CIRCULAR 83

Chemical Characteristics of New Mexico's Thermal Waters--A Critique

by W. K. SUMMERS

Prepared for the Mineral Element of the New Mexico Resources Development Plan of the State Planning Office, this material was financially aided through a federal grant from the Urban Renewal Administration of the Housing and Home Finance Agency, under the Urban Planning Assistance Program authorized by Section 107 of the Housing Act of 1954, as amended.

STATE BUREAU OF MINES AND MINERAL RESOURCES
NEW MEXICO INSTITUTE OF MINING AND TECHNOLOGY
CAMPUS STATION SOCORRO, NEW MEXICO

CIRCULAR 83

Chemical Characteristics of New Mexico's Thermal Waters--A Critique

by W. K. SUMMERS

Prepared for the Mineral Element of the New Mexico Resources Development Plan of the State Planning Office, this material was financially aided through a federal grant from the Urban Renewal Administration of the Housing and Home Finance Agency, under the Urban Planning Assistance Program authorized by Section 107 of the Housing Act of 1954, as amended.

1965

STATE BUREAU OF MINES AND MINERAL RESOURCES
NEW MEXICO INSTITUTE OF MINING AND TECHNOLOGY
CAMPUS STATION SOCORRO, NEW MEXICO

For sale by the New Mexico Bureau of Mines and Mineral Resources
Campus Station, Socorro, N. Mex.—Pricc $1.00

Contents

Illustrations

TABLES

FIGURES

Abstract

As part of a preliminary report on the geothermal energy resources of New Mexico, chemical analyses of thermal water (65°F or higher) and thermal wells (75°F or higher) were compiled. This paper summarizes the data available on waters 90°F or greater and discusses their significance and shortcomings.

The thermal waters of New Mexico are located along faults and generally can be related to nearby igneous rocks of Tertiary or Quaternary age. Many of the thermal waters are related to the faults at the margin of the Rio Grande trough. The discussion of the chemistry of thermal water is limited to those waters with temperatures of 90°F or more because this temperature seems to mark a lower limit of thermal anomaly.

These waters are sodium-rich with chloride, sulfate, bicarbonate, bicarbonate-sulfate, and bicarbonate-chloride. Fluoride concentrations range from 0 to 24 ppm (parts per million) and are generally higher than in nonthermal waters.

The pH of the thermal waters is usually greater than 7.0, but at Sulphur Springs and Alamo Canyon Spring, the pH is low-2.0 and 2.9. At these springs, aluminum and hydrogen are the principal cations and sulfate is the anion. Chemical analyses of water from Sulphur Springs show many inconsistencies.

Unusual concentrations of boron occur at Soda Dam Springs and at Jemez Springs, and unusual concentrations of radium occur at Faywood Hot Springs.

The thermal waters at Truth or Consequences are sodium-chloride waters and are amazingly uniform in chemistry, whether the water issues as springs from the alluvium or is intercepted by wells penetrating the limestone.

Some of the thermal springs have built large travertine deposits; others (with similar chemical make-up) have not. Some of the springs show remarkable uniformity in discharge and temperature; others fluctuate over a wide range. Some of the thermal waters are clearly warmed meteoric waters; others may have a component of juvenile water. Some thermal waters have circulated to only shallow depths, whereas others have circulated to depth—possibly great depth.

Although the available data reveal much about the character of the thermal waters of New Mexico, they leave much to be desired for a geological interpretation of the hydrothermal process, because the analyses were made largely from the standpoint of water supply. The available data do not answer many questions relating to the active hydrothermal process; yet, such data may lead to a complacency that bodes ill for understanding of the hydrothermal process in New Mexico.

Introduction

As part of a preliminary report on the geothermal energy resources of New Mexico, prepared for the Mineral Element of the New Mexico Resources Development Plan of the State Planning Office, chemical analyses of the water from thermal springs (65°F or higher) were assembled (Summers, 1965, table 3). The literature was searched and files of state and federal agencies as well as those of individual researchers were examined for unpublished data. In addition to the analyses for thermal springs, chemical analyses of thermal waters (75°F or more, to take into account the effect of a normal geothermal gradient) issuing from wells were also compiled. In short, a concerted effort was made to learn the "facts" about the chemistry of the thermal waters of New Mexico. Figure 1 shows the locations of thermal waters in New Mexico.

This report summarizes the information obtained for waters with temperatures of 90°F or greater and discusses the significance and shortcomings of the data from a *geologist's* point of view.

Previously published work on the thermal waters of New Mexico has been limited to the study of the Truth or Consequences area by Theis, Taylor, and Murray (1941); to short discussions in reports about ground-water resources or the geology of selected regions (for example, Reeder, 1957, p. 26, and Hall, 1963); or to itemized listings of thermal springs (for example, Jones, 1904, and Stearns, Stearns, and Waring, 1937). Summers (1965) lists published sources of data in his bibliography.

The analyses discussed here were compiled by many people who gathered the data for various reasons, so several different analytical techniques were used.

Most of the analyses were made for water to be used for irrigation, stock, or domestic purposes (as, in fact, some thermal waters of New Mexico are). Consequently, the analysts looked for those constituents likely to influence the water's use. Other analyses came from programs designed to gain insight into some particular aspect of water chemistry. For example, Scott and Barker (1962) reported analyses made as part of a study by the U.S. Geological Survey to determine the occurrence and distribution of naturally radioactive substances in water.

This discussion is not intended to decry the original purpose of the data or to cast doubt on the integrity or ability of the investigators. Its fundamental purpose is to prevent complacency among geologists by alerting them to the need for a particular suite of data—data which they may feel, erroneously, are already being gathered.

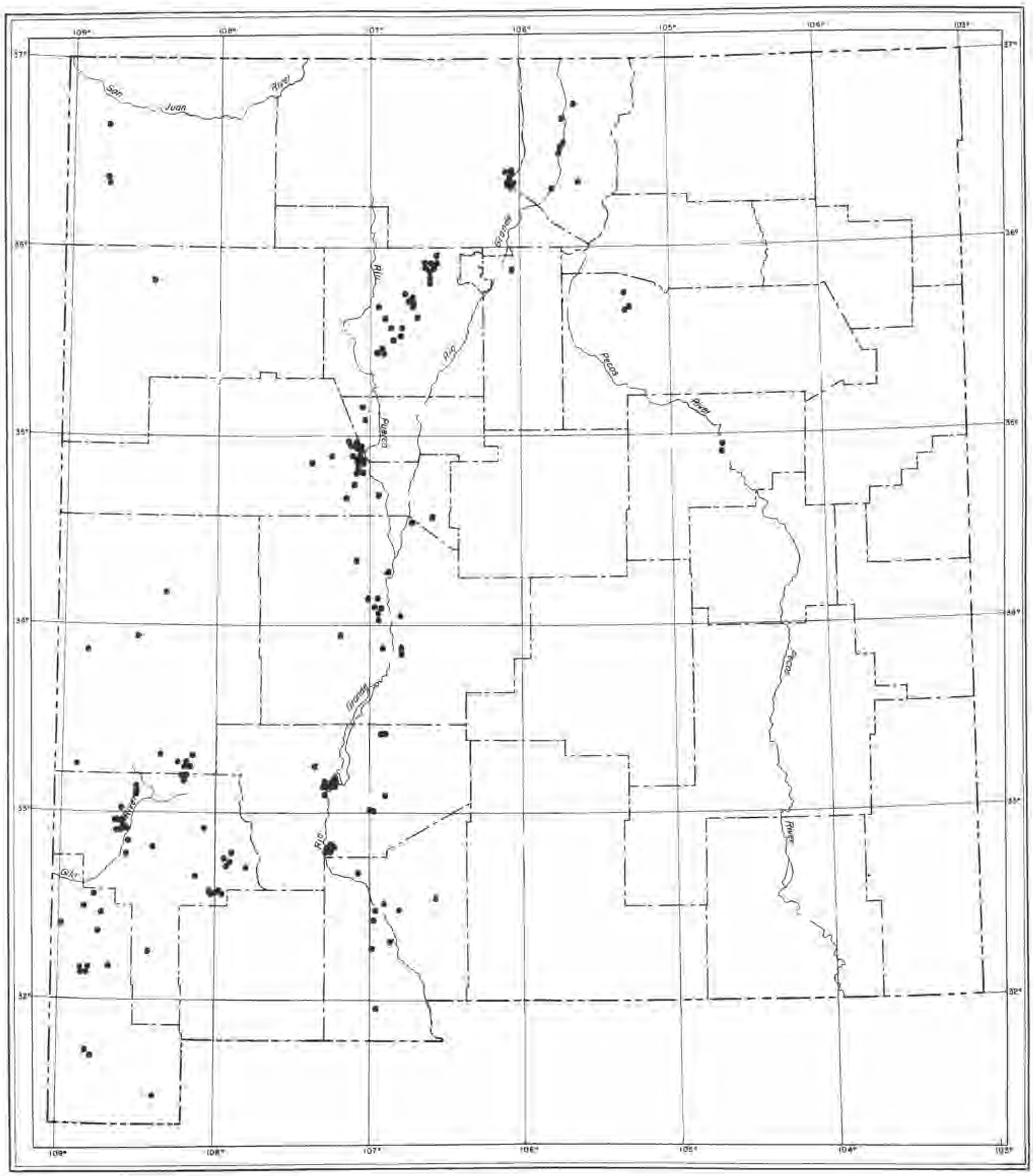

Figure 1
THERMAL SPRINGS AND WELLS IN NEW MEXICO

GEOLOGICAL BACKGROUND

The thermal waters of New Mexico are generally related to faults associated with igneous rocks of Tertiary or Quaternary age. The only exceptions to this are those where the faults are obvious but the source of heat is not, such as Truth or Consequences. For the most part, the thermal waters are located along the fault zones of the Rio Grande trough and are scattered through the southwest quarter of the state where there are numerous faults and volcanic remnants.

Thermal waters in New Mexico are difficult to inventory in one sense; they occur both as discrete units and as a series of springs or wells. For this report, the concept of spring or well group is introduced. If several springs or wells discharge water which seems for any reason to be genetically related and if the springs or wells are relatively close together, they are considered as one spring or well group. Well groups were separated from spring groups, even when the wells and springs were closely related, because the chemistry of discharging well waters is not necessarily the same as that of discharging spring waters even though the water discharges from the same aquifer.

THE 90°F DIVIDING POINT

The decision to discuss the properties of those waters having a temperature of 90 degrees or more was somewhat arbitrary. Temperatures of 80, 85, 95, or 100 degrees could have been used. If Meinzer's definition (1923, p. 54) of a hot spring, ". . . one whose water has a higher temperature than that of the human body . . . ," had been used, only those springs with temperatures of 98.6°F or more would have been included. The 90°F point was chosen primarily because it marks the approximate breaking point on a frequency plot of a number of thermal groups versus temperature. There are, relatively speaking, many more thermal groups whose maximum temperatures are less than 90°F than there are groups whose maximum temperatures are more than 90°F (table 1). Moreover, there are no groups in the temperature range from 87° to 89.9°F.

Also, the 90°F water, whether it comes from wells or springs, is definitely anomalous. At low discharge rates (less than 1 gpm), discharging waters warm rapidly. For the observed discharges, it is unlikely that air temperature artificially elevated any of the reported temperatures. Then the chemistry of water at 90°F plus seems to be much more distinctive than for waters at less than 90°F, thereby meriting special attention. And finally, these waters are the first-order prospects in exploring for natural steam, so an economic reason exists for studying the higher temperature waters.

TABLE 1. FREQUENCY OF THERMAL WATER IN NEW MEXICO

RANGE OF MAX. RPTD. TEMPS. (°F)	NO. OF SPRINGS	NO. OF SPRINGS W/CHEM. ANAL.	NO. OF CHEM. ANAL. AVAILABLE	NO. OF WELL GROUPS	NO. OF WELL GROUPS W/CHEM. ANAL.	NO. OF CHEM. ANAL.
65-79.9	70	40	57	15	12	13
80-89.9	12	9	18	11	4	4
90 or more	35	23	135	25	9	19
Total	117	72	210	51	25	36

Statistical Character

Tables 2 and 3 list the well and spring groups of New Mexico; tables 4 and 5 summarize the available chemistry of water data. Wherever possible, all the available information has been given. Notable exceptions include obvious misstatements. For example, one analysis showed 35,000 ppm sulfate ion and only 13,000 ppm total dissolved solids. Such obvious inaccuracies were not used in the computations of averages.

Where the results of chemical analysis are expressed either as the concentration of individual sodium and potassium ions or as their sum, the concentration of individual ions was used wherever possible, even if it meant not using several other bits of data.

Figures 2 and 3 are the analyses plotted in trilinear diagrams, which show the relative concentrations of the eight most common ions in solution in water—

TABLE 2A. SPRINGS IN NEW MEXICO WITH TEMPERATURES OF 90°F OR MORE FOR WHICH CHEMICAL ANALYSES ARE AVAILABLE

NO.*	COUNTY	NAME	LOCATION	TEMP. (°F)	DIS-CHARGE (gpm)	DISCHARGE FROM	NO. OF ANAL.
1	Catron	Frisco Hot Springs (upper)	5S.19W.34.200	98	—	Alluvium and Gila Conglomerate	1
2		Frisco Hot Springs (lower)	12S.20W.23.100	117.0	20+	Lava of Tertiary age	3
3	Dona Ana	Radium Hot Springs	21S.1W.10.213	128	10	Rhyolite dikes intruded into latitic tuffs	5
4	Grant	Gila Hot Springs	13S.13W.5.241	147	100	Lava	2
5		Hot Spring	13S.13W.10.121	126	10	—	1
6		Mimbres Hot Springs	18S.10W.18.100	137	20	From Mimbres fault zone; latite and rhyolite at surface	3
7		Faywood Hot Springs	20S.11W.20.243	129.2	50	From base of laval slope, issues from top of travertine mound	3
8	Rio Arriba	Ojo Caliente	24N.8E.	115	15	—	6
9		Spring	25N.8E.25.	97	—	Dakota Sandstone?	5
10	San Miguel	Montezuma Hot Springs	16N.16E.6.	130	5	—	6
11	Sandoval	Spring and oil test	16N.1W.1.410	180	—	—	2
12	Sandoval	Indian Spring	16N.2E.29.142	95	2	—	1
13		Soda Dam Springs (The Sulphurs)	18N.2E.14	110	40	Tuff deposit in river channel; contact with granite of Precambrian age and Magdalena Group	22
14		Jemez Hot Springs	18N.2E.23	164	25	Fault in red beds of Permian age	10
15		McCauley Hot Spring	18N.3E.4	98	110	From base of recent volcanic flow on contact with red beds of Permian age	1
16		Sulphur Springs on Sulphur Creek	19N.3E.4	188	15	From andesites and rhyolites of Tertiary age	28
17		Natural Bath Tub Hot Spring	19N.3E.28.310	100	—	From base of recent volcanic flow on contact with red beds of Permian age	1
18		Alamo Canyon Spring	20N.3E.35	—	—	—	1
19		Spring on Rio Antonio	20N.4E.7	101	25	From rhyolite of Tertiary age	1
20	Sierra	Springs at Truth or Consequences	13S.4W.33 & 14S.4W.4	110.5	8.5	From alluvium and Magdalena limestone	16
21	Sierra	Derry Warm Springs	17S.4W.29.340	93.2	50	From limestone buff; small deposits of travertine	3
22	Socorro	Socorro Warm Springs	3S.1W.22.113	92	353	From lake beds of Tertiary age lying against lava hills; rhyolite agglomerate	8
23		Sedillo Spring	3S.1W.22.131	90	240	From rhyolite breccia	2

*Number refers to Figure 2.

calcium, magnesium, sodium, potassium, bicarbonate, carbonate, sulfate, and chloride. These diagrams indicate that the most quantitatively significant cations in solution in the thermal waters of New Mexico are sodium and potassium. Inspection of the basic data in Tables 4 and 5, however, reveals that the major portion of this combination is sodium.

The anions show no such simple pattern. Several of the springs are clearly rich in chloride, one is rich in sulfate, still others are rich in bicarbonate; and a few are mixtures of either bicarbonate and sulfate or bicarbonate and chloride. This is somewhat in contrast to the results of a comprehensive study of the springs of the Socorro area made by Hall, who found that for 72 springs with temperatures from 43° to 90°F, the waters ranged from calcium-rich to sodium-rich and from bicarbonate-rich to sulfate-rich, with the preponderance of samples being calcium-bicarbonate wa-

TABLE 2B. SPRINGS IN NEW MEXICO WITH TEMPERATURES OF 90°F OR MORE FOR WHICH NO CHEMICAL ANALYSES ARE AVAILABLE

COUNTY	SOURCE	LOCATION	TEMP. (°F)	DIS-CHARGE (gpm)	DIS-CHARGE FROM
Catron	spring	11S.14W.25	160	900	—
	spring	12S.13W.11	151	30	Lava
	spring	12S.13W.14	100	—	—
Grant	warm spring	16S.12W.22	150	—	—
	Hudson's Hot Spring	18S.10W.4.100	142	—	Lava
	Apache Tejo Warm Spring	19S.12W.19.300	97	2000	—
Sandoval	Spense Hot Springs	14N.3E.28	110	100	—
	San Antonio Spring	20N.3E.29	130	150	—
Sierra	springs	14S.4W.4	110.8	—	—
	Cabello Springs	14S.5W.12.4	136	—	—
Taos	Ponce de Leon Hot Spring	24N.13E.7	98	100	—
	Mamby's Hot Spring	26N.11E.1	100	—	—

TABLE 3A. WELLS IN NEW MEXICO WITH TEMPERATURES OF 90°F OR MORE FOR WHICH CHEMICAL ANALYSES ARE AVAILABLE

NO.	COUNTY	SOURCE	LOCATION	TEMP. (°F)	DIS-CHARGE (gpm)	DISCHARGE FROM	DEPTH (feet)	NO. OF ANAL.
1	Dona Ana	well	23S.1W.31.400	90	13.2		1200	1
2		Wildcat oil well	28S.2W.24.213	113	500	Limestone; Cretaceous age	675	1
3	Grant	Drilled well	15S.17W.27.111	92	10	Gila Conglomerate	300	1
4	Hidalgo	Three wells	25S.19W.7.234	240	—	"hard rock"; "solid rock"	106	6
5-6	Sandoval	Spring and oil test	16N.1W.1	115 130	— 1500	Aqua Zarca, San Andres, Abo, and Magdalena formations	500 2008	1 1
7-8		Steam well Oil test well	20N.3E.35 16N.1W.1.410	— 140	— —		 2000	2 1
9	Sierra	Oil test: Victoria Land and Cattle Co. No. 2	10S.1W.25.100	94	900	San Andres limestone	1328-1347	1
11		Drilled wells at Truth or Consequences	13S.4W.33	114	—	Magdalena limestone	105	3
11		Wells of Truth or Consequences	14S.4W.4	—	—	Magdalena limestone	212	2
10		Wells at Yucca Baths at Truth or Consequences	14S.4W.4	108	8.5		14	2
12	Socorro	Well (Blue Canyon)	3S.1W.16.323	90.4	20	Rhyolite breccia	210	3

TABLE 3B. WELLS IN NEW MEXICO WITH TEMPERATURES OF 90°F OR MORE FOR WHICH NO CHEMICAL ANALYSES ARE AVAILABLE

COUNTY	SOURCE	LOCATION	TEMP. (°F)	DIS-CHARGE (gpm)	DISCHARGE FROM	DEPTH (feet)
Bernalillo	well	10N.2W.21.343	90	—	—	1180
Dona Ana	well	19S.2W.9.120	120	100	—	110
	Kilbourne Hole	27S.1W.8	100	—	—	100
Grant	well	16S.17W.10.433	90	—	—	—
Hidalgo	well	25S.19W.7.143	98	—	—	—
	Humble Oil and Refining Co. No. 1	32S.16W.25	BH 320	—	—	14588
Sandoval	Westates Petroleum No. 1	20N.3E.35	BH 400+	—	—	3675
Sierra	Victoria Land and Cattle Co. No. 2	10S.1W.25	BH 122	—	—	6059
	Victoria Land and Cattle Co. No. 1	10S.1W.27	BH 170	—	—	6352
	Sixteen wells	13S.4W.33	98.6—112.5	—	Magdalena limestone	20-250
	Eight wells	14S.4W.4	107—116	—	Magdalena limestone	105-225
	Barney Iorio No. 1 fee	14S.5W.25	90	30	—	1550
	Sunray—Midcontinent No. 1	15S.2W.23	BH 236	—	—	9765

ters. He located only one spring with water rich in chloride (fig. 4).

Hall noted that water which came largely from volcanic rocks was richest in sodium, whereas water which issued from sedimentary rocks was richest in calcium. He states, "Apparently, a sodium bicarbonate content can be obtained in . . . rhyolitic material either by solution, . . . or by cation exchange. . . ." Of the 72 springs Hall sampled, he considered only 5 to be in equilibrium with a $CaCO_3$—CO_2—H_2O system and only 3 to be in equilibrium with a $CaCO_3$—CO_2—$CaSO_4$—H_2O system.

Of the springs included in this discussion, only the Derry Warm Springs has nearly equal concentrations of the three anion components, and only the analyses of water from the "Spring and oil test" (no. 11 table 2A; nos. 5-6, table 3A) in Sandoval County show a sulphate-chloride water.

The fluoride ion concentration is, generally speaking, high. According to Hem (1959, p. 113), "Ordinarily waters having [fluoride] concentrations of 10 ppm or more are rare and surface waters seldom contain more than 1.0 ppm." Yet of the chemical analyses presented in Tables 4 and 5 which report fluoride, six have concentrations of 16 ppm or more and ten have concentrations of 5.0 ppm or more. Only five have a concentration of less than 1.0 ppm.

In general, the pH of thermal water is greater than 7.0. Thermal water is, therefore, more alkaline. The major exceptions are the acid waters of Sulphur Springs in Sandoval County (pH = 2.0) and its neighbor, Alamo Canyon Spring (pH = 2.9).

Unusual concentrations of boron occur at Soda Dam Springs and at Jemez Springs; unusually high concentrations of radium occur at Faywood Hot Springs. The other constituents given in Tables 4 and 5 occur in concentration ranges that are not unusual for natural water (Hem).

CHARACTERISTICS OF SELECTED THERMAL AREAS

As a foundation for later critical evaluation of the data, it is necessary to describe features of some of the thermal areas in the state. In the following paragraphs, various aspects of the available data are reviewed from the standpoint of subsequent evaluation, rather than attempting to describe them completely.

TRUTH OR CONSEQUENCES AREA

Theis, Taylor, and Murray described the Truth or Consequences area in some detail. The water generally ranges in temperature from 98° to 114°F, is obtained principally from limestones of the Magdalena Group of Pennsylvanian age, and is essentially sodium chloride with lesser amounts of calcium-magnesium carbonate. Theis, Taylor, and Murray believed the thermal water to be ground water that circulates to great depth, comes in contact with a hot igneous rock, and finds a convenient conduit to the surface through a fault-fracture zone that terminates beneath the alluvium at Truth or Consequences. They estimated that the amount of thermal water discharged from the area is about eight times that discharged by Old Faithful geyser in Yellowstone Park and that the amount of heat brought to the surface is about two and a half times as great.

The thermal waters of Truth or Consequences are particularly noteworthy for their uniform chemical characteristics, whether the water issues from springs or wells. Samples of the water from the Yucca Hotel (Ponce de Leon Springs) collected intermittently since 1939 indicate that there has been no change in the gross chemical characteristics of the water.

SPRINGS OF THE VALLE GRANDE CALDERA

The Valle Grande caldera in the Jemez Mountains is the product of a long history of volcanism that began in Pliocene time (Ross, Smith, and Bailey, 1961, p. 143). In and around the caldera are thermal springs which seem to be the last vestiges of the volcanism. Sulphur Springs is a spring group in the caldera within a mile of the only steam wells ever drilled in New Mexico. Soda Dam Springs and Jemez Springs are two related spring groups occurring outside of but near the caldera.

Sulphur Springs

Figure 5 is a sketch map showing locations of the several springs at Sulphur Springs. Analyses are available for each of these, but of the 26 samples collected, 21 at best can be related with confidence to the springs from which they came. Some of these springs have been sampled several times; others have been sampled on only a few occasions.

Difficulties in interpretation arise in using the data because some springs are known by several names, and apparently two or more springs have been called by the same name. The difficulty is further compounded in that the chemical analyses from individual springs are inconsistent. Analyses made of the water from a given spring over a period of years give quite different concentrations of the constituents without any pattern in their variations.

The maximum reported temperature of the springs is 188°F. Mr. W. E. Culler, owner, says (personal communication, June 1965) that he has drilled into the area near Lemonade Spring (fig. 5) four or five feet and measured temperatures as high as 200°F. Three fumaroles (figs. 5 and 6) near Lemonade Spring emit steam. Native sulphur impregnates the rock throughout the area. Crystals of sulphur collected in the area are on display in the museum of the New Mexico Institute of Mining and Technology.

Each spring bubbles (fig. 7). Analyses of the gases (White, Hem, and Waring, 1963, p. F58, n. 28; Renick, 1931, p. 89) indicate that these bubbles are about 78 per cent carbon dioxide, 20 per cent hydrogen sulfide, and 1 per cent each of nitrogen and oxygen.

The chemical analyses are consistent in that they show that the predominant ions in solution are sulfate, aluminum, silica, and hydrogen, with only minor amounts of other ions and no carbonate or bicarbonate ions at all. The pH is also consistent, ranging from 1.4 to 3.1.

The steam wells 0.5 and 1.0 mile north of the springs, which presumably tap the same heat reservoir, have a somewhat different chemical character. The steam condensate is rich in bicarbonate with lesser amounts of sulfate and chloride. Its pH is 8.0 or higher. In one respect, the steam condensate is like the water from the springs: It has relatively low concentrations of calcium, magnesium, sodium, and potassium. Some other cations must balance the anions. Since no analysis has been made to determine what these cations might be, the first guess is aluminum or hydrogen ions like those found in the Sulphur Springs analyses.

The waters of Sulphur Springs are either a mixture of meteoric water and water released from the cooling rocks of the heat reservoir (White, 1957, p. 1651) or meteoric water that has taken on unique chemical properties because of the heat of the reservoir it has passed through and the chemical character of the rocks constituting the reservoir (Ellis and Mahon, 1964).

Jemez Springs and Soda Dam Springs

Outside the caldera, several spring groups discharge water that is warm or hot. Ross, Smith, and Bailey (p. 143) seem to think these springs tap the same heat reservoir as the water discharging at Sulphur Springs. However, other factors influence the chemical character of the discharging waters, which are only slightly acid (pH = 6.7) to alkaline (pH = 8.1) and are sodium chloride-bicarbonate waters with only minor concentrations of sulfate. The springs bubble at their source, releasing dissolved gases that have strong odors of hydrogen sulfide, but analysis of the associated gas (Renick) shows no hydrogen sulfide, 83 per cent carbon dioxide, 14 per cent nitrogen, and 3 per cent oxygen.

At Soda Dam, the discharging spring waters have built a dam of travertine across the Jemez River (fig. 8). Although the waters of Jemez Springs are similar, the total concentrations of ions is less at Soda Dam. No deposit corresponding to Soda Dam has built up at Jemez Springs. The water issues from joints (fig. 9) presumably associated with a fault that brings rocks of the Magdalena Group into contact with rocks of Precambrian age.

The waters of Jemez Springs and Soda Dam Springs are probably meteoric ground water that has circulated into a heat reservoir, then carried the heat to the surface.

TABLE 4. SUMMARY OF CHEMICAL ANALYSES OF WATER
(constituents in parts per

CONSTITUENT	UPPER FRISCO HOT SPRING	LOWER FRISCO HOT SPRING	RADIUM HOT SPRINGS				GILA HOT SPRINGS	HOT SPRING GRANT
			NO. OF ANAL.	MIN.	AVG.	MAX.		
Dischg. (gpm)	—	20+	—	—	10	—	25-100	10
Temp. °F (max. rpt.)	130	124	—	—	168	—	147	126
SiO_2	58	80*	3	66	70	75	51*	—
Al	—	—	1	—	0.1	—	0.31	—
Fe	—	—	2	0	0.08	0.15	0.00*	—
Mn	—	—	2	0.1	0.25	0.40	0.00	—
Pb	—	—	—	—	—	—	—	—
Cu	0.00	0.00	1	—	0.0	—	—	—
Zn	0.01	0.00	1	—	0.25	—	—	—
Ca	—	—	3	126	133	142	11.5*	—
Mg	—	—	3	12	17	23	0.1*	—
Ba	2.2	0	1	—	0	—	—	—
Na	66	280	3	1100	1100	1100	121	—
K	0.5	16	3	155	150	163	3.6	—
Li	—	—	—	—	—	—	—	—
As	—	—	—	—	—	—	—	—
Se	—	—	—	—	—	—	—	—
HCO_3	57	131*	4	317	396	424	108*	108
CO_3	55	0	2	0	0	0	0*	0
SO_4	6.6	43*	4	255	267	277	43*	22
Cl	5.0	473*	4	1650	1667	1680	103*	59
F	1.0	1.7*	4	4.6	5.1	5.7	10.5*	—
NO_3	0.8	1.4	4	0.26	1.2	2.0	0.5, 0.07	—
PO_4	—	—	—	—	—	—	0.0	—
B	0.04	0.32	1	—	0.32	—	—	—
Total Solids	—	—	3	3540	3606	3660	401*	—
Hardness as $CaCO_3$	10	150*	4	364	396	449	29*	15
Noncarbonate Hardness as $CaCO_3$	0	42*	1	—	32	—	0	0
Specific conductance (μmhos/cm)	284	1795*	4	5540	5950	6100	646*	432
pH	9.7	7.6	3	7.2	7.2	7.2	8.2, 7.5	8.1
Acidity as SO_4	—	—	—	—	—	—	—	—
H_2S	—	—	—	—	—	—	—	—
Total β-γ activity ($\mu\mu c/l$)	—	—	1	—	170	—	—	—
Ra ($\mu\mu c/l$)	—	—	1	—	0.6	—	—	—
U ($\mu g/l$)	—	—	1	—	18	—	—	—

* average of two analyses
† average of three analyses

FROM 23 OF NEW MEXICO'S WARMEST SPRINGS
million unless noted)

MIMBRES HOT SPRING	FAYWOOD HOT SPRING	OJO CALIENTE RIO ARRIBA COUNTY (analyses from three springs)				SPRINGS SEC. 25, T. 25 N., R. 8 E. RIO ARRIBA COUNTY			
		NO. OF ANAL.	MIN.	AVG.	MAX.	NO. OF ANAL.	MIN.	AVG.	MAX.
20	50	—	0.25	—	15	—	—	—	—
137	129	—	90	—	113	—	—	—	97
53	43	5	56	62	66	2	15	—	22
—	0.0	—	—	—	—	—	—	—	—
—	0.1	2	0.01	—	0.02	1	—	0.01	—
—	0.00	—	—	—	—	—	—	—	—
—	0.00	—	—	—	—	—	—	—	—
—	0.00	—	—	—	—	—	—	—	—
—	0.00	—	—	—	—	—	—	—	—
12	37.5*	5	23	24.4	25	2	44	—	145
2.6	7.9*	5	7.6	8.6	9.0	2	11	—	59
—	—	—	—	—	—	—	—	—	—
80	85	3	928	953	997	2	11	—	187
86	7.8	3	29	31	34	2	11	—	187
—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—
90†	281†	5	2160	2182	2210	5	73	571	698
17*	0†	5	0	0	0	5	0	0	0
65	51*	5	156	161	168	2	110	—	270
17†	17†	5	238	240	245	5	2.5	88	111
16†	6.9*	5	16	16	16	2	0.2	—	1.4
0	0.15*	5	0.3	10	1.7	2	0.2	—	0.2
—	0.00	—	—	—	—	—	—	—	—
—	—	4	1.0	2.4	4.6	—	—	—	—
308	384	5	2530	2596	2650	2	230	—	1140
20†	120†	—	—	—	—	2	115	—	604
0	0*	5	91	100	106	2	32	—	95
453†	604	5	0	0	0	5	347	1463	1760
—	7.4	3	6.9	7.1	7.2	1	—	7.0	—
—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—
—	19	—	—	—	—	—	—	—	—
—	29	—	—	—	—	—	—	—	—
—	0.1	—	—	—	—	—	—	—	—

TABLE 4. SUMMARY OF CHEMICAL ANALYSES OF WATER

(constituents in Darts

CONSTITUENT	MONTEZUMA HOT SPRINGS NO. OF ANAL.	MIN.	AVG.	MAX.	SPRING AND OIL TEST
Dischg. (gpm)	—	1	—	.5	—
Temp. °F (max. rpt.)	—	—	—	130	180
SiO_2	2	59	—	68	33*
Al	—	—	—	—	—
Fe	2	0.02	—	0.03	0.00
Mn	—	—	—	—	—
Pb	—	—	—	—	—
Cu	—	—	—	—	—
Zn	—	—	—	—	—
Ca	4	14	7.9	4.5	315*
Mg	4	8.3	2.2	0.7	72*
Ba	—	—	—	—	—
Na	4	141	168	179	3545*
K	4	141	168	179	3545*
Li	—	—	—	—	—
As	—	—	—	—	—
Se	—	—	—	—	—
HCO_3	5	66	79	92	1440*
CO_3	5	11	15	22	0*
SO_4	4	66	50	42	3330*
Cl	6	154	157	160	2935*
F	2	20	—	20	4.5
NO_3	3	0.1	0.1	0.2	8.1
PO_4	—	—	—	—	—
B	—	—	—	—	6.6
Total Solids	6	523	534	554	10950*
Hardness as $CaCO_3$	2	15	—	16	1080*
Noncarbonate Hardness as $CaCO_3$	2	0	—	0	0*
Specific conductance (μmhos/cm)	6	872	875	878	14950*
pH	2	8.8	—	9.0	6.6, 7.2
Acidity as SO_4	—	—	—	—	—
H_2S	—	—	—	—	—
Total β-γ activity (μμc/l)	—	—	—	—	—
Ra (μμc/l)	—	—	—	—	—
U (μg/l)	—	—	—	—	—

* average of two analyses

FROM 23 OF NEW MEXICO'S WARMEST SPRINGS (cont)
per million unless noted)

INDIAN SPRING	SODA DAM SPRINGS NO. OF ANAL.	MIN.	AVG.	MAX.	JEMEZ HOT SPRINGS NO. OF ANAL.	MIN.	AVG.	MAX.
2	—	—	40	—	—	10	—	25
95	—	—	—	110	—	—	—	160
48	11	35	45	48	9	47	75	93
—	—	—	—	—	—	—	—	—
0.03	3	0.04	.08	0.1	6	0	0.2	1.2
—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—
100	14	221	321	344	9	18	106	166
8.6	14	23	29	33	9	4.4	8.7	14
—	—	—	—	—	—	—	—	—
1240	2	1000	—	1020	5	12	251	618
1240	2	183	—	197	5	3.0	30	70
—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—
1280	21	1200	1473	1590	10	94	577	791
0	21	0	0	0	9	0	0	0
286	17	37	107	912	9	15	36	51
1140	21	1080	1426	1590	9	4	558	870
7.3	12	2.4	3.1	4.0	8	0.8	3.7	7.1
0.3	14	0	1.4	4.3	9	0.3	1.2	5.0
—	—	—	—	—	—	—	—	—
6.1	9	8.7	9.7	14	2	6.3	—	11
3470	14	3060	3617	4150	9	153	1527	2190
285	14	670	919	999	9	70	300	452
0	12	0	0	0	8	0	0	0
5680	20	5160	6090	6720	9	184	2187	3860
8.0	8	6.7	6.86	7.0	5	6.7	7.2	7.7
—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—

TABLE 4. SUMMARY OF CHEMICAL ANALYSES OF WATER

(constituents in parts

CONSTITUENT	MCCAULAY SPRING	SULPHUR SPRINGS NO. OF ANAL.	SULPHUR SPRINGS MIN.	SULPHUR SPRINGS AVG.	SULPHUR SPRINGS MAX.	NATURAL BATH-TUB HOT SPRING	ALAMO CANYON SPRING	SPRING ON RIO ANTONIO
Dischg. (gpm)	110	—	—	—	—	—	—	25
Temp. °F (max. rpt.)	98	—	—	—	188	100	—	101
SiO_2	53	18	42	192	324	71	87	103
Al	—	17	36	271	694	—	—	—
Fe	0	20	0.6	200	1250	0	0.41	0
Mn	—	3	.33	1.6	3.3	—	—	—
Pb	—	1	—	0.12	—	—	—	—
Cu	—	1		trace		—	—	—
Zn	—	—	—	—	—	—	—	—
Ca	11	20	6.9	176	372	7.5	32	6.5
Mg	4.2	20	9.7	58	161	2.2	22	1.1
Ba	—	—	—	—	—	—	—	—
Na	23	7	6.7	13	24	56	—	40
K	23	5	12	31	47	56	—	40
Li	—	1	—	0.07	—	—	—	—
As	—	1	—	0.05	—	—	—	—
Se	—	2	0	—	0.03	—	—	—
HCO_3	87	18	0	0	0	139	0	77
CO_3	0	15	0	0	0	0	0	0
SO_4	8.0	24	614	3283	6154	17	242	15
Cl	8.0	19	1.0	113	649	11	3.0	17
F	1.6	10	0	0.9	1.5	0.8	0.3	1.6
NO_3	0.4	17	0	0.26	1.0	0.2		0.4
PO_4	—	7	2.4	50	154	—	0.6	—
B	0	—	—	—	—	0.8	—	0
Total Solids	152	12	967	4013	8617	234	—	230
Hardness as $CaCO_3$	45	10	57	361	676	28	—	20
Noncarbonate Hardness as $CaCO_3$	0	8	0	268	514	0	—	0
Specific conductance (μmhos/cm)	19.8	19	794	5821	13900	28.3	72.1	16.7
pH	8.1	20	1.4	2.0	3.1	7.3	2.9	6.7
Acidity as SO_4	—	4	2304	3151	5400	—	—	—
H_2S	—	5	1.6	2.8	8.2	—	—	—
Total β-γ activity (μμc/l)	—	—	—	—	—	—	—	—
Ra (μμc/l)	—	—	—	—	—	—	—	—
U (μg/l)	—	—	—	—	—	—	—	—

* average of two analyses

† average of three analyses

FROM 23 OF NEW MEXICO'S WARMEST SPRINGS (cont)

per million unless noted)

SPRING AT TRUTH OR CONSEQUENCES				DERRY	SOCORRO WARM SPRING				
NO. OF ANAL.	MIN.	AVG.	MAX.	WARM SPRING	NO. OF ANAL.	MIN.	AVG.	MAX.	SEDILLO SPRING
—	—	—	6.5	50	—	—	350	—	240
—	—	—	110.5	93.2	—	—	—	92	90
4	36	38	41	32	2	27	—	39	27
1	—	0.1	—	—	1	—	0.00	—	—
5	0.01	0.07	0.10	—	1	—	0.00	—	—
1	—	0.19	—	—	1	—	0.00	—	—
—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	1	—	0.00	—	0.00
—	—	—	—	—	1	—	0.04	—	0.04
7	148	158	174	50*	7	13	17.5	19	18
7	14	22	36	20*	7	3.9	4.6	5	5
—	—	—	—	—	1	—	1.6	—	0.00
5	678	716	751	298	3	52	54	55	54
4	36	47	61	298	3	2.8	3.6	5	2.9
—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—
15	212	219	228	370†	8	154	159	168	157*
13	0	0	0	0†	5	0	1	5	2.5*
11	79	91	98	306†	7	20	28	33	29*
16	1210	1286	1310	153†	7	8	13	16	12*
5	2.8	3.1	3.3	5.9*	3	0.6	0.8	1.0	0.8
4	2.0	4.9	10	1.7*	4	0.6	1.1	1.3	1.3
—	—	—	—	—	1	—	0.15	—	—
—	—	—	—	—	1	—	0.06	—	0.05
5	2418	2541	2670	1030*	2	224	—	234	—
13	236	463	537	203†	8	52	64	74	64*
9	283	318	429	0*	2	0	—	0	0
15	4290	4449	4590	1657†	7	340	353	370	344*
10	7.2	7.3	7.5	7.4	6	7.8	8.0	8.4	8.3*
—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—
1	—	100	—	—	1	—	41	—	—
1	—	0.7	—	—	1	—	0.2	—	—
1	—	3.3	—	—	1	—	1.8	—	—

CONSTITUENT	WELL DONA ANA COUNTY (23S.1W. 31.400)	WILDCAT OIL WELL (28S.2W. 24.213)	DRILLED WELL GRANT CO. (15S.17W. 27.111)	THREE WELLS HIDALGO COUNTY (25S.19W.7.234)			
				NO. OF ANAL.	MIN.	AVG.	MAX.
Dischg. (gpm)	13.2	500	10	—	—	—	—
Temp. °F (max. rpt.)	90	113	92	—	—	—	240
SiO_2	19	—	48	3	135	138	141
Al	0.02	—	—	1	—	0.1	—
Fe	—	—	0.00	1	—	0.07	—
Mn	—	—	—	1	—	0.00	—
Pb	—	—	—	—	—	—	—
Cu	—	—	—	—	—	—	—
Zn	—	—	—	—	—	—	—
Ca	110	—	3.0	4	19	22	24
Mg	1.1	—	0.1	4	0.7	1.2	1.5
Na	928	1380	150	1	—	364	—
K	928	—	150	1	—	21	—
Li	—	—	—	—	—	—	—
Mo	—	—	—	—	—	—	—
As	—	—	—	—	—	—	—
Se	—	—	—	—	—	—	—
HCO_3	55	934	130	6	145	159	181
CO_3	—	0	24	6	0	3.3	7
SO_4	927	856	103	4	459	476	509
Cl	910	1610	18	6	78	82	85
F	—	—	21	3	9.9	11.3	13
Br	—	—	—	—	—	—	—
I	—	—	—	—	—	—	—
NO_3	3.3	—	0.1	5	0.2	1.6	6
B	—	—	—	1	—	0.45	—
Total Solids	2930	—	435	4	1020	1105	1160
Hardness as $CaCO_3$	279	736	8	5	52	5.8	66
Noncarbonate Hardness as $CaCO_3$	—	0	0	4	0	0	0
Specific conductance (μmhos/cm)	4640	7380	665	6	1510	1590	1660
pH	8.6	7.3	9.0	3	7.6	8.1	8.4
Total β-γ activity ($\mu\mu$c/l)	—	—	—	1	—	12	—
Ra ($\mu\mu$c/l)	—	—	—	1	—	0.3	—
U (μg/l)	—	—	—	1	—	0.2	—

* average of two analyses
† average of three analyses

AND HOT WATERS FROM WELLS

per million unless noted)

"SPRING AND OIL TEST" SANDOVAL COUNTY (16N.1W.1)		STEAM WELL SANDOVAL COUNTY (20N.3E.35)		ALLUVIUM (14S.4W.4)	TRUTH OR CONSEQUENCES MAGDALENA LIMESTONE (14S.4W.4 & 13S.4W.33)				VICTORIA LAND AND CATTLE CO. NO. 2 (8.2W.25.100)	BLUE CANYON WELL (35.1W.16.323)
5??? ft deep)	(2008 ft deep)				NO. OF ANAL.	MIN.	AVG.	MAX.		
—	1500	—	—	—	—	—	—	—	900	20
115	130	—	—	110	—	—	—	114	94	90.4
18	31	—	—	40*	2	32	—	38	—	26*
—	2.6	—	—	0.1	—	—	—	—	—	—
2.3	3.9	12.6	1.05	0.04†	5	0.07	0.24	0.53	—	—
—	0.01	0.5	0.03	0.19	—	—	—	—	—	—
—	0.6	—	—	—	—	—	—	—	—	—
—	0.04	—	—	—	—	—	—	—	—	—
—	1.5	—	—	—	—	—	—	—	—	—
400	345	0.28	2	161†	5	150	153	155	—	19*
75	56	0	1.2	22†	5	15	16	18	—	4.8*
3450	3550	83	83	735	5	692	730	772	—	0.56
3450	87	27	31	61	2	43	—	45	—	3
—	0.9	—	—	—	—	—	—	—	—	—
—	0.00	—	—	—	—	—	—	—	—	—
—	0.60	—	—	—	—	—	—	—	—	—
—	0.00	—	—	—	—	—	—	—	—	—
1498	1450	623	854	218†	5	121	196	219	636	158†
—	0	—	—	0*	—	—	—	—	—	3†
3645	3260	335	177	92†	5	73	86	105	1660	35†
2660	2990	121	114	1273†	5	1230	1266	1330	22	15†
—	2.8	24	24	3.1†	5	2.6	3.0	3.4	—	0.6
—	0.3	—	—	—	—	—	—	—	—	—
—	4.6	—	—	—	—	—	—	—	—	—
0	0.2	0.00	0.00	2.4*	2	2	—	6.2	—	1.1*
—	4.8	—	—	—	—	—	—	—	—	0.76
11120	11000	2970	1700	2655*	2	2437	—	2486	—	—
1299	1090	70	10	490†	4	441	448	457	1850	72†
—	0	—	—	—	—	—	—	—	—	0
—	15300	2225	2070	4470*	—	—	—	—	1850	381†
—	7.3	8.0	8.3	7.3*	—	—	—	—	7.2	9.8*
—	—	—	—	100	—	—	—	—	—	—
—	—	—	—	0.7	—	—	—	—	—	—
—	—	—	—	3.3	—	—	—	—	—	—

THERMAL SPRINGS AT SOCORRO

Hall (p. 168) writes, "The thermal springs at Socorro are of interest for several reasons: (1) their temperatures are about 90° to 91°F which is significantly higher than the average annual air temperature of 58°F, (2) they are sodium bicarbonate waters with low dissolved solids, and (3) two of them supply a large part of water for the city of Socorro and apparently have done so since pre-Spanish days. The two large springs, Sedillo or Evergreen and Socorro Warm Spring, have flows in excess of 200 gpm and lie on definite fault zones. The water-bearing formation is a rhyolitic breccia." A well in Blue Canyon (table 5) was drilled into the same breccia and yields the same type of water.

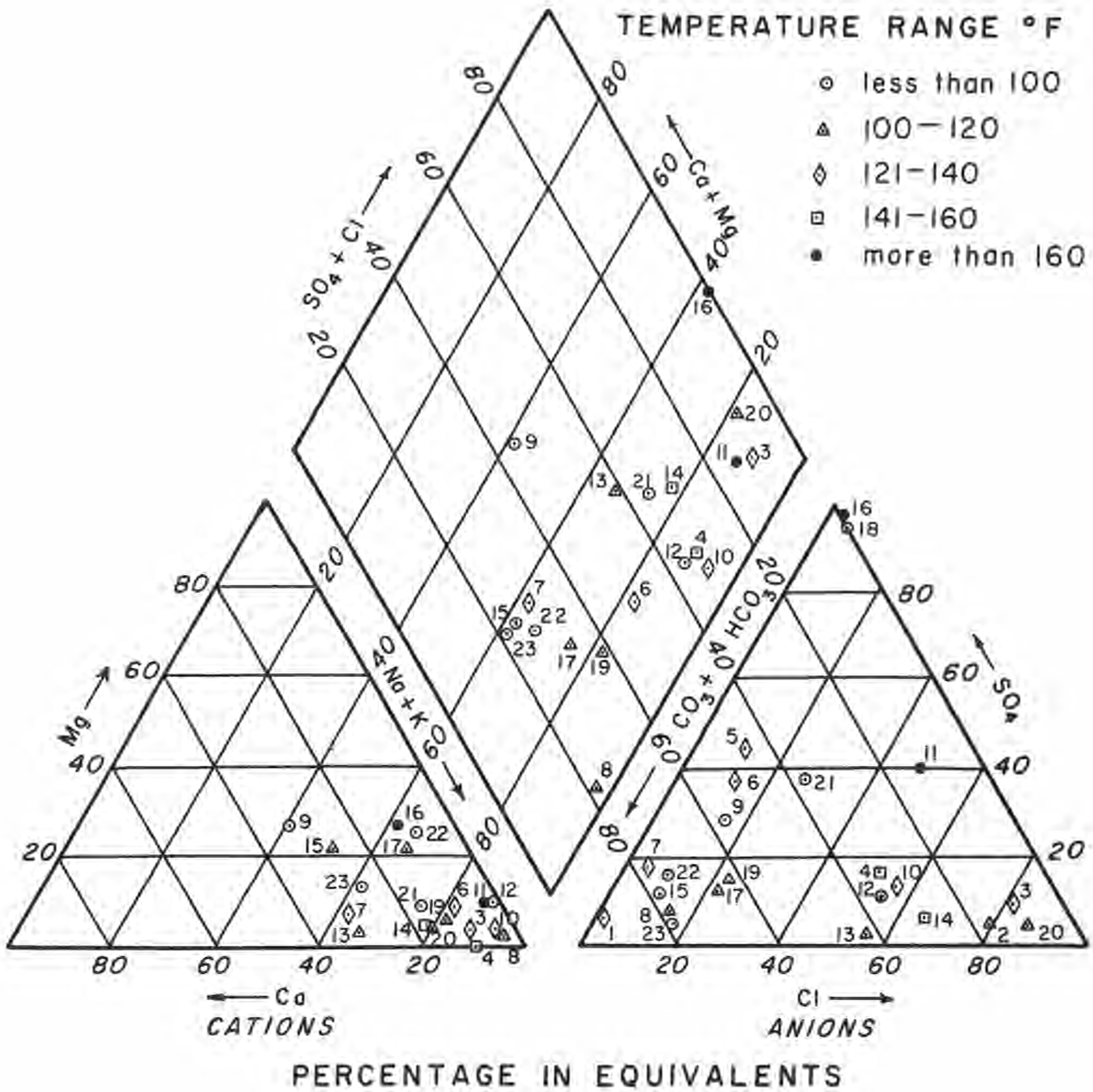

Figure 2

WATER-ANALYSIS DIAGRAM FOR 23 OF NEW MEXICO'S WARMEST SPRINGS

Hall goes on to say,

> At present, New Mexico Institute of Mining and Technology is conducting a study of the yield, temperature, chemical nature, and time in storage of water from the springs, with emphasis on the Socorro Spring. Samples have been taken for determination of tritium, and preliminary results indicate that the water has been out of contact with atmosphere for about four years (Holmes, 1963). Temperature measurements by a recorder since September 1962 have ranged between 90° and 91°F with no sharp fluctuations. Flow [290 gpm] in the spring has not varied since November 1962, when a recorder was installed.

Carbon dioxide discharges at the spring where the electrodes of a specific conductance meter (Hall) become covered with the gas bubbles, and the meter

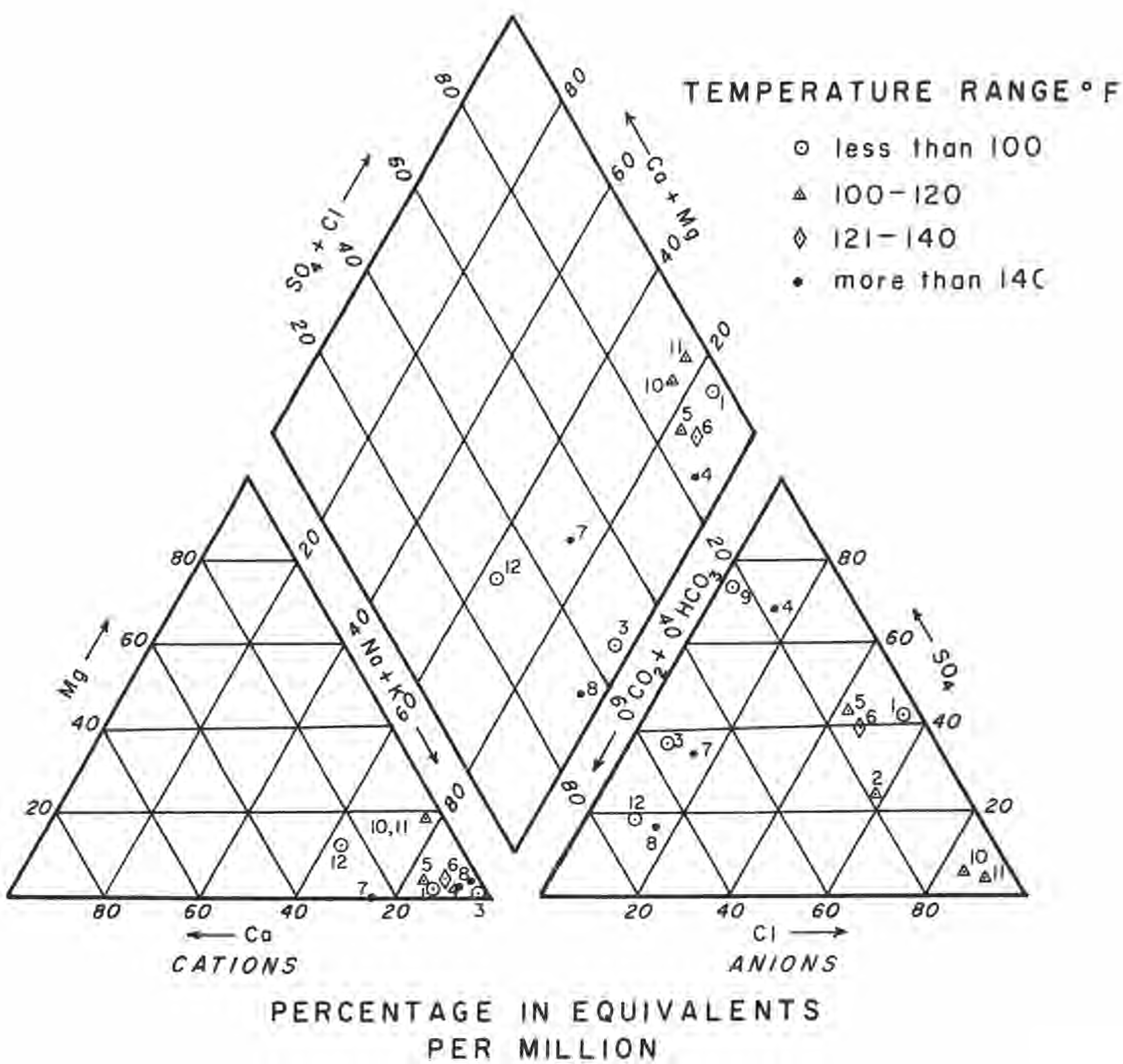

Figure 3
WATER-ANALYSIS DIAGRAM FOR 13 OF NEW MEXICO'S WARMEST WELLS

ceases to function if left in the spring overnight. The laboratory pH value of the water from the Socorro Warm Spring varies from 7.8 to 8.4. Following Hem's discussion of the relation of pH and carbon dioxide, this variation is probably due to sampling procedures more than to variation in the pH of the discharging water. The variations in the pH reflect the amount of carbon dioxide still in solution when the measurements are made.

THERMAL WELLS NEAR LORDSBURG

The occurrence of hot water (210° to 240°F) in a shallow alluvial water-table aquifer overlying a hot rhyolite(?) has been discussed by Kintzinger (1956) and by Reeder (p. 26). The water is meteoric water that has been warmed by the hot rock. Like that at Sulphur Springs, the water from the wells is sodium-sulphate, but unlike the Sulphur Springs water, it is alkaline rather than acid (pH = 8.2 to 8.4).

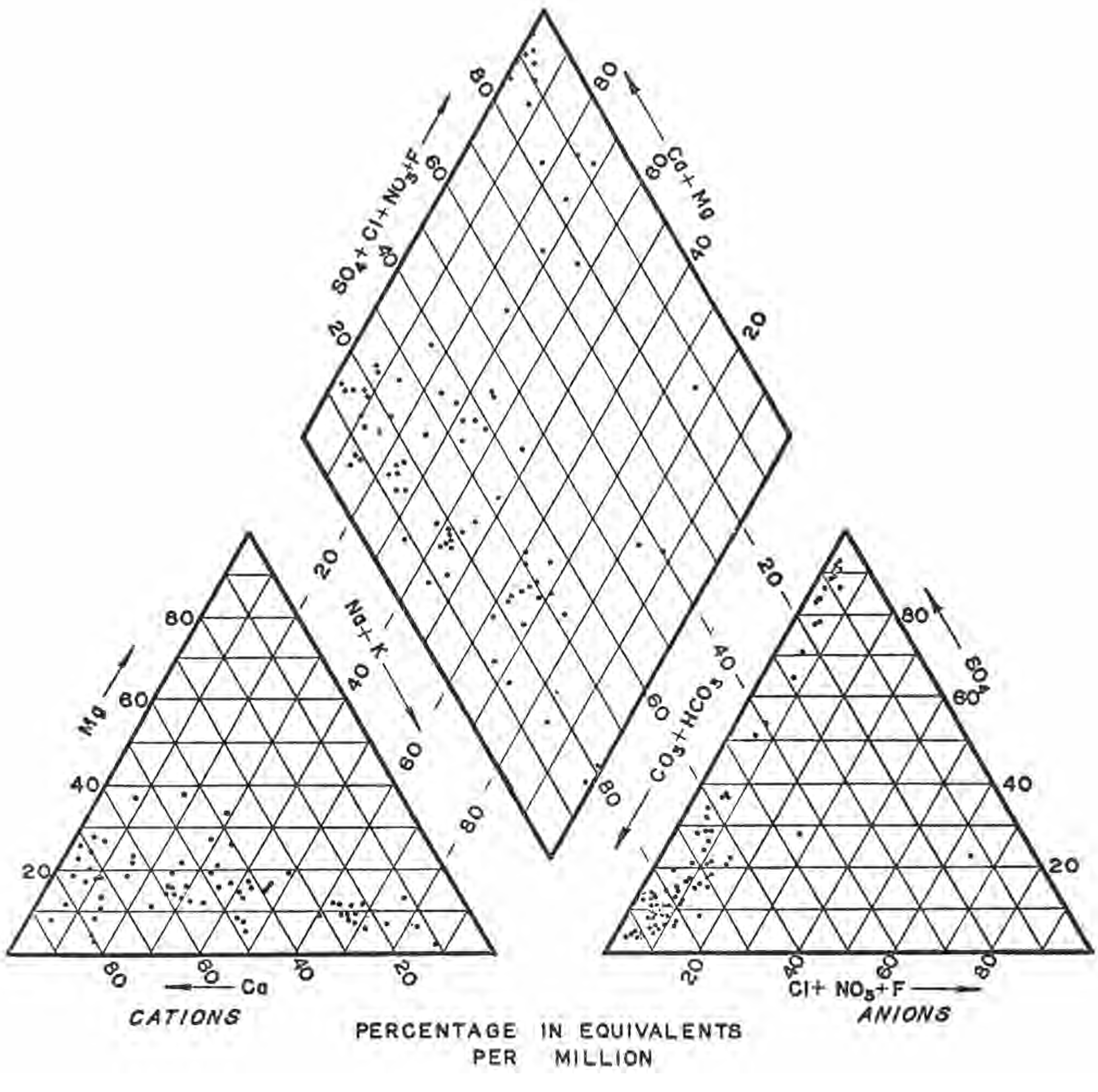

Figure 4
WATER-ANALYSIS DIAGRAM FOR SPRINGS IN THE VICINITY OF SOCORRO, SOCORRO COUNTY, NEW MEXICO
(After Hall, 1963)

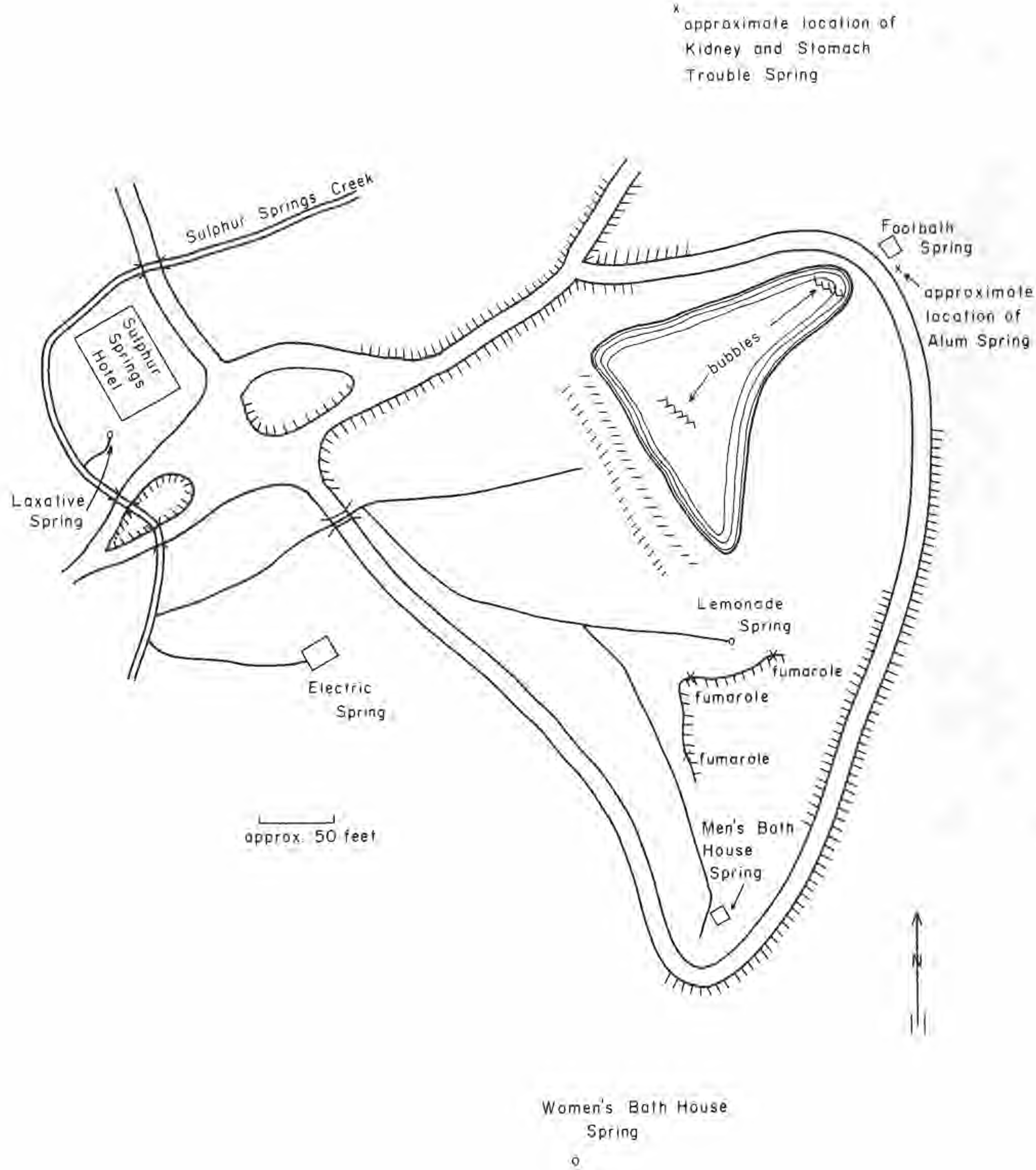

Figure 5
SKETCH MAP SHOWING THE LOCATIONS OF THE SPRINGS AT SULPHUR SPRINGS, NEW MEXICO

Figure 6
FUMAROLE NEAR LEMONADE SPRING, SULPHUR SPRINGS, NEW MEXICO
Steam issues from well-defined fracture in rock.

Figure 7
CARBON DIOXIDE-HYDROGEN SULFIDE GASES BUBBLE FROM WOMEN'S BATH HOUSE SPRING, SULPHUR SPRINGS, NEW MEXICO

Figure 8
SODA DAM
Calcareous tufa deposited from Soda Dam Springs dams the Jemez River.

Figure 9
SODA DAM SPRINGS
Water issues from fractures in rock. Three-eighths inch pipe centralizes part of the discharge.

Critique of the Data

Although the data reveal much about the chemical-physical characteristics of thermal waters in New Mexico, various aspects are open to criticism or leave significant questions unanswered.

TEMPERATURES

The temperatures reported leave much to be desired. A variety of factors influences temperature; yet, temperature measurements have been blandly made, apparently without effort to determine whether the temperature observed was a maximum for the discharging water or not.

At Lemonade Spring (Sulphur Springs), the temperature has been variously reported as 115°, 130°, and 150°F (all measured in July or August). Is this an indication that the spring is becoming warmer or does it reflect inadequate care in making the temperature measurements? Such measurements made at the other springs at Sulphur Springs show no warming trend.

Little or no information exists on how the temperatures of the New Mexico thermal springs vary, either in space or in time.

DISSOLVED GASES

Many of New Mexico's thermal waters have a strong smell of hydrogen sulfide and many give off carbon dioxide. Yet only token analyses (like those for Soda Dam Springs) exist of the dissolved gases, and these are not related to the total fluid volume that discharges. With the data available, answers are not possible for such questions as What weight per cent of the fluid discharging is gas and what per cent is water? What per cent of the dissolved gases is carbon dioxide? Hydrogen sulfide? Hydrogen? Oxygen? Ammonia? Methane? Nitrogen?

To what extent does the concentration of dissolved gases influence the total dissolved solids in the water? What is the source of the dissolved gases? Are the observed gases really dissolved gases or are they an associated fluid which never was actually in solution in the water?

CATIONS

Chemical analyses of water usually give the concentration of calcium, magnesium, and either sodium and potassium or sodium plus potassium. They may give the concentration of iron, manganese, aluminum, barium, lead, zinc, copper, or hydrogen. Analyses for other constituents are rare.

New Mexico is one of the mineral-rich states. In 1962, it ranked seventh among all the states in annual production of mineral resources and first among the states of the Rocky Mountain region (Bachman, 1965, p. 1). Many of the ore minerals have a hydrothermal origin, yet the chemical analyses of recent hydrothermal solutions are insufficient to make deductions about the process that generates hydrothermal deposits.

The geologist interested in the physics and chemistry of the earth finds no data on the minor or trace constituents; yet, the minor constituents make up the important economic deposits. In New Mexico, maps of the mines producing lead, zinc, copper, gold, and silver show that the mines are numerous in the same region that thermal waters are numerous. What is the relation of thermal waters to these deposits? Are thermal waters and the ore deposits genetically related? If so, how?

Analyses for the common constituents, likewise, leave something to be desired. Either the concentrations of the ions change in some spring waters or determinations have been made with less than absolute attention to accuracy or the accuracy of the analytical methods has improved significantly. For example, the magnesium concentration at Radium Springs has been reported at 23, 12, and 15 ppm, and the concentration of silica at Gila Hot Springs has been reported at 33 and 68 ppm. Did the concentration of these ions actually vary one hundred per cent or are these differences a reflection of technique? Or do these magnesium and silica differences reflect a changing organic population?

ANIONS

In the typical water analysis, the carbonate, bicarbonate, sulfate, and chloride ion concentrations are measured. The concentration of the fluoride, nitrate, phosphate, and boron ions may also be measured. Agreement between analyses made at different times is generally very good for the major constituents, but the concentration of the lesser ions seems to vary. For example, water from .Radium Springs has a fluoride concentration ranging from 4.6 to 5.7 ppm, and water from wells in Hidalgo County has a fluoride concentration **ranging from 9.9 to 13 ppm.** Do these figures reflect an actual variation in the concentration or a difference caused by sampling or analytic technique?

White, Hem, and Waring made use of the bromide/chloride, fluoride/chloride, iodide/chloride, and boron/chloride ratios to compare and classify waters. With the data collected for New Mexico's thermal waters, such comparisons are not possible, except in a few instances where the data permit the fluoride/chloride and boron/chloride ratios to be determined.

PH

Most pH measurements are made in the laboratory, with the result that the observed pH has a range that does not exist in nature. For example. a field determination at Socorro Warm Spring measures the pH at 7.4, yet the laboratory analyses reported pH as high as 8.4, even though there is no reason to suppose that it varies.

Many of the chemical analyses make no mention of pH (such as Truth or Consequences analyses, table 5). The question naturally arises: Is it more realistic to report a pH even though it is measured in the laboratory or is it more realistic to disregard all pH measurements unless they are field determinations?

FRAGMENTARY ANALYSES

A number of the analyses for New Mexico's thermal waters are fragmentary; that is, they were made to determine selected ions without regard to the total ionic concentration. This is a common procedure when a particular water supply is being evaluated. In effect, it means that some constituents were analyzed many times, others only a few. (Compare the number of analyses for the various constituents of Jemez Springs or Soda Dam Springs.)

The anions were analyzed far more often than the cations, bicarbonate having been determined for nearly every sample. Thus, comparison plots of Figures 2 and 3 have more points in the anion diagram. For purposes of comparison and appraisal, the concentrations of at least the major ions—both cations and anions—should be known.

In some areas, the chemistry of the water is well understood, and estimates of the concentration of one or more ions can be made with fair accuracy if the concentration of certain other ions is known. Unfortunately, the practice of estimating concentrations of ions is extended into areas where little is really known about the chemical character of the water, so such estimates are open to doubt. They may even be in considerable error.

For the purposes of the economic geologist and the ground-water geologist, it would be wise, despite the extra cost, to insist upon total chemical analyses of discharging water until relationships between the ions are understood.

Conclusions

Chemical analyses available for the thermal waters of New Mexico have been made from the standpoint of water supply. For this purpose, they serve their function adequately; however, for purposes of evaluating or describing geologic phenomena, they fall short. They seemingly lack precision—possibly because of the sampling procedure used; they fail to give concentrations of minor or trace elements; they are inconsistent in the ions for which analysis is made; they fail to describe the fluid issuing from the earth in that they do not state quantitatively the amount of liquid and the amount of gas.

If the chemical characteristics of water are to be used for geological explanations, data will have to be gathered that go far beyond those usually collected in a water-supply investigation. Samples need to be collected with care and with an eye to sampling not just the water but also the dissolved gases, and sampling them in their proportions. The analyses of the samples need to be made with great care also, and the concentrations of many more constituents (especially the metals) need to be determined.

When the waters are sampled, the geology should be carefully noted. The discharge rate of the fluid should be measured, using accurate procedures, and not only the discharging fluid but also the ambient air temperatures should be measured. Field measurements should be made of pH, specific conductance, and alkalinity or acidity, the method of sample collection ,should be noted, and the place of location should be recorded carefully and exactly. Too many of the available chemical analyses are of dubious value because their source is doubtful from the description given.

Repeated samplings should be made to determine changes as a function of time and variable discharge. The flora and fauna living in the water should be noted, if to do no more than recognize that living matter does or does not exist therein.

Much remains to be learned about thermal waters. The only way to obtain maximum benefit from the data is to sample carefully, completely, and repeatedly.

References

Bachman, G. O. (1965) *Mineral industry in New Mexico (in* Mineral and water resources of New Mexico), Report to the 89th Cong., 1st Sess., Committee on Interior and Insular Affairs, p. 13-17.

Ellis, A. J., and Mahon, W. A. J. (1964) *Natural hydrothermal systems and experimental hot-water frock interactions,* Geochim. et Cosmochim. Acta, v. 28, p. 1323-1357.

Hall, F. R. (1963) *Springs in the vicinity of Socorro, New Mexico, N.* Mex. Geol. Soc., Guidebook, Fourteenth field conference, The Socorro Region, p. 160-179.

Hem, J. D. (1959) *Study and interpretation of the chemical characteristics of natural water,* U.S. Geol. Surv., Water-Supply Paper 1473, 269 p.

Holmes, C. R. (1963) *Tritium studies, Socorro Springs,* N. Mex. Geol. Soc., Guidebook, Fourteenth field conference, The Socorro Region, p. 152-154.

Jones, F. A. (1904) *New Mexico mines and minerals,* Santa Fe: New Mexican Printing Company, 349 p.

Kintzinger, P. F. (1956) *Geothermal survey of hot ground near Lordsburg, New Mexico,* Science, v. 124, p. 629.

Meinzer, O. E. (1923) *Outline of ground-water hydrology with definitions, U.S.* Geol. Surv., Water-Supply Paper 494, 71 p.

Reeder, H. O. (1957) *Ground water in Animas Valley, Hidalgo County, New Mexico,* N. Mex. State Engr., Tech. Rpt. 11, 101 p.

Renick, B. C. (1931) *Geology and ground-water resources of western Sandoval County, New Mexico,* U.S. Geol. Surv., Water-Supply Paper 620, 117 p.

Ross, C. S., Smith, R. L., and Bailey, R. A. (1961) *Outline of the geology of the Jemez Mountains, New Mexico,* N. Mex. Geol. Soc., Guidebook, Twelfth field conference, The Albuquerque Country, p. 139-143.

Scott, R. C., and Barker, F. B. (1962) *Data on uranium in groundwater in the United States,* U.S. Geol. Surv., Prof. Paper 42-C, 115 p.

Stearns, N. D., Stearns, H. T., and Waring, G. A. (1937) *Thermal springs in the United States,* U.S. Geol. Surv., Water-Supply Paper 679-B, 206 p.

Summers, W. K. (1965) *A preliminary report on New Mexico's geothermal energy resources,* N. Mex. Inst. Min. and Tech., State Bur. Mines and Mineral Res., Circ. 80.

Theis, C. V., Taylor, G. C., Jr., and Murray, C. R. (1941) *Thermal waters of the Hot Springs* [Truth or Consequences] *artesian basin, Sierra County, New Mexico,* N. Mex. State Engr., Fourteenth-fifteenth bienn. rpt., p. 419-492.

White, D. E. (1957) *Thermal waters of volcanic origin,* Geol. Soc. Am. Bull., v. 68, p. 1659-1682.

———, Hem, J. D., and Waring, G. A. (1963) *Chemical composition of subsurface waters (in* Fleischer, Michael (tech. ed.), Data of geochemistry, 6th ed.), U.S. Geol. Surv., Prof. Paper 440-F.