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SUSANVILLE GEOTHERMAL INVESTIGATIONS
CALIFORNIA

SPECIAL REPORT

June 1976

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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DISCLAIMER

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UNITED STATES
DEPARTMENT OF THE INTERIOR
Thomas S. Kleppe, Secretary

BUREAU OF RECLAMATION
G. G. Stamm, Commissioner

Mid-Pacific Region
Billy E. Martin, Regional Director

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Susanville Geothermal Investigations

INTRODUCTION

This report documents the investigations by the Bureau of Reclamation and others of the geothermal resource potential of the Susanville-Honey Lake Valley area, California, made during 1975 and the early part of 1976. Included are discussions on the nature of the resource and the analyses of the data gathered. Susanville is located in northeastern California about 210 miles (330 kilometers) northeast of San Francisco. (See plate 1.)

Purpose and Scope of Study

The purpose of the study was to appraise the geothermal resources in the Susanville-Honey Lake area within the constraints of limited funds and available personnel. The main thrust of the studies consisted of: gathering and analyzing existing data; conducting and evaluating an electrical resistivity survey and an aerial thermal infrared survey; and drilling and logging of temperature gradient holes. The heat flow or energy potential of the resource was not determined.

Study Area

The area selected for study was the north part of Honey Lake Valley from Susanville eastwardly to Amedee Hot Springs. Although the entire Honey Lake Valley was deemed prospectively valuable for geothermal resources by the U.S. Geological Survey, the area was much too large for even an appraisal-level study. An area in and immediately adjacent to Susanville has several warm-water wells, while boiling springs exist at Wendell and Amedee. In addition, the northern portion of the valley lies closer to the Cenozoic Basalts. Thus, the 30- by 10-mile (48- by 16-kilometer) study area was considered appropriate.

Background

At the request of the Secretary of the Interior, the Bureau of Reclamation programed a study to appraise the geothermal resources of the Susanville area in California. Secretarial approval of a $76,000 appraisal study came on September 26, 1974. The study was to determine the viability of the Susanville Geothermal Energy Project, then being proposed by private and local interests for Federal funding. The appraisal study was to investigate the uses and requirements of the resource as well as the magnitude of the resource itself.

Funding for the Susanville Geothermal Energy Project was informally approved in December 1975 by the National Science Foundation. In funding the $300,000 project through the city of Susanville, National Science Foundation stipulated that there be no duplication of effort between the Bureau appraisal study and the city's geothermal energy project. The Bureau was only to appraise the nature of the geothermal resource; the city would develop an economic model on the uses, requirements, and system analysis of the resource.

Introduction

The National Science Foundation requested there be a free flow of data and information between the Bureau and the city which was agreed to. Because of the complementary nature of the two studies, it was further agreed that the Bureau's appraisal report and the city's final report to the National Science Foundation would be published at about the same time. The geothermal program of the National Science Foundation was later shifted to the Energy Research and Development Administration (ERDA).

The city, through previous arrangements, contracted with VTN-CSL, a joint venture of VTN Consolidated, Inc., and CSL Associates, to conduct the project.

The Susanville Geothermal Energy Project (SGEP) is a study of the use of geothermal energy by a community for local economic development. The study, expected to be completed in July 1976, will define the economic model, specific energy systems, and a program plan for development of a demonstration geothermal utility system. In accordance with ERDA contractual guidelines, the study is based on the assumptions that there is a geothermal resource, that it will be adequate for intended uses, and that available technology will be used. Details of the project are presented in the Supplemental Technical Data, a separate volume.

Acknowledgments

During the course of the appraisal study, local citizens and governmental agencies were contacted to obtain basic information about the area.

Introduction

Information and assistance provided by the following agencies is gratefully acknowledged:

City of Susanville

County of Lassen

U.S. Geological Survey

Energy Research and Development Administration

Bureau of Land Management

California Department of Water Resources

California Division of Oil and Gas

Lawrence Berkeley Laboratories

Lassen Community College

Future Studies

Because of the interest shown in developing the area's geothermal resource for the explicit benefit of the community, Congress authorized the Bureau of Reclamation to engage in "A comprehensive resource analysis adequate to determine the feasibility of a geothermal energy utility system for the city of Susanville, California" (Public Law 94-156). This feasibility study was envisioned by Congress to be a $1 million 2-year study, with a series of test wells up to 5,000 feet (1,500 meters) deep. At the time this report was prepared, funds had not been appropriated for such a study.

SETTING

Physical

Susanville lies at the foot of the northeastern slope of the Sierra Nevada in the extreme western end of Honey Lake Valley. The city, which is the county seat of Lassen County, has about 7,000 of the county's 17,200 residents and is the county's only incorporated city. The Honey Lake Valley area, including the communities of Susanville, Johnstonville, Janesville, Standish, Litchfield, and Herlong, has 68.5 percent of the county's total population.

The area is served by the Southern Pacific Railroad and State Highways 36 and 139. U.S. Highway 395 approaches within 4 miles (8.1 km) of the city. A small municipal airport serves the area, but there is no scheduled airline service.

Honey Lake Basin varies in altitude from 4,000 feet (1,200 meters) at Honey Lake to 8,000 feet (2,400 meters) in the Sierras. The valley's position in the rain shadow of the Sierras creates a wide variation in temperature and climate. The temperature extremes vary from 100°F (38°C) to about -30°F (-34°C), with a mean annual temperature at Susanville about 50°F (10°C). Precipitation varies from about 4 inches (10 cm) per year at the eastern edge of the valley to about 30 inches (76 cm) in the Sierras. Susanville has a mean annual precipitation of about 15 inches (38 cm). The growing season is less than 4 months.

Setting

Economic

The city's Susanville Geothermal Energy Project and Reclamation's Susanville Geothermal Investigations are a direct attempt to alleviate the economic plight of the area. Economic conditions have led the city to request help in its endeavor to utilize the area's geothermal resources.

The city of Susanville and surrounding communities are in an economic bind. Few jobs are available and the younger generation migrates to larger cities. Unemployment reached 23 percent in May 1975. The economic plight results from the community's remoteness and severe winters. Utility and energy costs are high. Electrical power, transmitted by Pacific Gas and Electric Company over the mountains from the west, is purchased for resale and distribution by the California Pacific Utilities Company. Winter storms in the Sierras frequently interrupt service.

There is no natural gas service to the area. Heating is accomplished by use of electricity, liquid petroleum gas, fuel oil, or wood. With the exception of wood, all energy sources have to be brought in over long distances. Thus, costs are high.

Transportation to and from markets is long and costly. Although a railroad spur line serves Susanville, routes are circuitous. Shipments to and from the Central Valley and San Francisco markets are either by way of Klamath Falls, Oregon, to the north, or Winnemucca, Nevada, to the east. The railroad cars must then head back south or west, respectively. Industry is constrained by the resulting increased transportation costs and travel time.

Government employment accounts for 45 percent of the total work force. The main industries of the area are forest products, cattle production, livestock feed , and recreation.

Before the world's largest mill in Westwood, about 20 miles (32 kilometers) west of Susanville, was shut down in 1957, it was the biggest local industry. Two lumber mills presently operating near Susanville must compete with more modern lumber mills that are closer to markets.

Cattle production is the second largest industry in the area. However, the cold winters preclude the wintering of cattle in their natural environment. Any feed consumed by cattle during the winter months goes to keeping them alive and warm and not to added weight. Cattle feed is expensive because of the high energy costs associated with irrigation.

The community is at an economic disadvantage and needs a competitive edge to induce its few job-intensive industries to expand and to attract new ones. The residents are hoping to make use of their local geothermal resources to obtain this competitive edge.

NATURE OF THE RESOURCE

Heat sources and flow, hot water and vapor-dominated systems, and the characteristics favorable for geothermal reservoirs are briefly described in explaining the nature of the geothermal resources.

Heat Sources

Nature's most dramatic displays of natural steam are produced by volcanoes. Water coming into contact with molten lava (temperatures of 2000°F (1100°C) and higher) can only exist as steam. Rapid expansion of steam and other gases below the surface causes some of nature's most violent and explosive eruptions.

Almost all active volcanoes have fumaroles, or vents, that discharge steam and other hot gases. But, despite the large quantities of steam and energy that may be discharged, no means has yet been found to harness this energy.

More promising sources of controllable energy are found in areas of volcanism as subsurface or geothermal reservoirs. These reservoirs contain larger and more dependable volumes of steam or hot water.

Most of the known geothermal reservoirs contain hot water rather than steam. Water under the high pressures found at depth remains liquid at temperatures far above 212°F (100°C), the sea-level boiling point of water. When this water is tapped by wells and rises to the surface, the pressure falls. As the pressure decreases, the water boils, perhaps violently, and the resulting steam is separated from the remaining liquid water. The well itself acts as a continuously erupting geyser, because the expanding steam propels the liquid water to the surface.

Mineral exploration over the world has shown that in deep mines and oil wells temperatures usually rise with increasing depth below the surface. Natural radioactive decay of uranium, thorium, and potassium in rocks of the earth's crust and upper mantle is believed to be the fundamental cause of heat within the earth. The weight of evidence suggests that, contrary to the theory that present heat is residual heat from the earth's creation, a natural radioactivity, present in small amounts in all rocks, which has gradually heated the earth is still producing heat. Geophysical studies also indicate the earth's molten core, much smaller than was once supposed, is not in itself a source of the heat in the earth's crust. The reasons for the existence and specific location of the earth's volcanic belts are still subjects of vigorous scientific study and controversy.

Heat Flow

Throughout the world, temperatures in deep wells or mines increase, on the average, about 1°F for each 100 feet of depth (18.2°C/km). This is the normal geothermal temperature gradient. In some areas where the supply of heat is greater or the local rocks are better-than-average insulators in inhibiting the escape of heat, temperatures may increase at considerably higher rates.

Great differences in water temperature can occur as water seeps underground and circulates to vast depths. Such water, as it travels downward, is heated and may return to the surface to be discharged as a hot spring. If the heat supply is unusually great, as it may be in the vicinity of recent igneous activity, the water may become so hot that near the surface it erupts as a geyser. Near a hot spring system, temperature gradients may be several degrees for each foot of depth, but these high rates do not extend downward for great distances.

For the entire earth, the average flow of heat is very small, about 1-1/2 millionth (1.5×10^{-6}) calories per square centimeter per second, or 1.5 heat flow units (HFU). However, in localized hot spots, in the upper 10,000 feet (3,000 meters) of the earth's crust, the heat flow can reach up to 1,000 times the normal or average rate.

Geothermal Systems

A geothermal system includes a source of heat within the earth's crust and the rocks and water affected by that heat. When a geothermal system involves circulating waters, it is also called a hydrothermal system. The hot part of a hydrothermal system is commonly emphasized, but convective downflow of cold water is also essential. A hot spring area, which is the surface expression of a geothermal system, contains hot springs, fumaroles, and other hydrothermal phenomena.

Hot water systems. Hot water systems are usually found in permeable sedimentary or volcanic rocks and in competent rocks such as granite that maintain open channels along faults or fractures. Typical discharges of hot water range from several hundred to several thousand gallons per minute.

Where near-surface rocks are permeable and the surrounding water table is relatively low, much or all of the circulating hot water escapes below the ground surface, with little or no water discharged from local springs. However, where spring outlets are below the level of the surrounding water table, all hot water of the system is likely to be discharged in local visible springs.

The temperatures of many hot water systems increase with depth to a "base" or constant temperature, differing in each system. The inflowing water is heated to its base temperature by rock conduction, perhaps augmented slightly by magmatic steam. It then rises in the channel of the spring system, losing only a little heat because of its relatively high rate of upflow through wall rocks of low thermal conductivity. As the hot water rises, the hydrostatic pressure decreases, eventually reaching a level where the pressure is low enough for boiling to begin.

Vapor-dominated systems. The vapor-dominated or "dry steam" system is both less common and less understood than the hot water or "wet steam" system. A hot water system, because of the large heat supply and relatively low permeability of the system's reservoir, may become vapor dominated when the net discharge exceeds the net ground-water recharge. Steam then boils from the declining ground water. Although some steam will escape to the atmosphere, most will condense below the ground surface with its heat of vaporization conducted upward. This reservoir is actually a two-phase heat-transfer system. Vapor boiled from the water, or deep brine, flows upward while most liquid condensate flows down to the water table. However, some liquid might be swept out with the steam in channels of principal outflow. The liquid readily traverses small pores and channels because of its high surface tension. Steam, however, because of its lower surface tension, is largely excluded from smaller pores but predominates in the larger channels and discharges. Although less than 5 percent of all systems are vapor-dominated, the Larderello fields in Italy and The Geysers in California are of this type.

Characteristics Favorable for Geothermal Reservoirs

The most favorable geologic factors for a commercial geothermal reservoir include:

1. A large source of heat, such as a large chamber of molten magma. The chamber should be deep enough to insure adequate pressure and a slow rate of cooling, and yet not too deep for natural circulation of water and effective transfer of heat to the water.

Magma chambers of this type are most likely to occur in regions of recent silicic volcanism, such as the Rocky Mountain and Pacific States.

2. Large and porous reservoirs with channels connected to the heat source, in which water can circulate and be stored. Even in areas of slight precipitation, over many years enough water may percolate underground to sustain the reservoir.

3. Capping rocks or clayey sediments of low permeability that inhibit the flow of water and heat to the surface. In very favorable circumstances, this is not essential for a commercial field. However, a deep reservoir well insulated by cap rocks is likely to have much more stored energy than a shallow and uninsulated reservoir.

4. A source of water to recharge the system and to act as a convective medium to transfer the heat upward.

INVESTIGATIONS

The appraisal investigation made during 1975 and the early part of 1976 consisted primarily of gathering existing physical, geological, geophysical, and chemical data, analyzing these data, and generating new data. Numerous reports and papers, both on geothermal exploration and on the study area, were studied. Local citizens and governmental agencies were contacted to obtain basic information of the area. Some of the more pertinent existing data consisted of:

1. Drillers' well logs
2. Gravity map
3. Water quality analyses
4. Public landownership map
5. Electric logs of drill holes
6. Aerial photos (1:20,000)
7. Private geothermal well data (proprietary information)
8. California Department of Water Resources Bulletin 98 - Northeastern Counties Ground-water Investigations. Bulletin 98 contains the most comprehensive geohydrologic data available for Honey Lake Valley.

New data generated or funded by the Bureau consists of:

1. Aerial thermal infrared scanning by U.S. Forest Service.
2. Computed geochemical temperature indicators from existing water quality analysis.
3. Regional electrical resistivity survey.
4. Temperature gradients in selected existing wells.

5. Temperature gradients from project-drilled holes.

6. Reconnaissance study by the U.S. Geological Survey.

The Supplemental Technical Data for this report includes reproductions of geologic logs and resistivity plots. It also includes an administrative report from the U.S. Geological Survey on its analysis of existing data. This report, titled "Susanville-Honey Lake Geothermal Reconnaissance, Southern Lassen County, California," is the result of a contract with the Geological Survey to define and appraise the geothermal resource on the basis of data available during the late summer of 1975.

Regional Geology

The Susanville-Honey Lake area occupies a western embayment of the Great Basin physiographic province. To the north lies the Modoc Plateau, underlain by Tertiary and Quaternary volcanic rocks. To the southwest is the northern Sierra Nevada, in which the exposed rocks adjacent to the area of study are chiefly Mesozoic granitic rocks and overlying Tertiary volcanic rocks. Thermal springs are numerous in the region; they are associated with both volcanic rocks and faults.

The Tertiary Period was marked by widespread volcanism and the pouring out of enormous lava floods and ash flows. Minor volcanism continued into the Pleistocene. Volcanic rocks older than 10 million years have long since cooled to the temperatures of other rocks, but the younger volcanic rocks of latest Tertiary and Quaternary age might be associated with shallow crustal sources of heat. Some geothermal activity is associated with geologically recent volcanic or fault activity as tectonic forces generate the heat.

The Susanville-Honey Lake area is flanked by volcanic rocks (basalt) on the north and granitic rocks on the southwest. (See plate 2, Areal Geology.) The Skedaddle and Amedee Mountains, to the northeast, are the remains of a large eroded volcano that has been truncated by the Amedee fault. Shaffer Mountain, another volcano farther west, has not been greatly modified by faulting. North of Susanville the valley is flanked by a low basaltic plateau modified by block faulting. The upland west of Susanville, also underlain by volcanic rocks, is a transition zone between the Basin and Range province to the east and the Cascade Range to the west.

Earlier water resources investigations have shown gross areal relationships in the shallow ground-water flow system in the Susanville-Honey Lake area and vicinity. The shallow ground water flows into the Honey Lake Valley from the highlands to the north, west, and south, and then eastward toward Pyramid Lake. The shallow ground water in springs and wells in the basalt and in the unconsolidated deposits is typically cold.

The rocks exposed north of the Susanville-Honey Lake area are Plio-Pleistocene basalt. Study of stratigraphic sections in Honey Lake Valley suggests that these rocks may represent the deepest aquifer for extensive movement of ground water in the Honey Lake area. The basalt is estimated to be up to 4,000 feet (1,200 meters) thick; it interfingers with the generally poorly permeable lake deposits. Because of their expected low permeability, the lake deposits, possibly 5,000 feet (1,500 meters) thick, may act as a hydrologic barrier to the movement of ground water, causing upward movement of ground water in the area of faults inferred to cut the valley floor near Amedee and near Litchfield. Volcanic or granitic rocks of unknown hydrologic characteristics lie beneath the lakebeds.

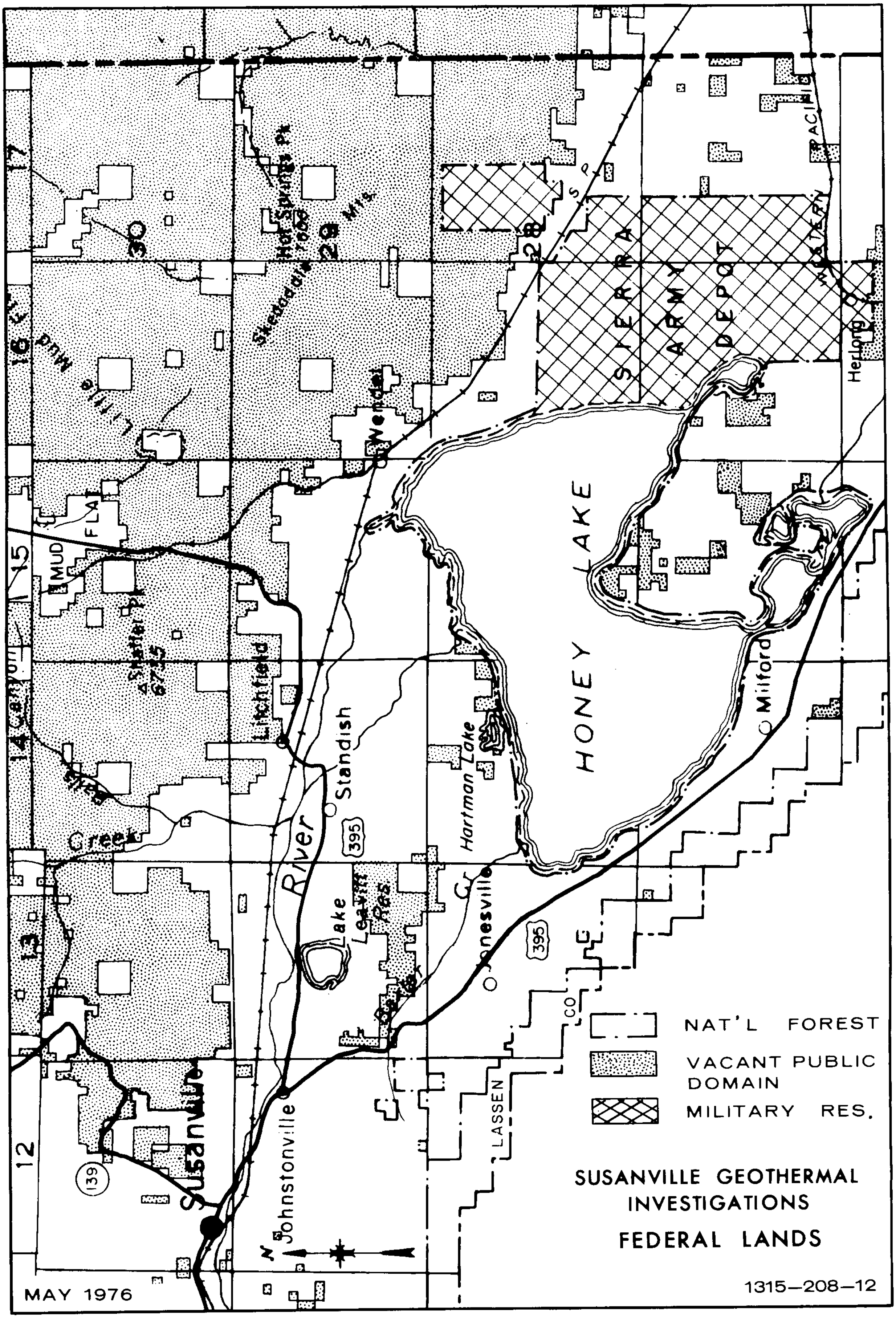
The pattern of ground-water movement in the Susanville-Honey Lake area is not known in sufficient detail to permit an accurate appraisal of the geothermal resource. Movement of near-surface cold ground water through aquifers could mask deeper thermal anomalies. Temperatures and temperature gradients in shallow holes might therefore fail to reveal the presence of thermal reservoirs beneath the zone of shallow ground-water flow.

The regional heat flow in the Susanville-Honey Lake area is not known. Measurements in the region to the south by the USGS suggest that the heat flow in the Susanville-Honey Lake area is about 2 HFU. Data may soon be available from a recently completed USGS heat flow test hole north of Susanville. The source of the heat in the thermal waters of the valley is also not known. Of potential interest to this study are the Plio-Pleistocene and Pleistocene basalts at the Wendel-Amedee area, the volcanic-granitic association at Susanville, and the series of north- and west-trending faults in the valley. The thermal areas appear to be structurally controlled by the faults, as is suggested by the occurrence of thermal waters at Susanville and at Amedee and Wendel Hot Springs. It is possible that the heat carried by the thermal waters is brought from considerable depth by deeply circulating water, or that it is derived from shallow heat sources such as volcanic vents that may be present beneath the basin fill of sediment. However, there are no known significant-sized bodies of silicic volcanic rocks younger than Plio-Pleistocene in the region. Therefore, chances are poor that there are good-sized silicic magma chambers still hot in the region.

Land Accessibility

Nearly all the land in the study area is under non-Federal ownership, as shown on figure 1. Some of the lands northeast of Wendel and Amedee, and at the higher elevations of Bald Mountain, are public resource lands administered by the Bureau of Land Management. Because most of the valley land is privately owned, the electrical resistivity survey was run along existing road rights-of-way after obtaining permission from the County Road Department. As several of the resistivity lines extended onto public domain land, a "Notice of Intent to Conduct Geothermal Resource Exploration Operations" was filed with the Bureau of Land Management (BLM). Although BLM normally requires at least 30 days to process a permit, approval for Reclamation's work, because the survey was already in progress, came in a few days.

FIGURE 1


HONEY LAKE
SIERRA ARMY DEPOT
Susanville
Johnstonville
Standish
Litchfield
Wendel
Jonesville
Milford
Herlong
Hartman Lake
Lake Leavitt Res
River
Shaffer Pk 6735
Hot Springs Pk 7000
Skedaddle Mts
MUD FLAT
Little Mud
LASSEN CO
NAT'L FOREST
VACANT PUBLIC DOMAIN
MILITARY RES.
SUSANVILLE GEOTHERMAL INVESTIGATIONS
FEDERAL LANDS
MAY 1976
1315–208–12

Some of the resistivity lines originally planned had to be moved onto private land because of buried wire fences or other interferences along the road right-of-way. In most cases, permission was received from the landowner. However, a few landowners objected, so some highly desirable lines could not be run.

Nearly all shallow temperature gradient holes were drilled on private land. Written permission to drill on these lands was obtained for the Bureau by the city of Susanville. Here again, some drill sites had to be changed slightly because the owners requested drilling be restricted to certain areas of their land. A few landowners volunteered or requested that holes be drilled on their land.

Some sites planned between Litchfield and Wendel were found to be on land leased by Gulf Oil Company or owned by VTN Consolidated, Inc., in partnership with others. To eliminate any possible conflict of interest, those sites were abandoned.

Environmental Concerns

No particular environmental problems were encountered. With the exception of the drilling operations, actual entry was made upon very little land and then no damage was done. Use permits required from Lassen County for the drilling operations were obtained by the city of Susanville. Before the use permits could be issued, negative environmental declarations were also required. The city wrote these declarations. For the three drill sites within the city limits, the city processed the required paperwork with no delay. Approval of the County Board of Supervisors was required for the eight drill sites outside the city limits. The county interpreted State regulations to require a 30-day public review of the negative environmental declarations for these sites. This review process delayed the drilling program for 2 months, into adverse weather conditions, which slowed down drilling operations.

REMOTE SENSING IMAGERY

To locate features which may be associated with geothermal anomalies, the Remote Sensing and Engineering Physics Section of the Bureau's Engineering and Research Center analyzed high-altitude color infrared photography and thermal infrared scanner imagery of the study area. Plate 3 shows those features found.

The remote sensing investigation involved mapping of linear geologic features and thermal anomalies which may be related to geothermal resources.

Mapping of Linear Features

Substantial evidence suggests near-surface geothermal reservoirs are associated with complex faulting in the area. Therefore, to detect and map any linear features which might be associated with the faulting, a series of high-altitude 1:120,000 scale overlapping photographs of the entire area were studied. Equipment used in this study included a stereoscope and a film density slicer equipped with an edge-enhancement feature.

Linear features detected on each photo were traced onto an overlay. A stereo comparison of photos and their overlays was made to assist in transferring the linears to a 1:62,500 scale map. Many of the linears are associated with faults and can be followed through the mountain ranges surrounding Honey Lake Valley. However, because of extensive cultural disturbance of the land surface, for the most part these linears cannot be followed down into the valley.

Those linears shown extending through the valley are highly subjective and may or may not follow the paths indicated.

Thermal Anomalies

Thermal infrared scanner imagery of the study area was obtained during April 1975 through a contract with the U.S. Forest Service. The scanner was a Texas Instruments modified military RS-7 with 200 lines per second, mounted in a Beechcraft King Air (B-90). The scanner produces 5-inch-wide (127-centimeter) continuous strip negatives. Two detectors, utilizing the 3-5 micrometer band and the 8-14 micrometer band, were run simultaneously. Because of the high mountain peaks surrounding the valley, 7 of the 11 predawn flight lines run were flown at an elevation of 5,000 feet (1,500 meters) above the valley floor. The other four lines were flown at 3,000 feet (900 meters) when the first morning light made it safe.

It was intended that isothermal contours of the study area would be plotted on the film imagery using a vidicon scanning film densitometer (density slicer). This information was then to have been correlated with ground temperatures obtained at the same time to provide more exact information on observed relative temperatures. Unfortunately, the imagery contained severe streaking throughout because of nonuniform processing of the imagery by the aircraft's onboard film processor. Also, frequently made gain changes in the scanner system resulted in abrupt changes in film density. These factors made it impossible to use the density slicer for detailed processing of the imagery.

It was necessary, therefore, to make a visual interpretation of the imagery and locate qualitatively any areas which appeared to be warmer than the surrounding areas. When temperature anomalies became suspect, corresponding color infrared photographs of the anomalous area were also studied to determine the significance. The thermal scanner imagery, because of certain inherent geometric distortions, was not used for mapping of the anomalous areas. Instead, the anomalous areas were located on the color infrared photography and transferred to the map overlay with a zoom-transfer scope. The significance of these anomalous areas (see plate 3) is discussed below.

Area A. Along the extension of an apparent fault approximately halfway between Susanville and Lake Leavitt. The area, heavily devoted to agriculture, lies in the flood plain of the Susan River. The appearance of the imagery suggests that a thermal anomaly other than that due to high soil moisture may be present.

Area B. North of Lake Leavitt near the Conservation Center and surrounding area. The area has some agriculture, the conservation center, and housing development. The appearance in the imagery suggests that it is very likely a true thermal anomaly, although an alternative explanation would be a high water table.

Area C. West of Lake Leavitt. The area has extensive agriculture and a considerable amount of lowland drainage along a small creek flowing into the Susan River. The apparent high temperature in the thermal infrared imagery is probably due to very wet soils and high water table; this area does not appear to be a good geothermal site.

Area D. Directly north of Lake Leavitt along the Susan River. The area is part of the flood plain of the Susan River and probably has a higher apparent temperature due to high soil moisture content.

It is not considered to be a good prospect for geothermal investigation.

Area E. Immediately east of Lake Leavitt and extending eastward. As it passes Bald Mountain, the area also broadens out toward Honey Lake and extends eastward throughout Honey Lake Valley. Only a portion of the area is shown on plate 3. A trend observed in the thermal infrared imagery indicates that the temperature gradually increases eastward through the valley. However, most of this area is lowland drainage and flood plain and may not offer much geothermal potential.

Area F. A possible hot spring in Lake Leavitt near the eastern shore. Figure 2 is a black and white reproduction of a color density slicer image from the thermal infrared imagery. It gives indication of the temperature differences.

Note that the top or northernmost hotspot on the right side corresponds with a film processing streak and is probably not a true hotspot. The southern hotspot could be a hot spring under the surface. The prevailing winds have apparently piled up the warmer water on the eastern shore, and it has been so mapped. However, during late summer of 1975 when the lake was nearly empty, the entire east side of the lakebed was explored and no discernible temperature differences or springs could be found.

Area G. Three small dry lakebeds northeast of Lake Leavitt. The observed higher temperature is probably due to increased soil emissivity or high soil moisture content. This does not appear to be a good geothermal prospect.

Area H. Southeast of Bald Mountain. Some agriculture is located in the area and a large area which could be the flood plain of a small creek. This area appears to be quite swampy. The small circular area mapped at the northeast end of area H is in the center of an uncultivated 1/4-section agricultural field. It appears as a large circular swirl, interpreted to be a salt incrustation due to excessive irrigation of a field with poor drainage. However, because of certain indications in the thermal imagery, further investigation of this area as a secondary geothermal site may be warranted.

Area J. The northwest corner of Honey Lake. It is extensively devoted to agriculture and appears to be a large flood plain from a small creek flowing into the lake at this point. Geothermal potential is uncertain.

FIGURE 2

SUSANVILLE GEOTHERMAL INVESTIGATIONS
ISOTHERMAL CONTOURS IN LAKE LEAVITT

Area K. West end of the waterfowl management area northwest of Hartson Lake. It consists of several areas of swamp and standing water. There may be several warm-water springs in the area.

Area L. Just north of Honey Lake in the center of the waterfowl management area. There is some agriculture and extensive lowland drainage areas that appear to be swamp. Higher apparent temperature is probably due to high soil moisture and geothermal potential is doubtful.

Area M. The northeast part of Honey Lake Valley, north of Wendel Hot Springs. The area seems to be slightly warmer than its surroundings and there is a slight indication that it becomes progressively warmer south into the Known Geothermal Resource Area (KGRA).

Area N. Northwest to southeast along the northeast corner of Honey Lake, generally corresponding to the KGRA. In the thermal imagery a number of hot springs can be detected and have been indicated on the map. Also, there are a large number of small areas mapped as fine structure along the eastern border of the area which appear to be considerably warmer than their surroundings. These same areas in the photography appear to be relatively bare of vegetation and appear white, which may indicate the presence of large quantities of salt. There is a definite hotspot just north of the highway inside the northeast corner of section 14 of R. 15 E., T. 29 N. In the photographs a vigorous growth of vegetation can be observed at this point but there is no apparent standing water. Field examination indicated that this is probably a small manmade sump for stock water.

Area O. One main area over the Amedee Hot Springs and two smaller areas which appear to be in a small gulch running northeast from the main area. At one time there may have been a hot spring at the upper end of this area.

Area P. North and south along the eastern shore of Honey Lake. There appears to be nothing significant about the area in the photography, but it definitely appears warmer in the thermal imagery. The relative geothermal potential of this area is uncertain.

Area Q. Three small areas east of Honey Lake which are somewhat warmer than the nearby surroundings. The northernmost area appears to be a natural drainage ditch which is relatively bare of vegetation and appears white in the color infrared photographs. There may be substantial salt deposits in the soil at this location. The two southern areas appear to be low spots in a field where surface runoff tends to pond and are probably wet spots in the field. The western portion of these areas contains a small hot ring with a cool center. Photographs reveal that this is probably a small circular pond with a small tree or other vegetation growing in the center. The two southern areas probably do not represent geothermal potential but the northern area may warrant further investigation.

The entire waterfowl management area is virtually covered with large areas of swamp and standing water. If there is any significant geothermal potential in this area, it is not apparent with the available imagery.

Because of the low gain settings on the thermal scanner, all of the imagery over Susanville and vicinity is washed out and no significant thermal patterns in the land surface could be distinguished. However, because of this washed-out appearance, a small stream is visible northwest of Susanville. This stream appeared to be substantially warmer than the surrounding area, but presence of a hot spring could not be determined from the imagery. A field inspection of the stream found no discernible temperature differences.

TEMPERATURE INDICATORS FROM WATER QUALITY ANALYSES

Geothermal systems or heat sources that are relatively close to the surface of the earth are related to the circulation of meteoric water through faults, fissures, and various passageways in the ground. Temperature and chemical characteristics of water from wells and springs give an indication of location and relative heat of geothermal systems.

Data on over 232 water quality analyses from wells and springs were gathered in the Honey Lake Basin. Most of these analyses are from wells that were sampled by the California Department of Water Resources during the last 18 years. Most of these analyses include the normal cation and anion distribution, and the water temperature and electrical conductivity. See table 1 for sample water quality analyses.

Water Temperature

The average water temperature of wells less than 100 feet (30 meters) deep was 57°F (14°C). Using this temperature as a base or nominal ambient temperature, a plot was made of all wells that were greater than 5°F (3°C) above the ambient temperature or above 62°F (17°C). The location and temperatures of these wells are shown on plate 4. There is a definite correlation between these temperatures, the resistivity anomalies, and the major faults systems. At many places these temperatures have probably been appreciably lowered by the admixture of shallow cold water with deeper thermal water, as well as by upward conductive heat loss.

Table 1. Quality of water from selected wells and springs in Susanville-Honey Lake area (from California Division of Oil and Gas)

Sample number	Location	Name	Date sampled (mo/dy/yr)	Producing depth (m)	Altitude (m)	Water temp. (°C)	pH	Conductivity (micromhos/cm)	Discharge (l min)
1	NE/NE Sec. 6, T. 29 N., R. 12 E., M.D.	Roosevelt Swimming Pool	7/18/73	90(?)	1295	35.8	8.01	254	Pumped
2	SE/NE Sec. 6, T. 29 N., R. 12 E., M.D.	Latter Day Saints Church	7/18/73	169-181	1268	48.8	7.87	1,070	800 Pumped
3	SW/SE Sec. 23, T. 29 N., R. 15 E., M.D.	Wendel Hot Springs	7/17/73	spring	1231	95.6	8.38	3,340	1,200
4	NE/SW Sec. 30, T. 29 N., R. 16 E., M.D.	Southern Pacific Railroad	7/17/73	93	1223	28.2	8.33	332	300 Pumped
5	NW/NE Sec. 8, T. 28 N., R. 16 E., M.D.	Amedee Hot Springs	7/17/73	spring	1219	95.1	8.43	2,860	500

Chemical Constituents (in mg/l)

Sample number	Cations									Anions			Others		Calculated dissolved solids
	Li	Na	K	Rb	Mg	Ca	Zn	F	Cl	HCO_3	CO_3	SO_4	SiO_2	B	
1	<0.01	20	3.8	<0.01	3.4	19	0.043	<0.1	2.0	120	1	11	53	<0.02	233
2	0.05	140	4.6	0.02	1.6	24	0.009	1.2	64	68	1	190	62	1.4	558
3	0.12	280	7.5	0.04	<0.1	18	0.015	4.1	190	50	1	360	120	5.5	1,040
4	0.01	58	8.0	0.01	2.2	6.0	<0.005	0.2	17	112	1	32	42	0.22	279
5	0.08	250	5.5	0.02	<0.1	14	<0.005	4.4	160	44	2	300	95	4.0	879

Trace constituents below detection:

Cs <0.1, Mn <0.01, FE <0.06, Cd <0.01, Co <0.05, Cu <0.02, Ni <0.04, Pb <0.1

Temperature Indicators from Water Quality Analyses

Electrical Conductivity

Electrical conductivity of water samples is an indication of the amount of salts in solution, which in turn is a rough indication of heat at depth. A plot of about 123 wells and conductivities is shown on plate 5. The average electrical conductivity is 509 µmhos/cm. Conductivities above this average again correlate roughly with the resistivity anomalies.

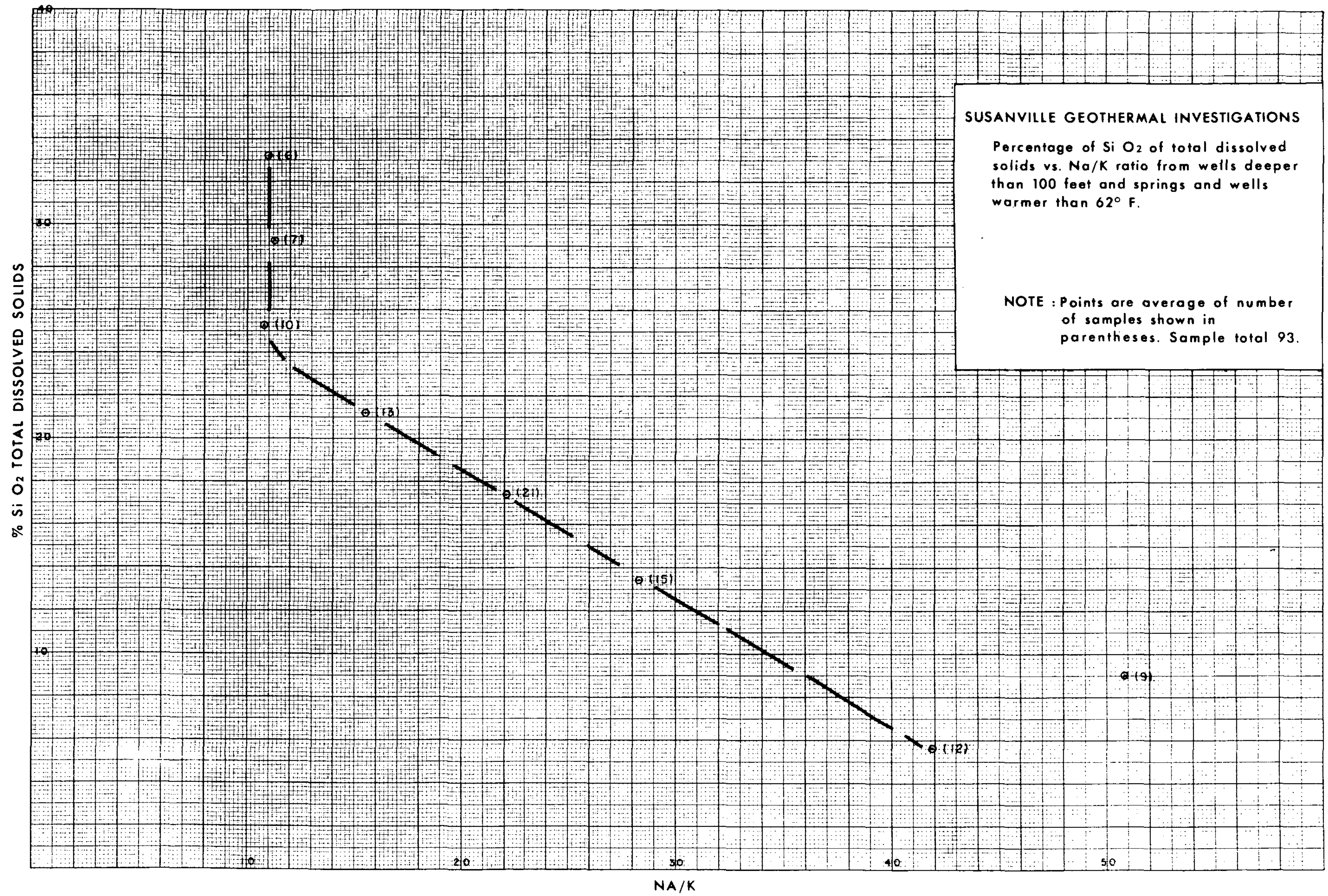
Inferred Temperatures

The minimum temperature of a geothermal reservoir can be estimated by analyzing the various chemical constituents in a given sample of water. Correlation of chemical analysis of thermal waters with temperature at depth is based on the assumption that chemical equilibria, being temperature dependent, might retain its equilibria configuration as the water makes its way along faults and fissures from the geothermal reservoir to the surface. Naturally, if any of the chemical constituents are precipitated from solution, or cold water mixes with the geothermal water, the indicated temperatures could be entirely different.

A total of 232 chemical analyses were computed for temperatures, given various relationships of quartz (both conductive and adiabatic), amorphous silica, chalcedony, cristobalite, sodium potassium ratio (Na/K), and sodium, potassium, and calcium. The computations were made using existing data not specifically collected for geothermal analysis. Also, it is likely that most of the water, especially that from wells, may not have been part of a geothermal reservoir. Thus, interpretation of results must be qualified with this in mind. Of the 232 analyses, only 184 samples had data for computing both quartz and Na/K temperatures. The resulting temperatures were compared to see how closely they agreed with each other and with the resistivity data. The quartz estimated temperatures are believed to be more nearly representative of the reservoir temperature than the others. This is explained by the widespread occurrence of basalt, whose mineral concentration does not favor equilibrium dissolution of Na, K, and Ca.

In order to determine if a relationship exists between silica and Na/K ratio, the percent silica of the total dissolved solids was plotted against Na/K ratios. Averages of the individual Na/K ratios over equal intervals (i.e., 7.6 - 11.5, 11.6 - 15.5, etc.) were used to reduce the total number of plotted points. Samples used were limited to those from wells deeper than 100 feet and from springs or wells warmer than 62°F (17°C). As figure 3 shows, a general relationship exists, which supports other published curves where an inverse relationship exists between silica and Na/K ratios at a given temperature (i.e., high silica content and low Na/K ratios indicate high temperatures).

A total of about 123 computed temperatures from the quartz (conductive) analysis were plotted and are shown on plate 6. The average temperature plotted was 208°F (98°C) with about 60 percent



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PERCENTAGE SiO_2 vs. Na/K RATIO

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of those plotted greater than 212°F (100°C). The highest temperature was at Amedee Hot Springs with 279°F (137°C), and the lowest to the south of Susanville at 127°F (53°C). These plotted temperatures indicate a reasonable correlation with the resistivity anomalies. In addition, some of the high values seem to line up along the Antelope Mountain Fault down to and west of Lake Leavitt. The generally consistent temperatures throughout the basin would indicate that the major part of the region is underlain by a low temperature geothermal reservoir. However, it must be stressed that all inferred temperatures are highly speculative.

ELECTRICAL RESISTIVITY SURVEY

In most geothermal areas observations show that electrical conductivity increases (resistivity decreases) with temperature in the reservoir. This is mainly due to the increase of dissolved minerals or salinity in the ground water which acts as an electrolyte. By passing a current through electrodes in the ground and measuring the resulting voltages on separate electrodes, the apparent resistivity of various areas can be determined. Caution is required in interpretation of data because some areas, where clay and shale predominate, naturally have lower apparent resistivity. Therefore, the thermal effects of heat may be masked by electrically conductive sediments.

A broad regional coverage was made of the north Honey Lake Valley area from Susanville to Amedee Hot Springs, using in-house capabilities. Because shallow hot-water reservoirs are known to exist in this area, a portable battery-powered resistivity set was considered adequate. A McPhar R20 1/2/3, capable of providing 450 volts and 220 milliamperes of current was used. A smaller portable Bison 2350 was used to obtain representative resistivity values over outcrops of basalt, andesite, and granite. Rocks of these types make up the basement throughout most of the basin.

Wenner array soundings were used with a maximum spacing of 2,000 feet (600 meters) between potential electrodes or 6,000 feet (1,800 meters) total length wherever feasible. In most cases, 19 spacings per sounding were made. A total of 81 soundings were originally planned, mainly along county road right-of-way to avoid entry on private land. In some cases the proposed sounding lines had to be moved off the road right-of-way and onto private land. In a few cases, access was not granted. Therefore, some highly desirable lines could not be run. Because buried wire fences, canals, standing water, and other obstacles found in the field eliminated other lines, 52 sounding lines were actually run. Plate 7 shows the location of the 52 lines. The circle indicates the center of the soundings and the short line shows the direction and length of the maximum distance between the current or outer electrodes. This distance was generally 6,000 feet (1,800 meters).

Analysis

Most of the resistivity soundings were grouped for display in cross-sectional form as shown on plate 7. The cross sections are shown on figure 4. This procedure facilitates the correlation of patterns. These represent the field data plots (apparent resistivity vs. spacing) reduced in size. The actual plots of apparent resistivity vs. spacing for each sounding are included in the Supplemental Technical Data. On these plots apparent resistivity increases from left to right, spacing from top to bottom.

The next step in the data analysis deviated from the usual practice of contouring apparent resistivities at the same spacing. Spacing corresponds to depth penetration only in a general way, and

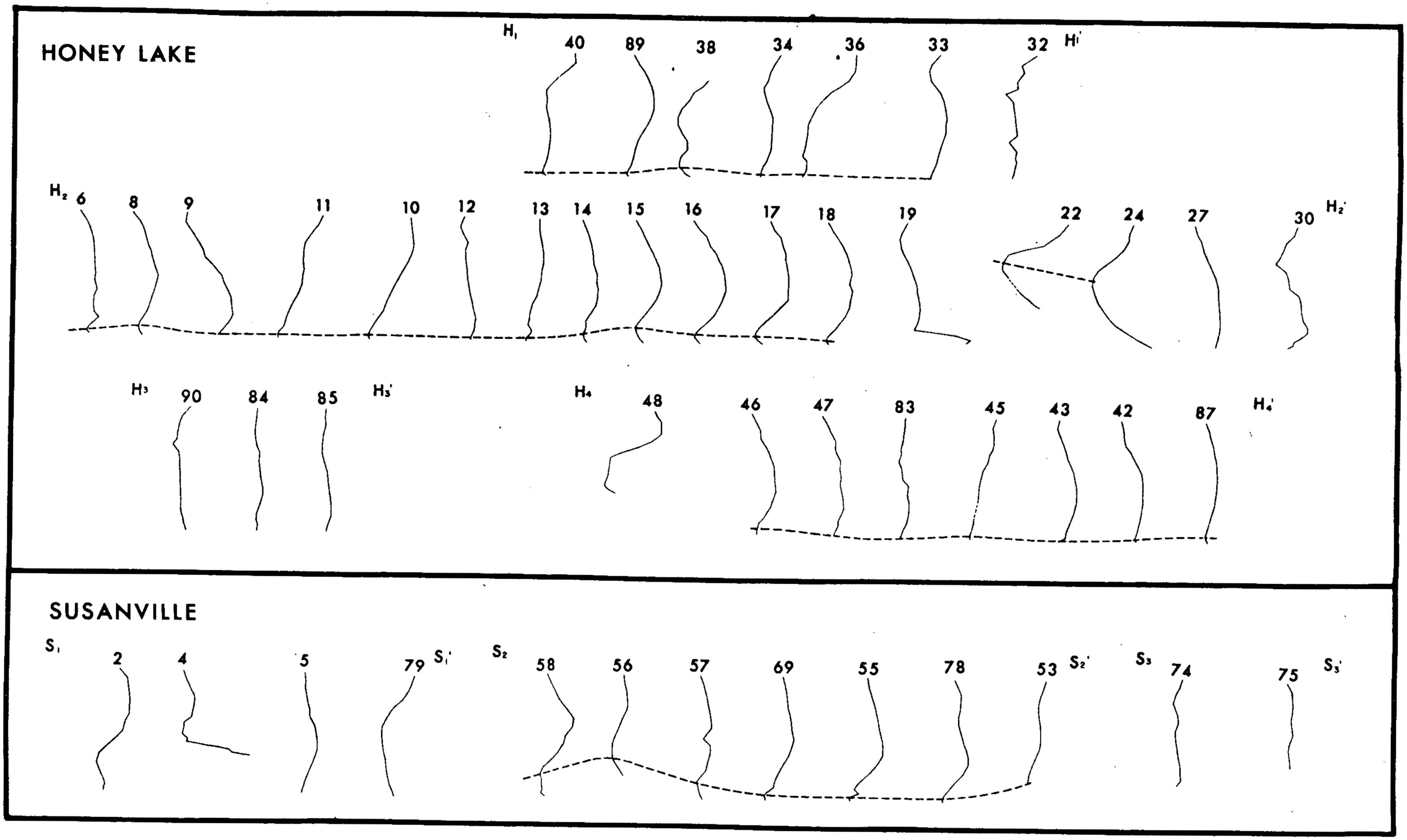

FIGURE 4

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SUSANVILLE GEOTHERMAL INVESTIGATIONS
CROSS SECTIONS OF RESISTIVITY SOUNDINGS

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despite its convenience, it is not very practical in a regional survey of this kind. Several maps might have to be constructed to outline anomalies. Recontouring could be readily accomplished, if needed, from the field data plots in the Supplemental Technical Data. The contouring done was on an "event of interest" correlatable on the cross-sectional display of the soundings. The event that was chosen for contouring is shown on figure 4 by the dashed line.

Apparent resistivities given in ohm-feet (1 ohm-foot = 0.305 ohm-meters) corresponding to the above event were contoured on plate 8. Areas of apparent resistivity lows indicate possible thermal anomalies. As a result of the contouring, five anomalies were defined, i.e., Susanville, Litchfield, Wendel, Amedee, and Bald Mountain. Except for Amedee, none of these anomalies have exceptionally low resistivity. Near Wendel, 147°F (64°C) water was produced from a 620-foot (186-meter) well.

The bulk or true resistivity can be estimated by use of Archie's Law, which states:

$$\rho_t = \rho_w \phi^{-k}$$

where: ρ_t = bulk resistivity

ρ_w = water resistivity

ϕ = porosity

k = cementation exponent

Electrical Resistivity Survey

Conductivities obtained at Wendel Hot Springs and extrapolated to the given surface temperature result in a water resistivity ρ_w = 9.84 ohm-feet (3.00 ohm-meters). Unpublished geologic cross sections for the area show a relatively uniform section of unconsolidated sand with some clay or silt.

The cementation exponent "k" may then be taken as 1.3 for unconsolidated sand or silt. For a porosity of 30 to 35 percent, a bulk (true) resistivity of 47.1 - 38.5 ohm-feet (14.4 - 11.7 ohm-meters), respectively, is obtained. The sounding nearest to this area that has been computer curve-matched is line 15. The apparent resistivity low on this sounding is 22.1 ohm-feet (6.7 ohm-meters) at a spacing of 1,000 feet (300 meters). Computer curve-matching to obtain the true resistivity of this particular layer results in a resistivity of 15 ohm-feet (4.6 ohm-meters). Clay content lowers the resistivity; in addition, there will be some mixing of fresh (low conductivity) ground water with the more highly conductive thermal waters. Nevertheless, the resistivities that are encountered are sufficiently low to indicate thermal anomalies. As shallow thermal waters are known to exist at the corresponding depth, the low resistivities can be utilized to designate other anomalous areas in the Honey Lake Valley with similar conditions. The Litchfield and Bald Mountain anomalies can be classified as possible thermal reservoir areas because geologic conditions are similar to those of the Wendel anomaly.

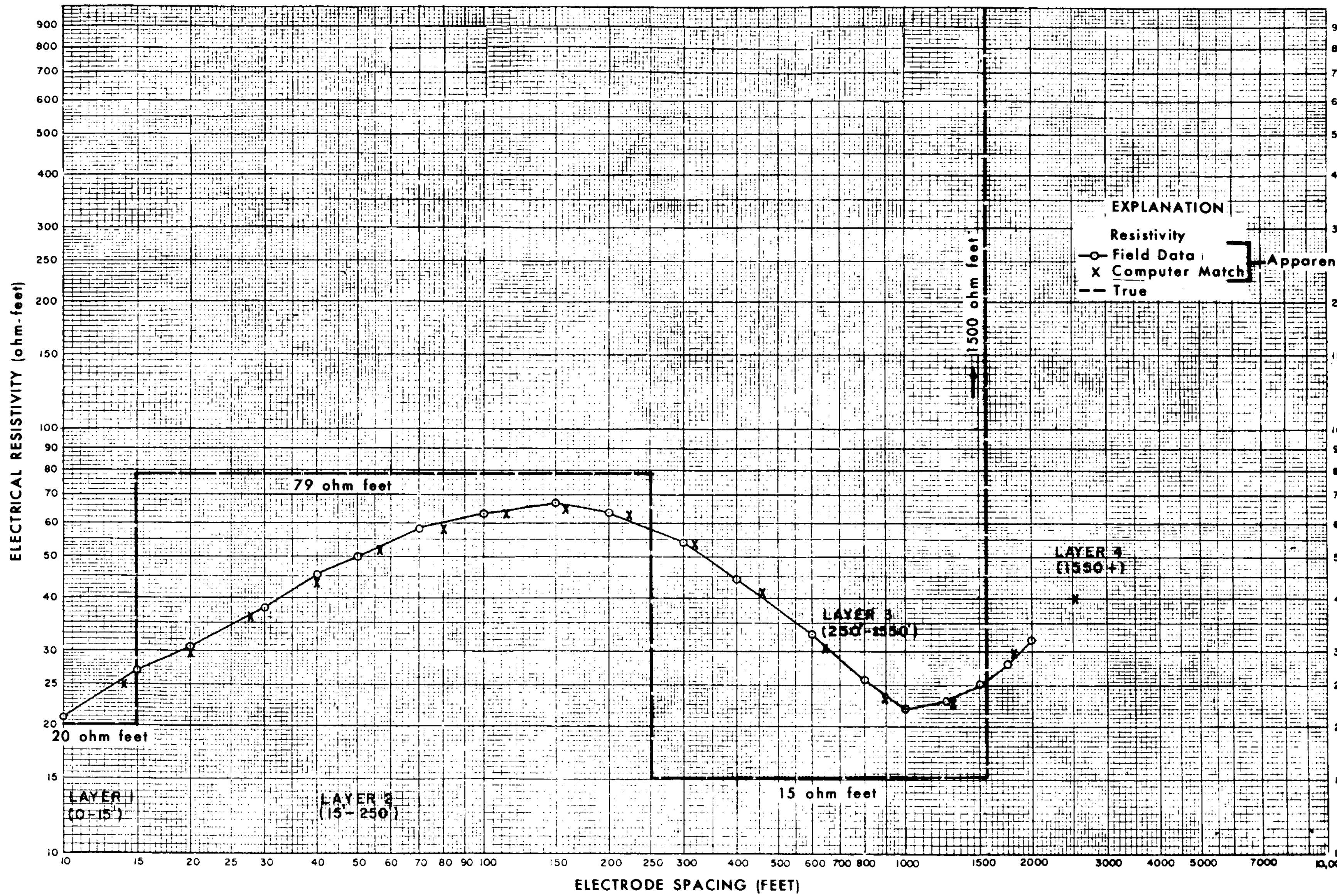
Electrical Resistivity Survey

The California Department of Water Resources geology map (plate 2) agrees quite well with lineaments shown on NASA color IR imagery and those found on the thermal IR imagery flown by the Forest Service for the Bureau of Reclamation (plate 3). Superimposing the major faults on the resistivity contour map, it becomes evident that the resistivity anomalies are alined with these major faults.

The Honey Lake Basin conforms to the classical model of a major graben with thermal liquids upwelling along the faults and spreading into the adjacent sediments. The resistivity data support the general fault locations on a number of soundings (for examples, see lines 32, 19, 4, and 6 on figure 4). A more precise location of the faults, possibly from the resistivity data, was not attempted or deemed necessary.

Computer Curve-Matching

In order to obtain estimates of depth and true resistivity, soundings in selected areas were submitted by the Geotechnology Section of the E&R Center to a curve-matching computer program. This program iteratively adjusts true resistivities in conjunction with a given distribution of layer thicknesses, computes a model curve, and compares this curve to the field data (see figure 5). After obtaining a best fit, further improvement is obtained by adjusting the boundaries of the given layers or the number of layers itself. The program makes the assumption of homogeneous, isotropic horizontal layers above a semi-infinite half space.



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TRUE RESISTIVITY FROM COMPUTER CURVE MATCHING LINE 15

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FIGURE 5

Electrical Resistivity Survey

After initially submitting all soundings to this program, it was decided that due to a changeover in computer systems, and manpower, time, and cost limitations, only a few representative resistivity soundings should be treated in more detail. Only one (line 15, figure 5) is discussed in this report. Data on formation resistivities or geoelectric boundaries from well logs were totally lacking in this area. The results of this curve-matching are elaborated on in the discussion of the individual anomalies.

TEMPERATURE GRADIENTS

A total of 16 temperature profiles were obtained from existing wells and new test holes drilled by the Bureau. Temperature readings were taken with the Region's Enviro-Lab Model DT-101 digital thermometer. A few wells in the south part of Susanville were known to yield warm water. Five of these wells were measured early in the investigation. The other 11 temperature profiles are from test wells sited and drilled on the basis of information gained from the electrical resistivity survey. Plates 9 and 10 show the location of wells and holes used for temperature measurements.

The encouraging results of the electrical resistivity survey led to the determination that the best use of remaining funds would be to drill shallow temperature gradient holes. The Susanville, Litchfield, and Bald Mountain anomalies were chosen. The Wendel and Amedee anomalies were excluded because most of the lands in the area have been leased by Gulf Oil Company or owned by VTN and considerable geophysical exploration had already been completed.

The remaining funds available would cover about 4 weeks of drilling. Sixteen holes 150 feet (45 meters) deep were proposed only for the purpose of obtaining temperature profiles. If the holes were designed and tested for other purposes, fewer holes could be drilled. The city of Susanville contacted landowners for permission to drill on their land. The city has been very cooperative in all aspects of the Bureau study, and has given the Bureau invaluable information and assistance.

Temperature Gradients

All necessary permits were obtained by the city, including negative environmental declarations from the county. Drilling commenced in November 1975. Because of cold weather problems, equipment breakdown, and hard drilling encountered near Susanville, the original 4-week schedule was extended to 6 weeks and yet only 11 of the planned 16 holes were drilled. Five holes were located on the Susanville anomaly, five on the Litchfield anomaly, and one on the Bald Mountain anomaly.

The holes were drilled with the Bureau's Failing 1500 drill rig using a 4½-inch (11.5-cm) rock bit and bentonite drilling mud. A geologic log of each hole, based on the cuttings, was made by Bureau geologists. (These geologic logs are included in the Supplemental Technical Data.) No abnormal mud temperatures were noted while drilling. The holes were cased with sealed 1¼-inch (3.2-cm) water-filled PVC pipes, backfilled with cuttings, and protected with steel guardrail and 4x4-inch (10x10-cm) location posts. Approximately 4-6 weeks elapsed between drilling and temperature measurements. This period was necessary to allow the water in the pipes to come to an equilibrium temperature with the surrounding formations.

Approximately 2 months after the Bureau obtained temperature profiles the Geological Survey ran additional temperature logs as well as gamma logs on these holes. Although the results of the gamma logs are not yet known, the temperature profiles agree markedly well with the Bureau data.

RESULTS OF THE INVESTIGATION

Results of the appraisal studies for Wendel, Amedee, Susanville, Litchfield, and Bald Mountain anomalies are summarized in this part.

Wendel

The Wendel anomaly straddles the Litchfield Fault and probably represents the largest anomaly. Apparent resistivity values are as low as 13 ohm-feet (3.9 ohm-meters). Most of this area is included in the Wendel-Amedee KGRA (known geothermal resource area). The most prominent surface expressions are the Wendel Hot Springs. At the surface, water temperatures reach 204°F (96°C) (boiling for this elevation). Associated with this area are a number of wells with anomalous water temperatures (see plate 4). They are:

Well No.	Temperature °F	Temperature °C	Depth feet	Depth meters
143	64	18	115	35
164	75	24	865	266
163	80	27	Artesian	
167	88	31	Hot spring	
175	62	17	90	27
176	83	28	190	57

Some anomalously high well-water conductivities and high silica temperatures are also found in this area. A series of tufa mounds, located about a mile north of Wendel, are trending northeast and appear to correlate with another major fault, the Skedaddle Fault, crossing this anomaly. These mounds have been observed to discharge steam. An expression of these highly resistive series of mounds is seen on line 38 (see plate 8 and figure 4). Here the tufa deposits are at some depth below the surface. A thermal exploration well drilled near Wendel by Magma Power Company produced 147°F (64°C) water at 620-foot (186-meter) depth. Resistivity line 15, located approximately 1.6 miles (2.6 kilometers) to the northwest of Wendel Hot Springs, was computer curve-matched. A four-layer model gives an excellent fit to the field data (see figure 5). Layer thicknesses and resistivities are:

Layer	Thickness (feet)	Thickness (meters)	Resistivity (ohm-feet)	Resistivity (ohm-meters)
1	15	5	20	6
2	235	77	79	24
3	1,300	390	15	5
4	-	-	1,550	465

Based on these data, the resistivity basement would be in the neighborhood of 1,500 feet (450 meters) deep. Anistropy would, of course, introduce an error into this estimate. Using 1.1 throughout for a coefficient of anisotropy for this type of lithology would reduce total sedimentary thickness by about 150 feet (45 meters). Resistivities of 1,500 ohm-feet (450 ohm-meters) were found in a resistivity sounding over an outcrop of andesite at the edge of the basin. The field data showed a least possible conductance of 87 mhos/foot (290 mhos/meter). Curve-matching gives a total conductance of about 89 mhos/foot (297 mhos/meter).

Unpublished geologic cross sections show a well to the northeast of the Litchfield Fault where, at about 225-foot (67-meter) depth, a questionable break was picked between the Lahontan Lake deposits and possibly the pre-Lahontan Lake deposits. This raises the possibility that the 1,300-foot (390-meter) layer of 15 ohm-feet (4.5 ohm-meters) resistivity could be an indication of a pre-Lahontan clay-rich layer causing the lower resistivities encountered, rather than an increase in temperature. <u>It is stressed again that resistivity information is not a direct indicator of geothermal resources</u>.

The depth estimate of 1,500 feet (450 meters) to the resistive basement indicates that line 15 and, similarly, lines 13 through 18 are located on the upthrown side of the Litchfield Fault. Estimates from gravity data put the central portion of the basin at a depth of about 5,000 feet (1,500 meters). This is corroborated by drilling information from two deep wells. The shallow surface reservoirs could be an expression of leakage along the faults from a larger and more attractive reservoir at greater depth.

<u>Amedee</u>

The Amedee anomaly is partly located in the Wendel-Amedee KGRA. It has the lowest apparent resistivity (1.7 ohm-feet on line 24) found anywhere in the basin. The most striking surface expression is found at the Amedee Hot Springs, having temperatures of 195° to 204°F (91° to 96°C). Silica temperature estimates show 246° and 279°F (119° and 137°C), respectively. This is coupled with conductivities of more than twice the average for the area. At Amedee two major faults, the Litchfield and the Amedee Faults, come together.

Computer curve-matching puts the resistive basement at about 500 feet (150 meters) on line 24. A well drilled by Magma Power Co. near Amedee to 1,100-foot (330-meter) depth (finding water temperatures of 225°F (107°C)) shows a drop in basement closer to the fault. A deep well was drilled on the downthrown side of the Amedee Fault to a depth of 5,053 feet (1,516 meters), pointing to some sizable throw along this fault. Curve-matching also indicates a relatively shallow depth to the reservoir to the southeast of Amedee. The low apparent resistivities encountered leave little doubt that they are indicative of a thermal reservoir.

Susanville

Area geology. The Susanville anomaly lies in a graben between the major northwest-southeast trending Honey Lake Fault zone and the Antelope Mountain Fault. The valley fill consists of Pliocene to Recent interbedded volcanics and sediments. The basement complex is composed of Mesozoic granitic rocks.

Geothermal occurrences are controlled by the focus of faults in this area. The Honey Lake Fault zone passes through the anomaly. The zone consists of a number of steep northeast-dipping parallel normal faults forming a series of narrow stepped-down blocks. The Honey Lake Fault zone, with a displacement of at least 8,000 feet (2,400 meters), marks the eastern boundary of the Sierra Nevada.

The Antelope Mountain Fault northeast of Susanville has a displacement of some 2,000 to 4,000 feet (600 to 1,200 meters).

This fault extends under the valley floor and separates a western subbasin from the rest of the Honey Lake Basin.

Several north-northeast trending cross faults probably intersect the Honey Lake Fault zone near the anomalous area. For the most part, faults are concealed by Recent alluvium and basin deposits on the valley floor. Thermal waters moving up these fault conduits do not quite reach the land surface, but are often encountered at very shallow depths in wells and excavations.

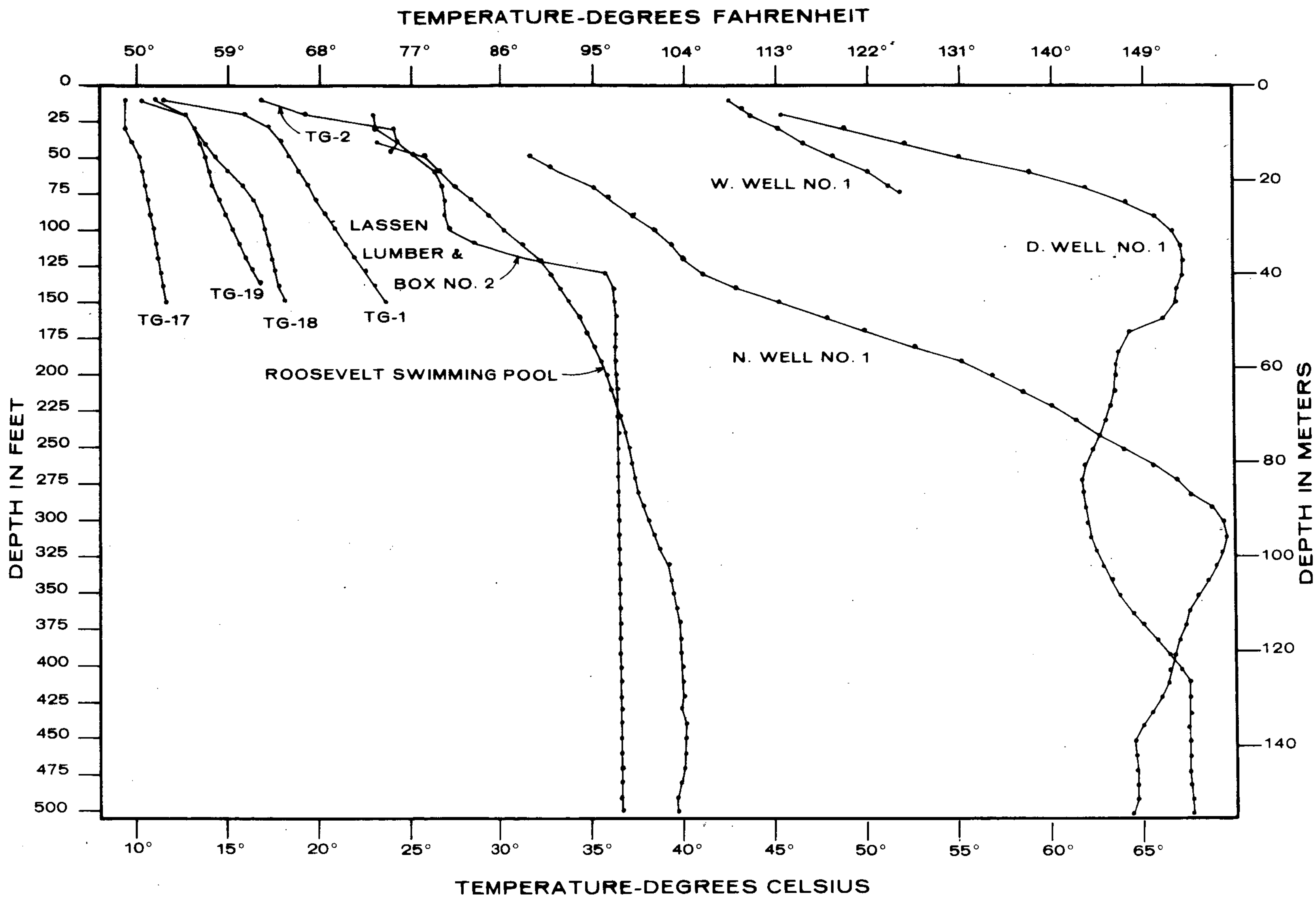
The many faults in the Honey Lake Basin have created a subbasin centered in the Johnstonville area (see plate 11, Bouguer Gravity). This subbasin has a valley fill of over 2,000 feet (600 meters). The thickness is undoubtedly much less near Susanville. Well logs indicate granitic basement rocks at a depth of some 450 feet (135 meters) just north of Susanville. The depth to basement is unknown in the thermal anomalous area. Granite outcrops are also found locally in the mountains about 4 miles (6.4 kilometers) northeast of Susanville. These outcrops are on the upthrown side of the Antelope Mountain Fault some 1,000 to 1,500 feet (300 to 450 meters) above the valley floor.

Major geologic features in the subbasin are the Pleistocene basalt flows. A prominent surface feature is the basalt flow extending southerly into the valley to the edge of Susanville. At least two major flows separated by several hundred feet (100$\pm$ meters) of Lake Lahontan and older lacustrine deposits are identified in well logs. These lava flows probably issued from the Antelope Mountain Fault area. The Pleistocene basalt flows are flat-lying or gently dipping into the valley, interfingering with the valley sediments, and pinching out toward the valley axis.

Resistivity. The resistivity anomaly is centered on the south part of Susanville. The lowest apparent resistivity encountered was 27 ohm-feet (8.1 ohm-meters) on line 56. Resistivity work in the city itself was impossible. The results of the survey outside the city, however, are useful as a guide in determining what values to expect in this type of low temperature reservoir. Temperatures of wells that are utilized commercially in the area range from about 90° to 150°F (32° to 66°C).

Existing wells. There are at least six wells near the southern city limits of Susanville that have warm water. Other wells reported warm were abandoned or plugged, or their locations are unknown. Five of these wells were measured for temperature profiles (see figure 6).

The Roosevelt municipal swimming pool, an indoor junior-size olympic pool built in 1933, utilizes geothermal hot water from a well pump located in the basement. The well water, approximately 100°F (38°C) is mixed about 3 to 1 with cold municipal water to fill and keep the pool warm. In addition, hot water is circulated through a large radiator to heat the building in cool weather. The pool is not used during the winter when temperatures may drop to -20°F (-29°C).



SUSANVILLE GEOTHERMAL INVESTIGATIONS

TEMPERATURE PROFILES—EXISTING WELLS & TEST HOLES—SUSANVILLE ANOMALY

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FIGURE 6

Results of the Investigation

The pump was pulled from the well in February 1975 for the first time to make repairs. No noticeable corrosion or scaling problems have been experienced. When the well was open, temperature profile measurements were made. Measurements were made to 500 feet (150 meters), the maximum depth of the Bureau's equipment. Total depth of the well is unknown.

A well (D. No. 1) just south of the city limits which was previously abandoned has been rehabilitated, pump tested, and is being used to furnish heat and water to greenhouses. This well was drilled in 1926-1927 to a depth of 632 feet (190 meters). Temperature profile measurements were made in February 1975. A temperature reversal is evident at about 100 feet (30 meters), when a maximum of about 153°F (67°C) was reached. The well has been pump tested for several days, with a drawdown of about 12 feet (4 meters) and a constant temperature of 140°F (60°C).

The third well, over 500 feet (150 meters) deep and on a small hill, was the N. No. 1 well. This well had a temperature reversal at about 300 feet (90 meters) when it reached nearly 158°F (70°C). The water level, when measured on February 21, 1975, was at 51 feet (15 meters). This well was reportedly pump tested for 2 hours with a constant discharge temperature of about 145°F (63°C).

The Lassen Lumber and Box Well No. 2 was the fourth warm well over 500 feet (150 meters) deep available for temperature measurements. This well, now abandoned, shows two abrupt gradient changes, at about

100 and 130 feet. The gradient of this well, and most of the other wells and temperature gradient holes measured by the Bureau of Reclamation, was confirmed by the independent temperature measurements by the U.S. Geological Survey.

The fifth accessible warm well monitored was the Wirth well No. 1. This well, reportedly about 140 feet (42 meters) deep, is used for cleaning equipment. The pump was "jacked up" to make room for the temperature probe. Maximum depth reached was 74 feet (22 meters) when the probe probably hung up on pump bowls. The temperature was about 125°F (52°C). It was not known how long the pump was idle and the water may not have reached equilibrium temperature with the surrounding formations. When measured on September 10, 1975, the water level was at 10 feet (3 meters). The well yielded 121°F (49°C) water for about 5-10 minutes before going dry.

A few other warm-water wells in the area are unaccessible for temperature probes. The LDS Church has been using goethermal water from a well 575 feet (172 meters) deep since 1962. Water of 128°F (53°C) is pumped through radiators to heat the church, and wasted to a county drainage ditch. The Lahontan Regional Water Quality Control Board is asking the church to use other means to control or waste the effluent. The existing (second) submersible pump has been in the well for 3 years. Although a 10-hp motor is used to drive the pump, the main valve is only opened slightly to obtain all the heat necessary.

Another well, located just north of the County Corporation Yard, is reportedly about 600 feet (180 meters) deep with 103°F (39°C) water. However, this well collapsed with loss of all pump equipment soon after its completion in about 1973. The well was to be used for heating a new large house, but it is presently plugged and abandoned.

A domestic well drilled during November 1975 just south of Lassen Lumber and Box No. 2 encountered 80°F (27°C) water at about 65 feet (20 meters). This well was completed satisfactorily by casing off the upper hotter water. A few other shallow wells in the vicinity also reportedly hit warm water at shallow depths.

In addition to these wells, hot ground and water was encountered within backhoe excavation depth on land just east of well D. No. 1.

<u>Test holes</u>. Five test holes were completed on the Susanville anomaly. Interbedded lava flows with sediments in the immediate Susanville vicinity caused very rough and slow drilling. Initially, before corrective methods were devised, below-freezing temperatures caused mud lines and pumps to freeze overnight. Later, time was still lost at the end of each day draining lines and dismantling pumps, then reassembling them again each morning. Equipment problems also caused considerable downtime.

TG-19 was completed at 138 feet (41 meters) because excessive time would be required to replace a worn bit and drill the remaining 12 feet (4 meters) to the target depth. TG-2 could not be advanced past 50 feet (15 meters) due to very rough and slow drilling, caving, and high mud loss. The hole was completed to about 46 feet (14 meters).

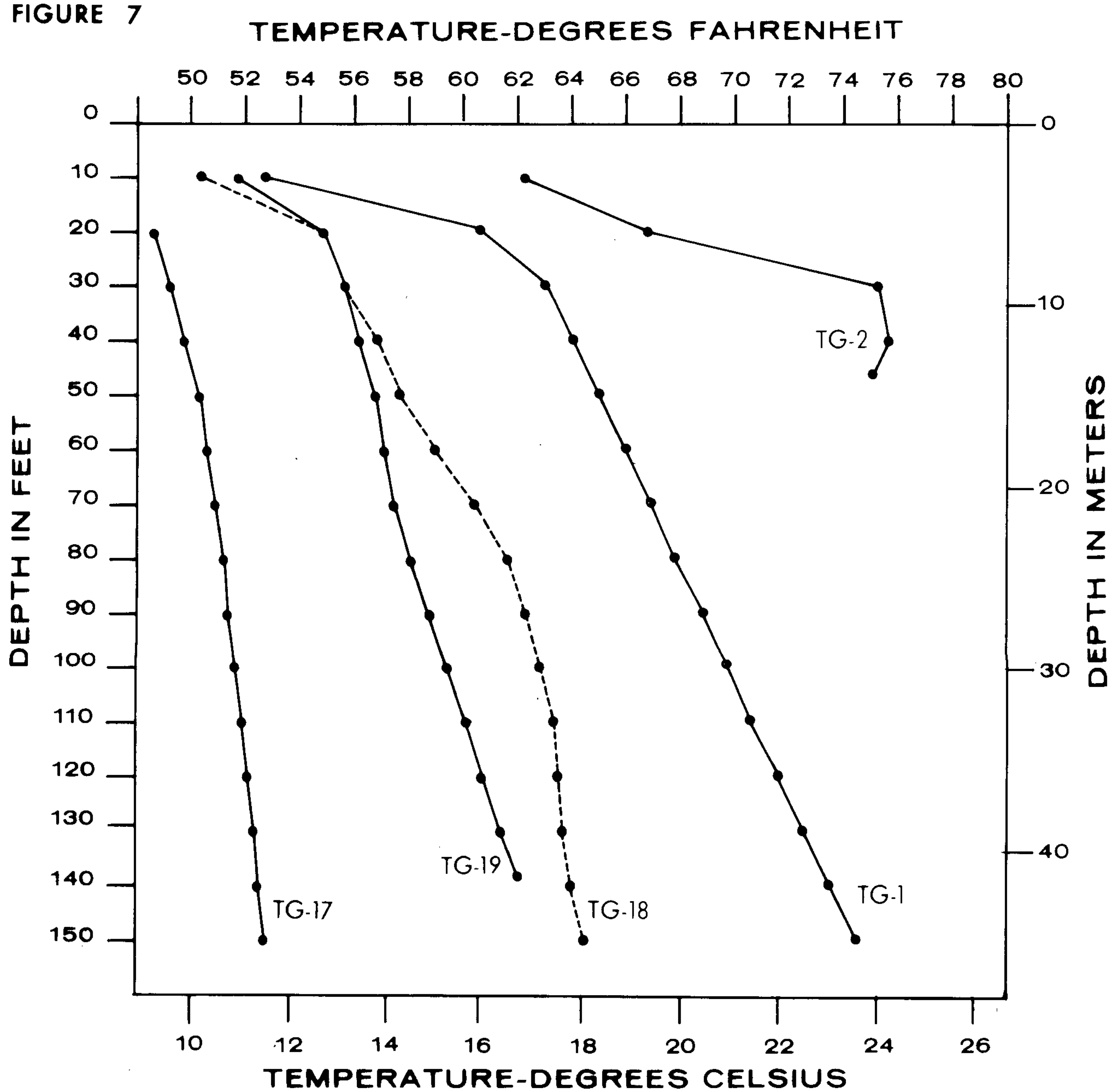
Similar conditions were encountered at TG-1. However, this hole was reamed to 8½ inches (21.6 cm) and 44 feet (13 meters) of 5-inch (12.7-cm) surface casing (unavailable at TG-2) was installed before the hole could be completed as designed. The remaining two holes in the Susanville anomaly were drilled and completed without difficulty.

All test holes in the Susanville anomaly except TG-17 encountered interbedded sediments and volcanics. In contrast, TG-17, the southernmost hole, penetrated mostly granitic sediments derived from the nearby Sierra Nevada. Although the hole was grouped with the Susanville anomaly, previous resistivity data indicate that it lies outside the thermal area. TG-17 was drilled primarily to determine the extent of the Susanville anomaly. A lacustrine deposit of blue-black clay and silt 35 feet (11 meters) thick was encountered at TG-18, but was absent in all other holes.

The immediate Susanville area appears to be complexly faulted. This, along with an active geologic history, including several periods of volcanism, makes more than a general correlation between geologic logs of test holes and other wells very difficult.

The temperature gradients in the Susanville anomaly holes (excluding TG-2 and TG-17) ranged from 6.7° to 11.5°F per 100 feet (122° to 210°C/km). (See figure 7.) TG-2 was not deep enough to

FIGURE 7



TG No.	Drilled 1975	Measured 1976	Gradient Interval (ft)	°F/100ft	°C/km
1	Nov 18-25	Jan 12	40-140	9.4	171
2	Nov 14-17	Jan 12	20-30	86.0	1568
17	Dec 4-5	Jan 13	50-150	2.4	43.8
18	Dec 2-3	Jan 13	{ 20-80 90-150	{ 11.5 3.7	{ 209.6 67.5
19	Nov 12-13	Jan 12	80-138	6.7	122.1

SUSANVILLE GEOTHERMAL INVESTIGATIONS

TEMPERATURE PROFILES — TEST HOLES — SUSANVILLE ANOMALY

establish a meaningful thermal gradient but did show a rapid thermal rise. TG-2 is located near the center of the Susanville resistivity anomaly and the warmest portion of the known thermal area.

The gradient in TG-17 was 2.4°F per 100 feet (44°C/km). Geologically, its location in granitic-derived sediments puts the hole south of the Susanville thermal area.

Litchfield

The Litchfield anomaly lies along the buried Litchfield Fault. There are no surface expressions of rising thermal waters; however, well data indicate thermal waters may be encountered at depth.

The Litchfield Fault extends roughly east-west along the northern edge of the Honey Lake Valley between the Antelope Mountain and Amedee Faults. The Litchfield Fault was detected in 1960 from a gravity survey which indicated a break in the bedrock surface. There is no topographic expression of the fault, or possibly a fault zone. The displacement of the fault is unknown but sizable, probably in the 2,000- to 5,000-foot (600- to 1,500-meter) range. No wells logged have reached basement rocks in the anomalous area.

The valley fill consists mostly of Lake Lahontan and older lacustrine deposits with possible interbedded Pliocene basalt. The deepest nearby well log indicated sediments to its total depth of nearly 600 feet (180 meters). The anomalous area lies along the edge of the major Honey Lake Subbasin, which has a maximum fill of approximately 5,000 feet (1,500 meters). Because the Litchfield anomaly lies near the extreme northern edge of the basin, the valley fill is probably much less than 5,000 feet (1,500 meters) maximum.

This area has a value of 29 ohm-feet (8.8 ohm-meters) as its lowest value for apparent resistivity. Anomalous temperatures for three deep wells along the periphery are:

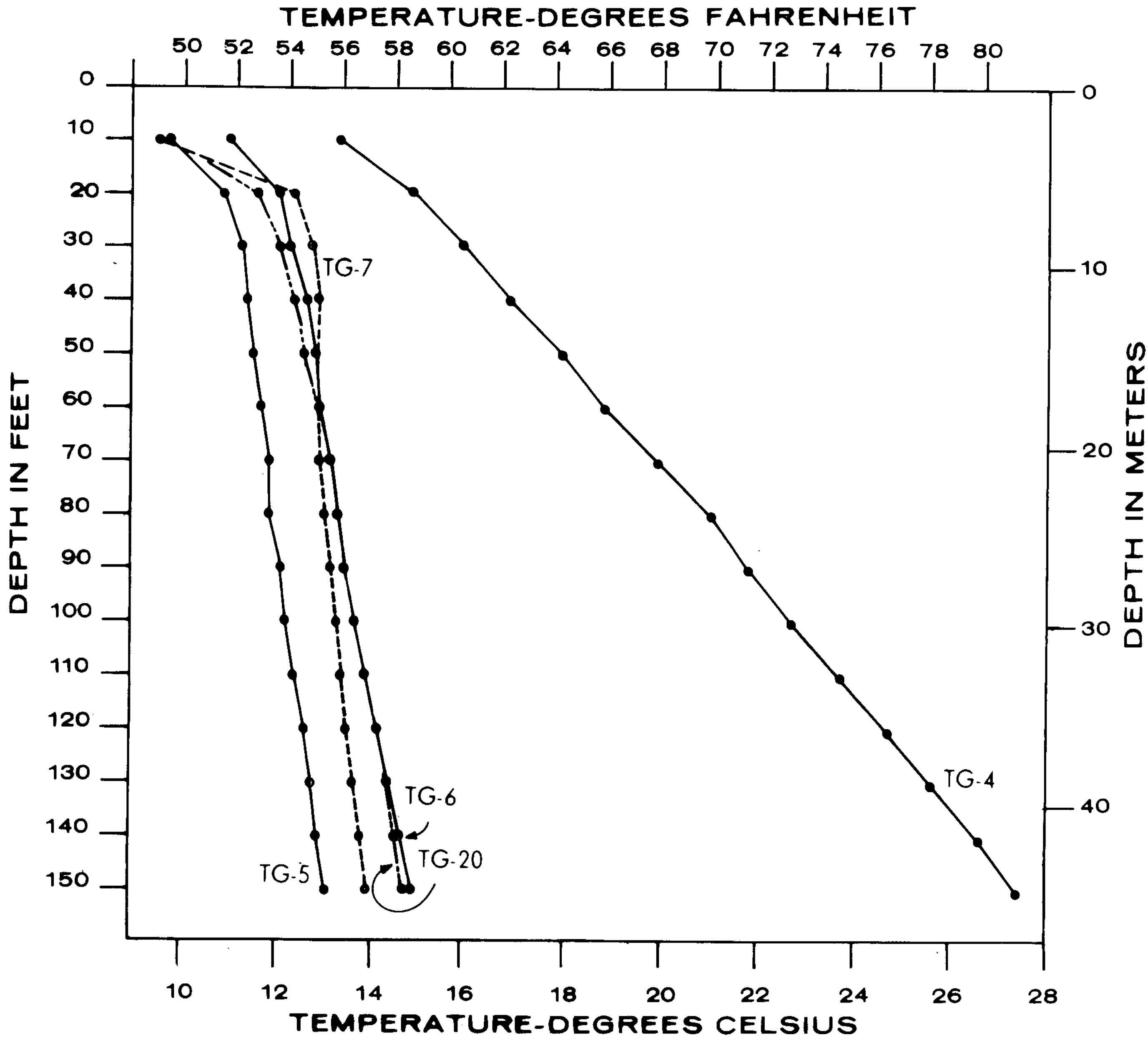
Well No.	Water temperature (degrees) F	Water temperature (degrees) C	Depth (feet)	Depth (meters)	Computed silica (conductive quartz) temperature (degrees) F	Computed silica (conductive quartz) temperature (degrees) C
119	66	19	600	180	226	108
124	67	19	702	211	208	98
125	65	18	314	94	237	114

The relatively low resistivities encountered, similarity of lithology, and location associated with a major fault make this area deserving of additional exploration.

The five test holes drilled on the Litchfield anomaly were completed rapidly without any major equipment problems or difficult drilling. The materials encountered were predominantly clays, silts, and sand; however, TG-7 and TG-20 both encountered interbedded volcanic material terminating at a depth of 108 feet (33 meters).

All of the holes in the Litchfield anomaly except TG-4 had thermal gradients in the order of 2.3° to 3.8°F per 100 feet (42° to 69°C/km). TG-4 was a notable exception with a gradient of 17.6°F per 100 feet (321°C/km). (See figure 8.)

FIGURE 8



TG No.	Drilled 1975	Measured 1976	Gradient Interval (ft)	°F/100ft	°C/km
4	Dec 8-9	Jan 13	40-140	17.6	320.8
5	Dec 9-10	Jan 13	40-140	2.6	47.4
6	Dec 10-11	Jan 13	40-140	3.6	65.7
7	Dec 15-16	Jan 13	80-150	2.3	41.9
20	Dec 11-12	Jan 13	40-140	3.8	69.3

SUSANVILLE GEOTHERMAL INVESTIGATIONS

TEMPERATURE PROFILES — TEST HOLES — LITCHFIELD ANOMALY

MAY 1976 1315—208—17

Bald Mountain

The Bald Mountain anomaly is the nearest anomalous area to the deepest portion of Honey Lake Basin. There are no surface or positive subsurface indications of thermal water in the Bald Mountain anomaly.

No presently known major faults or structures control this anomaly; however, there is a possibility that a buried east-west fault extends across the valley from Wendel to Bald Mountain. This may be a westward extension of the buried fault referred to as the Skedaddle Fault in Wendel Canyon.

Logs of existing wells indicate at least 600 feet (180 meters) of predominantly sandy and clayey lacustrine sediments in the area. The total thickness of valley fill probably is more in the order of several thousand feet (1,000± meters).

This anomaly encompasses a rather poorly defined area starting on top of a large fault to the south of Bald Mountain and trending northeast to a cluster of warm temperature wells. The lowest apparent resistivity encountered was 39 ohm-feet (11.8 ohm-meters). Centered on this resistivity low is a generally warmer zone at the surface shown on the thermal infrared interpretation. Associated with this area are the following wells:

Results of the Investigation

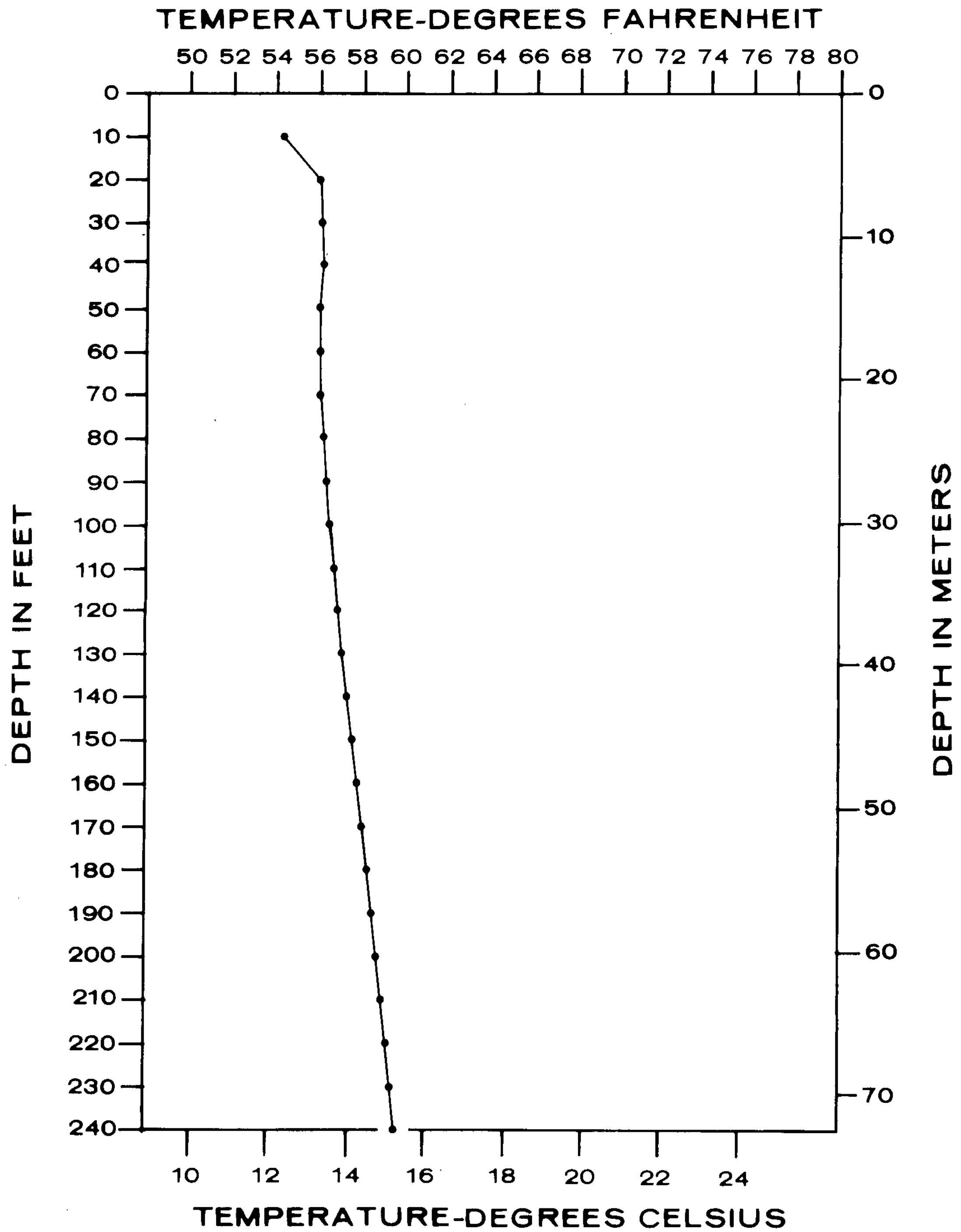
Well No.	Water temperature (degrees) F	C	Depth (feet)	(meters)	Computed silica (conductive quartz) temperature (degrees) F	C
64	63	17	16	5	235	113
65	57	14	18	5	244	118
67	52	11	260	78	232	111
160	58	14	55	17	230	110
171	60	16	75	23	216	102
172	56	13	450	135	216	102

The Bald Mountain anomaly is a likely candidate for deeper resistivity sounding, since at the maximum spacing obtained, the curves are seen to be on a down trend. Hence, much lower resistivities at depth are possible. Coupled with a large interpreted thickness from the gravity map, this is a target area for deeper exploration.

The test hole TG-10 was drilled to a depth of 240 feet (72 meters) (the extent of available drill pipe). The hole was drilled fast (approximately 3 hours) and smoothly, predominantly in sandy material with lesser amounts of clay.

The Bald Mountain anomaly test hole TG-10 had a gradient of 2.1°F per 100 feet (38°C/km). (See figure 9.)

FIGURE 9



TG No.	Drilled 1975	Measured 1976	Gradient Interval (ft)	°F/100ft	°C/km
10	Dec 17	Jan 13	140-240	2.1	38.3

SUSANVILLE GEOTHERMAL INVESTIGATIONS

TEMPERATURE PROFILE — TEST HOLE — BALD MTN ANOMALY

CONCLUSIONS

The appraisal investigation was made with limited funds to determine whether the Susanville-Honey Lake area has a significant geothermal resource, and possibly, the size or extent of that resource. The studies never intended to determine heat flow or the energy potential of the resource. With this in mind, the following generalizations can be made:

1. Heat in the form of hot water is available at or near the ground surface in two general locations. This is evidenced by warm water (100-150°F or 38-66°C) from existing wells in the Susanville area, and boiling water from the Wendel and Amedee Hot Springs just northeast of Honey Lake.

2. Data from the electrical resistivity survey shows five distinct low resistivity anomalies. Two of these anomalies (Wendel and Amedee) are partly in the Wendel-Amedee Known Geothermal Resource Area. All five anomalies appear to be fault controlled.

3. The Wendel and Amedee anomalies definitely show the greatest prospect for hot water at shallow depths. However, because of the private interest shown in these areas through geothermal leases and land purchase, no further analysis by the Bureau is contemplated.

4. Water temperatures, electrical conductivity, and computed reservoir temperatures from existing ground-water chemical analyses, as well as the analysis of thermal infrared imagery and shallow

temperature gradients, generally correlate with the resistivity anomalies.

5. The in-house equipment available for the electrical resistivity survey was limited in depth penetration capabilities to about 2,000 feet (600 meters); thus the resistivity anomalies can show only shallow thermal reservoirs.

6. The distribution, size, and quality of these shallow reservoirs, and the fact that much greater sedimentary thicknesses can be found in the central parts of the basin, suggest the possibility that the shallow resistivity anomalies could be expressions of leakage from a larger reservoir at depth.

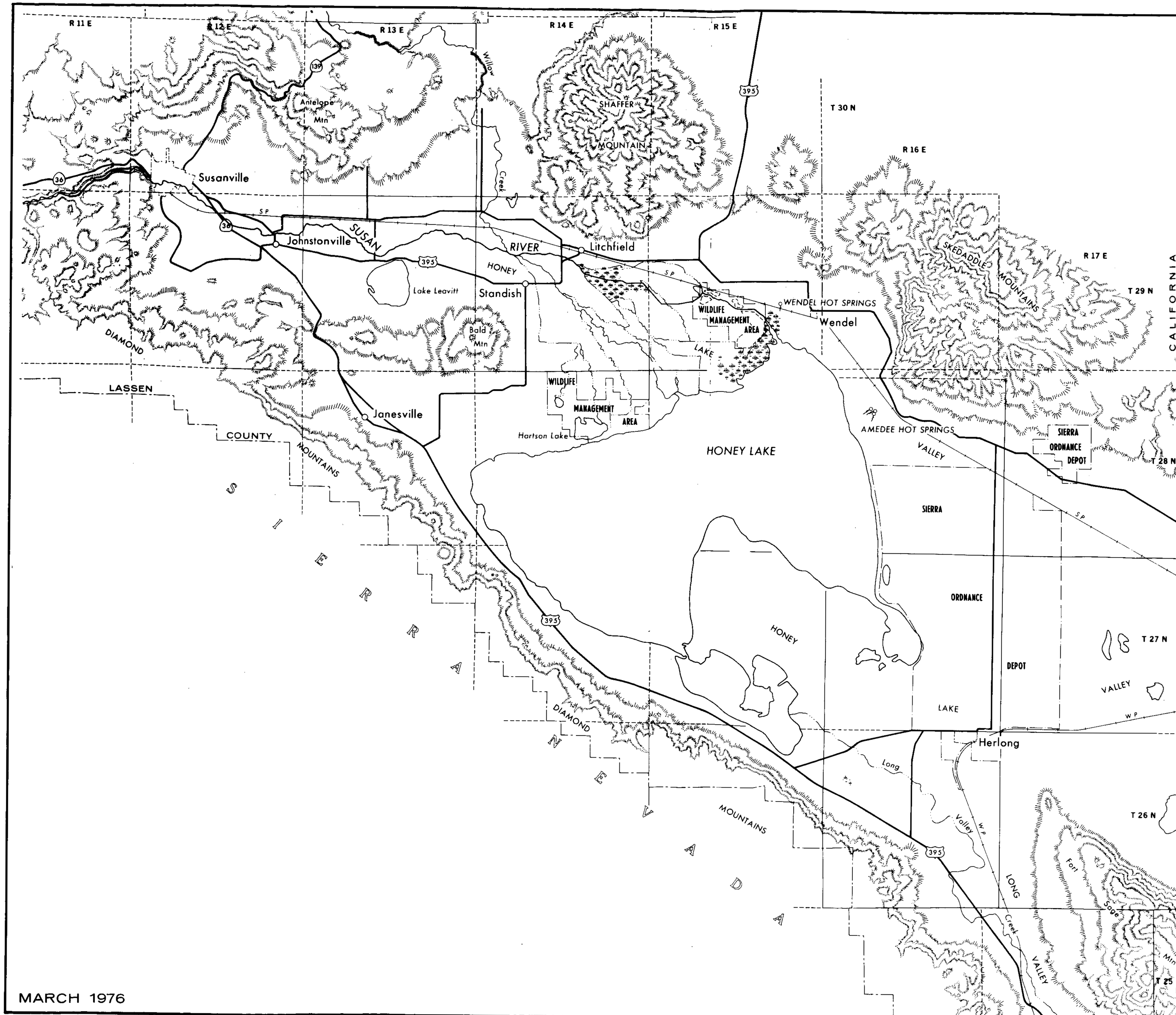
7. The Susanville and Litchfield resistivity anomalies show definite correlation with temperature gradients. The extent of these areas should be further defined with additional shallow temperature gradient test holes and geophysical studies. Temperature gradients in the Susanville anomaly are greatly influenced by mixing with cold water.

8. The Bald Mountain resistivity anomaly is very nebulous because of insufficient data. More geophysical exploration, including resistivity and temperature gradients, is needed, particularly with greater depth penetration.

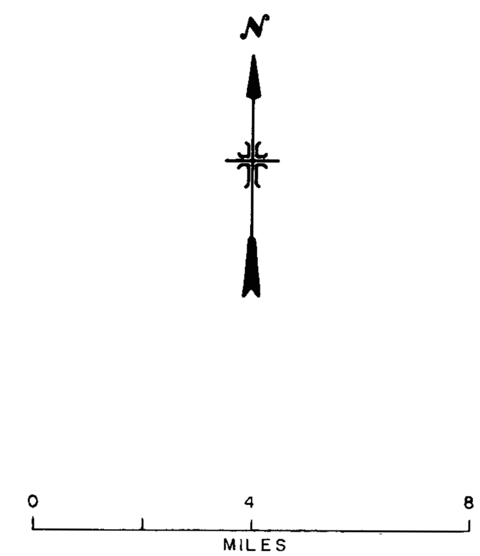
9. Because of the area's semiarid location, the amount of ground-water recharge to any thermal reservoir must be further considered in development of the resource.

Conclusions

10. Without additional geophysical, geological, and geochemical studies, it is practically impossible to evaluate the geothermal resource more definitively.



MARCH 1976



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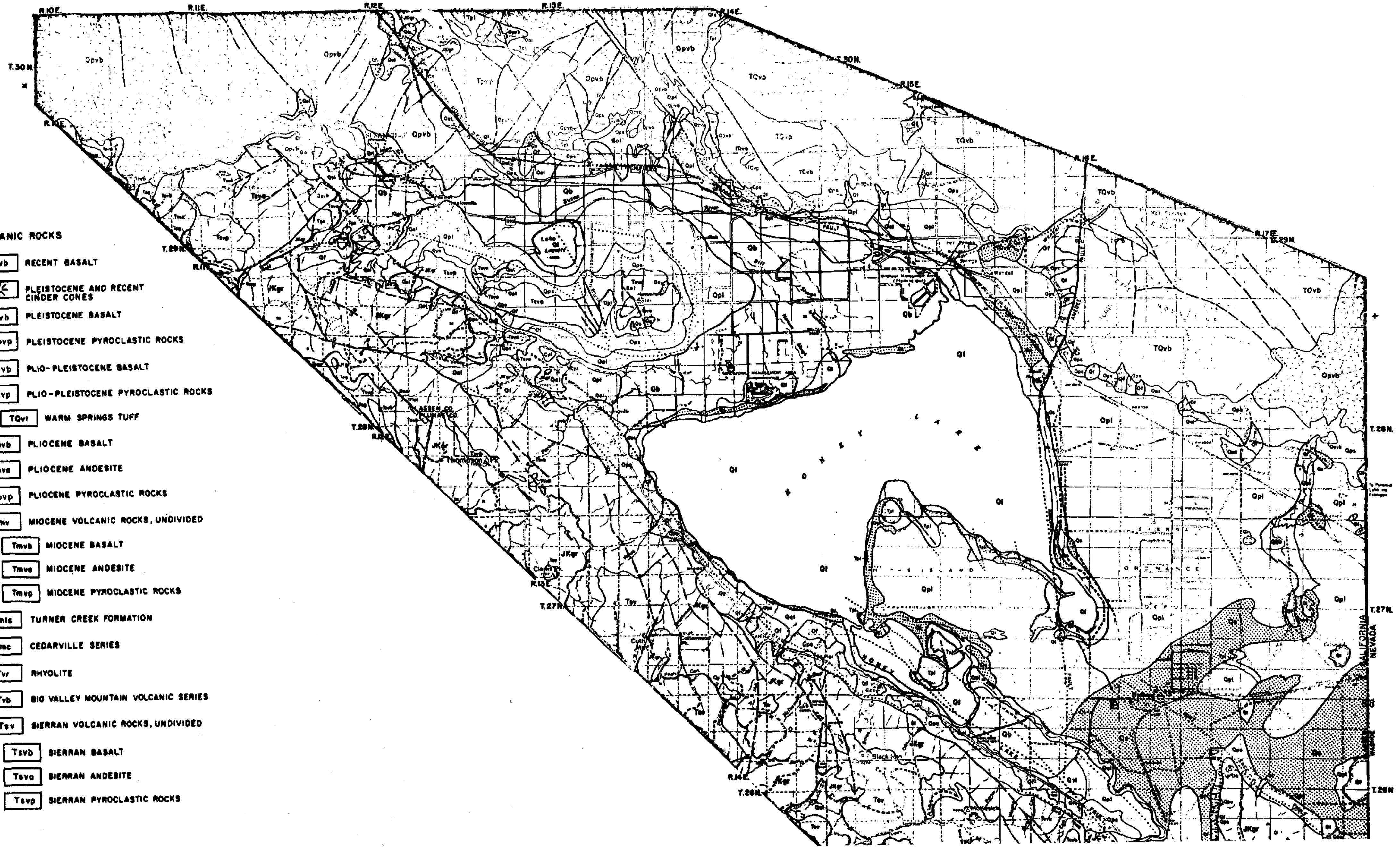
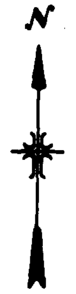
SUSANVILLE GEOTHERMAL INVESTIGATIONS

LOCATION MAP

1315—208—1





GEOLOGIC UNITS

SEDIMENTARY ROCKS

CENOZOIC	QUATERNARY	Recent	Qsd	SAND DUNES
			Qs	SAND AND SILT DEPOSITS
			Ql	RECENT LAKE DEPOSITS
			Qls	LANDSLIDES
			Qta	TALUS
			Qmp	MUCK AND PEAT DEPOSITS
			Qb	BASIN DEPOSITS
			Qal	INTERMEDIATE ALLUVIAL DEPOSITS
			Qf	ALLUVIAL FANS
			Qt	TERRACES
		Pleistocene	Qps	NEAR-SHORE DEPOSITS
			Qpl	PLEISTOCENE AND LAHONTAN LAKE DEPOSITS
			Qpo	GLACIAL OUTWASH
			Qpm	MORAINES
			TQa	ALTURAS FORMATION
			TQb	BIEBER FORMATION
	TERTIARY	Pliocene	Tpl	PLIOCENE LAKE DEPOSITS
		Miocene	Tmfc	FORTY-NINE CAMP FORMATION
		Oligocene	TΦdc	DEEP CREEK CONGLOMERATE
		Eocene	Teg	AURIFEROUS GRAVELS
		Undivided	Tgs	GOLD RUN SANDSTONE
			Tfs	FORT SAGE SANDSTONE

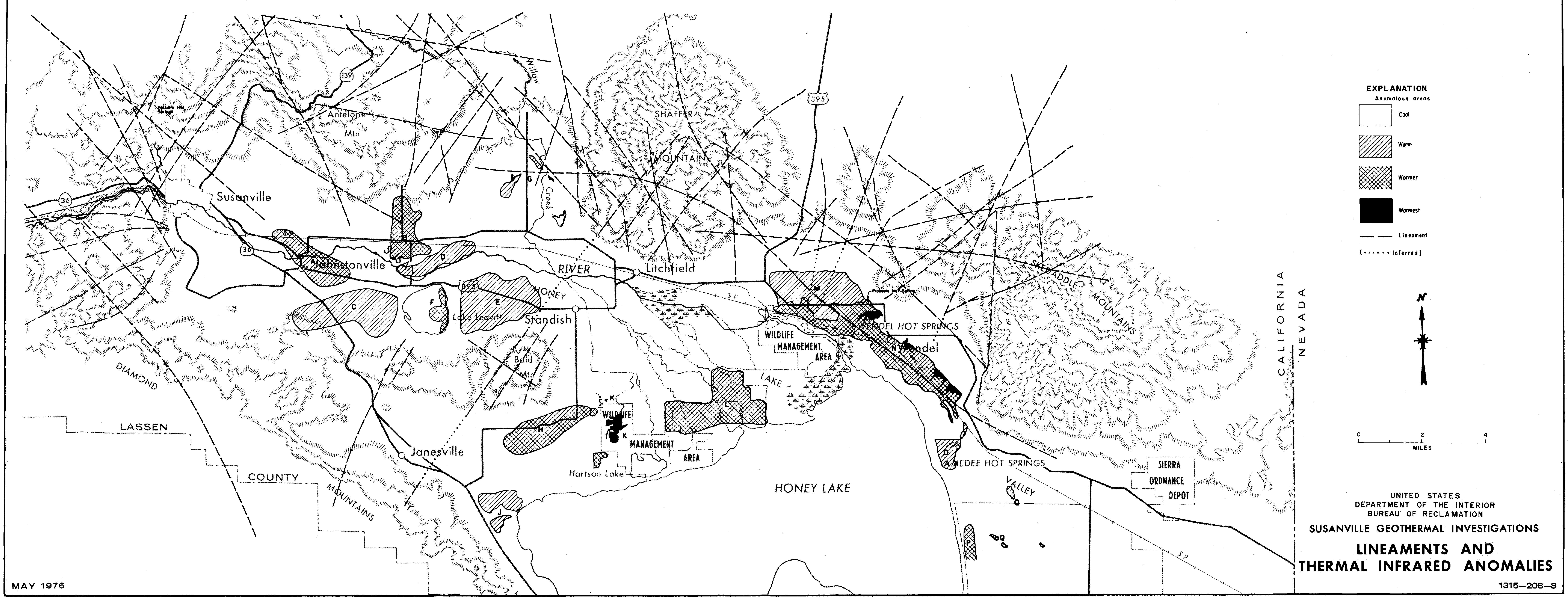
VOLCANIC ROCKS

CENOZOIC	QUATERNARY	Recent	Qrvb	RECENT BASALT
		Pleistocene	(symbol)	PLEISTOCENE AND RECENT CINDER CONES
			Qpvb	PLEISTOCENE BASALT
			Qpvp	PLEISTOCENE PYROCLASTIC ROCKS
			TQvb	PLIO-PLEISTOCENE BASALT
			TQvp	PLIO-PLEISTOCENE PYROCLASTIC ROCKS
			TQvt	WARM SPRINGS TUFF
	TERTIARY	Pliocene	Tpvb	PLIOCENE BASALT
			Tpva	PLIOCENE ANDESITE
			Tpvp	PLIOCENE PYROCLASTIC ROCKS
		Miocene	Tmv	MIOCENE VOLCANIC ROCKS, UNDIVIDED
			Tmvb	MIOCENE BASALT
			Tmva	MIOCENE ANDESITE
			Tmvp	MIOCENE PYROCLASTIC ROCKS
			Tmtc	TURNER CREEK FORMATION
			Tmc	CEDARVILLE SERIES
		Undivided	Tvr	RHYOLITE
			Tvb	BIG VALLEY MOUNTAIN VOLCANIC SERIES
			Tsv	SIERRAN VOLCANIC ROCKS, UNDIVIDED
			Tsvb	SIERRAN BASALT
			Tsva	SIERRAN ANDESITE
			Tsvp	SIERRAN PYROCLASTIC ROCKS

BASEMENT COMPLEX

MESOZOIC

PLATE 3



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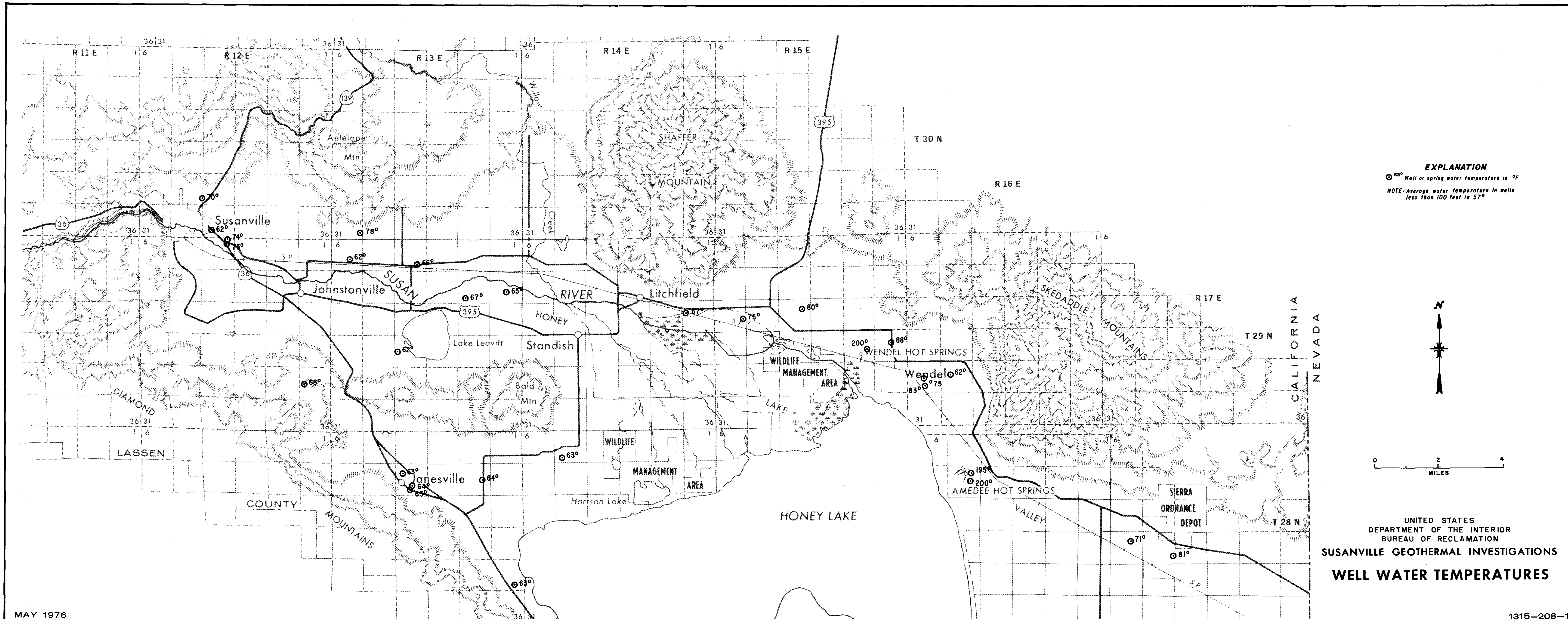
SUSANVILLE GEOTHERMAL INVESTIGATIONS

LINEAMENTS AND THERMAL INFRARED ANOMALIES

MAY 1976

1315-208-8



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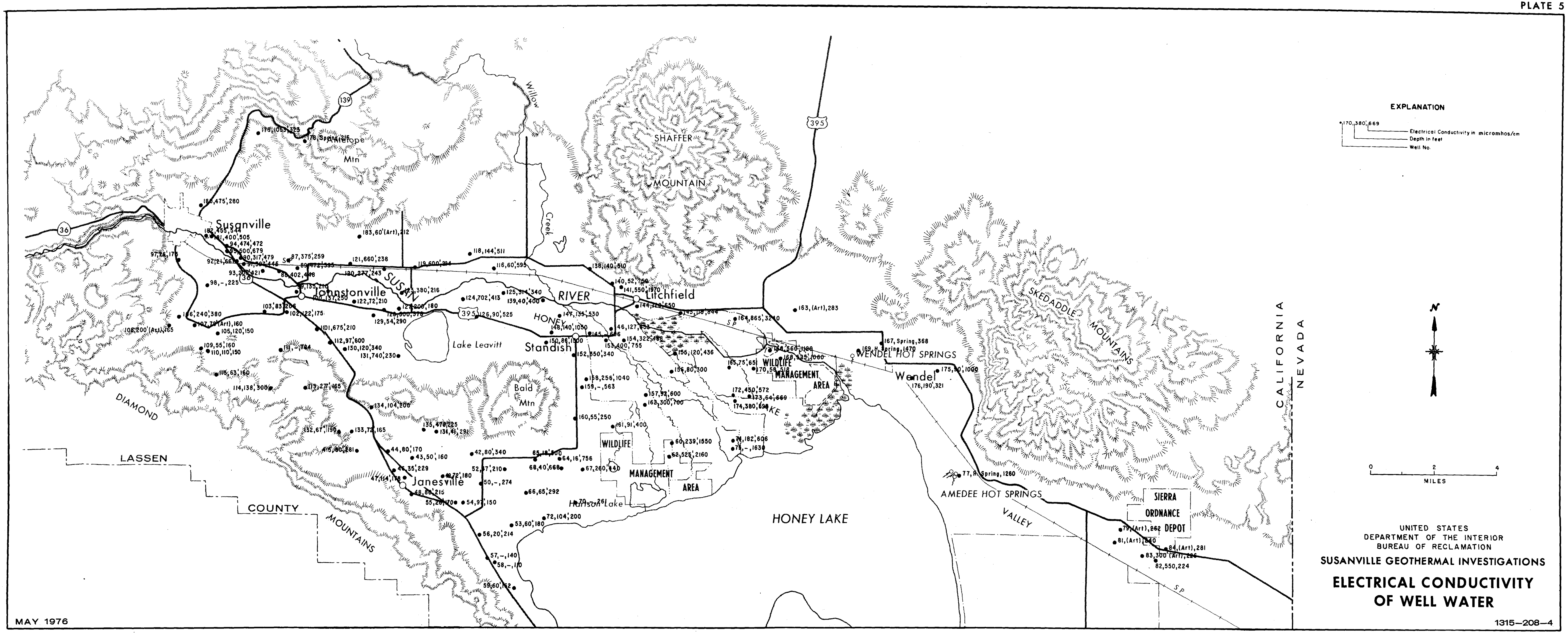
WELL WATER TEMPERATURES

MAY 1976

1315—208—19



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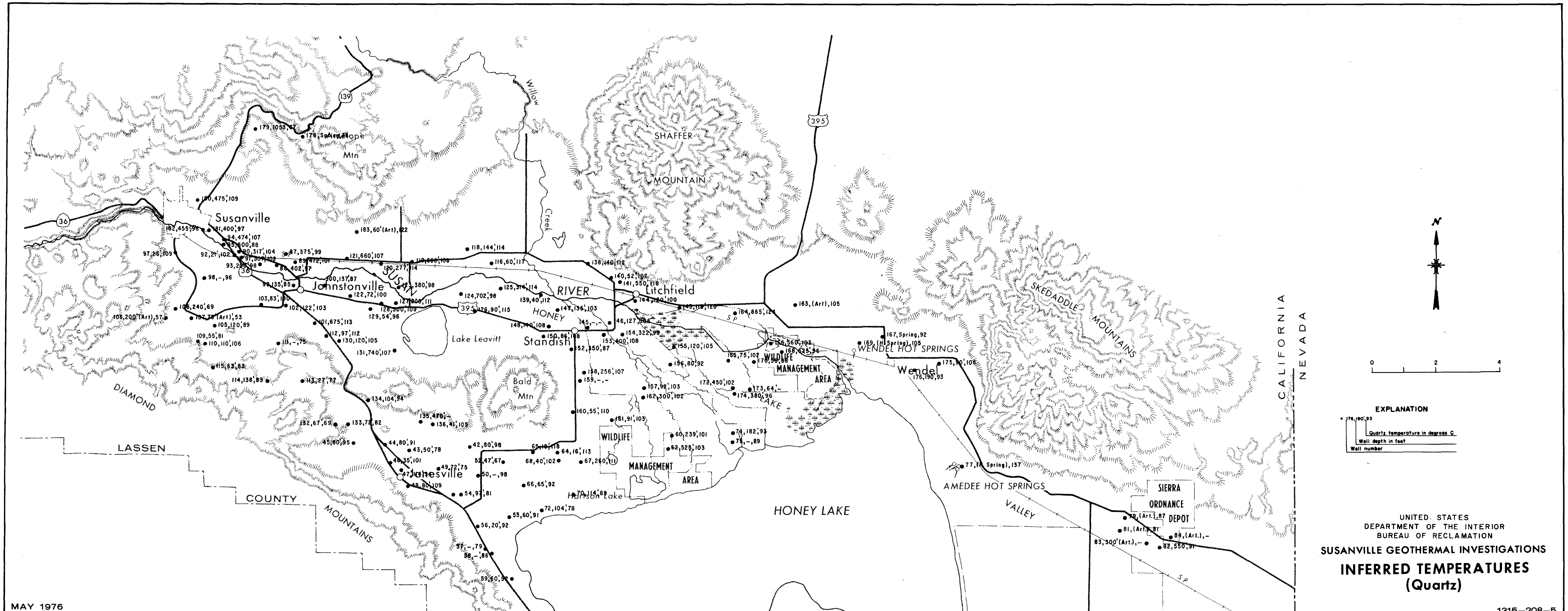
ELECTRICAL CONDUCTIVITY OF WELL WATER



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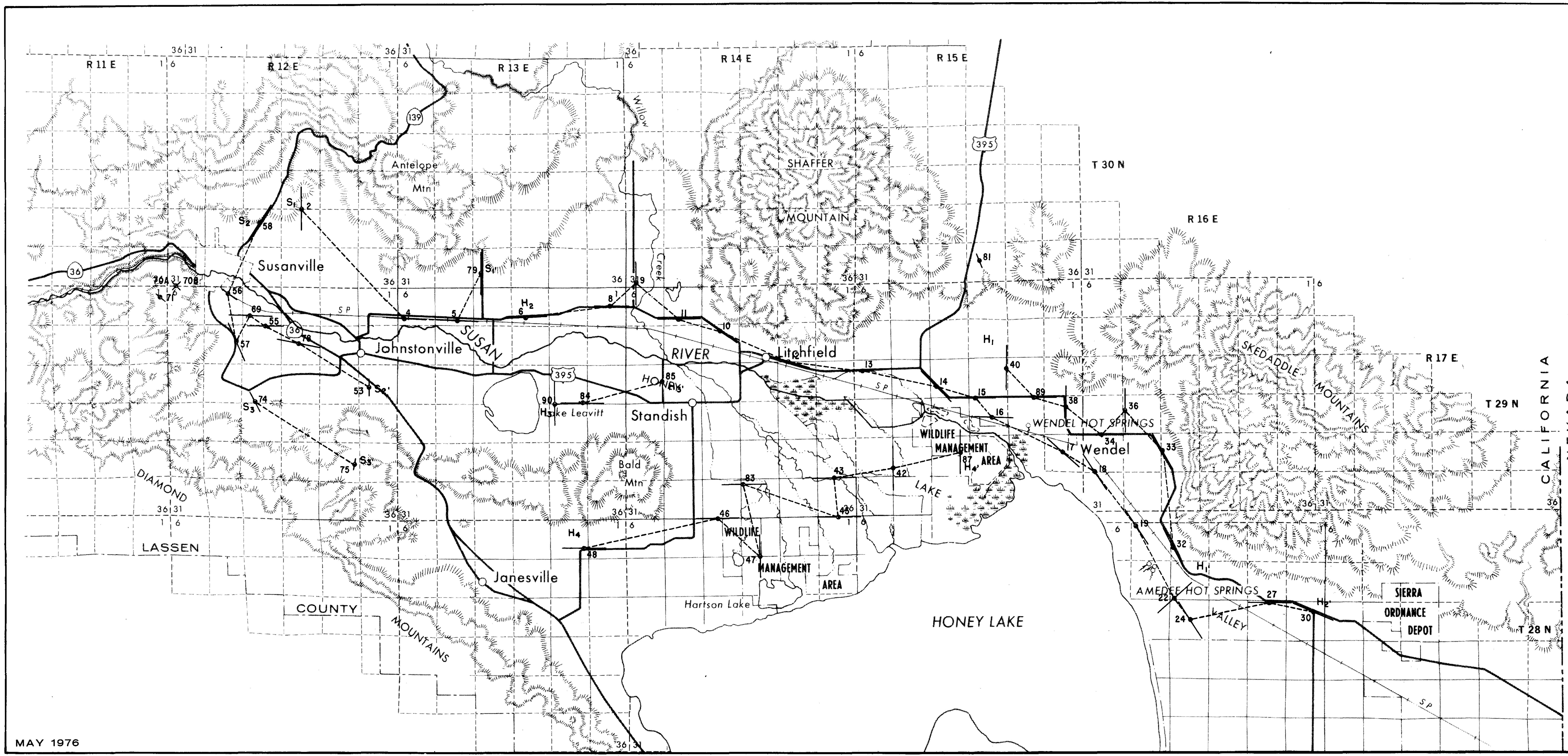
INFERRED TEMPERATURES
(Quartz)

MAY 1976

1315–208–5



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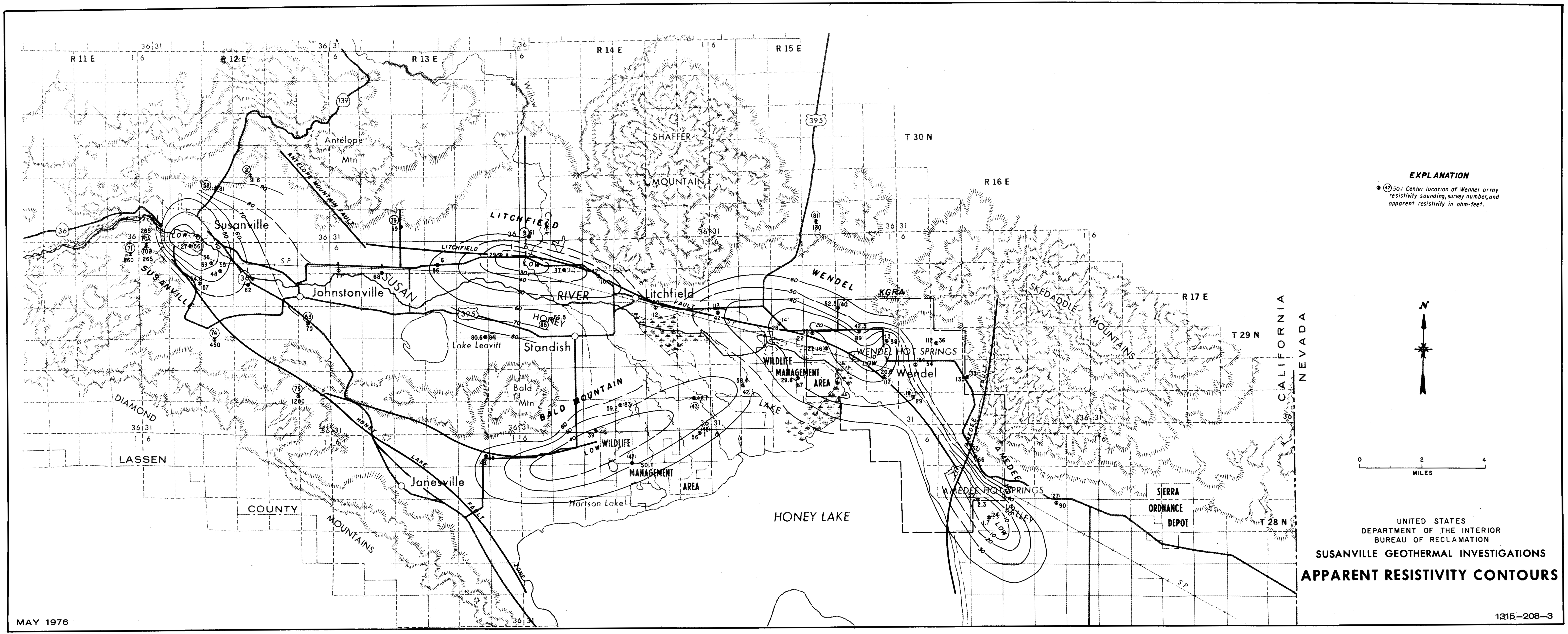
LOCATION RESISTIVITY SOUNDINGS

MAY 1976

1315-208-6



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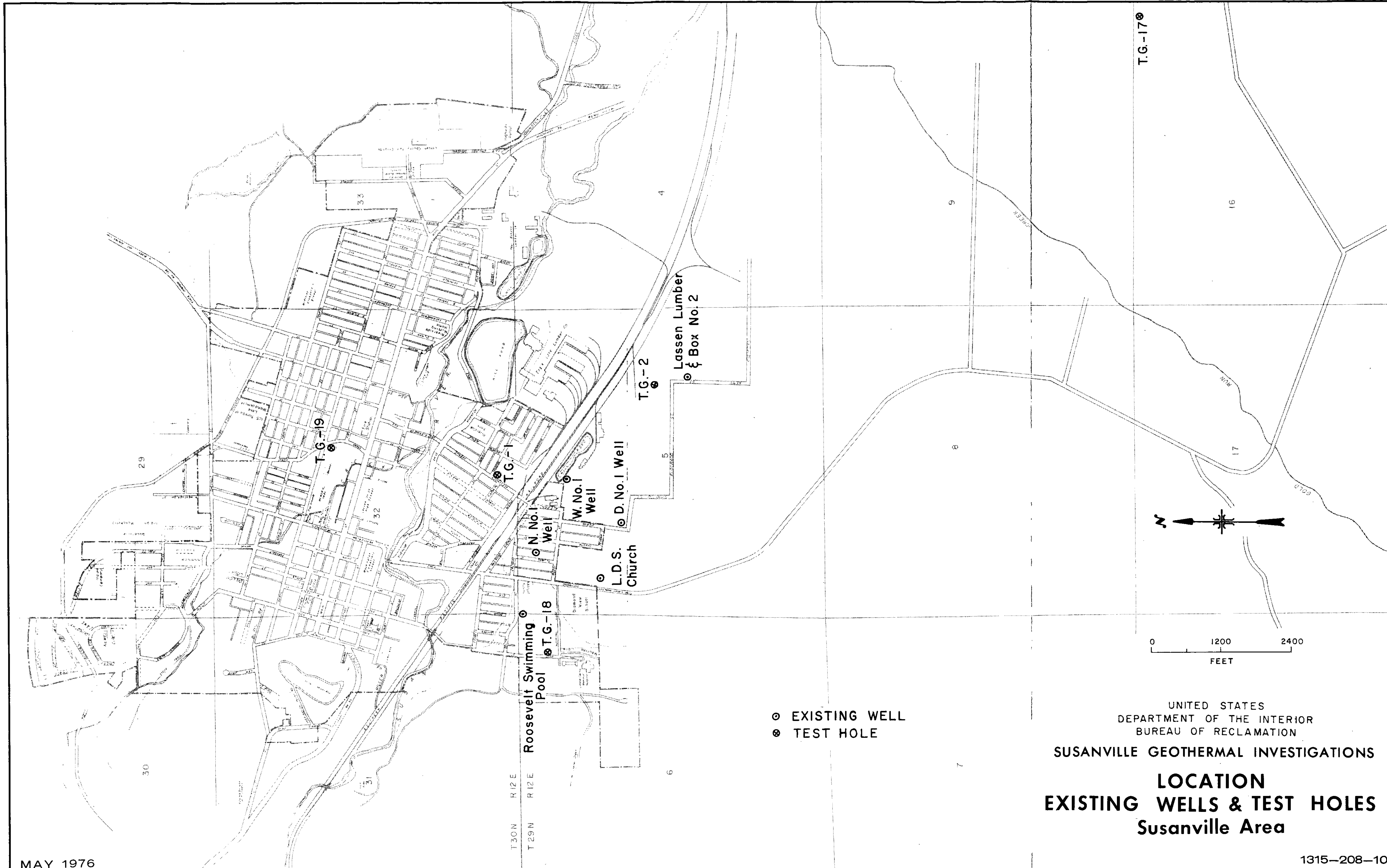
APPARENT RESISTIVITY CONTOURS

MAY 1976

1315—208—3



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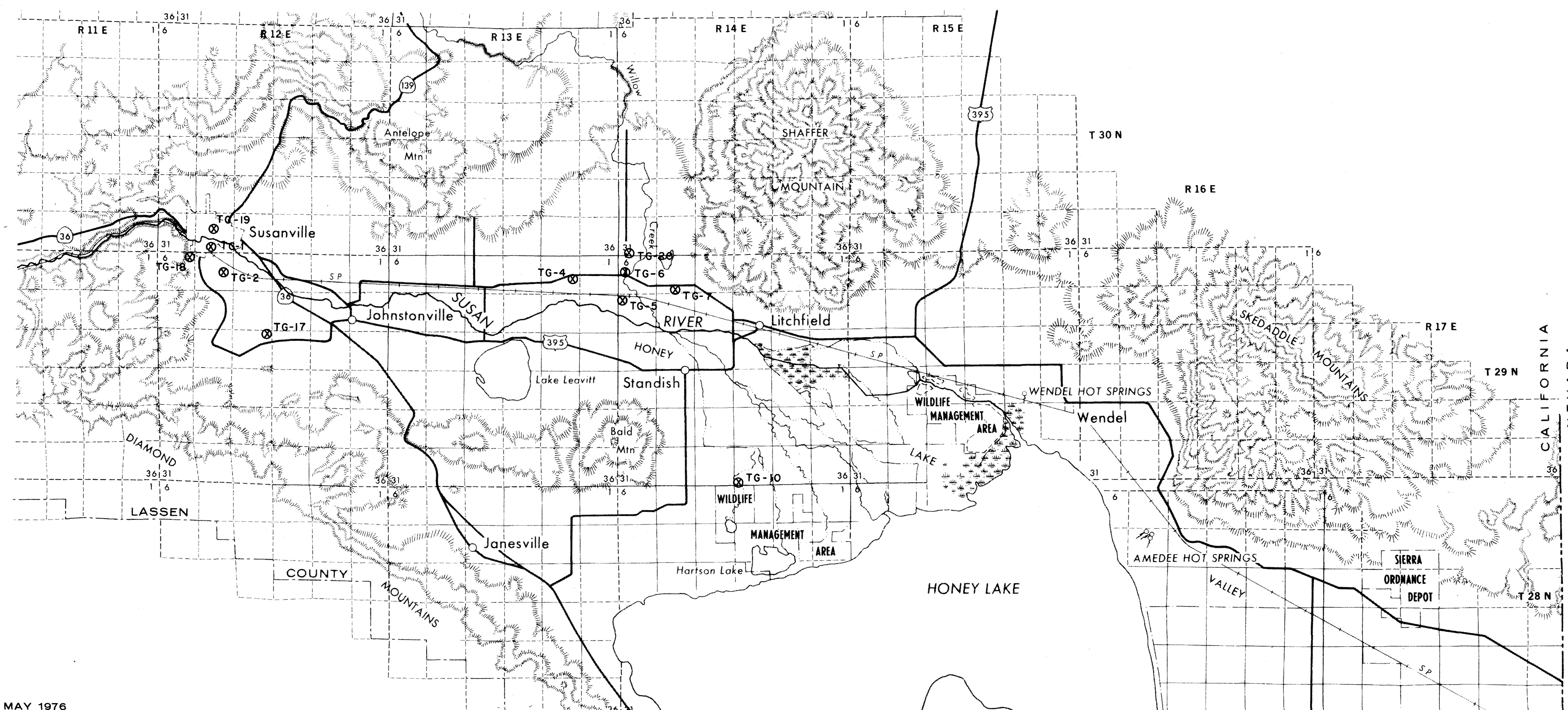
SUSANVILLE GEOTHERMAL INVESTIGATIONS

LOCATION
EXISTING WELLS & TEST HOLES
Susanville Area

MAY 1976

1315-208-10



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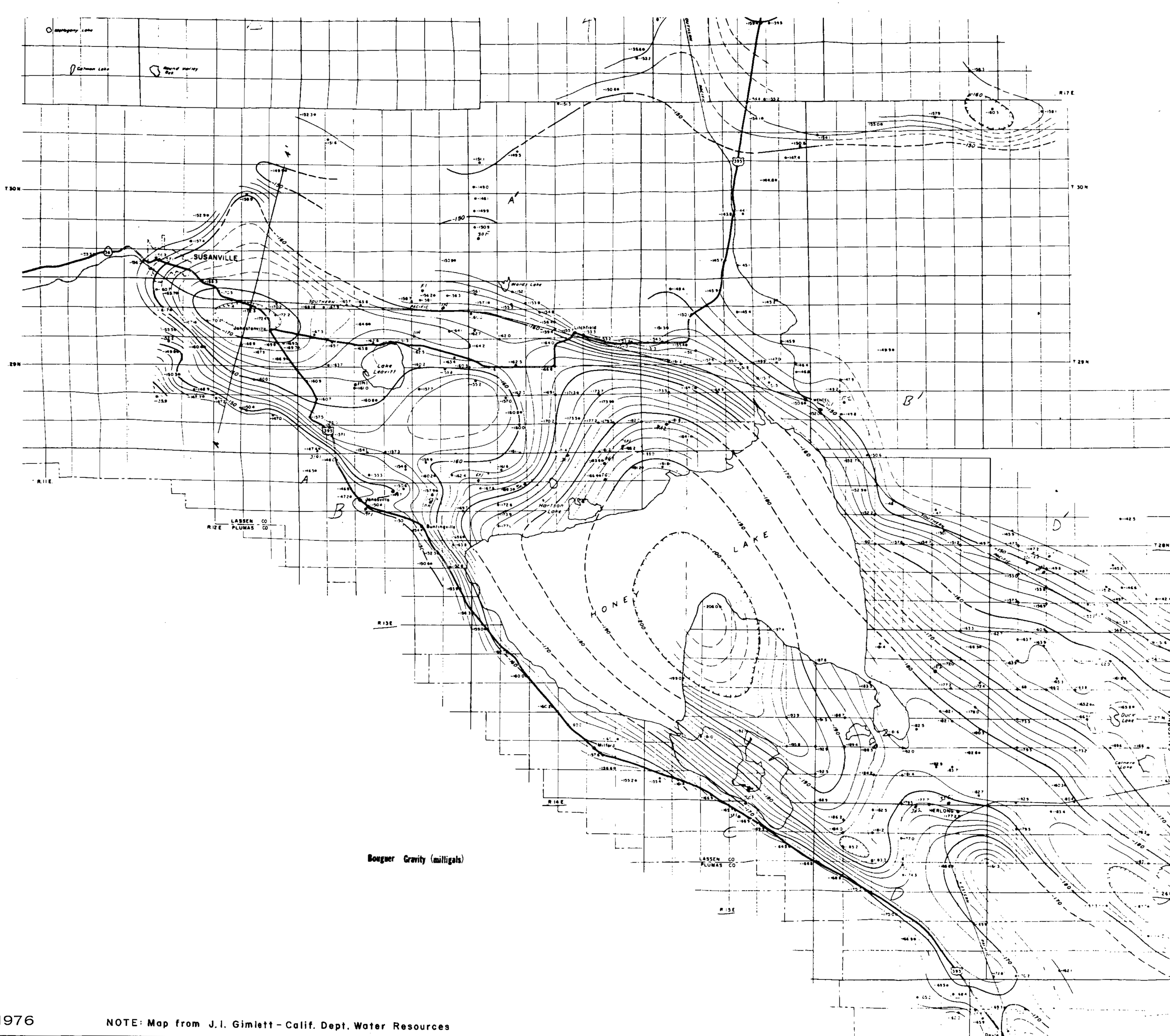
SUSANVILLE GEOTHERMAL INVESTIGATIONS

LOCATION OF TEST HOLES
Susanville-Honey Lake Valley

MAY 1976

1315–208–11



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BOUGUER GRAVITY

MAY 1976

NOTE: Map from J. I. Gimlett - Calif. Dept. Water Resources

1315—208—9