Hydrologic Report 4

New Mexico Bureau of Mines & Mineral Resources

A DIVISION OF
NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY

Catalog of Thermal Waters in New Mexico

by W. K. Summers

SOCORRO 1976

First edition, 1976

Published by Authority of State of New Mexico, NMSA 1953 Sec. 63-1-4
Printed by University of New Mexico Printing Plant, March, 1976

Available from New Mexico Bureau of Mines & Mineral Resources, Socorro, NM 87801

Price $10.00

Contents

TABLES

continued on next page

CHEMICAL ANALYSES ON MICROFICHE IN POCKET AT BACK:

FIGURES

Abstract

Waters at 67 locations in New Mexico discharge at anomalous temperatures. Details on these thermal water resources such as the location, temperature, discharge rate, field pH, and specific conductance are presented in 29 tables and 47 figures. Included also are 244 chemical analyses of water from 38 areas.

Introduction

PURPOSE AND SCOPE

This document presents in one volume all available information that geologists, engineers, and chemists have been preparing for many years on the anomalously warm and hot waters of New Mexico. Two types of thermal data are included:

1) Information about individual occurrences that could be gleaned from the literature and from searching the files of state and federal agencies.

2) Results of investigations by the New Mexico Bureau of Mines and Mineral Resources, including a field inventory and laboratory analyses of the waters made during the period October 1965 through June 1966, data obtained at intermittent intervals from 1967 through 1974, and results obtained when 15 thermal areas were revisited in December 1974.

Earlier lists of thermal water occurrences have not been entirely accurate. Some springs have been listed several times in some compilations but under different names. Some compilers made assumptions about locations that were not valid. For example, some of the references report a hot spring on the Rio Grande at the present site of Truth or Consequences. Others report Palomas hot spring at the location of the old community of Palomas. Still others report Caballo hot springs. A study of the area's history and field inspection reveals that only one thermal water area occurs in the immediate vicinity of Truth or Consequences, that the community was once called Palomas Hot Springs, and that the springs are located at or adjacent to the Caballo Mountains. Thus, these springs, which have been given different locations by at least one author are, in fact, identical, so that misinterpretations by one compiler have been carried forward by several others, making the reports in error.

To overcome these inaccuracies, this report lists only those occurrences of thermal waters that I have field-checked or whose location and character I believe to be accurately and responsibly described. Insofar as possible, discrepancies are identified and explained.

Two other problems arose repeatedly:

1) When water issues from multiple outlets, observers failed to describe the outlet sampled. As a result, some data are of dubious or limited value. For example, 9 chemical analyses of water for Mimbres Hot Springs collected in May 1904 and reported by Hare and Mitchell (1912, p. 48-49) cannot be related to their outlet source.

2) A surprising number of reporters are inclined to overstate or overestimate the temperature and discharge of thermal springs, so various quantitative reports are inconsistent with the other reports and with my measurements.

To overcome the descriptive problem for the hydrothermal areas listed here, all the data for each are presented, even though (as in the Hare and Mitchell case) we now lack the capacity to relate specific data to their specific source within the area. There is no solution to the authenticity problem, so no data have been omitted simply because they look wrong.

As a consequence of the descriptive problem and the authenticity problem, great care has been exerted to identify the exact location of each water sample collected during Bureau-sponsored investigations.

This is a water-resource report; yet it is also an energy-resource report because it describes natural phenomena that may indicate a geothermal energy resource. Actually, it describes the character and distribution of water from an amazing variety of hydrogeologic settings. About the only factor that the thermal areas of the state seem to have in common is that they discharge water with anomalously high temperatures. The source of the heat, the mechanism by which the water becomes warm, the volume of hot water extant, and the long-range consequences of developing the thermal-water resources are not immediately evident. Nor is there necessarily a clear indication of the role water has played, if any, in the hydrologic cycle, even though most thermal springs occur in settings comparable to those of their nonthermal cousins.

No attempt has been made to explain the occurrence and distribution of the observed hydrothermal phenomena.

ORGANIZATION OF REPORT

This catalog presents the thermal areas by drainage basin, as defined by the Inter-Agency Committee on Water Resources, Subcommittee on Hydrology (1960, written communication), with the drainage basins listed in alphabetical order. Within drainage basins the thermal areas are listed in "conventional" downstream order; that is, the uppermost area in the drainage basin is presented first, then each area downstream is presented in order of its occurrence. This sequence brings related areas together.

The information is presented via text, tables, maps, graphs, and microfiche. The microfiche (in pocket) contains the chemical analyses of thermal waters made in various laboratories and, identified by the letter M, appear in numerical order by drainage basin.

ACKNOWLEDGMENTS

Numerous individuals contribute to a report of this kind, ranging from those who permitted access to wells or springs on their property to students who worked in the laboratory helping with the chemical analyses or with plane-table mapping to professional colleagues who assisted by contributing data or advice.

Many people merit individual recognition, but to give each the credit he deserves would be physically impossible in the space allotted here. To each of you who have contributed, in whatever form, I express my gratitude.

This study was supported in part by funds provided by the U.S. Department of the Interior, as authorized under the Water Resources Act of 1964, Public Law 88-379.

HISTORICAL RECORD

The earliest report containing an eyewitness account of a thermal water in New Mexico, uncovered during the literature search, is that of Bartlett (1856), who describes a visit to Faywood Hot Spring in 1851. However, Stanley (1950) refers to a document written in 1848 that mentions the warm springs near Socorro. Hayden (1869) briefly mentions visiting Las Vegas (Montezuma) Hot Springs.

From about 1870 to about 1890, George W. Wheeler, of the U.S. Army Corps of Engineers, was in charge of the U.S. Geological Survey west of the 100th meridian. Under his orders, surveying parties crisscrossed New Mexico and prepared a series of topographical atlas sheets. Several of the thermal springs described in this report appear on Wheeler's sheets:

Spring name used in this report	Delineated by Wheeler
San Ysidro Spring	Economic Features of Central New Mexico, Atlas Sheet No. 77 (B) (1877) (expeditions of 1871 and 1876)
Ojo Caliente Ponce de Leon Warm Springs San Antonio Hot Springs San Antonio Warm Springs Jemez Hot Springs	Land classification map of part of north-central New Mexico, Atlas Sheet No. 69 (D) (1876) (1878) (expeditions of 1873, 1874, 1875, 1876)
Montezuma Hot Springs	Land classification map of part of central New Mexico, Atlas Sheet No. 78 (A) (1879) (expeditions of 1874, 1875)
Apache Tejo Warm Springs Kennecott Warm Springs Faywood Hot Springs Mimbres Hot Springs	Land classification map of part of western New Mexico, Atlas Sheet No. 84 (C) (1880?) (expeditions of 1877, 1878)

Loew (1875a) presented the first chemical analyses of waters collected from hot springs around the state. Crook (1899) visited several of the thermal-water spas. Jones (1904) compiled a list of thermal waters in this state and presented various pieces of new information where available. The hot springs in the Jemez region received attention from Kelly and Anspach (1913), Clark (1929), and Renick (1931). From 1931 to 1965, the thermal waters in the state have been studied individually or in groups of two or three as part of other areal studies. The following publications contain lists of thermal waters that by and large are repetitive statements of information gathered earlier by field workers: Gilbert (1875), Peale (1886, 1894), Reagan (1903), Lindgren (1910), Lindgren, Graton, and Gordon (1910), Steams, Stearns, and Waring (1937), Waring (1965), and Summers (1965a, b).

Several papers and reports, such as Trauger and Doty (1965), simply state that thermal waters occur at one or more localities.

Since 1965, new information has been generated at a more rapid rate.

For the period 1965-1971, the chemical analyses of water from springs and wells made by the U.S. Geological Survey for the most part have, been published annually in *Water Resources Data for New Mexico Part 2, Water Quality Records.*

Trauger (1972) discussed briefly the temperatures of water in Grant County and presented tables describing the location of wells and springs in the county and tables of chemical analyses of ground water that include some thermal water.

Purtymun, West, and Adams (1974) sampled the thermal waters of the Jemez River basins, and F. W. Trainer (1974a,b), a hydrologist with the U.S. Geological Survey, described the preliminary results of his detailed study of the thermal waters of the Jemez River basin.

Biology of thermal waters of New Mexico has been mentioned briefly in papers by Richardson (1898) and Brues (1928, 1932). Dr. Austin Phelps, professor emeritus, Zoology Department, University of Texas (Austin) and his students (Duke, 1967) spent considerable effort in the study of organisms that dwell in the thermal waters at Mimbres Hot Springs and Gila Hot Springs.

In recent years, large areas of the state have been the subject of intensive regional mapping efforts. Some of these efforts have been published *in toto*, others have been published incrementally. A few of them are available only as open-file maps and reports of the U.S. Geological Survey or of the New Mexico Bureau of Mines & Mineral Resources. Several are not yet complete.

To enumerate all of the reports and maps that cover thermal areas would produce a list of 100 to 500 documents. The length of the list would depend upon the scale of the compiler's interest and upon the factors an individual compiler considers significant. Readers interested in compiling a comprehensive bibliography will find the pertinent maps and reports indexed by area and author in the New Mexico Bureau of Mines & Mineral Resources bulletins, *Bibliography of New Mexico Geology and Mineral Technology:*• through 1950, Bull. 43; 1951-1955, Bull. 52; 1956-1960, Bull. 74; 1961-1965, Bull. 90; 1966-1970, Bull. 99; 1971-1975, in preparation.

Although a concentrated effort was made to consolidate literature, the following publications were not inspected, even though they may contain some information on New Mexico's thermal waters: Abert (1848a,b), Fitch (1927), Moorman (1867, 1871), Walton (1873, 1874, 1883).

PROGRAM OF NEW MEXICO BUREAU OF MINES & MINERAL RESOURCES

Work on this publication actually began ten years ago. It started with the compilation of the extant data (Summers, 1965a) and a critical review of the data's usefulness for geological purposes (Summers, 1965b).

With the blossoming interest in geothermal energy in the mid-1960's, a program to inventory New Mexico's thermal waters was initiated and carried out during 1966 and 1967. It was made possible by a matching-fund grant from the U.S. Office of Water Resources Research obtained through the New Mexico Institute of Water Resources Research. The unpublished project completion report, *New Mexico Thermal Waters*, consisted of two parts: Part 1 cataloged the basic data obtained during a field inventory of 46 to 57 known thermal areas and all the nonproprietary data generated by others through 1966. Part 2 contained a summary, text, and general discussion of the data contained in Part 1.

Since completion of the project, I have learned of a few wells that discharge hot water. Thanks to J. C. Ratte of the U.S. Geological Survey, I was able to helicopter into The Meadows, a warm-spring area in the Gila Wilderness, to map the springs and collect water samples.

In December 1974 Frank Trainer of the U.S. Geological Survey, Robert F. Kaufman of the U.S. Environmental Protection Agency, and I, as the representative of the New Mexico Bureau of Mines & Mineral Resources, visited 15 of the thermal areas.

The Bureau program has produced several shorter reports. As a prelude to this catalog, preliminary reports on New Mexico thermal water were presented to the scientific community (Summers, 1966a,b,c, 1969b, 1972b, and Summers and Deju, 1972). Geothermal prospects in the state were discussed repeatedly (Summers, 1968a,b, 1969a, 1970, 1972b,c, and Summers and Kottlowski, in press). The validity of chemical analyses of thermal water was studied in detail (Summers, 1972b), and some aspects of the geochemistry of New Mexico's thermal waters were considered (Summers, 1966c, Summers and Brandvold, 1967, Summers and Deju, 1972).

1966-1967 INVENTORY

The procedures used during the inventory of 1966-1967 were established to obtain maximum data in minimum time. Although the thermal waters discharge under a variety of circumstances and each area was treated as a unique situation, the approach in the field was as systematic as time and conditions permitted. The area was mapped, field measurements were made of the discharging water, rock and water samples were collected, and photographs were taken to illustrate various features of the area.

Because an exact statement of the sample location was deemed a must, the individual wells or springs discharging hot (and in some instances, cold) water were located on a map. These maps ranged in quality from simple field sketches to standard U.S. Geological Survey topographic maps to detailed plane-table surveys. The plane-table maps were drawn at scales varying from 5 to 200 ft to the inch. In some instances, plat maps and aerial photographs augmented the field mapping.

After the areal distribution of the thermal discharge was established, measurements were made at selected sites of flow, temperature, pH, and specific conductance. A modified Parshall flume, designed by A. I. Johnson (1963) of the U.S. Geological Survey, was constructed in the metal shop of the New Mexico Institute of Mining and Technology. This particular flume was not rated in the laboratory, the rating curves that Johnson gives being used to determine the flow in gpm (gallons per minute). Ideally, the flume should have been rated, but several factors contributed to the decision not to do so. First, the measurements in all probability would not be duplicated for many years; therefore, "order of magnitude" accuracy would be entirely satisfactory for most purposes. Second, setting the flume under field conditions probably introduces more error than is inherent in the flume design. Third, a cross-check in the field against discharge measurements from other sources indicated that the probable error is less than five percent.

In some areas, no discharge measurements were possible, but visual estimates of the discharge were made. Discharge from wells generally occurred only if a pump operated or the well flowed naturally. The discharge of pumping wells was estimated from pump size and power. The discharge of flowing wells was generally measured with the flume.

The pH of the discharging water was measured wherever practical with an E. H. Sargent and Company portable pH meter (catalog number S-30007-10). Buffer solutions used in the field were pH 4, 7, and 10. The meter was calibrated before each use. Under field conditions, this meter is accurate to at least ± 0.2 pH unit.

The accuracy of the meter proved to be the least of the problems. Experience in the field soon showed that the mode of discharge and storage of the water had a considerable impact upon the observed pH. In general, the pH of the water in the range of 6 to 10 reflects the CO_2 (carbon dioxide) concentration in the water. Thus, the pH of a water as it discharges is not necessarily the pH after it has ponded. Similarly, if the water cascades, it becomes aerated and will have a pH different from that where it leaves the zone of saturation.

To overcome the variations created by mode of discharge and storage (many springs have been channeled into closed reservoirs or have been ponded), the pH measurement was made in the discharging water by lowering the glass electrode into the water at a point where it discharged from the rock. Measurements were also made in spring ponds or reservoirs.

For some springs, it was not possible to measure the pH at the point of emergence because of reservoirs or ponds. The pH of water discharging from a well was also suspect, especially if the water passed through a pressure tank; nonetheless, it was measured and reported, whenever possible. A pH probe capable of measuring pH at various depths below the water surface would have added much valuable information about natural thermal waters.

Specific conductance was also measured *in situ*, using an Industrial Instruments, Inc., conductivity bridge accurate to about ±10 percent and recorded in micromhos per centimeter at 25°C.

Temperatures were measured with a Whitney Underwater thermometer—a direct-reading, self-calibrating thermistor unit. This thermometer is internally accurate to ±0.1°F; that is, it is possible with the instrument to duplicate measurements to ±0.1°F. Such checks as were performed showed that this instrument was at least as reliable as many non-Bureau of Standards mercury thermometers that could be read to ±0.1°F. Because the thermistor is at the end of 300 ft of cable, measurements were made to that depth whenever possible.

A Hach Chemical Company portable colorimeter was used to obtain values for the concentrations of silica and ammonia. The procedures followed are those given on pages 47-48 (ammonia) and pages 77-78 (silica) of the Hach DR Colorimeter Methods Manual, fifth edition.

The presence of H_2S (hydrogen sulfide) was established by the Hach Chemical Company procedure, in which the H_2S is aerated out of a water sample by the addition of an Alka-Seltzer effervescent tablet to the sample. The gas is made to pass through a disk of H_2S-sensitive paper inside the cap of the test bottle. The paper becomes brown if H_2S is present. The amount of H_2S is determined by comparing the color of the moist paper with a color chart.

Samples were then collected, the number and type being determined by the mode of discharge (whether from a well, an upwelling spring, or a cascading spring), the number of discharging units, the prior knowledge of geology and hydrology, and the on-site measurements.

A complete set included: a 5-gallon sample from the principal orifice and 1-gallon samples at other principal outlets (to these samples, about 1 ounce of chloroform was added to kill any microorganisms present); and 8-ounce samples from most outlets (these samples were acidified to prevent precipitation of the cations upon oxidation).

The data in this report differ from those in the completion report of 1967 in one very significant way. L. A. Brandvold, of the New Mexico Bureau of Mines & Mineral Resources, painstakingly reviewed all chemical analyses made in the Bureau's analytical laboratory and made the following corrections and deletions:

1) Carbonate (CO3) and bicarbonate (HCO3) concentrations were reported as ppm $CaCO_3$ rather than ppm $CO^-{}_3$= and ppm HCO3 . These values were corrected and appear here as ppm COT and ppm HCO3 .

2) The method used to determine nitrate concentration, the calcium reduction method, has been proved unreliable, so the nitrate values have been deleted.

3) When sulfate concentrations were less than 100 ppm, a turbidimetric method was used for determining that concentration. This method has also been proved unreliable, so sulfate concentrations of fewer than 100 ppm have been deleted.

4) A check of the original laboratory data books revealed some data that had been left out. These data have been included herein.

5) A check of the original data books showed that a set of chloride analyses was in error. This was deleted.

6) Where one or more major ion concentration values were deleted from the water analyses, the "calculated dissolved solids" value has also been deleted.

7) Numeric typographical errors have been corrected.

DECEMBER 1974

During the period December 2-5, 1974, 15 thermal areas inventoried during 1966-1967 were resampled.

Kaufman, U.S. Environmental Protection Agency, collected water, soil, and algae samples to ascertain the radon and radium content. Trainer, U.S. Geological Survey, collected 10 water samples for analysis by the U.S. Geological Survey laboratory in Salt Lake City. Bureau personnel collected 17 samples of water for conventional analyses, including trace elements, and 18 samples for heavy metals. Trainer and Bureau personnel made individual measurements of specific conductance, temperature, pH, and bicarbonate and carbonate concentrations.

Bureau personnel also made field measurements for conductivity, using a Yellow Springs conductivity meter; pH, using a Sargent portable pH meter; and carbonate and bicarbonate, using a Hach alkalinity kit, model AL-AP. In the laboratory, chloride (mercuric nitrate method), sulfate (gravimetric method), boron (carmine method), bromide (phenol red method), and nitrate (diazotization method) were determined by standard procedures (American Public Health Association, 1971). Fluoride and nitrate were determined using ion selective electrodes. Sodium, potassium, lithium, magnesium, manganese, silica, and zinc were determined directly by atomic absorption. The graphite furnace attachment to the atomic absorption was utilized to determine aluminum, iron, copper, chromium, cadmium and lead. Calcium was titrated by the method of Yalman and others (1959). The flameless atomic absorption method of Hatch and Ott (1968) was used to determine Mercury. Molybdenum was determined colorimetrically using the thiocyanate method of Ward (1951).

The following table lists the detection limits for the trace-level ions reported for these samples:

Element	Limit in ppm
Al	0.010
B	0.2
Br	0.05
Cd	0.0001
Cr	0.001
Cu	0.005
Fe	0.010
Hg	0.001
Mn	0.01
Mo	0.01
Pb	0.001
Zn	0.01

DEFINITION OF ANOMALOUSLY THERMAL WATER

Subsurface temperatures are affected by climatic conditions to a depth of about 100 ft. Below 100 ft, they increase about 1.8°F every 100 ft, on the average. Ground-water movement carries heat from recharge areas to discharge areas, thus depressing temperatures in the recharge areas and increasing them in the discharge areas (Domenico and Palciauskas, 1973). Collins (1925) demonstrated that ground-water temperatures to a depth of 100 ft in discharge areas average about 4°F warmer than the average annual air temperatures. Since springs by definition are in discharge areas, we should expect the temperature of water discharging from springs that derive from shallow-flow systems to have temperatures that reflect climatic conditions, and those that derive from deeply circulating flow systems to have temperatures higher than the annual air temperatures and to show little seasonal variation.

The definition of anomalous temperatures must be based upon some prespecified difference between expected and observed termperatures because ground-water temperatures depend upon both the heat and water budgets. In most areas, we lack the information needed to make analytic predictions of the expected temperature, so even if we could specify a difference, we lack the data to determine it. Simply choosing some minimum absolute temperature is not entirely practical, because this catalog would then include many wells whose water temperature is normal for their depth and, depending upon the temperature chosen, could exclude some occurrences that are truly anomalous. Yet it is the method used here.

A frequency analysis of the temperatures of warm and hot springs in New Mexico (Summers, 1965b) showed that 90°F offered a convenient dividing point between the more abundant cooler spring temperatures and the less frequent warmer springs. A consideration of the water temperatures in Grant County from springs and wells less than 1000 ft deep (Trauger, 1972, p. 120-200) shows that they may be divided into two populations with normal distributions. The population that includes most of the temperatures observed is such that the temperature which is warmer than 99.99 percent of the population is about 80°F. The second population includes the anomalous temperatures, and 0.01 percent of this population is colder than 85°-90°F. Thus the choice of 90°F anomalous seems reasonable. The probability of a water•source having a temperature of less than 90°F and being anomalous is small.

When water temperatures from wells in New Mexico are plotted as a function of depth, the probable average gradient is usually less than 2.0°F/100 ft. For example, data for wells at the Pueblo of Zuni indicate a gradient of 1.2°F/100 ft (Summers, 1972d); data from the San Cristobal Grant, Santa Fe County, indicated a gradient of 1.9°F/100 ft (Summers, 1970).

Therefore, the following criteria have been adopted for this report:

1) The water from any spring or from any well less than 500 ft deep with a temperature of 90°F or higher is assumed to be anomalous.

2) The water in a well 500 ft or deeper is considered anomalous if the temperature is at least 90°F and if the temperature is greater than that obtained by the relationship,

$$T < A + 4 + 0.027 Z,$$

where T is the temperature predicted (°F),
A is the mean annual air temperature (°F),
Z is the average depth of the contributing interval in the well (ft).
(The factor 0.027°F/ft is an arbitrary choice of a gradient that is 1.5 times the average.)

3) If circumstances suggest that cooling from these requisite temperatures has occurred, the water temperature is still assumed to be anomalous.

DEFINITION OF THERMAL AREA

The definition of thermal area must also be arbitrary. For example, the Truth or Consequences thermal area (Hot Springs Basin of the State Engineer) is one thermal area. The area is compact and continuous. A well anywhere in the area would produce anomalously warm water. But what about the Faywood Hot Springs, Kennecott Warm Springs, Apache Tejo Warm Springs area in Grant County? The springs appear along a line 12 miles long and are similar in occurrence and basic chemistry. Is this one area or three? To resolve questions of this sort, the following criteria have been used to determine those occurrences which are cataloged separately:

I) The area must have at least one occurrence of anomalous temperature.

2) If two outlets occur, they must be either a) less than one mile apart or b) the geology and hydrology must be such that a continuous anomaly could exist among the several known anomalies.

In the Faywood case, field evidence indicates that the zones are not continuous near the surface.

Thus, the Socorro area and the Cliff-Gila-Riverside area, encompassing several square miles each, are presented as one thermal area, whereas the occurrences of thermal water in the upper Gila River drainage, occupying small areas, are each counted as one thermal area.

Doubtless as we learn more about the geology and hydrology of these areas, some that seem to be isolated will be found to be extensions of other areas, and some areas that now seem to be continuous will be found to be divisible into separate parts.

SYSTEM FOR NUMBERING WELLS AND SPRINGS

The numbering system used herein (used by the New Mexico State Engineer) is based on the common units of township and range.

The location number consists of four segments separated by periods, as 4S.13W.27.314. The first segment on the left designates the township and the next, the range, with the letter indicating direction; the third segment designates the section; and the fourth, or right-hand segment, locates the well or spring within the section, as follows: each section is divided into quarters numbered from left to right. The northwest quarter is number 1; the northeast quarter, number 2; the southwest quarter, number 3; and the southeast quarter, number 4. Each quarter section is again divided into

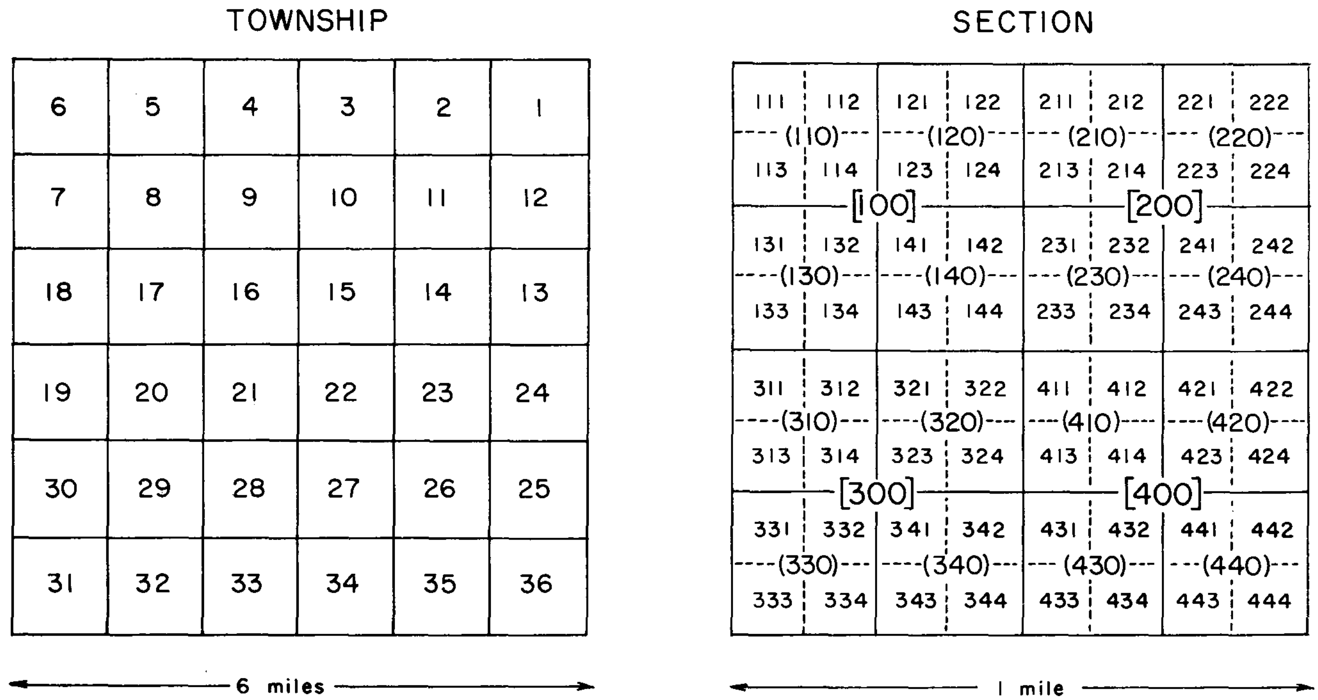


FIGURE 1—Method of numbering sections in a township and tracts in a section.

quarters and numbered in the same order. Each quarter-quarter section is similarly divided and numbered, thus locating a spring or well to the nearest 10-acre tract. Therefore, the first digit of the fourth segment locates the quarter section; the second digit, the quarter-quarter section; and the last digit, the 10-acre tract (fig. 1). For a location that cannot be established to a 10-acre plot, the indefinite subdivisions are indicated by zeros; for example, a spring that is known to be in the northwest quarter section but which cannot be located with reference to smaller subdivisions is known as ".100."

So the location number above, 4S.13W.27.314, places the well in SE¼NW¼SE¼ sec. 27, T. 4 S., R. 13 W.

In unsurveyed areas, the locations were estimated by superimposing a township grid on the best map available.

Gila River Basin

UPPER GILA RIVER BASIN

The thermal waters of the upper Gila River basin occur in the Gila Wilderness and the Primitive Area. Ratte and others (1972) mapped the geology of the wilderness and primitive area at a scale of one inch to one mile. Their report also includes a complete Bouguer gravity map, an aeromagnetic map, and geochemical analyses of 573 rock samples. According to their report (p. 191), "A northwest-trending belt of thermal springs within the complex arcuate Gila Hot Spring graben, indicates a possible geothermal energy resource in the Gila study areas."

THE MEADOWS (WARM SPRING) (1 1S. 14W.30.200)

The Meadows (fig. 2) is an area about 200 ft wide by 750 ft long, where thermal waters discharge from discrete points and from a bog. On November 12, 1969, the flow (table I) from individual outlets ranged from less than 1 to 23 gpm. The total flow from The Meadows was 69 gpm.

Temperatures of discharging water ranged from 57° to 91°F. Air temperatures ranged from 45° to 52°C. The chemical character of the water seems to be independent of the outlet. Field specific conductance values ranged from 180 to 240 Amho/cm at 25°C. Chemical analyses of 6 samples (table M 1) show only

Table 1 - Discharge, temperature, and specific conductance measurements November 12, 1969, The Meadows (warm spring) (sec. 30, T. 11 S., R. 14 W., Catron County, New Mexico)

Site*	(fig. 1)	Flow (gpm)	Air temp. (°C)	Warmest water temp. (°C)	Specific conductance (@ 25°C) micromhos	Remarks
1		>1				
2		>1				
3		5.8				
4	11	7.6		31.0	210	
5	10	20.2		30.0	220	Water sample
6	12	>1		29.5	200	
7	15	22.9		30.5	190	
8	16	25.6		29.0	-	
9	17	68.7		26.0	-	
10	19	34.1		27.5	-	Water sample
	1		11	19.0	220	
	2		-	23.2	200	Water sample
	3		7	16.0	190	
	4		-	20.0	190	
	5		-	28.0	195	Water sample
	6		-	15.0	240	Stagnant pool
	7		10	14.0	-	
	8		-	16.0	195	
	9		-	22.0	210	
	13		-	31.0	180	
	14		-	32.5	220	Water sample
	18		-	11.0	-	Gila River

* see fig. 2

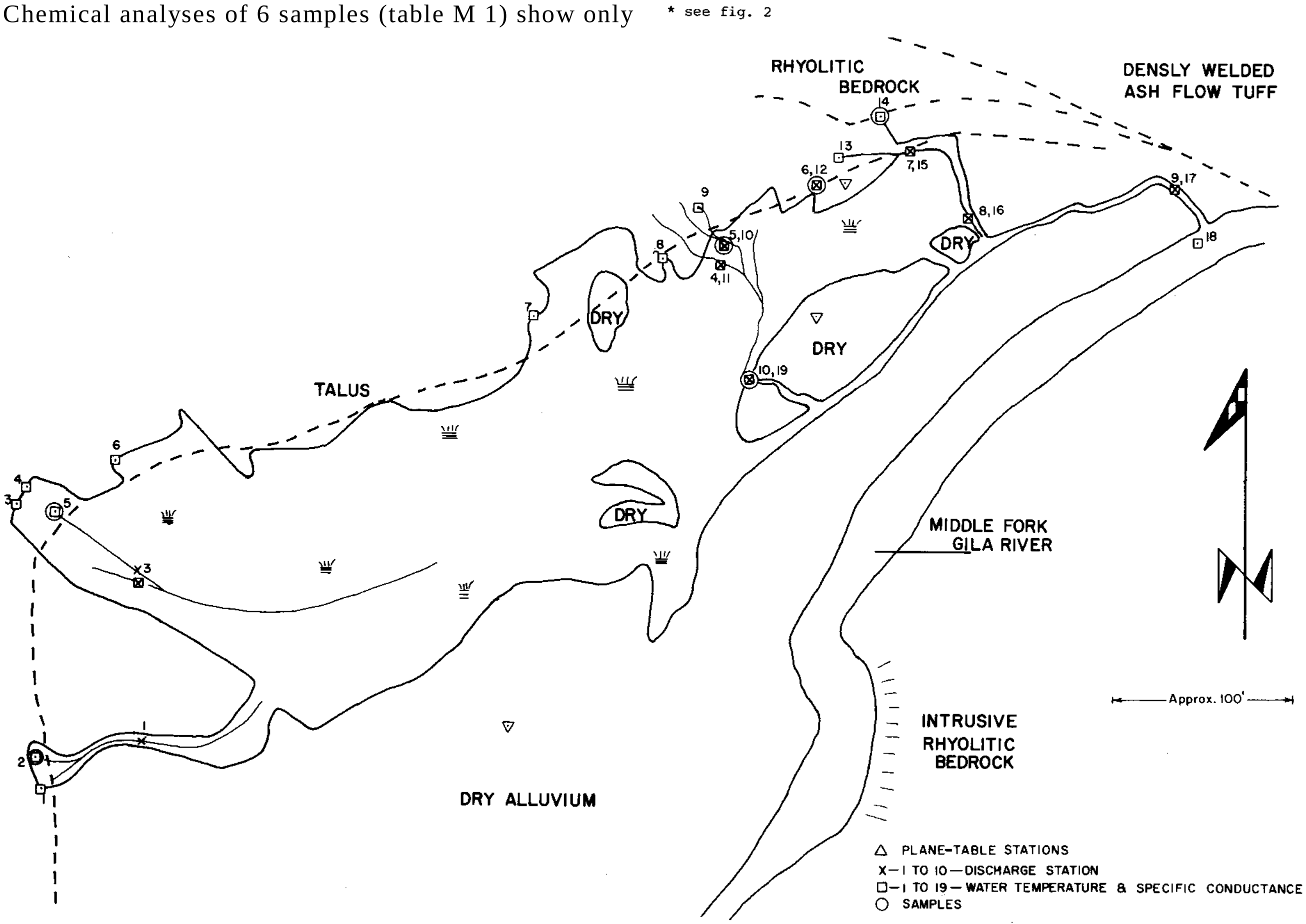


FIGURE 2—PLANE-TABLE MAP OF THE MEADOWS, SHOWING THE LOCATIONS AT WHICH FLOW RATE, TEMPERATURE, AND SPECIFIC CONDUCTANCE OF DISCHARGING WATER WERE MEASURED NOV. 12, 1969, AT THE POINTS WHERE WATER SAMPLES WERE COLLECTED.

trivial differences. The total dissolved solids range from 145 to 160 ppm.

No NAME SEEP ON MIDDLE FORK GILA RIVER (11S.14W.35.400)

This small seep is about one-third of a mile upstream from Jordan Canyon on the south side of the Middle Fork Gila River in the Gila Wilderness, Catron County. The water discharges from horizontal fractures in rhyolite about a foot above the valley fill alluvium and 15 ft above the low-water stage of the river. The discharge seeps into the alluvium or evaporates; it does not run off.

On February 26, 1966, the discharge was so small that it could not be measured by any conventional means (an eight-ounce sample bottle filled in three or four minutes). Although the flow was very slow and the air temperature was 32°F, the water temperature was 80.9°F. These facts, together with the observation that the snow in the immediate area of the seep had melted, suggest that this seep reflects a significant thermal anomaly.

A meaningful field measurement of the specific conductance of the discharging waters was not possible.

No NAME SPRING, MIDDLE FORK GILA RIVER (12S.13W.7.340)

This spring is near the Middle Fork Gila River, Catron County, about 3 miles downstream from Little Bear Canyon. The water discharges from multiple outlets on the east side of a little canyon on the northeast side of the river. It discharges from the base of a talus slope made up of blocks of basalt, rhyolite, rhyolite breccia, and rhyolite tuff that has been truncated by an arroyo. Here it cascades over a steep, rock-rubble slope. Water also discharges from small boils in the floor of the little canyon.

Willard, Weber, and Kuellmer (1961) show that the rock of the area consists of basalt and basaltic andesite of Quaternary age that contains thin beds of rhyolite tuff, with Gila Conglomerate overlying the basalt to the north and east. The Gila Conglomerate is a locally derived, massive, buff-colored, volcanic sandstone and conglomerate containing interbedded thin rhyolite tuffs in a few places. It is possible that the springs emerge from the contact between the conglomerate and the basalt but that this contact is concealed by the talus.

The discharge of the cascade or of individual boils could not be measured. However, the net discharge to the Middle Fork Gila River was gaged at 54 gpm.

The temperature, density, pH, and specific conductance at the cascade, a seep in the canyon floor, and at the flume where the discharge was measured were minor (table 2) as were differences in chemical analyses of water samples collected at the cascade and at a boil.

No NAME SPRING, MIDDLE FORK GILA RIVER (12S.13W.31.100)

On the Middle Fork Gila River, Catron County, is the spring that Gilbert (1875, p. 153), Peale (1886, p. 194), and Jones (1904, p. 311) referred to as "Diamond Creek, near mouth, Socorro County." Wheeler's 1876 topographic atlas sheet No. 83 shows the stream now called Middle Fork Gila River as Diamond Creek. Stearns, Stearns, and Waring (1937, p. 169) give a location that suggests they used a modern map to estimate the location. However, no field check was made of the location, and a thermal spring may exist near the mouth of present-day Diamond Creek.

This spring issues at the contact between the recent alluvial deposits of the Gila River and a basaltic andesite. A thin section of this rock contains 27 percent plagioclase feldspar (probably andesine), 8 percent zeolite, probably heulandite, 5 percent hematite, 1 percent glass, and 1 percent calcite; 19 percent of the thin section is an opaque mineral that may be hematite. The remaining 39 percent is a matrix made up of an intimate mixture of microcrystalline feldspar, clay, and hematite. On the west side of the river, the basalt is overlain by the Gila Conglomerate.

The water discharges at three distinct places: The most and the hottest water (149.6°F) comes from a small pool, 2 ft in diameter, at the rock face; it issues from a fracture in the andesitic basalt; and it seeps (114°F) from a bog a few feet from the opening in the rock. This bog occurs in a small depression 10 to 15 ft in diameter in the alluvium.

About 100 yards downstream, thermal water discharges directly into the Gila River. The discharge given in table 2, 47 gpm, comes from both the seep and the principal pool. The chemical analyses of the water from the pool and a partial chemical analysis of the water discharging directly into the Gila River (table M1) show that the water contains relatively few total dissolved solids.

TEST WELL (12S.13W.30.231)

In July 1964 a test well (12S.13W.30.231) was drilled into the Quaternary basalt to a depth of 600 ft. The water level was approximately 70 ft below the land surface when the well was finished. The temperature of the water was reported at 90°F. The hole was abandoned and is cited here as part of the available information on thermal waters of the upper Gila River drainage.

Approximately one quarter mile west, a second test well (12S.13W.30.124) was drilled in the alluvium of the Middle Fork Gila River valley on August 5, 1964, to a depth of 36.5 ft. The temperature of the discharging water was 62°F. On February 21, 1966, the following temperatures were observed in this well:

Depth (ft)	Temperature (°F)
0	*50.0
10	55.0
16	57.0
23	58.2
30	59.1

*Air temperature at top of casing.

A comparison of the chemical analyses of the water from these two wells with two analyses of water from the Gila River and an analysis of the water from a dug well—(12S.14W.25.341; table M1), 15 ft deep with the water level 6 ft below the land surface—shows that the water from the deep well contains roughly 5 times more dissolved solids.

Table 2 - Field data for hot springs, upper Gila River basin

Location	Date	Discharge (gpm)	Maximum temperature (°F)	pH	Specific conductance (micromhos)	Density (gm/ml)	H_2S (ppm)	NH_3 (ppm)	SiO_2 (ppm)	Remarks
11S.14W.35.400 No name seep, Middle Fork Gila River	2-26-66	1	80.9	7.4	---	---	0	0.00	70	Air 32°F
12S.13W.7.340 No name springs, Middle Fork Gila River										
cascade	2-26-66	---	94.0	7.4	200	---	No odor	0.00	70	
boil	2-26-66	---	91.0	7.7	200	---	No odor	---	---	
flume	2-26-66	54	71.5	8.5	200	0.988	No odor	---	---	
12S.13W.31.100 No name spring, Middle Fork Gila River	2-21-66	47	149.6	7.2	460	0.978	No odor	0.05	100	
13S.13W.5.241	6-23-57	25?	147	---	---	---	---	---	---	USGS meas.
Gila Hot Springs	7-25-62	100?	147	---	---	---	---	---	---	USGS meas.
	2-17-66	---	106.7†	7.4	550	---	No odor	---	---	
	2-27-66	150*	151.5	---	---	---	No odor	0.05	100	
	12-05-74	---	147	8.6 & 7.5	620	---	No odor	---	---	
13S.13W.10.121										
Swimming pool	6-23-57	10?	126	---	---	---	---	---	---	USGS meas.
Spring	2-20-66	5	125.0	7.7	410	0.982	No odor	0.05	75	
East Fork spring	2-20-66	---	96.0	7.9	325	0.986	No odor	0.05	70	
Water Supply spring	2-20-66	20*	114	8.2	400	0.984	No odor	0.05	90	
13S.13W.10.200(?)	2-22-66	31	106.5	7.4	450	0.984	No odor	0.1	91	
13S.13W.20.430 Hot Spring main stem Gila River	3-27-66	20*	112.5	7.4	---	0.986	No odor	0.00	110	

*estimate

†temperature at sample point

GILA HOT SPRINGS (135.13W.5.241)

These springs, which are in Grant County, are probably those referred to by Gilbert (1875, p. 153) and Peale (1886, p. 194) as "Gila River, near Diamond Creek, Socorro County," and by Jones (1904, p. 310) as "Gila River Hot Springs." Gilbert reports the temperature as "about 100°F" and, apparently, Peale (1886), Jones (1904), Stearns, Stearns, and Waring (1937, p. 169), and Waring (1965, p. 38) simply repeated him. However, D. A. Campbell, present owner of the springs, says to his knowledge they have always been much warmer. Stearns, Stearns, and Waring give the discharge as 900 gpm, but none of their data sources gives this number nor is a date given. The validity of this temperature report is suspect.

Note that the description of this spring, which has been known as Gila Hot Springs for many years, as being near Diamond Creek supports the contention that "Diamond Creek" here refers to Middle Fork Gila River and not to the present-day Diamond Creek.

These springs lie on the north side of the Gila River. They discharge approximately 150 gpm from multiple outlets—fractures in rhyolite—over an elevation interval above the river of 0 to 30 ft. The analyses indicate that the total dissolved solids of the discharging water are on the order of 400 to 500 ppm. Table M 1 gives the chemical analysis of water samples collected in 1957 and 1962 (Trauger, 1972), as well as those of samples collected during 1966 and 1974 surveys.

Jones (1904, p. 310) gives the following analysis, which ". . . was made by William M. Courtis of Detroit, Michigan, October 5, 1903."

Constituents	Parts in 100,000
Sulphuric acid combined with lime and potash	3.420
Ferrous sulphate	0.221
Calcium sulphate	2.829
Soda and potash carbonates	14.020
Silica	6.562
Total solids	27.052

Table 3 gives the analyses obtained for heavy metals and radon-222 in samples collected December 5, 1974. Scott and Barker (1962, p. 78-79) report the radioactivity in water from Gila Hot Springs as:

Beta-gamma activity	12±2 ni./C/1 (picocuries/liter)
Radium	<.1 nnC/1 (picocuries/liter)
Uranium	1.4±.01 ng/1

About 60 gpm are taken from the spring and delivered to Campbell's ranch and trading post. The water provides both heat and water to the ranch, the trading post, and several mobile homes.

Table 3 - Heavy metals and radon-222 in thermal waters of the Gila River basin (concentration in ppb unless noted)

	Gila Hot Springs (25S.19W.7.133)	Lower Frisco Hot Spring outlet		Upper Frisco Hot Spring
Date	12-05-74	5-22-58	12-05-74	5-22-58
Barium	--	0.8	--	2.2
Copper	6.5	0.0	15	1.1
Chromium	3.	--	6.7	--
Cadmium	.2	--	1.1	--
Lead	5.0	--	11	--
Mercury	<1	--	<1	--
Zinc	15	0.00	51	0.00
*Radon-222	640	--	1800	--
(picocuries/liter)	680			
		USGS 38864		USGS 38851

* Analysis by the U. S. Environmental Protection Agency

LYONS HUNTING LODGE HOT SPRINGS (13S.13W.10.121)

These springs are in Grant County on the East Fork Gila River and probably correspond to those mentioned by Stearns, Stearns, and Waring (1937, p. 169), and Waring (1965, p. 38) as being in sec. 3, T. 13 S., R. 13 W.

Thermal water discharges in about three distinct locations and, if reports are correct, at a possible fourth location:

1) Upstream approximately 100 yards from the Lyons Hunting Lodge—A pipe, set into a fracture in basalt and cemented in, conducts water from the fracture to a small swimming pool. This spring is named in this report the Swimming Pool Spring. Table M 1 contains the chemical analysis of a water sample collected at the tap in the 2-inch line, about a ft from the natural outlet. The measurements given in table 2 were also made at the tap. The temperature of the water in each cascade was more than 90°F. Trauger (1972) collected a water sample from the Swimming Pool Spring on June 23, 1957; table M 1 contains an analysis of this sample.

2) About 100 yards downstream from the Lodge in the bed of the East Fork Gila River—This spring is named in this report East Fork Spring.

3) Approximately one quarter mile up a narrow canyon from the East Fork Spring, water discharging from fractures in basalt—A collection system conducts the water to a central pipe that delivers it to the Lyons Hunting Lodge. These springs are named in this report the Water-Supply Springs. The water cascades into view at 3 distinct points from vertical fractures in rhyolite, rhyolite tuff, and rhyolite breccia. Andesite and basalt also occur in the steep-walled canyon. A fourth outlet is not a cascade but a seep from a gravel cover at the base of the fractures. These springs are 20 to 30 ft above a small stream that runs in the canyon floor. The collection pipe is about 50 ft above the East Fork Spring at the mouth of the canyon. The uppermost discharge may be as much as 100 ft above the East Fork Gila River.

Water-Supply Springs were sampled at 3 points, upstream, midway, and downstream. Table M1 contains a partial chemical analysis of these samples. The observations reported in table 2 are of a necessity for water at the central collection point or at a cascade point, because the cascade begins at an altitude well above that which could be reached easily; in some instances, as much as 20 ft above the most accessible level.

4) According to D. A. Campbell, another spring lies in a small canyon upstream from the Swimming Pool Spring, about one quarter of a mile north of the East Fork Gila River. No effort was made to locate this spring.

The chemical analyses of waters which range in temperature from 96° to 126°F show only superficial differences and that the water contains about 400-500 ppm total dissolved solids.

NO NAME SPRING, EAST FORK GILA RIVER (13S.13W.10.200)

Because of the inadequacy of the existing maps, the location of this spring can only be approximated to half a mile east of the Lyons Hunting Lodge. The spring discharges about 31 gpm at 106°F from fractures in rhyolite tuff. The outlets for the discharging water occur over an elevation range above the river. Table 2 contains the measurements made at the spring; the chemical analyses (table M 1) show that this water contains less than 400 ppm total dissolved solids.

No NAME SPRING (13S.13W.20.430)

This spring was noted by Stearns, Stearns, and Waring (1937, p. 169), and Waring (1965, p. 38). It is on the east bank of the main stem of the Gila River in the Gila Wilderness, Grant County. The spring discharges 20 gpm at 112.5°F from beneath a talus cover 20 to 40 ft above the elevation of the river, cascading to the river.

The talus covers a rhyolite—one rock among several in a complex fault zone.

CLIFF-GILA-RIVERSIDE AREA

In T. 15 and 16 S., R. 17 W., an area roughly bounded by the communities of Cliff, Gila, and Riverside, springs and wells yield water with temperatures ranging from 68° to 92°F. In the immediate area of Riverside temperatures range from 85° to 90°F. Fig. 3, a map showing the location of some springs and wells, gives the temperature of the various sources (Trauger, 1972). The only well sampled during the 1965-1966 inventory was well 15S.17W.27.111. The temperature was 95°F (March 3, 1966). This well was drilled to 300 ft, but only

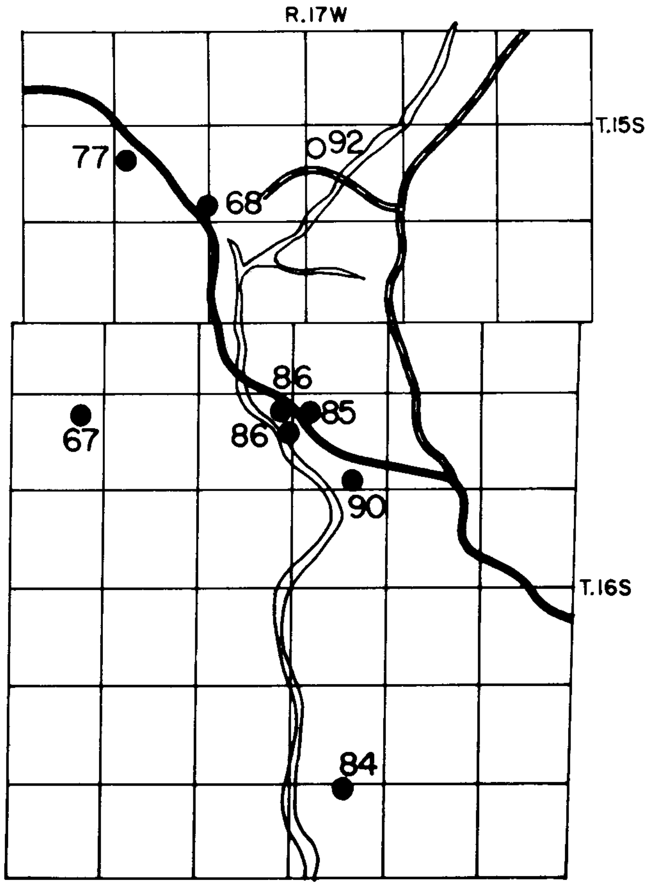


FIGURE 3—MAP OF CLIFF-GILA-RIVERSIDE AREA, GRANT COUNTY, SHOWING LOCATIONS OF WELLS AND SPRINGS HAVING ANOMALOUS WATER TEMPERATURES.

200 ft of 8-inch casing were installed. The casing is perforated from 75 to 85 ft and from 170 to 180 ft. The driller reported that water-yielding rock is a coarse sand and gravel. Trauger (1972) measured the water level in July 1962 and found it 17.5 ft below the land surface. The water-bearing formation at this site is reported to be the Gila Conglomerate; however, it may be more recent alluvium or terrace gravels.

Trauger (1972) made the following comments about water from other wells in the area:

Page	Well	Well Depth (ft)	Comment
1128	15S.17W.29.211	28	well tastes of soda and kills plants
1129	15S.18W.2.333	450	water unusable because of mineral content
1344	16S.17W.10.433a	35	pumped warm water that had a high concentration of fluoride

The chemical analyses of water from the area (table M2) show that the water contains less than 500 ppm total dissolved solids and is richer in fluoride and silica than the nonthermal water of Grant County as reported by Trauger.

According to Trauger (1972, p. 21) the Cliff-Gila-Riverside area is in the Mangas Trench, a northwest trending structural trough, which is in the transition zone between the Basin and Range Province to the south and the Colorado Plateau Province to the north.

ANIMAS VALLEY

WELL (22S.21W.3.312)

This well was drilled in 1946 for stock use. Records in the files of the State Engineer indicate that on June 14, 1955, the water level was 445.65 ft below land surface and that the temperature of the discharging water was 95°F. This well was reported by Reeder (1957, p. 73). Hood and Kister (1962, p. 46 and 58) cited it as one of those that produce saline water. They gave the temperature as 88°F on July 8, 1955. An attempt was made on June 20, 1966, to measure the temperature and to collect a water sample. The discharge rate was slow, less than 10 gallons per hour, and only a token sample could be collected. The maximum temperature observed was 88.5°F. However, the air temperature was between 70° and 80°F, so the water temperature at depth must be somewhat greater.

Hood and Kister reported the following:

HCO_3	431 ppm
Cl	102 ppm
Hardness as $CaCO_3$	128 ppm
Specific conductance	1590 mhos (at 25°C)
pH	7.8

The sample collected in June 1966 produced the following results:

Na	91 ppm
K	2.1 ppm
Ca	265 ppm
Mg	6.9 ppm

HOT WELLS (25S.19W.7.000)

In 1948, irrigators began developing the Lower Animas Valley as a cotton-producing region. Several wells were drilled in the valley. In 1948, one well struck steam (fig. 4) at 88 ft. One report in the State Engineer's files says the temperature of the discharging water was 240°F. By 1955, two other wells drilled within 100 yards of this well also produced steam at a shallow depth.

In 1955 Kintzinger (1956) made a study of the area around these wells. He drilled a series of holes to a depth of one meter, filled them with sand, shoved a thermistor probe through the sand, permitted it to stabilize, and then recorded the temperature at the one-meter depth. His work (fig. 5) shows that the maximum anomaly is located in the center of NW1/4SE1/4 sec. 7, T. 25 S., R. 19 W.

Reeder (1957, p. 26), as part of a thorough discussion of ground water in the Animas Valley, said:

> Water of about 210°F was encountered in well 25.19.7.234, which is 95 feet deep. Water in this well is a few degrees above the boiling point for this altitude and at all times is turbulent and appears to boil. This is especially so when the water in the well is agitated.

Later in the same paragraph, he says:

> Water from well 25.19.7.143, which is half a mile to the west of the well 25.19.7.234, has a temperature of 98°F. Water from well 25.19.7.234, depth 74 feet, about 0.6 mile west of well 25.19.7.234, has a temperature of 85°F. Other areas may exist in which hot water occurs relatively near the surface.

Strangway and Holmer (1966) made an airborne

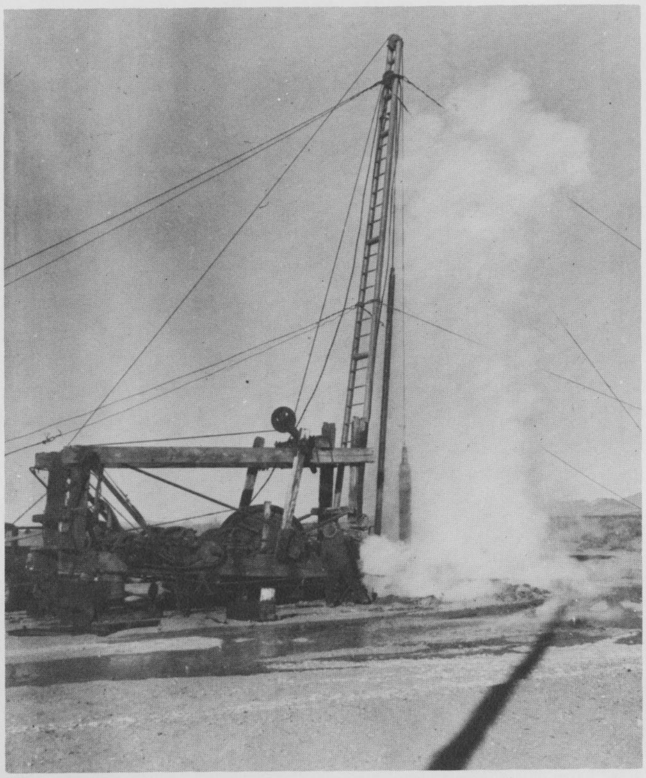


FIGURE 4—DRILLING FIRST HOT WELL (25S.19W.7.234) IN ANIMAS VALLEY, HIDALGO COUNTY.

infrared survey in the area of the thermal anomaly. They write (p. 231),

> The airborne profile recorded on the infrared detector is shown in Figure 7 [not included in this report] together with Kintzinger's ground temperature data. This temperature difference drove the recorder off scale so that the peak anomalies were not detected. It should be noted, moreover, that the flight was conducted 3000-feet terrain clearance and yet the apparent temperature difference was quite distinct. Estimating the thermal conductivity of the ground, the heat flow from the ground is approximately 6 x 10^{-4} cal/sq cm/ per sec.

Kintzinger estimated ". . . a power flow of approximately 7500 kw for the area enclosed by the 18°C contour line."

Color photos taken from the air by W. K. Summers during January 1966 and by Stirling A. Colgate during March 1966 reveal that in the area of the thermal anomaly identified by Kintzinger, the vegetation becomes green much earlier than the vegetation surrounding the anomaly.

The thermal anomaly lies west of the southern part of the Pyramid Mountains and along the eastern edge of the Lower Animas Valley. Flege (1959, p. 2) says,

> The Pyramid Mountains are a linear north-south range about 22 miles long. The width, which ranges from 3 to 7 miles, averages about 5 miles. Lower Animas Valley, bounded 15 miles to the west by the Peloncillo Mountains, is a typical desert basin filled with detritus from the bordering mountain ranges. It is flat in its axial part and slopes gently upward toward the mountains. An alkali flat, which has a total area of 15 square miles, is located in the northern part of the valley. Lake Animas, which is thought to be contemporaneous with glaciation in North America, was mapped and studied by Schwennesen (1918, p. 86-88). Study of the drillers' logs suggests that the lake filled rather quickly and that the deposits of the lake are alternate beds of clay, silt, and sand.
>
> The Pyramid Mountains are composed exclusively of igneous rocks ranging in age from Cretaceous to late Tertiary. Basalt, resting on valley fill, occurs in the lower Animas Valley about 15 miles west and south of the anomaly.

Figure 6 is a geologic map of the immediate thermal anomaly after Spiegel (1957) and Flege (1959). Wells at the anomaly penetrate a red rhyolite welded tuff that

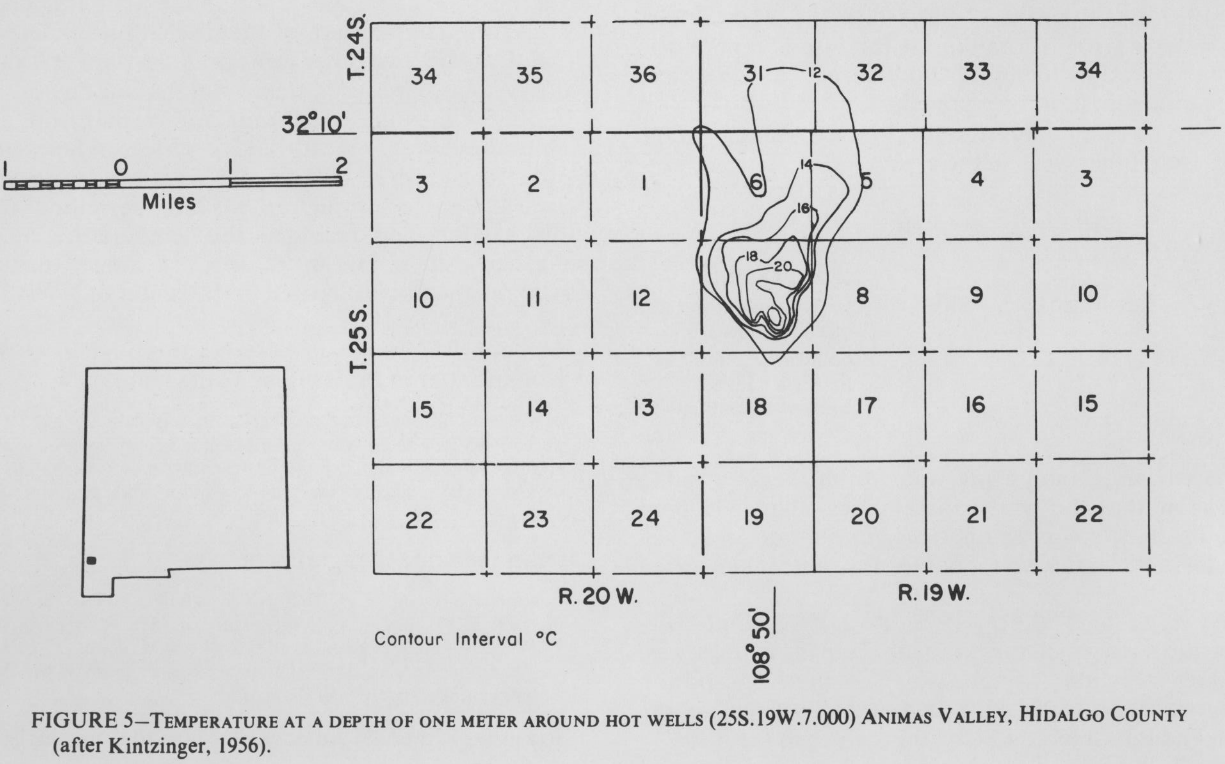


FIGURE 5—TEMPERATURE AT A DEPTH OF ONE METER AROUND HOT WELLS (25S.19W.7.000) ANIMAS VALLEY, HIDALGO COUNTY (after Kintzinger, 1956).

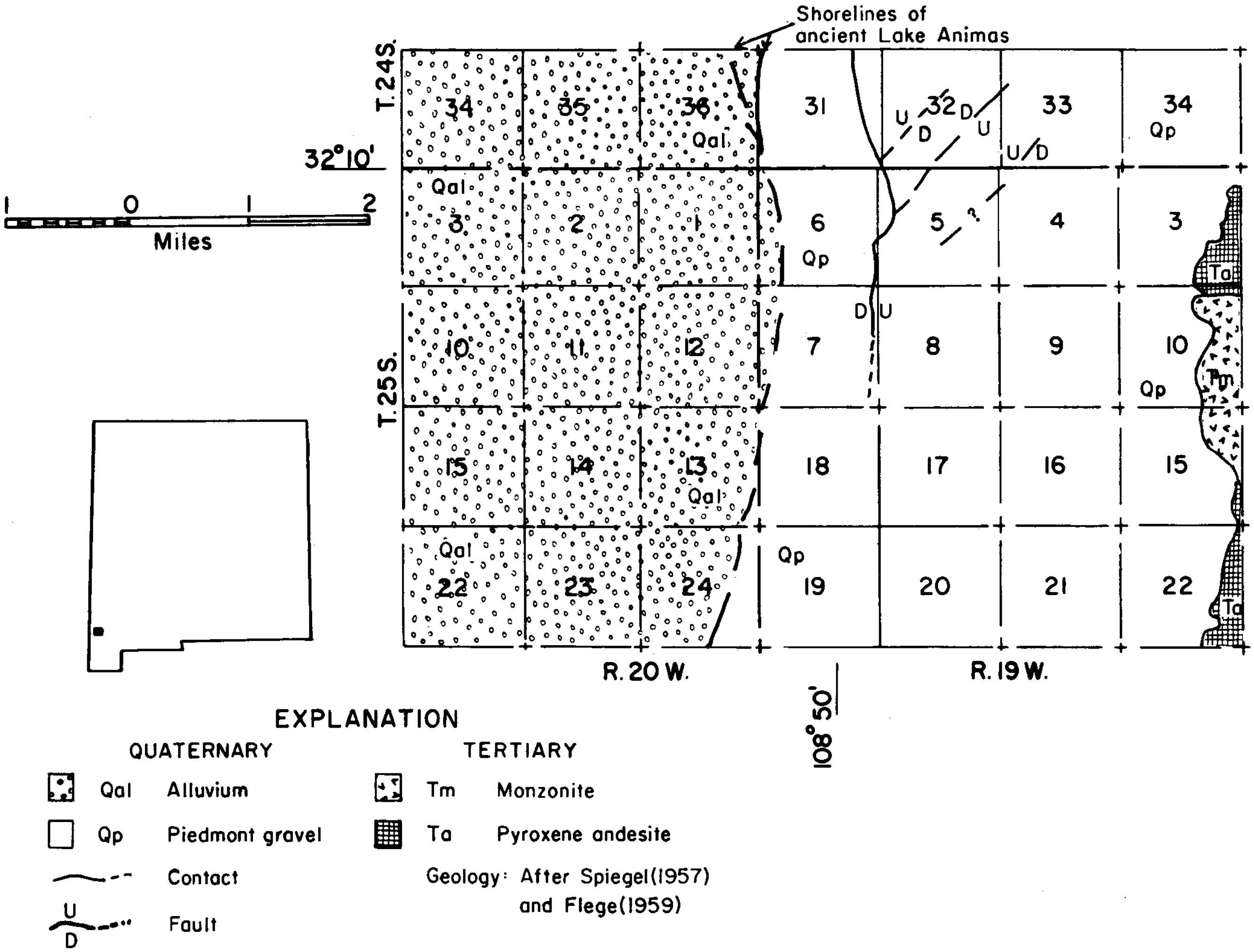


FIGURE 6—Geologic map of the Animas Valley in the vicinity of the thermal anomaly, Hidalgo County.

fits the description of a rhyolitic welded tuff observed by Flege (p. 14-15) in outcrops both north and south of the anomaly in the Pyramid Mountains. At the anomaly, the rock is highly silicified. One attempt to drill a deep test well produced the following log: 0-85 ft sand, gravel and clay; 85-157 ft red, silicified rhyolitic welded tuff. The driller reported using 3 rotatry cone bits to drill the 72 ft of silicified tuff. The rhyolitic welded tuff is younger than pyroxene andesite (figs. 6 and 7). Detailed gravity data and driller's logs of water wells suggest that a fault with a vertical displacement of several (perhaps several thousand) feet exists between wells 25S. 19W.7.133 and 25S.19W.7.234. Fig. 8 presents an east-west cross section of the anomaly. It is one interpretation of the data; other interpretations are equally possible.

An oil test (Cockrell Corp., No. 1 Federal-Pyramid) was drilled in the SW¼NE¼ sec. 31, T. 24 S., R. 19 W. The log of this well shows:

Depth (ft)		
From	To	Description
0	1890	Valley fill
1890	5795	Volcanics
5795	7130	Paleozoic rocks
7130	7394	Precambrian

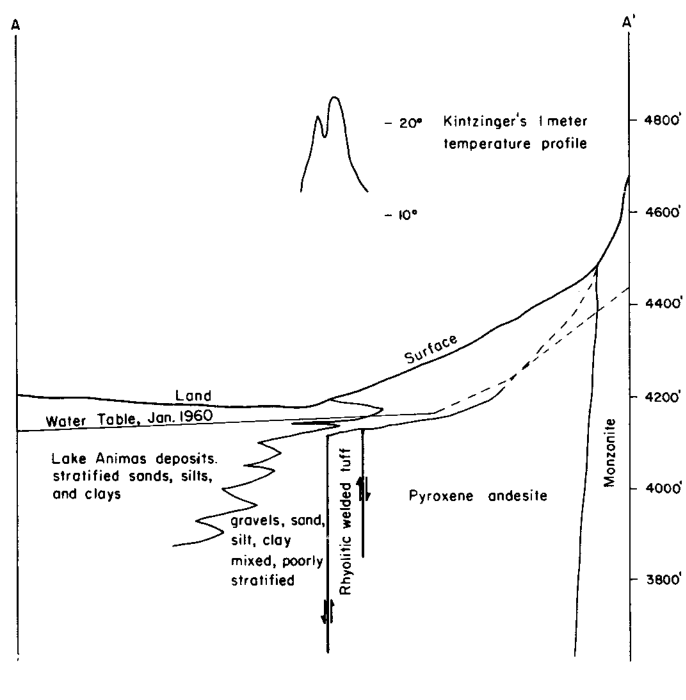


FIGURE 7—Cross section of thermal anomaly, Animas Valley.

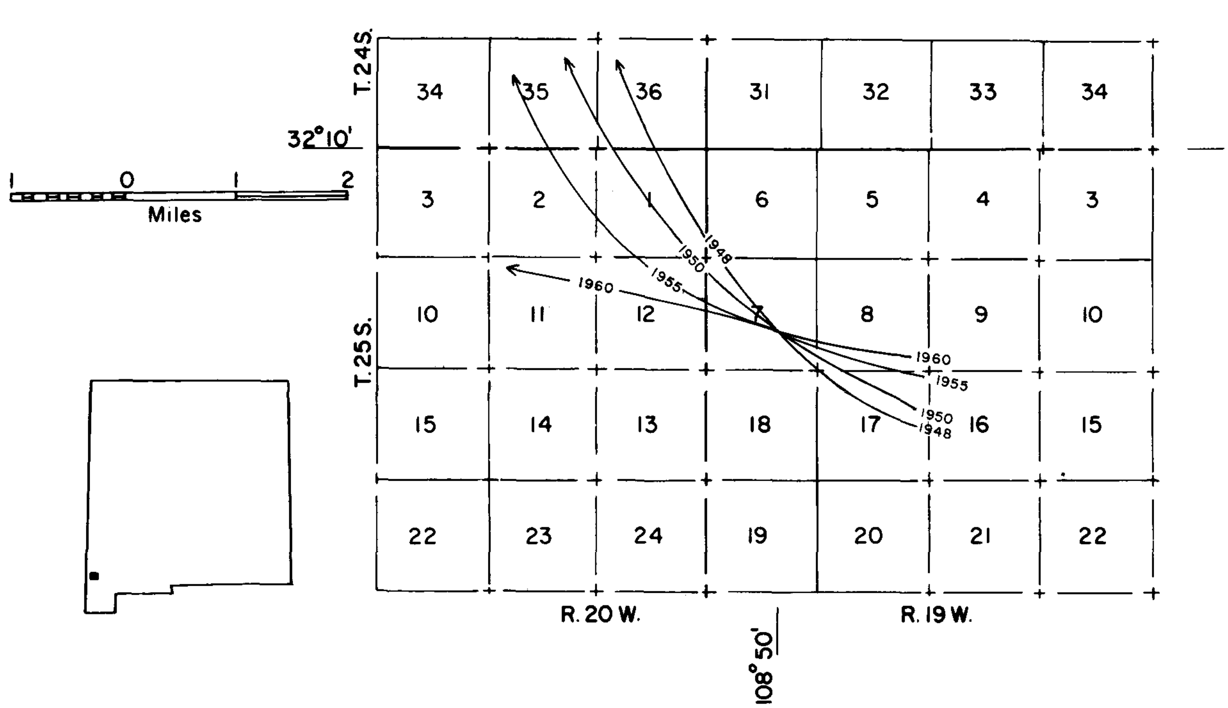


FIGURE 8—Direction of ground-water movement over the thermal anomaly in the Animas Valley.

The bottom-hole temperature recorded on the gamma-ray log was 250°F.

Before 1948, ground-water movement in the valley was essentially south to north; during 1948, irrigation began. A center of pumpage developed south and west of the anomaly. As a consequence, the direction of ground-water movement has altered, as indicated by fig. 8, which shows the direction of ground-water movement over the anomaly for several years.

The ground-water discharge has been taken from storage, and water levels are falling. The water-table decline at the anomaly amounts to approximately 25 ft from 1948 to 1966. Figs. 9 and 10 are water-table maps for 1948 and 1960.

Since 1948, many chemical analyses have been obtained for water from several wells around the anomaly. Table M3 gives the chemical analyses obtained for both the thermal waters and the nonthermal waters in the immediate area of the thermal anomaly. Fig. 11 not only shows the wells sampled but also shows that the sodium ion concentration reflects the anomaly.

Fig. 12 shows the distribution of temperatures of discharging water and the locations of the wells in which temperature profiles were obtained. Table 4 gives the temperature profiles for these wells.

The only analyses for a heavy metal in the Animas Valley are for copper, as follows:

Well	Date	Copper (ppb)
25S.19W.7.234a	4-30-66	20 USGS 59532
25S.20W.13.433	4-30-66	0 USGS 59536

Scott and Barker (1962, p. 79) report the radioactivity in water from well 25S.19W.7.234 as:

Beta-gamma activity	12 $\mu\mu$C/1 (picocuries/liter)
Radium	0.3 $\mu\mu$C/1 (picocuries/liter)
Uranium	0.2 μg/1

SAN FRANCISCO RIVER BASIN

Upper Frisco Hot Springs (5S.19W.35.100)

The upper Frisco Hot Springs are on the San Francisco River in the Apache National Forest, Catron County, approximately 8½ miles east of the U.S. Forest Service Ranger Station at Luna, and approximately 1½ miles upstream from the deep canyon through the San Francisco Mountains known locally as "The Box." The springs discharge from beneath a talus cover at an elevation approximately 40 ft above the bed of the river on a flat bench that cuts into an otherwise fairly steep slope.

Although the local residents and some geologists have said that the discharge is from the Gila Conglomerate, Weber and Willard (1959) mapped the bedrock of the area as a volcanic conglomerate—a unit within the Datil Formation. They described this formation as:

> Largely massive buff to gray, locally red, conglomerate of latite and andesite pebbles, cobbles, and boulders; grades into red andesite breccias in Pueblo Creek drainage area. Upper portion in San Francisco Mountains consists of tuffaceous sandstone and quartzose cross-laminated sandstone with interbedded rhyolite tuff. Local facies difficult to distinguish from Gila conglomerate.

The talus block consists of andesite and rhyolite tuff with sanidine, quartz, and biotite. Weber and Willard noted that both these rocks overlie the volcanic conglomerate, so a talus slope cover made up of such rocks is not surprising.

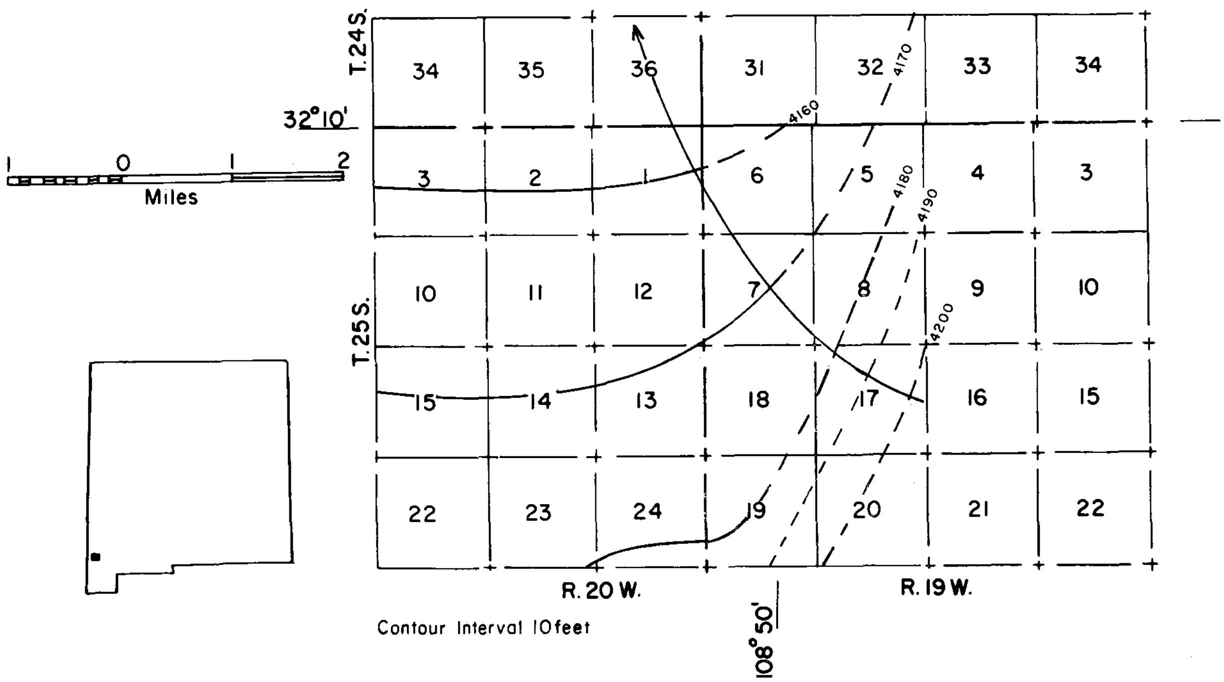


FIGURE 9—WATER TABLE, 1948, IN VICINITY OF THE THERMAL ANOMALY IN THE ANIMAS VALLEY.

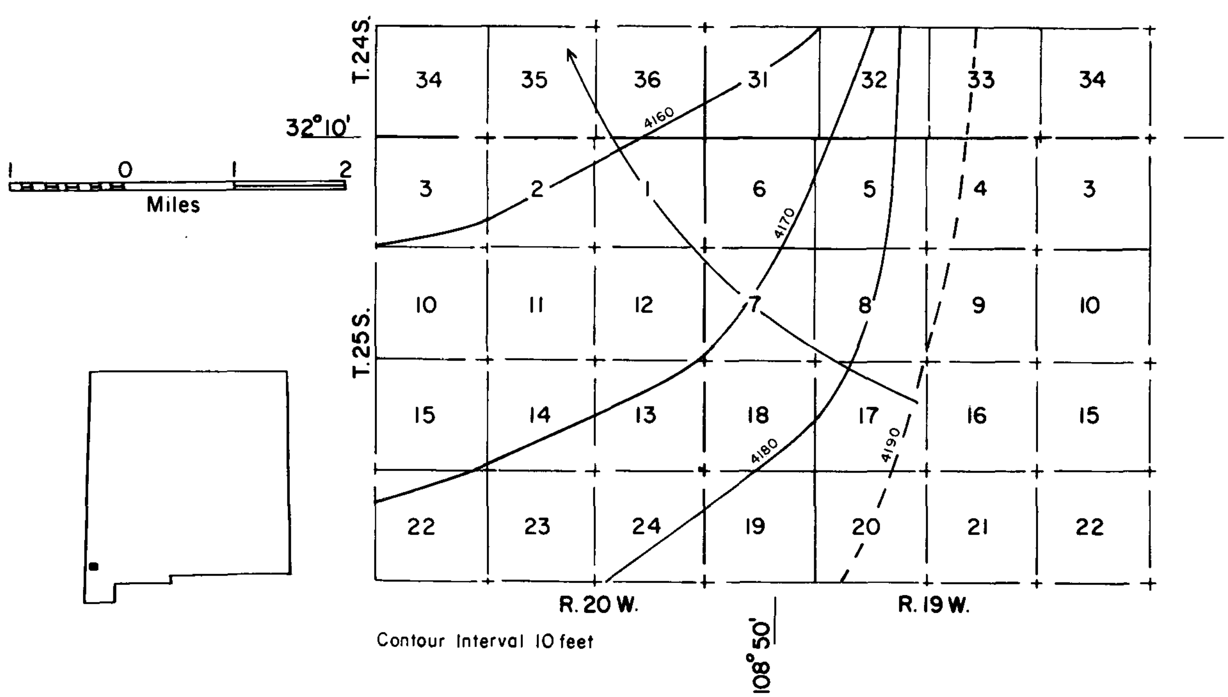


FIGURE 10—WATER TABLE, 1960, IN VICINITY OF THE THERMAL ANOMALY IN THE ANIMAS VALLEY.

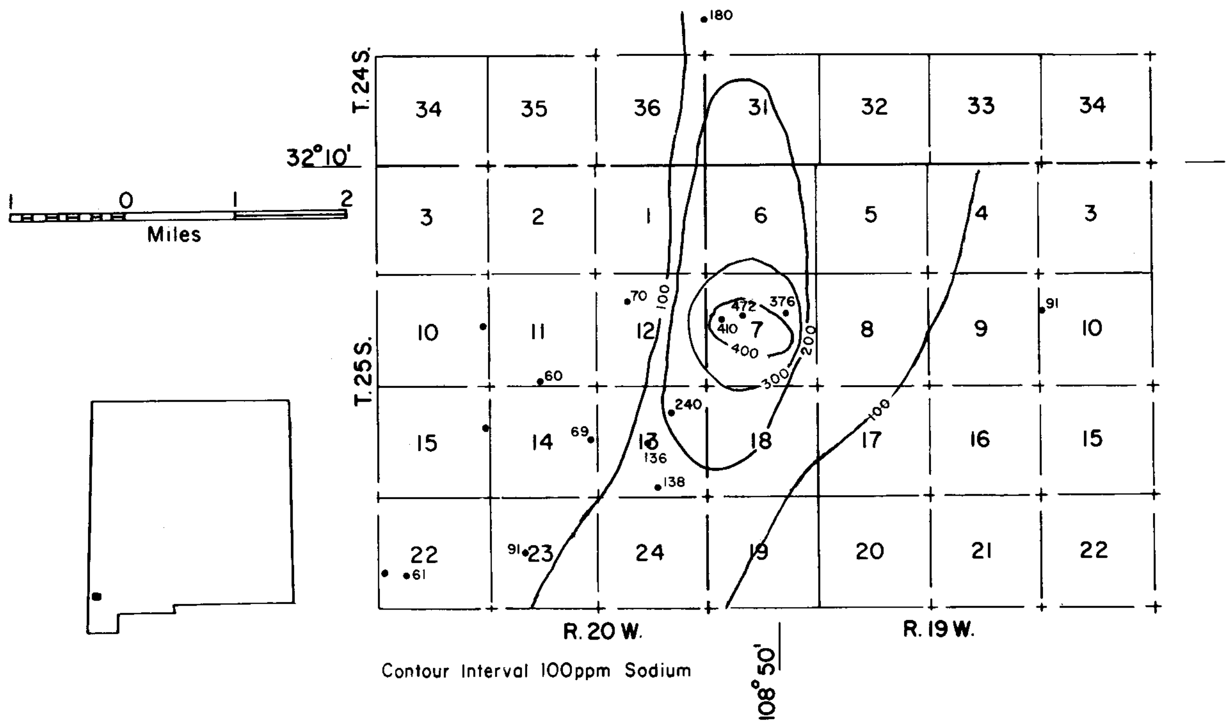


FIGURE 11—Location of wells from which water samples were obtained and the sodium-ion concentration in the area of the thermal anomaly in the Animas valley.

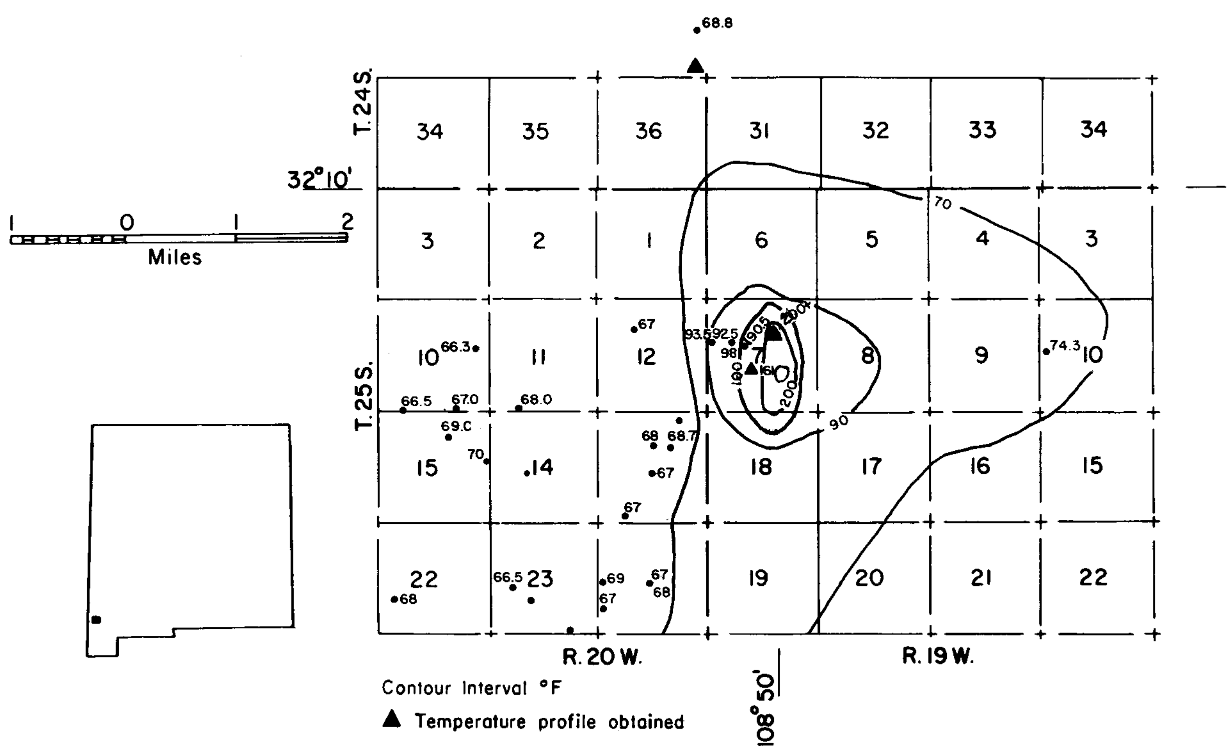


FIGURE 12—Map of the area of the thermal anomaly in the Animas Valley, showing the temperatures of discharging ground water and the locations at which temperature profiles were obtained.

Table 4 - Temperature profiles in wells in the Lower Animas Valley

Well	Casing	Date	Depth (ft)	Temp. (°F)
25S.19W.7.234	18"(perforated 42-90 feet)	12-31-65*	0	92.5
			10	108
			20	127-137
			30	150-160
			40	167-172
			50	178
			56	204.5†
			62	204.8‡
25S.19W.7.234a	10"(unperforated)	3-2-66	0	--
			10	110
			20	130
			30	160
			40	183
			50	196
			52	206†
			60	206.8
			70	209.2
			80	212.3
			90	215.0
			94	216.0
			104	No. Meas.‡
25S.19W.7.234b	12"(perforated 50-82 feet)	12-31-65§	0	--
			10	139-165
			20	176-187
			30	190.8
			40	191.5
			50	192.2-193.0
			60	206.7
			70	206.8
			80	209.6
			83	213.8-216.0‡†
25S.19W.7.244	--	3-2-66	0	--
			10	73
			20	76
			30	79.5
			37	82.0
			43	84.5
			50 (dry hole)	87.5‡†
25S.19W.7.342	16"(perforated 35-300 feet)	12-31-65	0	72
			10	80
			20	90-100
			30	105-118
			40	118-127
			50	160.5†
			60	161.7
			66	162.5
			75	163.5
			83	164.0
			92	165.1
			99	165.5
			108	166.5
			119	167.3
			129	167.3
			139	167.3
			149	163.0
			158	164.0
			162	162.5
			165	156.3
			172	152.5
			178	180.2
			188	148.2
			195	147.4
			198	146.5
			205	145.3
			211	144.0
			218	142.5
			224	141.1
			230	140.0
			238	139.4
			244	139.0
			251	138.7
			257	138.3
			264‡†"	138.0
24S.20W.36.222	18"(perforated 16-145 feet)	6-18-66	20	100.5
			33	96
			47.4	--†
			50	69.7
			60	68.1
			79	68.1
			99	68.3
			130	68.5
			139	68.5‡†

* Air temperature 51°F † top of water ‡ bottom of well

§ temperature probe lowered at one minute intervals and left on bottom of hole 10 minutes

" reported depth 300 feet

Water discharges at several points; a concrete reservoir has been built around the principal one (5S.19W.35.100; fig. 13a). The water wells up from the bottom and discharges through an overflow outlet at the land surface. This reservoir is 3 ft deep. Figure 13b shows the talus slope and some of the other small marshy areas that develop where the springs discharge. The total area of discharge is about one quarter acre. Table 5 summarizes the measurements of the spring. Flow from 3 of the outlets, estimated to be 90 percent of the total, was 6.2 gpm. The temperature at the concrete reservoir, 98°F, was also the maximum temperature observed for these springs.

The chemical analysis for water collected at the reservoir (table M4) shows that the wash contains a relatively low concentration of total dissolved solids. People who live in the area use the reservoir as a bathtub with a continuing source of warm water.

FREIBORN CANYON SPRING (7S.21W.8.442)

This spring is in Freiborn Canyon in the Apache National Forest, Catron County. It discharges 9.4 gpm at 92°F from what appears to be bedding planes in the volcanic conglomerate described by Weber and Willard (1959) and described here in the discussion of the upper Frisco Hot Springs. The area of discharge is only a few square feet, and the spring is only 5 to 10 ft above the floor of Freiborn Canyon. Table 5 contains measurements made at this spring in February 1966. The water contains only 150 ppm dissolved solids (table M4).

The temperature of the water at the confluence of the discharging spring waters with the small stream that runs through Freiborn Canyon was 79°F; upstream from the confluence, the temperature was 37.2°F and downstream, it was 38.5°F at the top and 43°F at the bottom of the stream. The temperature of the spring water apparently had very little effect on the temperature of the stream.

LOWER FRISCO HOT SPRINGS (12S.20W.23.120)

The lower Frisco Hot Springs are on the San Francisco River in Catron County. These springs occur upstream from the point where the San Francisco River crosses a thick sequence of basalt of Tertiary age.

The river also cuts through the Gila Conglomerate, which overlies the basalt at this point. The Conglomerate here is a stream deposit that filled an old drainage-way that crossed the basalt at an angle of roughly 60 degrees to the present drainage. It constitutes only a small part of the rock at the site.

A thin section of a specimen indicates that the basalt is 15 percent andesine, 7 percent pyroxene, 3 percent olivine, 66 percent black glass, and 9 percent vesicles.

These are probably the springs referred to by Gilbert (1875, p. 152) as "at copper mines of the San Francisco River, New Mexico." He gave the temperature as 130°F, citing Oscar Loew as the authority. This reference was repeated by Peale (1886, p. 194) and Jones (1904, p. 311). Stearns, Stearns, and Waring (1937, p. 168), and Waring (1965, p. 37), citing unpublished data in the files of the U.S. Geological Survey, report 8 springs "1 mile south of Pleasanton, SW1/4 sec. 23, T. 12

A B

FIGURE 13—PHOTOS OF UPPER FRISCO HOT SPRINGS.
A. UPPER FRISCO HOT SPRINGS, PRINCIPAL CONCRETE-LINED POOL
B. UPPER FRISCO HOT SPRINGS, SEEPS AT BASE OF TALUS

Table 5 - Field data for San Francisco River basin

Location	Date	Discharge (gpm)	Maximum temperature (°F)	pH	Specific conductance (micromhos)	Density (gm/ml)	H_2S (ppm)	NH_3 (ppm)	SiO_2 (ppm)	Remarks
Upper Frisco Hot	5-22-58	---	98	---	---	---	---	---	---	USGS meas.
Spring (5S.19W. 35.100)	2-18-66	6.9*	98.0	9.1-9.3	300	.986	0	0	60	
Freiborn Canyon Spring (7S.21W. 8.442)	2-16-66	9.4	92.1	8.2-9.0†	140	.984	0	0	35	
Lower Frisco Hot Springs (12S.20W.23.120)										
1‡	2-15-66	9.4	99.3	7.7	750	---	0	---	---	USGS meas.
2	2-15-66	1	98.0	7.5	900	---	0	---	---	
3a	2-15-66	37	101.2	7.6	---	---	0	---	---	
	6-11-59	---	115	---	---	---	---	---	---	USGS meas.
3b	2-15-66	---	103.2	7.7	800	---	0	---	---	
	2-16-53	20§	117.0	---	---	---	---	---	---	USGS meas.
3c	6-13-58	---	109.0	---	---	---	---	---	---	USGS meas.
	2-15-66	---	97.0	---	---	---	0	---	---	
	12-5-74	---	95.4	6.5-7.3	1200	---	---	---	---	HCO_3^- = 135 to 167 mg/l, l
4	2-15-66	1	106.2	7.6-7.7	180	---	0	---	---	
5	2-15-66	1	100.5	---	1000	---	0	---	---	
6	2-15-66	1	108.3	7.9	1100	---	0	---	---	
7	2-15-66	1	113.2	7.9	1100	---	0	---	---	
8	2-15-66	1	116.5	7.9	950	---	0	---	---	
9	2-15-66	3§	117.5-121.0	7.9	1400	.980	0	---	---	
10	2-15-66	1	119.5	7.7	900	---	0	---	---	
11	2-15-66	1	114.0	7.7	1050	---	0	---	---	

* estimate based upon measurement of approximately 90% of flow

† over a six inch interval at the rock face in cascading water

‡ see Figure 14 for location numbers § estimated

S., R. 70 W." They say the temperature ranges from 80° to 124°F and the discharge, 50 gpm, comes from late Tertiary lava. Waring (1965, p. 37) repeated this reference.

Trauger (1960, pl. 2) prepared a water-table map of the area showing ground water throughout the area moving to the San Francisco River.

Warm and hot water discharge at temperatures ranging from 98° to 121°F into the river from the bank (and probably from the river bottom as well) along intervals upstream from the basalt for about 300 ft. Fig. 14 shows the relation of the basalt to the springs in the San Francisco River on February 15, 1966. The exact discharge of this system is difficult to measure; however, the bulk of the discharge occurs from the bathhouse and near the basalt. Discharge of 37 gpm was measured at the outlet from the bathhouse 2 ft from the river (fig. 14, location 3a), and the net discharge from the area 10 to 40 ft upstream from the basalt was 9.4 gpm (location 1). The total discharge probably does not exceed 50 gpm. Table 5, which gives the field measurement, shows how the specific conductance of the discharge varies with temperature from 900 to 1500 micromhos/cm. Table M4 gives the chemical analyses of water samples collected from these springs, including

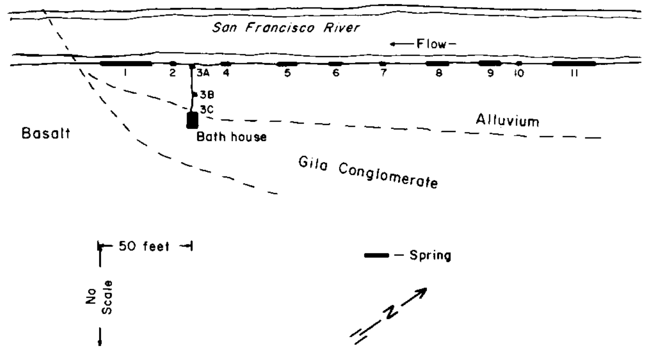


FIGURE 14—Sketch showing relation of lower Frisco Hot Springs to San Francisco River and to basalt and Gila Conglomerate.

the results of 3 analyses made by the U.S. Geological Survey of water collected at the bathhouse or just below it. Table 3 contains the analyses of heavy metals and radon-222 of a sample collected December 5, 1974, at the bathhouse (fig. 14, location 3c). The reported temperatures seem to be somewhat higher than those observed on February 15, 1966. These springs have been used extensively, but quite informally, by people taking baths in the naturally hot water.

Rio Grande Basin

For the most part thermal waters of the Rio Grande basin occur in the Rio Grande rift. Detailed studies of the rift are under way. Reiter and his students (Reiter and others, 1975; Hartman and Reiter, 1972; Edwards, Reiter, and Weidman, 1973; Reiter, Edwards, and Weidman, 1973) and Decker and his associates (Decker and Smithson, 1973; Decker, 1972, 1973; Smithson and Decker, 1972) have been measuring heat flow in the rift.

Sanford and his associates have investigated the gravity and seismicity of the rift (Sanford, Alptekin, and Toppozada, 1973; Sanford and others, 1972; Singh and Sanford, 1972, 1973; Singh, 1970; Toppozada and Sanford, 1973; Toppozada, 1974; Toppozada and Sanford, 1972; Budding, Sanford, and Toppozada, 1971).

Chapin (1971) has discussed the geologic characteristics of the rift. Detailed studies of the geology of the lower part of the rift are under way (Clemons and Seager, 1973; Seager and Hawley, 1973; Seager, 1973; Seager, Hawley, and Clemons, 1971; Seager and Clemons, 1974; Hoffer, 1971a,b; Hoffer and Hoffer, 1973).

UPPER RIO GRANDE BASIN

NO NAME SPRING, SOUTH OF JOHN DUNN'S BRIDGE (27N.12E.36.411)

This spring is approximately half a mile south of John Dunn's bridge in the Rio Grande Canyon a few hundred feet downstream from the Arroyo Hondo confluence, Taos County, and approximately 11/2 miles upstream from the Mamby's (American) Hot Spring. It occurs at the base of a thick sequence of basalts at the level and on the west side of the river. It apparently discharges from a fracture in the basalt that has developed a small drainageway in the rock. The flow comes from beneath a talus cover, so no direct observation is really possible. The discharge at this point is extremely small; it seeps in at the top on the west side of a pool that drains into the Rio Grande (fig. 15a). The temperature of the top 2 inches of the pool is 98.5°F. Considerably lower temperatures occur throughout the remainder of the pool. Estimated discharge is half a gallon a minute. Fig. 16 shows the observed temperatures in the pool and the Rio Grande. No use is made of this pool or of the seepage; however, minnows live in the pond and the water quality is apparently satisfactory to sustain their life. Table 6 gives the measurements made at the spring; table M5 gives the chemical analysis of the water collected at this site.

MAMBY'S (AMERICAN) HOT SPRING (26N.11E.1.120)

This spring is on the east side of the Rio Grande in Rio Grande Gorge. It is about 10 ft above the low-water stage of the river and at the base of a basalt cliff some 600 ft high. About 30 gpm discharges from fractures in the basalt into a small pool discharging into the Rio Grande. Small bubbles issue from the bottom of the pool. The spring is surrounded by the remains of an old bathhouse (fig. 15b) and is sometimes used by the residents of Taos County for bathing purposes. Seepage also occurs along the bank at and below river level. The only reference to this spring in the literature is that of Herron (1916) in his river profile survey of the Rio Grande in New Mexico. Herron gave no information about the character of the water; he only noted its occurrence as part of his survey. The chemical analyses (table M5) of water from this spring show that the total dissolved solids content is about 500 ppm. Table 7 gives the results of analyses for selected heavy metals and radon-222 in a sample collected December 3, 1974.

This spring may be the Wamsley Hot Springs to which Jones (1904, p. 295) refers when he writes:

> These springs occur in the deep gorge of the Rio Grande, just below the toll bridge on the road leading from Taos to Tres Piedras. This water is little more than lukewarm and very similar to the warm springs at Glen-woody camp, about 18 miles below. It is observed that the flow from each of these springs is from the west and on that side of the river.

Jones' descriptions generally are inaccurate. The old wagon trail is still evident as are remnants of structures (fig. 15b).

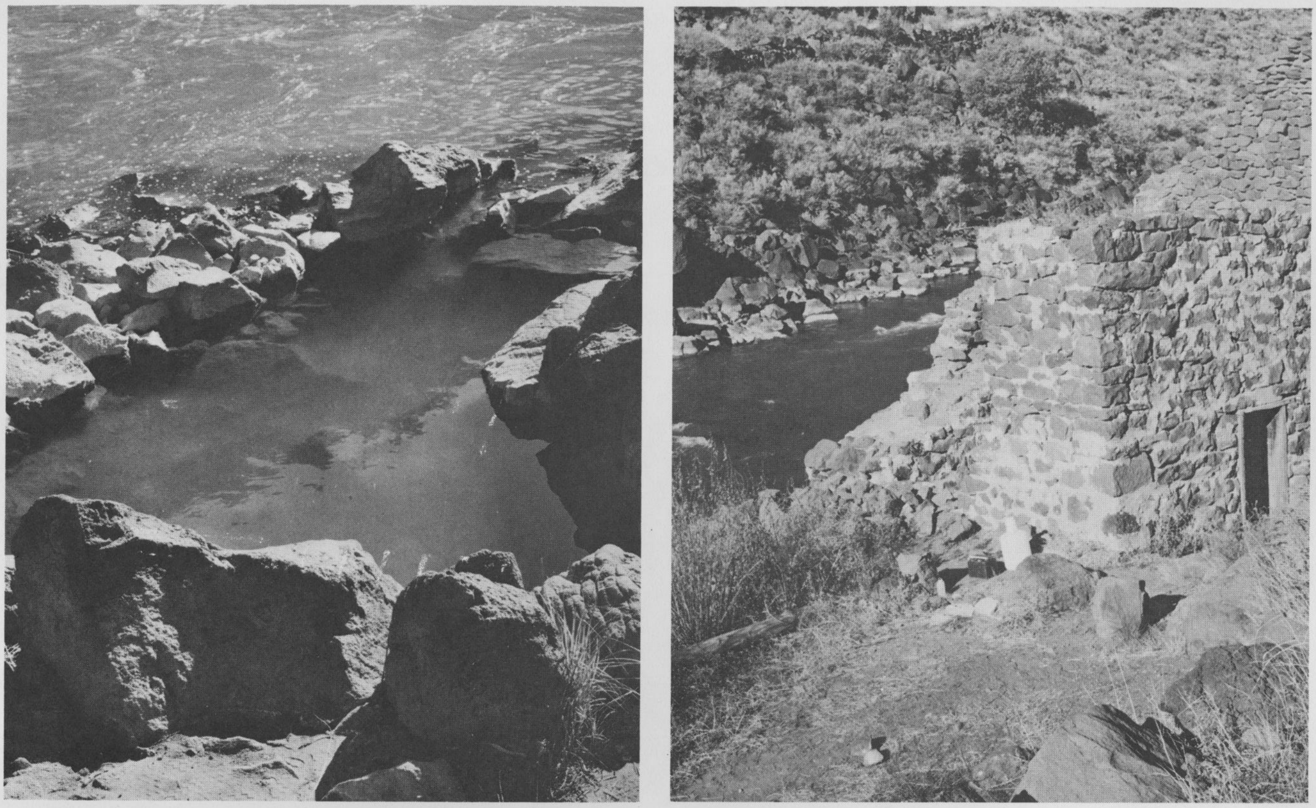
PONCE DE LEON HOT SPRING (24N.13E.7.000)

Ponce de Leon Hot Spring is in a small drainageway tributary to Arroyo Miranda southwest of Talpa, in the Cristoval de la Serna Grant, Taos County. It lies at the northeast edge of the Picuris Mountains. The geology of the region was studied in some detail by Montgomery (1953).

The springs discharge from fractures in a fault zone in the Embudo granite. This rock is of Precambrian age. According to Montgomery (1953, p. 38), it is actually a quartz monzonite or quartz diorite. At the springs, it consists primarily of potash feldspars and quartz with a small quantity of hornblende and biotite. It has zones of hydrothermal alteration in which epidote, chlorite, and secondary silica are common. An altered pyroxene was noticed in one specimen. Where alteration is severe, the biotite and chlorite have converted to limonite. A thin section of one specimen shows an altered granite containing quartz, 17 percent; albite, 7 percent; microcline, 67 percent; and epidote, 9 percent. The principal fractures at the site strike N. 5° W. and N. 48° E. and dip from 75° E. to 85° W. Fig. 17 is a series of maps of the springs showing the layout, the geology, and the points at which samples were collected or measurements made on December 5, 1965, and December 3, 1974. The total discharge of the springs is 240 gpm and the maximum temperature observed is 95.3°F. The measurements made at the springs (table 6) and the chemical analyses of water from sites 2 and 6 (table M5) show that the water has an essentially uniform character with temperatures ranging from 88° to 95°F. Table 7 gives the result of analyses for selected heavy metals and radon-222 in a sample collected December 3, 1974.

OJO CALIENTE (JOSEPH'S HOT SPRINGS; 24N.8E.24.110)

In many reports, because of the uncertainty of the



A

B

FIGURE 15—Photos of upper Rio Grande basin.
A. No name spring, one half mile from John Dunn's bridge (27N.12E.36.411), Taos County
B. Decaying walls are all that is left of a bathhouse over Mamby's (American) Hot Spring (26N.11E.1.120)

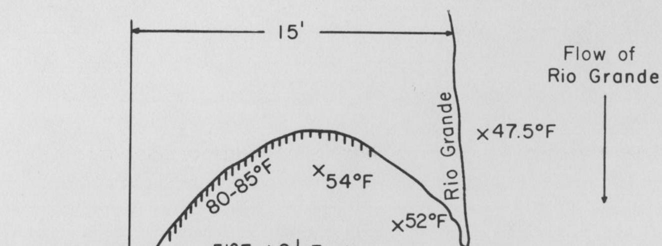


FIGURE 16—Sketch of no name spring, one half mile below John Dunn's bridge.

location of the county line, these springs are placed in Rio Arriba County. A recent plat shows that all discharge takes place within Taos County, albeit very close to the county line. The springs occur along the west edge of the Valley Ojo Caliente Creek, a tributary to the Chama River, at the base of a steep slope. According to Jones (1904, p. 240), these springs were visited and named by Cabeza de Vaca, an early explorer of New Mexico, in 1534. They are shown on James S. Calhoun's 1844 map, *Inhabited Places in New Mexico.*

These springs have been used as a spa for many years. They are first mentioned in the geologic literature by Gilbert (1875, p. 153), who cites "Colton's map of New Mexico" as his source. Later in the same volume, Loew (1875a, p. 624-625) describes these springs in some detail:

> Fifteen miles northwest [sic] of Abiquiu is the Mexican village Ojo Caliente, in the valley of the creek of the same name. One mile above the village four warm springs issue from the foot of a hill. While the surrounding region consists of sand-hills, and volcanic dykes, and mesas, the hill in question is composed of gneiss, through which run veins of a very coarse-grained granite, the feldspar and quartz forming masses of several cubic feet, and the muscovite large plates several inches thick. An American, who here built a few bathhouses for visitors, stated that last summer from forty to fifty invalids were there using the waters for medicinal purposes; the majority of these suffered from rheumatism and syphilis. The waters are of good quality. Where they evaporate on the rocks, a white residue is formed, erroneously called there "borax." Three of the springs have been widened and otherwise improved.
>
> No. 1 has a basin 20 feet long, 9 feet wide, and a temperature of 114.5°F; a reddish deposit is formed, containing a trace of iron [Iron Spring].
>
> No. 2, basin 10 feet square; temperature 108°F. [Sodium Sulphate Spring?].
>
> No. 3, basin 5 feet long, 2 feet wide; temperature same as No. 2 [Soda Spring?].
>
> No. 4, basin 6 feet square; unimproved; temperature same as No. 2 [Arsenic Spring?].
>
> The taste of all these springs is saline and alkaline.
>
> In one hundred thousand parts of water are contained parts as follows:

Constituents	No. 1	No. 2
Sodium carbonate	196.95	184.29
Lithium carbonate	0.21	0.16
Calcium carbonate } Magnesium carbonate }	6.25	5.40
Iron carbonate	trace	trace
Potassium sulphate	5.17	5.34
Sodium sulphate	13.60	19.33
Sodium chloride	38.03	39.78
Silicic acid	trace	trace
Total solid constituents	260.21	254.30
Gases: Carbonic acid.		

Peale (1886, p. 195) and Jones (1904, p. 293), repeated these analyses.

Cope (1875, p. 66) noted: "The springs of Ojo Caliente number three, the most important issuing from a vertical ledge of gneiss, which is then traversed by a wide quartz vein. The temperature of the warm springs is from 116° to 120°; they contain an abundance of confervoid algae."

Peale (1886, p. 194) reported that the springs discharge 60 gpm from 4+ outlets at temperatures ranging from 108° to 122°F. Jones (1904, p. 293) said the temperature ranged from 90° to 122°F and the discharge was "300,000 gallons in 24 hours" (210 gpm).

Clark (1893, p. 114, table 9) gave an analysis made by Hillebrand that Jones (1904, p. 294), Lindgren (1910, p. 26), and Lindgren, Graton, and Gordon (1910, p. 72) subsequently republished. Clark (1924, p. 192-193) used this analysis as an example of "carbonate water."

Table 7 - Heavy metals and radon-222 in thermal waters of the upper Rio Grande basin (concentration in ppb unless noted)

	Mamby Hot Spring (26N.11E.1.120)	Ponce de Leon Hot Spring (24N.13E.7.000)	Ojo Caliente (24N.8E.24.110)		
			Arsenic Spring	Iron Spring	Lithia Spring
Date	12-3-74	12-3-74	12-3-74	12-3-74	12-3-74
Copper	5.5	5	7.5	8.5	25
Chromium	3.5	1.0	5.5	3.0	12
Cadmium	.18	.25	1.9	2	--
Lead	9	6	20	21	18
Molybdenum	~20	~22	98	0	40
Mercury	<1	<1	<1	<1	--
Zinc	.034	ND	.026	ND	.0877
Radon-222* (picocuries/liter)	820	6600	5000	9400	6300

*Analyses by the U. S. Environmental Protection Agency

Table 6 - Field data for the upper Rio Grande basin

Location	Date	Discharge (gpm)	Maximum temperature (°F)	pH	Specific conductance (micromhos)	Density (gm/ml)	H_2S (ppm)	NH_3 (ppm)	SiO_2 (ppm)	Remarks
No Name Spring south of John Dunn's Bridge (27N.12E.36.411)	12-4-65	.5*	98.5	10.3	580	.986	0	.1	55	Air=62°F
Mamby (American) Hot Spring	12-3-65	30†	100	9.0	700	.988	0	.15	55	
(26N.11E.1.120)	12-3-74	---	94	6.9	760	---	---	---	---	
Ponce de Leon Hot Spring (24N.13E.7.000)										
#1‡	12-5-65	9.4	88.3	---	520	.988	0	---	---	Air=68°F
2	12-5-65	140	94.2	---	540	---	0	0	45	
3	12-5-65	4.5	95.3	---	500	---	---	---	---	
4	12-5-65	9.4	94.5	---	500	---	---	---	---	
5	12-5-65	50	91.5	---	---	---	---	---	---	
6	12-5-65	---	93.3	---	520	.996	---	---	---	
	12-3-74	---	93.2	7.2	740	---	---	---	---	
7	12-5-65	240	85.5	---	---	---	---	---	---	
Ojo Caliente (24N.8E.24.110)										
Iron Spring:										
Collector	12-1-65	---	109.0	6.9	3000	---	---	0.5	59	
	12-3-74	---	109	6.9	3900	---	---	---	---	
Pool	12-1-65	---	107.0	6.8	3100	.990	0	---	---	
Arsenic Spring	10-6-49	---	113	---	---	---	---	---	---	USGS meas.
	12-3-74	---	101	6.9	3800	---	---	---	---	
Sodium Sulfate	10-1-47	---	±90§	---	---	---	---	---	---	USGS meas.
Spring	10-6-49	---	105	---	---	---	---	---	---	USGS meas.
Soda Spring	10-1-47	---	±95§	---	---	---	---	---	---	USGS meas.
Lithia	12-3-74	---	99	6.8	---	---	---	---	---	

* estimate † estimate based on measurement of part of total flow ‡ see figure 20 § at tap

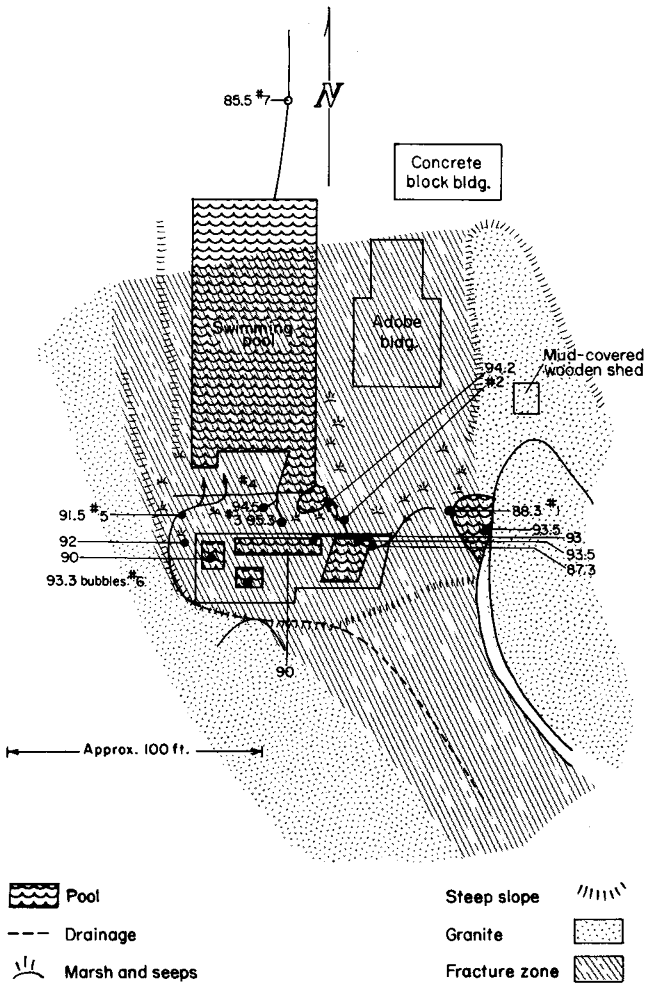


FIGURE 17—SKETCH MAPS OF THE PREMISES OF PONCE DE LEON HOT SPRINGS, TAOS COUNTY, SHOWING PHYSICAL FEATURES, GEOLOGY, AND WATER TEMPERATURE AND SAMPLING SITES.

Crook (1899, p. 335) said the springs discharge "4200 gallons hourly" (70 gpm) at temperatures ranging from 90° to 122°F. He also gave the following chemical analysis made by O. C. Marsh:

One U.S. gallon contains: Solids	Grains
Sodium carbonate	91.52
Magnesium carbonate	1.26
Iron carbonate	5.90
Lithium carbonate	0.12
Sodium chloride	22.18
Calcium carbonate	2.42
Potassium sulphate	3.00
Sodium sulphate	2.92
Silica	1.22
Total	135.54

White, Hem, and Waring (1963, p. F50-F51) used the Hillebrand analysis augmented by a partial analysis of a sample collected October 6, 1949, as an example of "chemical analyses of thermal water closely associated with epithermal mineral deposits." Stearns, Stearns, and Waring (1937, p. 167) and Waring (1965, p. 37) reported the temperature range as 98° to 113°F and the discharge as 350 gpm.

Since 1947, the U.S. Geological Survey and the New Mexico State Public Health Laboratory have made 7 analyses of samples from 3 of the 5 springs and 2 nearby wells (table M5).

Fig. 18 is a geologic map of the Ojo Caliente area. It shows the distribution of the metarhyolite of Precambrian age from which the water discharges through fractures. The fractures are predominantly vertical joints that strike approximately N. 10° E., N. 35° W., and N. 60° E. A fourth set of fractures strikes N. 75° E. and dips 18°E. and gives the massive metarhyolite a bedded appearance. The rock has a number of shear zones (but no obvious faults or displacements) and is crisscrossed by numerous pegmatite dikes that strike N-S and dip 45°W.

Fig. 19 is a map of the premises of the Ojo Caliente Mineral Springs Company. It shows the main features of the area, including the locations of three wells for which some data are available. The following temperatures were observed in the unused well, which was drilled to 49 ft in 1951 and deepened to 87 ft in 1952:

Depth (ft)	Temperature (°F)
1	125.5
6	128.5
10	129.5
12	130.4
15	130.7
19	131.3
25	131.7
31	131.8
37	131.8
43	131.9
50	131.9
62	132.0
68	132.1
74	132.2
80	132.2

The hot water was reported to have been encountered at 87 ft; at 49 ft, the water in the aquifer was "cold."

The driller's log of well No. 1, drilled in 1940 and redrilled in 1954, is as follows:

Material	Depth (ft)
Surface soil	0-3
Cobblestones, boulders, and water	3-17
Brown clay	17-20
Boulders	20-30
Sand and water	30-42
Clay	42-48

The bottom 18 ft of casing in this well are perforated; the temperature of the water pumped is 89.5°F.

The driller's log of well No. 2, drilled in 1962, follows:

Material	Depth (ft)
Topsoil	0-2
Gray sand and boulders	2-9
Gray clay and boulders	9-22
Gray sand and gravel	22-33
Yellow clay	33-53

The casing in this well is perforated from 15-33 ft. The temperature of the water pumped is 58.3°F.

The five developed springs are called Iron, Arsenic, Soda, Sodium Sulphate, and Lithia. Some small springs and bogs also occur that discharge some thermal water.

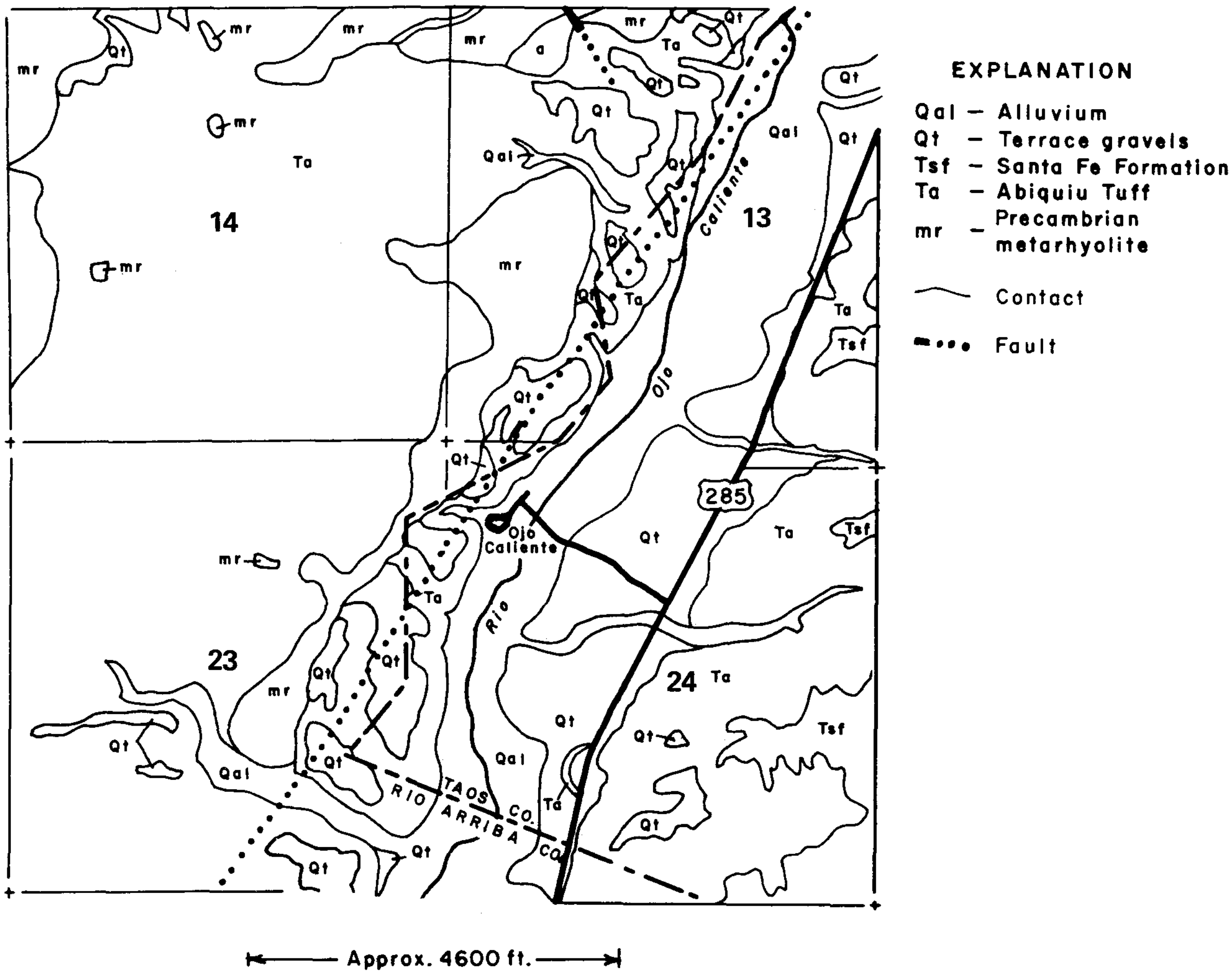


FIGURE 18—GEOLOGIC MAP OF THE OJO CALIENTE AREA, TAOS AND RIO ARRIBA COUNTIES (from an unpublished map by Johns, Smith, Muehlberger, and Shomaker, 1947, revised by Muehlberger, 1960).

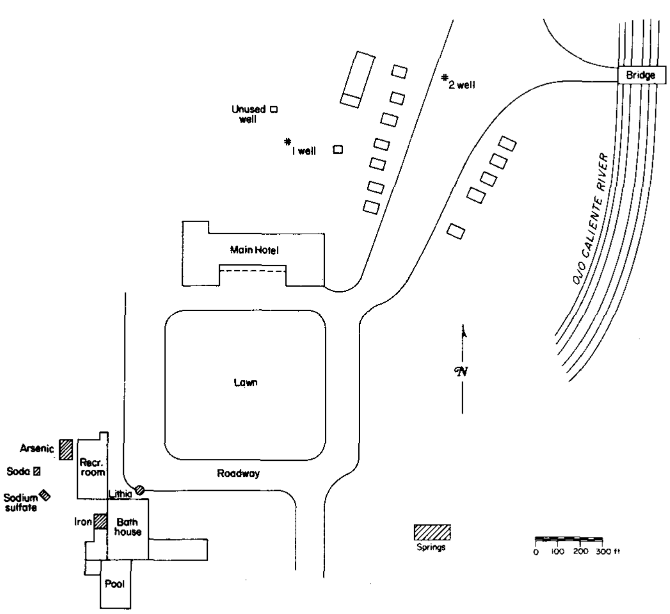


FIGURE 19—MAP OF THE OJO CALIENTE PREMISES SHOWING THE DATA POINTS.

The total outflow from the developed springs was 97 gpm, December 1, 1965.

Iron Spring, the only one looked at in any detail in the field inventory, is inside the bathhouse. The water discharges from joints in the metarhyolite, collects in a small concrete trough, then cascades into a swimming pool. An iron stain covers the rocks, concrete, and pipes. Table 6 contains measurements made at the collectors and in the pool.

JEMEZ RIVER BASIN

The Jemez River is a tributary of the Rio Grande. Included within its divides are most of the Valles Caldera and most of the Nacimiento Mountains. The upper Jemez River basin includes the caldera, several natural thermal features (including hot springs, fumaroles and solfatara) and the only wells drilled for steam in New Mexico (fig. 20).

Near the divides between the upper Jemez River basin and the Rio Guadalupe basin, in another portion of the Jemez River basin, the Los Alamos Scientific Laboratory of the University of California is carrying out its research on the dry-hot rock concept of geothermal energy (Aamodt 1973, 1974; West, 1974; Smith, 1973).

Within the caldera Westates Petroleum Company,

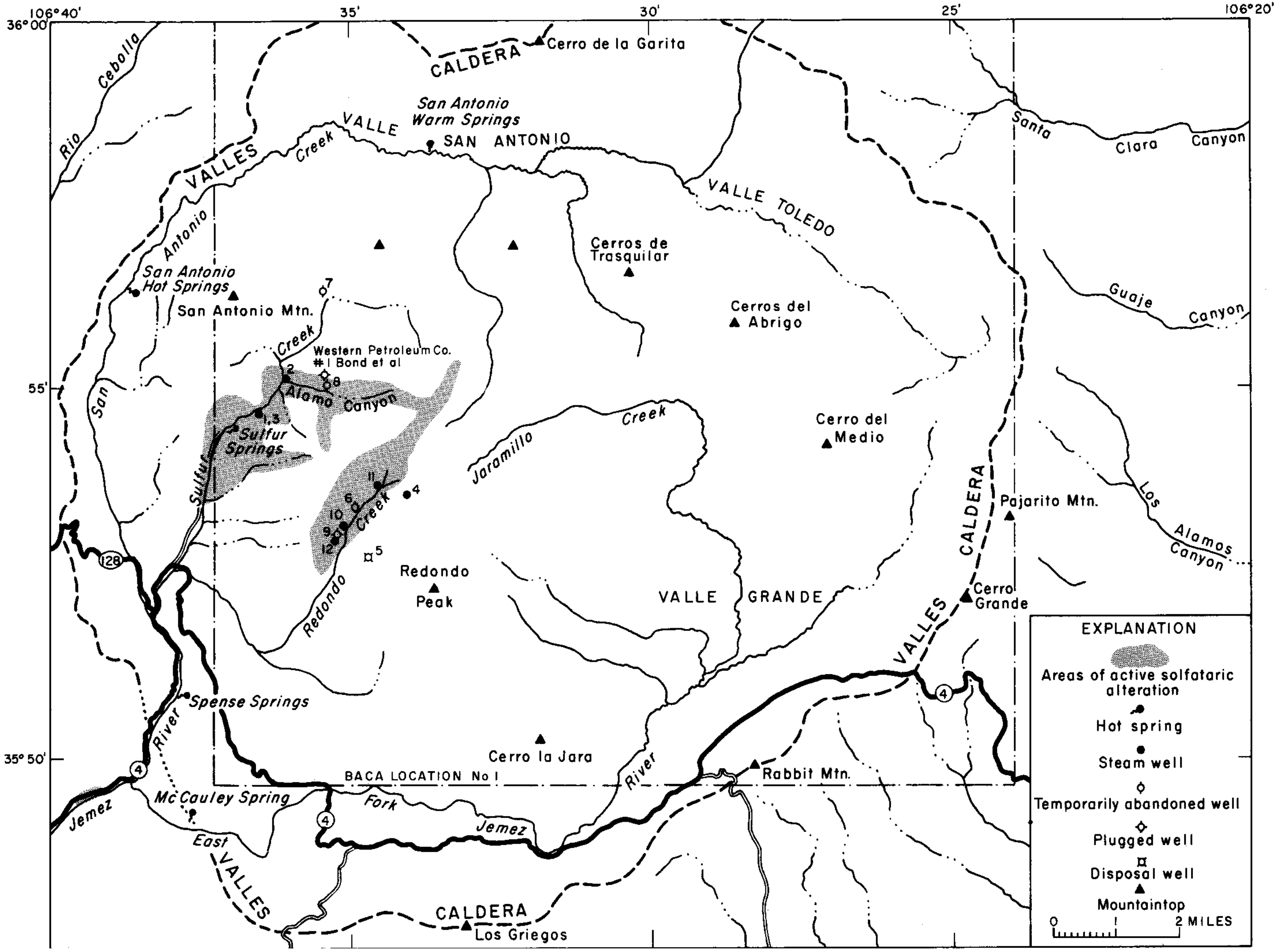


FIGURE 20—MAP OF THE VALLES CALDERA SHOWING HOT SPRINGS, SOLFATARIC AREA, AND STEAM WELLS.

Baca Land and Cattle Company, and Union Oil Company have drilled wells that produced steam and hot water.

Geologists and hydrologists of the U.S. Geological Survey have been responsible for more than 30 publications dealing with the Jemez River basin. Smith, Ross, Bailey and their associates have studied the volcano history of the Jemez Mountains in detail (Bailey, 1961; Ross, Smith and Bailey, 1961; Smith, 1961; Bailey, Smith and Ross, 1969; and Smith, Bailey and Ross, 1970).

Perkins (1973) described the petrology of some of the rock types of the Precambrian basement in the Jemez Mountains. Purtymun (1973) and Kudo (1974) have also reviewed aspects of geology of the basin.

Extensive geophysical work, including gravity and aeromagnetic mapping, has been carried out in the basin (Potter, 1973; U.S. Geol. Survey, 1972; Cordell, 1972; West, 1973b; Jiracek, 1974; Brandwein, 1974; Jiracek and Kintzinger, 1975). Lovering (1956) included areas in the basin in his study of radioactive deposits in New Mexico.

Hydrology and geohydrology of the region have been addressed by Clark, 1929; Kelly and Anspach, 1913; Renick, 1931; Titus, 1961; Conover, Theis, Griggs, 1963; Griggs, 1964; Cushman, 1965; Summers, 1965a,b; Purtymun and Cooper, 1969; Purtymun and Herceg, 1972; Woltz, 1972; West, 1973a,b; Purtymun and Johansen, 1974; Purtymun, West and Pettitt, 1974; and Trainer, 1974a,b.

Five thermal water areas (called in this report San Antonio Warm Spring, San Antonio Hot Spring, Sulphur Springs, Soda Dam Springs, and Jemez Hot Springs) have been confused by early writers (table 8). The confusion seemed to arise because their geography was not adequately understood. Consequently more than one spring has been called by the same name; 3 areas are discussed as if only 2 exist; and several names have been applied to the same spring. Some difficulties are discussed in detail below; others remain unresolved.

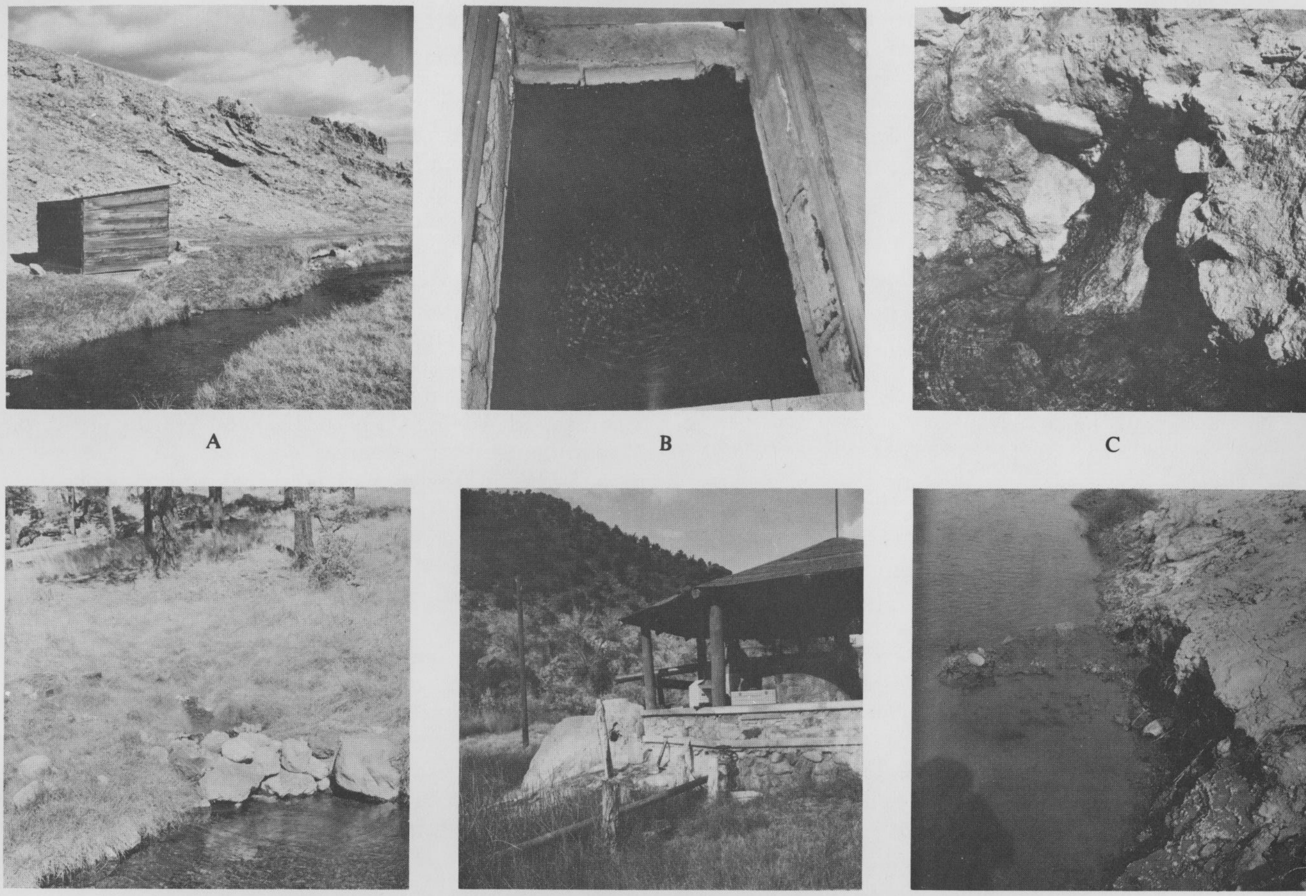
SAN ANTONIO SPRINGS

Two springs on San Antonio Creek (fig. 20), herein called San Antonio Warm Spring (20N.4E.7.000) and San Antonio Hot Spring (20N.3E.29.120), have been confused in the past by various writers: Reagan (1903, p. 102) wrote, ". . . to the northeast are the San Antonio Springs . . . [that] attain a temperature about the same as Indian Springs to the east of the Jemez River. . . ." On the same page, he also wrote, "The San

Table 8 - Field data for thermal water in the upper Jemez River basin

Location	Date	Discharge (gpm)	Maximum temperature (°F)	pH	Specific conductance (micromhos)	Density (gm/ml)	H_2S (ppm)	NH_3 (ppm)	SiO_2 (ppm)	Remarks
San Antonio	8-1-47	25	101	---	---	---	---	---	---	Hem, 1959
Warm Spring	11-1-65	15.7	99	7.9	170	---	0	0	---	p. 55
(20N.4E.7.000)	11-11-65	---	---	7.9	---	0.986	---	0	105	
	6-26-66	---	99.4	---	---	---	---	---	---	
San Antonio	11-31-65	199	106	8.2	125	---	0	---	---	
Hot Spring	11-11-65	---	---	8.2	---	0.984	---	.05	82	
(20N.3E.29.000)	6-26-66	---	105.4	---	---	---	---	---	---	
	5-16-73	323	104.5	---	110	---	---	---	---	Frank W. Trainer, USGS
	5-24-73	41	120	---	---	---	---	---	---	PWA, p. 5
Sulphur Springs (19N.3E.4.000)										
Electric Spring	10-29-65	2.6	95	1.4	10,000	---	1.0	---	---	
	11-11-65	---	---	1.5	---	0.986	---	36	560	
	12-2-74	---	73	1.7	---	---	---	---	---	
Footbath Spring	10-29-65	1.1	92	2.4	3,000	---	1.0	---	---	
	10-30-65	---	92	2.0	3,400	0.85	1.0	---	---	
	11-11-65	---	---	2.3	---	0.990	---	34	416	
Ladies Bath-	10-30-65	0*	135	---	1,600	---	2.0	---	---	
house Spring	11-11-65	---	---	2.3	---	0.996	---	8.0	480	
Lemonade	10-29-65	0.5	120†	---	3,000	---	1.0	---	---	
Spring	11-11-65	---	---	2.0	---	---	---	16	216	
Men's Bath-	10-30-65	0	---	---	6,400	---	1.5	---	---	
house Spring	11-11-65	0	---	1.6	---	0.982	---	40	414	
	12-2-74	0	158	2.0	---	---	---	---	---	
Spense Hot Spring (19N.3E.28.310)										
Main spring and pool	8-1-47	---	111	---	---	---	---	---	---	USGS meas.
inflow	11-2-65	---	106	8.1	---	---	0	0.05	55	
pool	11-2-65	---	102	8.3	280	0.986	0	---	---	USGS meas.
	3-1-72	44	106	7.97	---	---	---	.1	---	
Southernmost spring	11-2-65	---	94	8.2	---	---	0	---	---	
McCauley Spring	11-12-65	200	90	8.4	230	0.986	0	0	41	
(19N.3E.32.000)	11-16-73	368	90	8.15	180	---	---	---	---	USGS meas.
Soda Dam Springs (18N.2E.14.000)										
Loc. 1, Fig. 23	11-3-65	106†	115	6.3	5,000	0.990	0	4.8	37	
	12-1-72	62†	118	6.1	---	---	---	.7(N)	---	USGS meas.
Cascade	12-2-74	---	116	6.3	---	---	---	---	---	
Loc. 2, Fig. 23 Bubbling pool	11-3-65	---	---	6.2	4,000	0.990	1	3.8	30	
Jemez Springs (18N.2E.23.000)	11-9-65	---	169	6.4	3,100	††	1	2.3	196	
Loc. 1, Fig. 24	12-2-73	---	160	---	4,700	---	---	---	---	USGS F. W. Trainer
	12-2-74	---	138	6.5	---	---	---	---	---	
Loc. 4	3-19-73	1.3	167	6.29	---	---	---	.3	---	USGS GT237 IB72
Loc. 6	9-26-72	1.9	114	6.40	3,500	---	---	---	---	USGS F. W. Trainer
	6-21-73	---	120	6.34	3,600	---	---	---	---	USGS F. W. Trainer
Indian Springs (loc. 83-85, table 15)	11-10-65	9.4	---	6.5	5,100	0.988	0	0.6	39	
Indian Springs (16N.2E.29.142) (Loc. 83-85, Table 15)	11-10-65	9.4	123.3	6.5	5,100	0.988	0	0.6	39	
Plugged well (16N.1E.7.100)	9-29-26	2450	115	---	---	---	---	---	---	Renick (1931, p. 79)
Flowing well at Warm Springs (16N.1W.1.410)	10-11-65	68	---	6.4	9,000	0.980	0**	2.8	32	
	6-5-73	85	127	---	21,300	---	---	---	---	USGS meas.
	1973?	---	106	---	13,800	---	---	---	---	Brandwein, 1974
	2-12-74	---	126	6.4	---	---	---	---	---	

* Water overflows, moves a few feet down slope, and disappears
** Strong odor but field test showed no trace
† Total discharge
†† Indeterminate



A B C

D E F

FIGURE 21—PHOTOS OF SPRINGS IN JEMEZ RIVER BASIN.
A. SAN ANTONIO WARM SPRING IS ENCLOSED BY A BATHHOUSE
B. SAN ANTONIO WARM SPRING
C. WATER CASCADES AROUND BOULDERS AT BASE OF TALUS AT SPENCE SPRINGS
D. McCAULEY SPRING IS AT BASE OF TREE-COVERED TALUS
E. JEMEZ HOT SPRINGS, FIG. 24, LOCATION 1
F. INDIAN SPRINGS DISCHARGES FROM ALLUVIUM IN THE JEMEZ RIVER

Antonio springs twelve miles to the northeast of the Sulphurs are only at bathing temperature. . . ."

Jones (1904, p. 301), under the heading "San Antonio Springs," says, "The springs are four to six miles west of the Sulphurs and are also heavily impregnated with minerals, giving them medicinal properties similar to those of the Jemez Hot Springs." Jones erred on at least two counts. First, his description of the Sulphurs fits Soda Dam Springs; second, whatever he was thinking about, his description fails to fit any description of the San Antonio Springs. In all probability, he confused Soda Dam, Sulphur, and the two San Antonio springs.

Kelly and Anspach (1913, p. 9-10), who made a most impressive study of the thermal water of the Jemez Plateau, wrote, ". . . about thirteen miles northeast of the Soda Dam and the Jemez Hot Springs, on the very top of the Jemez Plateau, are the famous sulphur springs and still further to the northeast are the San Antonio Springs. The latter attain a temperature about the same as that of the Indian springs to the east of the Jemez River." Kelly and Anspach tried to clarify Jones but did not realize that the 2 distinct springs on the creek are several miles apart.

San Antonio Warm Spring (*20N.4E.7.000*)—This spring is in the Baca Location, Sandoval County, on the north bank of San Antonio Creek. The earliest reference to it is that of Lieutenant P. M. Price, who noted it on his map showing the area of the expedition of 1874-75-76. Peale (1886, p. 175) noted a warm spring "at head of San Diego Canyon, Rio Arriba County," which could be this same spring. Stearns, Stearns, and Waring (1937, p. 167) called it "San Antonio Springs" (plural) and gave the discharge as 50 gpm at 120°F from Tertiary basalt. Hem (1959, p. 55, analysis 2) presented an analysis of water collected by the U.S. Geological Survey on August 1, 1947, as an example of water containing a high proportion of silica (table M6), even though the total dissolved solids content is less than 300 ppm.

The water discharges from a fracture in massive, stratified, rhyolite tuff, which appears to have vertical bedding with a N-S strike. It has been differentially silicified so that parts of it are extremely hard and weather-resistant. A thin section of the silica-free rock shows that it is 73 percent glass, 5 percent sanidine, 5 percent quartz, 1 percent albite, 2 percent divitrified glass, and 13 percent vesicles. The water discharges from the rock through alluvium into a small pool (fig. 21a,b) and then into the San Antonio River.

San Antonio (Murray) Hot Spring (20N.3E.29.120)—San Antonio Hot Spring is in the Santa Fe National Forest, approximately 250 ft above San Antonio Creek on the east wall of San Diego Canyon. Its approximate elevation is 8400 ft above sea level.

Lieutenant P. M. Price also noted this spring on his map of the 1874-75-76 expedition. Loew (1875b, p. 102) wrote,

> Ascending about 160 feet from the eastern margin of the stream, we meet with a large hot spring, called by our guide Spring San Antonio, the temperature of which is 105°F. The water is tasteless. The only mineral constituent it appears to contain is carbonate of lime, which forms thin crusts over the rocks with which the water comes in contact.

Stearns, Stearns and Waring (1937, p. 167) and Waring (1965, p. 371) called it "Murray Spring" and said that 150 gpm discharged at a temperature of 130°F from late Tertiary lava.

This spring issues from fractures in a rhyolite porphyry. The joints and fractures strike N. 30° E., N. 40° W., and N. 80° W. Two sets dip 75°E. to nearly vertical. A third set, which dips 25°W., gives the rhyolite a bedded appearance.

A thin section of the rhyolite revealed that it contains 15 percent sanidine, 2 percent biotite, 10 percent quartz, 10 percent plagioclase feldspar, 5 percent glass, 57 percent microfelsite, and 1 percent opaques. In the immediate vicinity of the spring, the rhyolite has been silicified.

This spring currently provides the water supply for a summer home.

STEAM WELLS

Fig. 20 shows the location of the steam wells that have been drilled in the Valles Caldera. Table 9 summarizes the information available on these wells. Table M6 contains chemical analyses of the condensate from well no. 2(?). The earliest wells were drilled in and near Alamo Canyon, an area of solfataric activity (Bailey, 1961); that is, the area bubbles gas, largely CO2. The ground water discharging at seeps and springs is acid (pH = 2.9), but temperatures are low (less than 60°F). Table M6 contains chemical analyses of water from Alamo Canyon. No data are available on the newest wells, most of which were drilled in Redondo Canyon.

SULPHUR SPRINGS (THE SULPHURS; 19N .3 E.4.000)

Sulphur Springs are on the east side of Sulphur Creek in the Baca Location, Sandoval County, at an altitude of 7950 ft (fig. 20).

The oldest reference to Sulphur Springs is an 1898 map by the U.S. Post Office entitled "Post Route Map of the Territory of New Mexico." It shows the post routes as of September 1, 1898, with a special supply route extending to Sulphur Springs.

The first mention in the literature of Sulphur Springs may be that of Reagan (1903, p. 98, 102), who wrote ". . . famous Sulphur Springs . . . ," implying that these springs were well known in 1903. However, Crook's 1899 listing of the mineral waters in the United States and their therapeutic uses does not mention Sulphur Springs, suggesting that they were not generally well known in Crook's time.

Jones, who compiled the most complete statement on thermal springs in New Mexico at the time of his writing in 1904, made no mention of Sulphur Springs. His section on "The Sulphurs" clearly refers to Soda Dam Springs. So Reagan may also be referring to Soda Dam Springs.

In 1913, Kelly and Anspach (p. 26-28) described the springs in some detail. Renick (1931, p. 78, 79, 89) provided additional information on the springs. Stearns, Stearns, and Waring (1937, p. 167) and Waring (1965, p. 37) summarized these sources.

In addition, the U.S. Geological Survey collected water samples at irregular intervals. An analysis of one of these samples was cited by Hem (1959, p. 95, analysis 4) and again by White, Hem, and Waring (1963, p. F46-F47, analysis 5) as an example of acid spring waters.

The springs discharge from volcanic tuff that ranges from poorly sorted to very well sorted. Some specimens are very fine grained, others contain coarse fragments. The tuff is extremely porous and contains secondary sulfur crystals in fractures and in vugs. In part, it is stratified and appears to be water-laid. Other beds do not show crossbedding or graded bedding and probably are not water-laid. The tuff is extensively fractured, the fractures striking N. 10° W., N. 40° W., N. 80° W., and E-W. The dip of the fractures ranges from 45°W. to approximately vertical.

According to Mansfield (1918, p. 367-369) and Wideman (1957, p. 37-39), sulfur was mined from underground workings at this locality from 1902 to 1904. Approximately 200,000 pounds were removed. Mansfield said,

> All the sulphur at Sulphur Springs was apparently deposited in vents, cracks, and pores within a few feet or a few inches of the surface. The available sulphur in this area is apparently not large in quantity and is irregularly distributed. Samples of ore taken from this site contain from 15 to 39 percent free sulphur and 6 to 8.5 percent sulphur combined as sulphates. The deposit occupies a roughly circular area over 600 feet in diameter. Sulphur deposit is not considered commercial. The sulphur is irregularly deposited and is in a relatively thin deposit measuring only 2 ft. 4 in. to 3 ft. 4 in. in four cuts in the more promising parts of the area. In one cut the deposit was not penetrated at a depth of 4 ft. 2 in. The sulphur ore contains from 15 to 39 percent free sulphur and from 6 to 8.5 percent of sulphur combined as sulphate. The rock under the ore contains no free sulphur and about the same percentage of sulphur combined as sulphate.

Fig. 22 is a sketch of the area in which the springs occur. Kelly and Anspach (1913, p. 26-28) listed 8 springs. However, bulldozers and floods have combined to reduce the number to those shown. The springs are distributed over an elevation range of approximately 50 ft, and fumaroles occur intermixed with the springs. Although they are called "springs," only 3 have any surface discharge; the others are pools with no surface overflow. Both the springs and the pools boil and bubble CO_2. The temperatures at the fumaroles (fig. 22) are as follows:

No. 1	190°-191°F
No. 2	190°-192.2°F
No. 3	193°F

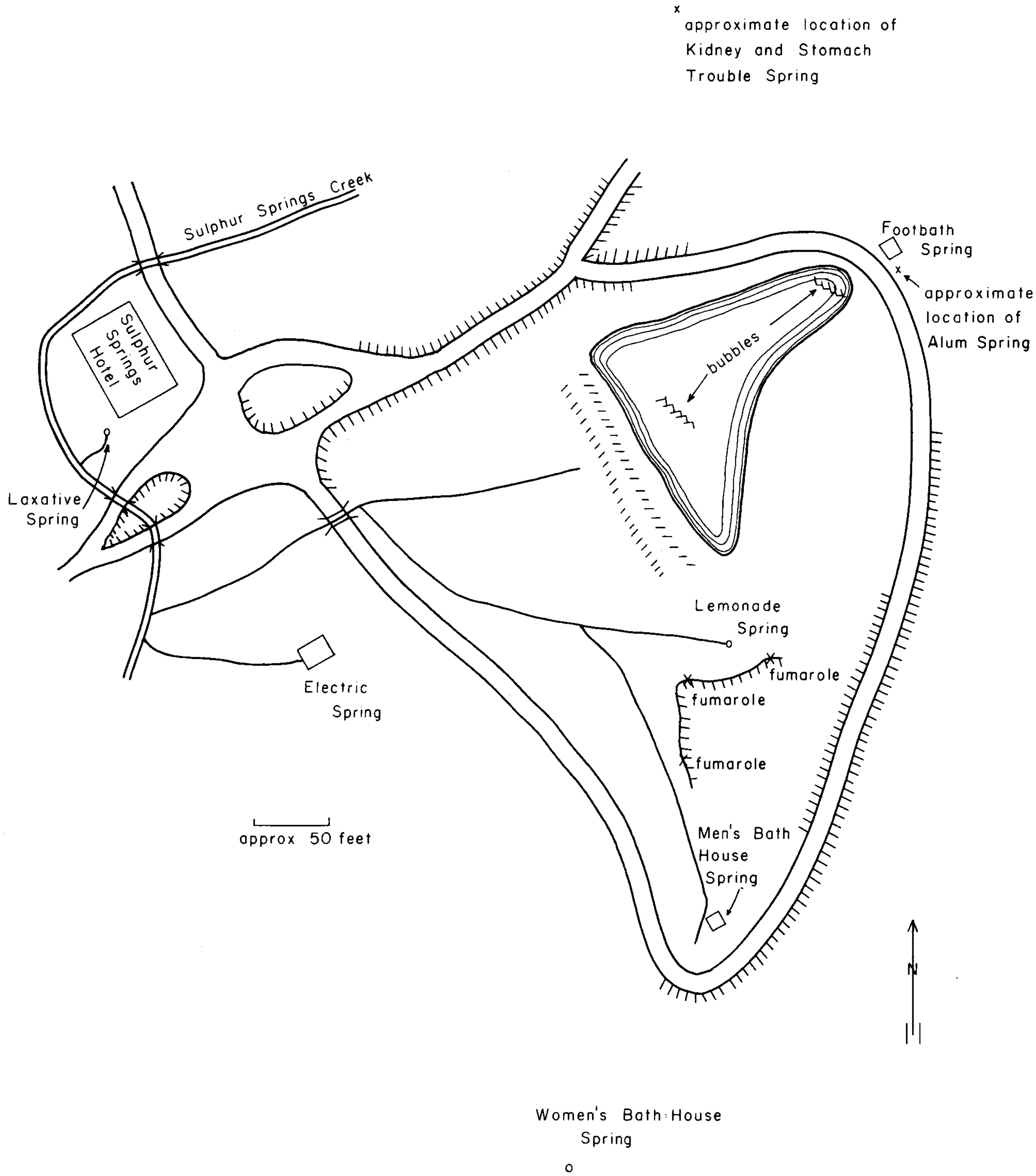


FIGURE 22—SKETCH OF THE PREMISES OF SULPHUR SPRINGS IN 1965.

The chemistry of the discharging gas sampled August 31, 1924, follows (Renick, 1931, p. 89):

	Men's Bathhouse	Alum Spring
Temperature of water	110°F	76°F
Gas per cubic centimeter of water	0.14	0.19
Carbon dioxide (CO_2)	85.9	77.9
Oxygen (O_2)	1.1	1.1
Hydrogen sulphide	7.1	20.1
Nitrogen	5.9	.9
Helium	0	0

Table 8 summarizes field data obtained for the individual springs and table 10 summarizes the temperatures reported for individual springs since 1912. Table 11 gives the results of analyses for selected heavy metals and radon-222 samples collected December 3, 1974, from Men's Bathhouse and Electric Springs.

A degree of confusion exists in the literature because Jones called Soda Dam Springs "The Sulphurs." Consequently, some reports, notably Stearns, Stearns and Waring (1937), and Waring (1965), give the discharge of these springs as 500 gpm. As a result, Pecora, Director

Table 9 - Steam wells in the Valles Caldera

Well	Operator	Altitude ((ft))	Depth (ft)	Casing Diameter (inches)	Casing From (ft)	Casing To (ft)	Open hole Diameter (inches)	Open hole From (ft)	Open hole To (ft)	Year	Production Rate lbs/hour	Production Interval (ft) From	Production Interval (ft) To	Shutin Pressure (PSI)	Discharge Temperature (°F)	Producing Formation	Remarks
Bond et al. #1	Westates Petroleum	8697.0	3675	13 3/8	0	404	?	1217	3675	1960	---	---	---	---	275	---	Plugged
				9 5/8	0	1217											
No. 1	Baca Land & Cattle Co.	---	2560	---	---	---	---	---	---	1963	85000	1300	1500	65	---	---	Test @ 1300-1500 ft., lost hole, plugged
2	"	---	5600	---	0	3460	?	1750	2300	1963	45000	1750	3160	---	500	---	
							?	2400	3160		35000	2400	3160	---	---	---	---
3	"	---	2600±	---	---	---	?	1780	1936	1964	---	---	---	---	---	---	Discharged steam & hot water
4	Baca Land & Cattle Co.	9307	5048	---	---	---	---	---	---	1970	100,000+	1900	5000	---	545	Bandelier tuff & Palize Canyon Andesite	Dry steam with ≈7000 ppm TDS
	Union Oil Co. of California	---	6376	13 3/8	0	1442	8 3/4	3031	6376	1973	25000	3182	8375	---	---		
				9 5/8	0	3182											
5*	"	9290	6973	20	0	658	?	4382	6955	1971	0	4400	6955	---	---	"	Disposal well for water produced while testing
				13 3/8	0	2810											
				9 5/8	2674	4382											
6*	"	8762	3715	13 3/8	0	22	7	2619	2696	1972	---	---	---	---	---	Bandelier Tuff	Completed as temperature observation well
				9 5/8	0	781	7	2876	3162								
				7	678	3686	7	3575	3685								
7*	"	8724	5518	13 3/8	0	496	7	2683	5501	1972	---	---	---	---	---	Bandelier Tuff, Tertiary sediments, Permian red-beds, Penn. Ls. & PC granite	Completed as temperature observation well
				9 5/8	0	2894											
8*	"	8631	4370	13 3/8	0	326	8 3/4	2281	4370	1972	---	---	---	---	---	Bandelier Tuff, Tertiary sediments, & Permian(?) redbeds	"
				9 5/8	0	2267											
				2 3/8	0	4211											
9*	Union Oil Co. of California	8605	5289	13 3/8	0	891	8 3/4	3585	5289	1972	---	---	---	---	---	Bandelier Tuff	Plugged
				9 5/8	371	3585											
10*	"	8735	5984	20	0	636	7	4427	5577	1973	---	---	---	---	---	Bandelier Tuff, Paliza Canyon andesite, and Tertiary sanidine	Production zone damaged, remedial work planned
				13 3/8	0	2777	7	5744	5969								
				9 5/8	0	4401											
				7	4261	5983											
11*	"	9065	6974	20	0	190	7	3471	4228	1973	205500	3471	6911	101	330	"	Basis of discovery announcement
				13 5/8	0	1319	7	4271	6600								
				9 5/8	0	3363	7	6682	6911								
				7	3303	6909											
12	"		9212	20	0	247	7	3343	9211	1973-74	---	---	---	---	---	Bandelier Tuff, Paliza Canyon andesite, Abiquiu Tuff(?) and "redbeds"	
				13 3/8	0	1453											
				9 5/8	0	3540											
				7	3343	9211											

* Depths relative to ground level--other depths may be relative to derrick floor

Table 10 - Temperature (°F) recorded for individual springs at Sulphur Springs, Sandoval County

Spring	10/11-12/1912*	8/31/24[+]	8/13/47[§]	7/28/49[§]	8/31/49[§]	10/30/65	6/26/66**	12/3/74
Footbath	100.4	---	---	---	---	---	---	---
(Mudbath, Mud Geyser)	87.8	99	97	99	105	92	92.2	---
Electric	98.8	---	97	102	NR	95	102.4	73
Alum	59.4	76	63	64	---	Destroyed	---	---
Lemonade	112.2	---	127	130	±150[†]	120	131.2	---
Men's Bath House	155.3	---	---	---	---	---	---	---
(no discharge at surface)	105.8	110	160(?)	162(?)	110[+]	188[++]	178.1	178
Ladies Bath House	167.0	---	---	---	---	---	---	---
	158.0	110	70[++]	---	---	135[+]	179.5	---
Seltzer[*], Stomach and Kidney	50.7	---	57	---	58	Destroyed	---	---
Laxative	57	61	---	---	---	Dry	---	---

* Kelly and Anspach, 1913, p. 30
\+ Renick, 1931, p. 78
† Hem, 1959, p. 95; White, Hem and Waring, 1963, p. F-46-F-47
§ Unpublished measurement of U. S. Geological Survey
** Maximum temperature
++ Location uncertain; measurement may be for another spring

Table 11 - Heavy metals and radon-222 in the thermal waters of the Jemez River basin

	Sulphur Springs			Soda Dam		Jemez Springs Figure 29		
	Men's Bathhouse	Electric Spring	Spense Spring	(Loc. 1, fig. 23)		Loc. 4	Loc. 1	Kaseman no. 2
Date	12-2-74	12-2-74	12-1-72	12-1-72	12-2-74	12-2-72	12-2-74	12-2-73
Copper	20	57.5	<20	20	11	<20	7.5	106
Cobalt	---	---	<50	<50	---	<50	---	---
Chromium	15	100	---	---	4.3	---	1.5	16
Cadmium	---	1.9	<10	10	.008	<10	20	20
Lead	64	85	<100	<100	10	<100	14	31
Molybdenum	---	≃34	---	---	0	---	0	<10
Nickel	---	---	<50	<50	---	<.05	---	---
Mercury	---	7	<0.1	<0.1	<1	---	<1	<1
Zinc	.18	.27	20	.04	.21	120	ND	27
Radon-222	940	120	---	---	450	---	220	210
Gold	---	---	<100	<100	---	<100	---	---
Beryllium	---	---	0	0	---	---	---	---
Cesium	---	---	<100	2000	---	1200	---	---
Rubidium	---	---	<40	2400	---	890	---	---
Antimony	---	---	<200	<200	---	<200	---	---
			USGS GT234IB72	USGS GT235IB72		USGS		

of the U.S. Geological Survey, in an often-quoted press release erroneously confused the acid drainage of Lemonade Springs (a trivial volume) to the acid mine drainage of the coal mines of the eastern United States.

SPENCE SPRING (19N.3E.28.310)

The pool at this spring, which is more than 100 ft above the Jemez River, has been used by local residents as a natural bathtub for many years; yet, there is no reference to it in the literature.

Moreover, even the local residents fail to realize that the spring they use is the largest of several small seeps and springs. These occur in an area of heavy brush and timber, perhaps 200 yards long (parallel to the river) and 100 yards wide. The area is a small bench on an otherwise steep slope, and the discharge is from beneath the talus that has accumulated on the bench.

This bench (or more properly its upper limit) is very likely the top of the Abo Formation of Permian age. Overlying the Abo Formation are vitrophyres and tuffs of late Tertiary age (fig. 21c). Presumably, the water discharges from the tuff, flows beneath the talus, and emerges at several discrete points at the base of the talus. Whether water emerges from the tuff at one place or at multiple points is not known. However, the length of the area over which discharge occurs and the fact that McCauley Spring (discussed below) has a similar setting suggest that the outlets are probably multiple.

The flow from the multiple springs and seeps merges to form a single little tributary to the Jemez River. The discharge of this little tributary was 57 gpm on November 2, 1965. The observations made at the spring and pool and at the southernmost smaller spring are given in table 8; the chemical analyses are given in table M6. Table 11 contains the heavy metal concentrations in a sample collected December 1, 1972, by the U.S. Geological Survey.

MCCAULEY SPRING (19N.3E.32.000)

McCauley Spring is a small, single-outlet spring more than 100 ft above the East Fork Jemez River and about 1.1 miles east of Battleship Rock.

Water discharges from beneath a talus slope on a small bench (fig. 21d), and the relation of the spring to the Abo Formation, the overlying volcanic sediments, and the talus slope is similar to that described for Spence Spring.

SODA DAM SPRINGS (18N.2E.14.000)

These springs issue from the west wall of San Diego Canyon, perhaps 25 ft above the bed of the Jemez River. The origin of the name Soda Dam is not clear. Loew (1875, p. 615), Peale (1886, p. 194-195), and Crook (1898, p. 336) referred to these springs as the Jemez Hot Springs (upper group). Reagan (1903, p. 101-102) was the first to refer to Soda Dam. Jones (1904, p. 300-301) called them The Sulphurs.

Loew wrote:

> The upper group consists of forty-two springs; the taste of the water is somewhat like Vichy; the temperature ranges between 70°F. and 105°F., with but few exceptions; the surface of each is less than 1 square foot. Most of these springs originate in cones and mounds, consisting of spring-deposits, chiefly carbonate of lime. One of these mounds is 20 feet high, 10 feet wide, and 130 feet long, with twenty-two springs on it. A few yards above, and at right angles to it, is another mound, 30 feet high, about 200 feet long, and 15 feet wide. On the eastern end of this mound is a cave 10 feet high, 25 feet long, and 7 feet wide, with snow-white walls and two columns. The water of the first spring, or the most southerly of this group, was subjected to analysis. After the loss of the free carbonic acid, it has an alkaline reaction.

Specific gravity = 1.0023
In 100 parts are contained–

Chloride of Sodium	0.2642
Sulphate of Soda	0.0059
Carbonate of Soda	0.0219
Carbonate of Lime	0.0548
Carbonate of Magnesia	0.0057
Silicic acid	0.0201
Phosphoric acid, Potassa, Lithia	traces
	0.3726

Peale, Crook, and Jones copied Loew.

Reagan wrote,

> The Soda Dam.—The Soda Dam is a long travertine ridge built directly across the Jemez River at a point two miles above the Jemez Hot Springs. The ridge of travertine has completely dammed the river. On it are situated 22 springs, or about one-half of the springs of this group. They all deposit travertine and their charged waters running over the dam causes the cap of the dam to be built out farther and farther to the south each year, thus leaving rooms beneath the cap. These rooms are decorated with stalactites suspended from the roof. They are exceedingly picturesque.
>
> The waters of the springs come to the surface after encountering a granite wall in their southern course, which crosses the country in an east and west direction; hence the line of springs.
>
> These springs existed in former geologic time and then dammed the river with their deposits the same as today. The remains of the first dam are nearly 1000 feet above the present one; and, as the river has cut its channel down, a succession of dams in step-like order has been formed. These dams, therefore, are evidence that Canyon San Diego was not formed altogether by a faulting of the strata; but that the Jemez River has here chiseled out for itself the present channel. They also indicate that the Jemez plateau has been raided by a series of uplifts, each dam marking a period of rest.

However, for his temperatures and water chemistry, he, too, copied Loew.

Kelly and Anspach (1913, p. 7) wrote,

> The Soda Dam, which lies about a mile above the Jemez Hot Springs, is a travertine ridge built directly across the Jemez River. It is about three hundred feet long, fifty feet high at its highest part near the east end, fifty feet wide at the base, and twenty-five feet wide at the top. The river was, at one time, completely dammed by the Soda Dam, but later it cut its way around the east end, and today flows over the dam underneath a large dome, which has been built out over the river by the deposits of a spring on top of the dam.
>
> In the American Geologist, Volume 31. Reagan states that there were twenty-two springs situated on the dam in 1902. While there are indications of many recent active springs on top of the dam, the authors were unable to find more than half this number when they visited the region in 1912.

Stearns, Stearns, and Waring (1937, p. 16) and Waring (1965, p. 37) repeated Loew's data, adding only that the flow was 10 gpm. Here they seem to be confused with Sulphur Springs, because the flow must have been much more than 10 gpm for many years; the total flow November 3, 1965, was 106 gpm.

On August 2, 1949, the flow of Jemez Creek a quarter mile above Soda Dam was 18.3 cfs (cubic ft per second). A quarter mile downstream, it was 18.9 cfs. Thus in the half-mile reach that includes the springs, the net increase in flow was 0.6 cfs, or 268 gpm.

Only a few measurements of the temperatures of the discharging water have been made:

Year	°F	Source
1875	70-105	Loew, 1875a, p. 615
1924	104	Renick, 1913, p. 79
1949	81-110	U.S. Geol. Survey, unpub. data
1965	115	W. K. Summers
1966	94.5-113.3	W. K. Summers
1972	118	U.S.G.S.—Frank W. Trainer
1973	115	U.S.G.S.—Frank W. Trainer
1974	116	W. K. Summers

Table M6 contains chemical analyses made of water collected from various sites at Soda Dam in the past. The exact location of the sampling sites is uncertain and cannot now be made certain, because a road has been built through the dam along the west side, destroying many of the features described by Loew, Reagan, and Kelly and Anspach.

Table 8 gives the data collected in the field for the Soda Dam Hot Springs. Table 11 gives the heavy metals and radon concentration and table 12 gives the results of a spectrographic analysis.

Fig. 23 is a sketch that shows the springs and the points at which they were sampled and the field measurements made during the 1966-1967 inventory. There are no other springs nearby either upstream or downstream.

Upstream from Soda Dam about 2 miles, there is an extensive deposit of free sulfur similar to that at Sulphur Springs, except it occurs in the Magdalena Limestone (Mansfield; Wideman). Free sulfur also occurs at the Dam, and despite Renick's reports of no hydrogen sulfide gas, the odor of hydrogen sulfide and sulfur dioxide is strong. Field tests show that at least one ppm of hydrogen sulfide occurs in solution in the water discharging at location 2 (fig. 23). The relation of the present springs to the sulfur deposits upstream is uncertain and should be examined in detail.

Granger (1956) reported that the calcareous tufa of the dam is radioactive with the newer material being more radioactive than the older. Water from the springs and the Jemez River was analyzed with the following results:

Location	Uranium Concentration (ppm)
Three springs and the river	0.040
One spring	0.036

Granger tentatively identified (p. 360) radium as the major radioactive element present in the tufa.

The following analyses of gases discharging at the spring have been made:

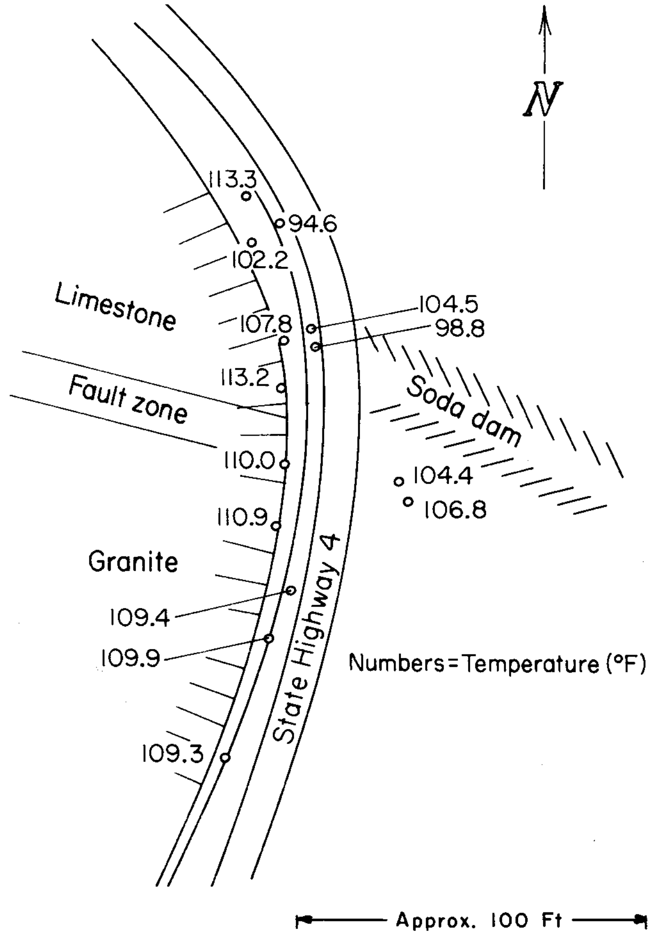


FIGURE 23—Sketch of Soda Dam Springs, Sandoval County, showing locations at which samples were collected and measurements were made in the field.

Table 12 - Spectrographic analyses of thermal waters from the Jemez River basin (concentration in ppb)

	Soda Dam	Jemez Springs Loc. 1, Fig. 24	Kaseman #2
Date of sample	2-21-73	2-21-73	6-6-73
Aluminum (Al)	110	130	1400
Barium (Ba)	340	180	<35
Beryllium (Be)	2	.8	.4
Bismuth (Bi)	<.5	<.5	<.1
Boron (B)	13000	6500	2600
Cadmium (Cd)	<10	<10	<12
Chromium (Cr)	1	<1	<2
Cobalt (Co)	<.5	<.5	<2
Copper (Cu)	<13	<8	<27
Gallium (Ga)	<27	<16	<70
Germanium (Ge)	<58	<34	<170
Iron (Fe)	52	160	850
Lanthanum (La)	<5	<5	<6
Lead (Pb)	<3	<3	<3
Lithium (Li)	?	?	>740
Manganese (Mn)	500	170	28
Molybdenum (Mo)	<1	<1	<7
Nickel (Ni)	<2	<2	<3
Silver (Ag)	<2	<2	<2
Strontium (Sr)	2200	870	10,000
Tin (Sn)	<58	<34	<170
Titanium (Ti)	<5	<5	<2
Vanadium (V)	<58	<34	<35
Ytterbium (Yb)	<.2	<.2	<.6
Yttrium (Y)	<1	<.1	<.3
Zinc (Zn)	<22	<22	<25
Zirconium (Zr)	<1	<1	<1
Antimony (Sb)	<.5	<.5	<.6
Arsenic (As)	13000	740	340
	USGS 731779	USGS 731780	USGS 732170

	Percent	
	Renick (1931, p. 89)	USGS sample no GT235 Irs 72
Date	--	12-1-72
Hydrogen (H_2)	--	not detected
Oxygen (O_2)	3.3	1.0*
Carbon dioxide (CO_2)	82.8	90.2
Hydrogen sulfide (H_2S)	0.0	--
Nitrogen	13.9	1.7
Helium	0.0	--
Methane	--	0.01
Other combustible gases	0.0	--
Total gas per cubic centimeter of water (cm^3)	0.26	--

*includes Argon

JEMEZ HOT SPRINGS (010 CALIENTE) (18N.2E.23.000)

Jemez Hot Springs are in San Diego Canyon at Jemez Springs, about 2 miles south of Soda Dam and 12 miles north of Jemez Pueblo.

These springs were first mentioned in the geologic literature by Loew (1875a, p. 613-614), who wrote,

> These far famed springs of New Mexico are situated twelve miles above the town of Jemez, on the Jemez Creek, and are enclosed in a deep spacious canon. The slopes of the cation are formed by strata of limestone and sandstone of Carboniferous age, often changed from their original positions by protruding volcanic material. There are two distinct groups of warm springs in the valley, two miles apart. The springs of the lower group consist of *[note:* the upper group is at Soda Dam]:
>
> (I) A geyser with a surface of 60 square feet, and an aperture of 1 square foot; the temperature is 168°F; large quantities of escaping carbonic acid keep the water in violent agitation; thick deposits of snow-white crusts are formed, consisting chiefly of carbonate of lime. This spring yields about fifty gallons of water per minute.
>
> (2) One spring with a surface of 6 square feet and a temperature of 180°F.; it contains free carbonic acid and forms a red-brown deposit.
>
> (3) Three springs, with a temperature of 119°F., covered with a vigorous growth of a peculiar alga. Dr. Schaeffer, of the Army Medical Museum, who kindly examined a specimen of this vegetable scum of intense green color, pronounces it as filaments of Oscillatoria, 0.005 of an inch in thickness. Globular Gonidia were also found.
>
> When this vegetable scum is left to stagnate in the small pools near the springs, a black deposit of sulphide of iron is formed. This is the result of the action of the sulphureted hydrogen upon the carbonate of iron in the water and the oxide of iron in the alga-plant. The sulphureted hydrogen is a product of the reduction of the gypsum contained in the water.
>
> (4) One spring of 110°F.
>
> (5) Two springs of 108° F.
>
> (6) Several small springs of 94° to 102°F. The water of the geyser contained in 100 parts—

Chloride of sodium	0.1622
Sulphate of soda	0.0035
Carbonate of lime	0.0641
Carbonate of magnesia	0.0103
Potassa	traces
Silicic acid	traces
Sulphate of lime	traces
Total amount of salts	0.2401

> Tests were made for iodine in the evaporation residue of several gallons of water; but none was detected.
>
> One of the springs of 119°F. gave the following composition:

Specific gravity = 1.0016

In 100 parts of water are—

Chloride of sodium	0.1508
Sulphate of lime	0.0262
Carbonate of lime	0.0300
Carbonate of magnesia	0.0240
Carbonate of iron	0.0002
Silicic acid	0.0010
Lithia	traces
Potassa	traces
Carbonate of iron	traces
	0.2322

Peale (1886, p. 194-195; 1894) and Crook (1899, p. 336) repeated Loew's work. Reagan (1903, p. 100-101) noted that there are actually two groups of springs in the Lower Group; he wrote,

> The Jemez Hot Springs.—The Jemez hot springs or "Ojos Calientes," as the Mexicans call them are situated in the Jemez River bed in Cation San Diego at Perca. The site is a beautifully picturesque one. The Red Bed walls of the canyon rise 1200 feet on either side of the river, while in the valley a little north of the springs is the ruins of the Indian village of San Juan de los Jemez and the Spanish Catholic church and fortification of the first occupation of the Spaniards.
>
> These springs are located geographically in two groups. The lower group is owned by a man by the name of Judt, and the upper one by the Oteros. Each firm has erected comfortable bathing houses and sweating rooms. Hotels have also been erected for the benefit of the health seekers. A stage also runs between these springs and Albuquerque.
>
> The temperature in Judt's group of springs is 119°F. The temperature of the Otero group of springs is 168°F. These springs are known throughout America and Europe; and it is not infrequent that one meets a foreigner here.

Jones (1904, p. 299-300) repeated the work of Loew, but apparently did not realize that the upper group of about 46 springs, referred to by Loew and Peale, is at Soda Dam. Nor did he realize that 2 groups of springs exist at Jemez Hot Springs proper. Consequently, later reports referring to Jones mistakenly report 1 group of 10 and another group of 40 springs with temperatures ranging from 94° to 168°F.

Kelly and Anspach studied the springs. They quoted Reagan verbatim (1913, p. 7), then (p. 25-26) described 3 springs of the Otero Group:

> Spring No. 1. This is the so-called Soda Dam Spring at Jemez Hot Springs, New Mexico. The vent, which lies about the center of the town, is in the river bottom, the waters coming up through the river-bed gravels. A green scum of organic matter fringes the vent and a deposit of the color of ferric hydroxide lines it inside. The pool is about one foot in diameter. A considerable quantity of gas is being evolved. Several larval worms about three inches long are in the water just outside the pool [fig. 24, location 2].
>
> Spring No. 2. This spring is known as the Original Spring. It lies about 30 yards northeast of the Soda Spring. The pool, into which the spring flows, is about seven feet in diameter and three feet deep. It is lined with a deposit of the color of ferric hydroxide and a green scum of organic matter fringes it at the surface of the water. A large quantity of gas bubbles from the spring. The pool is covered by a small summer house and pipes lead some of the water to the bathhouse about 50 feet to the south [fig. 24, location 1].
>
> Spring No. 3. This is the Iron Spring, so-called because of the color of the deposit, this color being that of iron rust. The color is not due to iron oxide but is due to a red algous growth. The spring is situated about 50 feet southeast of the Soda Spring. The deposit does not form a sinter but remains soft and flaky. The banks of the small stream flowing from the spring are covered with a dark green deposit of organic matter at the edge of the water. A platform is built over the spring with a cement box in the center into which the spring flows. [fig. 24, location 4].

Lindgren, Graton and Gordon (1913, p. 71), Fitch

(1927), Clark (1929), and Renick (1931, p. 78-79), mentioned the springs briefly. Stearns, Stearns, and Waring (1937, p. 167) and Waring (1965, p. 37) repeated the reports of Loew (1875a,b) and Jones (1904).

White, Hem, and Waring (1963, p. F42-F43 analysis 4) used an analysis of the water from "Spring, in pool behind bathhouse. . . ." as an example of "Chemical analyses of thermal sodium chloride bicarbonate waters from nongeyser areas associated with vulcanism." Fig. 24 is a map of these springs in November 1965. Locations 1-4 are at the Otero Group of Renick and locations 5 and 6 are at the Judt Group. The total discharge of the various springs has not been measured but is probably between 50 and 200 gpm.

Fig. 21e shows the tufa mound that has built up at the end of the overflow pipe at the main spring (fig. 24, location 1). Next to and south of the main spring is a vertical pipe that appears to be the top of the casing of a small-diameter well. The water discharging from this pipe had the highest temperature (162.2°F), June 26, 1966. The pool under the shelter, which discharges to the cooling reservoir for the bathhouse, had a temperature from top to bottom of 143.8°F.

Table 13 contains the measurements that have been obtained at Jemez Springs. Table 11 gives the heavy metals in the water at locations 1 and 4 (fig. 24) and table 12 gives the spectrographic analyses of water from location 4.

Chemical analyses of water from Jemez Springs (table M6) shows that the water is essentially the same throughout the area.

The pipe and the spring under the shelter at fig. 24, location 1 discharge gas copiously. The following analyses of gases have been reported:

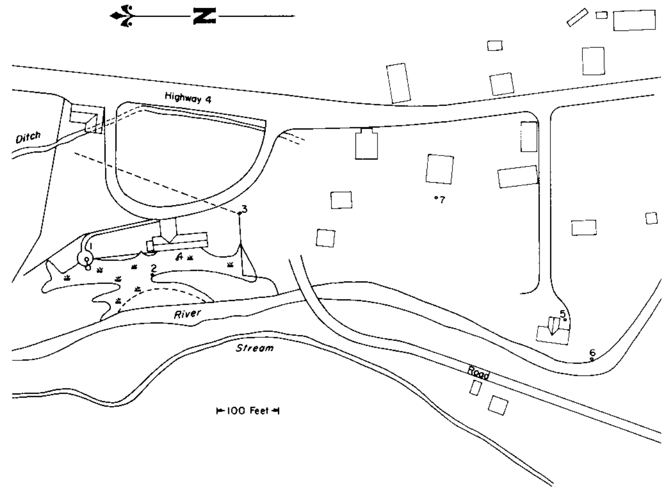


FIGURE 24—MAP OF JEMEZ HOT SPRINGS, SANDOVAL COUNTY.

	Kelly & Anspach (1913, p. 33)	Present USGS (sample no.) GT237 IB 72
Date	--	12-2-72
Carbon dioxide CO_2	91.0	89.7
Oxygen	0.6	.88+
Hydrogen	2.8	not detected
Methane	2.4	not detected
Nitrogen	5.2*	1.5
total	100.0	92.08

*remainder +includes argon

GRANITE TEST WELLS (19N.2E.1.400 AND 19N.2E.13.200)

As part of its investigation of the "dry-hot-rock concept," the Los Alamos Scientific Laboratory of the

Table 13 - Temperatures measured at Jemez Hot Springs

Location Figure 24	Date	Temperature (°F)	Source
1	1903	168	Reagan (1903, p. 100) exact date unknown
	10-11-12	154.5	Kelly and Anspach (1913, p. 30)
	8-1-47	163	Unpublished measurement, made by U.S. Geol. Survey
	6-28-49	146	Unpublished measurement, made by U.S. Geol. Survey
	4-3-56	160	Unpublished measurement, made by U.S. Geol. Survey
	10-9-65	169	
	6-26-66	162.2	
	1-16-73	156	Purtymun, West, and Adams, p. 21
	2-21-73	160	U.S.G.S., F. W. Trainer
	12-2-74	138	U.S.G.S., F. W. Trainer
2	10-11-12	155.3	Kelly and Anspach (1913, p. 30)
	6-14-49	150	Unpublished measurement, made by U. S. Geol. Survey
	8-31-49	150	Unpublished measurement, made by U. S. Geol. Survey
	10-24-51	152	Unpublished measurement, made by U. S. Geol. Survey
	6-26-66	151.5	
3	6-26-66	134.5	
4	10-11-12	119.8	Kelly and Anspach (1913, p. 30)
	8-31-49	150	Unpublished measurement, made by U. S. Geol. Survey
	12-2-72	167	U.S.G.S., F. W. Trainer
5-6	1903	119	Reagan (1903, p. 100) exact date unknown
	8-21-24	125	Renick (1931, p. 79)
	5-18-73	120	U.S.G.S., F. W. Trainer
7	2-26-73	136	U.S.G.S., F. W. Trainer

University of California has drilled 2 test wells to granite. These wells are called GT-1 and GT-2.

GT-1 (19N.2E.1.400) has a surface altitude of 8690 ft, is 9607 ft deep, and had bottom-hole temperatures of 295°F at 6704 ft and 387°F at 9607 ft.

Table M6 gives chemical analyses of water from GT-2 (19N.2E.13.200). This sample is representative of the water in the lower Madera Limestone (Purtymun, West, and Pettitt, 1974, p. 13). The temperature of this water was 133°F. The U.S. Geological Survey collected 4 samples from GT-1 August 25, 1972, to determine if any changes in water chemistry occurred at depths which could be attributed to a hole in the casing when the casing is cemented into Precambrian rocks. The results indicated that the water was residual water left in the casing from drilling operations.

THERMAL WATERS NEAR JEMEZ RIVER AND RIO SALADO

Near the confluence of the Jemez River and the Rio Salado, several sources of warm and hot waters have been noted. They are called in this report Indian Springs, a plugged well (Kaseman No. 1), a flowing well at Warm Springs (Kaseman No. 2), San Ysidro Springs, and Phillip's Springs. Only 2 of these (Indian Springs and the flowing well) meet the criterion (a temperature of 90°F or higher) for the field inventory, but to omit the others from the general discussion would be erroneous.

The literature for these springs is somewhat confused. Loew (1875a, p. 616) discussed San Ysidro Springs, but his description of their location fits Indian Springs.

Peale (1886, p. 194) listed "San Ysidro Spring, near Jemez, Bernalillo County . . . carbonated." This is probably a reference to Indian Springs taken from Loew.

In 1903, Reagan (p. 98-99) distinguished The Phillips Springs (springs in the Arroyo Pefiasco), The San Ysidro Springs, and The Indian Springs. He apparently did not realize that Loew's analysis was for Indian Springs, because he repeated it as an analysis of the water from the "San Ysidro Springs." Jones (1904, p. 300) gave Loew's Indian Springs data in a discussion of "San Ysidro Spring [sic]." In 1913, Kelly and Anspach repeated in detail the work of Reagan.

The first distinctive and definitive work on the springs of the Rio Salado was by Clark (1929), who visited and described each of the thermal water occurrences in the Rio Salado. Unfortunately, his descriptions of localities are not precise and not all of his data stations can be identified with confidence.

In 1931, Renick, apparently unaware of Clark's work, also described the thermal waters of the Rio Salado, drawing upon the same sources of information for his discussion of the 2 wells. Stearns, Stearns, and Waring (1937, p. 67) and Waring (1965, p. 37) listed Phillips Springs, 70°F; San Ysidro Hot Springs, 85°F; and San Ysidro Warm Springs, 68°F.

In 1948, Harrington discussed the origin and history of the travertine mounds.

Fig. 25 shows the locations of the various wells and springs, the sample sites of Clark as best they can be established. Table M6 gives the chemical analyses and tables 8 and 14 give the field measurements. Table 15 summarizes Clark's personal observations in the Rio Salado drainage.

Indian Springs (16N.2E.29.142)—These springs occur on the Jemez River, midway between the villages of San Ysidro and Jemez Pueblo on the Jemez Indian Reservation. The Jemez Indians have used these springs for many years, and the springs are well known. Loew (1875a, p. 616) wrote:

> This spring is situated three miles south of the Indian town of Jemez. Its water is rich in carbonic acid and of very agreeable taste. It contains in 100 parts-

Chloride of sodium	0.3072
Sulphate of soda	0.1639
Carbonate of lime	0.0670
Carbonate of magnesia	0.0243
Carbonate of iron	0.0008
Potassa	traces
Lithia	
Silicic acid	
	0.5632

In 1903 Reagan (p. 99-100) wrote:

> The springs here designated as Indian Springs are a heterogeneous group, and extend in an east and west direction in a narrow belt of land about a mile to the north of the Mexican village of San Isidro. At the west their waters are forced to the surface along the fault to the north of the little gypsum area just north of Salt River. It is also highly probable that this fault extends as far east as the springs do, though in that part it is covered with later deposits. The springs are alkaline, but not depositing springs. They are cold in the west but increase in temperature toward the east end of the belt. The temperature of the eastern springs, those to the east of the Jemez River, is about 120°F. They are being covered continually with debris brought down by an eastern arroyo and must be dug out when used. The Indians use these springs almost continually throughout the summer months; even the Ysleta Indians come there to bathe for their ailments. These sources of health and cleanliness are on Indian lands, whence the name. Should they be properly cared for there is reason to believe that they would afford a health resort of the first class.

Renick (1931, p. 86) wrote:

> The Indian Springs are about one and one-half miles north of San Ysidro, in the Jemez Pueblo grant. They occur mostly in an east-west belt. Kelly and Anspach report that they even extend east of the river, where the temperature of the water is 120°, but those east of the Jemez Creek were not observed by the writer; they may now be covered up by alluvium from the stream. The springs west of Jemez Creek are located in a faulted belt, in which the trend of the observable faults approaches due north. These springs have in places built up small deposits of sinter, but none approaching in magnitude the deposits of the Phillips Springs or the south group of the San Ysidro Springs.

Peale (1886, p. 322) and Jones (1904, p. 300) reported Loew's comments. Kelly and Anspach (1913, p. 6-7) quoted Reagan extensively. Stearns, Stearns, and Waring (1937, p. 167) and Waring (1965, p. 37) mentioned that the temperature was 120°F.

The springs west of the river were not visited during the 1965-1966 investigation; those along the river were visited twice. Fig. 21 shows the warmest seep along the river in November 1965.

On June 26, 1966, seepage was obvious for about 300 ft along the east bank of the river from the water line to about a ft above. An iron stain on the alluvium apparently associated with the thermal waters suggests

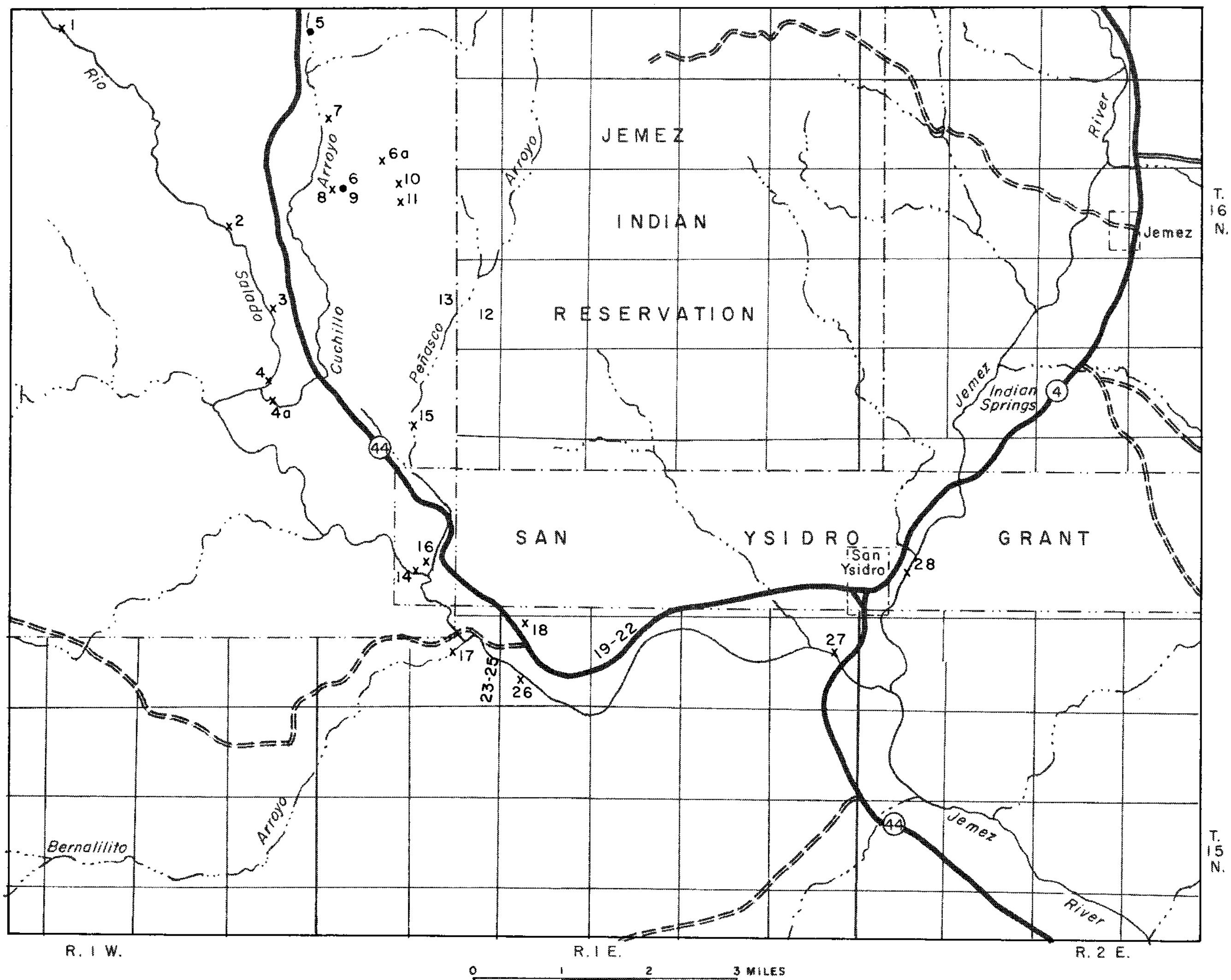


FIGURE 25—MAP OF THE JEMEZ RIVER—RIO SALADO CONFLUENCE. SAMPLE SITES LISTED IN FIG. 15.

Table 14 - Temperature and estimated discharge of Indian Springs, June 26, 1966

Distance downstream from first discernible flow (ft)	Temperature (°F)	Estimated flow (gpm)
9*	92.2	1
43*	109.7	1/4
61	118.4	---
64* (bubbles in streambed)	110.0	1/4
83-88*+	123.3	1
99	114.8	1/4
105-108*	115.6	1/4
119	96.3	almost zero
125 (bubbles in streambed)	111.3	almost zero
135*	104.5	1/4
158	90.5	almost zero
168*	89.5	1/4
218 (bubbles in streambed)	96.7	1/10
300 (last obvious discharge)	82.5	1/10

* water sample in Table M6

+ site sampled 11-10-65, see Table 8 and M6

that the thermal water discharge is sometimes more extensive than was observed during the field inventory. Table 14 gives the temperatures and discharge observed from the first discernible flow upstream to the last discernible flow downstream. Several of the observations are from boils in the stream bed.

Oil Tests—In 1926 two oil tests were drilled northwest of San Ysidro in the Rio Salado Valley: the Kaseman No. 1, the plugged well, and the Kaseman No. 2, the flowing well at Warm Springs.

Plugged Well (Kaseman No. 1; 16N.1E.7.100)—Clark (1929, p. 9) gave the following logs of this well:

> January 28, 1926. Spudded in.
> Set 35 feet 15 inch pipe and got water at 15 feet.
> From top to 315 Red Soft. Cave at 255 to 315 feet; set 12 inch pipe at 235.
> From 315 feet to 348 pink—will not cave. Set 361 feet of 10 inch pipe.
> From 348 to 360 blue shale. Will not cave.
> From 360 to 385 Red bed, hard—will not cave.
> From 385 to 390, hard sand cap.
> From 390 to 420, sand water that flowed.
> Had cave at 400 feet and set 415 feet of 8 inch pipe.
> From 420 to 445, red bed mixed with blue shale.
> From 445 to 550, white sand water bearing sand.
> The 12 inch pipe lacked 126 feet of being through the red bed. 12 inch pipe can be put through the red beds without under reaming, and water can be cased off with 10 inch pipe and then have 10 inch hole until more water is struck. (As to geologists report).
> Water flowed out of 8 inch hole 3 feet above casing.
> After 8 inch pipe was pulled water flowed 18 inches above casing.
> Drilled by Hitchcock and Dickason.

He then remarks:

Table 15 - Summary of Clark's (1929, p. 17-23) personal observation in the Rio Salado basin (see fig. 25 for locations)

Sample Site no. 1	Rio Salado above "The Bancos"
September 3, 1927	Water running on surface. Total solids, 2,192 ppm Water largely charged with gypsum
Sample Site no. 2	Rio Salado about two miles above junction with stream from artesian well
June 14, 1928	4,987 ppm total solids. Water running on surface
Sample Site no. 3	Rio Salado about one mile above junction with stream from artesian well
October 2, 1927	6,188 ppm total solids. Water running on surface
June 14, 1928	4,978 ppm total solids. Water running on surface
Sample Site no. 4	A pool about 100 yards long in the bed of the Rio Salado, at the junction with, but above, the stream from artesian well
October 2, 1927	14,812 ppm total solids
Sample Site no. 4a	Same as no. 4, except sample taken 100 yards up the stream coming from the artesian well
October 2, 1927	12,912 ppm total solids
Sample Site no. 5	The Artesian Well
August 31, 1927	11,542 ppm total solids
October 2, 1927	11,654 ppm total solids
January 14, 1928	11,654 ppm total solids - 123°F
February 22, 1928	11,608 ppm total solids - 123°F
April 29, 1928	11,708 ppm total solids
June 14, 1928	11,608 ppm total solids
February 23, 1929	11,644 ppm total solids - 123°F
September 29, 1929	11,496 ppm total solids
Sample Site no. 6	The Plugged Well
January 14, 1928	20,312 ppm total solids
After the first artesian well was drilled, the spring, from which boiler water had been secured for drilling, went completely dry. After this well was plugged, many small springs reappeared up the hillside close by the well.	
Sample Site no. 6a	Spring up arroyo from plugged well
March 18, 1928	27,926 ppm total solids
This spring started to flow after the well had been plugged. Sheep tracks at the spring indicated that animals had been there for water. This is the saltiest water the writer has known animals to drink. Other similar springs were beginning to reappear, down the arroyo from the plugged well.	
Sample Site no. 7	Pool in bed of intermittent stream, which flows into stream from Artesian well
October 2, 1927	16,292 ppm total solids
Sample Site no. 8	Damp swampy flat bed of stream flowing into arroyo from plugged well
March 18, 1928	26,192 ppm total solids
Sample Site no. 9	Small spring on hillside near Site no. 8.
April 29, 1928	11,448 ppm total solids
Sample Site nos. 10 and 11	Two small springs well up on hillside near old "craters"
April 29, 1928	15,938 ppm and 11,206 ppm total solids
Sheep were drinking this water. Near these springs is an old "crater" spring which appears to have ceased to flow within a matter of a few months. Its walls are perpendicular. The water level is now about 25 feet below the rim. These "craters" are travertine cones--a part of the group of some 50 Phillip's Springs.	
Sample Site no. 12	Swimming Pool
February 22, 1928	7,174 ppm total solids
This is an old "crater" spring which has remained full of water in spite of the flow from the artesian well. It appears to receive its water on an entirely different side of a fault line from the springs mentioned above.	
Sample Site no. 13	Large spring on north side of the canyon from Swimming Pool
February 22, 1928	11,398 ppm total solids
On the same side of the canyon but nearer the main highway is another spring whose mouth is not that of a "crater", but rather that of a geyser. J. Wick Miller of San Ysidro says that before the wells were drilled, water stood in this spring to within a few feet of the top. It is now some twenty feet down to water. Mr. Miller says he has dropped sounding lines in the water to a depth of about 80 feet.	
Sample Site no. 14	Rio Salado above junction with a stream from Swimming Pool Canyon
September 3, 1927	12,486 ppm total solids
Sample Site no. 15	Stream from Swimming Pool Canyon at highway.
January 14, 1928	6,842 ppm total solids
Sample Site no. 16	Stream from Swimming Pool Canyon near junction with Rio Salado
September 3, 1927	9,786 ppm total solids
This stream was about 20% the volume of the Salado.	
Sample Site no. 17	Spring on south side of Salado at base of Cuchillo ridge
March 18, 1928	2,404 ppm total solids
Where the Albuquerque-Cuba highway makes a turn to the north along the Rio Salado there is a prominent gypsum ridge on the south of the stream. The spring here seems to be caused by water following this ridge, coming to the surface near the river. The water is nearly saturated with gypsum. This ridge is west of sample sites 23, 24, and 25 of the diagram.	
Sample Site no. 18	A small intermittent stream close to highway seeps along the stream
March 18, 1928	19,226 ppm total solids
Sample Site nos. 19, 20, 21 and 22	These are some of the larger of the San Ysidro Springs which are on each side of the highway They are cold
February 22, 1928	7,376; 6,363; 6,082; and 6,320 ppm total solids respectively
Sample Site nos. 23, 24 and 25	Travertine ridge south of Rio Salado
Near where the highway to Cuba makes a turn to the north one may see across the Salado, a ridge on which the water from many springs is glistening. This ridge runs north and south, and has hundreds of tiny springs and many old "craters" upon it. Near its north end are some springs.	
November 6, 1927	12,418; 11,230 and 9,518 ppm total solids respectively
April 25, 1929	9,582 & 11,516 ppm total solids
Sample Site no. 26	A rain pool near sites nos. 23, 24, and 25.
On the surface, at least, the water from the springs of the travertine ridge does not reach the Salado, but evaporates. Each rain picks up the mineral matter deposited by the springs and carries it to the river. Even diluted with rain water, the concentration of this transported spring deposited (sic) is high.	
November 12, 1927	(shortly after a rain storm) 7,698 ppm total solids

The water from this well was hot (accurate record was not kept, but the temperature was over 100 degrees F.), and strongly saline as is shown by an analysis made June 4, 1926. . . .

When this volume of hot water, heavily charged with sodium chloride and sodium bicarbonate, was encountered, this well was abandoned, and another was started about two miles further north. . . .

After the first artesian well was drilled, the spring, from which boiler water had been secured for drilling, went completely dry. After this well was plugged, many small springs reappeared up the hillside close by the well.

Renick (1931, p. 82) wrote:

Two wells drilled on the Rio Salado anticline in this locality to test the petroleum possibilities were visited by the writer in October, 1926. One of these wells, the Kaseman No. 1, encountered heavy flows of hot, salty artesian water at a depth of 500 feet. This water comes from the Poleo sandstone which crops out less than a mile to the east. When the writer visited this well, about 6 months after it was drilled, there was 12 inches of water flowing over a 10-inch casing at an estimated rate of 2,450 gallons a minute. It is claimed that the initial pressure in this well was 225 pounds to the square inch. The well was abandoned at 550 feet after an unsuccessful attempt had been made to shut off the water.

An analysis of the water is given as No. 16, page 78 (Renick, 1931). On page 78, he gave the water temperature as 115°F. Both Clark and Renick's chemical analyses are included in table M6.

Flowing Well at Warm Springs (Kaseman No. 2; 16N.1W.1.410)—This well is at Warm Springs, New Mexico. It constitutes the entire thermal water supply for the resort motel there. The name Warm Springs is misleading, because no springs occur nearby.

Clark (1929) and Renick (1931) compiled much information on this well.

Renick (1931, p. 82-83) wrote:

The other well, the Kaseman No. 2, about a mile farther north, was drilled to a depth of 2,008 feet. The first flow was obtained at 425 feet, and below that depth a number of other flows were encountered. When visited by the writer in October, 1926, this well had reached a depth of about 1,800 feet and drilling was still in progress. With three strings of casing in the hole, shutting off much water, Mr. F. H. Healy, of the State Engineer's office, estimated that the water coming to the surface around the several casings amounted to 2,050 gallons a minute.

The following data recorded by Mr. Houston, the driller, show that the water from successive beds increased in temperature with the depth.

Temperature of water in the Kaseman Well No. 2

Depth (ft)	Temperature (F°)	Depth (ft)	Temperature (F°)
425	108	1,060	125
490	108	1,570	125
550	112	1,760	142
610	116	1,920	142
910	124		

Water collected from several depths was sent to the New Mexico College of Agriculture and Mechanic Arts for analysis. The results are given below.

Partial analyses of water from Kaseman Well No. 2
(Parts per million. C. W. Botkin, analyst)

	1	2	3
Total mineral matter	11,760	7,780	5,580
Sodium Chloride (NaCl)	5,450	3,800	2,890
Carbonate (as $CaCO_3$)	1,130	1,510	1,710

Remained largely sulphates of calcium, magnesium, and sodium.

1. Water above 940 feet; between the 12 and 8 inch casings.
2. Water between 940 and 1,810 feet; between the 8 and 6 inch casings.
3. Water between the 1,810 and 1800 feet; below the 7 inch casing October 2, 1926.

Clark (1929, p. 13-14) wrote:

When the valves were closed at the top of the casing a pressure gauge indicated a pressure of 25 pounds per square inch.

The drilling of this second well was discontinued and exploration for natural gas abandoned.

During the early part of 1927, the first well was plugged with a mixture of Portland cement and sand, but before this could be repeated on the second well, very considerable corroding of the casing had taken place, and water was coming to the surface, outside of the casing. At this time the combined flow from the well had a temperature of 123°F., had a very, very faint odor of hydrogen sulfide, and discharged a quantity of carbon dioxide, which was estimated to be one-third of the total volume of the flow. A weir erected near the well in the summer of 1927 showed a flow of approximately 5.5 cubic feet of water a second.

A number of measurements of the volume of water coming from the well were made by different people, and a number of partial analyses were made of the water. Different strata delivered different volumes of water. As is shown above, the temperatures varied. The total mineral content of the water varied also. However, the figures for the mineral matter were between 11,000 and 12,000 parts per million, and, as the casing corroded, the total solid matter in the flow, as noted from time to time, became more uniform, and around 11,600 parts per million.

In August of 1927, a California concern, engaged in the business of plugging wells, sent an expert to this artesian well to shut off this flow of water by using a method which had been shown upon investigation to have worked very successfully in many other places.

A tube of galvanized iron, eight inches in diameter, was charged as follows from bottom to top: blasting gelatine; 80% dynamite; quick setting Portland cement mixed with large lathe turnings; 80% dynamite; and, finally, blasting gelatine. The tube was lowered into the well by means of a cable and sank because of a railroad rail attached to the bottom. At a depth of about 350 feet, both upper and lower charges were fired almost, but not exactly, simultaneously. The cement, compressed between the two explosions set to a plug, and for a few moments it appeared that the water had been shut off. Then pieces of the red shale from the sides of the hole began to come to the surface, and within an hour the well was flowing as usual.

The writer was present when the attempt was made to plug the well, and, having some years before made an investigation of the waters of the Jemez Canyon, he became interested in the situation and raised the question as to whether it was really wise to shut off the water. Water for livestock was no longer available along the Rio Salado very frequently, as, since recent filling of its bed from excessive erosion, the river flowed underground most of the time. Opinion prevailed, when the well first flowed, that livestock would not drink water so heavily charged with salt and soda. Observation was, however, confined to the vicinity of the well and here the animals would not drink the water, as it was later shown, not because it was saline, but because it was hot. Out of sight from the well, and from the highway, sheep and cattle were drinking the water regularly.

The following is a summary of the discharge reported for the well:

Date	Discharge (gpm)	Source
Summer 1927	2500	Weir (Clark)
9-28-48	450	USGS estimate
3-14-64	1500	USGS estimate
10-11-65	68	Summers' estimate based on time required (15 hours) to fill 68,000-gallon swimming pool
6-5-73	85	USGS measurement

The 1964 report of 1500 gpm is probably in error because the channel from the well to the swimming pool is not adequate for a flow of that magnitude.

The following is a summary of the temperatures that were measured through 1964:

Date	Temperature (°F)	Source
Early 1927	123	Clark (1929)
1-14-28	123	Clark (1929)
2-22-28	123	Clark (1929)
2-23-29	123	Clark (1929)
9-29-48	140	USGS estimate
4-3-56	180 (130?)	USGS
3-14-64	130	USGS
10-15-64	128	USGS

Phillip's Springs—These springs (fig. 25, location 13 and 17) were not included in the 1965-1966 inventory. However, in 1903 Reagan (p. 98-99) wrote:

The Philip's [sic] springs are forty in number. They are situated in a little cove between the granite spur to the southwest of the Nacimiento range and the Red Beds to the west of Jemez on their western side. The space occupied by them is not greater than thirty acres, though at an earlier date their area was much more extensive than now, as is attested by the travertine cones left by the extinct springs. The cove, occupied by these springs, is about a mile to the northeast of Salt River; and eight miles nearly west of Jemez Pueblo. The springs of this group are soda or iron springs. The soda springs are nondepositing. The springs of this group usually have a bathing temperature; but they are not used for bathing purposes on account of their isolation, though their site would make an excellent place for a health resort. The scenery is as good as could be desired; and what adds more to their value, is that they are so situated in this cove that they are sheltered from the sand storms so prevalent in New Mexico. These springs, however, have one drawback to their becoming of value in the near future: They are situated on the Ojo del Espiritu Santo land grant; and title to the area cannot now be obtained.

Kelly and Anspach (1913, p. 4-5) repeated Reagan's comments. In 1931 Renick (p. 87-88) wrote:

The Phillips [sic] Springs issue at the north end of the Sierrita Mesa, mostly along the Arroyo Penasco, near the west edge of the Jemez Indian Reservation. Their arrangement is in line with the major Sierra Nacimiento overthrust. There are at least a dozen large springs and a number of smaller ones, extending from a point about half a mile west of the highway for a distance of about 11/2 miles to the east. The Swimming Pool Spring has built up a crater at least 50 feet high, with a gentle slope on the outside and an almost vertical wall on the inside. It is about 35 feet in diameter, and the water is 40 feet or more deep. This water has a decidedly saline taste. Its temperature is 70°. The water spills over the edge of the crater at several places and deposits calcium carbonate. The flow was estimated at about 8 gallons a minute, and there is considerable bubbling of gas in the center of the pool. An analysis of a sample of water from this spring is given as No. 13 (p. 78) This spring, like most others in this area, issues along a fault.

There are a number of craters of extinct springs along a line extending northward parallel to the mountain and just north of the Arroyo Penasco and west of Poleo hogback, which defines the west limit of the mountain. . . . Some of them are 50 feet in diameter and at least 50 feet deep. These craters, also, were formed by deposition of calcareous material as the water spilled over the rim; the inside wall is almost vertical, but the outside slope is gentle, the configuration thus being similar to that of the Swimming Pool Spring. The amount of material deposited by these extinct springs is great, as shown by the fact that for a mile or more to the west the high-level gravel above the stream has been cemented by calcium carbonate.

On page 29, Renick gave the following chemical analysis of the gas issuing from the Swimming Pool Spring of this group:

Gas per cubic centimeter of water (cm³)	0.07
Carbon dioxide (CO_2)	70.4%
Oxygen (O_2)	8.3%
Hydrogen sulfide (H_2S)	0.0%
Combustible gases	0.0%
Nitrogen (N_2)	21.3%

shortly after the 2 wells were drilled and that the water level of the pools declined 25 to 20 ft. Swimming Pool Spring apparently was unaffected.

San Ysidro Springs—These springs (fig. 25, locations 19-36) were not included in the 1965-1966 inventory; however, in 1903 Reagan (p. 99) wrote:

> The San Ysidro (San Isidro) springs are situated on either side of Salt River in its lower course all along the front of Mesa Blanco, their waters coming to the surface along the fault. These springs are some forty in number. Those to the south of the river are bitter magnesium, and those to the north are soda springs. The waters of the springs are cold. They have medical qualities; and throughout the summer months, the Mexicans bathe in them. These springs are on government land, but, as all salt lands in New Mexico have been reserved for the benefit of the university of that territory, they will most likely be claimed by that institution on account of the magnesium and sodium salts.

Kelly and Anspach (1913, p. 5) repeated Reagan's comment. In 1931, Renick (p. 86-87) wrote:

> There are two groups of springs in the so-called San Ysidro Springs—one north and the other south of the Rio Salado. These two groups are referred to as the north group and the south group.
>
> The springs of the north group, not less than 20 in number, issue along the San Ysidro-Cuba road, mostly in the N. 1/2 sec. 9, S. 1/2 sec. 3, and NW. v7 sec. 10, T. 15 N., R. I E. Analysis 11 (p. 78) shows the chemical character of the water from one of these springs. The observed temperature did not exceed 68°F. Many of the springs have built small craters of calcareous tufa 1 to 4 feet high and 3 to 6 feet or more in diameter. The land near the springs is marshy. Gas is being evolved from most of these springs. The water comes to the surface mostly in the area of outcrop of the Chinle (?) formation near the contact with the underlying Poleo sandstone. Although the water is nonpotable for human beings, stock apparently drink it in preference to the water in the Rio Salado. There are certain of these springs which the stock apparently prefer; it is uncertain whether or not there is any considerable variation in the quality of the water in different springs.
>
> The springs of the south group are mostly in the central part of sec. 8, T. 15 N., R. I E. These springs are thermal, the average temperature for the group being about 85°F. They issue on the north slope of the Tierra Amarilla anticline, and some of them are more than 200 feet above the Rio Salado, showing that the water is under appreciable head. This water comes to the surface near the contact of the Chinle (?) formation and Wingate sandstone, but the actual contact is concealed by a great accumulation of calcareous tufa. This deposit of tufa covers the north slope and the surface of the hill over an area at least 11/2 miles in length and almost one-half mile in width. On the summit of this hill, which is the axis of the Tierra Amarilla anticline, there are many craters, some as much as 20 ft in diameter and 30 ft or more in depth, which mark the site of extinct thermal springs, the water in which must have been at considerably greater head than the present springs . . . An analysis of water from one of the springs on the north slope (No. 12, p. 78) *[See* table M6 in this report] shows that it is highly mineralized.

On page 89 Renick provided the following analyses of the gas issuing from these springs:

	Spring North of Rio Salado	Spring South of Rio Salado
Gas per cubic centimeter of water (cm³)	0.45	0.22
Carbon dioxide (CO_2)	97.5%	96.3%
Hydrogen sulfide (H_2S)	0.0%	0.0%
Combustible gases	0.0%	0.0%
Oxygen (O_2)	0.5%	0.6%
Nitrogen (N_2)	2.0%	2.7%
Helium (He)	0.0%	0.0%

MIDDLE RIO GRANDE BASIN WELL (6N.3E.5.234)

Water Resources Data for New Mexico, Part 2, Water Quality Record (U.S. Geological Survey 1970, p. 275) gives chemical analyses of a sample from a well 720 ft deep which reportedly had a temperature of 80°C (176°F). These analyses are repeated in table M7.

SOCORRO THERMAL AREA

The Socorro thermal area (by F. R. Hall and W. K. Summers) is in the Socorro Mountains about 3 miles west of Socorro. The region extends at least 2 miles along the front of the mountain and at least half a mile westward (fig. 26).

Thermal water issues from 3 galleries (Socorro, Evergreen or Sedillo, and Cook), sometimes referred to as springs because they were built to intercept the flow of natural springs. Thermal water is also pumped from the Blue Canyon well (3S.1W.16.323) of the New Mexico Institute of Mining and Technology. Water having a temperature of 108°F was reached in a core hole deep in a mine shaft north of Blue Canyon.

Numerous reports mention thermal waters of Socorro Spring, but they give few specific measurements. The earliest reference to the springs is that of Jacob S. Robinson, November 28, 1846. According to Stanley (1950, p. 62-64), Robinson, a soldier, wrote: "About three miles distant [is] a somewhat remarkable warm spring that comes from beneath a range of hills, and immediately falls into a pool which forms a fine place for bathing."

Stanley (p. 213) also quotes Mrs. Sadie Abernathy,

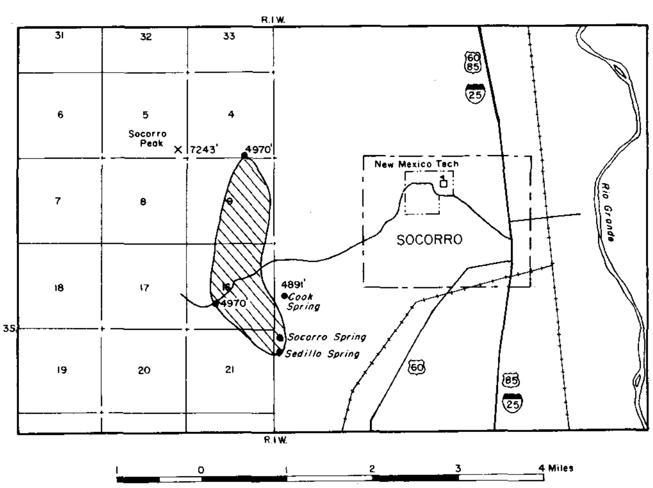


FIGURE 26—MAP SHOWING THE EXTENT OF THE SOCORRO THERMAL AREA, SOCORRO COUNTY.

one of the old timers, who said that in 1876: "The water was brought down (to Socorro) from the spring in acequias, but everything was well watered and produced abundantly."

Jones (1904) described the springs briefly and gave a flow estimate and a chemical analysis for the water from Socorro Spring. Stearns, Stearns, and Waring (1937, p. 168) and Waring (1965, p. 37) listed Socorro Spring but gave little information. Waldron (1956) collected some data for the Socorro Spring, made some geologic observations, and speculated on the probable recharge area and source of heat. Hall (1963) discussed the thermal springs and presented some chemical data in a paper covering springs in the Socorro area.

Hall carried out a data collection program from 1962 to 1964. Although he gave the Socorro Gallery, which is the most accessible, most of his attention, he also collected data for the other galleries and the Blue Canyon well whenever possible and collected information for the springs prior to 1962.

As part of the 1965-1966 inventory, in addition to the procedures followed elsewhere, Summers mapped the Socorro Gallery and made measurements in it. Members of the geology department, New Mexico Institute of Mining & Technology, mapped the geology of the area. As part of other New Mexico Tech projects, several test holes were drilled in the thermal area. The remarks that follow summarize the available information.

Jones observed that water oozed and bubbled out at several places along a fractured zone or fault in the mountains, with the chief flow from the lower or big spring used by Socorro. According to Stanley, the Socorro Gallery is at or very close to the site of the natural spring that supplied domestic and irrigation water to Socorro from at least the 1850's until the present shaft and tunnel were dug.

Jones does not mention either the Evergreen (Sedillo) Gallery or the Cook Gallery. A surveyor's notes for the western boundary of the Socorro Grant, dated in the 1890's (copy in the files of the New Mexico Bureau of Mines & Mineral Resources) contains a reference to a spring called Ojita Chiquita at a location very close to the present Cook Gallery. The name means Little Chica Spring and interestingly enough other material in the files of the New Mexico Bureau of Mines & Mineral Resources suggests that at one time the spring at the location of Socorro Gallery was called Chico Spring or Ojo Chico. The surveyor's notes do not mention the Evergreen Gallery or a spring in the vicinity, but they do place a spring at the present location of the Socorro Gallery. The notes also describe a spring 264 ft north of the Socorro Spring, but no indication of this one can be found at present.

There seems little doubt that the area has supplied water for human use since the Spanish occupation and probably for hundreds of years prior to the arrival of the Spanish. However, the conditions of discharge have been much modified in the last 100 years. The Socorro and Evergreen Galleries still supply a part of the water used by Socorro. The galleries are nearly horizontal tunnels in the east face of the mountains.

The water discharges within the elevation range 4900 to 5000 ft above sea level. The terrain west of the galleries is steep and reaches an elevation of more than 6000 ft in less than a mile. East of the galleries, the land surface slopes moderately toward the Rio Grande. The general vicinity of the galleries is drained by the upper ends of eastward-trending arroyos. The galleries, however, are independent of the local drainage.

The Socorro Gallery is reached by way of a 25-ft vertical shaft. It is a tunnel 82 ft long in a volcanic breccia—which may be a lahar. The water issues from fractures in the rock intercepted by the tunnel and flows by gravity to a settling basin and then into the Socorro water system. The depth of water in the tunnel is only about a ft at the deepest, averaging about 4 inches.

Fig. 27 is a map of the Socorro Gallery showing the locations of the fractures from which the water issues. It also gives the discharge at several points in the gallery,

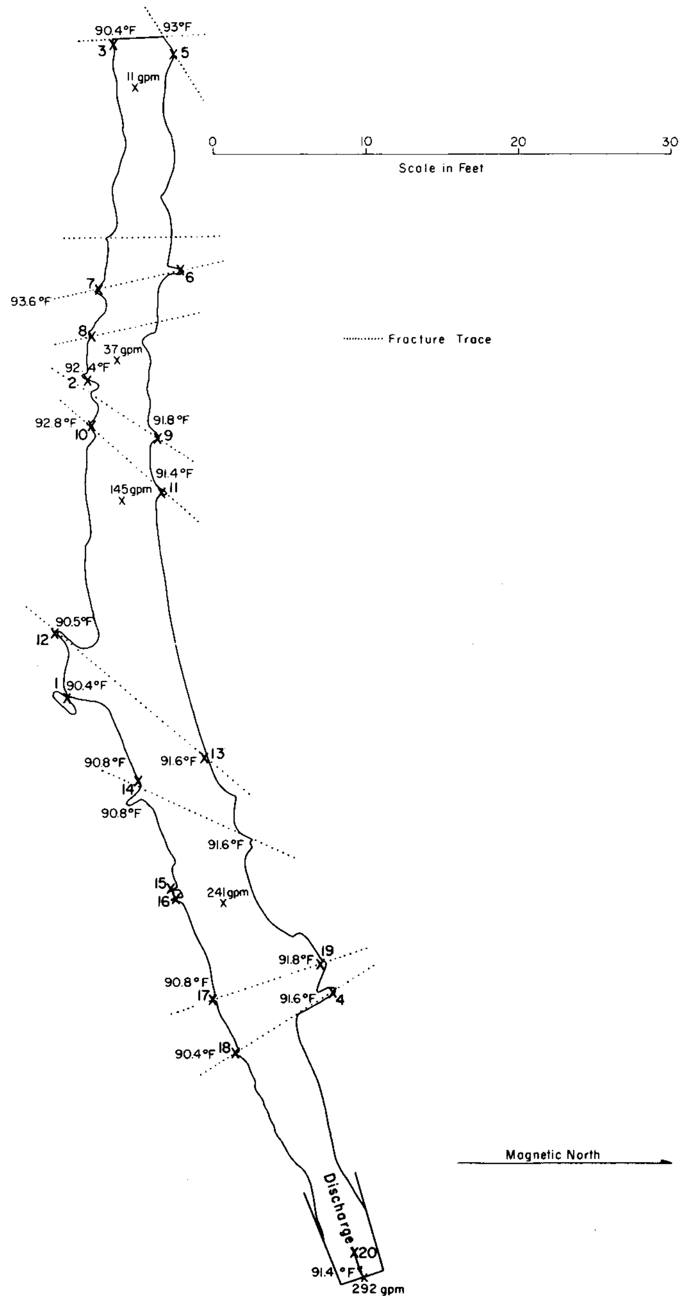
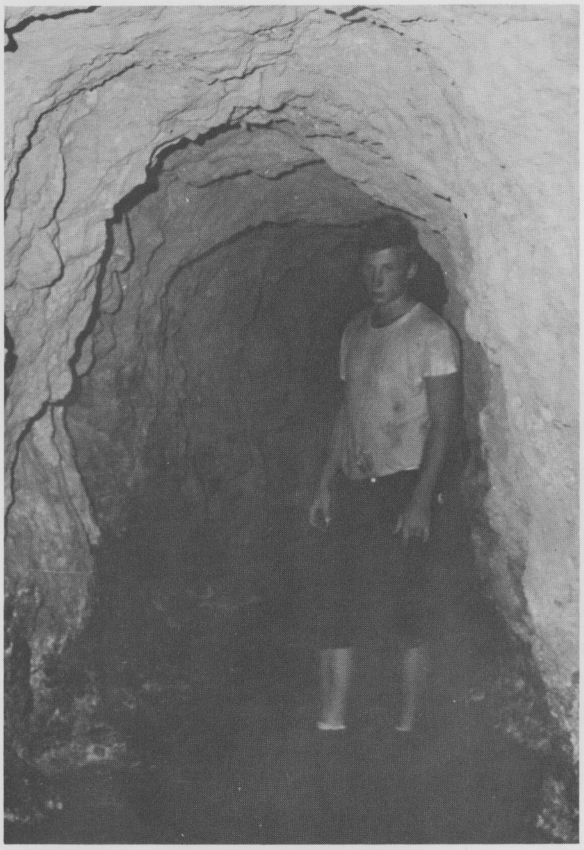


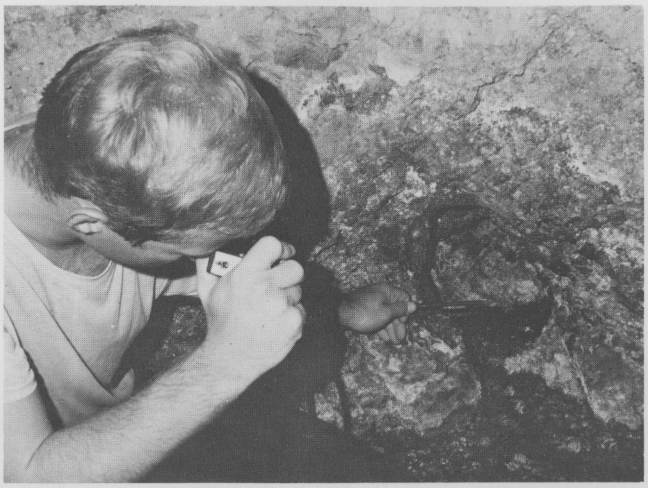
FIGURE 27—MAP OF THE SOCORRO GALLERY, SHOWING THE LOCATION AT WHICH THE SAMPLES WERE COLLECTED AND TEMPERATURES WERE MEASURED.

the temperatures of the discharging water at several fractures, and the locations at which water samples were collected. Fig. 28 shows the Socorro Gallery and two of the fractures from which water discharges.

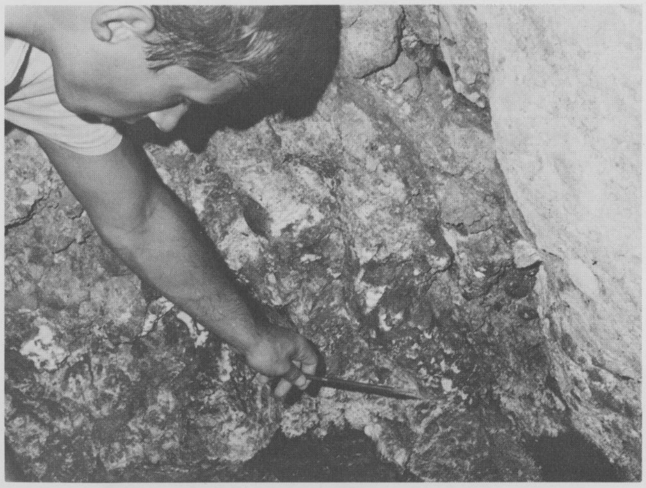
The temperature of the water does not appear to have varied greatly since the 1890's (table 16 this report and Stanley, 1950). In September 1962, a Fischer-Porter (Model No. 110TF02) mercury capillary type of temperature recorder with a circular chart and 2°F scale divisions was installed at the bottom of the shaft of the Socorro Gallery. The recorder has a seven-day clock and the chart is changed once each week. The water temperature is measured independently with the same mercury-in-glass thermometer accurate to 0.1°C each time the recorder chart is changed. The average for all these mercury thermometer measure-



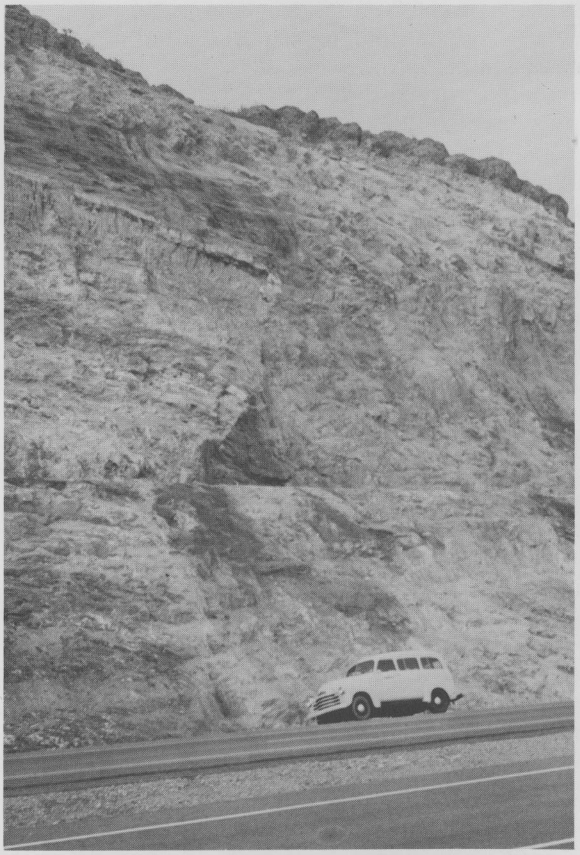
A



B



C



D

FIGURE 28—Photos of Socorro area.
A—Cross section of the Socorro Gallery, about 6 ft high and 4 ft wide
B—Fig. 27, location 1, an enlarged fracture in Socorro Gallery
C—Fig. 27, location 3, fracture from which water discharges in Socorro Gallery
D—Fault at Derry Warm Spring

Table 16 - Water temperatures (°F), Socorro thermal area

Date	Socorro Gallery 3S.1W.22.113	Evergreen Gallery 3S.1W.22.131	Cook Gallery 3S.1W.15.313	Blue Canyon Well 3S.1W.16.323	Observer
1890	90	----	----	----	Surveyor's notes in NMBMMR files
1952	91	----	----	----	Waldron (1956)
7-24-56	----	----	----	90-92	Bushman notes in NMBMMR files
8-23-56	----	----	----	91.7	Bottom hole temperature
3-20-57	88.8	90	66	----	Hall
12-12-61	91.4	88	----	88	Hall, Blue Canyon well measured at end of pipelines
1-22-64	----	90	56	90	"
4-10-65	91.6	----	----	90	U. S. Geol. Survey
10-1-65	----	92.3	----	----	Summers at manhole above settling basin
10-22-65	91.4	----	----	----	"
10-25-65	----	----	----	91.5	"

ments is 91.3°F. More significant than an average is the fact that, except for 3 low temperatures, all measurements fall within the narrow range of 90.9° to 91.6°F.

The temperature recorder charts show practically no variations during the period considered here. The pen trace without exception is a nearly perfect circle with minor variations of less than 1°F, due most likely to the chart not being perfectly centered. At a few places in the record small fluctuations occur, but they are of smaller magnitude than the width of the pen trace. If any significant variations do occur in water temperature, they are less than one half a degree Fahrenheit or the accuracy of the recorder.

Fig. 27 shows that the temperatures of the discharging water at the fractures range from 90.1° to 93.7°F.

Table M7 contains the chemical analyses made of the thermal waters in the Socorro thermal area. The actual point of collection is unknown or doubtful for some of the analyses, or the sample was collected somewhere in the Socorro water system rather than at the gallery. Table 17 contains partial analyses of 20 samples collected in the Socorro Gallery at the locations noted in fig. 27. Table 18 gives the analyses obtained for heavy metals and radon-222 at the galleries and the Blue Canyon well.

An attempt was made to operate a conductivity recorder at the shaft of the Socorro Gallery. Suitable results were not obtained, however, because of problems with gas bubbles, probably CO_2, around the electrodes and what appeared to be deposition of calcium carbonate on the electrodes.

A sample for a laboratory determination of conductivity was collected from the Socorro Gallery each time the temperature and water-level recorders were serviced, once a week, beginning on September 21, 1962. The conductivity was measured with an Industrial Instruments RC-16B2 Conductivity Bridge, using either a glass dip or a pipette cell with constants of 0.10 and 1.00, respectively. Duplicate measurements made with these cells should vary no more than 2 percent, according to the manufacturer. The conductivity bridge does not have a temperature compensator; therefore, the measurements are for conductivity at the sample temperature. Fig. 29 shows the results of 118 laboratory measurements of conductivity and sample temperature.

A linear regression analysis of the conductivity and

Table 17 - Partial chemical analysis of water collected in the Socorro Gallery December 1, 1965 (concentration ppm).

Loc. Fig. 27	SiO_2**	Ca	Mg	Na	K	Li	pH*	Specific* conductance (micromhos)
1	27	18	3.6	52	3.0	.06	7.8	330
2	25	18	3.6	51	3.0	.06	7.8	340
3	27	18	3.6	62	3.0	.05	7.85	340
4	26	18	3.5	58	3.0	.06	7.75	325
5	--	18	3.5	68	3.0	.06	--	--
6	--	18	3.5	62	3.0	.07	--	--
7	--	18	3.5	54	2.9	.07	--	--
8	--	18	3.5	64	2.8	.07	--	--
9	--	18	3.5	58	2.8	.06	--	--
10	--	18	3.5	55	2.8	.05	--	--
11	--	18	3.4	52	2.8	.07	--	--
12	--	18	3.4	54	2.8	.06	--	--
13	--	18	3.5	60	2.8	.06	--	--
14	--	18	3.5	50	2.8	.07	--	--
15	--	18	3.6	54	3.0	.07	--	--
16	--	17	3.6	58	2.8	.07	--	--
17	--	18	3.6	52	2.8	.07	--	--
18	--	18	3.6	56	2.8	.08	--	--
19	--	18	3.6	59	2.8	.07	--	--
20	--	18	3.6	55	2.8	.06	--	--

* October 27, 1965

** December 14, 1965

Table 18 - Heavy metal and radon-222 in the water from the Socorro thermal area (concentration ppb unless noted)

	Sedillo (Evergreen) Gallery	Socorro Gallery	Blue Canyon Well
Date	7-2-73	6-19-73	12-4-74
Copper	<10	<10	6.5
Cadmium	<5	<5	<.1
Lead	<50	<50	3
Molybdenum	--	--	≈5
Zinc	<10	<10	37
Mercury	--	--	ND
Radon-222	--	--	520*
Picocuries per liter			
	NMHSS 1975, p. 145	NMHSS 1975, p. 145	

*U.S. EPA

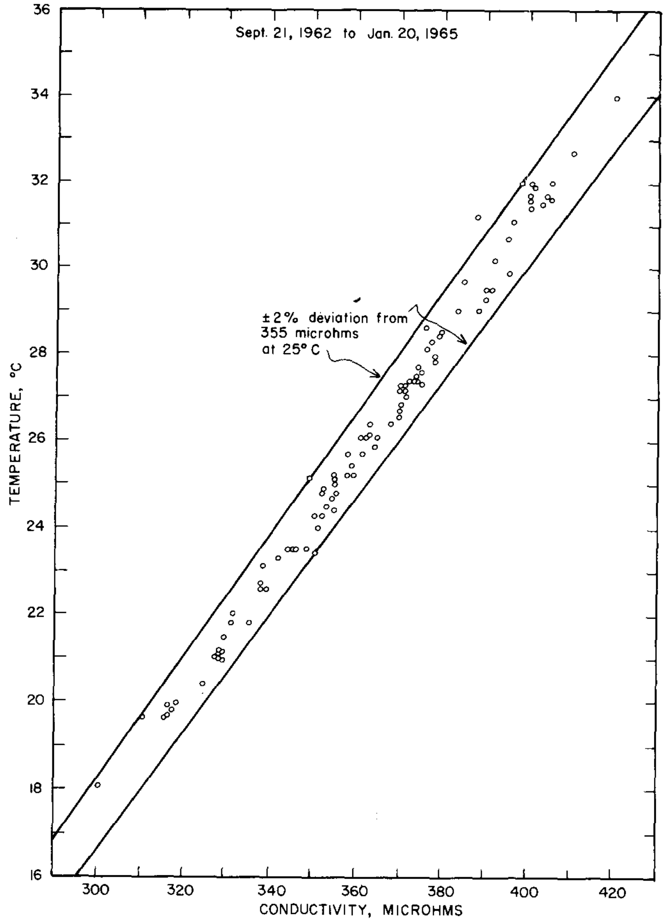


FIGURE 29—CONDUCTIVITY AND TEMPERATURES OF WATER SAMPLES FROM SOCORRO GALLERY.

temperature data yields an equation $x = 7.13y + 177$ where x = conductivity in micromhos and y = temperature in °C.

The correlation coefficient for the 118 measurements is 0.985 with a probable error of ±0.002. The use of student's t-distribution (Snedecor, 1956) shows that at the 0.001 level, the regression coefficient is 7.13 ± 0.24, which gives a range of a little less than 2 percent in the equation. The solution of the equation at a standard temperature of 25°C is 355 micromhos, a value in substantial agreement with most measurements for the Socorro Gallery in table M7. Lines showing 2 percent deviation from the regression equation are drawn in fig. 29. Several values fall on the lines, but only one falls well outside it. Since the instrumental measurements can be expected to vary by at least 2 percent, it does not seem unreasonable to conclude that the conductivity has remained nearly constant during the period of record. An added check is to assume a solution with a standard conductivity of 355 micromhos at 25°C and to use a table of temperature corrections (U.S. Salinity Laboratory Staff, 1954) to see what the conductivity would be at other temperatures. For the temperature range of 18° to 34°C, shown in fig. 29, these calculations give a line varying from the regression equation by only a few micromhos.

Scott and Barker (1962, p. 78-79) report the radioactivity in water from the Socorro Gallery as:

Beta-gamma activity	11 $\mu\mu$C/1 (picocuries/liter)
Radium	0.2 $\mu\mu$C/1 (picocuries/liter)
Uranium	1.8 ppb

Bushman of the New Mexico Bureau of Mines & Mineral Resources. Little is known about the value for January 24, 1957, but it is not close to any other measurements.

The discharge measurement (291 gpm) for the Socorro Gallery on April 15, 1964, is a mean-section calculation of a velocity meter survey made by Mr. Lorenzo Baca of the U.S. Geological Survey. A midsec-

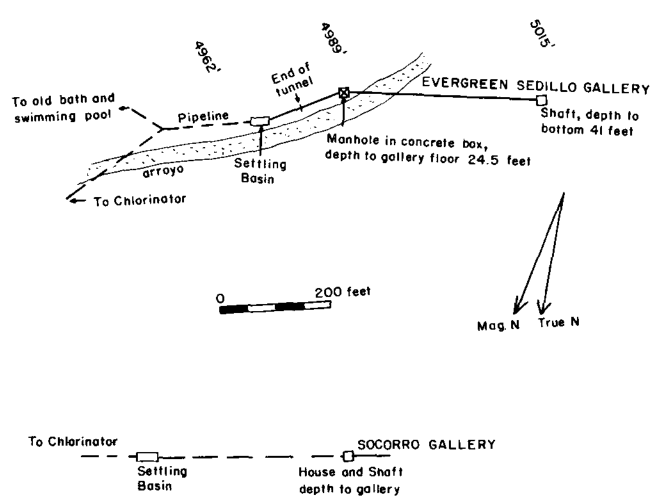


FIGURE 30—RELATION OF EVERGREEN AND SOCORRO GALLERIES, SOCORRO THERMAL AREA, SOCORRO COUNTY.

Table 19 - Ground-water discharge (gpm), Socorro thermal area

Date	Socorro Gallery (3S.1W.22.113)	Evergreen Gallery (3S.1W.22.131)	Cook Gallery (3S.1W.15.313)	Blue Canyon Well (3S.1W.16.323)	Observer
1901	494	---	---	---	Jones (1904) total Socorro Springs area
1950(?)	900	---	10	---	Waldron (1956)
1955	305	151	---	---	Bushman, notes on file, NMBMMR
1956	310	166	---	19*	"
1957	313	172	5-10	---	"
1-24-57	353	---	---	---	U. S. Geological Survey
3-20-58	220	240	10	---	NMIMT
4-15-64	291	---	---	---	U. S. Geological Survey, velocity meter
5-25-64	277	---	---	---	Hall, volume-time method
10-23-65	292	---	---	---	Summers modified Parshall Flume

*pumping test

tion calculation of the same survey gives 303 gpm. The meter survey was not entirely satisfactory, as the water depth was 0.5 ft or less and the velocities ranged from 0.72 to 0.87 ft per second, except for one at 0.52 ft per second. The value of May 25, 1964, is the average of 3 measurements obtained by plugging the outlet of the settling basin below the spring and measuring the volume of inflow for a given period of time. Problems occurred in determining the exact volume of basin per unit rise in water level and in preventing leakage at the outlet. The assignment of an accurate discharge for the Socorro Spring at one time is difficult; however, 291 ± 22 gpm includes all the better measurements from 1955, 1956, 1957, and 1964.

A Leopold and Stevens Type F water-level recorder with an eight-day clock and 1:1 water-stage to chart gear ratio was installed at the Socorro Gallery on October 29, 1962. The recorder operated until 1966. The depth to water below a reference point ranged from 24.47 to 24.51 ft, or a difference in water level of 0.04 ft during the entire period. At times, minor fluctuations or flutters of slightly greater width than the ink trace lasted for many hours. The significance of these variations is not known, although they might be caused by friction between the float and stilling well or interference by animals, such as rats or mice. The recorder charts do show that the flow remained nearly constant for the 48 months of record. Figure 30, which gives flow at five places in the gallery, shows that some segments of the tunnel produce much more water than others, ranging from about 1.4 to 10.1 gpm/linear ft of gallery.

Studies of tritium (von Buttlar, 1959, p. 1034; Holmes, 1963) indicate that the water discharging from the Socorro Gallery fell as rain about 4 years earlier.

Direct measurement of discharge from the Evergreen Spring is difficult. The values of 151 to 172 gpm for 1955, 1956, and 1957 were calculated in 1960 by Francis X. Bushman and probably are reasonably good. The measurement of March 20, 1958, seems too high.

The Cook Gallery is the lowermost of a series of tunnels into the mountainside. No satisfactory measurements are available for the Cook Spring; however, the flow appears to be on the order of 10 gpm (table 18). The discharge point is inaccessible, so water temperatures must be taken in a pond at the mouth of the tunnel. As a consequence, they are lower than the temperatures of the discharging water. Temperatures in a tunnel about 100 ft above the Cook Gallery are above normal.

The water samples for which chemical analyses are given in table M7 were also collected from the pool. They are, therefore, only a guide to the chemical character of the water discharging from the aquifer.

The Blue Canyon Well was drilled in 1956. It is about half a mile west of the east face of the Socorro Mountains. It has a well head elevation of 5200 ft and is 265 ft deep, and the static water level is about 5000 ft.

The log of the well follows:

Material	Interval (ft)
Gravel	0-25
Rhyolite tuff breccia in part welded (lahar?)	25-295
Andesite	295-300

The maximum sustained yield of the Blue Canyon Well is 19 gpm, as determined by a pumping test by Francis X. Bushman in 1960, although the well is normally pumped at a rate of 3 to 5 gpm.

The temperatures observed at various depths on August 23, 1956, follow:

Depth (ft)	Temperature (°F)	Remarks
217.5	89.8	water level = 216.8 ft casing perforated 217.5-250 ft
220	89.9	
223.5	89.95	
223.5	90.1	
223.5	90.15	
238.5	90.2	
243.5	90.3	
248.5	90.25	
253.5	90.4	
255	90.45	
258.5	90.5	bottom of casing
259.5	91.2	
260.5	91.6	
261.5	91.7	
262.5	91.8	
263.5	91.7	
264.5	——	bottom of hole

During a pumping test July 23-24, 1956, the temperature of the discharging water varied with the pumping rate as follows:

Minutes since pump began	Discharge (gpm)	Temperature (°F)
3	46	91
7	46.5	90
66	49.5	90.2
152	40.3	92
156	39.8	91.8
243	38.7	91.8
280	38	91.8
343	30.5	91.8
373	30.0	91.8
463	29.2	91.8
523	28.8	91.8
583	28.2	91.8
978	18.7	90.8
1128	18.4	90.6
1240	18.6	90.4
1333	18.7	90.3
1457	18.8	90.3

During the spring of 1966, a vertical 2-inch core hole was drilled at the end of a tunnel into the mountain (35.1W.4.433). The portal elevation of the tunnel is 5131 ft. The elevation of the core hole is slightly higher but no more than 5135 ft. Land surface lies at an elevation of about 5550 ft. This hole was drilled in granite of Precambrian age to a depth below the tunnel of 260 ft. The water level in the hole is about 160 ft. The hole could be neither blown dry by compressed air nor bailed dry with an 8-ft-long, 1-gallon capacity bailer. Table 18 contains a chemical analysis of a sample collected when the hole was bailed August 2:3, 1966.

Bottom-hole temperatures as the hole was drilled, measured on a Monday morning after the hole had sat idle for 2 days, were as follows:

Date	Depth (ft)	Temperatures (°F)
March 7, 1966	145	107.2
March 14, 1966	160	106.7
March 21, 1966	177	107.4
April 5, 1966	210	108.8

(Note: Air temperature in the tunnel—even with the ventilation system working—ranged from 80" to 88°F.) The temperatures measured in the finished hole were as follows:

	Temperature (°F)	
Depth (ft)	June 24, 1966	July 8, 1966
33	93.2	–
66	95.9	–
99	98.8	–
132	101.8	–
153	–	101.2
166	105.5	105.5
187	107.4	–
230	108.8	108.9

The Socorro Mountains are part of a series of low mountain ranges along the western margin of the Rio Grande valley. They are bordered on the west by the Snake Ranch Flats.

An up-to-date summary of the geology of Socorro and vicinity is given in a guidebook of the New Mexico Geological Society (De Brine, Spiegel, and Williams, 1963; Smith, 1963; Weber, 1963).

Fig. 31 is a generalized geologic map of the thermal area. Mapping in the area is complicated by the large volume of landslide material, which has slid onto the mudstone that, when wet, serves as a good gliding surface.

Basically, the Socorro Mountains are a pile of interlayered, interbedded, and intruded volcanic rocks, volcanically derived rocks, and a red gypsiferous, mudstone of Tertiary age. Paleozoic and Precambrian rocks are found in exposures and mine workings north of Blue Canyon. An extensive perlite deposit is situated south of the thermal springs. Basalt flows of Quaternary or late Tertiary age cap the older deposits. The most important structural feature appears to be the north-trending fault that separates the Socorro Mountains from the Rio Grande valley and along which the thermal springs occur.

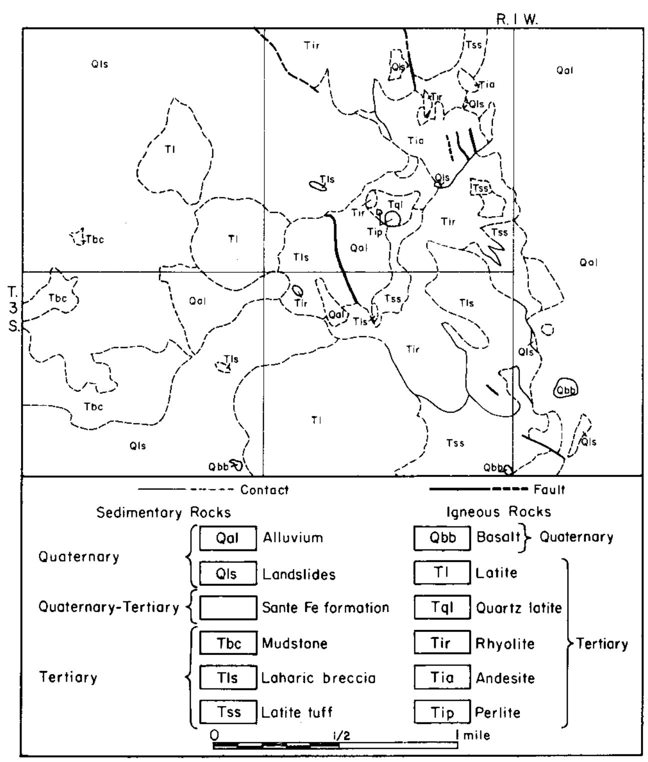


FIGURE 31—GEOLOGIC MAP OF THE SOCORRO MOUNTAINS, SOCORRO COUNTY.

Two geologic features of interest in the Socorro Mountains are the presence of mineralization and siliceous sinter north of Blue Canyon along the eastern front (Smith, 1963). The mineralization formed deposits consisting mainly of secondary cerargyrite from oxidized parts of veins actively mined in the past. Some barite is also present. The siliceous sinter is of Quaternary age and was deposited on outcrops of Paleozoic rocks just north of the mining area. Smith (1963) suggested that the sinter was deposited by springs during final stages of volcanism.

The Snake Ranch Flats are part of a structural trough with an unknown thickness of fill. The upper part consists of some Quaternary alluvium and slope wash underlain by the Santa Fe Group of late Tertiary and Quaternary age. The mudstone may underlie the Santa Fe in this trough.

JORNADA DEL MUERTO

One well has been drilled in the Jornada del Muerto in which an anomalous temperature was observed—Victoria Land and Cattle Company No. 1 (10S.1W.25.100). Table M7 contains a partial chemical analysis of the water. Hood and Kister (1962, p. 41 and 51) used the water from this well as an example of saline water from the San Andres Formation.

The well with land surface altitude of 4809 ft was drilled during 1951 and 1952. Original total depth was 6055 ft. The hole was plugged back and the casing was perforated from 1270 to 1348 ft. Two samples analyzed by the state chemist contained 2540 and 2400 ppm dissolved solids. Hood and Kister (p. 51) reported the shut-in water level was 164 ft above the land surface on July 8, 1955, that the well was flowing 900 gpm, and that the water temperature was 94°F.

LOWER RIO GRANDE BASIN

TRUTH OR CONSEQUENCES AREA (LAS PALOMAS HOT SPRINGS, CABALLO HOT SPRINGS, HOT SPRINGS; 13S.4W.33.400; 14S.4W.4.100)

The Truth or Consequences thermal area occurs along the west side of the Rio Grande between the northwest-trending Mudsprings Mountain and the Sierra Caballos (Caballos Mountains; fig. 32). The thermal waters apparently occur entirely within Truth or Consequences (fig. 33).

Peale (1886, p. 194) referred to these springs in 2 ways: "Caballo Springs (?), 5 miles from Fort McRae, Socorro County . . . 136°F" and "Near the Rio Grande, north of Palomas, Socorro County." In 1904 Jones (p. 304-305) listed Las Palomas Hot Springs and says, "This spring is in Sierrra County on the Rio Grande, and can be reached from Engle, the nearest station on the Atchison, Topeka and Santa Fe Railway."

Hare and Mitchell (1912, p. 56-69) gave the following dissolved solids of water from Las Palomas Hot Springs:

Lower Spring	{July 1901	2580 ppm
	October 1904	2995 ppm
	October 1904	2802 ppm
Warm Spring	jJuly 1901 k	2670 ppm
	December 1901	2635 ppm
Upper Spring	October 1904	2879 ppm
Upper Bath	October 1904	3040 ppm

In 1928, Brues (p. 143) referred to Hot Springs, New Mexico. Peale, of course, did not realize that he was referring to the same spring in his 2 references. Nor did he realize that Sierra County had been formed in 1884 by taking land from Socorro, Dotia Ana, and Grant Counties.

The name Las Palomas Hot Springs apparently derived from the fact that people who visited the springs during the period 1900 to 1911 for therapeutic reasons were forced to stay at the village of Palomas, a few miles south of the thermal area. The site of this village is now inundated by the Caballo Reservoir.

The town of Palomas Hot Springs developed about 1911 when construction of Elephant Butte Dam began. About 1913, the village name was changed from Palomas Hot Springs to Hot Springs. In 1950, Hot Springs changed its name to Truth or Consequences. Thus, early data for the Truth or Consequences area appear in the literature under several names.

The area has been studied extensively. Brues (1928, 1932) repeatedly refers to the organisms he collected there in his classic work on the fauna of North American hot springs. Moreover, because of the extensive development of the thermal springs for spas, mineral baths, and resort hotels, the New Mexico State Engineer has published several studies of the hydrology of the region (Powell, 1929; Minton, 1941; Theis, Taylor, and Murray, 1941; Murray and Theis, 1946; Murray, 1949, 1959; Cox and Reeder, 1962), and measured water levels in selected wells in the area since 1939. Kelley and Silver (1952) discussed the geology of the area in detail and provided an extensive bibliography (p. 265-775). In addition to the published work, since 1939 the U.S. Geological Survey has periodically sampled the spring at Yucca Lodge.

In 1955 Conover and others summarized the occurrence of ground water in south-central New Mexico and included a summary of Theis, Taylor, and Murray's work (p. 111). In the 1965-1966 inventory, only the Yucca Lodge was visited and sampled.

The earliest description of the springs is that of Brues (1928, p. 143-144):

> The springs are near the town at the foot of a small hill. Some have been turned into baths, but there is a small amount of seepage forming small pools in a large marshy meadow. Some of these pools are barely tepid, but a flowing stream which forms the overflow from several small springs near the upper edge of the marsh, traverses the marsh for a distance of several hundred yards. The temperature of this stream, which is several feet wide, is not very high, in the neighborhood of 40°(C) along most of its course. The specific gravity, corrected for temperature is 1.0039 and pH 8.1. It supports a fauna of snails, chironomid larvae, and fish.

The following discussion of the springs is modified slightly from Kelley and Silver (1952, p. 190-194). The thermal-water area outlined by wells and springs lies on the south side of an inselberg of Paleozoic limestone. The immediate area of the thermal springs and wells is covered with alluvium through which the springs issue, in addition to the artesian thermal water in the overlying alluviuin and the nearby valley fill.

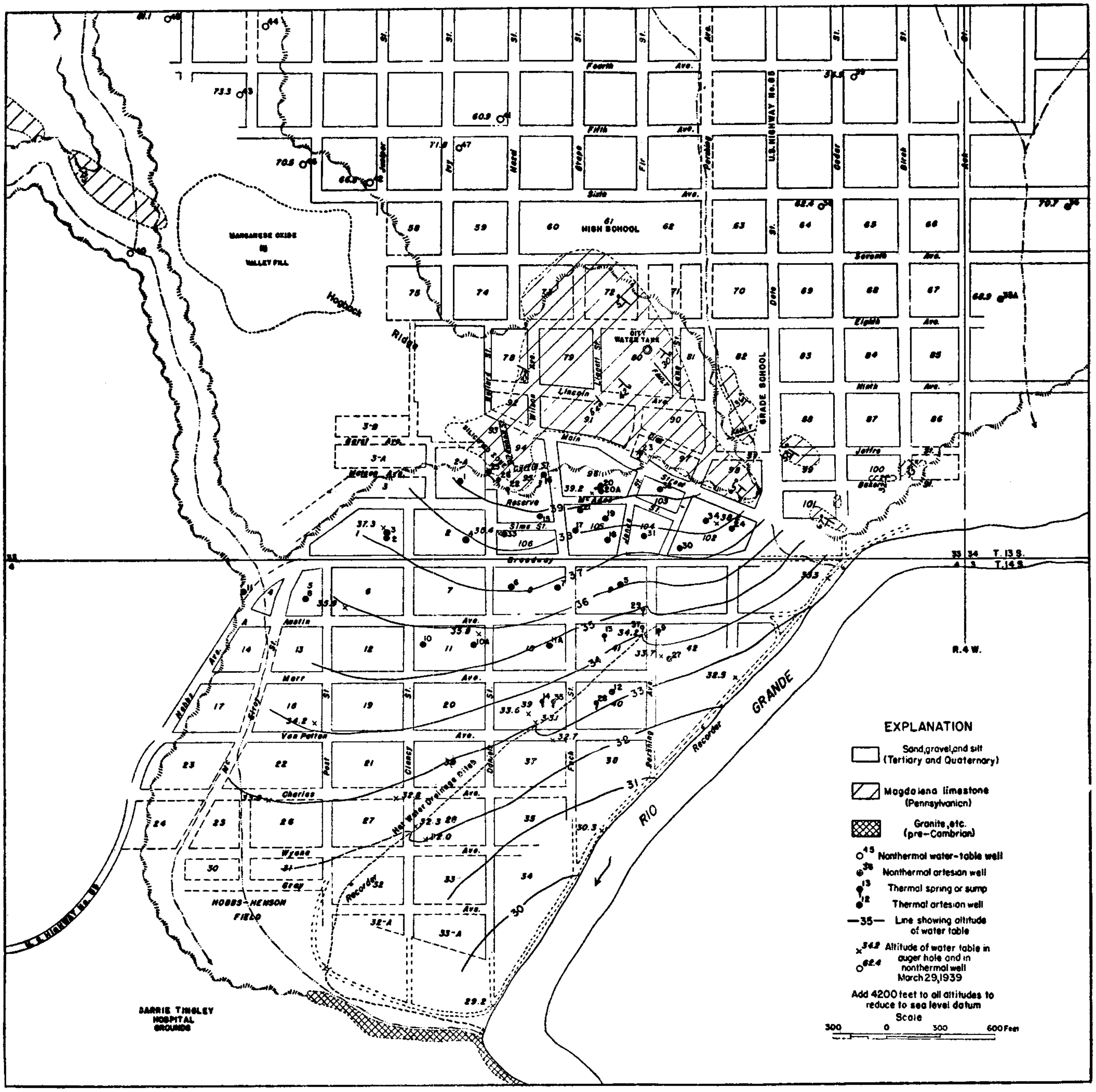


FIGURE 32—MAP OF TRUTH OR CONSEQUENCES, SIERRA COUNTY, SHOWING LOCATIONS OF WELLS AND SPRINGS. (after Theis, Taylor, and Murray, 1942).

Explanation of the thermal-water occurrence is somewhat complicated by the mingling of thermal and nonthermal waters in the alluvium overlying the bedrock.

Fig. 34 shows that the thermal-water area overlies lower Paleozoic strata overturned and dipping to the south 30 to 65 degrees. To the east of town, these rocks are offset by 2 buried faults parallel to the Hot Springs fault, but in the immediate thermal-water area no offset is apparent. Drillers' logs of some of the wells in the thermal-water area reported subsurface rocks. The log of the G. L. Egbert well in Block 10, NW¼NW¼NE¼ sec. 4, T. 14 S., R. 4 E., Hot Springs Townsite (Theis, Taylor, and Murray, 1941, p. 432), recorded "hard red rock with white rock" from 101 to 146 ft in depth. Likewise the log of the E. L. Morris well about 300 ft due west of the Egbert well reported "granite" at a depth of 190 ft below 98 ft of "caprock." Despite the general unreliability of these logs and the varied interpretations possible, they fit the areal geology of fig. 34 quite well.

The presence of an eastward-trending fault beneath the town between the sedimentary beds and the Precambrian rocks is problematical. If the beds are inclined very steeply, it appears that the entire section might be present in the subsurface in normal contact with the Precambrian. However, if an average dip of 50 degrees exists in the subsurface, then the contact of the sediments and the Precambrian may be a fault on which the south side moved relatively down. Theis, Taylor,

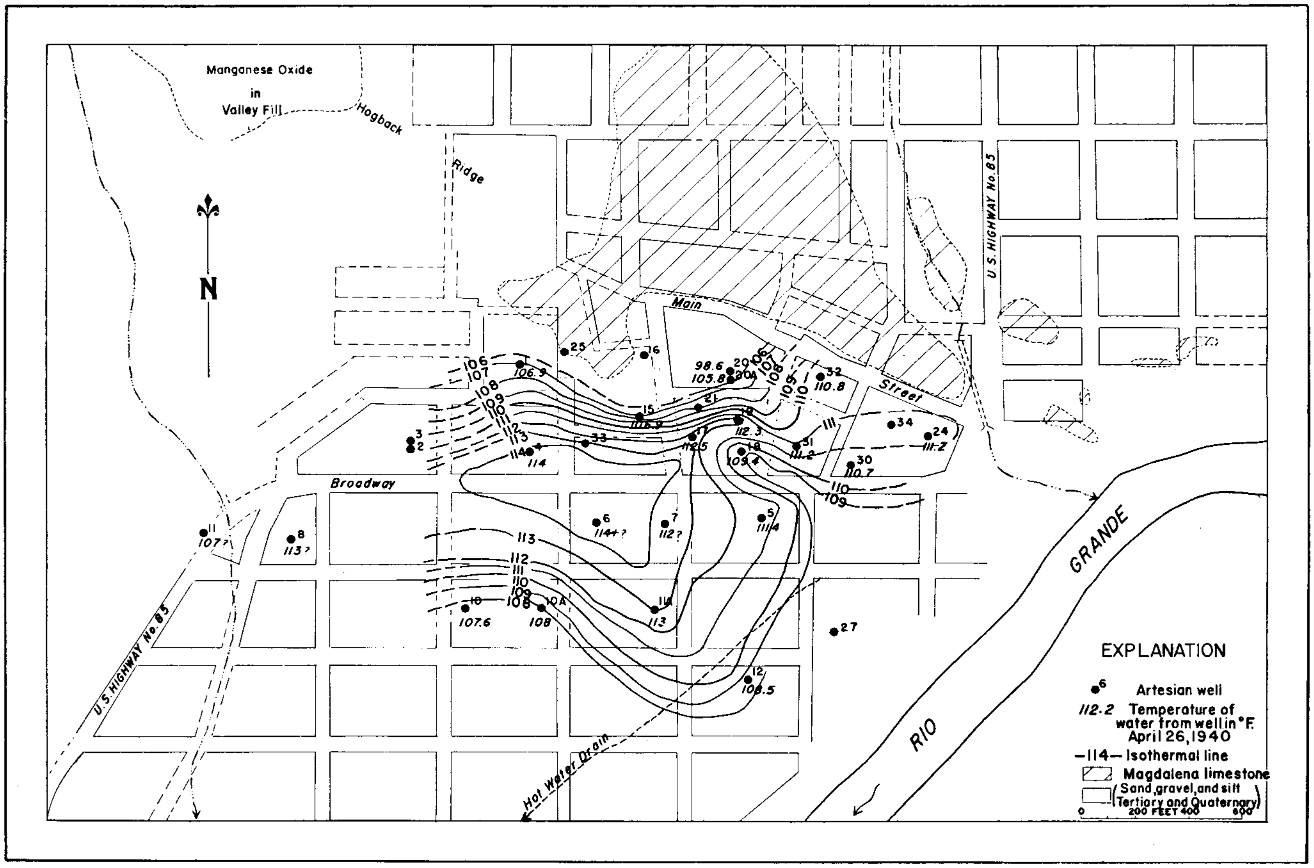


FIGURE 33—MAP OF TRUTH OR CONSEQUENCES SHOWING DISTRIBUTION OF TEMPERATURES OF THERMAL WATER FROM ARTESIAN WELLS, APRIL 26, 1940 (after Theis, Taylor, and Murray, 1942).

and Murray (1941, p. 441) deduced the presence of an eastward-trending fault beneath the town but concluded that the north side was downthrown, owing possibly to the fact that older (Precambrian) rocks occupy the south side of the postulated fault. The movement deduced herein may appear at first to be in error and to contradict the mapped relations, but if the section is overturned, upthrow of the south side as postulated by Theis, Taylor, and Murray would duplicate the outcrop of Paleozoic strata rather than bring the Precambrian to the surface. As indicated, the fault may or may not be present beneath Truth or Consequences. The presence of the hot springs suggests some sort of fracture below the relatively thin cover of sand and gravel; if it is a fault of easterly trend, then the south side is downthrown similar to the Mud Springs fault. If this interpretation is correct, then Paleozoic strata underlie the Precambrian rock at depth along a

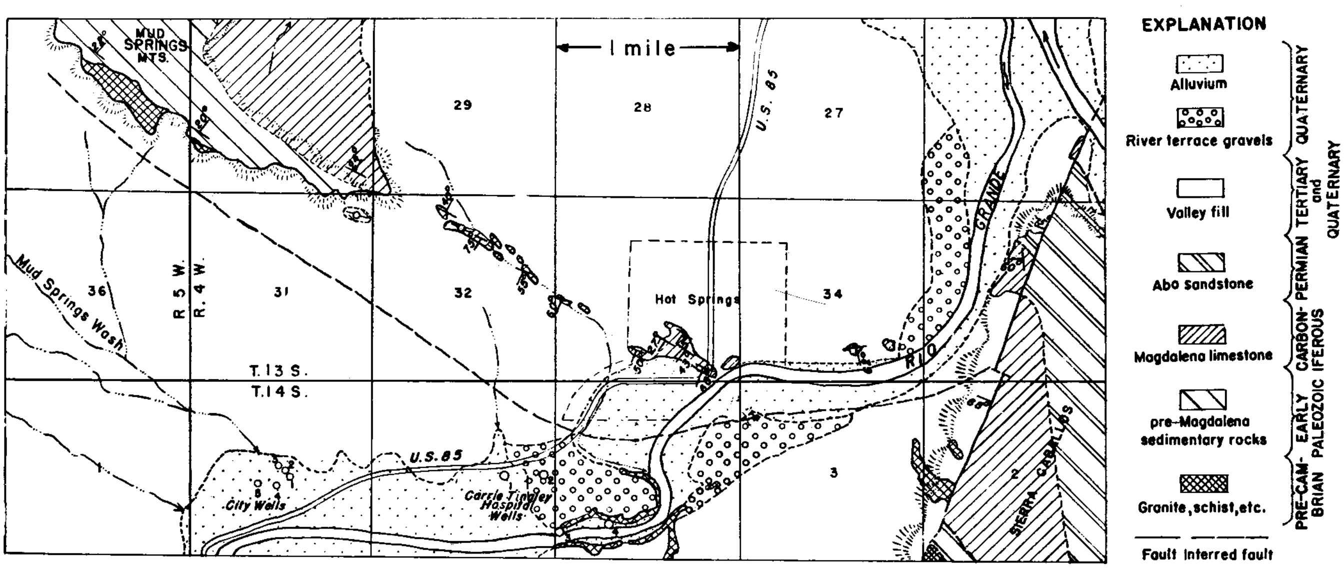


FIGURE 34—MAP SHOWING GEOLOGY IN VICINITY OF TRUTH OR CONSEQUENCES (after Theis, Taylor, and Murray, 1942).

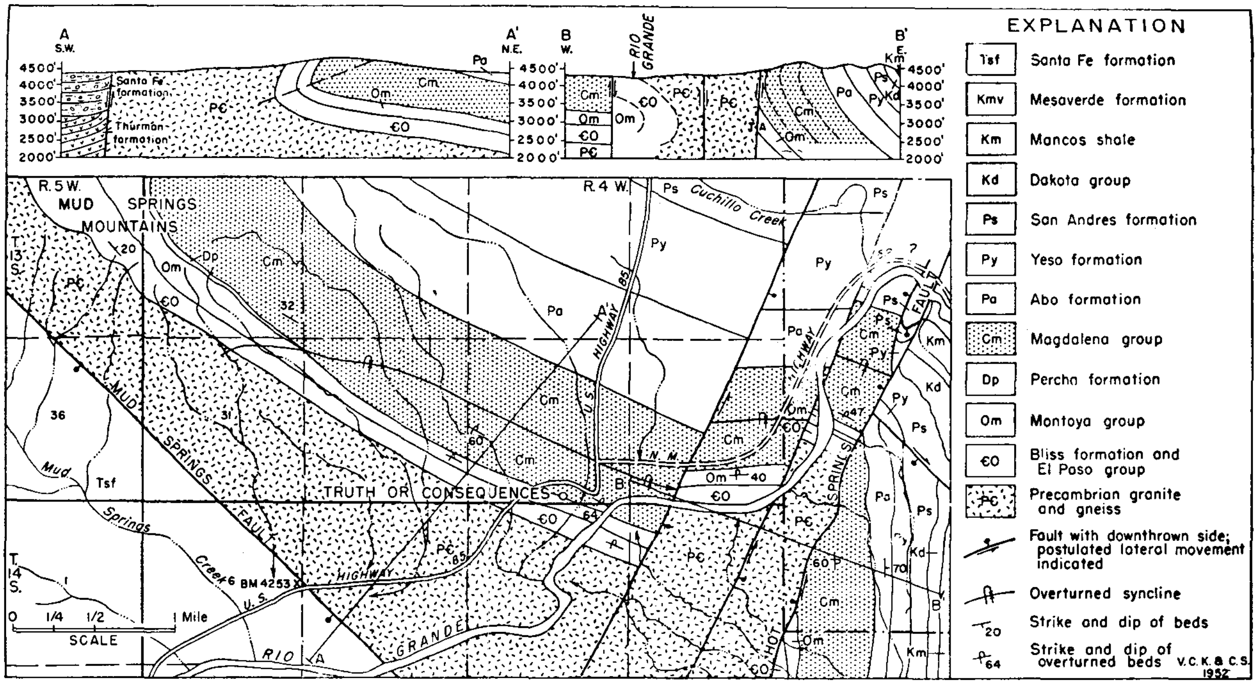


FIGURE 35—GEOLOGIC MAP AND CROSS SECTIONS OF TRUTH OR CONSEQUENCES AREA (KELLEY AND SILVER, 1952).

narrow band south of the fault. Fig. 35 interprets these conditions.

Evidence of Quaternary spring activity in the form of manganese and travertine deposits, solution openings, and altered rock extends at least half a mile northwest of town.

The thermal water discharging in the area amounted to 3.5 second-ft or 2,260,000 gpd in 1941 (Theis, Taylor, and Murray, p. 456), of which approximately 130,000 gpd were discharged from artesian wells, the natural means of balancing the system. The temperature of the thermal water ranged between 98° and 114°F, and the discharge of heat was about 180 million calories per minute. The daily output equaled the amount of heat that would be obtained from the complete combustion of about 40 tons of coal per day (p. 457).

Theis, Taylor, and Murray concluded that the thermal water was distinctly different and had an entirely different source from that of nonthermal ground water of the vicinity. This is borne out not only by the chemical composition but by the artesian pressure of the thermal water as compared to the lack of pressure in the unconfined nonthermal water (figs. 32 and 36). The water issues from Paleozoic strata into the overlying clay, sandstone, and gravel, which are apparently capable of holding some back pressure, and moves laterally through the alluvium to the river.

Theis, Taylor, and Murray (1941, p. 481) estimated that "if 3.5 second-feet of thermal water emerging at Truth or Consequences is derived from rainfall in the area, it represents a yearly addition to the deep ground water of about $^{5}/_{8}$ inch over 70 square miles of area." They also concluded that "the hot water at Truth or Consequences must be derived over an extensive area and probably drains by deep circulation an area considerably larger than 70 square miles."

They estimated (p. 483) that "the condensation of superheated steam would furnish the necessary heat to the water discharged at Truth or Consequences if the resulting condensed magmatic water amounted to less than 5 percent of the meteoric water," and concluded that "the most probable source of the heat of the hot water is igneous rock at depth, either acting by conduction of heat through the rock and steepening of the geothermal gradient or by yielding steam and hot gases that rise through fractures to mingle with the normally circulating meteoric ground water. The latter alternative seems to be favored by the chemical character of the water" (p. 484). A slight increase in radioactivity was noted with a Geiger counter in proximity to the thermal water, thus lending some support to the juvenile origin of a small fraction of the water. The existence of overturned structure and associated fracturing of the rock would appear to allow the transfer of heat through vapors and fluids.

In 1935, an order of the New Mexico State Engineer declared an area of about 38 square miles to be the "Hot Springs Underground Water Basin."

The basin was closed to further appropriation of mineral (thermal) water July 1, 1937, and 10 years later it was closed to further appropriation of fresh (nonthermal) artesian water. An area of about 1.5 square miles of the basin was reopened for appropriation of mineral water in 1947 and 1950. Appropriation of shallow, nonthermal water to supplement surface-water rights was permitted. The Hot Springs underground water basin to the north adjoins the Rio Grande underground water basin (declared November 29, 1956, by order of the State Engineer).

Water levels measured in 10 thermal wells and 6 nonthermal wells showed that daily fluctuations in artesian head resulted from wells being pumped; annual changes in head resulted primarily from changes in river stage, as the natural discharge of the thermal water is to the river. The maximum fluctuation from the highest level to the lowest level in the thermal water

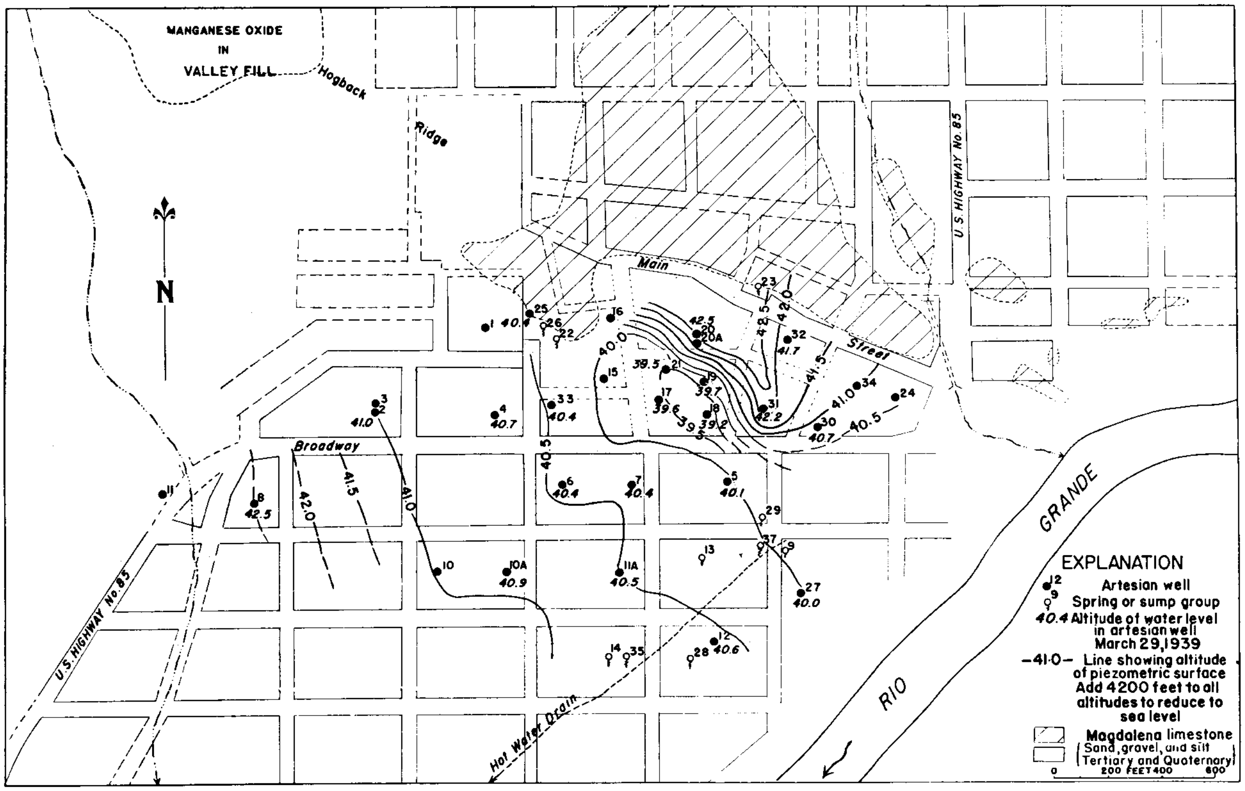


FIGURE 36—MAP OF PART OF TRUTH OR CONSEQUENCES SHOWING ALTITUDE OF THE PIEZOMETRIC SURFACE IN ARTESIAN WELLS IN THE THERMAL WATER AREA (after Theis, Taylor, and Murray, 1942).

aquifer ranged from 1.39 to 2.94 ft. The highest level occurred in 1942, the lowest from 1956 to 1959, depending upon the observation well.

The Yucca Lodge has 3 sources of thermal water: One is a spring developed into an indoor pool, now a regular part of the bathing facilities; the second is an outdoor decorative pool, also a developed spring; and the third is a shallow, driven, point well about 15 ft deep, which flows. The Yucca Lodge samples of table M8 all come from the flowing well. Table 20 contains the measurements made at the Yucca Lodge. Table 21 gives the heavy metal and radon-222 concentration samples from this well.

The temperature, pH, and discharge reported for this well follow:

Date	Temperature (°F)	pH	Discharge (gpm)
2-10-39	110	–	–
4-28-43	109.4	–	–
3-31-52	110	7.2	2
5-28-54	109	7.3	1.1
7-12-54	–	–	0.5
8-2-55	110	–	0.77
9-17-56	110.5	7.3	0.77
8-5-57	108	7.2	8.5
4-15-58	104	7.2	–
8-3-59	107	7.2	–
4-4-60	104	7.5	–
8-13-62	107.5	7.2	–
8-5-63	108	7.2	–
8-8-64	107	7.8	7.7
12-14-65	105.5	7.1	–

Wells in the Magdalena Limestone discharge waters with the following temperatures:

Depth (ft)	Temperature (°F)
212	113
208	102
105	114
100	111.2
27	112.3

Springs in the alluvium discharge water with the following temperatures:

Spring	Temperature (°F)
Yucca Lodge Springs	105-108.5
State (Geronimo) Springs	99-103
Old Government Spring	101-106

BARNEY IORIO No. 1 FEE (14S.5W.25.410)

The Barney Iorio No. 1 Fee well lies 6 miles south of Truth or Consequences. It was drilled as a wildcat oil test but was completed as water well in April 1941. It has a 51/2-inch casing set at 1115 ft in"red sticky clay with breaks of volcanic ash." At a depth of 1160 ft, the driller noted an "increase of water." At a depth of 1165 ft the well penetrated a stratified volcanic ash (Thurman formation; Kelley and Silver, p. 122 and 189), and water rose to a depth of 73 ft below the land surface. As drilling proceeded, the water level continued to rise. When the well was 1200 ft deep, it was flowing 2 gpm. The interval from 1470 to 1501 ft,"water sand," produced approximately 25 gpm. At a depth of 1514 ft, the well penetrated a "hard volcanic ash" and no additional water was noted. Shows of gas were reported at 2004 and 2010 ft. The total depth of the hole was 2100 ft, but it was plugged back to 1530 ft so that the

Table 20 - Field data for lower Rio Grande and Mimbres River basins

Location	Date	Discharge (gpm)	Temperature (°F)	pH	Specific conductance micromhos	Density gm/ml	H_2S ppm	NH_3 ppm	SiO_2 ppm	Remarks
Truth or Consequences thermal area										
Yucca Lodge										
Indoor Pool	12-14-65	---	108.5	---	---	---	---	---	---	ave. Temp. = 105.0
Outdoor Pool	12-14-65	---	107.0	7.1	2900	0.986	0	---	---	95.
Well	12-14-65	---	105.5	7.1	3100	0.986	0	0.2	39	air = 48°F
	12-4-74	---	104	6.8	2800	---	---	---	---	
Derry Warm Springs										
(17S.4W.29.340)	4-17-47	---	93	---	---	---	---	---	---	USGS meas.
	3-17-52	5-10	93.2	---	---	---	---	---	---	USGS meas.
	4-30-57	10-15	93	---	---	---	---	---	---	USGS meas.
	12-16-65	23	92.8	6.6	1120	0.988	0	0.15	29	
	12-4-74	---	92.8	6.85	1150	---	---	---	---	
Radium Springs										
(21S.1W.10.213)										
Radium Springs Hotel										Water passes
Well 2	12-16-65	---	140	5.8	4700	0.982	0	---	---	through
(Fig. 39)	12-4-74	---	127	6.7	6100	---	---	---	---	pressure tank
Bailey's Bathhouse	2-7-66	5*	141.5	6.5	3400	0.981	0	0.4	90	"
Faywood Hot Spring	12-26-65	34	130.9	7.3	550	0.980	0†	0	42	
	12-5-74	---	131	6.95	580	---	---	---	---	

* estimate

† test was negative, but occasional odor noted

finished water well delivered water from the interval 1115 ft (bottom of casing) to 1530 ft (top of plug), with most of the water discharging from the 1470 to 1501 "water sand" interval.

On December 15, 1965, the valve was opened and the well was allowed to flow for 180 minutes. As it flowed, measurements were made of discharge (gpm), temperature (°F), pH, and specific conductance at five- and ten-minute intervals (fig. 37). Five 8-ounce samples of the discharging water were collected (table 22).

Assuming that the casing was standard 51/2-inch outside diameter, the water discharged during the early part of the experiment (0 to 30 or 40 minutes) had been standing in the casing, whereas the water discharged during the period from 160 to 180 minutes probably represented the water in storage in the aquifer.

The measured discharge remained steady for about 15 minutes, then proceeded to drop off gradually. The steady discharge during the first 15 minutes probably reflected instrumental error. Water had to flow about 15 ft in an earth ditch, some was lost to seepage in the early part of the experiment, and the first measurement was made 4 minutes after discharge began. Presumably, the discharge actually followed the usual pattern of a well discharging at constant head in which the discharge diminishes continually with time (Jacob and Lohman, 1952).

The temperature gradually increased from 63.0°F to a maximum of 91.4°F (air temperature during the experiment was less than 40°F; fig. 33). The discrepancy between the reported 90°F and the observed 91.4°F was probably caused by instrumental differences. The pH declined from 9.2 to 8.4. Specific conductance ranged from 2500 to 3100 micromhos/cm at 25°C.

The specific gravity of the water varied with the temperature (as measured by a hydrometer in the field) and ranged from 0.992 to 0.988 g/cm^3. The concentrations of NH_3 and SiO_2 in the water were each measured twice in the field, using a portable colorimeter. The NH_3 values obtained were 0.5 ppm (at 85 minutes) and 0.45 ppm (115 minutes). The SiO_2 values obtained were 21 ppm (at 45 minutes) and 25 ppm (at 135 minutes).

Table 22 contains chemical analyses of water samples collected in 1952 and 1965.

Table 21 - Heavy metals and radon-222 in thermal water from the lower Rio Grande basin (all concentrations except radon-222 in ppb)

	Truth or Consequences Yucca Lodge Well	Derry Warm Springs (17S.04W.29.343)	Radium Springs	Well 25S.1E.17.111A	Berino Well 25S.3E.11.111
Date	12-4-74	12-4-74	12-4-74	7-28-73	1-24-73
Copper	7	6	14	6	<25
Cobalt	--	--	--	--	--
Chromium	9.2	1.0	4.7	--	<10
Cadmium	.97	.95	2.2	--	<10
Lead	12	12	25	0	<10
Molybdenum	<10	≃36	≃10	--	--
Nickel	--	--	--	--	<100
Zinc	17	8	60	20	100
Mercury	ND	<1	<1	.1	--
Silver	--	--	--	--	<50
Radon-222 picocuries/liter	1400	530	5800	--	--
				USGS 1221153	NMHSS 1975, p. 46

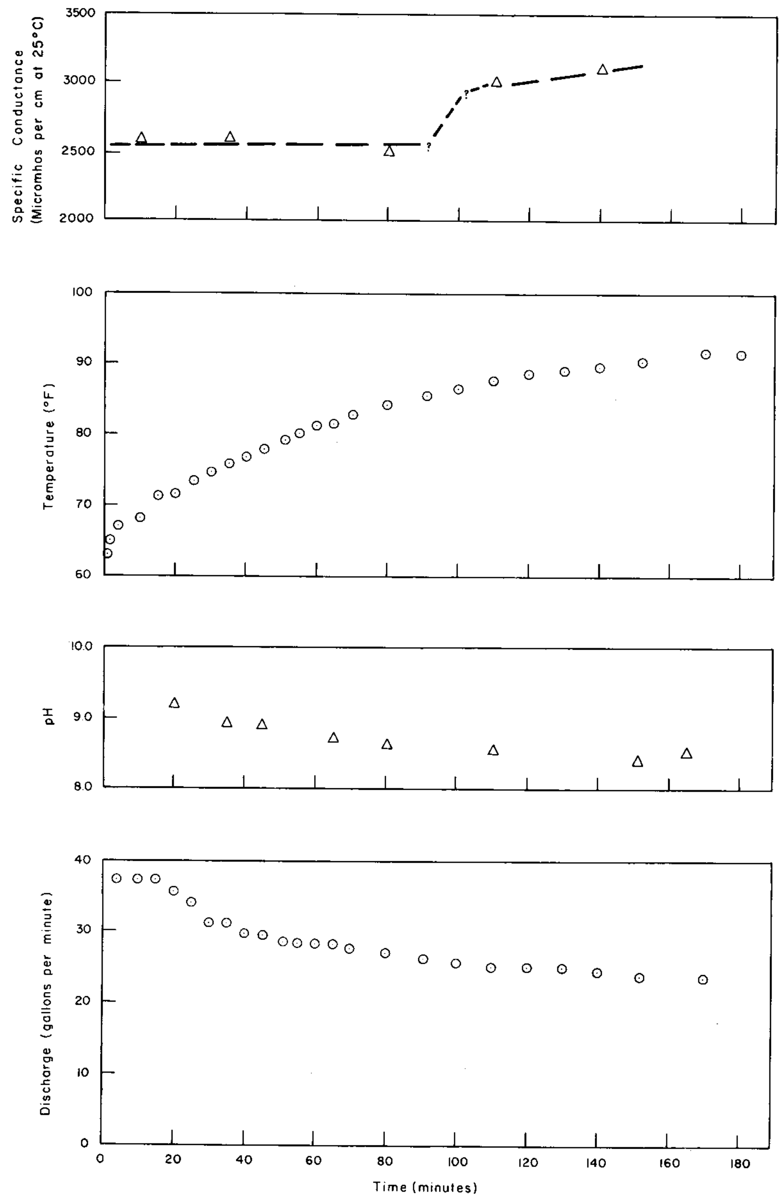


FIGURE 37—VARIATION IN DISCHARGE, PH, TEMPERATURE, AND SPECIFIC CONDUCTANCE OF WATER DISCHARGING FROM BARNEY IORIO NO. 1 FEE, SIERRA COUNTY (after Summers and Brandvold, 1967).

DERRY WARM SPRINGS (17S.4W.29.340)

Derry Warm Springs occur on the east side of the Rio Grande valley about a mile north of the town of Derry.

These springs are not well known. Although they appear on several maps and although the Rio Grande valley has been studied in considerable detail, references to this spring in the literature are limited. Conover (1954, p. 18, 81) noted their existence next to a limestone bluff and gave a chemical analysis (p. 15253). Kelley and Silver (1952, p. 194-95) described the springs this way:

> Half a mile east of Derry, there are a few small springs with an estimated aggregate flow of about 50 gallons per minute issuing from openings in a small spring deposit of travertine. The waters appear to issue at two levels, ten feet apart. one a foot higher than the other. One spring issues about 5 feet and the other 6 feet above the valley floor. The temperature of the higher spring is 66°F. and that of the lower spring is 92°F. Readings were taken at 5 p.m. on a warm day (May 8, 1951). The warmer spring had a very mild sulfurous odor and taste and was noticeably radioactive to about the same extent as the thermal water at Truth or Consequences.
>
> The springs apparently rise along a fault at the west base of the Derry fault block and issue through alluvial material at the base of the hill. There appears to be some mingling of the thermal water with the water supplying the cooler spring, and it may be possible to develop water of higher temperature from wells which intercept the thermal water at depth before it is cooled by the addition of water of normal ground temperature.

Table 22 - Variations of ionic concentrations in water discharging from Barney Iorio No. 1 Fee

Time (minutes)	Concentration (parts per million)					
	Ca	Mg	Na	K	Li	Fe
27	380	0.42	1281	6.9	0.74	--
57	376	0.41	1210	6.8	0.77	.07
83	366	0.43	1233	6.8	0.78	.07
133	364	0.40	1256	7.3	0.92	.13
175	375	0.46	1280	7.8	0.91	.18

Interstate highway construction has altered the position of the springs. In 1966, they discharged from the valley floor and from the fill below a roadcut (fig. 38). The well was probably completed in the sand and gravel of the Santa Fe Formation. Table M8 contains a chemical analysis of the water from this well by the New Mexico Department of Public Health.

Rincon Well (19S.2W.9.120)

The Rincon well is about 300 ft south of the southern edge of the Santa Fe Railway Company right-of-way and 8 ft east of the western edge of the highway right-of-way. Seager and Hawley (1973) have discussed the geology of the Rincon area in detail.

Radium Springs Thermal Area (Selden Springs; 21S.1W.10.213)

The Radium Springs thermal area is on the extreme east side of the Rio Grande valley about a quarter mile north of Leasburg Dam and one and a half miles north of the ruins of Fort Selden. It was first noted by Peale (1886, p. 322), who listed simply "Aqua Caliente, near Mesilla(?), Doña Ana County."

In 1899 Crook (p. 336) called it Selden Hot Springs and wrote, "These springs are sixteen miles north of Las Cruces, and are patronized by those afflicted with rheumatism. Visitors camp out, there are no accommodations."

Brues (1928, p. 144) wrote, "About 60 miles south of this locality (Hot Springs, New Mexico) is another hot spring known as Radium Hot Springs emitting water at 85°(C), but this is piped to a bathhouse from the rocky hillside and affords no opportunity for biological collecting."

Despite the fact that these springs occur in a much studied area of the Rio Grande valley, the first reference to them by hydrologists did not occur until 1937, when Stearns, Stearns, and Waring (p. 169) listed them and wrote, "Radium Hot Springs near Radium Springs railway station 17 miles north of Las Cruces." They noted temperatures of 165° and 185°F in 2 springs discharging "small" volumes of water from rhyolite of Tertiary age. They said "the water is brackish, used for bathing and heating hotel."

Conover (1954, p. 17, 82, 85), in his study of the Rincon and Mesilla valleys mentioned this briefly and gave a chemical analysis (p. 152-53).

Scott and Barker (1962, p. 79), in their work on uranium and radium in ground water in the United Sates, included an analysis of water from one of these sources. They gave the temperature as 128°F but did not give the site at which the sample was collected.

Although the thermal water may have issued as springs in the historic past, now thermal water is obtained only by well. Three wells tap the water, 2 at the Radium Springs Hotel and the other at Bailey's Bathhouse. Fig. 39 is a crude sketch that shows the relative position of the wells at Radium Springs.

Well 1 (fig. 39) at the Radium Springs Hotel is an uncased excavation into the rhyolite. This may be the original spring. It is about 10 ft in diameter and 12 to 14 ft deep. The water level started about 10 ft below land surface on December 16, 1965. It had no discharge unless pumped. The maximum temperature of the water was 78.7°F at the bottom of the well. The dissolved solids precipitated from the water and formed a hard scum on the surface.

Well 2 (fig. 39) is 34 ft deep and is equipped with 2 small pumps that pump water into individual pressure

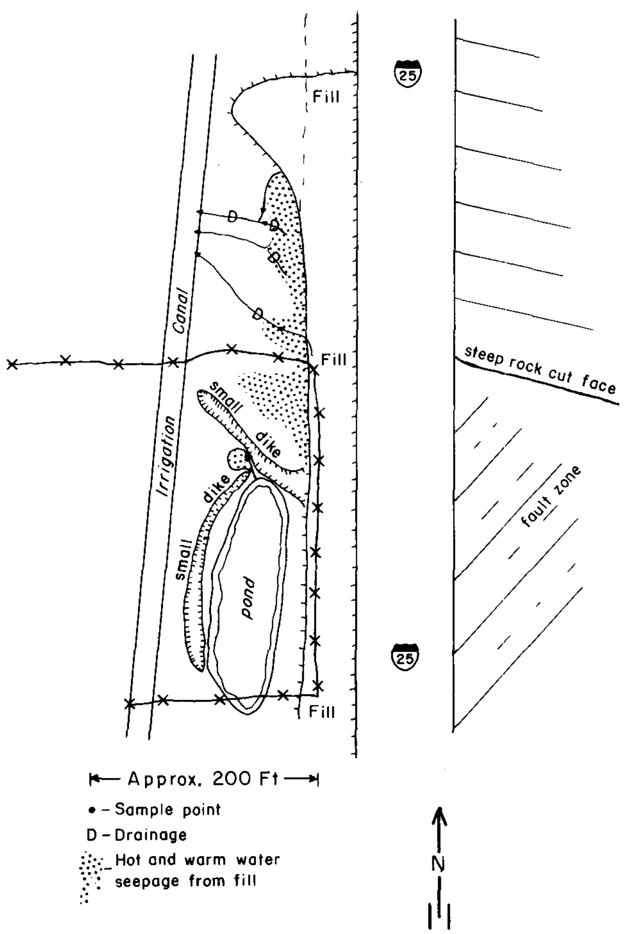


FIGURE 38—Freehand sketch of the premises of Derry Warm Spring, Sierra County.

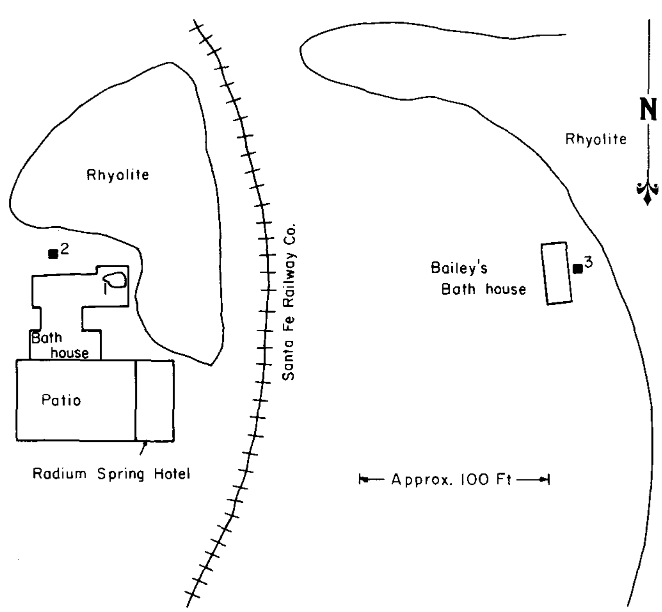


FIGURE 39—Freehand sketch of Radium Springs area, Doña Ana County, showing the locations of thermal water wells.

tanks from which it flows to the hotel bath and to the domestic water supply. The depth of water in the well on December 16, 1965, was about 2 ft below the land surface. The maximum temperature in the well was 140.5°F at a depth of 18 ft; the temperature at the bottom of the well was 139.0°F.

One unpublished report in the U.S. Geological Survey files gave the temperature of the water discharging from a well 24 ft deep at the Radium Springs Hotel as 186°F on May 17, 1948.

One analysis reportedly made by the University of New Mexico gave the radium concentration as 2.57 picocuries/liter ($\mu\mu C/l$). Scott and Barker (1962), for a 1954 sample reported beta-gamma activity, 170 picocuries/liter; radium, 0.6 picocuries/liter; and uranium, 1.8 $\mu g/l$.

The well at Bailey's Bathhouse (fig. 39, well 3) is also a dug well. The well is about 8 ft by 8 ft square and about 20 ft deep. There was no access into this well on February 7, 1966, so the depth to water and temperature in it could not be measured. The water discharged through a small pressure tank and was used in the baths and for domestic supply.

Chemical analyses of water from the several sources (table M8) show that the discharging water had essentially uniform character with 3500 ppm total dissolved solids.

The rock from which the water discharged is a rhyolite, with sanidine being the principal feldspar. The quartz content is low, but the fine-grained mass may be silica. At least 2 small faults occur in the rhyolite near the springs.

Las Alturas Estates Subdivision (23S.2E.34.000)

The Las Alturas Estates subdivision is southeast of Las Cruces on the east edge of the Rio Grande valley. In 1967 the subdivision was beyond the reach of city water, and homeowners drilled wells for their water supply. In some instances, one well served several homes. The water from these wells ranged from mildly warm (77°F) to hot (113°F). Fig. 40 shows the location of wells in the subdivision for which some data have been assembled. Table 23 summarizes the available data on 5 of these wells.

W. H. Schieffer, Schieffer Drilling Company, made the following logs of wells 7 and 8 (fig. 40):

WELL 7 (June 1, 1963)

	Depth (ft)
Sand and gravel	0-45
Sandy clay	45-61
Sand, small gravel, streaks of clay	61-83
Sand and small gravel	83-107
Clay and gravel	107-129
Cemented gravel and hard clay	129-152
Sand, streaks of hard gravel	152-171
Hard gravel, streaks of clay	171-194
Sand, streaks of clay and gravel	194-226
Clay	226-231
Sand and sandy clay	231-255
Sand	255-264
Sand, streaks of sandy clay	264-276
Clay and sandy clay	276-281
Clay, streak of hard gravel	281-293
Sand and sandy clay	293-315
Sand	315-332
Screen	326-332
Water level	174

WELL 8 (November 1, 1964)

	Depth (ft)
Surface	0-6
Clay	6-14
Sand and gravel	14-90
Clay and gravel	90-128
Sand	128-145
Clay	145-153
Sand, clay, streaks of sand	153-245
Sand, thin sandy clay streaks	245-256
Screen	251-256

B. Boyd's driller's log of well 8 (January 23, 1959) is as follows:

Material	Depth (ft)
Caliche	0-15
Sand	15-20
Caliche	20-30
Sand and gravel	30-35
Caliche and sand	35-60
Gravel and sand	60-71
Sand and boulders	71-91
Caliche	91-110
Sand and boulders	110-117
Caliche	117-177
Rock	177-200
Boulders and sand	200-230
Rock	230-270
Sand and gravel	270-280
Caliche	280-295
Sand and gravel	295-312
Caliche	312-318
Sand and boulders	318-370
Caliche	370-372
Sand and fine gravel	372-433

Mr. Boyd reported that this well penetrated horizons of both hot and cold water and that the temperature of the discharging water was 115°F.

An oil well, Clary and Ruther No. 1 State (23S.2E.36.222) about 2 miles northeast of the subdivision, was drilled to a depth of 2573 ft in 1948-1949. The driller's log of this well (log No. 6862, New Mexico Bureau of Mines & Mineral Resources) indicated that the well was drilled into rocks of Mississippian age, but made no mention of unusual temperature. However, at least one resident of Las Cruces (William T. Bixler, according to Jack A. Soules, president of the Las Alturas Development Company) mentioned that the well had encountered "steam and hot water."

Well (23S.1W.31.432)

Hood and Kister (1962, p. 46, 58) reported that a well 1200 ft deep, obtaining water from rocks of the Santa

Table 23 - Summary of data available for five wells in Las Alturas Estates subdivision near Las Cruces

Well no.	Date drilled	Depth (ft)	Reported water level (ft)	Casing diameter (inches)	February 6, 1966			
					Temp. °F	Sp. cond.	pH	SiO_2
1	5-2-57	296	161	4	77.5	--	--	--
2	--	311	190	4	94.1	1100	6.7	--
3	--	330	190-200	4	98.2	500	6.8	55
4	2- -64	348	180	4	108.5	1100	6.9	--
5	5- -64	355	240	4	113.1	2500	6.35	85

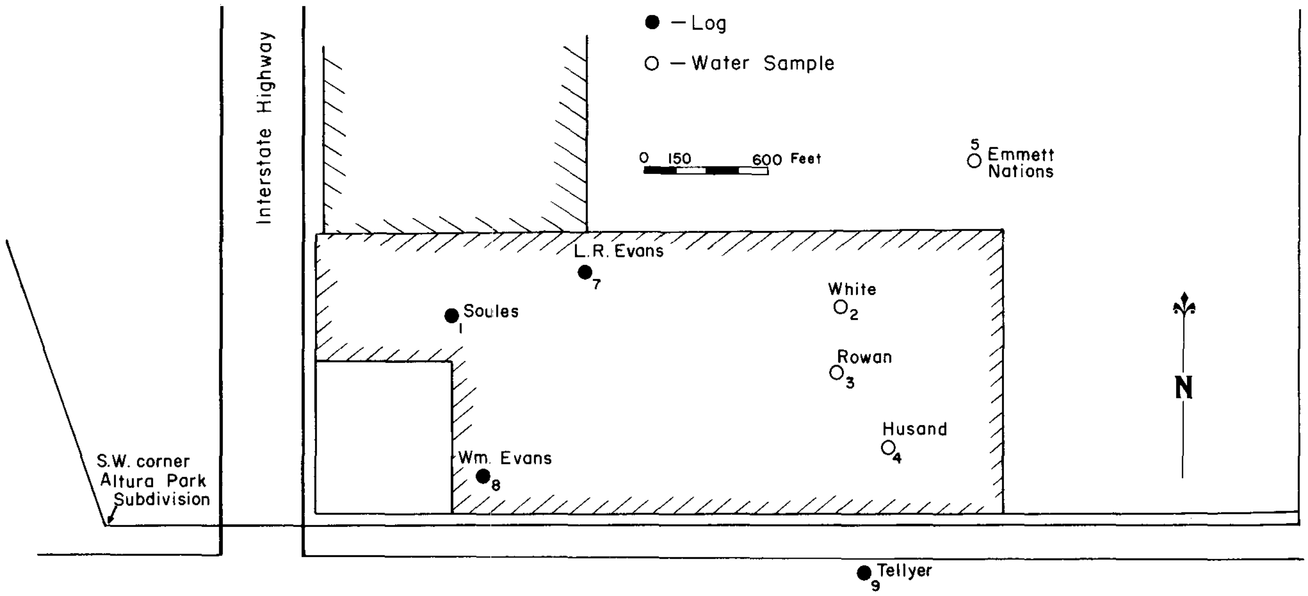


FIGURE 40—MAP OF LAS ALTURAS ESTATES SUBDIVISION SHOWING THE LOCATION OF THERMAL WATER WELLS.

Fe Group and related bolson fill, pumped 13.2 gpm. The temperature of the water was 90°F. The water came from a zone between 1030 and 1197 to 1200 ft. The depth to water on February 19, 1955, was 597 ft. A chemical analysis of the water sampled on that day is given in table M8. The date the well was drilled and the drawdown while pumping are unknown.

Although the well was extant February 5, 1966, its use to drain the back flush fluid from a large water softener prevented sampling it. The well is within 1000 ft of an outcrop of basalt of Quaternary age (Kottlowski, 1960).

WELL (23S.2W.35.411)

This well, which was drilled in 1961, is on the western margin of the Rio Grande structural trough. The well is 1050 ft deep; its casing record and depth to water are not known. The water is lifted with a large pump jack, suggesting that the depth of the well and the depth to water are great. The temperature of the discharge at the pump from around the sucker rods was 95°F. The pH of the water varied from 8.6 to 9.3, depending upon whether the sucker rods were going up or down.

The analysis of the water collected in 1966 that is presented in table M8 is suspect, because the sample was collected at a tap after the water had passed through an elevated wooden storage tank, a pressure tank and pump, and more than 100 ft of pipe. Clyde Wilson (U.S. Geological Survey, personal communication) collected a sample in 1973 (table M8) and measured a temperature of 97°F.

GRIMM WELL (25S. 1E.32.114)

Officially the Grimm Well is known as Grimm, Hunt, Brown and American Artic, Ltd. No. 1 Mobil. It is a deep (21,759 ft) oil test, about which Jack Grimm said (joint meeting of the Southwest Section, American Association of Petroleum Geologists, and Permian Basin Section, Society of Economic Paleontologists and Mineralogists, El Paso, Texas, January 31-February I, 1971): "The hole was a hot hole. Petroleum Information reported it so hot that the drill pipe could not hold. It was not quite that hot, but the heat gradient was higher than normal."

Two nearby water wells (25S.1E.17.111A and 26S.1W.25.414) discharge warm water (88° and 91°F, respectively). Table M8 contains a chemical analysis of water from well 25S.1E.17.111A, and table 21 contains an analysis of the heavy metals in the sample.

WEAVER-FEDERAL No. 1 (26S.1E.35.333)

Texaco Inc. drilled the S. H. Weaver-Federal No. 1 in 1965-1966 to a depth of 6620 ft. Electric logs report bottom hole temperature as follows:

Depth (ft)	Temperature (°F)
2434	95
6484	174
6520	176

However, residents report the water was very hot, so hot that a dog scalded to death in the mud pot.

BERINO AREA (26S.3E)

During 1967 the New Mexico State Highway Department drilled a new well at the New Mexico Port of Entry Station (265.3E.2.000). This well is 720 ft deep and the water temperature is reported to be 96°F. The Berino Water Consumers Association well (26S.3E. 11.111), which has a depth of 501 ft, has a water temperature of 88°F (Clyde Wilson, personal communication, 1973). Table M8 contains chemical analyses of water from these wells.

WELL (26S.8E.33.200)

Knowles and Kennedy (1952, p. 48-49) report that this well of unknown depth discharged hot, highly mineralized water. C. F. Berkstresser (personal communication, 1970) recalls measuring (about 1953) temperatures of about 155°F in water discharging from a well near this locality.

KILBOURNE HOLE (27S.1W.8.000)

Kilbourne Hole is in southern Dona Ana County (Lee 1907, Reiche, 1940; De Hon, 1965). It is an oblong crater about 250 ft deep, 2 miles long, and 11/4 miles wide.

Lee (1907, p. 217) wrote:

> The valley filling is saturated with water below a depth of 100 feet beneath the bottom of the Kilburn crater, a level nearly corresponding with that of the river, as shown by wells sunk in various parts of La Mesa. The water obtained in the Kilburn crater is charged with hydrogen sulphide and has a temperature of nearly 100°Fahrenheit, 15° or more warmer than water from the same horizon in surrounding wells.

Reiche (1940, p. 217) wrote:

> Dr. W. M. Tucker states (personal communication) that Mr. J. F. Kilbourne, the owner informed him in 1930 that broken basalt was encountered in the bottom of two wells in Kilbourne Hole and that these wells were 180 and 173 feet deep, with water at 100°F rising about 70 feet.

The well was abandoned before Reiche did his field work.

Clyde Wilson's notes (personal communication, 1973) of a conversation with Jay Gardner, who ranches the area, mention that Mr. Gardner's father spoke of a very hot well that was drilled in Hunt's hole in 1902. Apparently neither the present well in Hunt's hole (27S.1W.9.000) nor the well in Philip's hole (27S.1W.26.413a) shows abnormal temperature characteristics.

FEDERAL "H" No. 1 (28.S.2W.24.213)

This well is a wildcat oil test drilled from October 10, 1961, to February 8, 1962, by the Pure Oil Company. The well had a total depth of 7346 ft. At a depth of 675 to 680 ft, water was struck that had a temperature of 113°F, according to unpublished data in the files of the U.S. Geological Survey. The well reportedly pumped 500 gpm of water from a limestone of Cretaceous age. One observer said this water discharged at temperatures as high as 180°F.

The analysis of the water given in table M8 is of a sample collected during the drilling operation. The water sample was muddy and foamy when collected, because it contained detergents and other drilling additives. The analysis is therefore only a suggestion of the probable water chemistry.

A drill stem test record for the internal 4354 to 4412 ft gives a temperature of 118°F. Bottom-hole temperatures from electric logs are as follows:

Depth (ft)	Temperature (°F)
3831	112
7345	158

MIMBRES RIVER BASIN

MIMBRES HOT SPRINGS (18S.10W.13.110)

These springs are in the south end of the Black Range on the south side of the Mimbres Mountains. They are 3 miles east of the Mimbres River in Hot Springs Canyon. Although they have served as a spa and were noted in 1879 by Birnie (p. 250), who gives their temperatures as 120°F, they have received only sporadic attention in the literature of geology and hydrology.

Peale (1886, p. 194) called them Ojo Caliente and listed them under Mineral Springs. Jones (1904, p. 311) copied Peale. Table 24 contains chemical analyses of water from these springs, reported by Hare and Mitchell (1912, p. 48-49). Apparently they sampled 9 of the springs in May 1904 and resampled 20 of them in June. Unfortunately, they did not report the particular spring from which each sample came.

These springs are not mentioned again until Bushman (1955, p. 6 and 14) and Elston (1957, p. 76-77) included brief references to them in their studies of ground water and geology and mineral resources of Dwyer quadrangle.

Bushman's work aimed at providing some basic ground-water information for Elston; consequently, the 2 reports contain some of the same information. Table M9 contains the chemical analyses made for Bushman.

Elston (p. 77) summarized: "Mimbres Hot Springs is a group of about 30 springs, with a combined flow considerably in excess of 100 gallons per minute. The springs lie in the Mimbres Hot Spring Fault zone. At the surface the country rock is Rubia Peak latite and Kneeling Nun (?) rhyolite."

Fig. 41 is a map of the premises showing the area of outcrop, springs and seeps, and the places at which the measurements reported in table 25 were made.

A sample for tritium analyses, collected at fig. 41, location 3, December 1965 measured 61± 8 tritium units.

Duke (1967) made a four-year (1963-1966) study of the ecosystem of one of the springs (fig. 41, location 8). She determined that the mean temperature of the water was 133°F, with temperature variation less than 11°F. The temperature of the water entering the pool varied only 5.4°F, and the average discharge was 2.8 gpm. The large and fairly frequent gas bubbles consisted largely of nitrogen; the water entered the spring free of oxygen (p. 9-32).

On December 5, 1974, the pH of the water discharging from location 3 (fig. 41) ranged from 8.3 to 8.75 and the temperature was 142°F. The specific conductance of the discharging water was 450 micromhos/cm (iimho/cm). Table 26 gives the heavy metals and radon-222 in the thermal water on that day.

Table 24 - Chemical analyses of water from Mimbres Hot Springs in 1904 (Hare and Mitchell, 1912, p. 48-49) (concentration ppm)

Date	Ca	Mg	Na	K	SO_4	Cl	CO_2	Total Solids	Hd	NC Hd
	3.6	2.1	57	1.6	47.6	17.7	116	340	0	16
	3.9	2.3	66	3.0	44.5	17.1	116	336	0	17.8
	4.3	1.9	65	3.1	54.6	15.9	110	334	0	14.3
	7.8	1.9	58	0	44.5	16.5	106	318	0	26.3
May	3.4	--	59	0	55.6	16.5	111	322	0	8.6
	4.4	--	56	0	48.2	17.7	110	314	0	11.1
	3.1	1.9	65	2.6	35.5	38.9	272	342	0	1.46
	11.0	5.4	133	4.0	0	2.3	314	708	0	46.3
	3.7	1.6	65	1.6	36.6	17.1	106	350	0	18.0
June	6.9	--	57	5.6	51.5	16.5	79	336	0	17.5
	5.6	--	61	6.8	55.1	171	59	340	0	14.3

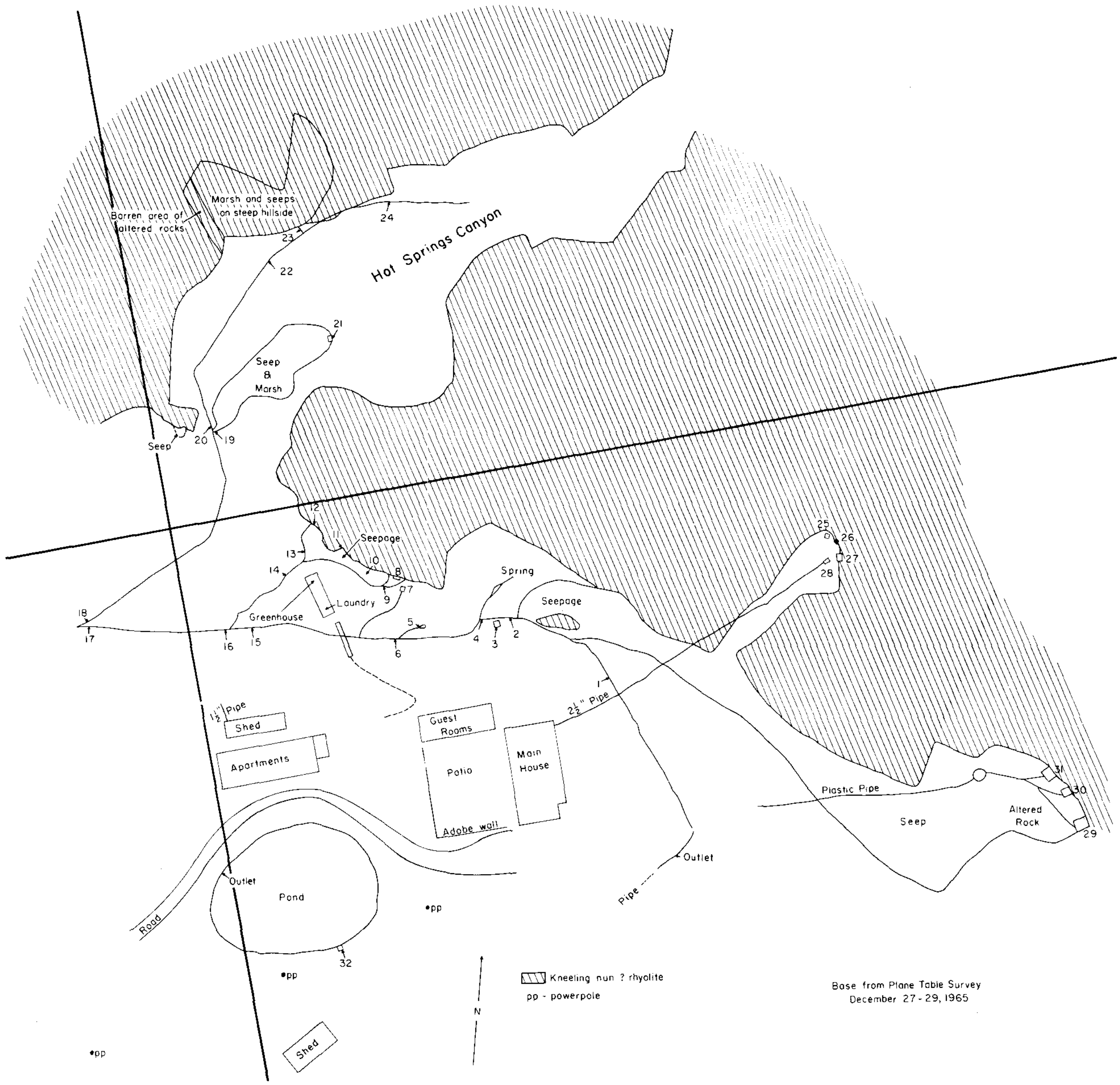


FIGURE 41—MAP OF THE PREMISES OF MIMBRES HOT SPRINGS, GRANT COUNTY, SHOWING THE PLACES AT WHICH SAMPLES WERE COLLECTED AND MEASUREMENTS MADE, DECEMBER 1965.

The rock from which the water discharges appears in hand specimen to be rhyolite and rhyolite porphyry with biotite and sanidine. A thin section showed that the rock is a lithic crystal tuff with approximately equal proportions of groundmass and fragment. The groundmass consists of glass, 25 percent; limonite, 12 percent; calcite, 10 percent; and opaque minerals, 3 percent. The fragments include sanidine, 15 percent; andesine, 27 percent; quartz, 4 percent; and biotite, 6 percent. Accessory minerals included 3 percent magnetite, 5 percent zircon, and a trace of sphene.

The rock has 3 prominent sets of joints striking roughly NW, N-S, and NE, which are dominantly vertical. Some of these fractures can be traced for several feet on the outcrop.

FAYWOOD HOT SPRING (20S.11W.20.243), KENNECOTT WARM SPRINGS (20S.11W.18.310), AND APACHE TEJO WARM SPRING (19S.12W.19.300)

These springs are in south-central Grant County near the City of Rocks State Park (fig. 42), 4 to 15 miles from the Mimbres River in a region where streams flow only during and immediately after rainstorms. Of the 3, Faywood Hot Spring has received the most attention by geologists and hydrologists. Apache Tejo and Kennecott Warm Springs no longer flow, because wells have been drilled to intercept the spring flow and deliver it to the Kennecott mill at Hurley.

Table 25 - Field data for Mimbres Hot Springs, December 29, 1965

Location Fig. 50	Discharge (gpm)	Temperature (°F)	pH	Specific Conductance (micromhos)	Density gm/ml	H_2S ppm	NH_3 ppm	SiO_2 ppm	Remarks
1	2.0	49	8.1	280	---	odor	---	---	
2	12.3	92.8	8.1	370	---	---	---	---	
3*	---	top 143.5	Concrete box over spring, depth of water 4 feet.						
		bottom 144.3							
		dischg. 144.1	8.6	400	.972	---	0	44	132.6, 6-5-52+
4	46.7	131.6	8.4	390	---	---	---	---	
5	almost zero	139.5	8.7	250	---	---	---	---	
6	72.7	129.0	8.4	430	---	---	---	---	
7	---	123	8.3	390	---	---	---	---	
8	0	139.0	8.4	410	---	---	---	---	135.5°F, 6-5-52+
9	1.1	---	---	---	---	---	---	---	
10	---	135.5	8.9	370	---	---	---	---	134.1°F, 6-5-52
11	---	134.9	8.5	400	---	---	---	---	
12*	---	133.5	8.2-8.4	350	.978	0	0.1	41	
13	1.1	---	8.7	---	---	---	---	---	
14	13.5	---	8.8	---	---	---	---	---	
15	76.3	123.2	8.6	400	---	---	---	---	
16	95.4	117.5	8.5	430					
17	93.0	115.5	8.7	410	---	---	---	---	
18	68.7	74.5	8.8	300	---	---	---	---	
19	1.1	75	9.3	310	---	---	---	---	Air = 59°F
20	49.8	63.1	8.4	450	---	---	---	---	
21*	---	132.5	---	---	---	---	---	---	at 6 foot depth
	---	131	8.5-8.7	460	.974	0	0.1	43	at surface
22	49.8	62.0	---	430	---	---	---	---	
23	2.6	130	8.0	370	---	---	---	---	
24	1.1	52.5	7.7	340	---	---	---	---	
25*	---	138.2	8.5	300	.974	0	0.1	31	at surface
	---	139.5	---	---	---	---	---	---	at 3-foot depth
26	---	136.5	8.3	430	.976	---	---	---	at surface
	---	137.5	---	---	---	---	---	---	at 3-foot depth
27	---	138.7	8.6	410	.976	---	---	---	at surface
	---	139.0	---	---	---	---	---	---	at 3-foot depth
28	---	136.5	---	---	---	---	---	---	136.9, 6-5-53+
29	---	71.1	8.7	260	---	---	---	---	29-31 are 79°, 6-9-52+
30*	almost zero	65.1	9.0	370	.988	---	0.2	40	
31	almost zero	72.1	8.9	270	.996	---	---	---	
32*	---	113.6	---	390	.980	---	0.15	36	

* Water sample site

\+ Bushman, F. X. Notes on file New Mexico Bureau Mines & Mineral Resources

In 1851, Bartlett (1856, p. 225) visited the Faywood Hot Springs. He wrote:

> This spring lies within a crater-like opening, twenty feet in diameter, on the top of a mound of tufa about six hundred feet in circumference at its base, and about thirty feet high, all of which seems to consist of the deposits made by its waters. The temperature of the water was 125°F. Its surface was some six or seven feet below the rim of the basin; and its depth I judged to be about the same. Dr. Webb collected the gas which bubbled up from the bottom, and found it to be neither hydrogen nor carbonic acid gas. He consequently judged it to be atmospheric air. The water was not unpleasant to the taste, and would be palatable if cooled. Lower down, upon one side of the hill, a small spring burst out, and at a short distance, where it collected in a pool, the water was cool enough to bathe in; but even there I found it literally a hot bath.

Gilbert (1875, p. 152) listed the temperature of Faywood Hot Spring as 130°F and Apache Tejo as 97°F.

Birnie (1879, p. 250) referred to Faywood Hot Spring as "the Hot Spring of Southwestern New Mexico"; he said only that the temperature was "very high." He then gave the temperature of Apache Tejo as 89°F and of

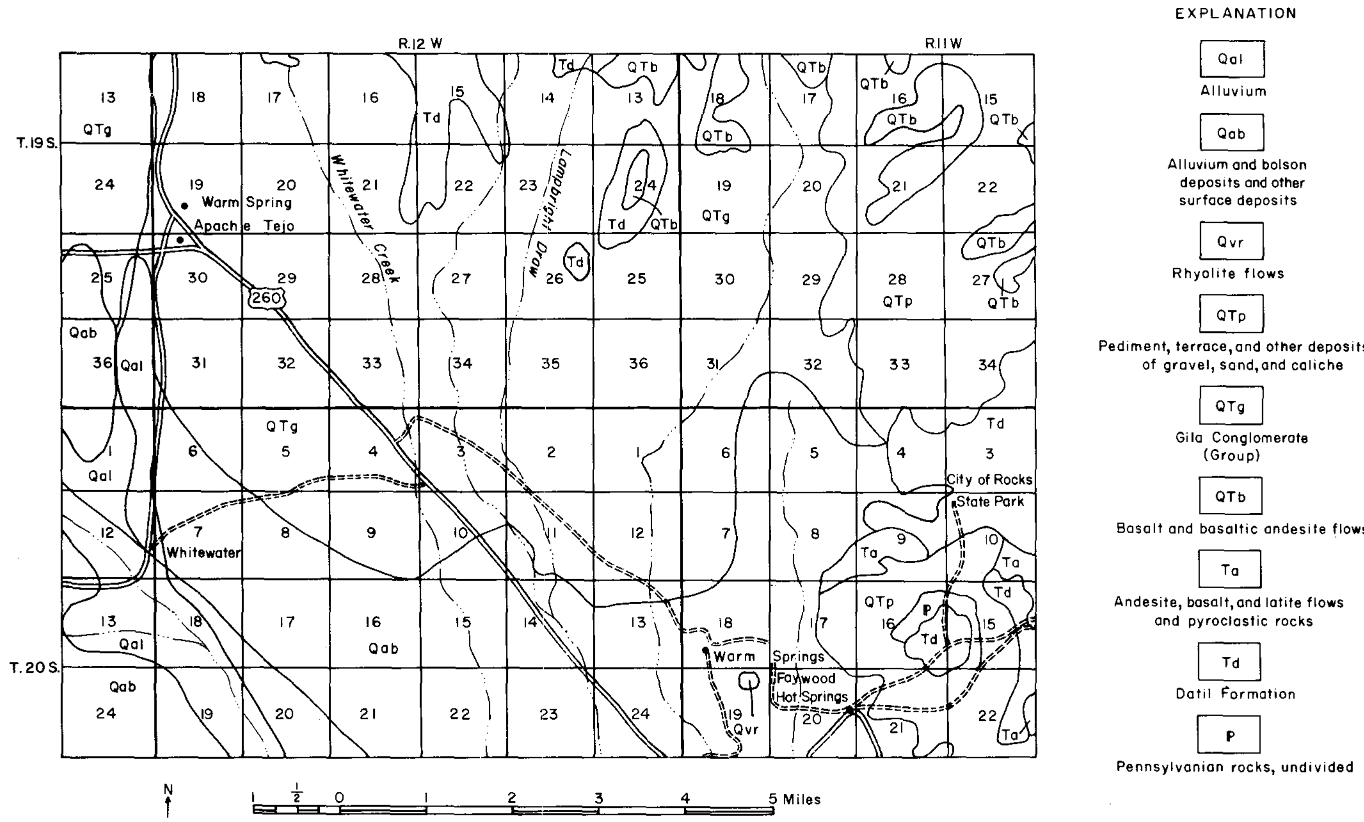


FIGURE 42—GEOLOGIC MAP OF THE FAY WOOD HOT SPRINGS, KENNECOTT WARM SPRINGS, AND APACHE TEJO WARM SPRINGS AREA, GRANT COUNTY (DANE AND BACHMAN, 1961).

Kennecott Warm Springs as 150°F. Apparently he confused Kennecott Warm Springs and Mimbres Hot Springs and relied on hearsay for their temperatures.

Powell and Kingman's (1883) maps of southwestern New Mexico showed the Faywood Hot Spring but called it Hudson's Hot Springs.

Peale (1886) listed Apache Tejo at 89°F and Hudson's Hot Springs, a resort on a warm spring (Kennecott) near Hudson, at 150°F.

Wheeler (1899, p. 122) quoting Birnie (1879, p. 250), gave temperatures as Faywood, 150°F; "Apache, Idaho," 89°F; and Kennecott Warm, 120°F.

In 1899 Crook, (p. 333-334) writing of Hudson Hot Springs, said, "The flow of water from these springs has not been measured but it is sufficient to irrigate eight acres of land." He also stated the temperature as 142°F and gave the following chemical analyses made by Professor W. D. Church:

One U.S. gallon contains:

Solids	Grains
Silica	1.55
Oxide of iron and alumina	0.50
Calcium carbonate	4.45
Magnesium carbonate	2.62
Soluble sulphates and carbonates of sodium and potassium	13.55
Sodium chloride	2.27
Total	24.94

Jones (1904, p. 295-298) discussed Faywood Hot Spring at length. He gave the temperature as 142°F and the discharge as 100 gpm. He also noted that in 1893 a large pump was installed, the water level lowered, and the sides cemented. He gave the following chemical analysis, made by Professor Arthur Gross, chemist, New Mexico College of Agriculture and Mechanic Arts, Mesilla Park:

Components	Grains
Lime (Ca)	4.50
Magnesia (MgO)	1.46
Soda (Na_2O)	11.17
Potassa (K_2O)	1.52
Iron and Alumina (Fe_2O_3, Al_2O_3)	1.28
Silica (SiO_2)	4.10
Sulphates (SO_3)	4.21
Carbonates (CO_2)	9.98
Chlorides (Cl)	1.77
	39.99
Less oxygen equivalent of Cl	0.40
Total solids	39.59

Paige (1916, p. 19) made the first comment about the geology of the springs. He wrote:

> The warm springs that occur at intervals from Apache Tejo to Faywood Warm Springs produce a large volume of water of underground origin. These springs lie along a northwestward trending fault plain and the high temperature of their water indicates that they rise from a considerable depth, presumably along a fault. At Apache Tejo the Chino Copper Company has dug a deep pit along the principal origin of these springs and has developed a greatly increased supply, now estimated at about four and a half second feet. This water is pumped primarily for use in the concentrator.

The next reference to these is that of Stearn, Steam, and Waring (1937, p. 169), who listed both Faywood Hot Spring and Hudson's Hot Springs, confusing Faywood Hot Spring and Kennecott Warm Springs. They also listed Apache Tejo Warm Springs as discharging 2000 gpm at 97°F. Waring (1965, p. 38) repeated this list.

Bushman (1955, p. 12 and 15) estimated the flow at Faywood Hot Spring as 5 to 10 gpm at a temperature of 129.2°F. Elston (1957, p. 76) repeated Bushman's data and also wrote:

> Faywood Hot Springs is a single spring, although other hot springs are known in the vicinity . . . The surrounding country is covered by gravels; hence the structural setting is unknown. The spring is within a mile of the Blue Mountain fault and the Faywood Rhyolite dome. The volcanic rocks beneath the gravels are believed to be relatively thin and probably lie on Paleozoic Limestone.

Fred Trauger, U.S. Geological Survey, collected water samples from Faywood Hot Spring and estimated the flow as 50 gpm at 128°F on November 11, 1954, and April 19, 1957. His 1957 sample was analyzed for radioactivity with the following results: beta-gamma activity, 19 picocuries/liter (ppC/1); radium, 29 /42C/1; and uranium, 0.1 ppb (Scott and Barker, 1962, p. 79).

Table 20 gives the measurements made at Faywood Hot Spring on December 26, 1965, and December 5, 1974. Table 26 gives the heavy metals and radon-222 in a water sample obtained December 5, 1974. The water discharged from the top of the calcareous tufa mound; the crater in the center of the mound averaged 10 ft in diameter. The depth of this circular crater is unknown, but it is at least 18 ft below the concrete curb, because the underwater sampler used to sample this spring in 1965 could be lowered easily only to 18 ft; greater penetration was not possible. The temperature of the water was uniform throughout. Table M9 contains several chemical analyses of water from Faywood Hot Springs. Table 26 gives the heavy metals and radon-222 concentrations in a sample collected December 5, 1974.

Two analyses for tritium were made of the water from Faywood Hot Spring. The first, collected on May 1, 1957, measured 3.2-m.3 tritium units (von Buttlar, 1959, p. 1037). The second, collected December 29, 1965, measured 70 $^{-}$--^{1}= 8 tritium units.

Kennecott Warm Springs are so called in this report because the Kennecott Copper Company now owns them. A number of wells surround the old spring site, so it no longer flows.

Because so many wells have been drilled, a good deal of information about the subsurface geology has been obtained. Fig. 43 shows the wells and test wells that have been drilled. Table 27 summarizes the data on the Kennecott Warm Springs test wells. Fig. 44 gives the bottom-hole temperature observed as the wells were drilled. The temperature observed seems to be independent of discharge rate, specific conductance, and position and number of slots in the casing.

The spring discharged from rhyolite. Well 7 penetrated solid rhyolite over its entire depth; well 4 penetrated rhyolite from 200 to 292 ft. Table M9 gives chemical analyses of samples from wells 3, 11, and 12. Table 26 gives the heavy metals observed in samples from wells 3 and 11.

The driller's log of well 3 gave simply 0 to 223 ft of brown conglomerate. The driller's log of well 4 showed adobe, 0 to 20 ft; sand and gravel, 20 to 115 ft;

Table 26 - Heavy metals and radon-222 in thermal water of the Mimbres River basin
(all concentrations except radon-222 in ppb)

	Mimbres Hot Spring (fig. 42)		Faywood Hot	Kennecott Warm Springs		Apache Tejo
	Loc. 8	Loc. 3	Springs	Well #3	Well #12	Well #4
Date	?	12-5-74	12-5-74	5-17-72	5-17-72	5-17-72
Copper	+	10.5	20.5	170	160	20
Cobalt	--	--	--	--	--	--
Chromium	--	1	11.7	<10	<10	<10
Cadmium	--	.1	.14	5	<7	<5
Lead	+	7	7	60	<50	<50
Molybdenum	--	≃30	≃20	--	--	--
Nickel	--	--	--	<50	<50	<50
Zinc	--	34	10	<30	130	110
Mercury	--	<1	<1	2	<.2	<.2
Silver	--	--	--	<20	<20	<20
Tin	+	--	--	--	--	--
Radon-222 (picocuries/liter)	--	2100	5600	--	--	--
Source	(1)					

+ = presence indicated by
(1) Qualitative spectrographic analyses by Richard Miller (Duke 1967, p. 9)

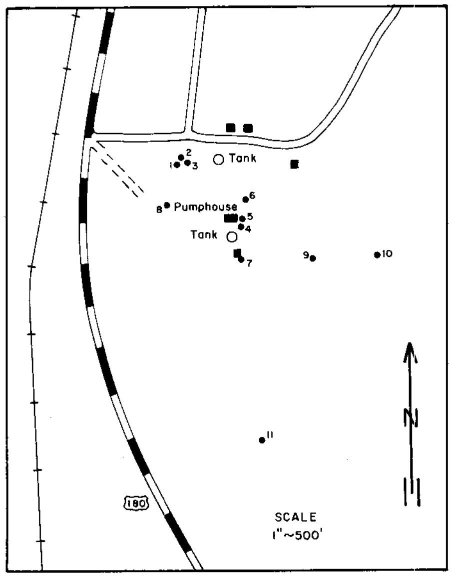


FIGURE 43—MAP SHOWING THE LOCATIONS OF WELLS AT KENNECOTT WARM SPRINGS.

conglomerate, 115 to 200 ft; and rhyolite, 200 to 292 ft. The driller's log of well 8 reported alternative intervals of sand, conglomerate, and rhyolite. The driller's log of well 11 reported only sand and conglomerate with some clay.

Although several people mapped the Santa Rita mining area to the north in detail and Elston (1957) mapped the Dwyer quadrangle to the east, the immediate area of Kennecott Warm Springs and Apache Tejo have been mapped only in the most general fashion by Paige (1916, 1932).

He included the rock at Kennecott Warm Springs in his rhyolite or latite lava flow unit, which is of Tertiary age. He mapped the surrounding consolidated material as sand and gravel of Quaternary age.

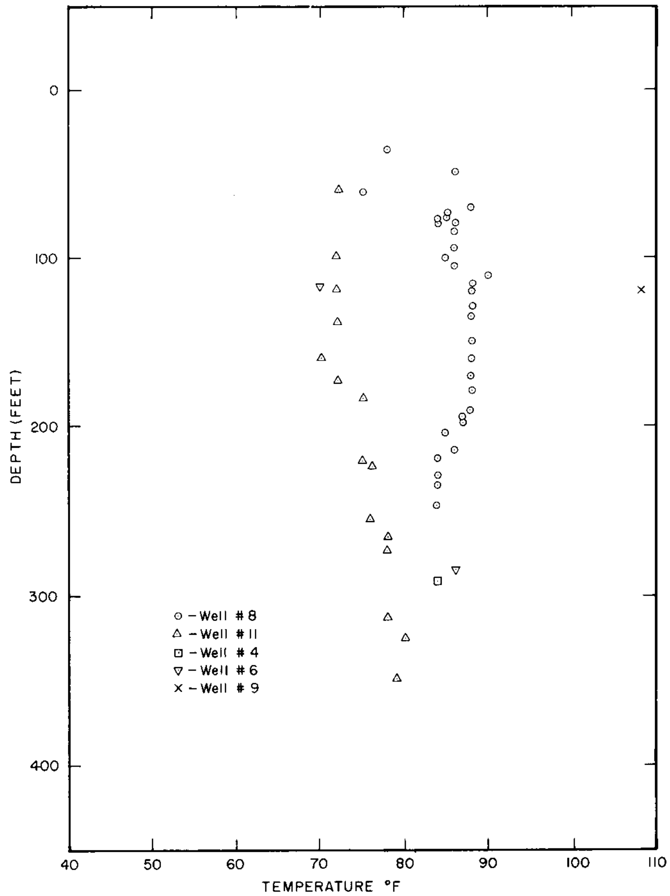


FIGURE 44—BOTTOM-HOLE TEMPERATURES OBTAINED AS WELLS WERE DRILLED AT KENNECOTT WARM SPRINGS.

Although the water-level data were not obtained for the purpose of drawing a water table or piezometric surface and were less than ideal for such purpose, a plot of these data showed that the piezometric surface slopes

Table 27 - Data for wells at Kennecott Warm Springs

Well number Figure 53	Total depth of hole (ft.)	Casing slotted (ft.)	Water level (ft.)	Date	Specific capacity (gpm/ft)	Temperature (°F)			pH
						Bottom hole	Initial pumping	3-1-66	3-21-66
1*	25	---	3	June 1950	92	---	92	---	---
2*	44	12-44	8	June 1950	49	---	94	---	---
3	223	15-180	6	Nov. 1950	43	---	94	94.1	7.4
4*	292	---	18		---	87	---	---	---
5	167	135-167	14	Aug. 1951	---	---	---	---	---
6	400	20-288	24	Feb. 1953	6	86			
7*	39	---	28		0	---	---	---	---
8	247	58-209	26	Nov. 1951	---	84	---	---	---
9	120	0-108	73		---	106	---	---	---
10	184	18-177	18		---	---	71	---	---
11	350	40-250	14	Apr. 1962	31	80	---	74	7.4

* destroyed

to the south and also suggested that the slope of the piezometric surface at the spring is steeper than the slope either north or south of the springs.

Bottom-hole temperatures suggest that the area of heat anomaly is significantly larger than the anomaly indicated by discharging water temperature.

A pumping test on well 3 (September 27, 1950, to January 14, 1951) was not susceptible to conventional analysis because of the uncertainty of the boundary conditions. However, it did show that the transmissivity of the aquifer ranged from 5000 to 30,000 gpd/ft. The yield of the wells ranged from about 50 to more than 1000 gpm.

Development of Apache Tejo Warm Springs by the Kennecott Copper Company began before 1916 (Paige, 1916). By 1965, 11 wells had been drilled, 5 of which

Description	Depth (ft) From	To
Alluvial sand and gravel	0	157
Magdalena Group: limestone and shale	157	776
Lake Valley Limestone	776	845
Percha Shale	845	1071
Fusselman and Montoya dolomites and El Paso Limestone	1071	2229
Bliss Formation	2229	2432
Precambrian granite	2432	2445

Well 7 was also drilled to the Percha Shale and the remaining wells were drilled into the limestone of the Magdalena Group, which yielded water from solution channels. The drillers report cavities in every well where bits dropped 4 to 10 ft. Wells 4 and 7 are now open only in the Magdalena Group limestone.

The net yield of the system ranges from 1000 to 3000 gpm. Water levels in the available wells are so influenced by pumpage that no estimate could be made of the slope of the piezometric surface in the region of the wells.

WELL (19S.12W.12.000)

E. Boone, a well driller, sent me the following log of a well he drilled in 1967

Depth (ft) From	To	Description
0	50	Brown conglomerate and boulders
50	100	Brown sandy clay
100	115	Red sandy clay
115	120	Yellow sandstone
120	130	Yellow hard rock
130	260	Red rhyolite
260	290	Red clay
290	305	Rhyolite
305	370	Hard rhyolite
370	380	Sandstone
380	400	Red rhyolite
400	450	Blue rock
450	520	Red rhyolite

The depth to water was 120 ft. Mr. Boone reported the temperature of the discharging water as 144°F.

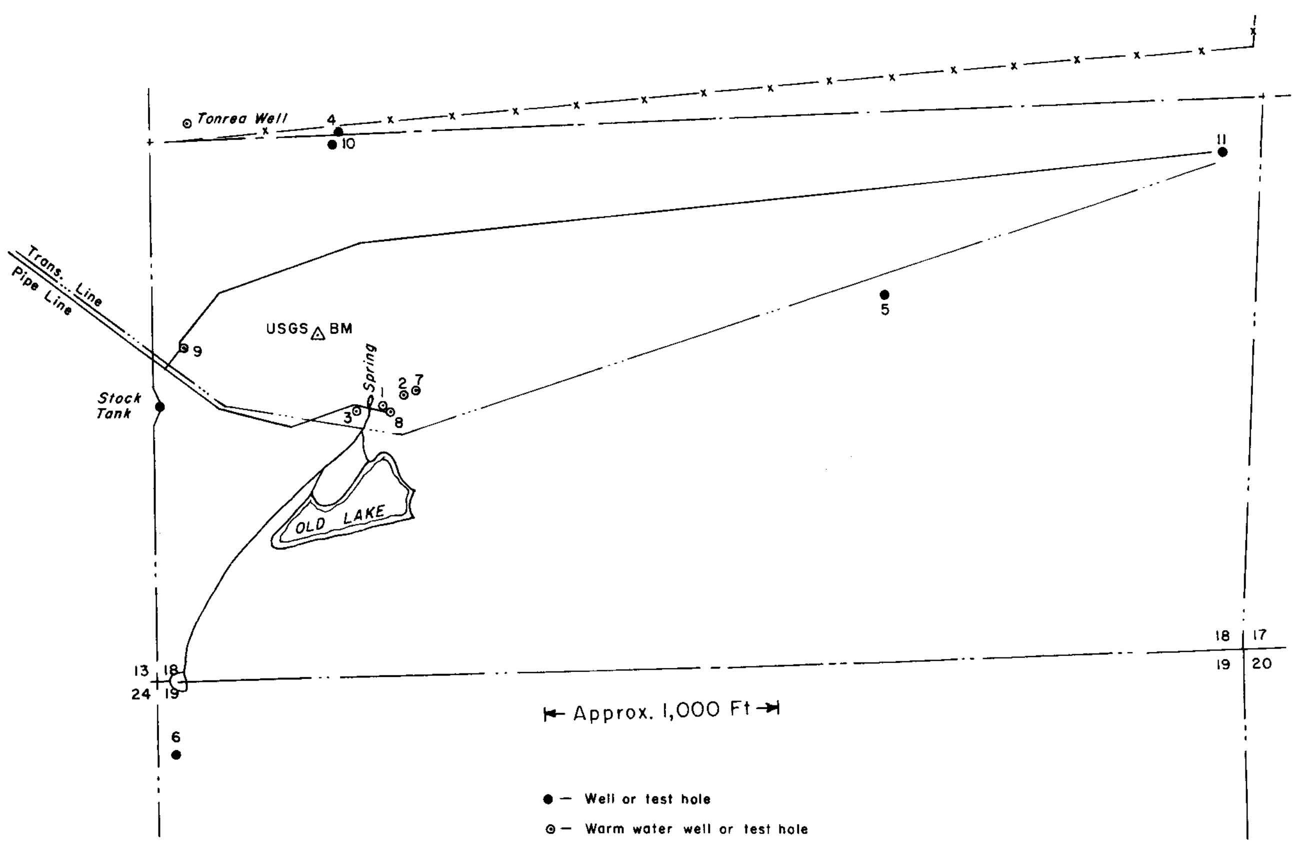


FIGURE 45—Map showing location of wells at Apache Tejo Warm Springs.

Well (24S.7W.5.100)

Table M9 gives a chemical analysis of water from this well. According to U.S. Geological Survey, Water Resources Data for New Mexico (1969, p. 202), the well is 1110 ft deep and discharging water has a temperature of 102°F.

PLAYAS LAKE BASIN

An oil test (Humble Oil and Refining No. 1 State AB [32S.16W.25.210]) was drilled to a depth of 14,585 ft on the western edge of the Big Hatchet Mountains (the eastern edge of the Playas valley) in southern Hidalgo County. The well penetrated a thick sequence of sedimentary rocks averaging in age from Lower Cretaceous to Ordovician, which Zeller (1965, p. 116-119) discussed in detail. Two significant reverse faults were crossed, one at about 3310 ft, the other at 14,120 ft. Igneous rocks were drilled at 11,180 to 11,198 and 14,192 to 14,218 ft.

Bottom-hole temperatures obtained from electric logs made as the well was being drilled are as follows:

Depth (ft)	Temperature (°F)
1,600	106
5,340	115
10,875	155
14,578	320

The first 3 measurements suggest a normal geothermal gradient of 1.8°F/100 ft of depth. The temperature of 320°F is therefore more than 100°F higher than would be predicted.

Pecos River Basin

Montezuma Hot Springs (17N.15E.36.440) are the only thermal springs in the Pecos River basin. These springs have been studied repeatedly. Hayden (1869, p. 64) wrote:

> The hot springs are most beautifully located in the valley of Gallinas Creek, just as it emerges from the mountains on the south side. The springs are twenty or thirty in number, and some of them are quite large. They vary in temperature from 80° to 140°. The spring from which the water is taken for the bath is quite hot, at least 140°. The supply is very abundant, enough to meet the demand for all time to come. There is no deposit about the spring, and the water is as clear as crystal. It was analyzed by Mr. Frazer, and found to contain carbonate of soda, carbonate of potash, and chloride of sodium, the potash in excess.
>
> It will be seen at once upon what its medicinal qualities depend. Every day in the week all the springs are occupied by women, in washing clothes. The water makes most excellent suds, and the ease with which the dirt is extracted from the clothes renders these springs great favorites. There is every facility for the proprietors to establish a place of resort for invalids and pleasure-seekers, when there shall be a sufficient demand.
>
> The temperature of these springs ranges from 90° Fahr. to 130° Fahr.
>
> No. 1. Temperature, 130° Fahr.; basin, six feet deep, five feet long, four feet wide; taste, weak saline; no odor observable; bubbles of carbonic acid constantly rising; yield, about fifteen gallons per minute.
>
> No. 2. Temperature, 123° Fahr.; basin, three by three and a half feet.
>
> No. 3. Temperature, 100.5° Fahr.; basin, two by three feet. No. 4. Temperature, 123° Fahr.; basin, two and a half by one and a half feet.
>
> In 100,000 parts of water are contained parts as follows:

Sodium carbonate	1.72	1.17	5.00
Calcium carbonate	––	––	––
Magnesium carbonate	9.08	10.63	11.41
Sodium sulfate	14.12	––	16.27
Sodium chloride	27.26	24.37	27.34
Potassium	Traces	Traces	Traces
Lithium	Strong traces	Strong traces	Strong traces
Silicic acid	1.04	Traces	2.51
Total acid constituents	53.22	52.10	62.53

Loew (1875b, p. 110) noted that ". . . the percolating mineral water, which contains besides sulphate, carbonate, and chloride of sodium, a trace of sulphurated hydrogen—a trace so small, however, that it is hardly perceptible by odor. . . ."

Stevenson (1881, p. 350) wrote, "The Las Vegas Hot Springs are at the foot of the Archean exposure, close to its junction with the carboniferous. There are twenty-two of them, the greater number being found on the south side of the creek."

Crook (1899, p. 334) wrote:

> These springs are situated upon the southeastern slope of the Santa Fe range of the Rocky Mountains at an altitude of 6767 feet above the sea-level. They are about forty in number, and vary in temperature from ice-cold to very hot, the thermal springs ranging from 110°F to 140°F. The final analysis of the waters of the largest of the latter, flowing 1250 gallons per hour, was made by Dr. Walter S. Haines, Professor of Chemistry at Rush Medical College, Chicago.
>
> Spring No 6 (Las Vegas Hot Springs)
> Saline
>
> One U.S. gallon contains:

Solids	Grains
Calcium carbonate	0.89
Magnesium carbonate	0.15
Sodium carbonate	8.38
Potassium carbonate	0.28
Sodium sulphate	3.35
Sodium chloride	14.68
Silica	3.50
Alumina	0.10
Volatile and organic matter	0.32
Lithium carbonate	Traces
Sodium bromide	Traces
Total	31.65

In more or less detail these observations have been repeated many times (Stevenson, 1881, p. 405-406; Peale. 1886, p. 194-195; Jones, 1904, p. 298-299; Lindgren, Graton, and Gordon, 1910, p. 71; Stearns, Stearns, and Waring, 1937, p. 168; and Waring, 1965, p. 37).

Hare and Mitchell (1912, p. 56-57) gave the following chemical analyses of a water sample collected during November 1910:

Constituent	Concentration (ppm)
Calcium (Ca^{++})	59.
Magnesium (Mg^{++})	16.
Sodium (Na^{+})	9.5
Carbonate ($CO_3^{=}$)	65.
Sulphate ($SO_4^{=}$)	55.
Chloride (Cl^{-})	24.
Total solids	279.

From 1939 to 1952, the U.S. Geological Survey. collected samples (table M10) intermittently, and reports in their files showed the following:

Probable location [fig. 46]	Date	Temp. (°F)	Flow (gpm)
1	7-2-40	>130	––
6	3-11-52	123	5
13	3-11-52	106	<1

Results of steam flow measurements made by the U.S. Geological Survey during February 1966 at map location 24, fig. 46 and at the gaging station downstream showed the following:

Site	Discharge (cfs)	Air Temp. (°F)	Water Temp. (°F)
24	0.42	28	33
gaging station	1.10	29	41

Assuming the difference to be due entirely to inflow at the springs, the spring flow was 325 gpm.

Figure 47 shows the geology in the vicinity of Montezuma Hot Springs. The water discharges from fractured granite of Precambrian age. The granite ranges from a quartz-plagioclase pseudogranite to a potash-rich granite containing hornblende. A thin section of one specimen contained 54 percent orthoclase, 4 percent microcline, 3 percent albite, 31 percent quartz, 2 percent biotite, 1 percent opaques, and 3 percent alteration clays.

Four sets of fractures are apparent in the granite, E-W to N. 24° W., N. 52° W. to N. 59° W., N. 75° W. to N-S, N. 23° E. to N. 38° E. The most pronounced fractures dip westward 44 to 80 degrees. A few fractures dip east 32 to 58 degrees. Several small faults are evident in the immediate area of the springs. A major fault occurs approximately a mile east of the spring.

On the slopes above the springs are limestone and sandstone of Pennsylvanian age. Figure 47 shows the geology in the vicinity of Montezuma Hot Springs. Baltz (1972) mapped the geology of the Gallinas Creek area at a scale of 1:24,000.

Table 28 - Field data for Montezuma Hot Springs, February 4, 1966

Location Fig. 56	Depth to water below land surface (feet)	Depth (ft)	Discharge (gpm)	Temperature (°F)	pH	Description
1*	3	3	---	130.1	8.8	A circular stone and brick well which extends 1-1/2 feet above the general land surface and has an internal diameter of 2-1/2 feet
	---	10	5.8	131.2		
	---	20	---	131.2		
	---	21	---	131.3		
2*	---	---	4.5	100.5	8.2	End of a 1-1/4 inch discharge pipe which probably delivers water from location 3 and a concrete covered well to which there is no access
3	3	3	---	129.5	---	A circular stone and meter lined well whose top is at the average land surface
	---	10	---	130.5		
3a	---	---	.5	---	8.6	Concrete covered well, no access
4	0	0	.5	77-78	---	Concrete through, averages 2 feet deep
	0	2	---	---		
4a	---	---	---	---	8.5	Concrete covered well to which there is no access, pH is of seepage
5	---	7	---	55	---	A circular stone and mortar lined well, partially filled with debris
6*	0	---	---	---	---	A concrete reservoir which ranges from 0 to 6 feet above the land surface and is dug into a steep slope. Its depth is about 11 feet
7*	0	1	4.5	71.3	8.2	A rock lined cavity covered with a rectangular stone slab with limited access
8	1	1	---	80.5	8.3	A partly destroyed stone well, whose top is at the land surface
	---	2	---	83.6	---	
9	---	---	3.2	43	8.2	End of 8 inch pipe which brings water from under the road
10	0	3	0	48.0	---	A square concrete and stone well
11	---	---	.1	39.2	---	End of 6 inch pipe which trickles water from under road
12*	---	---	.1	42.0	---	End of 2-1/2 inch pipe which trickles water from under road
13*	1/2	1/2	---	124.1	---	A concrete lined well which extends 3 feet above the general land surface
	---	6	---	124.0	---	
14	0	---	---	84	---	A concrete and stone well which receives discharge from loc. 15 and also discharges water itself into the seepage zone below
15*	2	2	---	51.5	8.4	A concrete and stone well which is full of rubble, depth indeterminable. Temperature of the discharging water 103.1°F
16*	0	0	3.2	108.7	8.9	A break in a wooden pipeline carrying water from map location 13
17	3	4	---	50	---	Well inside an old foundation, about 10 feet above Gallinas River

Table 28 - Field data for Montezuma Hot Springs, February 4, 1966 (cont.)

Location Fig. 56	Depth to water below land surface (feet)	Depth (ft)	Discharge (gpm)	Temperature (°F)	pH	Description
18*	0	0	2.0	125.0	7.9	Undeveloped spring
19*	---	---	5.2	117.3	8.3	Discharge pipe from concrete block reservoir. This reservoir supplies the seminary with water
20*	1	1	---	119.5	7.5	A small well
	---	6	---	120.5	---	
25	3.5	3.5	---	113.0	---	
	---	10	---	114.0		
	---	20	---	117.1		
	---	30	---	119.4		
	---	40	---	120.6		
	---	50	---	122.7		12 inch diameter well
	---	60	---	126.5		
	---	70	---	128.1		
	---	80	---	129.5		
	---	90	---	133.2		
	---	100	---	136.9		
	---	115	---	137.1		
26	4	5	---	42	---	6 inch diameter casing
27	---	---	---	---	---	Ice common on Gallinas River above this point
28	---	---	---	34.2	---	Gallinas River
29	---	---	---	33.8	---	Gallinas River
30	---	---	---	33.5	---	Gallinas River
31	---	---	---	39.0	---	Gallinas River
32	---	---	---	48.5	---	Gallinas River
33	---	---	---	48.8	---	Gallinas River
34	---	---	---	49.3	---	Gallinas River
35	---	---	---	49.6	---	Gallinas River
36	---	---	---	52.0	---	Gallinas River
37	---	---	---	55.0	---	Gallinas River
38	---	---	---	55.0	---	Gallinas River
39	---	---	---	56.0	---	Gallinas River
40	---	---	---	61.0	---	Gallinas River
41	---	---	---	106.0	---	
42	---	---	---	81.8	8.4	
43	---	---	---	67.5	7.9	
44	---	---	---	60.0	---	
45	---	---	---	94.0	---	
46	---	---	---	78.0	---	

* Chemical analyses in Table M10.

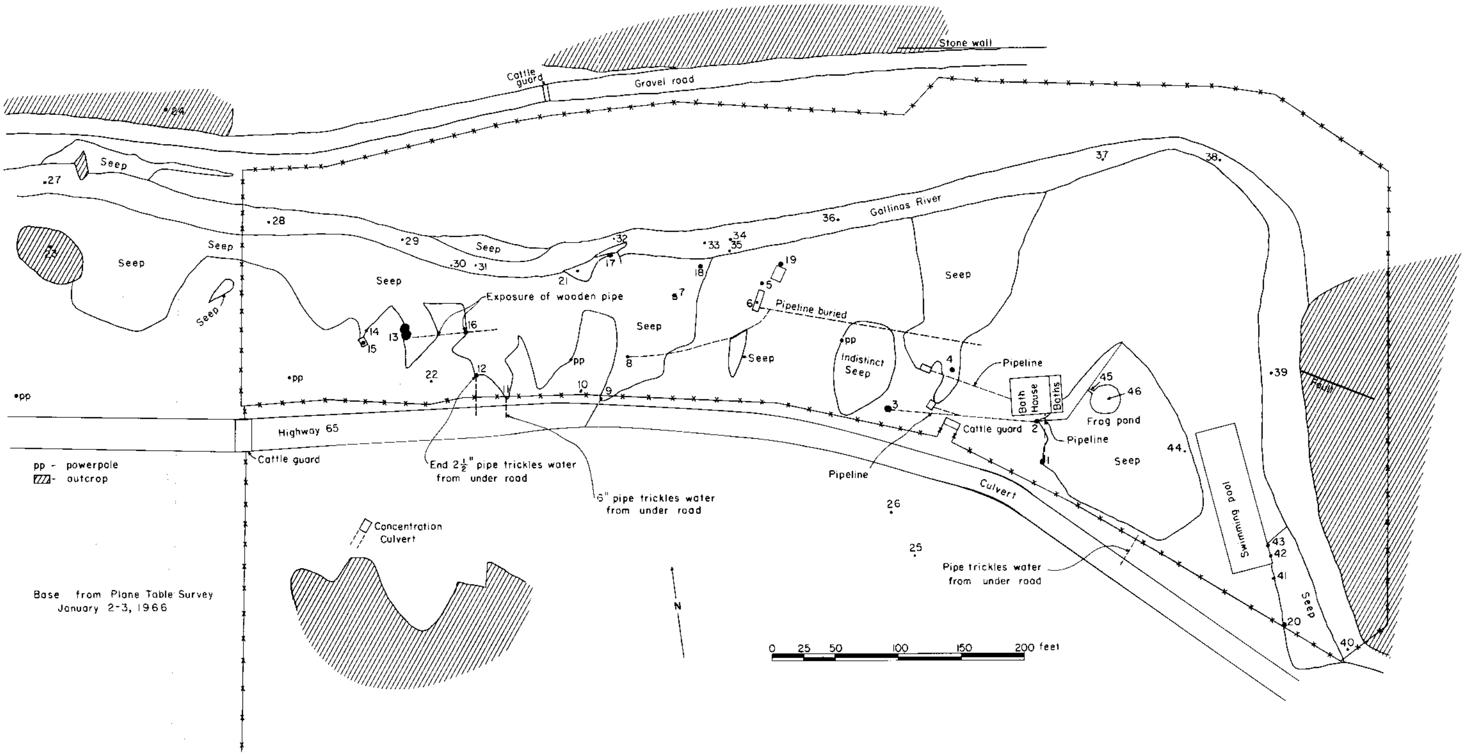


FIGURE 46—MAP OF THE PREMISES OF MONTEZUMA HOT SPRINGS, SAN MIGUEL COUNTY, SHOWING THE LOCATIONS AT WHICH SAMPLES WERE COLLECTED AND FIELD MEASUREMENTS WERE MADE IN JANUARY AND FEBRUARY 1966.

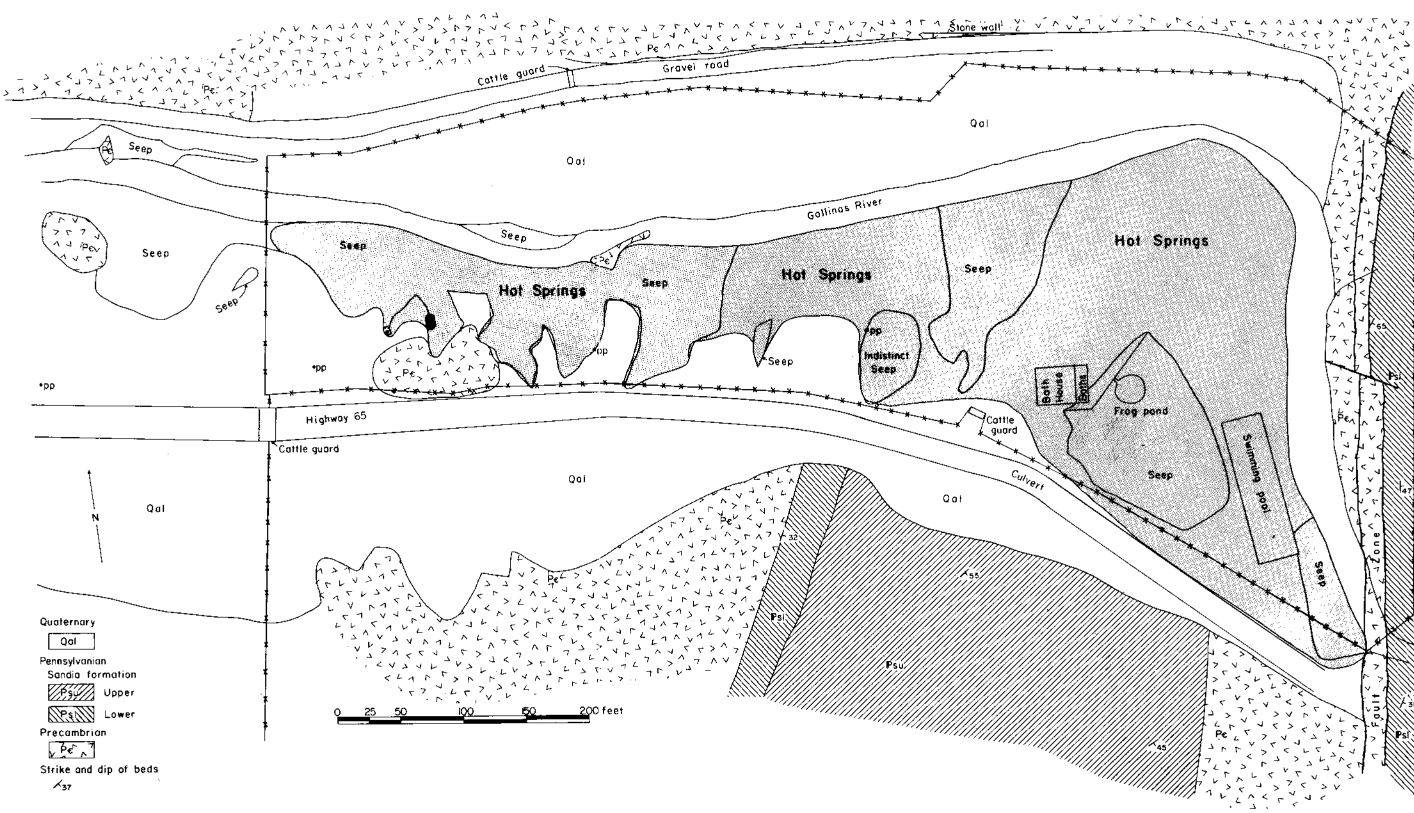


FIGURE 47—GEOLOGIC MAP OF THE MONTEZUMA HOT SPRING PREMISES.

Tularosa Basin

The Garton well (18S.8E.5.144) is in the Tularosa Basin on the White Sands National Monument grounds, about a mile east of the Sands themselves. It was drilled as an oil test before 1929, but the exact date is not known. This well flows naturally at the surface.

In a letter dated June 5, 1965, Donald A. Dayton, Superintendent of the White Sands Monument, said,

> The hole had a 15 inch, a 10 inch, and an 8 inch casing at the surface in 1937. In July 1937, the casings were broken when an attempt was made to pull the casings. The casing was evidently offset at the break. Cratering occurred and the project of relining the well was abandoned. A copy of the log is attached.
>
> The flow is said to have been 1100 gallons per minute initially. An estimate in 1937 placed the rate of flow at ten to twenty gallons per minute. We suspect the present rate is about half of that figure. It is sufficient to maintain two acres of open lake and several acres of marsh.
>
> In 1937 the temperature of the water was reported as 96°F. A measurement at the well head earlier this year gave a reading of 92°F.

The driller's log by George E. Moffett follows:

0-783	Valley fills, clays and gypsum
783-797	Red sandstone
797-802	Clay and gypsum
802-821	Limestone
821-846	Red limes
846-858	Hard lime (red)
858-889	Soft green shale, gas pockets
889-892	Open cavity, artesian water
902-907	Brown shale, flowing oil, gas, th best free oil showing
907-909	Light thin limes
909-913	Brown and greenish clays
913-926	Limestone, red, gas
926-930	Limestone, hard, red
930-937	Limestone
937-945	Shale and thin lime, red
945-952	Hard lime
952-953	Soft brown shale, flowing oil
953-989	Tough gray lime

The measurements in table 29 for December 12, 1965, were made in the pond near the well. The average temperature of the water near the well was 89°F, the maximum at a depth of about 15 ft was 92.7°F, and the shallow pond, remote from the well, had an average temperature of 52°F. Air temperature was 64°F.

Table 29 - Field data for Pecos River basin

Location	Date	Discharge (gpm)	Temperature (°F)	pH	Specific conductance (micromhos)	Density gm/ml	H_2S ppm	NH_3 ppm	SiO_2 ppm
Montezuma Hot Springs (17N.13E.36.440)	1-3-66	5.8	131.3	8.8	790	.974	1	0.3	78
Garton Well (18S.8E.5.144)	12-17-65	---	92.7	7.1	5000	.995	0	3.4	20

San Juan River Basin

WELL (15N.16W.30.3443)

This well at the Fort Wingate Army Depot was drilled and test-pumped in 1968 under the supervision of the U.S. Geological Survey (Shomaker, 1969). The well was drilled to a total depth of 1945 ft and cased to 980 ft. A packer test October 2, 1968, of the interval from 1284 to 1945 ft produced a water sample which was reported to have a temperature of 142°F. The interval tested consists of the Meseta Blanca Member of the Yeso Formation and the Abo Formation. Table MI1 contains the chemical analysis of the sample.

The bottom-hole temperature on electric logs was reported to be TLTM (too low to measure). The well was plugged near the bottom of the casing, and the casing was perforated in the interval 726-928 ft, the Glorieta Sandstone, and tested. The water from this interval was not anomalous.

PURE OIL COMPANY TESTS

Two wells with anomalous temperatures were drilled in T. 19 N., R. 17 W. by the Pure Oil Company. The Navajo No. 1 (19N.I7W.29.000) was 7053 ft deep originally but was plugged to the surface and then unplugged to 2500+ ft. It flows 900 gpm from the Morrison Formation.

According to notes in the files of the U.S. Geological Survey, on April I, 1966, the discharge temperature was 97°F, and on September 9, 1963, it was 96°F. These notes indicated that the temperature fluctuated but did not give the range of fluctuation. Table Mll contains 2 chemical analyses of the water from this well.

The Pure Oil No. 3 (19N.17W.22.000) was drilled in 1951. The well is 800 ft deep and also flows at the land surface. On March 13, 1975, the discharging water had a temperature of 95°F (T. Kelley, U.S. Geological Survey, personal communication).

Thermal Waters Not Inventoried

Several springs probably exist as reported, but because of their remote locations, they cannot be reached economically. A secondary reason for not inventorying these springs is that their remote location would preclude their use in the near future.

The thermal waters and areas that probably exist but are not discussed include:

Hot Springs in Turkey Creek in the Gila Wilderness (14S.16W.3.000 and 14S.16W.26.000): several local residents confirm the existence of thermal springs in this area.

Hot Spring in the Gila Wilderness in a canyon north of the Middle Fork Gila River (1 I S.14W.25.000).

Agua Caliente (23N.1E.3.000): this spring was reported by Rangers of the U.S. Forest Service.

Spring Canyon area (17S.17W.34.000): the U.S. Soil Conservation Service reported (personal communication) that the Pacific Western Land and Cattle Company has a well or spring that flows 30 gpm from a 4-inch pipe at a temperature "too hot for bathing."

Price-Daniels wells (24S.3E.31.000): the U.S. Soil Conservation Service reported (personal communication) 1000 to 2000 gpm water discharging from a group of wells 300 to 400 ft deep at a temperature "just right for bathing."

Hot stock well (30S.19W.7.000): this well was reported by the U.S. Soil Conservation Service (personal communication), and a well did exist at the location (June 20, 1966) but the windmill would not lift water for field tests; the well was drilled in 1938 but no specific information is available for it from either state for federal files.

Several reports of thermal areas proved to be unsatisfactory. These include:

A well (24S.18W.32.000) reported as "hot" (Summers, 1965a, p. 12) proved upon field inspection to have always produced waters at a temperature of less than 70°F; this well still belongs to the original owner.

A thermal pipe (30S.20W.35.000) (Summers, 1965a, p. 12) proved to be a travertine deposit that might have discharged thermal water in the past.

Springs near La Madera (25N.8E.23, 24, 25, and 35.000) (Stearns, Stearns, and Waring, 1937 and Waring, 1965). These springs appear to be the warm (70° to 85°F) springs in 25N.8E.36.100 and 200 on the west side of the Ojo Caliente River; except for those in sec. 25, no springs exist at the location given; moreover, independent conversations with 3 longterm residents of the area indicated that no springs have ever existed at the locations given; the spring in sec. 25 had a temperature of 45°F, on December 2, 1965.

Spence Spring (14N.3E.28.000) (Summers, 1965a, p. 12); this is a poor location for Spence Hot Spring (19N .3E.28.310).

Thermal waters reported but probably not existing at ie location given include the following:

Hot spring on Diamond Creek (12S.13W.11.000)

Hot spring near Diamond Creek (12S.13W.14.000)

Warm spring (16S.12W.22.000); this is probably a poor description of Kennecott Warm Springs

Spring on Gila River (14S.14W.16.000); location is not in Gila River, probably refers to 14S.16W.16.000, a spring reported to exist on or near Turkey Creek

The thermal waters reported as having temperatures f more than 90°F but which had temperatures of less 'Ian 90°F when visited in the field include the follow-

Well (2 IS.1W.20.200); discharging water had a temperature of less than 70°F; the well owner, who had the well drilled, said the temperature had never been greater.

Statue Spring (25N.8E.26.400); December 2, 1965, the temperature of this spring was 82.5°F at a depth of 9 ft below land surface and the specific conductance was 1200 micromhos.

Ojo Caliente, Socorro County (8S.7W.30.000); December 13, 1965, the maximum temperature of the discharging water was 82.7°F and the specific conductance was 750 micromhos.

References

Aamodt, R. L., 1973, The Los Alamos Scientific Laboratory hot dry rock geothermal energy program (abs.): New Mexico Geol. Soc., Guidebook 24th Field Conf., p. 204-205.

———, 1974, The Los Alamos Scientific Laboratory hot dry rock geothermal energy program, *in* Energy Crisis Symposium, J. W. Shomaker and W. L. Hiss, eds.: New Mexico Bureau Mines Mineral Resources, Circ. 140, p. 106-107.

Abert, J. W., 1848a, Report of the examination of New Mexico in the years 1846-47: U.S. Senate 30th Cong., 1st sess., Senate ex. doc. 23, p. 3-130.

———, 1848b, Report of the examination of New Mexico in the years 1846-47: U.S. House 30th Cong., 1st sess., House ex. doc. 41, p. 417-546.

American Public Health Association, 1971, Standard methods for the examination of water and waste water, 13th ed.: New York, 874 p.

Bailey, R. A., 1961, Hot springs and solfataric areas in the Valles Caldera, Jemez Mountains, New Mexico (map): U.S. Geol. Survey, Open-File Rept.

Bailey, R. A., Smith, R. L., and Ross, C. S., 1969, Stratigraphic nomenclature of volcanic rocks in the Jemez Mountains, New Mexico: U.S. Geol. Survey, Bull. 1274-p, 19 p., 2 figs.

Bartlett, J. R., 1856, Personal narrative of exploration and incidents in Texas, New Mexico, California, Sonora, and Chihuahua, connected with the United States and Mexican Boundary Commission during the years 1850, '51, '52 and '53: New York, D. Appleton and Co.

Birnie, R. S., Jr., 1879, Appendix E, Report of Roger S. Birnie: U.S. Geog. and Geol. Survey west of the 100th meridian, Wheeler, G. M., p. 237-253, Appendix OO.

Brandwein, S. S., 1974, Selected shallow electrical resistivity surveys at Volcano Cliffs, Bernalillo County, New Mexico: M.S. thesis, Univ. New Mexico, 139 p.

Brues, C. L., 1928, Studies on the fauna of hot springs in the Western United States and the biology of thermophilous animals: Am. Acad. Arts and Sci., Proc., v. 63, p. 139-228.

———, 1932, Further studies of the fauna of North American hot springs: Am. Acad. Arts and Sci., Proc., v. 67, p. 186-303.

Budding, A. J., Sanford, A. R., and Toppozada, T. M. R., 1971, Seismicity and tectonics of the Rio Grande rift zone in central New Mexico (abs.): Geol. Soc. America, Abstracts with Programs, v. 3, no. 7, p. 515-516.

Bushman, F. X., 1955, Ground-water data for Dwyer quadrangle, Grant and Luna Counties, New Mexico: New Mexico Bureau Mines Mineral Resources, Circ. 37, 19 p.

Chapin, C. E., 1971, The Rio Grande rift, Part I: modifications and additions: New Mexico Geol. Soc., Guidebook 22nd Field Conf., San Luis basin, Colorado, p. 191-201.

Clark, F. W., 1893, Report of the work done in the division of chemistry: U.S. Geol. Survey, Bull. 113, 115 p.

———, 1924, The data of geochemistry: U.S. Geol. Survey, Bull. 770, 841 p.

Clark, J. D., 1929, The saline springs of the Rio Salado, Sandoval County, New Mexico: Univ. New Mexico, Bull. 163, chem. ser., v. 1, no. 3.

Clark, J. D., and Priest, K. F., 1932, Public water supplies of New Mexico: Univ. New Mexico, Bull., chem. ser., v. 2, no. 1.

Clemons, R. E., and Seager, W. R., 1973, Geology of Souse Springs quadrangle, New Mexico: New Mexico Bureau Mines Mineral Resources, Bull. 100, 31 p.

Collins, W. D., 1925, Temperature of water available for industrial use in the United States: U.S. Geol. Survey, Water-Supply Paper 520-F, p. 97-104.

Conover, C. S., 1954, Ground-water conditions in the Rincon and Mesilla valleys and adjacent areas in New Mexico: U.S. Geol. Survey, Water-Supply Paper 1230.

Conover, C. S., Herrick, E. H., Wood, J. W., and Weir, J. E., Jr., 1955, The occurrence of ground water in south-central New Mexico: New Mexico Geol. Soc., Guidebook 6th Field Conference, south-central New Mexico, p. 108-120.

Conover, C. S., Theis, C. V., and Griggs, R. L., 1963, Geology and hydrology of Valle Grande and Valle Toledo, Sandoval County, New Mexico: U.S. Geol. Survey, Water-Supply Paper 1619-Y, 37 p.

Cope, E. D., 1875, Appendix 61, Report on the geology of that part of New Mexico surveyed during the field season of 1874: U.S. Geog. and Geol. Survey west of the 100th Meridian, p. 61-97, Appendix LL.

Cordell, L., 1972, Complete Bouguer gravity anomaly map of the Jemez area, New Mexico: U.S. Geol. Survey Open-File Map, 1 sheet, 1:250,000.

Cox, E. R., and Reeder, H. D., 1962, Ground-water conditions in the Rio Grande valley between Truth or Consequences and Las Palomas, Sierra County, New Mexico: New Mexico State Engineer, Tech. Rept. 25.

Crook, J. K., 1899, The mineral waters of the United States and their therapeutic uses: New York and Philadelphia, Pennsylvania, Lea Bros. & Co., 588 p.

Cushman, R. L., 1965, An evaluation of aquifers and well characteristics of municipal well field in Los Alamos and Guaje Canyons, near Los Alamos, New Mexico: U.S. Geol. Survey, Water-Supply Paper 1809-D, 50 p.

Dane, C. H., and Bachman, G. O., 1961, Preliminary geologic map of the southwestern part of New Mexico: U.S. Geol. Survey, Misc. Inv. Map I-344.

DeBrine, B., Spiegel, Z., and Williams, D., 1963, Cenozoic sedimentary rocks in Socorro valley, New Mexico: New Mexico Geol. Soc., Guidebook 14th Field Conf., Socorro region, New Mexico, p. 123-131.

Decker, E. R., 1972, Heat flow and radioactivity in Colorado, New Mexico, Texas, Utah and Wyoming (abs.): Am. Geophys. Union, Trans., v. 53, no. 4, p. 516.

———, 1973, Geothermal studies in the southern Rocky Mountain region, 1971-1973 (abs.): Rky. Mtn. Sec. Geol. Soc. America, 26th Ann. Mtg., Abstracts with Program, v. 5, no. 6, p. 475-476.

Decker, E. R., and Smithson, S. B., 1973, Geophysical studies in the southern Rio Grande rift (abs.): Am. Geophys. Union, Trans., v. 54, no. 4, p. 463.

DeHon, R., 1965, Maars of the Potrillo area of southern New Mexico (abs.): New Mexico Geol. Soc., Guidebook 16th Field Conf., southwestern New Mexico II, p. 238.

Domenico, P. A., and Palciavskas, V. V., 1973, Theoretical analysis of forced convective heat transfer in regional ground-water flow: Geol. Soc. America, Bull., v. 84, p. 3803-3814.

Duke, M. E. L., 1967, A production study of a thermal spring: Ph.D. dissert., Univ. Texas Austin, 159 p.

Edwards, C. L., Reiter, M., and Weidman, C., 1973, Geothermal studies in New Mexico and southern Colorado (abs.): Am. Geophys. Union, Trans., v. 54, no. 4, p. 463.

Elston, W. E., 1957, Geology and mineral resources of Dwyer quadrangle, Grant, Luna, and Sierra Counties, New Mexico: New Mexico Bureau Mines Mineral Resources, Bull. 38, 86 p.

———, 1960, Reconnaissance geologic map of Virden thirty-minute quadrangle: New Mexico Bureau Mines Mineral Resources, Geol. Map 15.

Fitch, W. E., 1927, Mineral waters of the United States and American spas: Philadelphia, Pennsylvania, and New York: Lea & Febiger, 799 p.

Flege, R. F., Jr., 1959, Geology of the Lordsburg quadrangle, Hidalgo County, New Mexico: New Mexico Bureau Mines Mineral Resources, Bull. 62, 36 p.

Gilbert, G. K., 1875, Report on the geology of portions of California, Nevada, Utah, Colorado, New Mexico, and Arizona, examined in the years 1871, 1872, and 1873: U.S. Geog. and Geol. Survey west of the 100th meridian, Wheeler, G. M., v. 3, p. 19-187.

Granger, H. C., 1956, Radioactive spring deposits, Perry Robb property, Jemez Springs, *in* Lovering, L. G., Radioactive deposits in New Mexico: U.S. Geol. Survey, Bull. 1009-L, p. 358-361.

Griggs, R. L., 1964, Geology and ground-water resources of the Los Alamos Area, New Mexico, with a section on quality of water by John P. Hem: U.S. Geol. Survey, Water-Supply Paper 1753, 107 p.

Hall, F. R., 1963, Springs in the vicinity of Socorro, New Mexico: New Mexico Geol. Soc., Guidebook 14th Field Conf., Socorro region, p. 160-179.

Hare, R. F., and Mitchell, S. R., 1912, Composition of some New Mexico waters with a discussion of their fitness for irrigation and domestic purposes: New Mexico Coll. Agric. Mech. Arts, Agric. Exper. Station, Bull. 83, 76 p.

Harrington, E. R., 1948, Craters and crater springs of the Rio Salado: Jour. Geology, v. 56, no. 3, p. 182-185.
Hartman, H., and Reiter, M., 1972, First report on a preliminary geothermal study of the Rio Grande rift (abs.): Am. Geophys. Union, Trans., v. 53, no. 4, p. 516.
Hatch, W. R., and Ott, W. L., 1968, Determination of submicrogram quantities of mercury by atomic absorption spectrometry: Anal. Chemistry, v. 40, no. 14, p. 2085-2087.
Hayden, F. V., 1869, Preliminary field report of the United States Geological Survey of Colorado and New Mexico: Washington, D.C.
Hem, J. D., 1959, Study and interpretation of the chemical characteristics of natural water: U.S. Geol. Survey, Water-Supply Paper 1473, 269 p.
Herron, W. H., 1916, Profile surveys in 1915 along the Rio Grande, Pecos River, and Mora River, New Mexico: U.S. Geol. Survey, Water-Supply Paper 421.
Hoffer, J. M., 1971a, Mineralogy and petrology of the Santo Tomas-Black Mountain Basalt Field, Potrillo volcanics, south-central New Mexico: Geol. Soc. America, Bull., v. 82, no. 3, p. 603-612.
———, 1971b, Herradura, a new lava flow feature: Geol. Soc. America, Bull., v. 82, no. 10, p. 2949-2953.
Hoffer, J. M., and Hoffer, R. L., 1973, Composition and structural state of feldspar inclusions from alkali olivine basalt, Potrillo basalt, southern New Mexico: Geol. Soc. America, Bull., v. 84, no. 6, p. 2139-2142.
Holmes, C. R., 1963, Tritium studies, Socorro Spring: New Mexico Geol. Soc., Guidebook 14th Field Conf., Socorro region, p. 152-154.
Hood, J. W., and Kister, L. R., 1962, Saline-water resources of New Mexico: U.S. Geol. Survey, Water-Supply Paper 1601, 70 p.
Jacob, C. E., and Lohman, S. W., 1952, Non-steady flow to a well of constant draw-down in an extensive aquifer: Trans. Amer. Geophys. Union, v. 33, p. 559-569.
Jiracek, G. R., 1974, Geophysical studies in the Jemez Mountains region, New Mexico: New Mexico Geol. Soc., Guidebook 25th Field Conf., Ghost Ranch, central-northern New Mexico, p. 137-144.
Jiracek, G. R., and Kintzinger, P. R., 1975, Deep electrical resistivity investigations coupled with "dry" geothermal reservoir experiments in New Mexico (abs.): Geophysics, v. 40, p. 175.
Johnson, A. I., 1963, Modified Parshall flume: U.S. Geol. Survey, Hydrologic Lab., Denver, Colorado, Open-File Rept., 6 p.
Jones, F. A., 1904, New Mexico Mines and Minerals: Santa Fe, New Mex. Printing Company, 349 p.
Kelley, V. C., 1955, Regional tectonics of south-central New Mexico: New Mexico Geol. Soc., Guidebook 6th Field Conf., south-central New Mexico, p. 96-104.
Kelley, V. C., and Silver, C., 1952, Geology of the Caballo Mountains with special reference to regional stratigraphy and structure and to mineral resources, including oil and gas: Univ. New Mexico, Pub. Geology, no. 4, 286 p.
Kelly, C., and Anspach, E. V., 1913, A preliminary study of waters of the Jemez Plateau, New Mexico: Univ. New Mexico, Bull., chem. ser., v. 1, no. 1.
Kintzinger, P. R., 1956, Geothermal survey of hot ground near Lordsburg, New Mexico: Science, v. 124, p. 629.
Knowles, D. B., and Kennedy, R. A., 1956, Ground-water resources of the Hueco Bolson northeast of El Paso, Texas: Texas Board Water Engineers, Bull. 5615, 263 p. Also published later as U.S. Geol. Survey, Water-Supply Paper 1426, 186 p.
Kottlowski, F. E., 1960, Reconnaissance geologic map of Las Cruces thirty-minute quadrangle: New Mexico Bureau Mines Mineral Resources, Geol. Map. 14.
Kudo, A. M., 1974, Outline of the igneous geology of the Jemez Mountains volcanic field: New Mexico Geol. Soc., Guidebook 25th Field Conf., Ghost Ranch, central-northern New Mexico, p. 287-289.
Lee, W. T., 1907, Afton craters of southern New Mexico: Geol. Soc. America, Bull., v. 18, p. 211-220.
Lindgren, W., 1910, The hot springs of Ojo Caliente and their deposits: Econ. Geology, v. 5, no. 1, p. 22-27.
Lindgren, W., Graton, L. C., and Gordon, C. H., 1910, The ore deposits of New Mexico: U.S. Geol. Survey, Prof. Paper 68, 361 p.
Loew, O., 1875a, Report upon mineralogical, agricultural, and chemical conditions observed in portions of Colorado, New Mexico, and Arizona: U.S. Geog. and Geol. Survey west of the 100th Meridian, Wheeler, G. M., v. 3, p. 613-627.
———, 1875b, Appendix G2, Geological and mineralogical report on portions of Colorado and New Mexico; Wheeler, G. M., ed., Appendix LL: U.S. Geog. Survey west of the 100th meridian, Ann. Rept., p. 97-116.
Lovering, T. G., 1956, Radioactive deposits in New Mexico: U.S. Geol. Survey, Bull. 1009-L, p. 315-390.
Mansfield, G. R., 1918, Sulphur in Jemez Canyon Sandoval County: U.S. Geol. Survey, Min. Res. 1918, pt. 2, p. 367.
Minton, E. G., Jr., 1941, Report of investigation Hot Springs artesian basin, New Mexico: New Mexico State Engineer, 15th Bienn. Rept., p. 34J-36S.
Montgomery, A., 1953, Pre-Cambrian geology of the Picuris Range, north-central New Mexico: New Mexico Bureau Mines Mineral Resources, Bull. 30, 89 p.
Moorman, J. J., 1867, Mineral waters of the United States and Canada, Baltimore, Maryland: Kelly and Piet, 507 p.
———, 1871, Mineral springs of North America, Philadelphia, Pennsylvania: J. B. Lippincott & Co., 294 p.
Murray, C. R., 1949, Ground-water conditions in the nonthermal artesian water basin south of Hot Springs, Sierra County, New Mexico: U.S. Geol. Survey, Open-File Rept.
———, 1959, Ground-water conditions in the nonthermal artesian water basin south of Hot Springs, Sierra County, New Mexico: New Mexico State Engineer, Tech. Rept. 10.
Murray, C. R., and Theis, C. V., 1946, Memorandum of the safe yield of ground water in the Hot Springs ground-water districts, Sierra County, New Mexico: U.S. Geol. Survey, Open-File Rept.
Paige, S., 1916, Description of the Silver City quadrangle, New Mexico: U.S. Geol. Survey, Geol. Atlas, Silver City Folio, No. 199, 19 p.
———, 1932, The region around Santa Rita and Hanover, New Mexico, *in* Ransome, F. L. and others, eds., Ore deposits of the Southwest: 16th Internat. Geol. Cong. United States 1933, Guidebook 14, Excursion C-1, p. 23-40.
Peale, A. V., 1886, List and analysis of the mineral springs of the United States: U.S. Geol. Survey, Bull. 32.
———, 1894, Natural mineral waters of the United States: U.S. Geol. Survey, 14th Ann. Rept., 1892-93, pt. 2, p. 49-88, maps.
Perkins, P. C., 1973, Petrography of some rock types of the Precambrian basement near the Los Alamos Scientific Laboratory geothermal test site, Jemez Mountains, New Mexico: Univ. California Los Alamos Sci. Lab., Rept. LA-5129, 12 p.
Potter, R. M., 1973, Heat flow of the Jemez Plateau (abs.): Am Geophys. Union, Trans., Fall Ann. Mtg., v. 54, no. 11, p. 1214.
Powell, W. C., 1929, Report on an investigation of the Hot Springs artesian basin, Hot Springs, New Mexico: New Mexico State Engineer, 9th Bienn. Rept., p. 121-129.
Purtymun, W. D., 1973, Geology of the Jemez Plateau west of Valles Caldera: Univ. Calif. Los Alamos Sci. Lab., Rept. LA-5124-MS, 13 p.
Purtymun, W. D., and Cooper, J. B., 1969, Development of ground-water supplies at the Pajarito Plateau, Los Alamos County, New Mexico: U.S. Geol. Survey, Prof. Paper 650B, p. B149-B153.
Purtymun, W. D., and Herceg, J. E., 1972, Summary of Los Alamos municipal well field characteristics, 1947-1971: Univ. California Los Alamos Sci. Lab., Rept. LA-5040-MS, 69 p.
Purtymun, W. D., and Johansen, S., 1974, General geohydrology of the Pajarito Plateau: New Mexico Geol. Soc., Guidebook 25th Field Conf., Ghost Ranch, central-northern New Mexico, p. 347-349.
Purtymun, W. D., West, F. G., and Adams, W. H., 1974, Preliminary study of the quality of water in the drainage area of the Jemez River and Rio Guadalupe: Univ. California Los Alamos Sci. Lab., Informal Rept. LA-5595-MS, 26 p.
Purtymun, W. D., West, F. G., and Pettitt, R. A., 1974, Geology of geothermal test hole GT-2 Fenton Hill Site, July, 1974: Univ. California Los Alamos Sci. Lab., Informal Rept. LA-5780-MS, p. 15.
Ratté, J. C., Eaton, G. P., Gaskill, D. L., Peterson, D. L., Stotelmeyer, D. L., and Meeves, H. C., 1972, Mineral resources of the Gila Primitive area and Gila Wilderness, Catron and Grant Counties, New Mexico: U.S. Geol. Survey, Open-File Rept., 428 p.
Reagan, A. B., 1903, Geology of the Jemez-Albuquerque region, New Mexico: Am. Geologist, v. 31, no. 2, p. 67-111, 7 pls.
Reeder, H. O., 1957, Ground water in Animas Valley, Hidalgo County, New Mexico: New Mexico State Engineer, Tech. Rept. 11, 101 p.
Reiche, P., 1940, The origin of Kilbourne Hole, New Mexico: Am. Jour. Science, v. 238, p. 212-225.

Reiter, M., Edwards, C. L., and Weidman, C., 1973, Heat-flow studies of New Mexico and neighboring areas of the southwest United States (abs.): Geol. Soc. America, Abstracts with Programs, v. 5, no. 7, p. 779.

Reiter, M., Edwards, C. L., Hartman, H., and Weidman, C., 1975, Terrestrial heat flow along the Rio Grande rift: Geol. Soc. America, Bull., v. 86, no. 7, p. 811-818.

Renick, B. C., 1931, Geology and ground-water resources of western Sandoval County, New Mexico: U.S. Geol. Survey, Water-Supply Paper 620.

Richardson, H., 1898, Description of a new crustacean of the genus *Spheroma* from a warm spring (Socorro?) in New Mexico: U.S. Natl. Mus., Proc., v. 20, no. 1128, p. 465-466.

Ross, C. S., Smith, R. L., and Bailey, R. A., 1961, Outline of the geology of the Jemez Mountains, New Mexico: New Mexico Geol. Soc., Guidebook 12th Field Conf., Albuquerque Country, p. 139-143; Am. Geol. Inst. Geosci., Abs., v. 4, no. 4-4220, p. 7 (1962).

Sanford, A. R., Alptekin, O., and Toppozada, T. M. R., 1973, Use of reflection phases on microearthquake seismograms to map an unusual discontinuity beneath the Rio Grande rift: Seismol. Soc. America, Bull., v. 63, no. 6, p. 2021-2034.

Sanford, A. R., Budding, A. J., Hoffman, J. P., Alptekin, O. S., Rush, C. A., and Toppozada, T. R., 1972, Seismicity of the Rio Grande rift in New Mexico: New Mexico Bureau Mines Mineral Resources, Circ. 120, 19 p.

Schwennesen, A. T., 1918, Ground-Water in the Animas, Playas, Hachita, and San Luis basins New Mexico: U.S. Geol. Survey, Water-Supply Paper 422, 152 p.

Scofield, C. S., 1938, Quality of water of the Rio Grande Basin above Fort Quitman, Texas: U.S. Geol. Survey, Water-Supply Paper 839.

Scott, R. C., and Barker, F. B., 1962, Data on uranium and radium in ground water in the United States 1954-1957: U.S. Geol. Survey, Prof. Paper 426, 115 p.

Seager, W. R., 1973, Resurgent volcano-tectonic depression of Oligocene age, south-central New Mexico: Geol. Soc. America, Bull., v. 84, no. 11, p. 3611-3626.

Seager, W. R., and Clemons, R. E., 1974, Tertiary tectonics and mineralization. Doña Ana County, New Mexico (abs.): New Mexico Geol. Soc., Guidebook 25th Field Conf., Ghost Ranch, central-northern New Mexico, p. 381.

Seager, W. R., and Hawley, J. W., 1973, Geology of Rincon quadrangle, New Mexico: New Mexico Bureau Mines Mineral Resources, Bull. 101, 42 p.

Seager, W. R., Hawley, J. W., and Clemons, R. E., 1971, Geology of San Diego Mountain area, Doña Ana County: New Mexico Bureau Mines Mineral Resources, Bull. 97, 38 p.

Shomaker, J. W., 1969, Drilling and testing of well 340, Fort Wingate Army Depot, McKinley County, New Mexico: U.S. Geol. Survey, Open-File Rept., 57 p.

Singh, S., 1970, Statistical analysis of microearthquakes of the Socorro region, New Mexico: Ph.D. dissert., New Mexico Institute Mining Technology, 156 p.

Singh, S., and Sanford, A. R., 1972, Statistical analysis of microearthquakes near Socorro, New Mexico: Seismol. Soc. America, Bull., v. 62, no. 4, p. 917-926.

———, 1973, Poisson processes in earthquake studies, a reply: Seismol. Soc. America, Bull., v. 63, no. 2, p. 737.

Smith, C. T., 1963, Preliminary notes on the geology of part of the Socorro Mountains, Socorro County, New Mexico: New Mexico Geol. Soc., Guidebook 14th Field Conf., Socorro region, p. 185-196.

Smith, M. C., 1973, Promises and problems of geothermal energy: New Mexico Acad. Science, Bull., v. 14, no. 2, p. 22-24.

Smith, R. L., 1961, Structural evolution of the Valles Caldera, New Mexico, and its bearing on the emplacement of ring dikes: U.S. Geol. Survey, Prof. Paper 424-D, p. 145-149; Am. Geol. Institute Geoscience, Abs., v. 4, no. 4-1220, p. 11 (1962).

Smith, R. L., Bailey, R. A., and Ross, C. S., 1970, Geologic map of the Jemez Mountains, New Mexico: U.S. Geol. Survey, Misc. Geol. Inv. Map I-571, scale 1:125,000, sections.

Smithson, S. B., and Decker, E. R., 1972, Heat flow and gravity studies across the Rio Grande rift in southern New Mexico and western Texas (abs.): Am. Geophys. Union, Trans., v. 53, no. 4, p. 516.

Snedecor, G. W., 1956, Statistical methods (5th ed.): Iowa State Coll. Press, Ames, Iowa.

Spiegel, Z., 1957, Geology and ground water in Animas Valley, Hidalgo County, New Mexico: New Mexico State Engineer, Tech. Rept. 11, p. 9-12.

Stanley, F., 1950, Socorro—the oasis: World Press Inc., Denver, Colorado.

Stearns, N. D., Stearns, H. T., and Waring, G. A., 1937, Thermal springs in the United States: U.S. Geol. Survey, Water-Supply Paper 679-B.

Stevenson, J. J., 1881, Geological examinations in southern Colorado and northern New Mexico during the years 1878 and 1879: U.S. Geog. Survey west of the 100th Meridian (Wheeler, G. M.), v. 3, (Suppl. Geology), p. 15-420.

Strangway, D. W., and Holmer, R. C., 1966, The search for ore deposits using thermal radiation: Geophysics, v. 31, p. 225-242.

Summers, W. K., 1965a, Chemical characteristics of New Mexico's thermal waters—a critique: New Mexico Bureau Mines Mineral Resources, Circ. 83, 27 p.

———, 1965b, A preliminary report on New Mexico's geothermal energy resources: New Mexico Bureau Mines Mineral Resources, Circ. 80, 41 p.

———, 1966a, The sodium ion concentration in New Mexico's thermal water (abs.): New Mexico Acad. Science, Bull., v. 7, no. 1, p. 27.

———, 1966b, Distribution and occurrence of New Mexico's thermal waters—a statistical summary (abs.): New Mexico Geol. Soc., Guidebook 17th Field Conf., p. 122.

———, 1966c, The hydrologic significance of the Animas Valley hot spot, Hidalgo County, New Mexico (abs.): New Mexico Acad. Science, Bull., v. 8, no. 1, p. 24; 1968, Cordilleran Section Geol. Soc. America (abs.), p. 188.

———, 1968a, Geothermics—New Mexico's untapped resource: New Mexico Business, August, p. 1-9; Reprinted, New Mexico Bureau Mines Mineral Resources, Circular 98, 9 p.

———, 1968b, Scientist in hot water: New Mexico Mag., April, p. 17-19.

———, 1969a, Geothermics—what's next for New Mexico? (abs.): New Mexico Geol. Soc., Guidebook 20th Field Conf., border region, Chihuahua and United States, p. 215.

———, 1969b, Geological survey of thermal waters in New Mexico (abs.): Geol. Soc. America, Abstracts with Program, pt. 5, Rky. Mtn. Sec., p. 79.

———, 1970, Geothermal prospects in New Mexico: Geothermics, special issue 2, v. 2, pt. 2, p. 1009-1014.

———, 1972a, Hydrogeology and water supply of the Pueblo of Zuni, McKinley and Valencia Counties, New Mexico: New Mexico Bureau Mines Mineral Resources, Open-File Rept. 33, 118 p.

———, 1972b, Factors affecting the validity of chemical analysis of natural water: Ground Water, v. 10, no. 2, p. 12-17.

———, 1972c, Geothermal prospects in New Mexico, *in* Geothermal Overview of the Western United States: Paper G, Geothermal Resources Council, 23 p.

———, 1972d, Geothermal resources of New Mexico: New Mexico Bureau Mines Mineral Resources, Resource Map 1.

Summers, W. K., and Brandvold, L. A., 1967, Physical and chemical variations in the discharge of a flowing well: Ground Water, v. 5, no. 1, p. 9-10.

Summers, W. K., and Deju, R. A., 1972, A preliminary study of the geochemical characteristics of thermal water in New Mexico: 24th Internatl. Geol. Cong., Montreal, Canada, Proc., p. 241-250.

Summers, W. K., and Kottlowski, F. E., in press, Natural hot waters in New Mexico, *in* A report of the Governor's Task Force Committee on geothermal resources: New Mexico State Energy Resources Administration.

Theis, C. V., Taylor, G. C., Jr., and Murray, C. R., 1941, Thermal waters of the Hot Springs artesian basin, Sierra County, New Mexico: New Mexico State Engineer, 14th-15th Bienn. Rept., p. 419-492.

Titus, F. B., Jr., 1961, Ground-water geology of the Rio Grande trough in north-central New Mexico, with sections on the Jemez Caldera in the Lucero uplift: New Mexico Geol. Soc., Guidebook 12th Field Conf., Albuquerque country, p. 186-192.

Toppozada, T. M. R., 1974, Seismic investigation of crustal structure and upper mantle velocity in the State of New Mexico and vicinity: Ph.D. dissert., New Mexico Institute Mining Technology, 152 p.

Toppozada, T. M. R., and Sanford, A. R., 1972, Instrumental study of New Mexico earthquakes, January 1968 through June 1971: New Mexico Bureau Mines Mineral Resources, Circ. 126, 6 p.

———, 1973, Crustal structure in central New Mexico (abs.): Am. Geophys. Union, Trans., v. 54, no. 11, p. 1141.

Trainer, F. W., 1974a, Geothermal waters in the Jemez Mountains volcanic region, north-central New Mexico (abs.): Geol. Soc. America, Abstracts with Programs, v. 6, no. 7, p. 991.

———, 1974b, Ground water in the southwestern part of the Jemez Mountains volcanic region New Mexico: New Mexico Geol. Soc., Guidebook 25th Field Conf., Ghost Ranch, central-northern New Mexico, p. 337-345.

Trauger, F. D., 1960, Availability of ground water at proposed well sites in Gila National Forest, Sierra and Catron Counties, New Mexico: New Mexico State Engineer, Tech. Rept. 18, 20 p.

———, 1972, Water resources and general geology of Grant County, New Mexico: New Mexico Bureau Mines Mineral Resources, Hydrologic Rept. 2, 212 p.

Trauger, F. D., and Doty, G. C., 1965, Ground water—its occurrence and relation to the economy and geology of southwestern New Mexico: New Mexico Geol. Soc., Guidebook 16th Field Conf., southwestern New Mexico II, p. 215-227.

U.S. Geol. Survey, 1972, Aeromagnetic map of the Jemez area, New Mexico: Open-File map, 1 sheet, 1:250,000.

U.S. Salinity Laboratory Staff, 1954, Diagnosis and improvement of saline and alkali soils: U.S. Dept. of Agriculture Handbook 60, 160 p.

von Buttlar, Haro, 1959, Ground-water studies in New Mexico using tritium as a tracer, II: Jour. Geophys. Res., v. 64, no. 8, p. 1031-1038.

Waldron, F. F., 1956, Reconnaissance geology and ground-water study of a part of Socorro County, New Mexico: Ph.D. dissert., Stanford Univ.

Walton, G. E., 1883, Mineral springs of the United States and Canada: 468 p.

Ward, F. N., 1951, Determination of molybdenum in soils and rocks: Anal. Chemistry, v. 23, no. 5, p. 788-791.

Waring, G. A., 1965, Thermal springs of the United States and other countries of the world—a summary: U.S. Geol. Survey, Prof. Paper 492, 383 p.

Weber, R. H., 1963, Cenozoic volcanic rocks of Socorro County, New Mexico: New Mexico Geol. Soc., Guidebook 14th Field Conf., Socorro region, p. 132-143.

Weber, R. H., and Willard, M. E., 1959, Reconnaissance geologic map of Reserve thirty-minute quadrangle: New Mexico Bureau Mines Mineral Resources, Geol. Map 12.

West, F. G., 1973a, Geohydrology of the Jemez Plateau: Univ. California, Los Alamos Sci. Lab., Rept. LA-UR-74-119, 7 p.

———, 1973b, Regional geology and geophysics of the Jemez Mountains: Univ. California Los Alamos Sci. Lab., Rept. LA5362-M, 7 p.

———, 1974, Dry hot rock project: New Mexico Geol. Soc., Guidebook 25th Field Conf., Ghost Ranch, central-northern New Mexico, p. 355-358.

Wheeler, G. M., 1889, U.S. Geographical surveys west of 100th meridian, v. 1.

White, D. E., Hem, J. D., and Waring, G. A., 1963, Chemical composition of subsurface waters, *in* Fleischer, M., tech. ed., Data of geochemistry: U.S. Geol. Survey, Prof. Paper 440-F.

Wideman, F. L., 1957, A reconnaissance of sulfur resources in Wyoming, Utah, New Mexico, and Arizona: U.S. Bureau Mines, Info. Circ. 7770.

Willard, M. E., Weber, R. H., and Kuellmer, F. J., 1961, Reconnaissance geologic map of Alum Mountain thirty-minute quadrangle: New Mexico Bureau Mines Mineral Resources, Geol. Map 13.

Woltz, D., 1973, The chemistry of ground waters in the Jemez area and a magnetic survey of a potential source of magmatic fluids: M.S. thesis, Univ. New Mexico, 90 p.

Woods, G. H., and Northrop, S. A., 1946, Geology of Nacimiento Mountains, San Pedro Mountains and adjacent plateaus of Sandoval and Rio Arriba Counties, New Mexico: U.S. Geol. Survey, Oil and Gas Inv., Prelim. Map 57.

Yalman, R., Buregemann, W., Baker, P., and Garn, S., 1959, Volumetric determination of calcium in presence of phosphate: Anal. Chem., v. 31, p. 1230-1233.

Zeller, R. A., Jr., 1965, Stratigraphy of the Big Hatchet Mountains area, New Mexico: New Mexico Bureau Mines Mineral Resources, Memoir 16, 128 p.

Type faces: Text in 8 and 10 pt. Times Roman, leaded one-point; subheads 12 pt. Times Roman
Display heads in 24 pt. Times Roman, letterspaced

Presswork: Miehle Single Color Offset
Harris Single Color Offset

Binding: Sewn with softbound cover

Paper: Cover on 10 pt. Supertuff

CHEMICAL ANALYSES ON MICROFICHE IN POCKET: