545     9/29/1972    9 26 12.6      5.9    B      9  1.55     9    0              4400426
 •   4400499     38.388    122.606     9/11/1973    7 54  3.2      0.4    B      9  1.68     9    0              4400499
 •   4400547     38.392    122.570    12/ 1/1973    8 24 24.4      6.7    A      9  2.46     9    0              4400547
 •   4400385     38.393    122.652    12/31/1971    4 53 53.7      8.8    A      9  1.65     9    0              4400385
 •   4400368     38.393    122.656     9/ 8/1971   13 34 32.1      7.5    A      9  0.87     9    0              4400368
 •   4400556     38.395    122.652    12/26/1973    0  9 30.9      7.9    A      9  1.67     9    0              4400556
 •   4400420     38.397    122.651     7/25/1972    4 57  7.6      9.4    A      9  1.65     9    0              4400420
 •   4400433     38.398    122.554    11/19/1972    5 20 27.8      6.0    A      9  0.70     9    0              4400433
 •   4400421     38.399    122.653     7/25/1972   10 12 54.4      8.4    A      9  1.40     9    0              4400421
     4400076     38.400    122.450    10/19/1949    7  0  0.0      0.0    D      1  9.99     1    4C   001       4400076
 •   4400103     38.400    122.450     6/23/1951   22 48 29.0      0.0    C      1  2.40     1    0              4400103
     4400258     38.400    122.500    12/26/1959    0 18 51.0      0.0    D      1  2.30     1    0              4400258
 •   4400255     38.400    122.500    10/29/1959   23 29  7.0      0.0    D      1  2.90     1    0              4400255
     4400571     38.400    122.600     3/ 6/1865   14 30  0.0      0.0         008  4.700  008    8C   008       4400571
     4400144     38.400    122.600     2/25/1955    0 59  5.0      0.0    C      1  2.80     1    0              4400144
     4400307     38.400    122.600     7/18/1969    1 35 28.0      0.0           1  2.50     1    0A   001       4400307
     4400263     38.400    122.600     8/ 5/1960    6 15 53.0      0.0    D      1  2.00     1    0              4400263
 •   4400564     38.400    122.600     8/ 9/1893    9 15  0.0      0.0         008  5.100  008    7C   008       4400564
 •   4400492     38.400    122.620     8/26/1973    3 17 25.8      5.9    B      9  2.65     9    0              4400492
 •   4400120     38.400    122.670    11/21/1952   23 27 35.0      0.0    B      1  2.40     1    0              4400120
 •   4400569     38.400    122.700    10/13/1899    5  0  0.0      0.0         008  3.900  008    7C   008       4400569
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     4400079     38.400    122.750    11/ 4/1949   14 50  0.0      0.0    D      1  9.99     1    0A   006       4400079
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 •   4400357     38.403    122.579     6/26/1971    0 26 53.0      3.4    C      9  1.52     9    0              4400357
 •   4400354     38.408    122.562     6/ 4/1971    7 29  3.7      9.6    A      9  1.66     9    0              4400354
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     4400026     38.420    122.750     2/16/1934    9 31  0.0      0.0    D      1  9.99     1    5C   006       4400026
     4400029     38.420    122.750     2/16/1934   15 58  0.0      0.0    D      1  9.99     1    5C   006       4400029
     4400027     38.420    122.750     2/16/1934   14  1  0.0      0.0    D      1  9.99     1    4C   006       4400027
     4400006     38.420    122.750     2/18/1929    3 25  0.0      0.0           1  9.99A        5C   007       4400006
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     4400031     38.420    122.750     3/12/1934   16 10  0.0      0.0    D      1  9.99     1    0A   006       4400031
     4400018     38.420    122.750     2/14/1934   22 24  0.0      0.0    D      1  9.99     1    5C   006       4400018
     4400016     38.420    122.750     2/14/1934   18 51  0.0      0.0    D      1  9.99     1    0A   006       4400016
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     4400048     38.420    122.750    10/19/1944    9  7  0.0      0.0    D      1  9.99     1    0A   006       4400048
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     4400022     38.420    122.750     2/16/1934    5 47  0.0      0.0    D      1  9.99     1    0A   006       4400022
     4400024     38.420    122.750     2/16/1934    6 45  0.0      0.0    D      1  9.99     1    0A   006       4400024
     4400049     38.420    122.750    10/19/1944   10  0  0.0      0.0    D      1  9.99     1    0A   006       4400049
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 •   4400047     38.420    122.750    10/19/1944    8 37  0.0      0.0    D      1  9.99     1    0A   006       4400047
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 •   4400175     38.430    122.530     5/ 3/1956    3 30 30.0      0.0    C      1  3.00     1    0              4400175
 •   4400323     38.431    122.614     8/28/1970   20  8 21.4      0.7    C      9  1.53   009    0              4400323
 •   4400435     38.436    122.500    11/24/1972   16 52 23.1      5.9    A      9  1.84     9    0              4400435
 •   4400544     38.436    122.625    11/29/1973   14  4  2.0     11.8    B      9  1.16     9    0              4400544
 •   4400519     38.440    122.625    10/18/1973    0 21 32.1      8.2    B      9  1.38     9    0              4400519
 •   4400479     38.440    122.631     6/30/1973   14 39 21.0      8.8    B      9  0.62     9    0              4400479
 •   4400427     38.441    122.632    10/ 9/1972   13  8 35.8      8.8    B      9  1.00     9    0              4400427
 •   4400339     38.442    122.505     1/30/1971    2 44 57.0      1.1    D      9  1.57   009    0              4400339
 •   4400475     38.444    122.684     5/29/1973   17 31 29.3      6.8    B      9  1.56     9    0              4400475
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 •   4400325     38.451    122.643     8/30/1970   22  3 15.4      8.7    B      9  0.88   009    0              4400325
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 •   4400483     38.459    122.639     7/20/1973    6 37 32.0      9.2    A      9  1.68     9    0              4400483
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 •   4400328     38.466    122.693     9/30/1970    9 42 40.8      5.0    C      9  0.64   009    0              4400328
 •   4400527     38.469    122.686    10/29/1973    7 47 16.7      7.2    B      9  0.66     9    0              4400527
 •   4400467     38.470    122.641     4/24/1973    1  0 57.4     15.0    B      9  1.45     9    0              4400467
 •   4400309     38.470    122.690    10/ 2/1969    4 55 46.5      0.0           1  5.60   001    8C   006       4400309
 •   4400327     38.474    122.688     9/23/1970    5 29 22.9      8.4    C      9  0.56   009    0              4400327
 •   4400485     38.474    122.691     7/22/1973    0 18 43.6      7.9    B      9  2.04     9    0              4400485
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 •   4400337     38.479    122.676    12/11/1970    5 22 10.6      8.4    B      9  1.08   009    0              4400337
 •   4400302     38.480    122.730     4/25/1968   19 49 45.2      0.0           1  4.60   001    7C   006       4400302
 •   4400553     38.484    122.709    12/11/1973    9 42 37.7      5.8    A      9  2.40     9    4C   006       4400553
 •   4400388     38.486    122.660     1/ 9/1972   13 23 49.1     14.0    B      9  1.29     9    0              4400388
 •   4400476     38.486    122.670     6/21/1973    1 15 12.5      5.5    B      9  2.35     9    0              4400476
 •   4400419     38.486    122.674     7/14/1972   14 46 43.3      6.1    C      9  1.56     9    0              4400419
 •   4400396     38.486    122.715     3/20/1972   22 35 48.8      6.1    C      9  1.23     9    0              4400396
 •   4400313     38.490    122.690    10/ 2/1969   12 27  5.5      0.0           1  4.30     1    5C   006       4400313
 •   4400550     38.493    122.714    12/ 8/1973   10  2 34.0      5.4    B      9  1.94     9    0              4400550
 •   4400387     38.495    122.661     1/ 8/1972    4 42  4.6     14.5    B      9  1.21     9    0              4400387
 •   4400436     38.497    122.719    11/26/1972   19 14 35.0      5.1    B      9  2.86     9    0              4400436
 •   4400437     38.498    122.716    11/26/1972   19 17 54.5      5.2    B      9  2.98     9    4C   006       4400437
     4400042     38.500    122.500    10/17/1942    6 10  0.0      0.0    D      1  9.99     1    0A   006       4400042
     4400068     38.500    122.500    10/13/1948    0 23  0.0      0.0    D      1  9.99     1    5C   001       4400068
     4400072     38.500    122.500     8/15/1949   23 52 54.0      0.0    D      1  2.20     1    0              4400072
 •   4400105     38.500    122.500     8/11/1951   14 15 59.0      0.0           1  2.80     1    0              4400105
 •   4400134     38.500    122.650     1/29/1954    7 36 56.0      0.0    C      1  2.80     1    0              4400134
     4400310     38.500    122.700    10/ 2/1969    5 14 21.0      0.0           1  3.10A  001    0              4400310
     4400286     38.500    122.700    12/ 7/1963   12  4 11.6      0.0           1  2.70     1    0              4400286
     4400080     38.500    122.700    11/ 8/1949   12 41 16.0      0.0    D      1  2.50     1    0              4400080
 •   4400312     38.500    122.700    10/ 2/1969    7 10  9.0      0.0           1  3.40A  001    0              4400312

     -------- END OF REQUEST NUMBER  1-A -------- 124 RECORDS SELECTED -------- 83 RECORDS PLOTTED ----------------------
```

known warm water sources, in association with ground rupture from an earthquake, yield further evidence that the warm geothermal waters, in this far western region of the study area, are perhaps ascending to the surface along fracture zones of the Healdsburg and Rodgers Creek faults.

Historically, local newspaper accounts seem to indicate that earthquake activity in the Sonoma Valley area at times has some effect on the character of both hot and cold springs in the area. The water level at the McDonald Well (Warm Springs) Site (Plate 4, Location No. 13). was raised by an 1898 earthquake, as discussed earlier in the historic section of this report. Youngs and others (1983) document four other cases where earthquakes in the area affected the flow rate or water level in warm springs in Sonoma Valley, including Boyes Hot Springs.

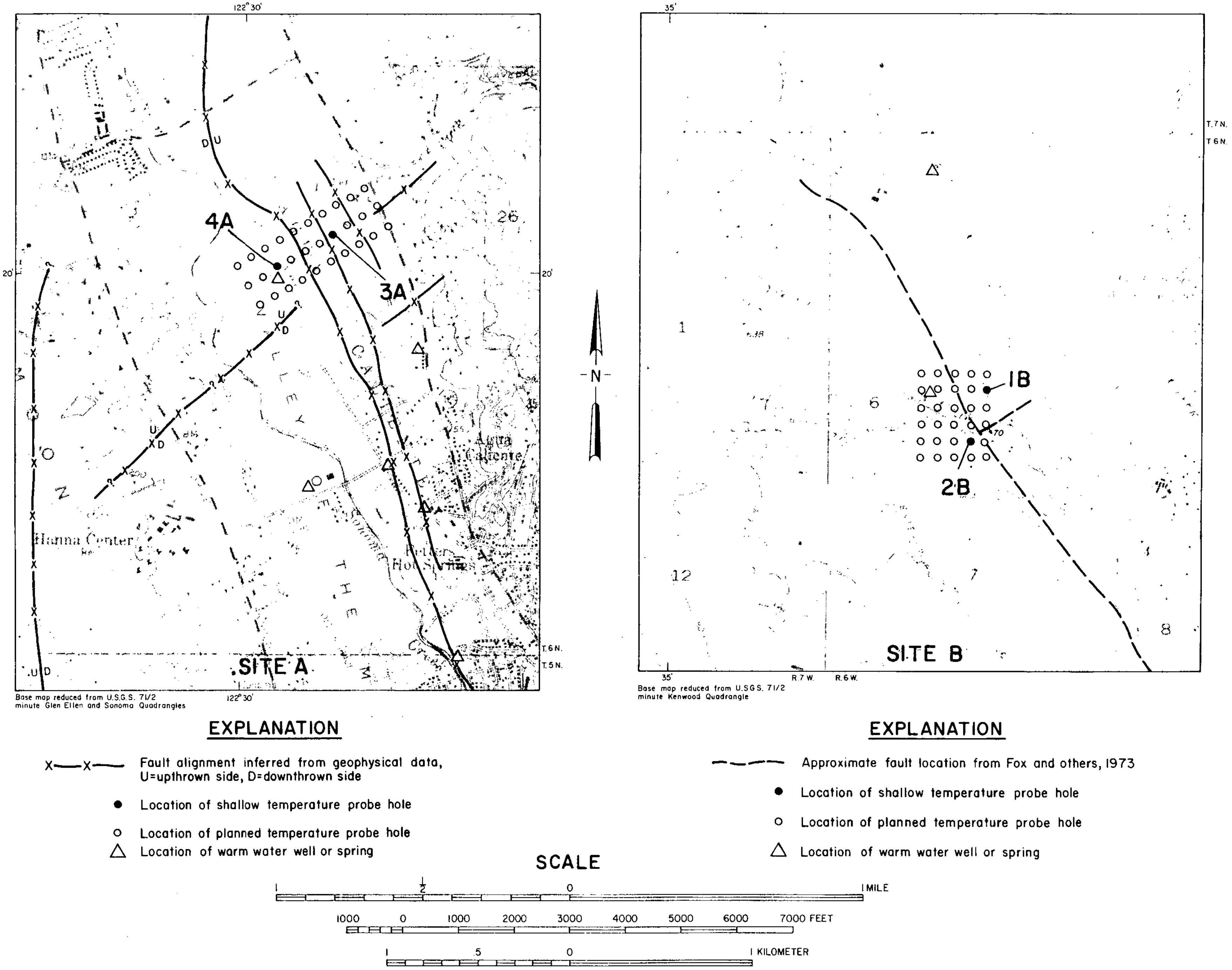
SHALLOW TEMPERATURE PROBE SURVEY

It has been shown (Chaturvedi, 1977; Le Schack and others, 1978) that temperature surveys conducted within a few meters of the surface can sometimes define the location of thermal groundwater aquifers and the possible upwelling of warm water from depth along faults or fractures. The method involves a grid pattern of shallow (2 meter/6.5 feet) holes in which precise temperature readings are recorded after the holes have thermally stabilized. This information is then plotted on a map and contoured. A greatly subdued version of the temperature pattern at depth is often reflected on such maps.

In the northern Sonoma area temperatures were taken with a sealed calibrated thermister that protruded approximately 2.5 centimeters (1 inch) from the bottom of a 2 meter (6.5 foot) length of 1.3 centimeters (1/2 inch) diameter PVC pipe; thermister leads were fed through he PVC pipe and the pipe sealed with clay all around. Time was allowed for temperature stabilization. For this study, corrections for elevations, topography, albedo, etc., were not considered necessary because all sites were on flat ground with nearly identical characteristics.

Due to the extremely heavy rainfall year and therefore the high groundwater, it was difficult to establish a dry hole. CDMG did drill two, 1.8 meter (6 feet) deep holes and two, 0.9 meter (3 feet) deep holes without encountering water, during the last week of field work. These locations are shown on Figure 19. It was intended to complete a grid pattern of 30 holes at Site B (Figure 19). At Site A (Figure 19), an initial line of 10 holes was planned to cross the valley faults. This was to be augmented by 20 more holes to finish the grid. Both locations were selected to cross faults near known warm water in an attempt to detect fault control, if any, on the warm water resource. Because of the small number of holes that could be satisfactorily completed, little useful information was obtained. In both of the 1.8 meter (6 feet) deep holes (holes numbered 1B and 2B on Figure 19) the temperature recorded was 12°C (53.6°F). In both of the 0.9 meter (3 feet) deep holes (holes numbered 3A and 4A on Figure 19) the temperature recorded was 11°C (51.8°F).

Because of saturated ground conditions that prevailed through the end of the field season, it was not possible to obtain dry holes in which to perform satisfactory temperature tests. The method has been shown to give excellent results when tests are performed under normal field conditions. If it had been possible to complete the study under such conditions, it is believed that much valid information would have been obtained. It is strongly recommended that further tests using this technique be performed, preferably under dry field conditions that prevail in late summer and fall in Sonoma Valley.



Base map reduced from U.S.G.S. 7 1/2 minute Glen Ellen and Sonoma Quadrangles

Base map reduced from U.S.G.S. 7 1/2 minute Kenwood Quadrangle

Figure 19. Location of shallow temperature probe holes.

HYDROLOGY

Two hydrologic drainages exist in the Sonoma Valley study area. The drainage divide shown on Figures 20 and 21 trends southward, from the vicinity of Buzzard Peak and Mt. Hood through Oakmont and across the crest of the Sonoma Mountains. The area to the east of the divide is drained principally by Sonoma Creek. The creek is perennial below Glen Ellen, where ground water discharge is significant, but it is intermittent in areas where it crosses the alluvium. Sonoma Creek continues south into San Pablo Bay. Water from the west side of the hydrologic divide flows into Santa Rosa Creek which joins the Russian River and then flows into the sea at Jenner.

Groundwater in the study area occurs in several of the formations described in the "Geology" section of this report. The oldest geologic unit in the study area is the Franciscan Complex of Jurassic and Cretaceous age. This consolidated rock complex yields water only through fractures. Aquifer continuity depends on the extent to which the fractures are interconnected. In essence, this unit has almost no specific yield, but Herbst (1982), assigns a specific yield of less than three percent and states that the quality of the water developed from this formation is poor in thermal areas.

The Petaluma, Glen Ellen, and Huichica Formations have generally low but varying specific yields. The Petaluma Formation can have a higher yield than the Glen Ellen and Huichica Formations when gravel lenses are intercepted. All are assigned specific yields of three to seven percent by Herbst (1982). Because of the nature of these formations, confined aquifers often occur. The quality of the water is generally good, but the Petaluma Formation, being marine in origin, frequently yields water that is brackish and highly mineralized.

The Pleistocene and Holocene alluvial fan and valley alluvium deposits of the study area are the best aquifers. Their specific yields are variable, but range from moderate to high. Herbst (1982), assigned a specific yield of 3-15 percent for valley alluvium deposits and 8-17 percent for the alluvial fan deposits. Although these are generally thin units, they are the principal sources of fresh water in Sonoma Valley. Water quality is excellent.

The geologic unit that appears to have the greatest direct bearing on the hydrology of geothermal fluids in the study area is the Mio-Pliocene Sonoma Volcanics. This unit is a thick interbedded sequence of discontinuous andesite and basalt flows, tuff, welded tuff, breccia, pumice, scoria, and volcanic sediments with minor intrusive igneous rocks. The volcanic flow rocks are essentially nonwater-yielding with water occurring only along fractures. Wells that penetrate the unwelded tuffs, scoria, and volcanic sediments are often good water producers, and yield moderate-to-large quantities of water, often as much as several hundred gallons per minute (Kunkel and Upson, 1960). Therefore, a specific yield collectively assigned to the formation will be highly variable. Herbst (1982) reports that specific yield is 0-15 percent. Ground water in the Sonoma Volcanics is frequently confined or semi-confined. The temperature of water from some wells known to be drilled in the Sonoma Volcanics ranges from 18°C (65°F) to more than 43°C (110°F) (Kunkel and Upson, 1960). Although few drilling logs of the warm wells in the area are readily available, it is likely that most, if not all of the warm water wells are in units of the Sonoma Volcanics (Chapman and Chase, 1982). Figure 37 shows that a warm water well at Boyes Hot Springs penetrates volcanic rocks.

Except for connate sea water, the ground water is derived from precipitation on the valley and adjacent hills and mountains. Seasonal changes cause an average fluctuation of 3 meters (10 feet) in the water table. Because of topographic constraints, the two basins are rarely filled above 79 percent of their storage capacities (Herbst, 1982). Recharge mainly occurs along stream beds incised into alluvial fans, but infiltration also takes place in the Sonoma Volcanics.

Kunkel and Upson (1960) state the source of water in the Sonoma Volcanics "...is precipitation on the outcrop area, infiltration of water from streams that flow over the outcrop area, and probably, in some places where the head is low and confinement is not complete, downward seepage of water from the overlying formations." It also seems likely that some water enters the upper permeable units by upward movement of deeper confined geothermal fluids along faults and fractures.

Geothermal fluids in the study area appear to be produced predominantly from permeable units of the Sonoma Volcanics. The predominate source of warm water is apparently deep circulation of meteoric waters, mainly from runoff in the outcrop areas of the Mayacmas Mountains east of the Sonoma Valley and the Sonoma Mountains west of Sonoma Valley. Artesian flow of geothermal wells is due to penetration by those wells of confined and semi-confined permeable aquifers usually in the Sonoma Volcanics. When geothermal waters enter the near surface hydrological system of the area, their movement is the same as for fresh water; generally inward toward the center of the valley and either southward or westward depending upon which of the two separate drainages the waters enter. This general movement trend is locally interupted by subsurface structural water barriers such as faults. It is not possible with the current data, which is significantly lacking in flow tests, to estimate the volume of water within the units of the Sonoma Volcanics; therefore the volume of geothermal resources available in Sonoma Valley is, at present, unknown.

GEOCHEMISTRY

Introduction

Geochemical analyses of fluids from a geothermal reservoir provide a means for determining many diagnostic properties of that reservoir. Analyses of mineral segregation in thermal fluids may indicate lateral and/or vertical structural features or barriers within or bounding a geothermal reservoir. Geochemical analyses of thermal fluids may also provide some clues to the type of thermal system being investigated including such parameters as heat source, reservoir rock types, path of fluids, etc.

Methodology

Several sources of geochemical data were used in this study. A research of published literature and of the California Department of Water Resources (CDWR) water quality data files was conducted. Some analyses of water samples were supplied by property owners and others were collected and analyzed by California Division of Mines and Geology (CDMG). A total of 110 analyses were available for the Sonoma Valley with 17 occurring in the study area. This information is tabulated on Plate 5. Well and spring locations are plotted on Plate 6. Locations are numbered consecutively from north to south. Both cold and warm wells and springs are represented. Also included on Plate 6 are the chemical characteristics of each well and spring. This is represented by a symbol code.

In order to make any mineral concentration patterns associated with warm wells and springs apparent, several zonation maps were constructed. Concentrations of calcium, chlorine, magnesium, silica, boron, and total dissolved solids were plotted. Also those wells or springs with sodium as the predominant cation were grouped on the base map. Only the last three mentioned provided zonation maps with meaningful trends.

Results

The chemical trends that are evident in these zonation maps include those for boron, total dissolved solids, and waters having sodium as the dominant cation. Plate 6 shows a long narrow band of wells and springs in which sodium is the dominant cation. This trend begins near Glen Ellen and runs south down the valley toward San Pablo Bay where it widens out. The band is associated with the "east side" fault and becomes broad near the bay due perhaps to sea water intrusion. To the north of this band, waters from wells with Locations No's. 29, 30, and 31 (Plate 6) also display sodium as the dominant cation. This group, all in the vicinity of Morton's Warm Springs, follows the trend and possibly could be an extension of the band to the south. To the northwest another belt of thermal water with dominant sodium cations occurs, apparently in association with faults in the Healdsburg-Rodgers Creek fault zone. The occurrence of waters with the dominant cation of sodium and faulting appear to play a role wherever known warm water exists.

Another zonation map that showed some chemical trends is the boron map (Figure 20). As in the case of the map for the sodium cation, water with boron concentrations greater than 1.0 mg/l trends down the valley spreading out near the bay and is also apparently associated with the "east side" fault and sea water intrusion. The trend may also extend to the north to include the thermal anomaly near Morton's Warm Springs. Other known geothermal occurrences included in this trend are Boyes Hot Springs, Fetter's Hot Springs, and Agua Caliente Springs. In comparison, in the northern part of the valley, boron concentrations do not exceed 0.4 mg/l (except at Morton's Warm Spring). Because of the high toxicity of boron to plants this lower concentration would facilitate the disposal of any effluent from a geothermal well. The CDWR (Herbst, 1982) notes that boron below 0.5 mg/l is satisfactory for all crops, 1.0 m /l is toxic to many plants including grapes, and 2.0 mg/l is toxic to most plants. Figure 20 shows shaded areas where boron concentrations greater than 2.0 mg/l have been measured in Sonoma Valley. The source of the boron probably varies. To the south, sea water intrusion is a possible source. The other high concentrations may be due to thermal water movement along faults.

The third zonation map shows the concentration of total dissolved solids (TDS). This map (Figure 21) shows trends similar to those of the two previous maps. The long narrow band which trends down the valley and widens out near San Pablo Bay to the south can be seen again. A similar trend also occurs in relation to the Healdsburg-Rodgers Creek fault zone. It is interesting to note that except for the sea water intrusion area near the Bay, Boyes Hot Spring is the only area that exceeds 1,000 mg/l TDS (Plate 5, Location No. 59), the California Department of Health's maximum limit for domestic consumption.

Conclusions

The distribution of boron, sodium, and high TDS in the Sonoma Valley appear to be associated with the faulting system and the warm water occurrences. The geothermometry results presented in the next section also seem to bear this out. On a whole the CDWR considers all the water in the valley to be of fairly good quality. This will be an aid to development when the disposal of the effluent must be considered.

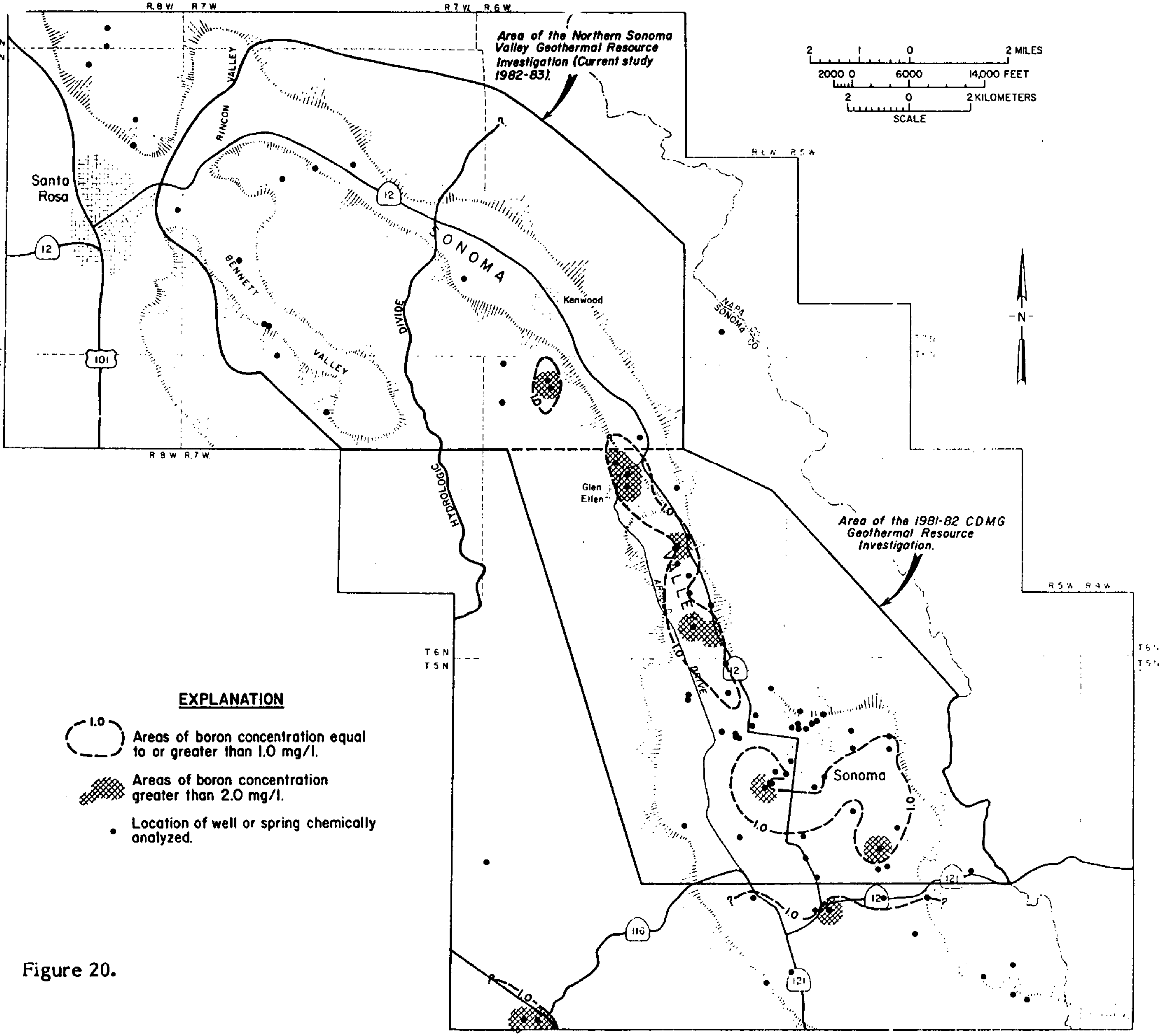
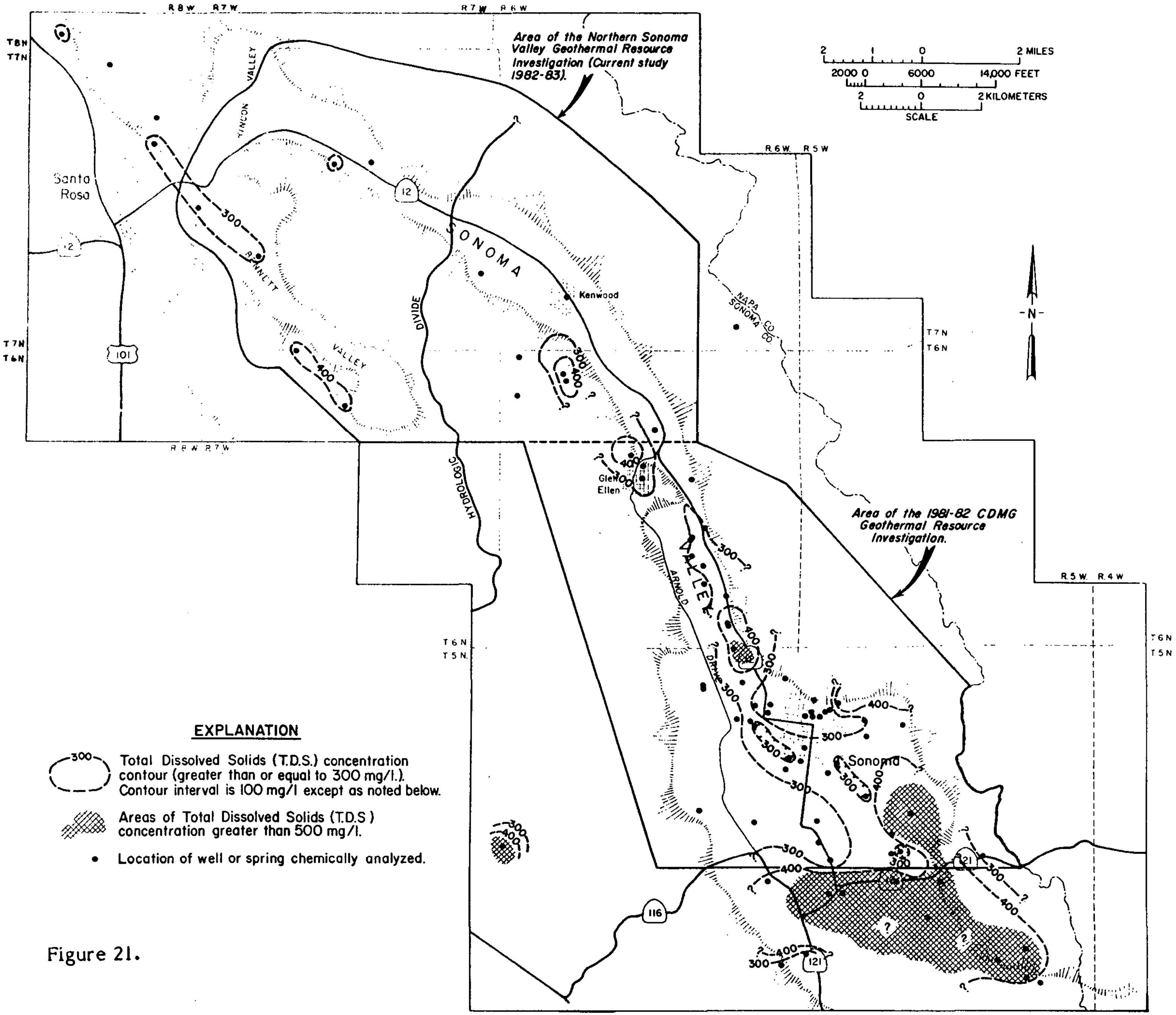

R.8 W. R.7 W.
R.7 W. R.6 W.
R.6 W. R.5 W.
R.5 W. R.4 W.
R.8 W. R.7 W.
T8N
T7N
T7N
T6N
T6N
T5N
Area of the Northern Sonoma Valley Geothermal Resource Investigation (Current study 1982-83).
Area of the 1981-82 CDMG Geothermal Resource Investigation.
2 1 0 2 MILES
2000 0 6000 14,000 FEET
2 0 2 KILOMETERS
SCALE
N
Santa Rosa
12
101
116
121
RINCON VALLEY
BENNETT VALLEY
HYDROLOGIC DIVIDE
SONOMA VALLEY
ARNOLD DRIVE
Kenwood
Glen Ellen
Sonoma
NAPA CO.
SONOMA CO.
1.0
?
EXPLANATION
1.0
Areas of boron concentration equal to or greater than 1.0 mg/l.
Areas of boron concentration greater than 2.0 mg/l.
Location of well or spring chemically analyzed.

Figure 20.



EXPLANATION

Total Dissolved Solids (T.D.S.) concentration contour (greater than or equal to 300 mg/l.). Contour interval is 100 mg/l except as noted below.

Areas of Total Dissolved Solids (T.D.S) concentration greater than 500 mg/l.

- Location of well or spring chemically analyzed.

Figure 21.

GEOTHERMOMETRY

Introduction

The use of chemical geothermometers (geothermometry) is one method of estimating the temperature of a geothermal reservoir. Geothermometry algorithms are based on temperature and pressure-dependent water-rock reactions which determine the chemical and isotopic composition of geothermal fluids. The most common solutes in thermal waters are SiO_2, Na, K, Ca, Mg, Cl, HCO_3, and CO_3. The two, most-generally-used geothermometers are the silica (SiO_2) and Na-K-Ca geothermometers. Several conditional assumptions must be made before using chemical compositions of spring and well waters to estimate subsurface temperatures:

1. Temperature-dependent reactions in the reservoir control the dissolved chemical concentrations of elements used in a particular geothermometer.

2. The reservoir contains a sufficient supply of the reactants.

3. Water-rock equilibrium is established in the reservoir for the specific elemental concentrations to be employed in the geothermometry calculations.

4. The constituents used in the geothermometer do not re-equilibrate with the confining rock as the fluids go from the reservoir to the surface or to the point at which the sample is collected.

5. Mixing of thermal and nonthermal groundwater does not occur, or if it does, an accurate mixing model can be established.

Problems and inaccuracies arise in calculating reservoir temperatures from a geothermometer when one or more of the above assumptions are violated. The geochemical data gathered for this report (Plates 5 and 6) come predominantly from wells that were drilled for a fresh or cold water supply. Typically, these wells are perforated over a large percentage of their total depth to maximize water production. The waters in such wells could be a mixture of water from distinct aquifers. If one or more of these aquifers contain geothermal fluids, those fluids would then be mixed (at unknown proportions) with waters from fresh water aquifers. Also, some wells undoubtedly are so shallow as to only encounter shallow groundwater tables and do not intersect geothermal aquifers. Such conditions do not conform to the five basic assumptions required for accurate geothermometry calculations. Hence, the geothermometric results presented below should be considered with great care and some skepticism.

Methodology

California Division of Mines and Geology (CDMG) was able to obtain 110 chemical analyses from cold and warm water wells and springs in the Sonoma Valley area (Plate 5). Eighty-six of these analyses contained sufficient data to be entered into the "FORTRAN Program to Compute Chemical Geothermometers for Geothermal Fluids" (Rapport, 1982) that is available in the CDMG computer program library. The resulting geothermal reservoir temperatures calculated by each geothermometer are listed in Table 2.

Bowen (1979) suggests that the quartz geothermometer is best suited for the temperature range of 150°-225°C (302°-437°F), the Na-K geothermometer works best for temperatures above 200°C (392°F), and the Na-K-Ca geothermometer is best suited for water equilibrated around 100°C (212°F). Since there is no physical evidence to indicate a very "hot" geothermal reservoir in the study area, the temperature values from the Na-K-Ca (ß = 4/3) geothermometer from Table 2 were chosen to be contoured on Plate 6. The calculated temperature values from this geothermometer were plotted and contoured regardless of well depth or whether or not a well contained cold or warm water.

Results

The calculated geothermometer temperatures in Table 2 are highly varied and range from negative to a maximum of 389°C (732°F). These outer limits of the data are, of course, incorrect. An average of all the values, as well as the average values from only those wells and springs with recorded temperatures greater than 25°C (77°F) throughout the Sonoma Valley area (from Table 2) are presented below:

GEOTHERMOMETER	AVERAGE TEMPERATURE OF ALL VALUES	AVERAGE TEMPERATURE T > 25°C
Silica-Conductive	113°C (235°F)	129°C (264°F)
Silica-Adiabatic	113°C (234°F)	135°C (257°F)
Silica-Chalcedony	84°C (183°F)	101°C (213°F)
Silica-Cristobalite	63°C (145°F)	78°C (172°F)
Silica-Amorphous	-4°C (25°F)	9°C (48°F)
Na-K	160°C (320°F)	179°C (354°F)
Na-K-Ca (ß = 1/3	148°C (298°F)	170°C (338°F)
Na-K-Ca (ß = 4/3	69°C (156°F)	100°C (212°F)
Mg Corrected Na-K-Ca (ß = 1/3)	44°C (111°F)	61°C (142°F)
Mg Corrected Na-K-Ca (ß = 4/3)	54°C (156°F)	65°C (149°F)

There is little correlation between the values calculated for each geothermometer or between the average values, hence, a regional predicted geothermal reservoir temperature is difficult to define from these data. However, the average of the Na-K-Ca (ß = 4/3) geothermometer values for 13 wells within the northern study area is approximately 70°C (158°F) (Plate 6 and Table 2). Youngs and others, 1983, suggested that the temperature of the geothermal reservoir underlying the central and southern portions of the Sonoma Valley may possibly be in the range of 52°-77°C (126°-171°F). The temperature of the northern Sonoma Valley geothermal reservoir or reservoirs appears to compare favorably.

The contoured geothermometer data on Plate 6 show some well-defined local correlations. The dominant feature is the 100°C closed elongate contour, trending north-northwest from the City of Sonoma in partial coincidence with the "east side" fault. Youngs and others (1983) suggest that this indicates a geothermal "plume" or up-welling occurring along the fault trace. This area of predicted "hotter" reservoir

Table 2. Geothermometry temperature (°C) values for selected water wells and springs in the Sonoma Valley area, California.

LOCATION NUMBER	SURFACE TEMPERATURE (°C)	SILICA					Na-K	Na-K-Ca (1/3)	Na-K-Ca (4/3)	Mg CORRECTED	
		CONDUCTIVE	ADIABATIC	CHALCEDONY	CRISTOBALITE	AMORPHOUS				Na-K-Ca (1/3)	Na-K-Ca (4/3)
6	24°	137°	133°	110°	87°	17°	179°	142°	26°	---	---
7	29.4°	---	---	---	---	---	183°	153°	45°	---	---
10	30°	137°	132°	110°	86°	16°	203°	179°	84°	---	---
12	22°	137°	133°	110°	86°	17°	206°	181°	84°	---	---
13	31.7°	---	---	---	---	---	196°	171°	72°	---	---
14	---	---	---	---	---	---	227°	183°	66°	---	---
15	---	---	---	---	---	---	144°	133°	43°	---	---
17	30.6°	---	---	---	---	---	204°	---	---	---	---
19	30°	142°	136°	115°	91°	21°	200°	180°	90°	---	---
20	22°	151°	144°	125°	100°	29°	134°	139°	75°	---	---
24	---	---	---	---	---	---	167°	141°	34°	---	---
27	20°	137°	132°	110°	86°	16°	259°	193°	56°	17°	44°
28	23°	136°	131°	109°	85°	15°	209°	170°	56°	---	---
29	31°	133°	129°	105°	82°	13°	186°	180°	110°	48°	52°
30	---	108°	108°	79°	58°	-9°	---	---	---	---	---
31	---	126°	123°	98°	75°	7°	186°	184°	119°	---	---
34	---	---	---	---	---	---	224°	177°	54°	---	---
35	---	121°	119°	93°	70°	3°	148°	170°	146°	---	---
38	---	131°	128°	104°	81°	12°	224°	187°	77°	---	---
40	16°	141°	136°	115°	90°	20°	235°	191°	73°	---	---

Table 2 (Cont.)

41	---	---	---	---	---	---	196°	182°	100°	---	---
42	21°	119°	117°	90°	68°	1°	167°	184°	155°	102°	96°
43	18°	121°	119°	93°	70°	3°	209°	195°	118°	42°	45°
45	---	---	---	---	---	---	216°	196°	108°	---	---
46	---	---	---	---	---	---	160°	174°	134°	---	---
47	22°	122°	120°	94°	72°	4°	230°	206°	116°	73°	68°
48	22°	136°	132°	109°	85°	16°	263°	186°	40°	94°	---
51	WARM	---	---	---	---	---	153°	173°	147°	---	---
52	35°	117°	115°	88°	66°	-1°	172°	172°	108°	101°	95°
53	29°	116°	115°	87°	65°	-2°	171°	171°	106°	86°	84°
54	43°	131°	128°	104°	81°	12°	127°	155°	141°	---	---
59	44°	---	---	---	---	---	126°	154°	138°	---	---
60	14°	87°	90°	56°	37°	-26°	389°	259°	85°	49°	49°
61	17°	111°	110°	81°	60°	-7°	189°	174°	87°	16°	30°
62	21°	111°	111°	82°	61°	-6°	123°	116°	31°	36°	---
63	---	---	---	---	---	---	75°	82°	9°	---	---
64	31°	---	---	---	---	---	121°	144°	114°	---	---
65	30°	104°	104°	74°	53°	-12°	174°	179°	124°	---	---
66	18°	---	---	---	---	---	105°	109°	38°	---	---
67	17°	113°	112°	84°	62°	-4°	148°	125°	21°	22°	---
68	16°	110°	109°	80°	59°	-7°	150°	143°	61°	---	---
69	19°	108°	108°	79°	58°	-9°	145°	138°	56°	18°	43°
70	---	---	---	---	---	---	135°	134°	58°	---	---
71	21°	135°	131°	108°	84°	15°	231°	192°	81°	25°	41°

Table 2 (Cont.)

72	21°	113°	112°	84°	62°	-4°	200°	151°	25°	64°	---
73	24°	63°	69°	31°	14°	-46°	219°	157°	19°	---	---
74	28°	132°	128°	105°	81°	12°	180°	161°	66°	29°	52°
75	28°	139°	134°	112°	88°	18°	193°	180°	99°	---	---
77	23°	127°	124°	99°	76°	8°	186°	158°	53°	29°	---
78	15°	72°	77°	40°	23°	-39°	226°	159°	18°	18°	---
79	29°	127°	124°	99°	76°	8°	215°	181°	73°	16°	35°
80	17°	136°	132°	109°	85°	16°	212°	188°	94°	17°	29°
81	---	87°	90°	56°	37°	-26°	151°	169°	135°	---	---
84	---	---	---	---	---	---	164°	167°	105°	---	---
85	18°	---	---	---	---	---	119°	116°	34°	---	---
86	20°	89°	92°	59°	39°	-25°	107°	125°	81°	28°	41°
87	14°	116°	115°	87°	65°	-2°	119°	123°	55°	39°	---
88	17°	118°	117°	90°	68°	0°	180°	146°	31°	---	---
89	---	55°	62°	23°	7°	-53°	100°	97°	13°	---	---
90	19°	158°	150°	134°	107°	36°	137°	135°	59°	---	---
91	19°	104°	104°	74°	53°	-12°	111°	126°	76°	52°	66°
93	---	55°	62°	23°	7°	-53°	151°	114°	-6°	---	---
94	10°	65°	71°	33°	16°	-45°	43°	74°	47°	42°	---
95	---	---	---	---	---	---	38°	74°	60°	---	---
96	16°	136°	132°	109°	85°	16°	80°	90°	24°	---	---
97	16°	137°	132°	110°	86°	16°	135°	135°	63°	---	---
98	11°	123°	121°	95°	72°	4°	189°	160°	54°	---	---
99	18°	126°	124°	99°	76°	7°	160°	143°	47°	---	---

Table 2 (Cont.)

100	---	115°	114°	86°	65°	-2°	168°	141°	34°	---	---
101	---	---	---	---	---	---	150°	125°	19°	---	---
102	20°	79°	83°	48°	30°	-33°	149°	137°	46°	42°	---
103	18°	81°	84°	49°	31°	-32°	72°	84°	21°	---	---
108	---	74°	78°	42°	24°	-38°	70°	96°	62°	---	---
109	38°	---	---	---	---	---	92°	124°	108°	---	---
110	---	---	---	---	---	---	81°	102°	58°	---	---
111	20°	78°	82°	47°	28°	-34°	43°	80°	68°	---	---
113	17°	112°	111°	83°	62°	-5°	72°	94°	50°	---	---
115	---	---	---	---	---	---	117°	119°	46°	---	---
116	20°	---	---	---	---	---	36°	70°	51°	---	---
117	28°	138°	134°	112°	88°	18°	292°	238°	124°	86°	71°
120	---	---	---	---	---	---	131°	109°	4°	---	---
121	---	---	---	---	---	---	218°	173°	52°	---	---
123	16°	79°	83°	48°	30°	-33°	146°	158°	109°	20°	27°
124	17°	88°	91°	57°	38°	-26°	89°	103°	46°	27°	---
125	12°	77°	81°	45°	27°	-35°	88°	107°	60°	---	---
126	20°	101°	102°	71°	50°	-15°	90°	103°	43°	---	---

temperature may be extended northwestward into the detailed study area as far as Morton's Warm Springs (Plate 6, Location No. 29). Subsurface temperatures as high as 110° (230°F) are suggested for this location based on calculations using the Na-K-Ca (ß = 4/3) geothermometer. However, this "hotter" zone may not be associated with faulting unless an unrecognizezd fault exists in the Morton's Warm Spring area, as no fault has been described there. Additional detailed geophysical work at this location may help determine whether a buried fault exists that may be responsible for the geothermal occurrence at Morton's Warm Springs. All other calculated reservoir temperatures from the Na-K-Ca (ß = 4/3) geothermometer for the northern study area are less than 100°C (212°F). In the western part of the study area, there are two closed 75°C (167°F) contours that parallel the Healdsburg and Rodgers Creek faults. These zones may indicate that geothermal temperatures in excess of 75°C (176°F) may be found along this alinement at greater depth than the existing water wells are drilled.

Conclusions

There are fewer geochemical analyses from wells and springs available in the norhtern Sonoma Valley study area than there are for the southern Sonoma Valley area. Therefore, there may be too few geothermometry values to give an accurate estimate of the temperature of the geothermal reservoir in this area. Nonetheless, the Na-K-Ca (ß = 4/3) geothermometer predicts an average temperature of approximately 70°C (158°F) for the geothermal resources in the north valley area. However, the overall reliability of the geothermometry calculations for the Sonoma Valley area may be questionable because one or more of the conditional assumptions are violated.

Plate 6, shows that the higher geothermal reservoir temperatures occur in the southern and central portions of the Sonoma Valley in association with the "east side" fault. Only at the Morton's Warm Springs area (Plate 6, Location No. 29) can comparable estimated geothermal reservoir temperatures be found in the northern part of the valley. However, a possible geothermal zone of lower reservoir temperature is indicated from the geothermometry data to be in association with or at least parallel to the Healdsburg-Rogers Creek faults in the western part of the northern Sonoma Valley study area. These two zones are the most likely areas for low-temperature geothermal development in the northern Sonoma Valley area.

DIRECT THERMAL TEMPERATURE MEASUREMENTS IN THE SONOMA VALLEY AREA

Introduction

Low temperature geothermal resources ($T \geq 20°C/68°F$) can be used for a variety of alternate energy uses. The primary characteristics of the resources that govern their potential use are temperature and volume. Direct temperature measurement of the resource is the primary method to obtain useful heat data. Several methods were employed by CDMG to obtain direct temperature values of the geothermal resources in the Sonoma Valley area.

Methodology

Locations of known warm water wells and springs and their measured temperatures for the Sonoma Valley area were researched in existing literature. Youngs and others, 1983, provided a compilation of the known warm water wells and springs in the Sonoma Valley area prior to this report. To augment these data, CDMG searched the microfiche files of water quality data in the California Department of Water Resources, as well as other sources, for locations of other warm water phenomena in the area. The complete list of references is shown at the bottom of Table 3.

Also, CDMG recorded surface discharge temperatures with a standard hand-held maximum recording thermometer while collecting some water samples from water wells and springs in the Sonoma Valley area.

Youngs and others, 1983, were able to obtain five downhole water temperature logs from warm water wells in the area. During the course of this survey, an additional eight downhole temperature profiles were gathered by CDMG for a total of thirteen temperature logs presented herein. These data were gathered by lowering a thermistor-tipped temperature probe into wells and recording the temperature at intervals of approximately 6 meters (20 feet). Later, these data were drafted on temperature logs depicting the graphical profile of water temperature versus the depth of measurement in each well.

Results

A listing of wells and springs with recorded temperatures $T \geq 20°C$ (68°F) compiled to date for the Sonoma Valley area is shown in Table 3. The Table lists 58 geothermal wells and springs located throughout the area shown on Plate 1. Note, only 14 of the 58 known locations are within the boundaries of the northern Sonoma Valley study area shown on Plate 1.

Temperatures listed in Table 3 as being measured at zero meters are temperatures measured in the discharge at the surface from the well or spring. The surface discharge temperatures of thermal wells or springs throughout the entire area shown on Plate 1 ranged from 20°-43°C (68°-109°F). The maximum temperature was recorded in a well at Boyes Hot Springs in the central portion of the Sonoma Valley (Plate 1, Location No. 54). However, in the northern Sonoma Valley study area, as outlined on Plate

Table 3. Direct temperature measurements of selected geothermal wells and springs (Temperature $\geq$ 20°C) in the Sonoma Valley area, California.

LOCATION NUMBER	FEATURE	REFERENCE NUMBER *A	LOCATION *B	TEMPERATURE AND DEPTH OF MEASUREMENT (°C/METERS) *C	GRADIENT (°C/100 METERS)	TOTAL DEPTH (METERS)	REMARKS
1	WELL	2	8N/8W, 34M	22.9°/103.6	6.8°/100	153.3	
2	WELL	2	7N/8W, 2E	21.8°/ 78.6	5°/100	112.5	
3	WELL	2	8N/8W, 35L	22.8°/140.8	1.7°/100	142.6	
4	WELL	2	8N/8W, 35P	20.1°/152.4	4.4°/100	155.4	
5	WELL	4	7N/8W, 12D	21°/0	---	9.1	Artesian
6	WELL	2	7N/8W, 12E	24°/0	---	70.1	Artesian
7	WELL	2	7N/8W, 12N	29.4°/0	---	153.6	Artesian
8	WELL	2	7N/8W, 12N	22.8°/0	---	36.6	Artesian
9	SPRING	2	7N/8W, 12N	22.4°/0	---	---	
10	WELL	2	7N/8W, 24A4	30°/0	---	305	Artesian
11	WELL	4	7N/8W, 24H	29°/0	---	366	Artesian
12	SPRING	2	7N/7W, 17J	22°/0	---	---	
13	WELL	2	7N/7W, 16G	31.7°/0	---	39	Artesian
17	WELL	2	7N/7W, 32G9	30.6°/0	---	125	
18	WELL	4	7N/7W, 32L	20°/0	---	86	
19	WELL	2	6N/7W, 5A	30°/0	---	?	
20	WELL	2	6N/7W, 9A	22°/0	---	177.4	
21	WELL	2	6N/8W, 1Q	WARM?	---	84	
23	WELL	2	7N/7W, 25G	23.8°/128	5°/100	166	
25	WELL	2	7N/6W, 33D	WARM?	---	?	Said to be "slightly warm" by owner.
26	WELL	2	7N/6W, 32A	WARM?	---	?	Said to be "slightly warm" by owner.

Table 3 (Cont.)

27	WELL	1	38°23.98', 122°34.00'	22°/0	---	?	
28	SPRING	1	38°23.30', 122°34.11'	23°/0	---	---	"McEwan Ranch" warm spring
29	WELL	1	38°23.66', 122°32.99'	31°/6.1	---	51	Morton's Warm Springs, Artesian
32	SPRING	3	7N/6W, 35J	20°/0	---	---	Nunn's Iron Spring
39	WELL	1	6N/6W, 22B	20°/7	---	7	Hand dug cistern, Sonoma State Hospital
42	WELL	1	38°20.80', 122°30.06'	21°/0	---	76	
44	WELL	2	6N/6W, 21R	37.5°/298.7	9.7°/100	436	Sonoma State (Hospital) No. 3
47	WELL	1	38°20.00', 122°29.82'	22°/0	---	76	
48	WELL	1	38°19.78', 122°29.40'	22°/0	---	79	
50	WELL	1	6N/6W, 35G	26°/57.3	28°/100	57.3	
51	WELL	2	6N/6W, 35E	28.1°/207.3	6.5°/100	207.3	
52	WELL	1	38°19.32', 122°29.40'	35°/0	---	91	Aqua Caliente Springs
53	WELL	1	38°19.32', 122°29.40'	29°/0	---	50	Fetter's Hot Spring
54	WELL	3	5N/6W, 2A2	43°/0	---	107	Boyes Hot Spring ? (Bath House)
58	WELL	1	5N/6W, 2B	28°/3.7	---	?	Boyes Hot Spring "No. 1"
59	WELL	2	5N/6W, 2B	50.6°/140.8	5.2°/100	140.8	Boyes Hot Spring "No. 2"
62	WELL	1	38°18.25', 122°29.81'	21°/0	---	52	
64	WELL	2	5N/6W, 12D	31°/0	---	∿ 213	
65	WELL	1	38°17.88', 122°28.40'	30°/0	---	226	
71	WELL	1	38°17.68', 122°27.51'	21°/0	---	70	Artesian
72	WELL	1	38°17.75', 122°27.42'	21°/0	---	73.2	
73	WELL	1	38°17.95', 122°27.41'	24°/0	---	61	
74	WELL	1	38°17.90', 122°27.01'	28°/0	---	67.1	

Table 3 (Cont.)

75	WELL	2	5N/5W, 7G	28°/0	---	∿ 137	
76	WELL	2	5N/5W, 7G	25°/0	---	46?	
77	WELL	1	38°17.76', 122°27.28'	23°/0	---	152	
79	WELL	1	38°17.65', 122°27.40'	29°/0	---	107	Artesian
82	SPRING	1	6N/4W, 34E	28.4°/0	---	---	
86	WELL	1	38°16.94', 122°27.81'	20°/0	---	53	
92	WELL	2	5N/5W, 17L	29.3°/171	5.9°/100	∿ 305	
102	WELL	1	38°16.02', 122°29.95'	20°/0	---	156	
109	WELL	1,3	5N/6W, 25P2	38°/0	---	195	
111	WELL	3	5N/5W, 31A1	20°/0	---	124	
116	WELL	3	5N/5W, 28R1	20°/0	---	85	
117	WELL	1	38°15.22', 122°23.30'	28°/0	---	213	
122	WELL	1	4N/5W, 7C	28°/33.5	---	61?	Artesian
126	WELL	1	38°12.98', 122°22.37'	20°/0	---	74	

FOOTNOTES:

*A REFERENCES

1. Youngs, L.G., Chapman, R.H., Chase, G.W., Bezore, S.P., and Majmundar, H.H., 1983, Investigation of low-temperature geothermal resources in the Sonoma Valley area, California - Part of the fourth year report, 1981-82, of the U.S. Department of Energy - California State-Coupled Program for reservoir assessment and confirmation: California Division of Mines and Geology, Open-File Report 83-13SAC, Report for U.S. Department of Energy, Contract No. DE-FG03-81SF10855, 103 p.

2. California Division of Mines and Geology, 1982-83, field investigations.

3. California Department of Water Resources, 1982, Microfiche files of water quality data, unpublished.

4. Chapman, R.H., Chase, G.W., and Youngs, L.G., 1982, Geophysical study of the Santa Rosa geothermal area, Sonoma County, California: California Division of Mines and Geology, report for the California Energy Commission, Interagency Agreement No. 500-80-102, 36 p.

*B

Location is either given as coordinates of latitude and longitude or as township, range and section referenced to the Mount Diablo base and meridian. For further discussion and diagram of locations within a section, see the Introduction section of this report.

*C

A depth of temperature measurement of 0 meters means the temperature was recorded in the well surface discharge either pumped or artesianing.

1, the temperature of surface discharges ranged only from 20°C (68°F) to a maximum of 31.7°C (89.1°F). The maximum temperature was recorded at Location No. 13 known as the McDonald well (Plate 1). In the southern and central portions of the Sonoma Valley, distribution of the known warm-water wells and springs is predominantly along an alignment coincident with the "east-side" fault as shown on Plate 4 and as discussed by Youngs and others, 1983. However, the distribution of the known warm wells and springs in the northern Sonoma Valley area appears to be somewhat random unless some known locations just northwest of the immediate study area are taken into consideration. It can then be seen that there is a long alignment of known geothermal phenomena trending north-northwest and parallel with the Healdsburg-Rodgers Creek fault zone. However, this alignment does not contain the warmest known geothermal resources in the study area. The higher direct temperature measurements are at the McDonald well in the Melita area (Plate 4, Location No. 13) and at the Morton's Warm Springs area (Plate 4, Location No. 29).

Of the 13 downhole temperature surveys obtained throughout the Sonoma Valley area, only two are immediately within the northern Sonoma Valley study area. These are Locations No. 23 and No. 29; the latter is Morton's Warm Springs (Plate 1). These two temperature profiles are shown on Figures 26 and 27, respectively. These profiles are similar in that both have temperature reversals. Figure 27 (Morton's Warm Spring well) shows a maximum temperature zone from approximately 5-12.5 meters (16-41 feet) deep in the well. The temperature curve reverses thereafter to a bottom hole temperature of approximately 29.1°C (84°F) at 37.5 meters (120 feet). The maximum temperature recorded is approximately 31°C (88°F). The profile may indicate that the warmer water-bearing aquifer at this site is quite shallow and is probably underlain by one or more cooler aquifers at least to the depth probed in the well.

Figure 26 is the temperature profile for well Location No. 23 as shown on Plate 1. The maximum temperature in this well was 23.8°C (74.8°F) at approximately 128 meters (419.8 feet) deep. There is a very slight temperature reversal shown in the bottom approximately 12 meters (39 feet) of the well. A straight line was manually fitted to the lower portion of the temperature profile shown on Figure 26. The slope of this line is an approximation of the temperature gradient of this profile. Similarly, nine other temperature profiles (Figures 22-25 and 29-33) were sufficient to construct the simplified approximation of temperature gradients. These are listed in Table 3. The average temperature reading discounting the anomalously high value at Location No. 50 is 5.6°C/100 meters (3.1°F/100 feet). Since these 13 temperature profiles are scattered throughout the Sonoma Valley area, this average temperature gradient value may be considered as representative of the regional temperature gradient. The value of 5.6°C per 100 meters (3.1°F/100 feet) is not overly significant. By extrapolating the regional temperature gradient, utilizing the generalized bottomhole temperatures from Figures 22-34, it can be shown that a well would have to be drilled to around 1300 meters (4265 feet) to produce 100°C (212°F) geothermal fluids. Seldom, however, are such long extrapolations reliable. The previously mentioned well drilled on the Sonoma State Hospital grounds showed a gradient of approximately 10°C/100 meters at a depth in excess of 300 meters (984 feet) (Plate 1, Location No. 44).

Of the 13 temperature profiles obtained throughout the Sonoma Valley area, the maximum recorded downhole temperature is 50.6°C (123.1°F) at 140.8 meters (461.8 feet) measured in a well at Boyes Hot Springs in the central portion of the Valley (Plate 1, Location No. 59).

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

LOCATION: No. 1

DATE: 12/30/82

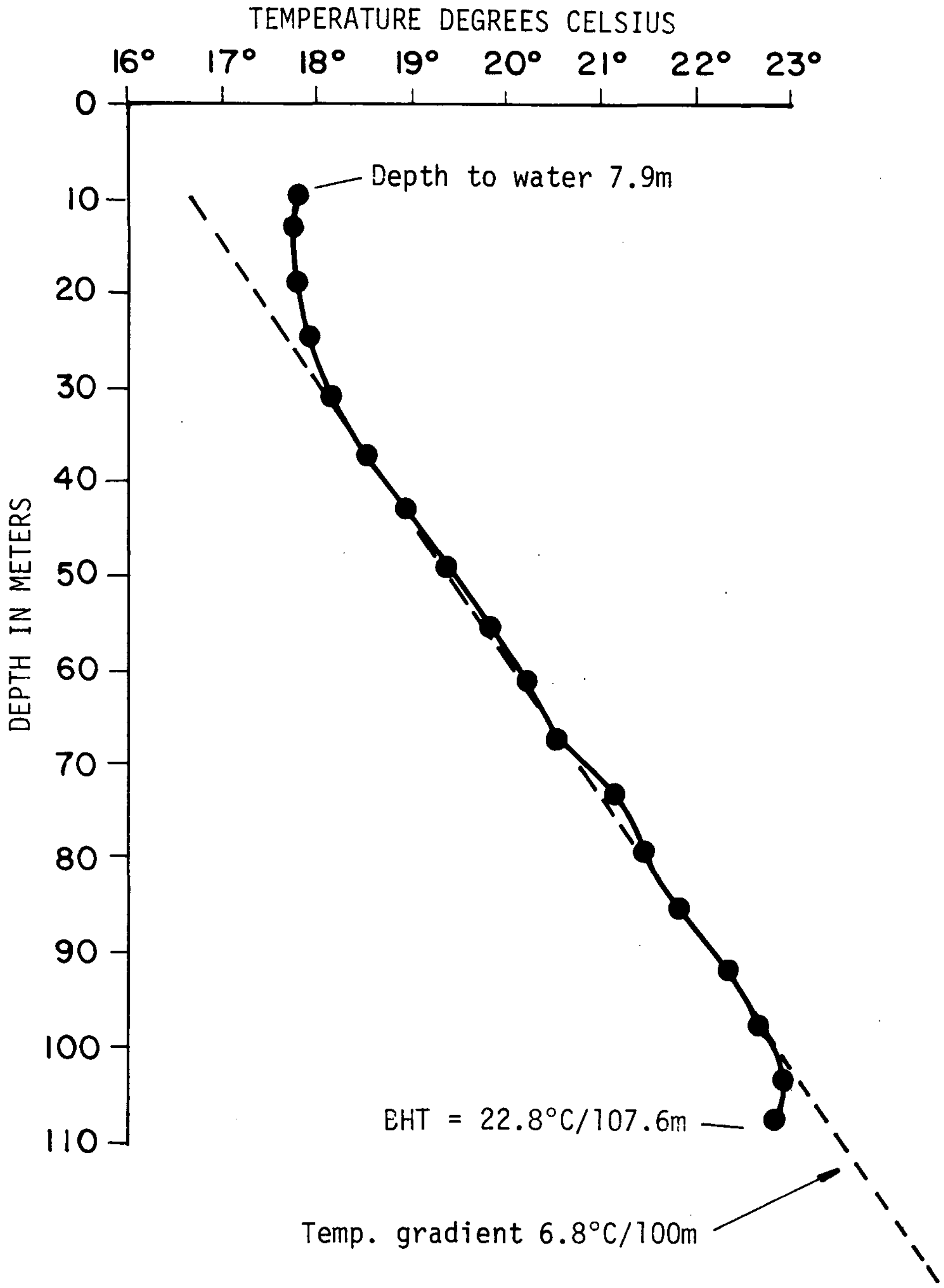


Figure 22.

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

LOCATION: No. 2

DATE: 12/13/82

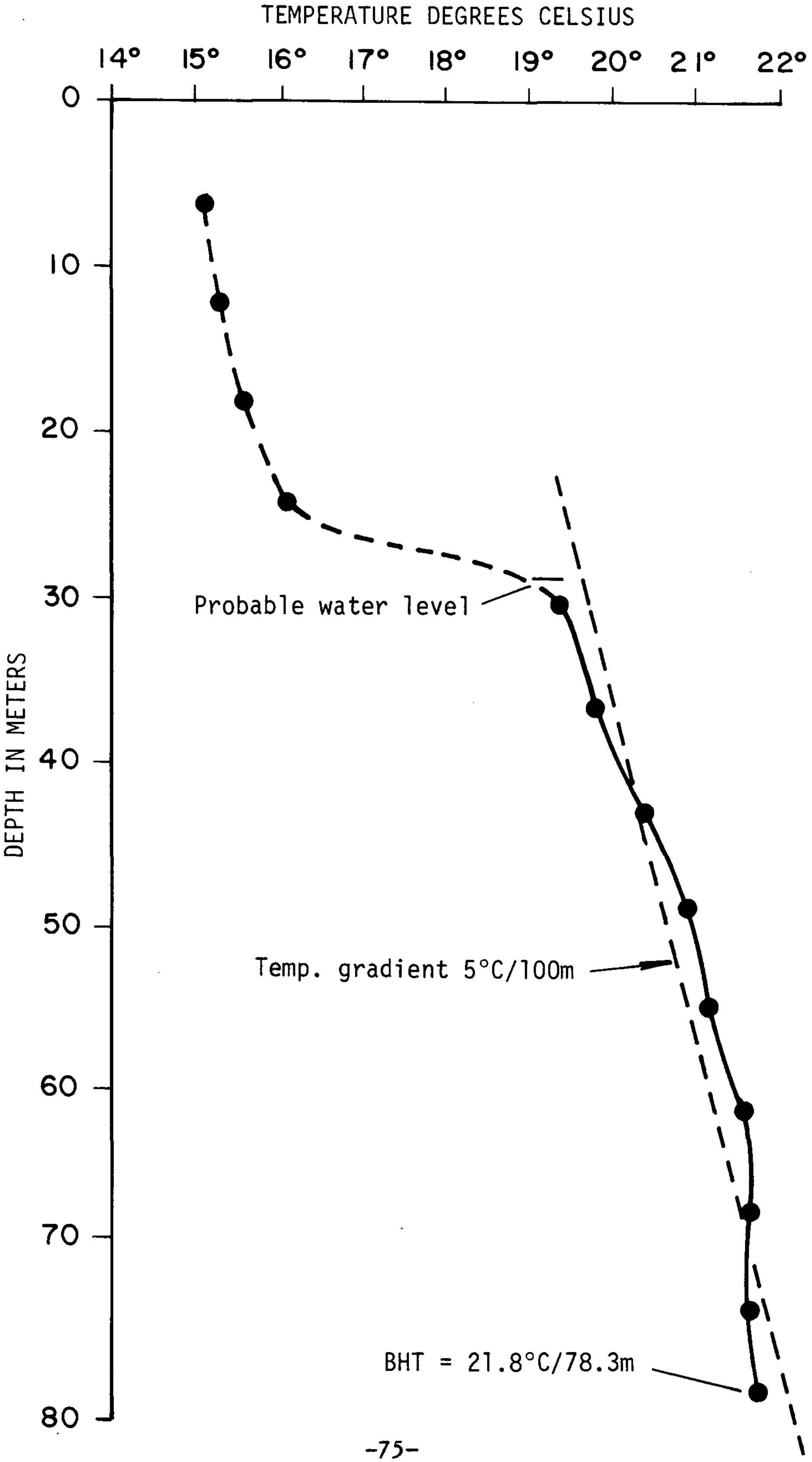
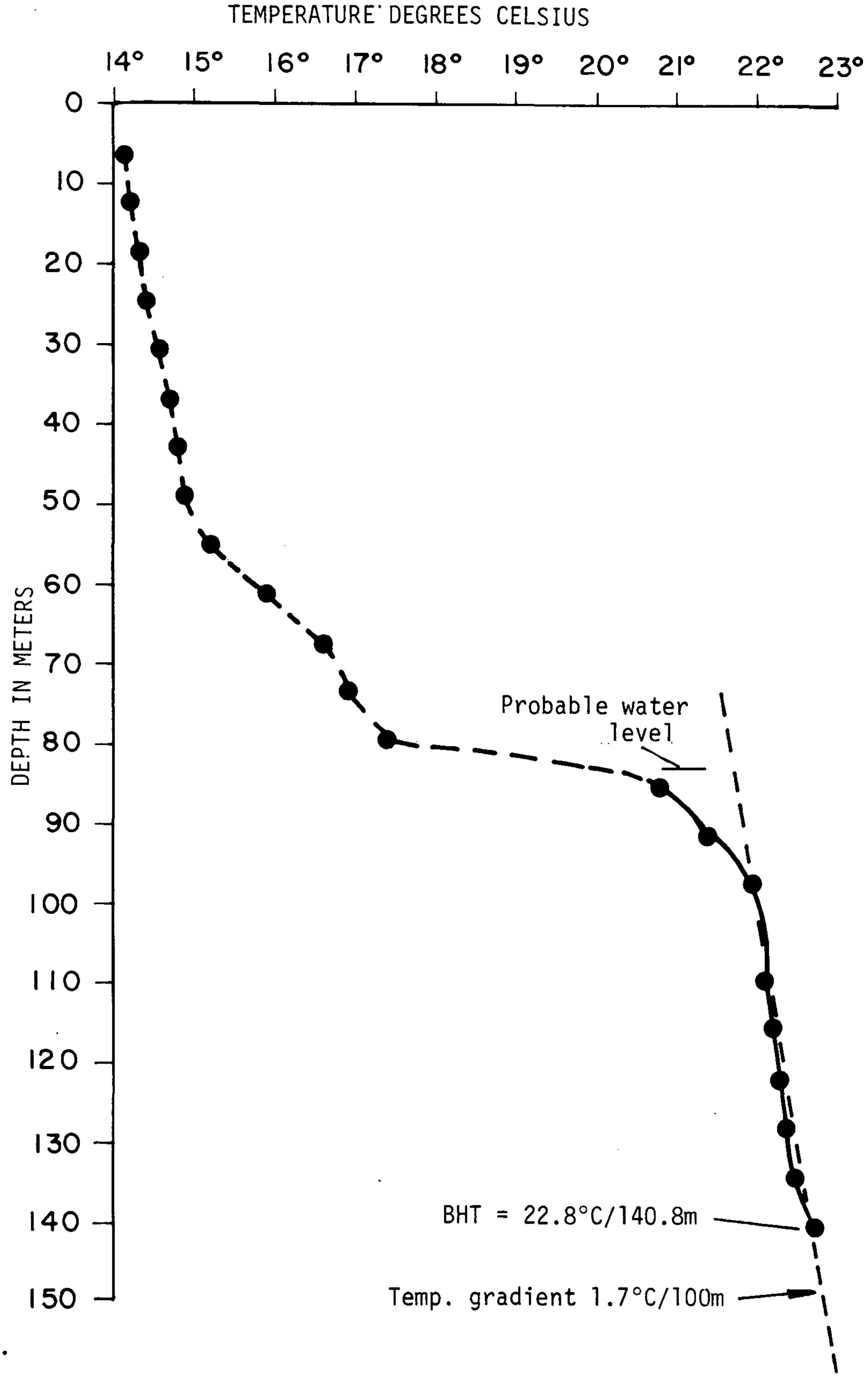


Figure 23.

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

LOCATION: No. 3

DATE: 12/13/82



BHT = 22.8°C/140.8m

Temp. gradient 1.7°C/100m

Figure 24.

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

LOCATION: No. 4

DATE: 12/13/82

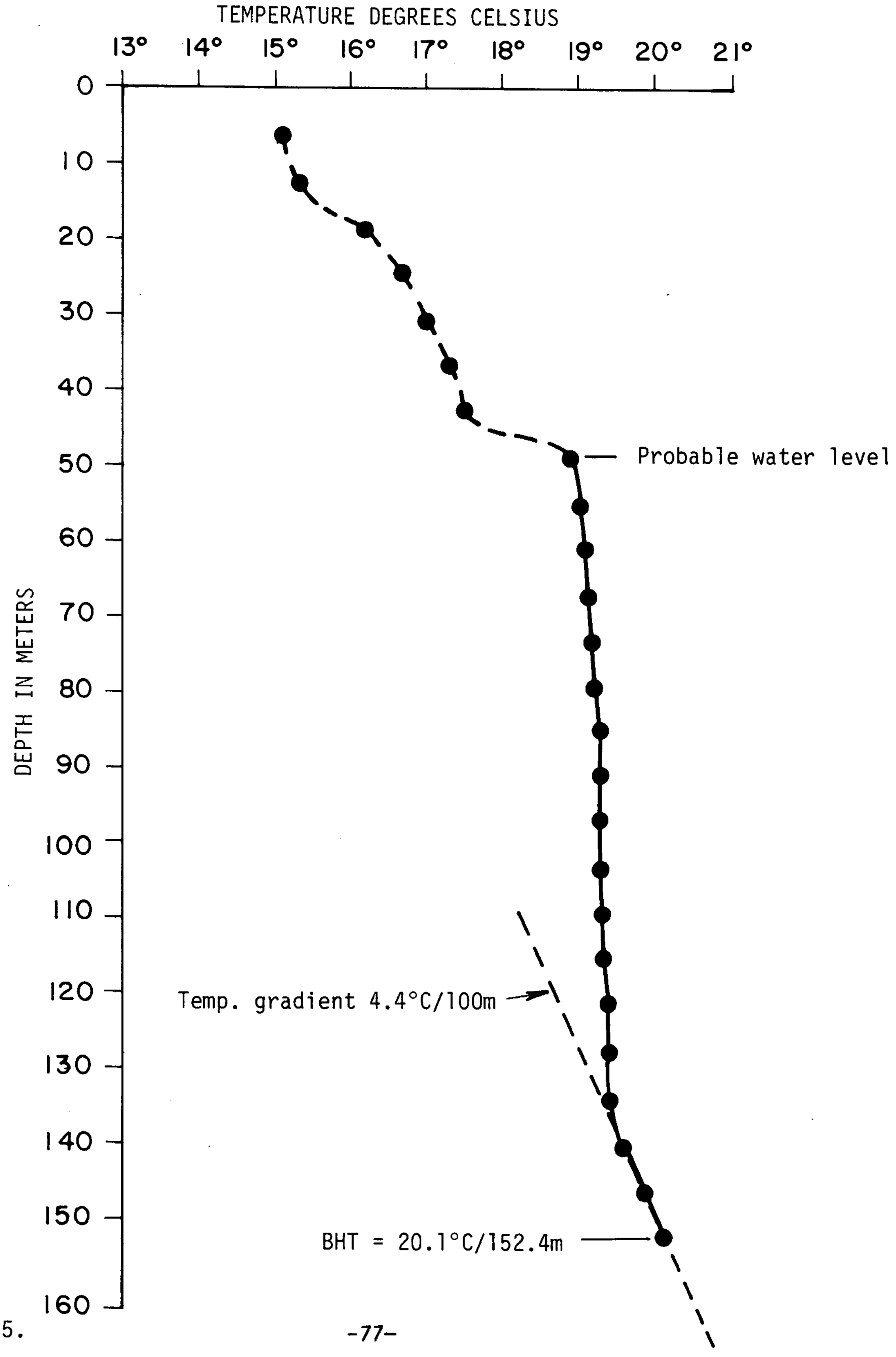


Figure 25.

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

LOCATION: No. 23

DATE: 12/14/82

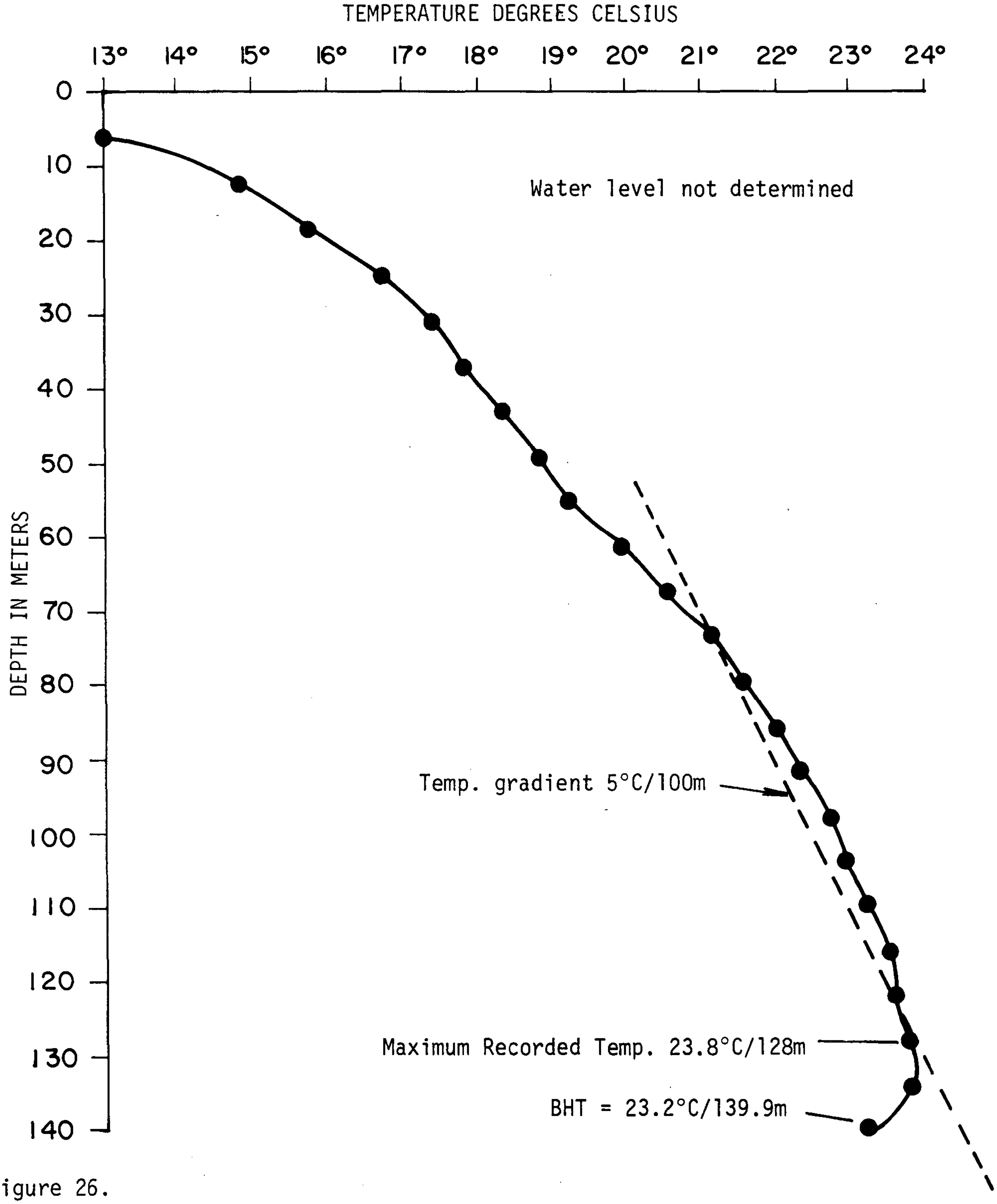
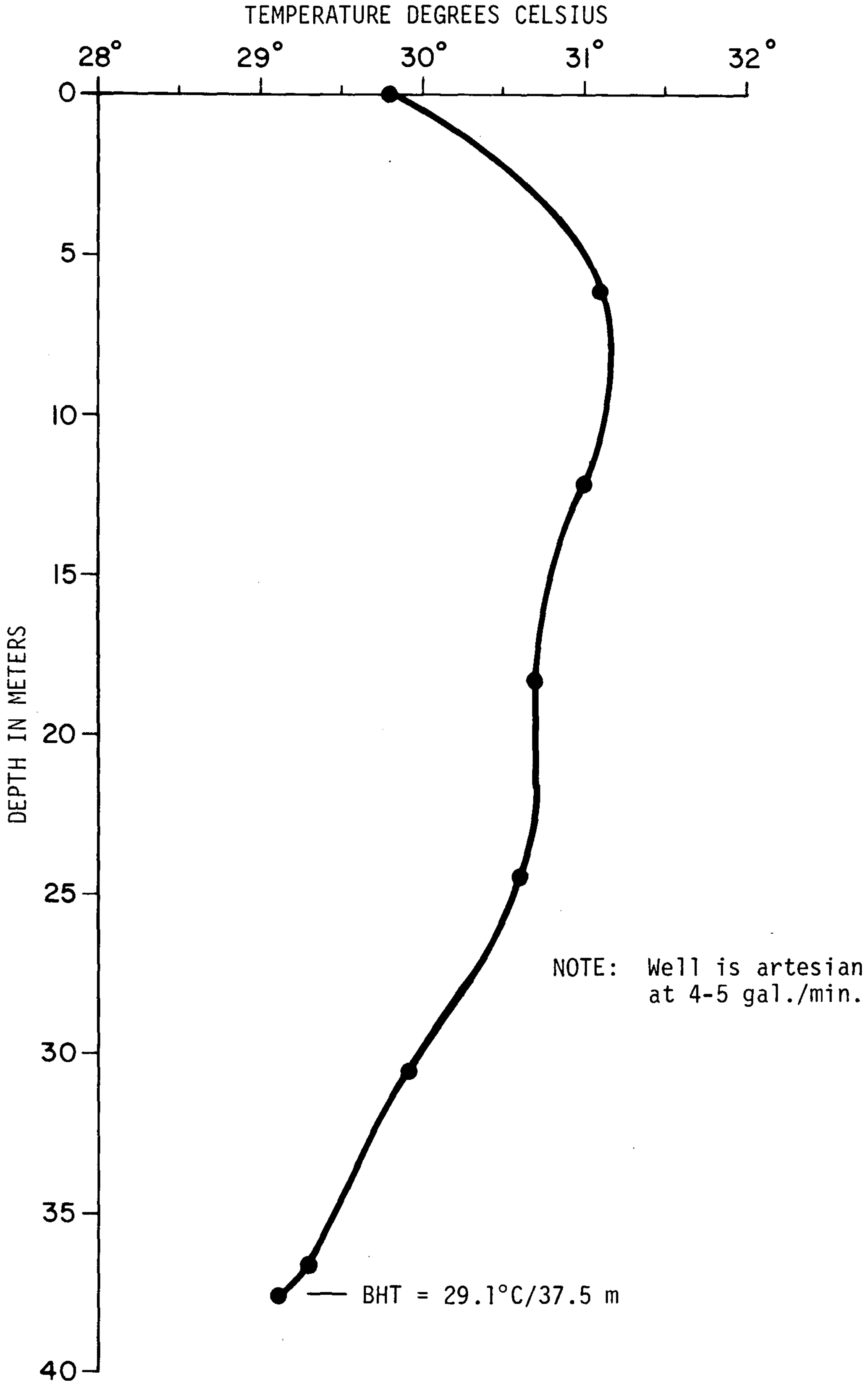


Figure 26.

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

LOCATION No. 29 DATE 2/24/82



NOTE: Well is artesian at 4-5 gal./min.

BHT = 29.1°C/37.5 m

Figure 27.

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

LOCATION No. 39

DATE 2/22/82

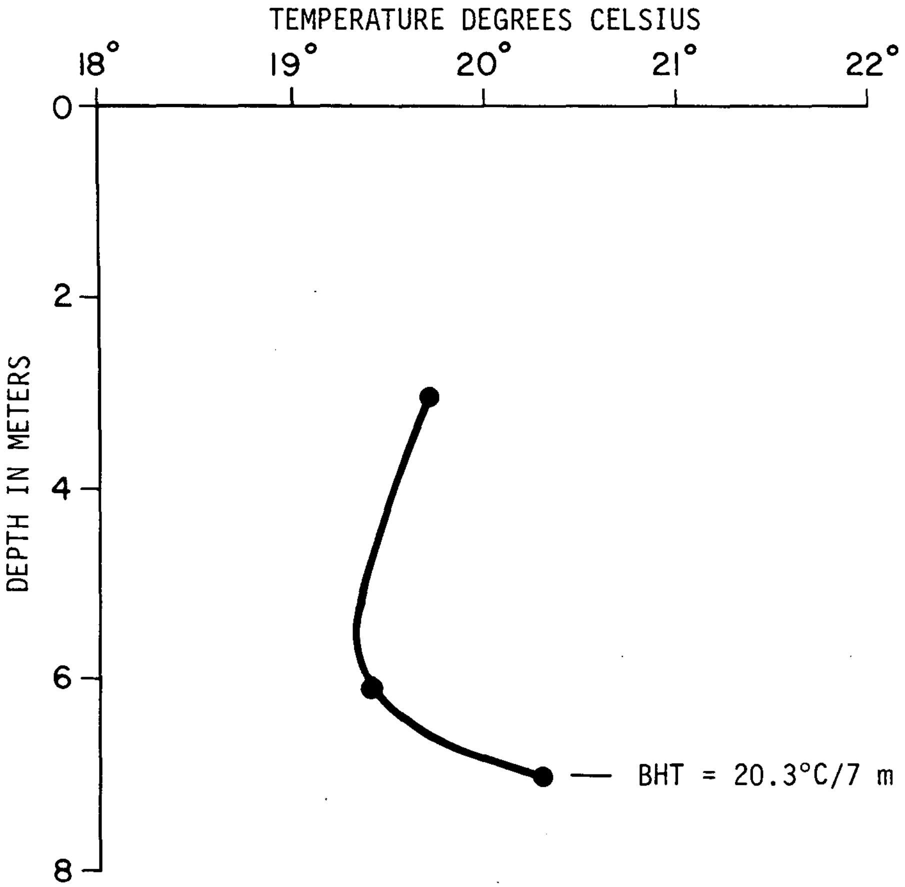
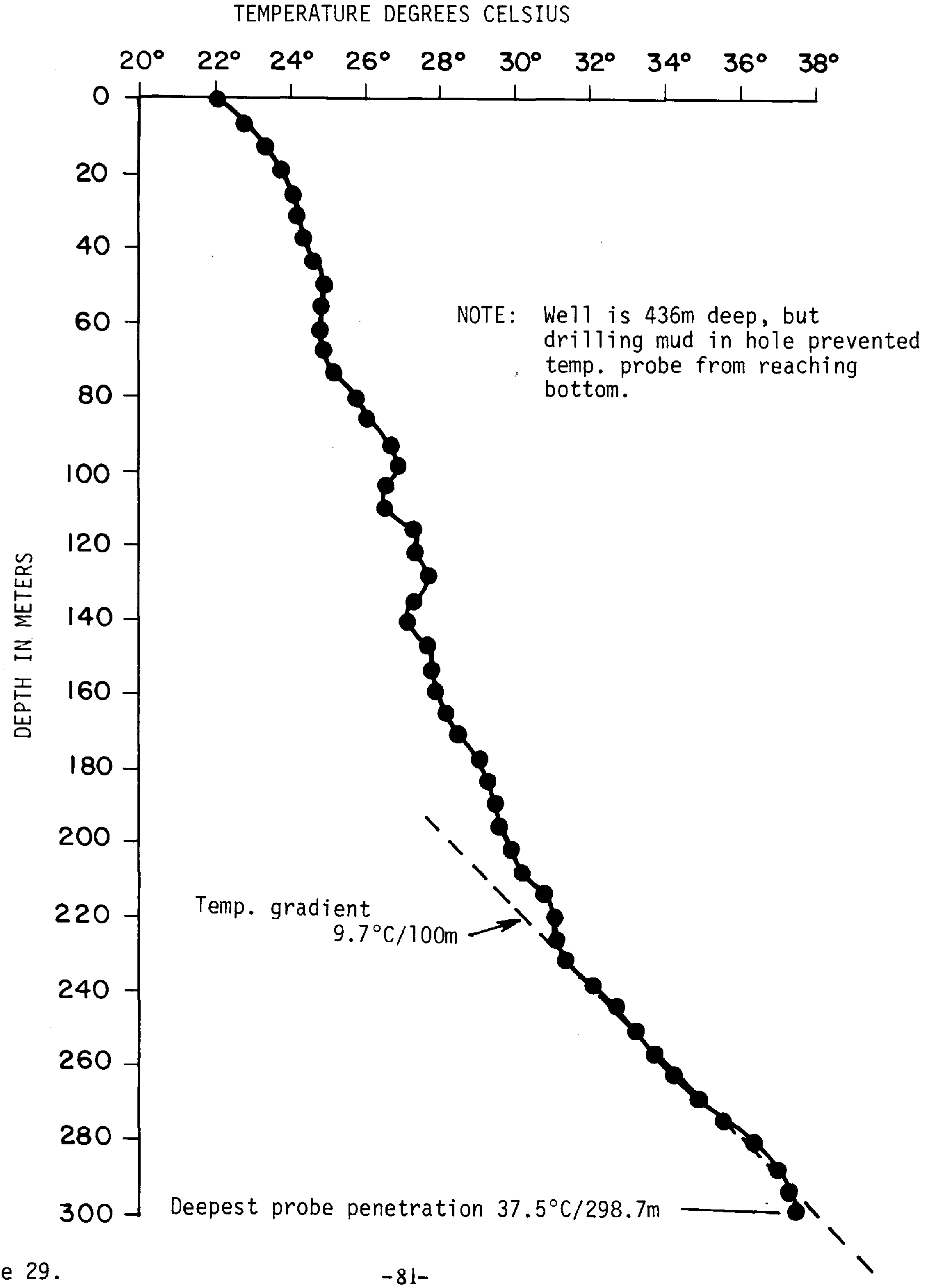


Figure 28.

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

LOCATION: No. 44

DATE: 8/24/82



NOTE: Well is 436m deep, but drilling mud in hole prevented temp. probe from reaching bottom.

Temp. gradient 9.7°C/100m

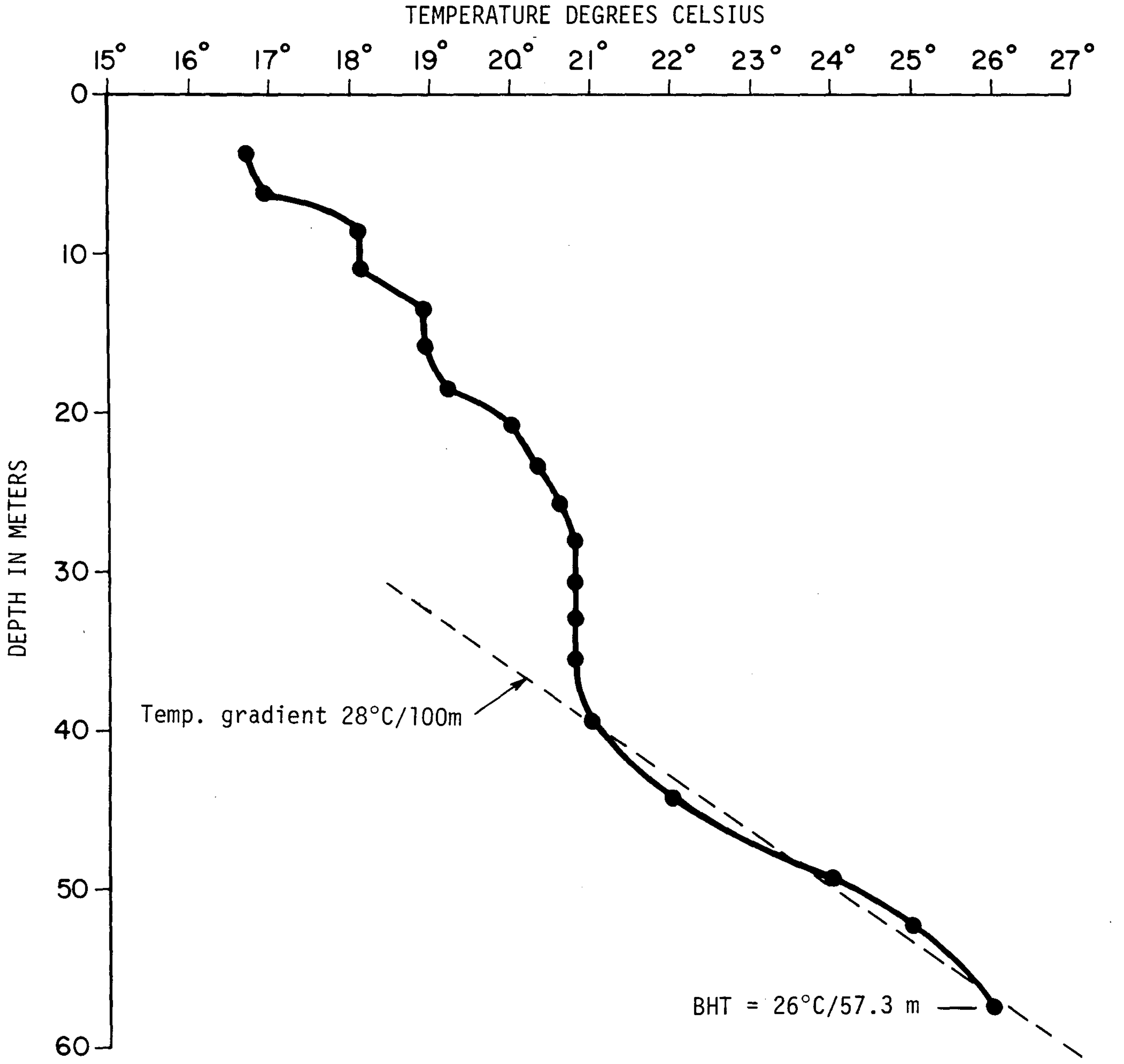
Deepest probe penetration 37.5°C/298.7m

Figure 29.

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

LOCATION No. 50

DATE 4/6/82



NOTE: Temperature log courtesy of Sylvester Associates,
Santa Rosa, California.

Figure 30.

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

LOCATION: No. 51

DATE: 10/14/82

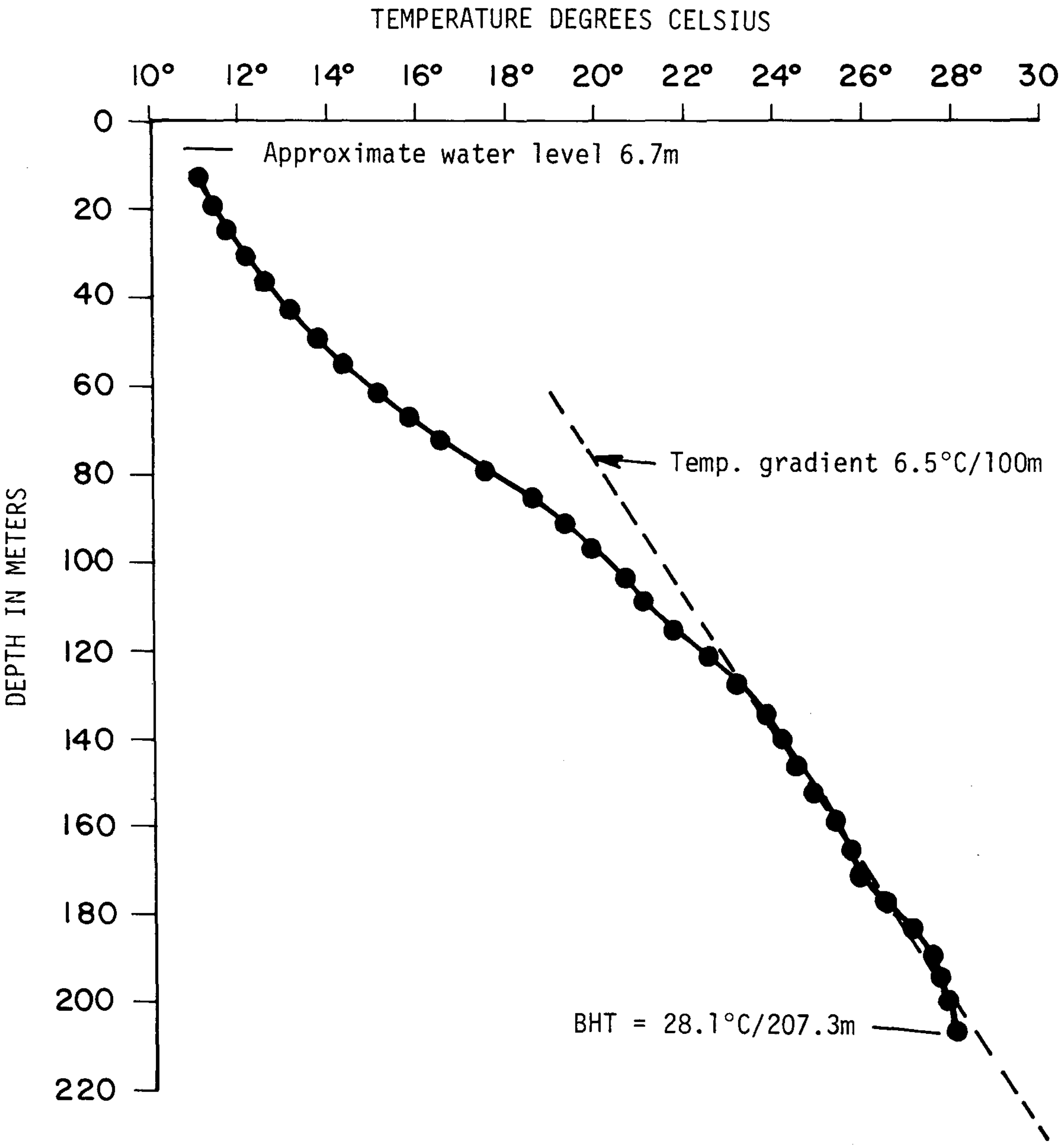


Figure 31.

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

LOCATION: No. 59

DATE: 8/12/82

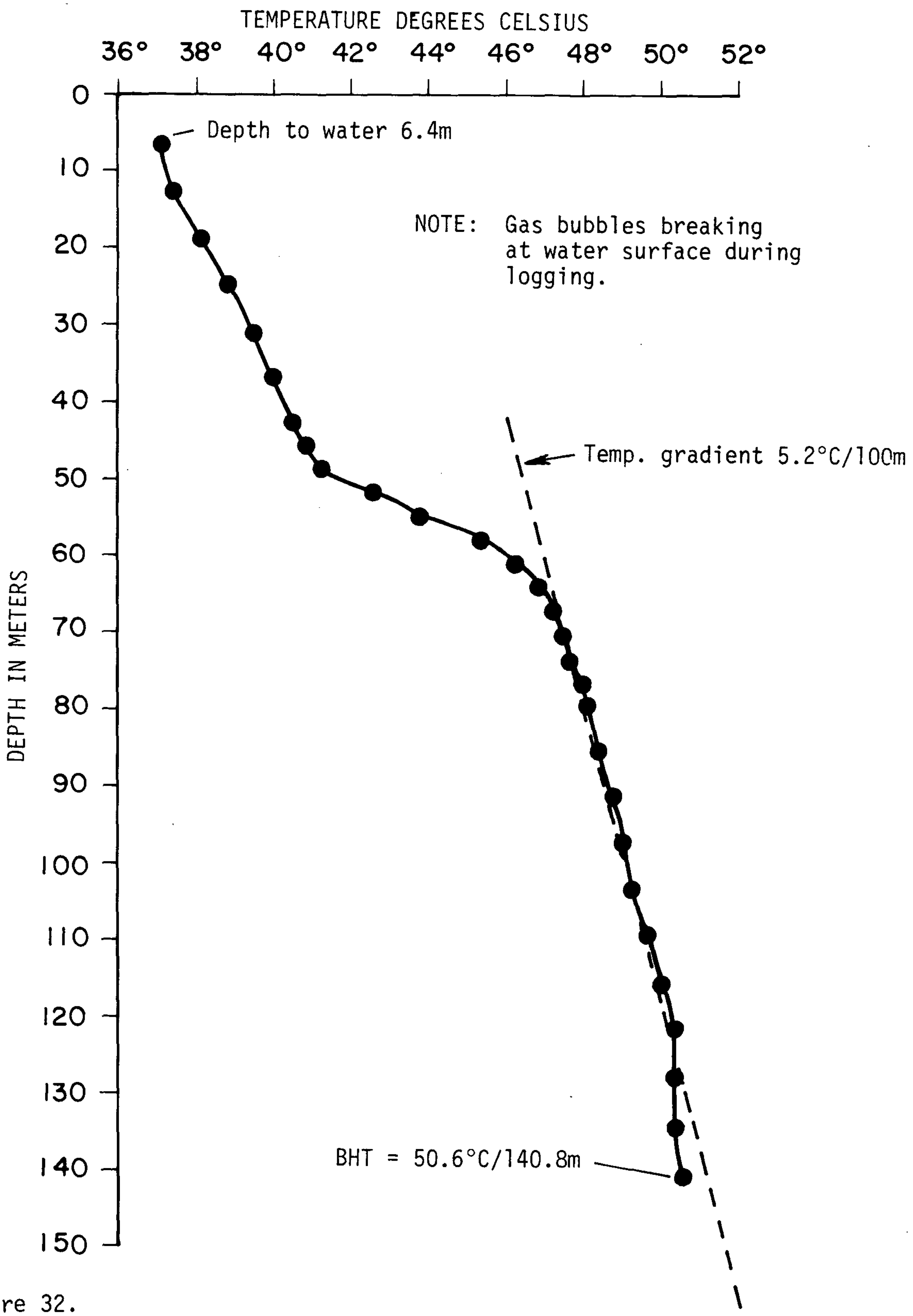


Figure 32.

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

LOCATION: No. 92
DATE: 2/10/83

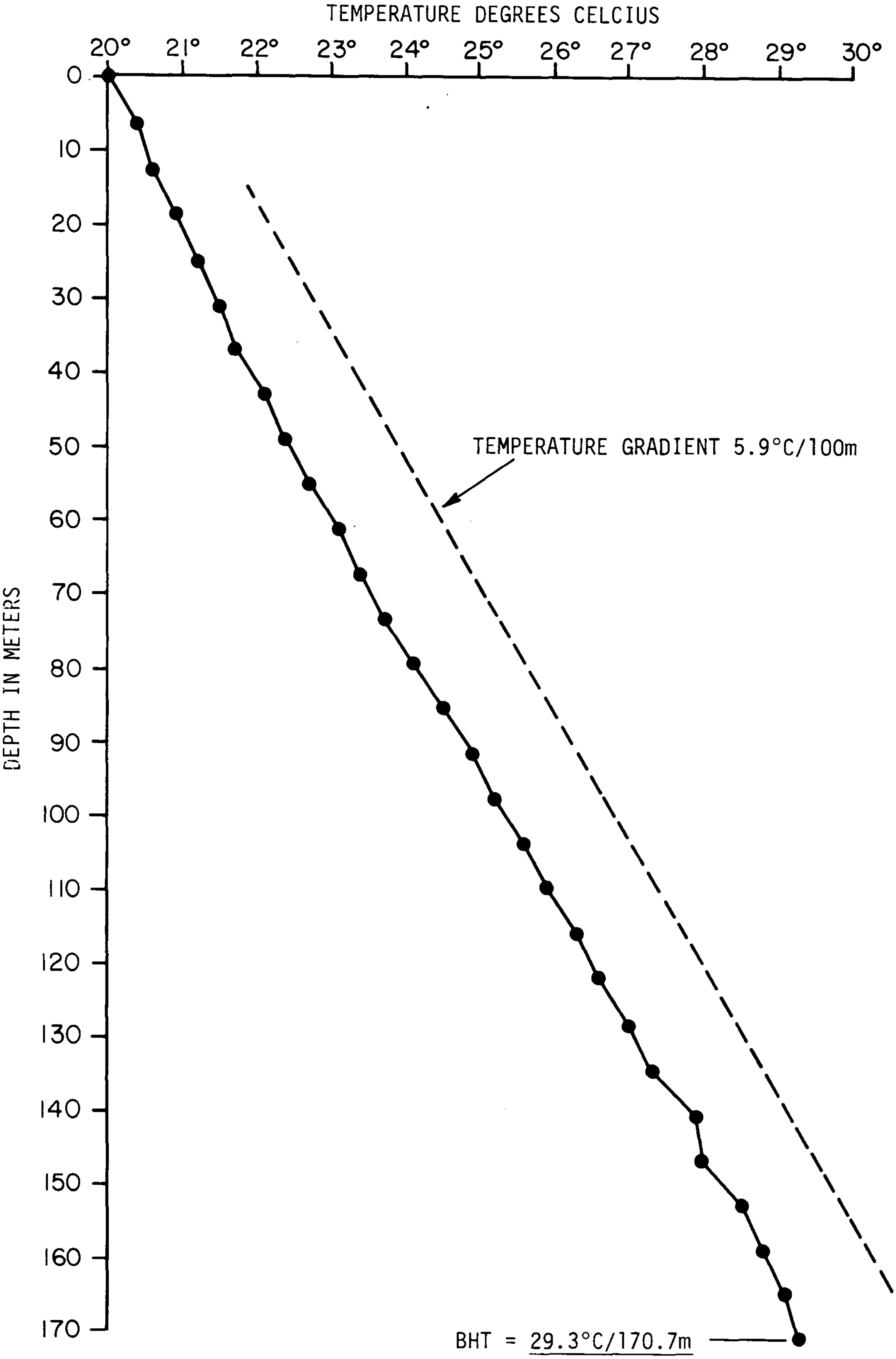
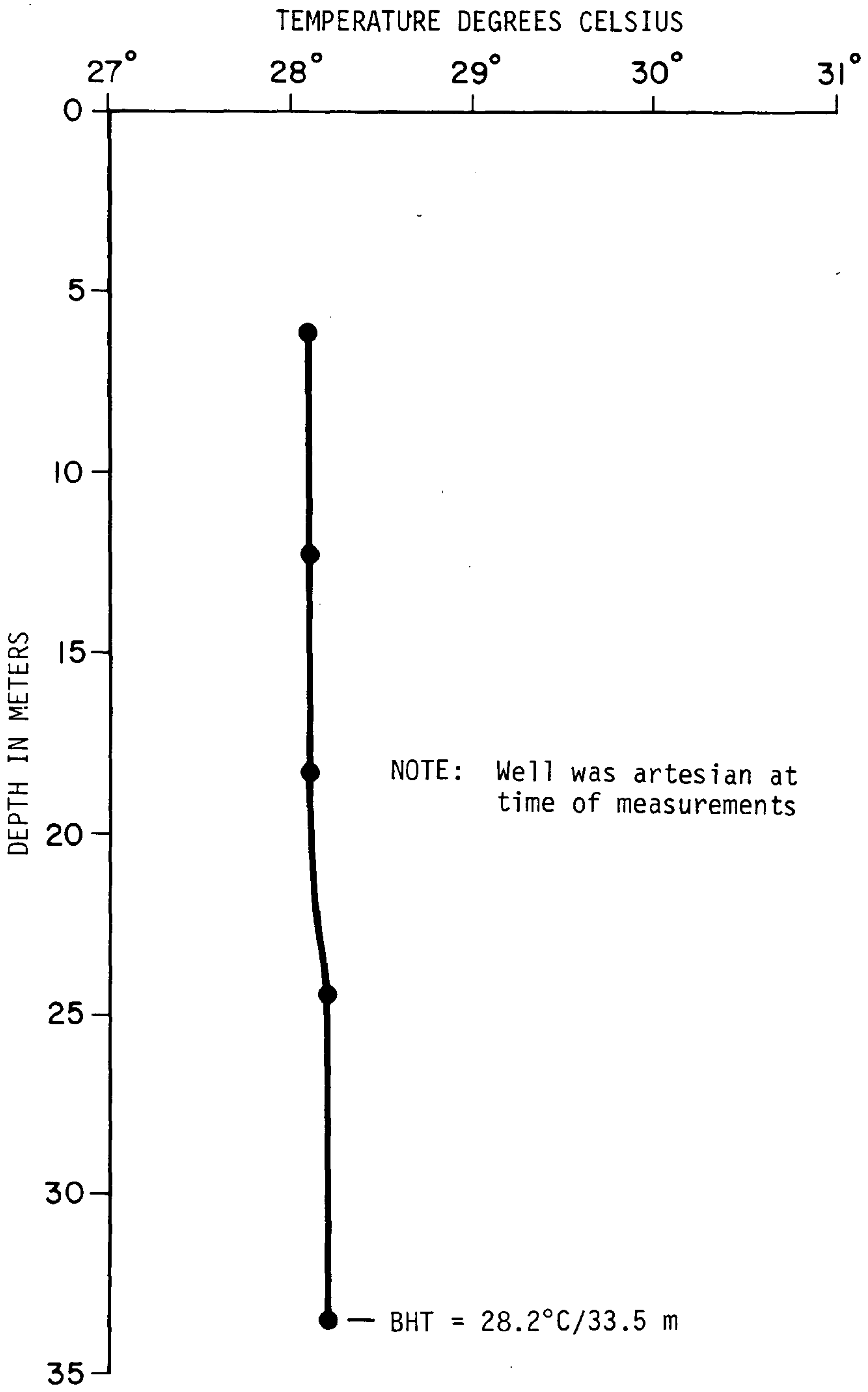


Figure 33.

CALIFORNIA DIVISION OF MINES AND GEOLOGY
TEMPERATURE LOG

LOCATION No. 122

DATE APRIL 1982



NOTE: Well was artesian at time of measurements

NOTE: Temperature log courtesy of G. Culver, Oregon Institue of Technology.

Figure 34.

Although a regional temperature gradient of 5.6°C/100 meters (3.1°F/100 feet) can be inferred from the data and Figures 22-26 and 29-33, there may be localized zones with higher temperature gradients. Comparing the temperature gradients of Figures 23, 25, and 24, which are the wells with Locations Nos. 2, 4, and 3, respectively on Plate 4 and Table 3, it can be shown that there is a temperature increase toward the Healdsburg fault zone in the northern part of the Santa Rosa area. This may imply that the Healdsburg-Rodgers Creek fault zone provides a path for relatively rapid transport of geothermal fluids from depth toward the surface.

Conclusion

The distribution of known geothermal wells and springs throughout the Sonoma Valley area shows that most warm water is located along or subparallel to major faults in the area. In the central and southern portions of Sonoma Valley, the majority of the warm water wells group about the "east side" fault, while in the northern Sonoma Valley study area, the majority of the known warm water wells are associated with and are subparallel to the Healdsburg and Rodgers Creek fault zones. Further evidence that these fault zones are the possible conduits or sources of geothermal fluids is the increase in temperture gradient toward the fault zone as shown in the comparison of Figures 23, 25, and 24. These two zones in the Sonoma Valley area are the best locales for geothermal development. Two other localized zones of thermal water in the northern Sonoma study area are at the McDonald well site area, Location No. 13 on Plate 1 and at the Morton's Warm Springs area, Location No. 29, Plate 1.

The greatest recorded surface temperatures as shown on Table 3 occurred in the central portion of Sonoma Valley and in particular at Boyes Hot Springs, Location No. 59, Plate 1. In the northern study area, the maximum recorded surface temperature appears to be just a little over 30°C (Location Nos. 10, 13, 17, and 29, on Table 3). This difference in the upper limits of direct temperature measurements between the northern and the central Valley areas may suggest that the higher geothermal reservoir temperatures occur in the central portion of the Sonoma Valley.

An overall regional temperature gradient of 5.6°C/100 meters (3.1°F/100 feet) can be inferred from the direct temperature measurement data. Although above average, this is not a very large temperature gradient value and may suggest that the maximum temperatures of the geothermal resources underlying the Sonoma Valley are modest.

GEOTHERMAL ASSESSMENT OF THE LOW-TEMPERATURE GEOTHERMAL RESOURCES IN THE NORTHERN SONOMA VALLEY AREA

Introduction

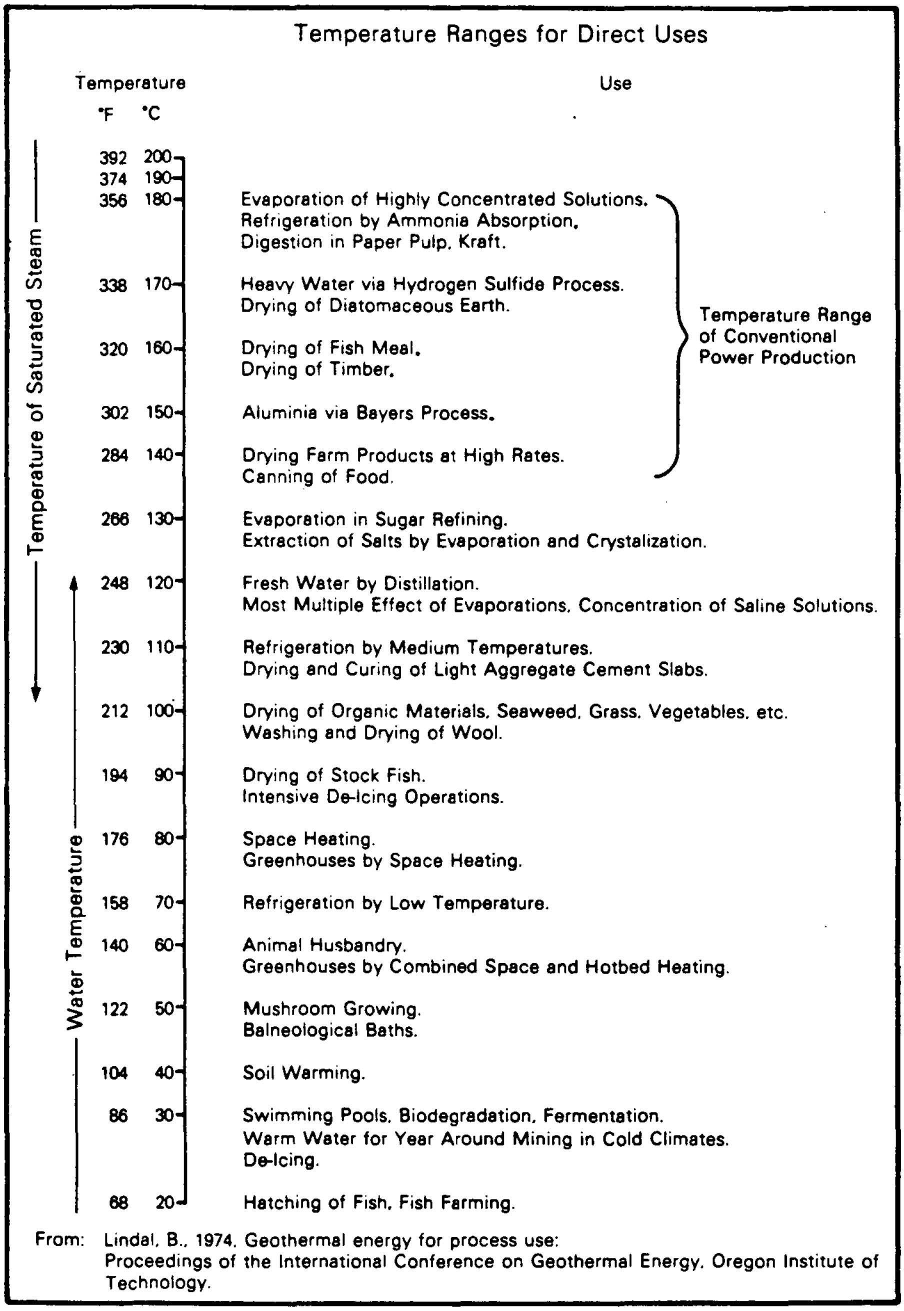
Surficial expression of low-temperature geothermal resources have long been noted in the Sonoma Valley area. The earliest commercial development of the resources was, perhaps, nearly 135 years ago in the central portion of the valley at Boyes Hot Springs. The oldest documented commercial development of the resources in the northern study area was, perhaps, 100 years ago at the site of Morton's Warm Springs. It is significant that geothermal fluids are still being produced at all of the documented warm springs areas in the northern Sonoma Valley area as discussed in the historical section of this report. Although some locales which may originally have been springs now produce warm water only from shallow to moderately deep wells (i.e., the MacDonald warm well site, Plate 1, Location No. 13). The presence of the Mio-Pliocene Sonoma Volcanics, blanketing the surrounding mountains and underlying Sonoma Valley, may imply the presence of associated geothermal resources in this area for the past several thousands of millennia, first associated with magmatic heat and then with still hot but solidified cooling masses in the subsurface. Most recently the Sonoma Volcanics have been shown to serve as reservoir rocks for thermal waters that may derive at least part of their heat from deep circulation along faults under near normal gradient conditions.

All of the direct temperature measurements observed in this study are less than 90°C (194°F). Therefore, the geothermal resources of the northern Sonoma Valley, as well as those of the central and southern portions of the valley, can only be classified as low-temperature geothermal resources 20°-90°C (68°-194°F). Although geothermometry data and extrapolation of temperature gradients may indicate greater temperature range than this at depth in certain portions of the Sonoma Valley area, these depths may be too great for feasible economic development of the resources. Low-temperature geothermal resources are not yet suitable for generation of electrical power. However, they are suited to small, direct-heat-use application that are usually developed close to the point of origin. Such resources are useful to local landowners, small business and agricultural projects, direct heating applications of single and multiple family housing, public buildings, and so on. Figure 35 is a partial list of potential uses of low-temperature geothermal resources.

Areal Distribution

Youngs and others, 1983, describe the location of 29 low-temperature geothermal wells and springs located in the central and southern portions of the Sonoma Valley. As the result of this study, a total of 58 warm wells and springs have been located throughout the entire Sonoma Valley region. Fourteen of these locations are within the northern study area.

The majority of these warm wells and springs are located along two major northwest-trending fault alignments. In the central portion of Sonoma Valley, the warm water locations are situated along the "east side" fault. Youngs and others, 1983,



Temperature Ranges for Direct Uses

Temperature °F	°C	Use
392	200	
374	190	
356	180	Evaporation of Highly Concentrated Solutions. Refrigeration by Ammonia Absorption. Digestion in Paper Pulp, Kraft.
338	170	Heavy Water via Hydrogen Sulfide Process. Drying of Diatomaceous Earth.
320	160	Drying of Fish Meal. Drying of Timber.
302	150	Aluminia via Bayers Process.
284	140	Drying Farm Products at High Rates. Canning of Food.
266	130	Evaporation in Sugar Refining. Extraction of Salts by Evaporation and Crystalization.
248	120	Fresh Water by Distillation. Most Multiple Effect of Evaporations, Concentration of Saline Solutions.
230	110	Refrigeration by Medium Temperatures. Drying and Curing of Light Aggregate Cement Slabs.
212	100	Drying of Organic Materials, Seaweed, Grass, Vegetables, etc. Washing and Drying of Wool.
194	90	Drying of Stock Fish. Intensive De-Icing Operations.
176	80	Space Heating. Greenhouses by Space Heating.
158	70	Refrigeration by Low Temperature.
140	60	Animal Husbandry. Greenhouses by Combined Space and Hotbed Heating.
122	50	Mushroom Growing. Balneological Baths.
104	40	Soil Warming.
86	30	Swimming Pools, Biodegradation, Fermentation. Warm Water for Year Around Mining in Cold Climates. De-Icing.
68	20	Hatching of Fish, Fish Farming.

From: Lindal, B., 1974, Geothermal energy for process use: Proceedings of the International Conference on Geothermal Energy, Oregon Institute of Technology.

Figure 33. Temperature ranges of some possible geothermal direct uses.

describe a 10 kilometer (6.2 miles) long zone, termed the "most likely geothermal production zone," bounded on the west by the "east side" fault. The authors suggested that the "east side" fault was a conduit for upward migration of thermal fluids and also acted as a barrier to the western lateral migration of the fluids. However, as a result of the additional investigations conducted for this report, some warm water wells were found to be located west of the "east side" fault (see Locations Nos. 51, 64, and 65, Plate 4). The presence of these locations immediately west of the fault suggest that there is, indeed, westward-lateral fluid migration from the "east side" fault and that, if the fault does act as a barrier, it is a localized occurrence. This suggests that geothermal fluids ascending the "east side" fault enter permeable aquifers both to the east and west side of the fault.

In the northern study area, the majority of the warm wells and springs are also located along a major fault zone. This alinement is associated with the Healdsburg-Rodgers Creek fault zone along that segment from north of the City of Santa Rosa to just south of Bennett Valley (Plate 4). The extent of the lateral occurrences of geothermal fluids from this fault alignment cannot be determined from the data presented in this report.

Other localized distributions of geothermal fluids are located southeast of Kenwood (Plate 1, Locations Nos. 28, and 29) and in the Spring Lake-Melita area (Plate 1, Locations Nos. 12, and 13). In the Kenwood area, the maximum water temperatures were recorded at Morton's Warm Springs and the McEwan Ranch warm spring. Although no faults have been mapped in the immediate vicinity of Morton's warm springs, this does not eliminate the possibility of a concealed fault acting as a conduit for ascending thermal water. A small, northwest-trending anticline, described in the geological section of this report, may have some bearing on the geothermal fluids in this area. The nearby McEwan Ranch warm spring probably occurs along an unmapped fracture associated with the nearby northwest-trending fault (Plate 1, Location No. 28). Well drillers and local landowners report that other wells drilled in this immediate vicinity have produced only cold, fresh water. This points out the very localized nature of these two springs.

In the Spring Lake-Melita area, the small, unnamed warm spring (Plate 1, Location No. 12) is located near the trace of the Bennett Valley fault zone. Nearby are several warm water wells represented by Location No. 13 (Plate 1). Although these locations are not on the Bennett Valley fault zone, it is possible that they are related to an unmapped fault.

There are several other slightly warm water wells scattered throughout the northern study area. The temperature in these wells may only correspond to the regional geothermal gradient and, therefore, are probably of little potential significance for geothermal development.

In summary, it appears that the anomalous geothermal occurrences throughout the Sonoma Valley area are distributed along fault zones. Lateral distribution of geothermal resources is dependent upon the nature and character of permeable aquifers adjoining these fault zones. A detailed study of the distribution and character of the individual geothermal fluid-bearing aquifers is not possible in this report. Further geothermal exploration should be directed to delineating the maximum lateral extent of warm water-bearing aquifers adjacent to the identified fault traces which bear geothermal fluids.

Depth of Resource

The economic success of a geothermal project often depends on the depth to an adequate thermal resource. Historically known warm springs in the central and southern portions of Sonoma Valley have "dried up," while most of the historically known warm springs in the northern Sonoma Valley are still flowing. In the Spring Lake-Melita area and in the Morton's Warm Springs area, water wells are producing geothermal fluids from only a few tens-of-meters deep. However, the average depths of wells that have encountered geothermal waters along or parallel to the Healdsburg-Rodgers Creek fault zone is approximately 150 meters (492 feet). In contrast, wells in the geothermal area, described by Youngs and others, 1983, along the "east side" fault in the central portion of Sonoma Valley, are approximately 90 meters (295 feet) deep.

Utilizing the generalized temperature gradient computed for the entire Sonoma Valley area of 5.6°C/100 meters (3.1°F/100 feet), it can be shown that typically a well would have to be drilled to approximately 1300 meters or greater (approximately 4200 feet) to produce 100°C (212°F) thermal fluids.

The depth to low-temperature geothermal resources throughout the entire Sonoma Valley area is obviously highly variable. Geothermal resources can be found that range from a minimum depth of 0 meters in warm water springs still discharging in the northern Sonoma Valley area to the known maximum in a 436 meter (1430-foot) geothermal exploration well on the grounds of Sonoma State Hospital (Plate 1, Location No. 44). If, as has been stated by Chapman and others (1982), Youngs and others (1983), and Kunkel and Upson (1960), the warm water aquifers in the Sonoma Valley area are generally contained within units of the Sonoma Volcanics, then it would be necessary to drill geothermal wells in the valley floor at least to a depth to intersect buried volcanic rocks.

Volume of Geothermal Resources

There is a significant lack of quantitative geothermal reservoir data, but the qualitative data that was developed during the progress of this report indicates that estimates of the potential volume of low-temperature geothermal production in the Sonoma Valley area should be stated very conservatively. The historic literature seldom indicates a flow rate of greater than 100 gpm for any of the historically described natural warm springs or for most of the wells that produced warm water in the valley. Some were reported to be less than 10 gpm. Local accounts report a few moderate-depth water wells that produce volumes of slightly warm water in the several hundreds of gpm range.

Herbst, 1982, assigned a highly variable specific yield of 0 - 15 percent for the Sonoma Volcanics. If, as data suggest, geothermal fluids are predominately produced from permeable units of the Sonoma Volcanics in the study area, then the highly variable specific yield suggests low or, at best, highly variable volumes contained within geothermal aquifers. However, occasionally wells that penetrate some highly permeable volcanic units, such as welded tuffs, scoria, and volcanic sediments, often produce several hundred gpm of thermal fluids (Kunkel and Upson, 1960).

Quantitative calculations of the volume of potential geothermal resources underlying the northern Sonoma Valley as well as the entire valley area would be highly speculative at best. The complexity of the warm water aquifer system and the general lack of production data precludes the capability of calculating any reliable volume figures at this time.

Temperature of Geothermal Resources

The maximum, directly recorded water temperature, whether in a surface discharge or downhole measurement, is 31.7°C (89.1°F) at well Location No. 13 in the northern Sonoma Valley area. Youngs and others, 1983, report that the highest direct-temperature measured in the central portion of Sonoma Valley was 62.7°C (145°F) at 137.2 meters (450 feet) obtained from an unconfirmed well log of a well at Boyes Hot Springs. However, during the course of this study, CDMG was able to run a temperature log of this well and recorded a maximum temperature of only 50.6°C (123°F) at 140.8 meters (462 feet). These are the highest known direct water temperature measurements in all of the Sonoma Valley area. Similarly, a well drilled to 436 meters (1,430 feet) (Plate 1, Location No. 44) on the Sonoma State Hospital properties encountered an equivalent temperature at the bottom of the hole. However, CDMG was only able to run a temperature log of a portion of the total depth of this well as shown on Figure 29. A comparison of the temperatures of wells in the northern Sonoma Valley area to those in the central and southern Sonoma Valley area shown on Table 3, suggest that overall geothermal temperatures in the northern study area are less than temperatures found in the central part of the valley.

Youngs and others, 1983, were able to suggest from geothermometry data that the reservoir temperatures in the south and central portions of the Sonoma Valley may range from 52-77°C (126-171°F). Some geothermometry values shown on Table 2 predict a reservoir temperature of approximately 70°C (158°F) in the northern part of the valley. The contoured geothermometry data shown on Plate 6 suggest the warmest reservoir temperature in the northern study area probably occurs at Morton's Warm Spring (Location No. 29). The Na-K-Ca ($\beta = 4/3$) geothermometer indicates a 110°C (230°F) reservoir temperature at this location. All other calculated reservoir temperatures for the northern study area using this particular geothermometer are less than 100°C (212°F). However, great care and some skepticism should be given to these geothermometry calculations due to uncontrollable factors mentioned elsewhere in this report.

An average of 9 temperature gradients shows that the overall Sonoma Valley Regional Temperature Gradient is approximately 5.6°C/100 meters (3.1°F/100 feet).

Resource Chemistry

Zonation or concentration distribution maps for boron, total dissolved solids (TDS), and water types where the sodium cation is the dominant constituent were produced and analyzed for this report (Figures 20, 21, Plate 6 respectively). In general, it was found that the highest concentrations of all three parameters were found along the alignments of the major faults that were associated with the known geothermal resources. However, the largest concentrations of boron, TDS, and the wells showing the largest concentration of sodium not related to the salt water intrusion in the very southern portion of the valley all occur along the "east side" fault alignment near the Boyes Hot Springs site. In general, the geothermal fluids in the northern Sonoma Valley area are relatively free of mineralization problems. This may also reflect the probable lower temperature of the geothermal resources in this area as compared to the central portion of the Sonoma Valley. However, deep drilling may encounter geothermal fluids with high mineral constituent concentrations that could be a potential problem for economic development.

Reservoir Model

The low-temperature geothermal resources throughout the entire Sonoma Valley area are characteristic of liquid-dominated hydrothermal convection systems. The common components of such systems include a heat source, transmitting fluid, sufficient permeability to allow fluid movement, sufficient porosity to provide an adequate reservoir volume, and often a cap rock overlying the reservoir to insulate and aid in the accumulation and storage of the heat energy. Gravity is the mechanism that transports cool meteoric water downward through the system, while convective circulation of the less-dense warmer fluids is the driving mechanism that transports heat energy from depth to a reservoir near the earth's surface. Hydrothermal convection systems are most likely recognizable in areas of extensive faulting where geothermal fluids can easily ascend along fractures. Such systems are usually controlled by several intersecting geological structures.

A diagramatic cross-section representing the various components of a hydrothermal convection system in the central Sonoma Valley was presented in Youngs and others (1983). The figure is reproduced herein with slight modifications (Figure 36). In the Figure 36, meteoric water (rain, snow, etc.) enters the geothermal system through permeable units or fracture zones in the surrounding mountains to the east and west of the valley. It is likely that some recharge into the system occurs from surface water that may descend along some or portions of some fault zones in and around the valley. The fluids are heated at depth from the earth's natural heat gradient. Warmed fluids that are less dense than cold water then ascend along "paths of least resistance" (such as faults, fractures, geologic contacts, etc.). In the central Sonoma Valley model, these ascending paths or conduits are represented by faults on the east and west sides of the valley. The ascending geothermal fluids then enter permeable aquifers near the surface or may rise all the way to the surface forming warm springs. Cap rocks overlying some of the aquifers in the valley may include clay strata or impermeable volcanic rocks. Figure 37 shows the stratigraphic column encountered for a water well drilled at Boyes Hot Springs. Accompanying this stratigraphic column is a downhole temperature log. Comparison of the two parameters shows that the warm water appears to be in an aquifer capped by probably impermeable andesite at a depth of about 185 feet (56 meters). The resulting reservoir system then includes geothermal fluids transmitted in the fault fracture systems and those fluids subsequently contained in discrete and discontinuous warm-water-bearing aquifers adjacent to the faults.

Such a hydrothermal convection system is not readily recognizable in the northern Sonoma Valley. However, such a system in the northern Sonoma Valley proper may lie at some depth within the deep sequence of volcanic rocks, comprising the syncline underlying the northern Sonoma Valley, as discussed earlier in the report. However, in the extreme western portion of the northern study area, such a system is proposed in conjunction with the Healdsburg-Rodgers Creek fault zone and probably is responsible for the northwest-trending alinement of geothermal wells in this area.

Often, the ascending portions of these hydrothermal convection systems are called "plumes." Therefore, the most easily recognizable geothermal "plumes" in the Sonoma Valley area are along the "east side" fault in the central portion of the valley and westward of the northern Sonoma Valley along or adjacent to the Healdsburg-Rodgers Creek fault zone.

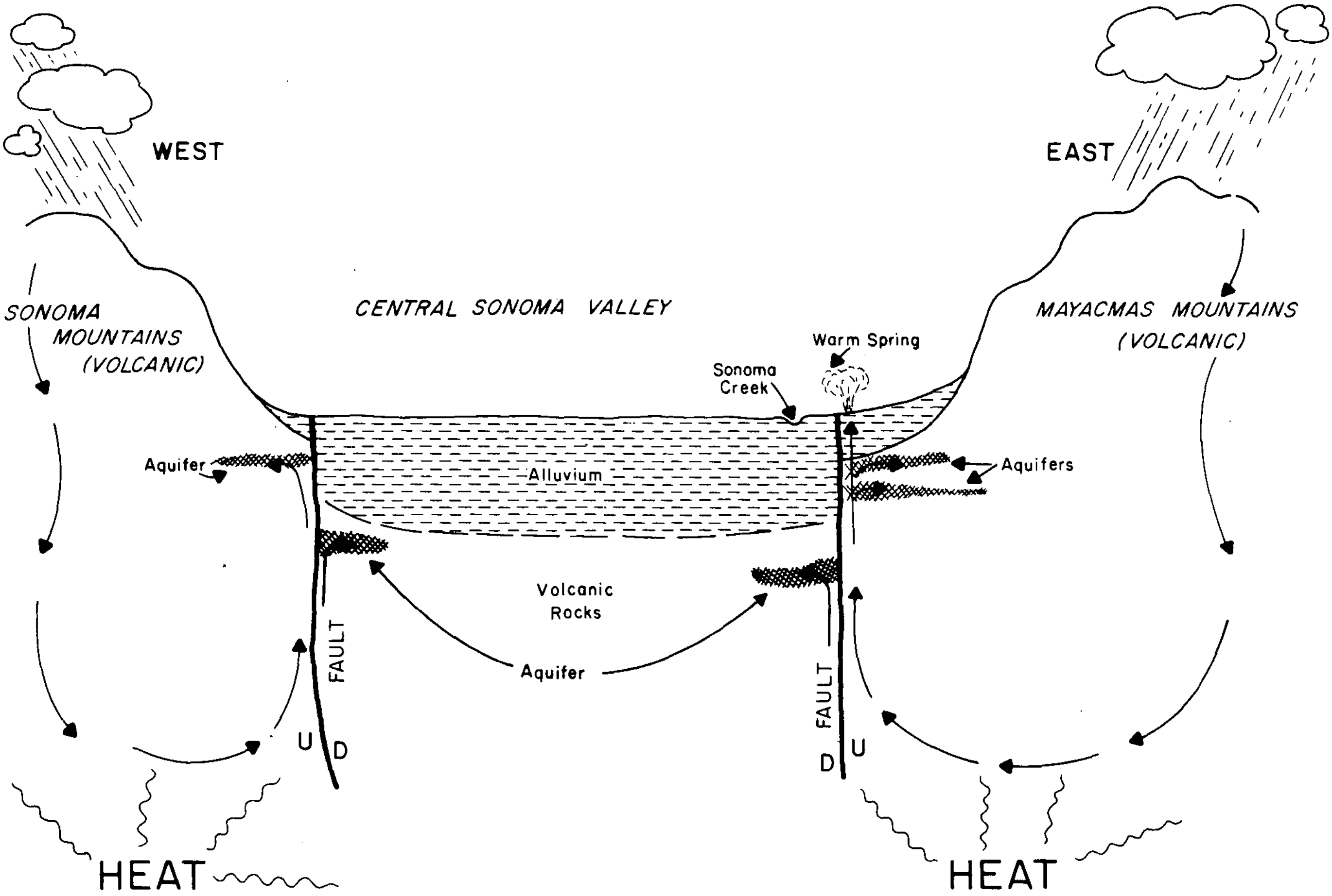


Figure 36. Diagrammatic cross-section of the low-temperature geothermal reservoir in the central Sonoma Valley area, California.

BOYES HOT SPRINGS WELL

DRILLED 1940

COMPOSITE RECONSTRUCTED FROM ORIGINAL WELL DRILLER'S NOTES

BY L.G. YOUNGS, 1982, C.D.M.G.

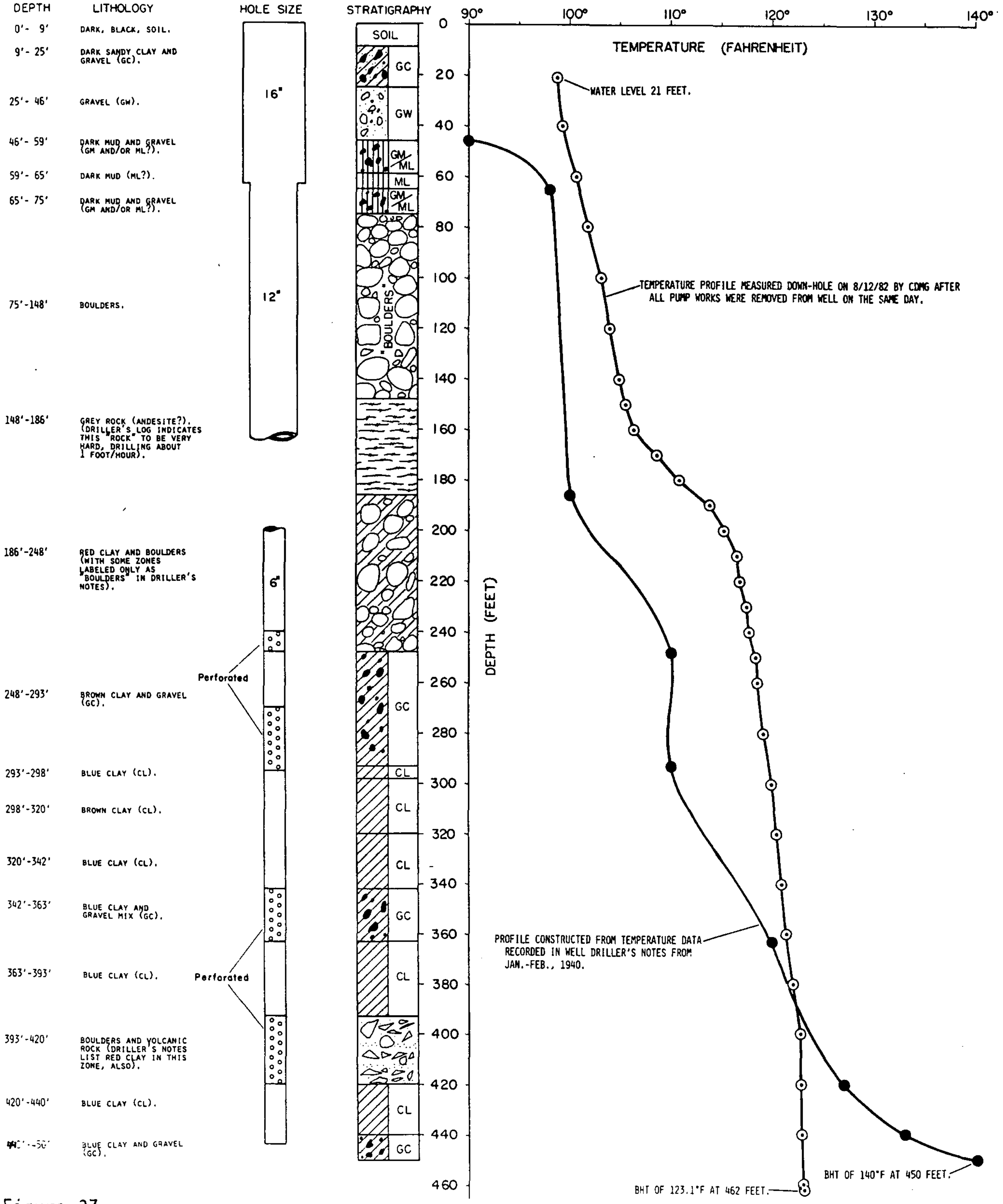


Figure 37.

CONCLUSIONS AND RECOMMENDATIONS

Conclucions

The low-temperature geothermal resources underlying the northern Sonoma Valley area are highly localized and of modest temperature. Perhaps the most economically feasible area for potential geothermal development is in the Spring Lake-Melita area where water temperatures in the low 30°C (86°F) range may be locally found at common water well depths. A much larger area with potential for geothermal resource development but perhaps of lower temperature is located along a northwest-trending zone subparallel to the Healdsburg-Rodgers Creek fault zone beginning in the City of Santa Rosa and extending to the Bennett Valley area. A third, highly localized area with geothermal resource potential is located south of Kenwood at the Morton's Warm Springs and McEwan Ranch warm spring sites. Subsurface temperatures as high as 110°C (230°F) are suggested for this location by geothermometry calcualtions. An overall average geothermometry temperature of approximately 70°C (158°F) was obtained for all geothermal occurrences in the northern Sonoma Valley. Considering the entire Sonoma Valley, the area of greatest potential for geothermal development probably occurs along the "east side" fault in the central portion of the valley. Here, water with the highest temperature measured in Sonoma Valley was recorded at Boyes Hot Springs. In addition, there are many warm water wells in this area which may indicate a more substantial volume of geothermal resources here than in any other part of the Sonoma Valley.

Geological mapping and geophysical surveys conducted throughout the northern and southern portions of Sonoma Valley have delineated the major faults underlying the Sonoma Valley and in the adjacent mountains. These fault zones form the conduits for hydrothermal convection systems and are the best areas for future geothermal exploration. Of the faults discussed above, those with the best potential for having developable geothermal resources associated with them appear to be the "east side" fault in the central portion of the valley, the Healdsburg-Rodgers Creek fault zone in the Santa Rosa and Bennett Valley areas, and suggested faulting in the Spring Lake-Melita area in the very northern part of Sonoma Valley. Other areas that contain known geothermal wells or springs are either of lower temperature or are perhaps too highly localized for primary geothermal exploration at this time. Deep exploration wells drilled in the valley could greatly modify the conclusions drawn in this report. The only relatively deep geothermal exploration well known to be drilled in the area is at Sonoma State Hospital (Plate 1, Location No. 44) where a temperature in the low 49°C (120°F) range has been reported at a bottom-hole depth of 436 meters (1430 feet). This is similar to the maximum temperature measured by CDMG in the central valley at Boyes Hot Springs (Figure 32).

Major geophysical anomalies and potential fault traces, discussed by Youngs and others, 1983, which occur in the central portion of Sonoma Valley, were investigated for possible extension into the northern parts of the Sonoma Valley during this study. Although a northern extension of the "east side" fault was not found by geophysical techniques, other anomalies related to the underlying geologic structure of the northern Sonoma Valley and adjacent mountains to the southwest were found that probably do bear on the geothermal resources in the area. This current study, combined with the CDMG study for the central and southern portions of the valley (Youngs and others, 1983), provide an overall view of the low-temperature geothermal resources of the entire Sonoma Valley area. Additional studies to evaluate the geothermal resources in the valley for their potential for development should probably include detailed geoscientific studies of the local areas delineated in these two studies. Perhaps the most useful data that could be gathered, for any of the areas with potential for geothermal resources pointed out in these studies, would be from exploration drilling. Data gathered from such drilling operations should include subsurface stratigraphy, temperature logging, flow testing, individual aquifer identification, and water quality analyses.

Knowledge of the nature of a geothermal resource improves with each bit of information gathered. Therefore, it is expected that some conclusions concerning the low-temperature resources in the northern Sonoma Valley, as well as the entire Sonoma Valley area presented in this report and in the previous report by CDMG (Youngs and others, 1983), will be modified by information developed in the future. It is hoped that these two reports will be useful to the local residents of Sonoma Valley and all potential developers of the low-temperature geothermal resources to be found there.

Recommendations

- A shallow-hole temperature probe survey may greatly refine our understanding of the distribution of heated fluids in the three main areas described and in the "Most Likely Geothermal Production Zone" that extends southward along the east side of the Sonoma Valley; this type of survey is recommended for any additional study.

- Drilling of deeper (300 meters +) test holes can provide confirmation of the geothermal gradient and of the higher resource temperatures that are suggested for the deeper subsurface by geothermometry. It can also isolate and test individual geothermal aquifers and thus provide temperature measurements (which may be much higher) for unmixed waters. Only by drilling to the resouce can the volume, temperature, and quality of the geothermal fluids and thus the final proof of the resource be obtained. Test drilling is strongly recommended for any additional study.

ACKNOWLEDGMENTS

We wish to thank the many residents and land owners of the Sonoma Valley area for allowing us access to water wells, springs, and entry to properties. Their help and cooperation during the field phase of this study were valuable assets to this investigation.

SELECTED BIBLIOGRAPHY INCLUDING REFERENCES CITED FOR THE NORTHERN SONOMA VALLEY AREA, CALIFORNIA

Aldridge, K.C., 1983, Magnetic susceptibility measurements of drill cuttings from an exploratory geothermal well - Sonoma State (Hospital) Well No. 3: California Division of Mines and Geology, Unpublished report, 4 p.

Armstrong, C.F., 1974, Unpublished active fault mapping in parts of the Glenn Ellen, Petaluma River, and Sears Point 7 1/2-minute quadrangles, California: California Division of Mines and Geology.

Axelrod, D.I., 1944, The Sonoma Flora, in Chaney, R.W., editor, Pliocene floras of California and Oregon: Carnegie Institute of Washington Publication 553, p. 167-206.

Bailey, E.H., Irwin, W.P., and Jones, D.L., 1964, Franciscan and related rocks: California Division of Mines and Geology, Bulletin 183, 177 p.

Barnes, I., Irwin, W.P., and Gibson, H.A., 1975, Geologic map showing springs rich in carbon dioxide or chloride in California: U.S. Geologic Survey, Water Resources Division, Open File Map.

Barnes, I., and O'Neil, J.R., 1971, Calcium-magnesium carbonate solid solutions from Holocene conglomerate cements and travertines in the Coastal Range of California: Geochimica et Cosmochimica Acta, v. 35, no. 7, p. 699-718.

Barnes, I., and O'Neil, J.R., 1969, The relationship between fluids in some fresh alpine-type ultramafics and possible modern serpentinzation, western United States: Geological Society of America Bulletin, v. 80, no. 10, p. 1947-1960.

Bedrossian, T.L., 1971, Fossils of the 'Merced' Formation, Sebastopol Region: California Geology, California Division of Mines and Geology: v. 27, no. 8, p. 175-182.

Bedrossian, T.L., 1969, Paleoecological evaluation of the 'Merced' Formation, Sonoma County, California: University of California, unpublished.

Berkland, J.O., Raymond, L.A., Kramer, J.C., Moores, E.M., and O'Day, M., 1972,What is Franciscan?: American Association of Petroleum Geologists Bulletin, v. 56, p. 2295-2302.

Berkstresser, C.F., Jr., 1968, Data for springs in the northern Coast Ranges and Klamath Mountains of California: U.S. Geological Survey, Water Resources Division, Open File Report, 49 p.

Blake, M.C., Jr., Bartow, J.A., Frizzell, V.A., Jr., Schlocker, J., Sorg, D., Wentworth, C.M., and Wright, R.H., 1974, Preliminary geologic map of Marin and San Francisco Counties and parts of Alameda, Contra Costa, and Sonoma Counties, California: U.S. Geological Survey and U.S. Department of Housing and Urban Development, Basic Data Contribution 64, San Francisco Bay Region Environment and Resources Planning Study.

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 and U.S. Department of Housing and Urban Development, Basic Data Contribution 12, San Francisco Bay Region Environment and Resources Planning Study.

Blake, M.C., Jr., Zietz, I., and Daniels, D.L., 1978, Aeromagnetic and generalized geologic map of parts of central California: U.S. Geological Survey, Geophysical Investigations, Map GP-918.

Bowen, R., 1979, Geothermal Resources: Halsted Press Division, John Wiley and Sons, New York, 243 p.

Bradley, W.W., 1915, Sonoma County - mineral water: California State Mining Bureau, Report XIV of the State Mineralogist, p. 334-341.

Burke, D.B., and others, (in press), Geologic map of the Flatland Deposits of the northwestern part of the San Francisco Bay region: U.S. Geological Survey, Professional Paper 943.

Cady, J., 1975, Magnetic and gravity anomalies in the Great Valley and western Sierra Nevada metamorphic belt, California: Geological Society of America, Special Paper 168, 56 p.

California Division of Mines and Geology, 1983, Alquist-Priolo Special Study Zones Maps - Santa Rosa, Glen Ellen, Petaluma River, and Sears Point 7 1/2 minute quadrangles: scale 1:24,000.

California Division of Oil and Gas, 1975, Descriptions of northern California low-temperature Geothermal Resource Areas: California Division of Oil and Gas, Report Number TR 13.

Cardwell, G.T., 1958, Geology and ground water in the Santa Rosa and Petaluma Valley areas, Sonoma County, California: U.S. Geological Survey, Water Supply Paper 1427, 273 p.

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

Chapman, R.H., and Bishop, C.C., 1974, Bouguer gravity map of California, Santa Rosa Sheet: California Division of Mines and Geology, scale 1:250,000, 7 p. text.

Chapman, R.H., and Chase, G.W., 1982, Geophysical study of the Rohnert Park geothermal prospect, Sonoma County, California: California Division of Mines and Geology, Unpublished report, 29 p.

Chapman, R.H., Chase, G.W., and Youngs, L.G., 1983, Geophysical study of the Santa Rosa geothermal area, Sonoma County, California: California Division of Mines and Geology Open-File Report, OFR 83-9SAC, 36 p.

Chaturvedi, L., 1977, Shallow thermal survey as a tool for geothermal site selection, <u>in</u> Abstracts for 1977 annual meeting: Association of Engineering Geologists, p. 22.

Christensen, M.N., 1966, Quaternary of the California Coast Ranges, in Geology of northern California: Chapter VI, San Francisco, California, p. 305-313.

Crawford, J.J., 1896, Mineral springs - Sonoma County: California State Mining Bureau, Report XIII of the State Mineralogist, p. 521-522.

Crawford, J.J., 1894, Mineral springs - Sonoma County: California State Mining Bureau, Report XII of the State Mineralogist, p. 347.

Dickerson, R.E., 1922, Tertiary and Quarternary history of the Petaluma, Point Reyes and Santa Rosa Quadrangles: Proceedings of the California Academy of Sciences, Fourth Series, v. XI, no. 19, p. 527-601.

Ford, R.S., 1975, Evaluation of ground water resources; Sonoma County: California Department of Water Resources, Bulletin 118-4, v. 1, 177 p.

Fox, Kenneth, F., Jr., in press, Tectonic setting of late Miocene, Pliocene, and Pleistocene rocks in part of the Coast Ranges north of San Francisco, California: U.S. Geological Survey, Professional Paper 1238, manuscript.

Fox, K.F., Jr., 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 and U.S. Department of Housing and Urban Development, Basic Data Contribution 56, San Francisco Bay Region Environment and Resources Planning Study, MF-483, scale 1:62,500.

G.R.I.P.S. Commission, 1981, Direct use geothermal Resources Map Series, Map Nos. XX and XXI.

Haines, D.N., and Campbell, D.L., 1979, Texas Instruments model 59 hand-calculator program to calculate gravity anomaly over 2-D prisms of as many as 18 vertices: U.S. Geological Survey Open-File Report 79-1620, 12 p.

Hauge, C., Kramer, C., Berkland, J., and Matthews, R., 1972, Field trip log, in Moores, Eldridge, J., and Matthews, R.A., editors, Geologic guide to the northern Coast Ranges--Lake Mendocino, and Sonoma Counties, California, Annual Field Trip Guide Book: Geological Society of Sacramento, p. 111-132.

Herbst, C.M., 1982, Evaluation of ground water resources - Sonoma County: Department of Water Resources, Bulletin 118-4, v. 4, 78 p.

Herd, D.G., and Halley, E.J., 1976, Faults wtih Quaternary displacement northwestern San Francisco Bay Region, California: U.S. Geological Survey. Miscellaneous Field Studies Map MF-818.

Honke, M.T., Jr., and Ver Planck, W.E., Jr., 1950, Mines and mineral resources of Sonoma County, California: California Division of Mines and Geology, Journal of Mines and Geology, v. 46, no. 1.

Hsu, K.J., 1968, Principles of melanges and their bearing on the Franciscan-Knoxville paradox: Geological Society of America, Bulletin, v. 79, p. 1063-1074.

Huffman, M.E., and Armstrong, C.F., 1980, Geology for planning in Sonoma County: California Division of Mines and Geology Special Report 120, 31 p.

Jennings, C.W., and Hart, E.W., 1956, Exploratory wells drilled outside of oil and gas fields in California to December 31, 1953: California Division of Mines and Geology Special Report 45, 104 p.

Koenig, J.B., 1963, Geologic Map of California, Santa Rosa Sheet: California Division of Mines and Geology, scale 1:250,000.

Kunkel, F., 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 1495, 252 p.

Laizure, C.M., 1926, Sonoma County - Mineral water: California State Mining Bureau, Report XXII of the State Mineralogist, p. 339-343.

Leivas, E., Martin, R.C., Higgins, C.T., and Bezore, S.P., 1981, Reconnaissance geothermal resource assessment of 40 sites in California - Part of the third year report, 1980-81, of the U.S. Department of Energy - California State-Coupled Program for reservoir assessment and confirmation: California Division of Mines and Geology, Report for U.S. Department of Energy, Contract No. DE-FG3-90SF10855, 243 p.

LeShack, L.A., Lewis, J.E., O'Hara, N.W., and Chang, D.C., 1978, Shallow-temperature surveys -- A rapid reconnaissance technique for geothermal prospects: Preprint for Annual Meeting Society of Exploration Geophysicists, pp. 1-36.

Lynch, J.F., date unknown, Captain Boyes memorable discovery - a flowing well of hot water at 70 feet: Unpublished manuscript, 3 p.

Mankinen, E.A., 1972, Paleomagnetism and potassium-argon ages of the Sonoma Volcanics, California: Geological Society of America Bulletin, v. 83, p. 2063-2072.

Miller, V.C., 1972, Soil Survey of Sonoma County: U.S. Department of Agriculture, Soil Conservation Service.

Morse, R.R., and Bailey, T.L., 1935, Geological observations in the Petaluma District, California: Geological Society of America Bulletin, v. 46, p. 1437-1456.

Osmont, V.C., 1905, Geological section of the Coast Ranges north of the Bay of San Francisco: University of California, Department of Geological Sciences, Bulletin, v. 4, pp. 39-87.

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

Rapport, A., 1982, FORTRAN program to compute chemical geothermometers for geothermal fluids: U.S. Geological Survey, Open-File Report 82-308, 25 p.

Real, C.R., Toppozada, T.R., and Parke, D.L., 1978, Earthquake catalog of California, January 1, 1900-December 31, 1974: California Division of Mines and Geology, Special Publication 52, 15 p.

Reed, M.J., 1975, Exploration and development of geothermal resources in Lake, Mendocino, and Sonoma Counties, California: California Division of Oil and Gas.

Sickles, J.M., 1974, Geology and geologic hazards of the Kenwood-Glen Ellen area, eastern Sonoma County, California: Unpublished Masters thesis, University of California, Davis, California, 103 p.

Steinbrugge, K.V., Cloud, W.K., and Scott, N.H., 1970, The Santa Rosa, California, Earthquakes of October 1, 1969: U.S. Department of Commerce, 62 p.

Taylor, G.C., Bacon, C.F., Chapman, R.H., Chase, G.W., and Majmundar, H.H., 1981, 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: California Division of Mines and Geology, Addendum to Open-File Report 81-13 SAC, Report for U.S. Department of Energy, Contract No. DE-FG03-79ET27035, 73 p.

Toppozada, T.R., Real, C.R., and Parke, D.L., 1981, Preparation of isoseismal maps and summaries of reported effects for pre-1900 California earthquakes: California Division of Mines and Geology, Open-File Report 81-11SAC, Annual Technical Report to the U.S. Geological Survey, Grant No. 14-08-001-19200, 182 p.

U.S. Geological Survey, 1974a, Aeromagnetic map of parts of the San Jose, Santa Rosa and Sacramento 1° x 2° quadrangles, California: U.S. Geological Survey Open File Report 74-80, scale 1:125,000.

U.S. Geological Survey, 1974b, Aeromagnetic map of parts of the Santa Rosa and San Francisco 1° x 2° quadrangles, California: U.S. Geological Survey Open File Report 74-81, scale 1:125,000.

U.S. Geological Survey, 1974, Aeromagnetic map of the northwest portion of the San Francisco Bay region, California: U.S. Geological Survey Open File Report 76-618.

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

Watts, W.L., 1892, Sonoma County - Springs and wells yielding inflammable gas: California State Mining Bureau, Report XI of the State Mineralogist, p. 458-459.

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., 1949, Geology and mineral deposits of an area north of San Francisco Bay: California Division of Mines and Geology, Bulletin 149.

Youngs, L.G., Chapman, R.H., Chase, G.W., Bezore, S.P., and Majmundar, H.H., 1983, Investigation of low-temperature geothermal resources in the Sonoma Valley area, California - Part of the fourth year report, 1981-82, of the U.S. Department of Energy - California State-Coupled Program for reservoir assessment and confirmation: California Division of Mines and Geology, Open-File Report 83-13SAC, Report for U.S. Department of Energy, Contract No. DE-FG03-81SF10855, 103 p.

Zietz, I., Bateman, P.C., Case, J.E., Crittenden, M.D., Jr., Griscom, A., King, E.R., Roberts, R.J., and Lorentzen, G.R., 1969, Aeromagnetic investigations of crustal structure for a strip across the western United States: Geological Society of America Bulletin, v. 80, no. 9, p. 1703-1714.

Zohdy, A.A.R., 1974, A computer program for the automatic interpretation of Schlumberger sounding curves over horizontally stratified media: U.S. Geological Survey Report USGS-GD-74-013, available from National Technical Information Service, U.S. Department of Commerce, Springfield, VA, 22161, Report no. PB-232-703, 31 p.

DMG OFR 83-27 GEOTHERMAL RESOURCES OF THE NORTHERN SONOMA VALLEY AREA, SONOMA COUNTY, CALIFORNIA

43346

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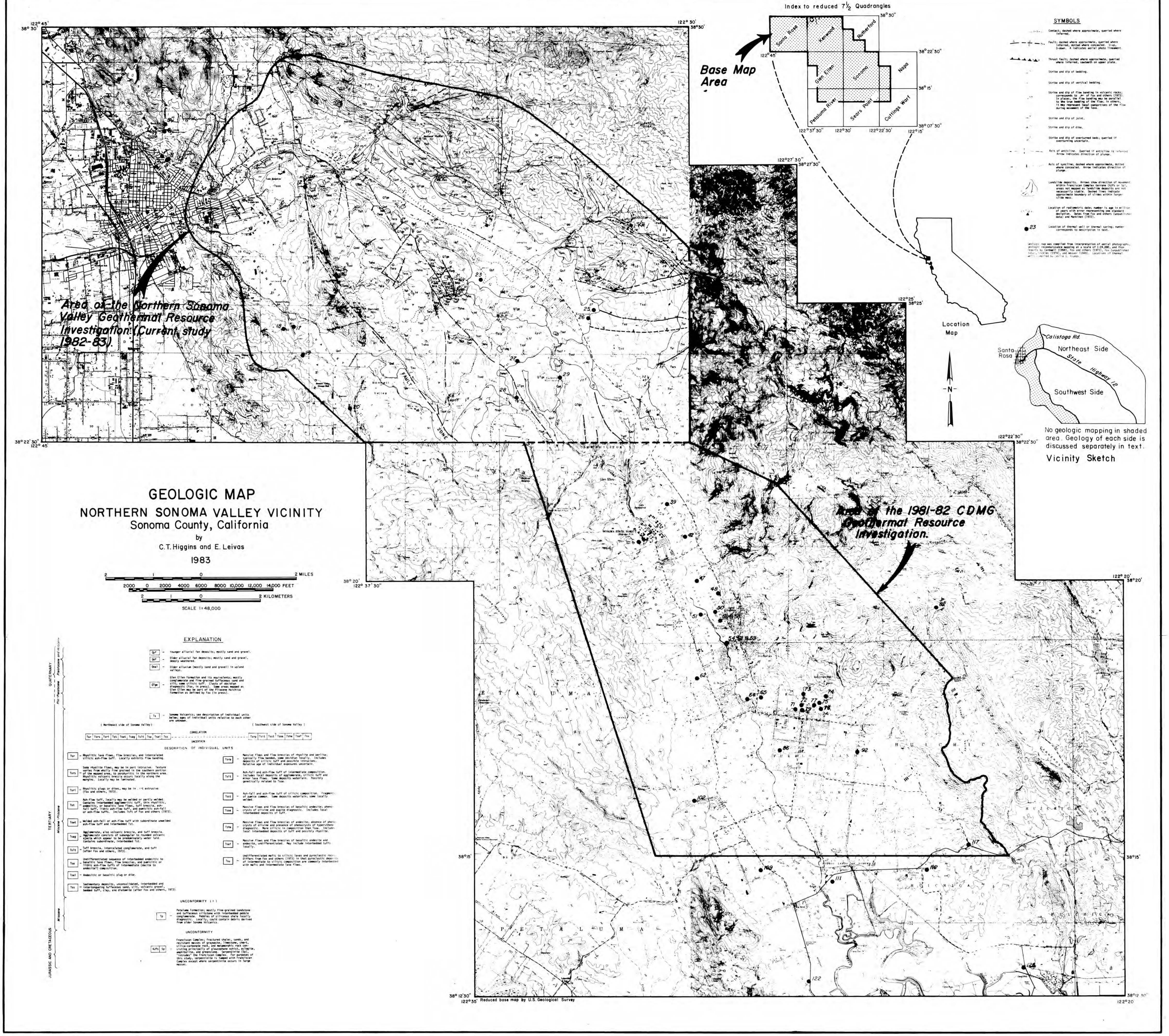
NORTHERN SONOMA VALLEY
GEOTHERMAL INVESTIGATION
OFR 83-27 SAC PLATE I



No geologic mapping in shaded area. Geology of each side is discussed separately in text.

Vicinity Sketch

Reduced base map by U.S. Geological Survey

GEOLOGIC MAP
NORTHERN SONOMA VALLEY VICINITY
Sonoma County, California

by

C.T. Higgins and E. Leivas

1983

2 1 0 2 MILES
2000 0 2000 4000 6000 8000 10,000 12,000 14,000 FEET
2 1 0 2 KILOMETERS

SCALE 1:48,000

EXPLANATION

QUATERNARY

Pleistocene and Holocene

Qyf – Younger alluvial fan deposits; mostly sand and gravel.

Qof – Older alluvial fan deposits; mostly sand and gravel, deeply weathered.

Qoal – Older alluvium (mostly sand and gravel) in upland valleys.

Plio-Pleistocene

QTge – Glen Ellen Formation and its equivalents; mostly conglomerate and fine-grained tuffaceous sand and silt; some silicic tuff. Clasts of obsidian diagnostic (Fox, in press). Some areas mapped as Glen Ellen may be part of the Pliocene Huichica Formation as defined by Fox (in press).

TERTIARY

Miocene - Pliocene

Ts – Sonoma Volcanics; see description of individual units below; ages of individual units relative to each other are unknown.

(Northeast side of Sonoma Valley)

(Southwest side of Sonoma Valley)

CORRELATION

Tsr | Tsrs | Tsri | Tst | Tswt | Tsag | Tslt | Tsa | Tsai | Tss – – – – – – – – – – Tsrp | Tsit | Tsst | Tsoa | Tsha | Tsaf | Tsu

UNCERTAIN

DESCRIPTION OF INDIVIDUAL UNITS

Tsr – Rhyolitic lava flows, flow breccias, and intercalated silicic ash-flow tuff. Locally exhibits flow banding.

Tsrs – Soda rhyolite flows, may be in part intrusive. Texture varies from wholly fine grained in the southern portion of the mapped area, to porphyritic in the northern area. Rhyolitic volcanic breccia occurs locally along the margins. Locally may be laminated.

Tsri – Rhyolitic plugs or dikes, may be in part extrusive (Fox and others, 1973).

Tst – Ash-flow tuff, locally may be welded or partly welded. Contains interbedded agglomeritic tuff, thin rhyolitic, andesitic, or basaltic lava flows, tuff breccia, ash-fall tuff, lithic ash-flow tuff, and pumicitic ash-fall or ash-flow tuffs. Includes Tsft of Fox and others (1973).

Tswt – Welded ash-fall or ash-flow tuff with subordinate unwelded ash-flow tuff and interbedded Tst.

Tsag – Agglomerate, also volcanic breccia, and tuff breccia. Agglomerate consists of subangular to rounded volcanic ejecta which appear to be predominately water laid. Contains subordinate, interbedded Tst.

Tslt – Tuff breccia, intercalated conglomerate, and tuff (after Fox and others, 1973).

Tsa – Undifferentiated sequence of interbedded andesitic to basaltic lava flows, flow breccias, and pumicitic or lithic ash-flow tuffs of intermediate (dacite to andesite?) composition.

Tsai – Andesitic or basaltic plug or dike.

Tss – Sedimentary deposits, unconsolidated, interbedded and intertongueing tuffaceous sand, silt, volcanic gravel, bedded tuff, clay, and diatomite (after Fox and others, 1973).

Tsrp – Massive flows and flow breccias of rhyolite and perlite; typically flow banded, some obsidian locally. Includes deposits of silicic tuff and possible intrusions. Relative age of individual exposures uncertain.

Tsit – Ash-fall and ash-flow tuff of intermediate composition. Includes local deposits of agglomerate, silicic tuff and minor lava flows. Some deposits waterlain. Possibly genetically related to Tsoa.

Tsst – Ash-fall and ash-flow tuff of silicic composition. Fragments of pumice common. Some deposits waterlain; some locally welded.

Tsoa – Massive flows and flow breccias of basaltic andesite; phenocrysts of olivine and augite diagnostic. Includes local interbedded deposits of tuff.

Tsha – Massive flows and flow breccias of andesite; absence of phenocrysts of olivine and presence of phenocrysts of hypersthene diagnostic. More silicic in composition than Tsoa. Includes local interbedded deposits of tuff and possibly rhyolite.

Tsaf – Massive flows and flow breccias of basaltic andesite and andesite, undifferentiated. May include interbedded tuffs locally.

Tsu – Undifferentiated mafic to silicic lavas and pyroclastic rocks. Differs from Fox and others (1973) in that pyroclastic deposits of intermediate to silicic composition are commonly interbedded with mafic and intermediate lava flows.

UNCONFORMITY (?)

Miocene

Tp – Petaluma Formation; mostly fine-grained sandstone and tuffaceous siltstone with interbedded pebble conglomerate. Pebbles of siliceous shale locally diagnostic. Locally, could contain debris derived from older Sonoma Volcanics.

UNCONFORMITY

JURASSIC AND CRETACEOUS

KJfs | Sp – Franciscan Complex; fractured shales, sands, and resistant masses of graywacke, limestone, chert, silica-carbonate rock, and metamorphic rock consisting principally of glaucophane schist, eclogite, amphibolite, and greenstone. Serpentinite (Sp), "intrudes" the Franciscan Complex. For purposes of this study, serpentinite is lumped with Franciscan Complex except where serpentinite occurs in large masses.

SYMBOLS

- – ?– ?– – Contact; dashed where approximate, queried where inferred.
- Fault; dashed where approximate, queried where inferred, dotted where concealed. U-up, D-down. A indicates aerial photo lineament.
- ▲▲▲▲?▲? Thrust fault; dashed where approximate, queried where inferred, sawteeth on upper plate.
- Strike and dip of bedding.
- Strike and dip of vertical bedding.
- Strike and dip of flow banding in volcanic rocks; corresponds to of Fox and others (1973). In places, the flow banding may be parallel to the true bedding of the flow; in others, it may represent local contortions of the flow during movement of the lava.
- Strike and dip of joint.
- Strike and dip of dike.
- Strike and dip of overturned beds; queried if overturning uncertain.
- Axis of anticline. Queried if anticline is inferred. Arrow indicates direction of plunge.
- Axis of syncline; dashed where approximate, dotted where concealed. Arrow indicates direction of plunge.
- Landslide deposits. Arrows show direction of movement. Within Franciscan Complex terrane (KJfs or Sp), areas not mapped as landslide deposits are not necessarily stable. Dashed lines indicate approximate boundary of slides within larger slide mass.
- ▲ Location of radiometric date; number is age in million of years with error representing one standard deviation. Dates from Fox and others (unpublished data) and Mankinen (1972).
- ● 23 Location of thermal well or thermal spring; number corresponds to description in text.

Geologic map was compiled from interpretation of aerial photographs, geologic reconnaissance mapping at a scale of 1:24,000, and from reports by Cardwell (1958), Fox and others (1973), Fox (unpublished data), Nickles (1974), and Weaver (1949). Locations of thermal wells compiled by Leslie G. Youngs.

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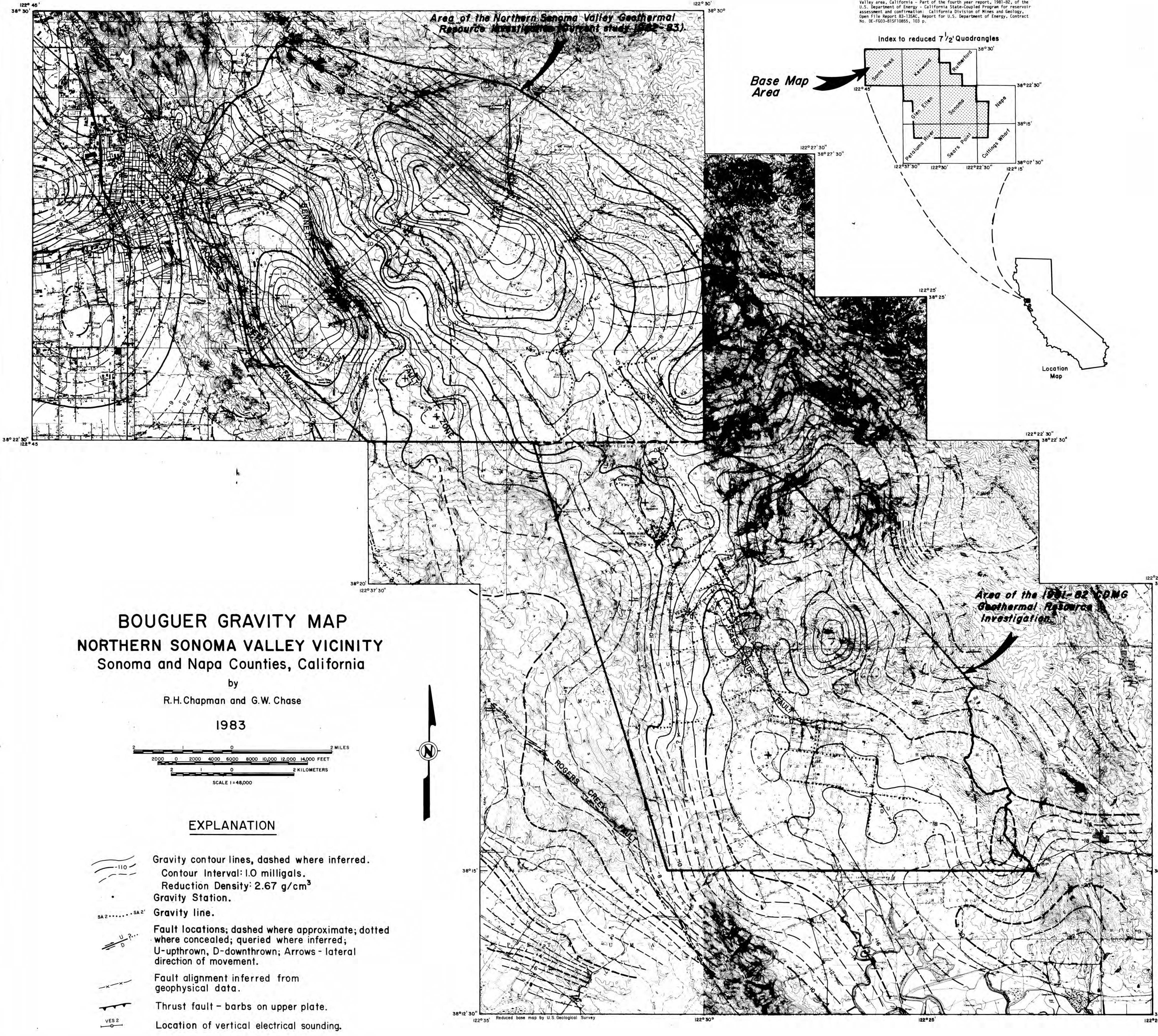

BOUGUER GRAVITY MAP

NORTHERN SONOMA VALLEY VICINITY

Sonoma and Napa Counties, California

by

R.H. Chapman and G.W. Chase

1983

EXPLANATION

Gravity contour lines, dashed where inferred.
Contour Interval: 1.0 milligals.
Reduction Density: 2.67 g/cm³

Gravity Station.

Gravity line.

Fault locations; dashed where approximate; dotted where concealed; queried where inferred; U-upthrown, D-downthrown; Arrows - lateral direction of movement.

Fault alignment inferred from geophysical data.

Thrust fault – barbs on upper plate.

Location of vertical electrical sounding.

Reduced base map by U.S. Geological Survey

* Youngs, L.G., Chapman, R.H., Chase, G.W., Bezore, S.P., and Majmundar, H.H., 1983, Investigation of low-temperature geothermal resources in the Sonoma Valley area, California - Part of the fourth year report, 1981-82, of the U.S. Department of Energy - California State-Coupled Program for reservoir assessment and confirmation: California Division of Mines and Geology, Open File Report 83-13SAC, Report for U.S. Department of Energy, Contract No. DE-FG03-81SF10855, 103 p.

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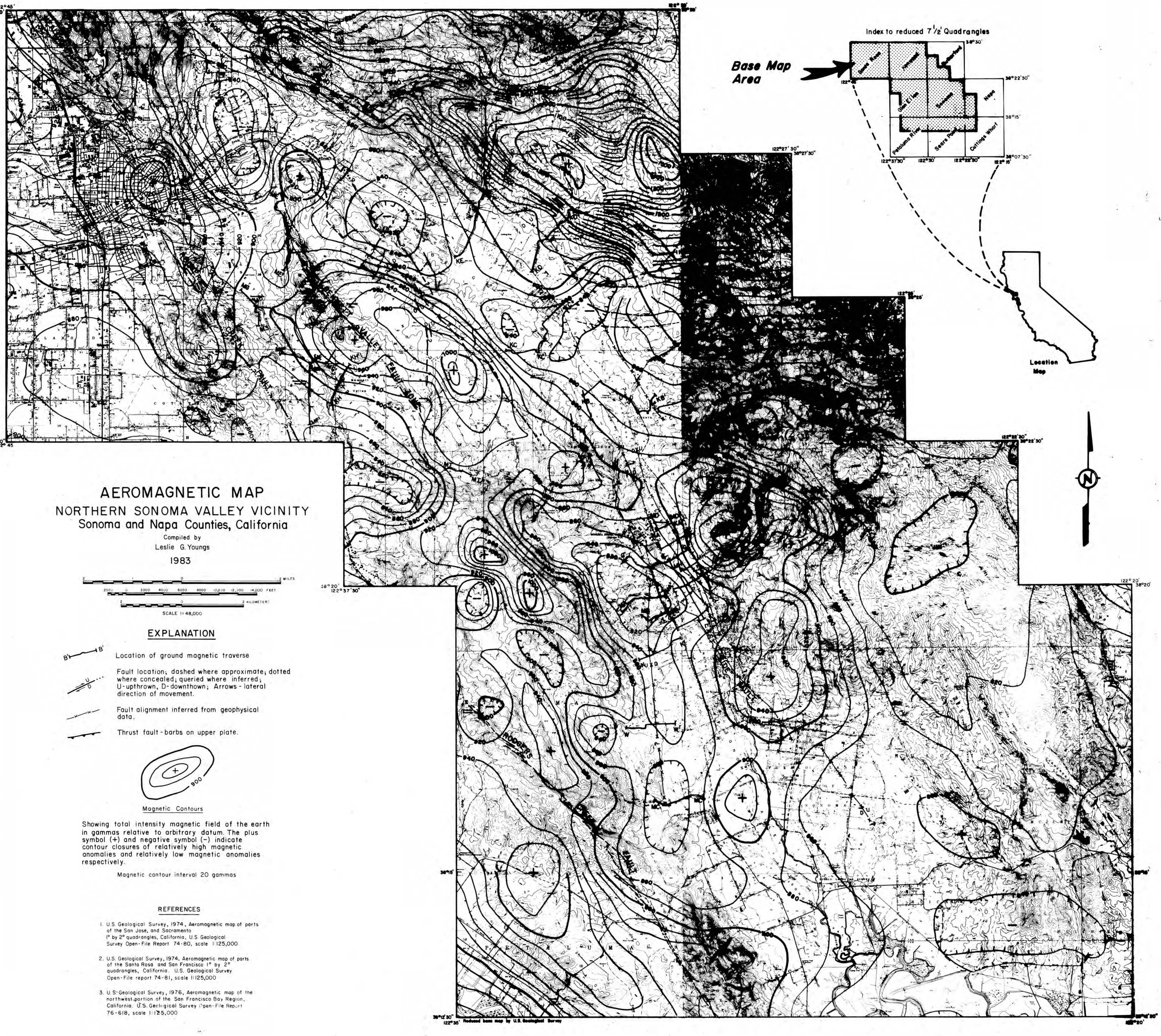
NORTH SONOMA VALLEY
GEOTHERMAL INVESTIGATION
OFR 83-27 SAC PLATE 3



AEROMAGNETIC MAP

NORTHERN SONOMA VALLEY VICINITY

Sonoma and Napa Counties, California

Compiled by
Leslie G. Youngs

1983

2 1 0 2 MILES
2000 0 2000 4000 6000 8000 10,000 12,000 14,000 FEET
2 0 2 KILOMETERS
SCALE 1:48,000

EXPLANATION

B'—B' Location of ground magnetic traverse

Fault location; dashed where approximate; dotted where concealed; queried where inferred; U-upthrown, D-downthown; Arrows - lateral direction of movement.

Fault alignment inferred from geophysical data.

Thrust fault - barbs on upper plate.

900

Magnetic Contours

Showing total intensity magnetic field of the earth in gammas relative to arbitrary datum. The plus symbol (+) and negative symbol (-) indicate contour closures of relatively high magnetic anomalies and relatively low magnetic anomalies respectively.

Magnetic contour interval 20 gammas

REFERENCES

1. U.S. Geological Survey, 1974, Aeromagnetic map of parts of the San Jose, and Sacramento 1° by 2° quadrangles, California, U.S. Geological Survey Open-File Report 74-80, scale 1:125,000

2. U.S. Geological Survey, 1974, Aeromagnetic map of parts of the Santa Rosa and San Francisco 1° by 2° quadrangles, California. U.S. Geological Survey Open-File report 74-81, scale 1:125,000

3. U.S. Geological Survey, 1976, Aeromagnetic map of the northwest portion of the San Francisco Bay Region, California. U.S. Geological Survey Open-File Report 76-618, scale 1:125,000

CALIFORNIA DIVISION OF MINES AND GEOLOGY
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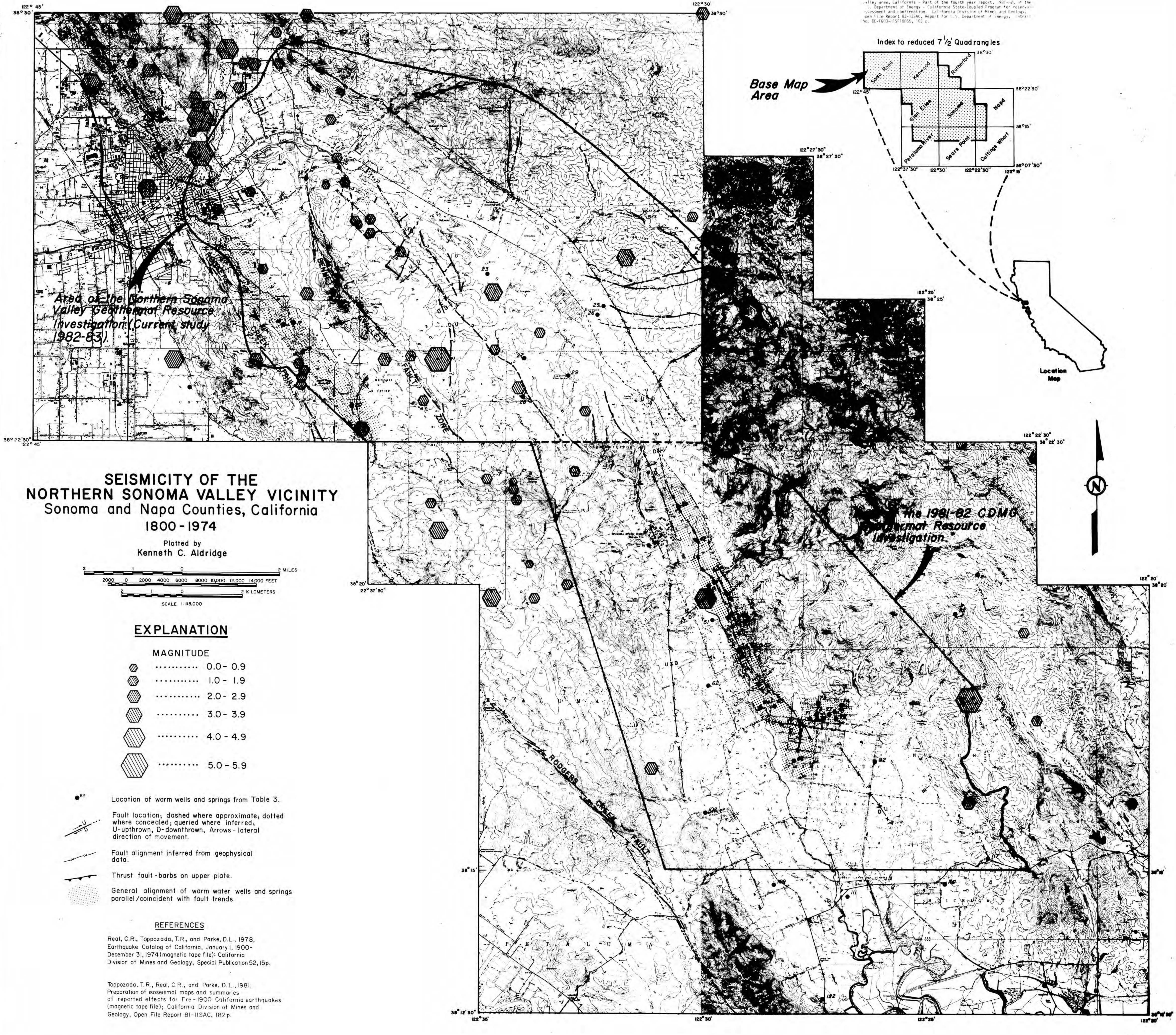
NORTHERN SONOMA VALLEY
GEOTHERMAL INVESTIGATION
OFR 83-27 SAC PLATE 4



* Youngs, L.G., Chapman, R.H., Chase, G.W., Bezore, S.P., and Majmundar, H.H., 1983, Investigation of low-temperature geothermal resources in the Sonoma Valley area, California - Part of the fourth year report, 1981-82, of the U.S. Department of Energy - California State-Coupled Program for reservoir assessment and confirmation. California Division of Mines and Geology, Open File Report 83-13SAC, Report for U.S. Department of Energy, Contract No. DE-FG03-81SF10855, 103 p.

SEISMICITY OF THE NORTHERN SONOMA VALLEY VICINITY

Sonoma and Napa Counties, California

1800-1974

Plotted by
Kenneth C. Aldridge

2 1 0 2 MILES
2000 0 2000 4000 6000 8000 10,000 12,000 14,000 FEET
2 1 0 2 KILOMETERS
SCALE 1:48,000

EXPLANATION

MAGNITUDE

⬡	0.0- 0.9
⬡	1.0- 1.9
⬡	2.0- 2.9
⬡	3.0- 3.9
⬡	4.0 - 4.9
⬡	5.0 - 5.9

●62 Location of warm wells and springs from Table 3.

Fault location; dashed where approximate; dotted where concealed; queried where inferred; U-upthrown, D-downthrown, Arrows - lateral direction of movement.

Fault alignment inferred from geophysical data.

Thrust fault - barbs on upper plate.

General alignment of warm water wells and springs parallel/coincident with fault trends.

REFERENCES

Real, C.R., Toppozada, T.R., and Parke, D.L., 1978, Earthquake Catalog of California, January 1, 1900-December 31, 1974 (magnetic tape file): California Division of Mines and Geology, Special Publication 52, 15p.

Toppozada, T.R., Real, C.R., and Parke, D.L., 1981, Preparation of isoseismal maps and summaries of reported effects for Pre-1900 California earthquakes (magnetic tape file); California Division of Mines and Geology, Open File Report 81-11SAC, 182p.

Reduced Base Map by U.S. Geological Survey

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

STATE OF CALIFORNIA GEORGE DEUKMEJIAN, GOVERNOR
RESOURCES AGENCY - GORDON K. VAN VLECK, SECRETARY FOR RESOURCES
DEPARTMENT OF CONSERVATION - DON L. BLUBAUGH, DIRECTOR

GEOTHERMAL RESOURCES INVESTIGATIONS
SONOMA VALLEY AREA
OPEN FILE REPORT 83-27 SAC, PLATE 5

LOCATION NUMBER	REFERENCE NUMBER *A	LOCATION *B	DATE SAMPLED	SURFACE TEMPERATURE (°C)	WELL DEPTH (METERS)	pH	SPECIFIC CONDUCTANCE (µS/cm)	CONCENTRATIONS IN MILLIGRAMS PER LITER (mg/l) *C																		TOTAL DISSOLVED SOLIDS	SALINITY %	SODIUM ADSORPTION RATIO (meq/l)	CHEMICAL CHARACTERISTIC (Cation-Anion)	REMARKS
								Na	K	Ca	Mg	SiO_2	Fe	Mn	Sr	Cu	Zn	Li	B	Cl	F	$CaCO_3$	HCO_3	SO_4	NO_3					
1	4	8N/8W, 34M	08/28/73	24	153	7.4	700	55	---	32	16.5	---	0.7	1.16	---	---	---	---	---	22.5	0.46	148	283	12.5	1.3	357	---	---	Mixed cations - Bicarbonate	---
2	4	7N/8W, 2E	11/24/81	31	113	7.1	240	15	---	17	12	---	2.5	0.19	---	---	---	---	<0.05	---	---	---	---	---	---	156	---	---	---	---
3	4	8N/8W, 35L	05/20/82	---	143	7.6	325	12	---	22	---	---	0.5	0.12	---	---	---	---	0.07	---	---	---	---	---	---	---	---	---	---	---
4	4	8N/8W, 35P	07/14/82	---	155	7.5	270	4.7	---	19	16	---	0.3	<0.05	---	---	---	---	0.06	4.2	---	---	---	12	---	---	---	---	Magnesium - Sulfate	---
6	5	7N/8W, 12E	02/28/83	24	70.1	7.7	---	19	2	34	19	100	0.11	<0.25	.08	<0.06	.12	.05	.12	9	.20	---	196	2	---	282	---	---	Mixed cations - Bicarbonate	Artesian
7	5	7N/8W, 12N	12/30/82	29	154	7.42	---	27	3	24	17	107	0.36	<0.25	0.07	<0.063	<0.125	<0.05	<0.125	9	0.22	---	231	1.2	---	316	---	---	Mixed cations - Bicarbonate	Zr = 0.6 mg/l, Artesian
10	5	7N/8W, 24A4	12/30/82	30	305	7.9	---	49	7	16	16	99	0.23	<0.25	0.06	<0.063	<0.125	0.08	0.4	20	0.42	---	285	1.2	---	362	---	---	Mixed cations - Bicarbonate	Ni = 0.2 mg/l, Artesian
12	5	7N/7W, 17J	01/06/83	22	0	---	---	24.37	3.64	4.32	12.5	99.68	---	---	---	---	---	---	0.28	10	0.18	---	188	< 10	---	---	---	---	Mixed cations - Bicarbonate	---
13	5	7N/7W, 16G	12/30/82	32	39	7.53	---	38	5	15	10	118	0.31	<0.25	0.05	<0.063	<0.125	<0.05	0.3	11	0.57	---	196	1.4	---	310	---	---	Mixed cations - Bicarbonate	---
14	1	7N/7W, 15C1	07/13/79	---	?	7.5	256	23	4.4	13	11	---	---	---	---	---	---	---	0.0	6.0	---	121	---	4.0	0.0	201	---	1.1	Mixed cations - Carbonate	---
15	1	7N/7W, 29D1	08/10/72	---	?	7.3	495	43	2.7	29	20	---	---	---	---	---	---	---	0.4	19	---	228	---	1.6	0.0	308	---	1.5	Mixed cations - Carbonate	---
16	1,2	7N/7W, 32G1	10/51	---	123	8.3	490	75	---	30	10	---	---	---	---	---	---	---	0.32	20	---	115	265	0.0	---	---	---	---	Sodium - Bicarbonate	---
17	4	7N/7W, 32G9	08/29/76	31	125	---	526	82	12	---	---	---	0.24	0.06	---	---	---	0.12	0.4	10	---	---	313	---	2.2	---	---	---	Sodium (?) - Bicarbonate (?)	---
19	5	6N/7W, 5A	02/10/83	30	?	7.4	---	72	10	26	10	108	0.29	<0.25	0.09	<0.06	0.20	0.11	0.30	18	0.30	---	280	23	---	426	---	---	Sodium - Bicarbonate	---
20	5	6N/7W, 9A	02/10/83	22	177.4	7.6	---	95	5	20	5	126	1.10	<0.25	0.11	<0.06	<0.12	C.13	0.20	9	0.30	---	293	15	---	446	---	---	Sodium - Bicarbonate	---
22	1	6N/8W, 12J1	02/15/50	---	68	---	357	---	---	---	---	---	---	---	---	---	---	---	---	41	---	75	---	---	---	---	---	---	---	---
23	4	7N/7W, 25G	04/27/76	WARM	166	7.4	230	---	---	---	---	---	0.24	<0.05	---	---	---	---	0.10	---	---	---	---	---	---	180	---	---	---	---
24	1	7N/6W, 29P1	06/05/75	---	34	7.5	240	18	1.6	14	10	---	---	---	---	---	---	---	---	5.1	---	109	---	0.8	0.1	172	---	0.9	Mixed cations - Carbonate	---
27	6	38°23.98', 122°34.00'	04/03/82	20	?	6.02	160	15	4	15	10	99	<0.025	<0.250	0.04	<0.063	<0.125	0.05	<0.125	8	0.3	---	131	<10	---	281	0.0	0.73	Mixed cations - Bicarbonate	---
28	6	38°23.30', 122°34.11'	02/24/82	23	---	6.90	285	26	4	20	14	97	<0.025	<0.250	0.05	<0.063	<0.125	<0.050	<0.125	8	0.2	---	195	<10	---	265	0.1	1.09	Mixed cations - Bicarbonate	"McEwan Ranch" Warm Spring
29	6	38°23.66', 122°32.99'	02/24/82	31	54.9	7.55	650	104	12	18	7	92	<0.025	<0.250	0.05	<0.063	<0.125	0.07	3.30	69	0.9	---	296	36	---	488	0.8	5.26	Sodium - Bicarbonate	Morton's Warm Spring, Artesian
30	1,2	6N/6W, 5L1	09/51	---	41	7.6	568	105	---	18	8.3	57	0.18	0.14	---	---	---	---	2.5*D	51	0.7	68	273	0.8	0.0	375	---	---	Sodium - Bicarbonate	Los Guilicos Spring ?
31	1,2	6N/6W, 5L3	05/52	---	2	8.0	611	112	13	15	6.2	81	---	---	---	---	---	---	3.5	58	0.8	63	282	0.3	1.2	430	---	---	Sodium - Bicarbonate	---
32	3	7N/6W, 35J	?	20	---	7.1	---	12	---	2.2	0.8	---	2.7	0.07	---	---	---	0.0	0.0	6.2	0.1	---	24	7.6	0.6	80	---	---	Sodium - Bicarbonate	Nunn's Iron Spring
33	1,2	6N/6W, 10G1	05/51	---	?	---	1310	---	---	---	---	---	---	---	---	---	---	---	---	164	---	395	---	---	---	---	---	---	---	---
34	1	6N/6W, 10M2	06/03/75	---	?	6.7	265	19	3.5	15	9.8	---	---	---	---	---	---	---	0.0	15	---	71	---	30	0.1	206	---	0.9	Mixed cations - Carbonate	---
35	1,2	6N/6W, 16B2	09/51	---	64	8.2	672	134	9.0	3.7	4.6	---	---	---	---	---	---	---	7.7	60	0.3	28	300	0.8	0.5	445	---	---	Sodium - Bicarbonate	---
36	1,2	6N/6W, 16H1	05/51	---	64	8.3	550	120	---	5	0	---	---	---	---	---	---	---	6.2	80	---	15	195	0	---	314	---	---	Sodium - Bicarbonate	---
37	1,2	6N/6W, 16J2	10/49	---	?	8.5	550	90	---	15	10	---	---	---	---	---	---	---	7.7	90	---	---	120	23	---	308	---	---	Sodium - Chloride	---
38	1,2	6N/6W, 15J1	09/51	---	23	7.7	344	32	5.9	14	9.5	90	---	---	---	---	---	---	0.54	24	0.5	74	126	12	0.6	252	---	---	Mixed cations - Mixed anions	---
40	6	38°20.96', 122°29.96'	03/21/82	16	?	6.62	150	24	5	11	11	107	<0.025	<0.250	0.03	<0.063	0.20	0.07	<0.125	28	0.6	---	111	<10	---	297	0.0	1.22	Mixed cations - Bicarbonate	---
41	1	6N/6W, 23M2	08/14/78	---	71	7.4	466	68	9.0	14	7.5	---	---	---	---	---	---	---	1.3	75	---	115	---	3.8	0.0	331	---	3.6	Sodium - Carbonate	---
42	6	38°20.80', 122°30.06'	03/21/82	21	76.2	7.38	510	113	10	3	1	71	0.37	<0.250	0.01	<0.063	<0.125	0.07	3.20	101	0.7	---	162	<10	---	381	0.1	14.48	Sodium - Chloride	---
43	6	38°20.78', 122°30.14'	04/03/82	18	121.9	6.91	70	52	8	5	3	74	1.54	0.40	0.04	<0.063	<0.125	<0.050	0.40	28	0.6	---	151	20	---	268	0.0	4.52	Sodium - Bicarbonate	---
45	1,2	6N/6W, 27A1	04/61	---	71	8.3	518	71	12	16	7.3	---	0.02	---	---	---	---	---	1.4	82	1.2	---	145	2.1	0.4	352	---	---	Sodium - Mixed anions	---
46	1	6N/6W, 26E1	08/09/77	---	93	7.7	400	81	6.5	2.6	0.4	---	---	---	---	---	---	---	1.9	44	---	122	---	2.3	0.0	306	---	12.5	Sodium - Carbonate	---
47	6	38°20.00', 122°29.82'	03/20/82	22	76.2	6.95	315	56	11	9	3	76	<0.025	<0.250	0.03	<0.063	<0.125	0.05	0.90	50	0.9	---	133	<10	---	273	0.0	4.12	Sodium - Bicarbonate	---
48	6	38°19.78', 122°29.40'	04/04/82	22	79.3	5.98	170	18	5	54	8	98	0.18	<0.250	0.05	<0.063	1.60	<0.050	<0.125	15	0.4	---	102	<10	---	300	0.0	0.60	Calcium - Bicarbonate	---
49	1,2	6N/6W, 26R1	04/52	---	?	---	653	---	---	---	---	---	---	---	---	---	---	---	---	121	---	12	---	---	---	---	---	---	---	---
51	4	6N/6W, 35E	02/10/77	WARM	2307	8.2	645	137	9.8	4.1	0.18	---	<0.04	<0.02	---	---	---	---	4.4	131	2.6	17	132	1.5	<0.4	---	---	18.4	Sodium - Bicarbonate	---
52	6	38°19.32', 122°29.40'	07/21/81	35	91.4	6.80	---	95	9	12	2	68	0.45	<0.250	0.04	<0.063	<0.125	0.42	3.4	142	2.8	---	182	<10	---	426	0.2	6.70	Sodium - Bicarbonate	Well at Agua Caliente Springs
53	6	38°19.32', 122°29.40'	07/21/81	29	50.3	7.10	---	53	5	4	1	67	0.21	<0.250	0.01	<0.063	<0.125	0.20	2.1	46	2.5	---	121	44	---	286	0.0	6.15	Sodium - Mixed anions	Well at Fetter's Hot Springs
54	1,2	5N/6W, 2A2	08/58	43	107	8.0	1350	256	12	9.1	0.1	90	0.04	---	---	---	---	---	.94*D	324	7.3	23	135	5.4	0.2	842	---	---	Sodium - Chloride	Boyes Hot Spring Well ? (Bath House)
55	1,2	5N/6W, 2A3	06/51	---	?	---	1220	---	---	---	---	---	---	---	---	---	---	---	---	273	---	35	---	---	---	---	---	---	---	Boyes Hot Spring Well ?
56	2	5N/6W, 2A4	06/51	---	?	---	1050	---	---	---	---	---	---	---	---	---	---	---	---	208	---	---	---	---	---	---	---	---	---	Boyes Hot Spring Well ?
57	1,2	5N/6W, 2A5	06/51	---	?	---	901	---	---	---	---	---	---	---	---	---	---	---	---	132	---	30	---	---	---	766	---	---	---	Boyes Hot Spring Well ?
59	4	5N/6W, 2B	08/19/80	44	~137	8.1	1780	290	13.5	13	0.5	---	<0.05	<0.02	---	---	---	---	---	412	6.6	34.5	146	3.5	0.2	1140	---	---	Sodium - Chloride	Boyes Hot Spring Well "No. 2"
60	6	38°18.33', 122°27.94'	03/16/82	14	26.2	5.43	90	8	6	5	3	36	0.56	<0.250	0.03	<0.063	<0.125	<0.050	<0.125	9	0.7	---	38	123	---	211	0.0	0.07	Mixed cations - Sulfate	---
61	6	38°18.28', 122°28.91'	03/16/82	17	27.4	6.75	430	58	7	15	11	60	0.98	0.60	0.11	<0.063	<0.125	0.39	1.30	56	0.3	---	203	27	---	338	0.2	2.78	Sodium - Bicarbonate	---
62	6	38°18.25', 122°29.81'	03/17/82	21	52.1	6.24	250	32	1.4	19	8	61	0.10	<0.250	0.13	<0.063	<0.125	<0.050	<0.125	15	0.4	---	145	<10	---	280	0.0	1.55	Mixed cations - Bicarbonate	---
63	1	5N/6W, 2N2	08/17/72	---	?	7.1	290	30	0.5	16	9.7	---	---	---	---	---	---	---	0.0	17	---	111	---	8.2	7.6	208	---	1.5	Mixed cations - Carbonate	---
64	4	5N/6W, 12D	10/10/80	31	~213	---	---	80	3.4	2	---	---	---	---	---	---	---	---	---	30.1	1.06	---	143	< 1	---	220	---	---	Sodium - Bicarbonate	CO_3 = 7.5 mg/l
65	6	38°17.88', 122°28.40'	03/15/82	30	225.6	7.78	225	51	5	2	< 0.500	52	0.07	<0.250	<0.01	<0.063	<0.125	0.10	0.30	12	0.6	---	142	<10	---	193	0.0	10.09	Sodium - Bicarbonate	Flow rate 492 l/m
66	1	5N/6W, 12F1	07/30/73	18	34	7.0	460	51	1.6	19	18	---	---	---	---	---	---	---	0.7	30	---	186	---	9.5	3.3	290	---	2.0	Mixed cations - Carbonate	---
67	6	38°17.62', 122°29.13'	03/19/82	17	25.9	6.25	275	21	1.4	28	16	63	0.32	<0.250	0.11	0.70	1.40	<0.050	<0.125	20	0.2	---	160	<10	---	231	0.0	0.98	Mixed cations - Bicarbonate	---
68	6	38°17.56', 122°28.81'	03/18/82	16	21.3	6.90	480	58	4	22	25	59	<0.025	0.70	0.14	<0.063	0.20	<0.050	0.20	38	0.3	---	302	<10	---	357	0.1	2.00	Mixed cations - Bicarbonate	---
69	6	38°17.52', 122°28.79'	04/04/82	19	22.9	6.90	110	63	4	31	20	57	0.13	0.50	0.16	<0.063	1.70	0.05	0.40	38	0.4	---	285	<10	---	356	0.0	2.17	Mixed cations - Bicarbonate	---
70	1	5N/6W, 12M1	08/17/72	---	?	7.6	495	54	2.9	16	21	---	---	---	---	---	---	---	0.4	33	---	197	---	3.4	1.9	295	---	2.1	Mixed cations - Carbonate	---
71	6	38°17.68', 122°27.51'	03/18/82	21	70.1	6.60	105	25	5	8	5	96	2.69	0.40	0.04	<0.063	<0.125	<0.050	<0.125	9	0.6	---	114	<10	---	211	0.0	1.71	Sodium - Bicarbonate	Artesian Well
72	6	38°17.75', 122°27.42'	03/11/82	21	73.2	6.40	850	18	2.5	50	11	63	0.15	<0.250	0.07	<0.063	3.50	<0.050	<0.125	9	0.6	---	114	<10	---	214	0.0	0.60	Calcium - Bicarbonate	Flow rate 191 l/m
73	6	38°17.95', 122°27.41'	03/15/82	24	61	6.62	190	8	1.4	20	13	20	<0.025	<0.250	0.16	<0.063	<0.125	<0.050	0.20	9	0.2	---	121	<10	---	132	0.0	0.34	Mixed cations - Bicarbonate	Flow rate 492 l/m
74	6	38°17.90', 122°27.01'	03/11/82	28	67.1	6.20	180	28	3	8	4	91	0.18	<0.250	0.02	<0.063	0.20	<0.050	<0.125	8	0.5	---	105	<10	---	409	0.0	2.30	Sodium - Bicarbonate	Flow rate 530 l/m
75	5	5N/5W, 7G	01/06/83	28	~137	---	---	33.1	4.2	3.26	4.3	---	---	---	---	---	---	---	0.28	10	0.48	---	122	<10	---	---	---	---	Sodium - Bicarbonate	---
77	6	38°17.76', 122°27.28'	03/10/82	23	152.4	6.20	215	26	3	15	7	83	0.09	<0.250	0.03	0.10	0.70	<0.050	<0.125	10	0.7	---	124	<10	---	206	0.0	1.38	Mixed cations - Bicarbonate	Flow rate 1800 l/m
78	6	38°17.65', 122°28.88'	03/10/82	15	70.1	6.50	200	8	1.5	24	14	25	0.10	<0.250	0.16	<0.063	<0.125	<0.050	0.20	6	0.3	---	145	<10	---	149	0.0	0.32	Mixed cations - Bicarbonate	Flow rate 1100 l/m
79	6	38°17.65', 122°27.40'	03/08/82	29	106.7	6.60	160	24	4	8	6	83	0.98	<0.250	0.02	<0.063	<0.125	<0.050	<0.125	8	0.6	---	117	19	---	211	0.0	1.55	Sodium - Bicarbonate	Flowing well
80	6	38°17.62', 122°26.31'	03/05/82	17	29.0	6.28	320	50	8	13	10	98	0.28	0.40	0.06	<0.063	<0.125	0.10	0.20	19	0.4	---	160	21	---	300	0.0	2.71	Sodium - Bicarbonate	---
81	1	5N/5W, 9M2	09/15/51	---	78	7.6	630	128	9.0	5.2	4.1	36	---	---	---	---	---	---	1.0	90	0.2	188	---	0.6	0.0	387	---	10.2	Sodium - Carbonate	---
83	1	5N/5W, 9N1	08/14/51	---	?	---	908	---	---	---	---	---	---	---	---	---	---	---	---	96	---	55	---	---	---	---	---	---	---	---
84	1	5N/5W, 8P2	08/01/74	---	75	7.3	520	88	7.5	10	6.8	---	---	---	---	---	---	---	0.7	40	---	165	---	26	1.4	360	---	5.3	Sodium - Carbonate	---
85	1	5N/5W, 18D2	07/31/79	18	23	6.8	485	44	1.8	26	21	---	---	---	---	---	---	---	0.4	35	---	149	---	20	37	360	---	1.6	Mixed cations - Carbonate	---
86	6	38°16.94', 122°27.81'	04/10/82	20	53.3	7.12	380	93	3	7	4	38	0.36	<0.250	0.07	<0.063	<0.125	0.09	1.30	15	0.6	---	272	<10	---	296	0.0	6.93	Sodium - Bicarbonate	---
87	6	38°16.88', 122°27.53'	03/05/82	14	15.9	7.05	350	74	3	23	9	67	0.51	<0.250	0.07	<0.063	1.10	0.06	1.00	22	0.4	---	220	22	---	332	0.1	3.32	Sodium - Bicarbonate	---
88	6	38°16.74', 122°27.85'	03/04/82	17	36.6	6.13	520	28	3	54	41	70	<0.025	<0.250	0.16	0.10	1.20	<0.050	<0.125	58	0.2	---	143	23	---	349	0.1	0.70	Mixed cations - Bicarbonate	---
89	1,2	5N/6W, 13K1	09/51	---	46	7.3	368	28	0.8	24	19	16	---	---	---	---	---	---	4.4	15	0.10	---	204	9.1	0.3	---	---	---	Mixed cations - Bicarbonate	---
90	6	38°16.67', 122°27.01'	03/03/82	19	64.0	6.30	220	54	3	16	13	142	<0.025	<0.250	0.08	<0.063	0.20	0.06	0.30	17	0.4	---	124	47	---	354	0.0	2.35	Sodium - Bicarbonate	---
91	6	38°16.85', 122°26.88'	03/03/82	19	114.0	7.30	280	71	2.5	6	2	52	0.38	<0.250	0.03	<0.063	0.30	<0.050	1.00	13	0.5	---	189	25	---	267	0.0	6.31	Sodium - Bicarbonate	---
93	1	5N/5W, 20C1	09/19/51	---	?	7.6	395	10	0.7	48	20	16	---	---	---	---	---	---	0.56	6.2	0.0	198	---	11	0.0	231	---	0.3	Calcium - Carbonate	---
94	6	38°15.98', 122°25.21'	03/02/82	10	41.8	6.60	3280	541	4	148	73	21	<0.025	0.80	1.44	<0.063	<0.125	0.14	1.60	1105	0.2	---	218	33	---	2036	2.0	9.09	Sodium - Chloride	---
95	1	5N/5W, 20R1	07/11/80	---	154	8.3	827	192	1.2	7.0	2.0	---	---	---	---	---	---	---	4.7	53	---	360	---	10	0.0	504	---	16.4	Sodium - Carbonate	---
96	6	38°15.30', 122°25.35'	02/26/82	16	135.3	5.72	270	38	0.7	11	7	98	<0.025	<0.250	0.08	<0.063	6.30	<0.050	<0.125	30	0.2	---	92	15	---	251	0.0	2.20	Sodium - Bicarbonate	---
97	6	38°15.28', 122°25.55'	02/26/82	16	30.5	5.71	390	56	3	13	15	99	<0.025	<0.250	0.09	<0.063	<0.125	<0.050	<0.125	76	0.3	---	99	11	---	322	0.1	2.52	Sodium - Chloride	---
98	6	38°15.15', 122°26.99'	03/01/82	11	20.1	6.20	280	25	3	14	19	77	<0.025	<0.250	0.07	<0.063	<0.125	<0.050	0.125	23	0.3	---	151	<10	---	235	0.1	1.03	Mixed cations - Bicarbonate	---
99	6	38°15.48', 122°26.30'	03/01/82	18	54.3	6.20	250	25	2	11	18	82	<0.025	<0.250	0.06	<0.063	<0.125	<0.050	<0.125	25	0.3	---	140	<10	---	228	0.0	1.08	Mixed cations - Bicarbonate	---
100	1	5N/5W, 19L1	09/28/59	---	?	7.9	322	19	1.7	16	19	66	---	---	---	---	---	---	0.08	14	0.2	122	---	8.6	11.0	228	---	0.8	Magnesium - Carbonate	---
101	1	5N/6W, 24M1	08/01/74	---	?	7.1	275	16	1.1	20	12	---	---	---	---	---	---	---	0.0	10	---	116	---	3.8	6.1	249	---	0.7	Mixed cations - Carbonate	---
102	6	38°16.02', 122°29.95'	04/11/82	20	155.5	6.91	240	44	3	29	10	30	0.11	<0.250	0.10	<0.063	1.70	0.06	<0.125	17	0.3	---	196	<10	---	233	0.0	1.79	Mixed cations - Bicarbonate	---
103	1,3	5N/6W, 30D1	09/23/59	18	47	7.9	1350	131	2.0	121	34	31	---	---	---	---	---	---	0.3	139	0.3	25	394	120	1.1	940*D	---	---	Mixed cations - Bicarbonate	---
104	3	4N/6W, 7H1	?	---	11	---	---	---	---	---	---	---	---	---	---	---	---	---	2.3	---	---	---	---	---	---	---	---	---	---	Affected by sea water intrusion
105	3	4N/6W, 7H2	?	---	4	---	---	---	---	---	---	---	---	---	---	---	---	---	3.1	---	---	---	---	---	---	---	---	---	---	Affected by sea water intrusion
106	3	4N/6W, 8E1	?	---	23	---	---	---	---	---	---	---	---	---	---	---	---	---	2.2	---	---	---	---	---	---	---	---	---	---	Affected by sea water intrusion
107	3	5N/6W, 33H8	?	---	175	---	1400	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
108	1,2	5N/6W, 25P1	08/58	---	52	8.4	---	124	1.8	9.4	3.8	26	0.0	---	---	---	---	---	1.2	1.2	0.3	---	324	12	1.0	---	---	---	Sodium - Bicarbonate	---
109	1	5N/6W, 25P2	07/21/81	38	195	8.3	574	133	3.2	3.6	1.0	---	---	---	---	---	---	---	0.8	22	---	266	---	10	0.0	405	---	16.7	Sodium - Carbonate	---
110	1,2	5N/5W, 31B1	09/51	---	17	---	5010	430	8.1	204	261	---	---	---	---	---	---	---	0.21	1480	0.0	285	---	199	2.9	2800	---	---	Mixed cations - Chloride	---
111	1,2	5N/5W, 31A1	04/52	20	124	8.3	854	205	1.5	6.8	---	29	---	---	---	---	---	---	5.3	66	0.0	32	488	0.7	0.2	585*D	---	---	Sodium - Bicarbonate	Artesian
112	1,2	5N/5W, 31A2	06/52	---	30	---	5380	848	---	159	192	---	---	---	---	---	---	---	0.8	1580	---	1190	---	---	---	---	---	---	Sodium - Chloride	---
113	1,2	5N/5W, 31A3	08/54	17	17	7.6	4710	418	6.5	229	189	62	0.01	0.0	---	0.0	0.0	---	0.13	1360	0.1	1350	296	182	2.1	2590	---	---	Mixed cations - Chloride	---
114	1,2	5N/5W, 31H1	04/52	---	?	---	1310	---	---	---	---	---	---	---	---	---	---	---	---	234	---	100	---	---	---	---	---	---	Sodium (?) - Chloride	---
115	1	5N/5W, 28N1	08/17/72	---	40	6.5	1050	71	2.8	32	48	---	---	---	---	---	---	---	0.0	242	---	67	---	12	19.0	583	---	1.9	Mixed cations - Chloride	---
116	1	5N/5W, 28R1	07/29/71	20	85	8.1	1000	218	1.3	14	8.8	---	---	---	---	---	---	---	1.1	89	---	377	---	36	0.8	615	---	11.3	Sodium - Carbonate	---
117	6	38°15.22', 122°23.30'	02/22/82	28	213.4	7.40	260	47	17	12	4	102	<0.025	<0.250	0.05	<0.063	<0.125	0.05	0.20	12	0.2	---	197	<10	---	291	0.1	3.00	Sodium - Bicarbonate	Artesian Well
118	1	5N/5W, 27H1	01/26/50	---	?	---	334	---	---	---	---	---	---	---	---	---	---	---	---	12	---	40	---	---	---	---	---	---	---	---
119	1,2	5N/5W, 33K1	09/60	---	58	---	20,571	284*D	---	---	---	---	---	---	---	---	---	---	0.07*D	7582	---	2540*D	---	9.2*D	---	13267	---	---	Sodium (?) - Chloride	---
120	1	4N/6W, 1K1	06/03/75	---	?	7.1	355	14	0.7	27	19	---	---	---	---	---	---	---	0.0	18	---	121	---	11	23	258	---	0.5	Mixed cations - Carbonate	---
121	1	4N/5W, 6E1	08/17/72	---	?	7.6	425	25	4.3	27	19	---	---	---	---	---	---	---	0.3	36	---	152	---	5.8	1.2	286	---	0.9	Mixed cations - Carbonate	---
123	6	38°13.38', 122°23.21'	02/23/82	16	54.9	7.88	1010	201	3	29	19	30	<0.025	<0.250	0.28	<0.063	<0.125	0.05	0.30	145	0.2	---	416	37	---	670	0.7	7.11	Sodium - Bicarbonate	---
124	6	38°13.58', 122°22.59'	02/23/82	17	?	7.80	900	133	3	48	28	37	<0.025	<0.250	0.39	<0.063	0.30	0.05	0.10	182	0.3	---	342	<10	---	601	0.6	3.78	Sodium - Bicarbonate	---
125	1	4N/5W, 2Q2	03/24/59	12	91	7.5	1050	162	3.6	34	20	28	---	---	---	---	---	---	0.15	135	0.1	299	---	33	2.0	597	---	5.5	Sodium - Carbonate	---
126	6	38°12.98', 122°22.37'	02/25/82	20	74.4	6.52	600	87	2	25	16	49	0.05	<0.250	0.16	<0.063	0.20	0.06	<0.125	122	0.3	---	168	<10	---	385	0.2	3.35	Sodium - Chloride	---

FOOTNOTES:

*A REFERENCES

1. California Department of Water Resources, 1982, Microfiche files of water quality data, unpublished.
2. Herbst, C.M., 1982, Evaluation of ground water resources - Sonoma County: Department of Water Resources, Bulletin 118-4, v. 4, 78 p.
3. Ford, R.S., 1975, Evaluation of ground water resources; Sonoma County: California Department of Water Resources, Bulletin 118-4, v. 1, 177 p.
4. Chemical analysis supplied by property owner.
5. California Division of Mines and Geology, 1982-83, Water sample analysis performed for this report.
6. Youngs, L.G., Chapman, R.H., Chase, G.W., Bezore, S.P., and Majmundar, H.H., publication in 1983, Investigation of low-temperature geothermal resources in the Sonoma Valley area, California - Part of the fourth year report, 1981-82, of the U.S. Department of Energy - California State-Coupled Program for reservoir assessment and confirmation: California Division of Mines and Geology, Open File Report 83-13SAC, Report for U.S. Department of Energy, Contract No. DE-FG03-81SF10855, 103 p.

*B

Location is given either as coordinate of latitude and longitude or as township, range and section referenced to the Mount Diablo base and meridian. For further discussion, and diagram of locations within a section see the Introduction section of this report.

*C

All samples from reference number 6 were also analyzed for Al, Ti, P, Ba, V, Cr, Co, Ni, Mo, Pb, Cd, Ag, Au, As, Sb, Bi, U, Te, Sn, W, Be, Zr, La, Ce, Th, and CO_3. All these concentrations were found to be less than the detection limit values.

*D

The data have been obtained from a different chemical analysis than the date shown.

CHEMICAL ANALYSES
OF
110 WELLS AND SPRINGS IN THE SONOMA VALLEY AREA, CALIFORNIA

1983

Compiled by
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Leslie G. Youngs

CALIFORNIA DIVISION OF MINES AND GEOLOGY
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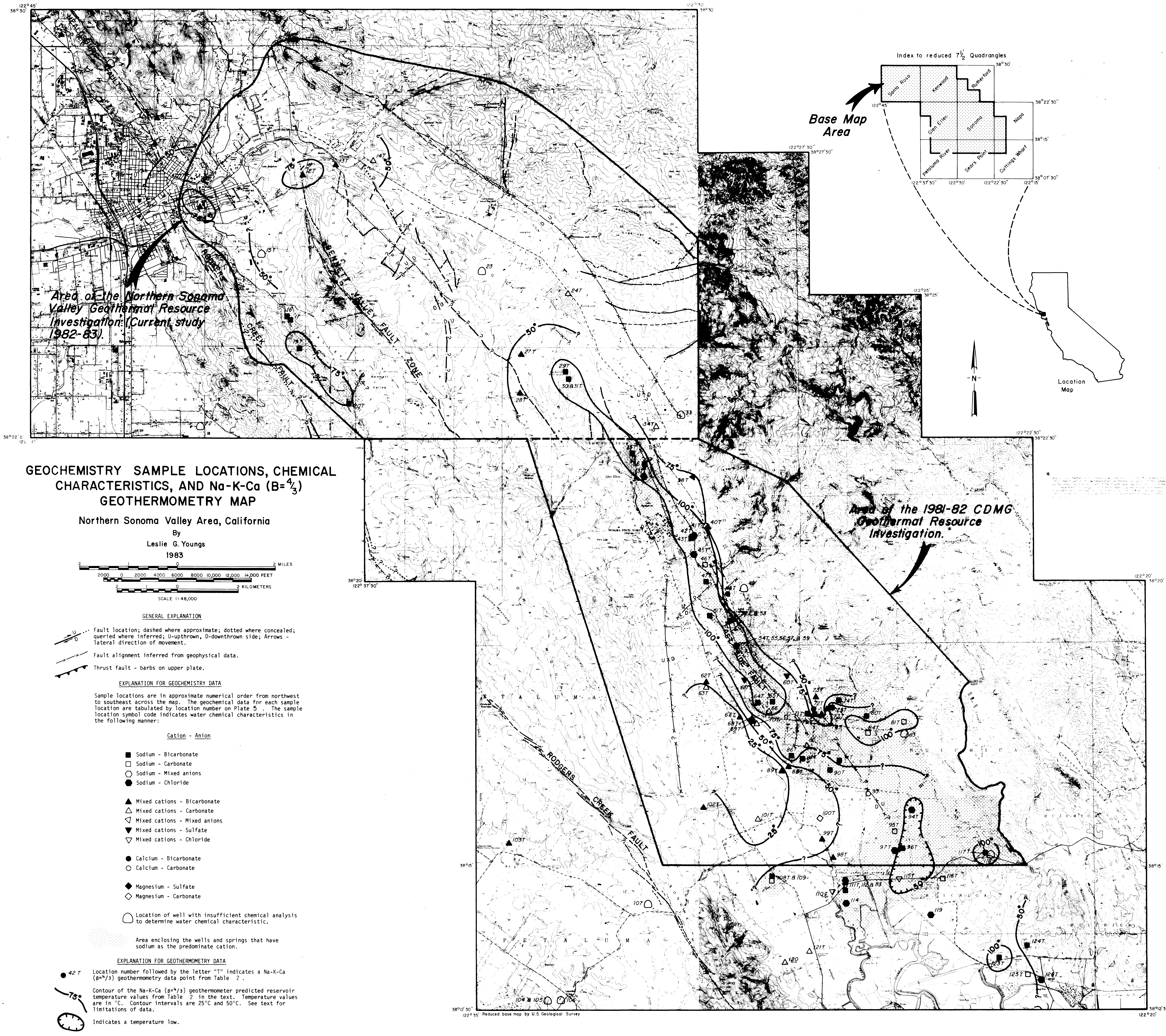
STATE OF CALIFORNIA - GEORGE DEUKMEJIAN, GOVERNOR
THE RESOURCES AGENCY - GORDON K. VAN VLECK, SECRETARY
DEPARTMENT OF CONSERVATION - M.G. MEFFERD, INTERIM DIRECTOR

NORTHERN SONOMA VALLEY
GEOTHERMAL INVESTIGATION
OFR 83-27 SAC PLATE 6



GEOCHEMISTRY SAMPLE LOCATIONS, CHEMICAL CHARACTERISTICS, AND Na-K-Ca ($B=4/3$) GEOTHERMOMETRY MAP

Northern Sonoma Valley Area, California

By

Leslie G. Youngs

1983

2 1 0 2 MILES
2000 0 2000 4000 6000 8000 10,000 12,000 14,000 FEET
2 1 0 2 KILOMETERS
SCALE 1:48,000

GENERAL EXPLANATION

Fault location; dashed where approximate; dotted where concealed; queried where inferred; U-upthrown, D-downthrown side; Arrows - lateral direction of movement.

Fault alignment inferred from geophysical data.

Thrust fault - barbs on upper plate.

EXPLANATION FOR GEOCHEMISTRY DATA

Sample locations are in approximate numerical order from northwest to southeast across the map. The geochemical data for each sample location are tabulated by location number on Plate 5 . The sample location symbol code indicates water chemical characteristics in the following manner:

Cation - Anion

■ Sodium - Bicarbonate
□ Sodium - Carbonate
⬡ Sodium - Mixed anions
⬢ Sodium - Chloride

▲ Mixed cations - Bicarbonate
△ Mixed cations - Carbonate
◁ Mixed cations - Mixed anions
▼ Mixed cations - Sulfate
▽ Mixed cations - Chloride

● Calcium - Bicarbonate
○ Calcium - Carbonate

◆ Magnesium - Sulfate
◇ Magnesium - Carbonate

Location of well with insufficient chemical analysis to determine water chemical characteristic.

Area enclosing the wells and springs that have sodium as the predominate cation.

EXPLANATION FOR GEOTHERMOMETRY DATA

● 42 T Location number followed by the letter "T" indicates a Na-K-Ca ($\beta={}^4/_3$) geothermometry data point from Table 2 .

75° Contour of the Na-K-Ca ($\beta={}^4/_3$) geothermometer predicted reservoir temperature values from Table 2 in the text. Temperature values are in °C. Contour intervals are 25°C and 50°C. See text for limitations of data.

Indicates a temperature low.

Reduced base map by U.S. Geological Survey