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GROUND WATER IN THE SOUTHWESTERN PART OF THE JEMEZ MOUNTAINS VOLCANIC REGION, NEW MEXICO*

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INTRODUCTION

Warm springs in the Jemez Mountains volcanic region have long been used for bathing, and their water has been thought by many to have therapeutic value. More recently the springs have taken on added significance as evidence of the geothermal resources of the region. These warm springs are few in number, and their total flow is much less than that of the nonthermal springs. The Jemez Mountains are relatively well watered, as compared with the surrounding lower country. Part of the water from rain and melting snow runs off quickly, but part drains more slowly, being stored temporarily in the ground and even circulating to some depth before reappearing at the land surface. The water supports a vegetative cover, including dense forest in the high country, provides the base flow of the streams, and is the source of water supply in the region. This report is a brief preliminary description of ground water in part of the Jemez Mountains region, with particular reference to the thermal water.

Acknowledgments

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GEOLOGIC SETTING

The Jemez Mountains mass is a complex pile of volcanic rocks athwart the northwest margin of the Rio Grande graben in north-central New Mexico (Ross and others, 1961; Griggs, 1964, p. 8-12; Smith and others, 1970; also see Kudo, this Guidebook). The central caldera is flanked by outward-sloping sheets of lavas and tuffs. To the west the volcanic rocks overlap Paleozoic and Mesozoic sedimentary rocks of the Sierra Nacimiento, the western prong of the Southern Rocky Mountains; to the north, east, and south the volcanic rocks lie on Tertiary valley fill in the graben and are in part interbedded with them. The graben is bounded on the northwest by a zone of normal faults that extends, from in or near the caldera, south-southwest to the vicinity of San Ysidro (Fig. 1) and north-northeast to the vicinity of Canones.

Major terrain units include the Valles Caldera, with its resurgent dome and intracaldera volcanic peaks; a northeast-trending upland, the Sierra de los Valles; the Jemez Plateau, to the west and north; and the Pajarito Plateau to the east. The flanks of the volcanic pile have been deeply eroded; steep-walled canyons indent the gently sloping plateau surfaces and divide them into innumerable smaller plateaus and mesas. The land surface in the caldera is drained by the Jemez River, a tributary of the Rio Grande. The flanks of the pile are drained by the Jemez River on the west, by the Rio Chama, a tributary of the Rio Grande, on the north, and by the Rio Grande on the east.

The area considered in this report, extending south and southwest from Valles Caldera to the vicinity of San Ysidro (Fig. 2), has been mapped and described by Wood and Northrop (1946), Ross and others (1961), and Smith and others (1970). Parts of it have been described, and additional information given, by Renick (1931), Purtymun (1973), and Purtymun and others (1974). Precambrian granitic rocks are exposed over large areas in the Sierra Nacimiento and locally in the Jemez Mountains. The Paleozoic and Mesozoic rocks include limestone of the Magdalena Group (Pennsylvanian and Permian); and sandstone, siltstone, and shale of the Abo and Yeso Formations (Permian) and of the Chinle Formation (Triassic). These rocks are overlain by Tertiary valley-fill deposits of several mapped units (in part Santa Fe Formation) and by lavas and tuffs. The volcanic rocks in several mapped units not differentiated on Figure 2 range from basalt to rhyolite. The older of these rocks are in part interbedded with the Tertiary valley fill, and in part they overlie it. The most extensive volcanic rock in the area here considered is the Quaternary Bandelier Tuff, which resulted from the explosive caldera-forming eruptions. The resurgent dome formed in the caldera after those eruptions is underlain by deformed Bandelier Tuff and other rocks, including caldera fill of volcanic detritus. The youngest volcanic rocks, tuffs and lavas of the late Quaternary Valles Rhyolite, formed volcanic peaks in the ring-fracture zone in the canyons on the flanks of the volcanic pile are underlain by Quaternary alluvium and Quaternary landslide deposits mantle slopes beneath cliffs at a number of places, both within the caldera and outside it.

The limestone of the Magdalena Group is as much as 1,000 feet (about 300 m) thick in the south-central part of the area described here, and the Abo and Yeso Formations total as much as 1,200 feet (about 370 m) (Wood and Northrop, 1946). The volcanic rock, consisting chiefly of the Bandelier Tuff, is several hundred feet thick in much of this part of the area (Smith and others, 1970). In a test hole on Jemez Plateau about 3 miles (5 km) west of Valles Caldera the volcanic rocks are 160 feet (49 m) thick, the Abo Formation 910 feet (277 m), and the Magdalena Group 1,035 feet (315 m) (Purtymun, 1973, p. 9-10; West, this Guidebook). The thickness of the Tertiary valley fill exposed in the southeastern part of the area considered here is not known; thicknesses of several thousand feet are known near the east side of the Jemez Mountains. About 8 to 10 miles (13 to 16 km) northeast of San Ysidro, the relief on the eroded surface of gently dipping

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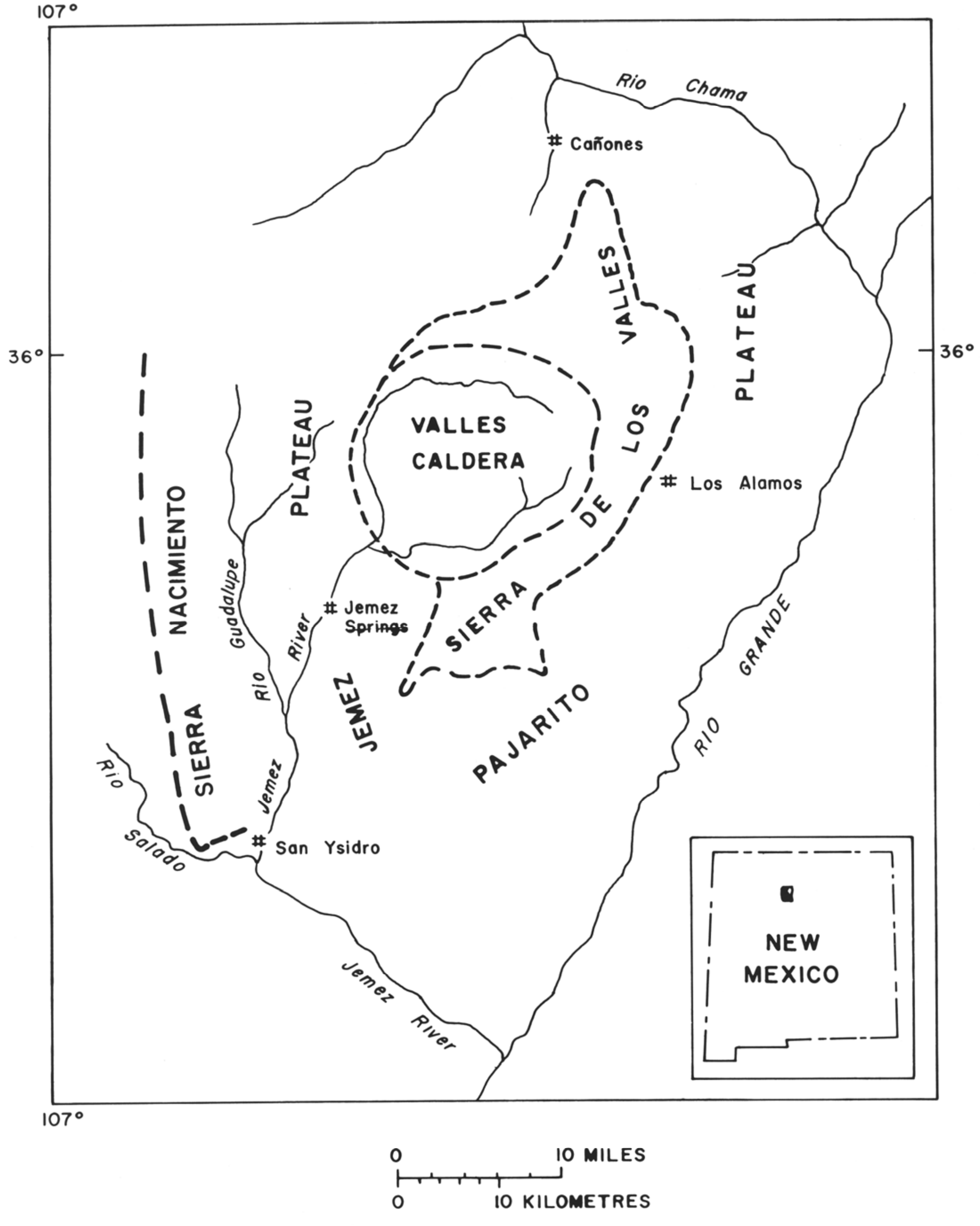

Figure 1. Location and general features of the Jemez Mountains, New Mexico.

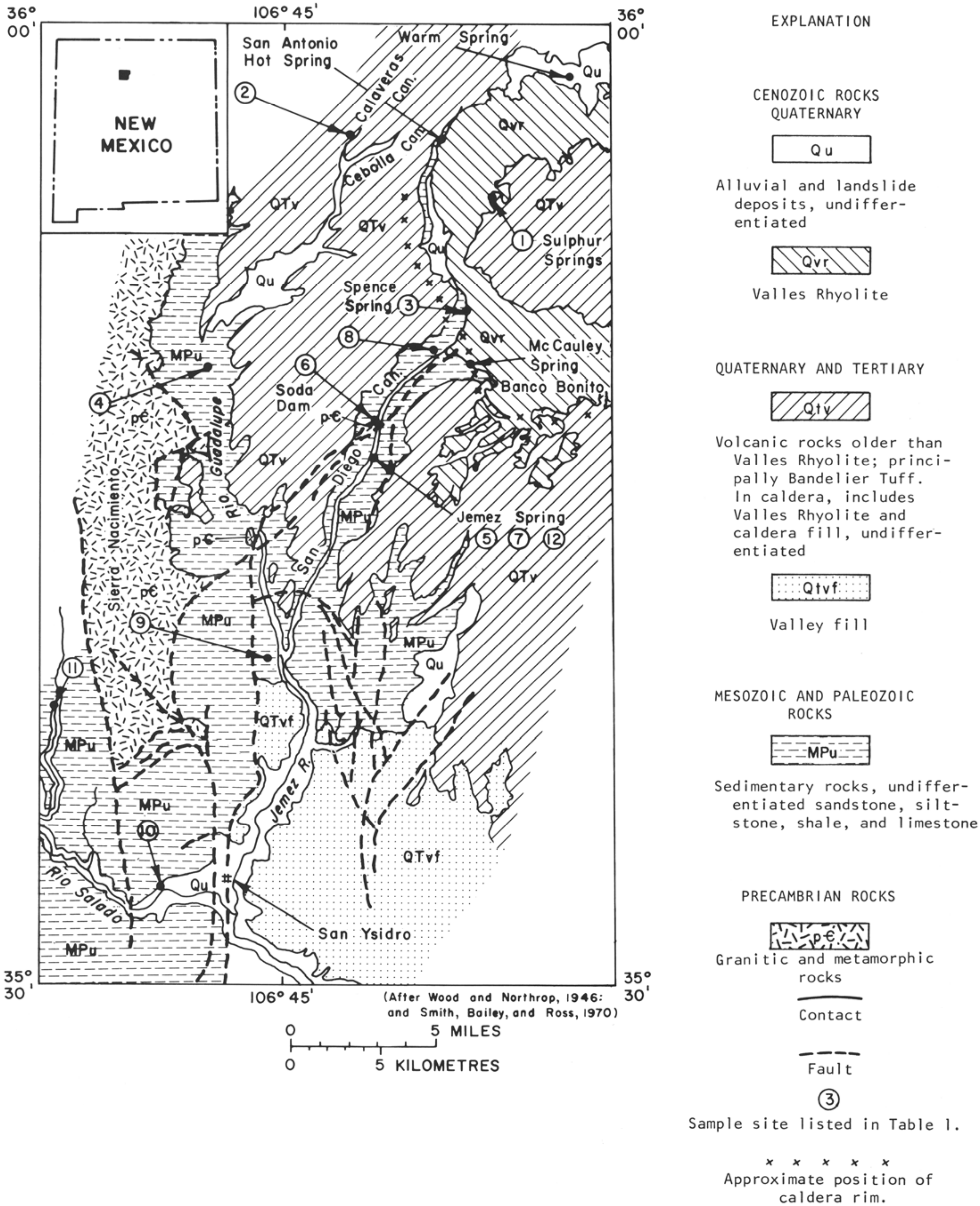

Figure 2. Generalized geologic map of part of the southwestern Jemez Mountains, New Mexico (after Wood and Northrop, 1946; Smith, Bailey, and Ross, 1970). Faults in caldera, or outside caldera but distant from west margin of graben, are not shown.

beds of the Tertiary valley fill is greater than 1,000 feet (300 m); areal relationships suggest that considerably greater thicknesses are preserved beneath basalt-capped mesas there. Scanty data available indicate that the Quaternary alluvium is several tens of feet thick at some places beneath the Jemez River floodplain.

WATER-BEARING CHARACTER OF THE ROCKS

Most of the rocks in the southwestern Jemez Mountains are of moderate to low permeability. Most of them are also layered or bedded, so that structure and stratigraphy accentuate the effect of differences in permeability between rock types. In many places the movement and discharge of ground water are controlled by faults, or by impervious horizontal strata that favor the development of perched aquifers. Only a few outcrops of these fault zones and perched aquifers are relatively permeable; natural discharge therefore occurs only locally, and there are few springs of even moderate discharge—for example, more than a few tens of gallons per minute.

The more permeable rocks in this area are commonly those with intergranular porosity, but even among these there is a large range in water-bearing character. The most permeable material, the modern alluvium, consists of interbedded permeable sand and gravel and less permeable silt and clay. Locally, as along the Jemez River near Jemez Springs and in drainage courses below some other mineral springs, the alluvium has been transformed by travertine cement into a tight conglomerate. The Tertiary valley fill appears to be considerably less permeable than the modern alluvium, perhaps in part because of finer average grain size and in part because of the cementation of some layers in it. Some granular materials other than alluvium, such as the soil and broken rock at the land surface in much of the area, are relatively permeable; they are important hydrologically, at the higher altitudes, because they accept infiltrating water during the snowmelt season, transmitting part of it downward and storing part of it as soil moisture. Locally, these materials are temporarily saturated after snowmelt or periods of rain, and they discharge small quantities of water through seeps and springs.

The consolidated rocks transmit water only through fractures except at those places where granular materials such as pumice in the volcanic rock, or sandstone with appreciable intergranular porosity, are interebedded with more dense rock. Some of the sandstones and siltstones are rather densely jointed while others, together with the shales, are sparsely jointed and tight. Contact springs in these rocks are attributed to interlayering of such beds. Other springs in these rocks are in or near fault zones. Most springs in the volcanic rocks drain perched aquifers in the tuff or at its contact with underlying shale and sandstone. Springs in the limestone are in densely jointed rock or are associated with fault zones. Widened joints, seen where the rock is well exposed, and travertine deposits show that the original fractures have been opened by solution. Despite this increase in permeability, the observed limestone springs yield only small to moderate quantities of water—from one gal/min (gallon per minute) or 0.063 l/s (liters per second) to several tens of gallons per minute.

THERMAL SPRINGS AND RELATED PHENOMENA

Hydrothermal features are relatively rare in the Jemez Mountains, as compared with the large number and variety of geysers, other hot springs, and solfataras found in Yellowstone National Park and in some other geothermal regions. In the Jemez Mountains the hydrothermal features include (1) warm springs that flow from Valles Rhyolite in the caldera, (2) solfataras and a group of warm springs (Sulphur Springs) in caldera fill (Fig. 2) and solfataras in a small area in San Diego Canyon just outside the caldera, and (3) warm springs at Soda Dam and at the village of Jemez Springs, farther down San Diego Canyon. Other features thought to be related to the geothermal system include mineral springs in San Diego Canyon near the caldera and near San Ysidro, and a flowing well, west of Sierra Nacimiento near its south end, that discharges warm water.

Warm Springs on Young Volcanoes

Several warm springs drain Quaternary Valles Rhyolite on volcanoes in the ring-fracture zone of the caldera. One of these, in the northern part of the caldera (Fig. 2), flows from alluvium at the base of a small rhyolite dome; three others—San Antonio Hot Spring, Spence Spring, and McCauley Spring (Fig. 2)—flow from piles of volcanic rubble near the base of lava flows and tuffs, and are interpreted as contact springs at a discontinuity within the rhyolite or at the unconformity between the rhyolite and underlying sandstone and shale of the Abo Formation. The discharge of these four springs ranges from 12 to 400 gal/min (0.76 to 25 l/s). Several smaller warm springs nearby flow from rubble or from fractures in the tuff. Chemical analysis (no. 3, Table 1) shows the Water, of low mineralization and a sodium bicarbonate composition, to differ markedly from water believed to have been derived in part from the geothermal reservoir (see analyses 6 and 7 and related discussion). Temperatures in the orifices of the three large springs that flow from rubble range from 32 to 41°C (Celsius). Relative constancy of these temperatures—at a given spring they do not seem to vary by more than a degree or so during the year—suggests that the measured values are representative of the rock near the land surface. However, the SiO_2 content of the water may provide a better estimate of the temperature of the rock along the deeper parts of the flow paths. If it is assumed that the dissolved SiO_2 was derived entirely from quartz, and that the SiO_2 content has not been decreased by precipitation or by dilution of the water nor increased through boiling and the escape of steam, the concentration of SiO_2 can be used to estimate the temperature at which the water was last equilibrated with quartz (Fournier and Rowe, 1966, p. 694). The concentrations of SiO_2 in water from the three larger springs that issue from rubble range from 56 mg/l (milligrams per liter) at McCauley Spring to 100 mg/l at Spence Spring. A concentration of 100 mg/l is equivalent, under the assumptions given above, to a temperature of about 130°C (Fournier and Rowe, 1966, fig. 5, p. 694). The depth of circulation is not known. However, the low dissolved-solids concentration on the water suggest flow entirely through rhyolite and not through the underlying Abo Formation (compare analyses 3 and 5, Table 1). Banco Bonito, the rhyolitic lava flow below which Spence Spring is situated, may be as young as 100,000 to 200,000 years (Smith and Bailey, 1968, p. 641), and may therefore indicate a source of appreciable near-surface heat. It seems likely that these waters have not circulated to great depth. Their composition shows that they have not mixed with water in or from the main geothermal reservoir beneath the caldera.

Table 1. Chemical analyses of selected ground-water samples from the southwestern Jemez Mountains, New Mexico. Constituents and characteristics in milligrams per liter unless other units are given. Locations of sample sites shown by number on Figure 2. Sample 1 from White and others (1963, p. F46); other samples from files of U.S. Geological Survey.

Name or location, and water-bearing rock:

1. *Sulphur Springs; caldera fill.*
2. *Spring in Calaveras Canyon; Bandelier Tuff (rhyolite).*
3. *Spence Spring; Valles Rhyolite.*
4. *U.S. Geological Survey test well, canyon of Rio Guadalupe; limestone in Magdalena Group.*
5. *U.S. Geological Survey test well near village of Jemez Springs; sandstone in Abo Formation.*
6. *Spring at Soda Dam; probably from limestone in Magdalena Group.*
7. *Spring at Jemez Springs; probably from limestone in Magdalena Group, beneath alluvium.*
8. *Spring in San Diego Canyon near caldera rim; limestone in Magdalena Group.*
9. *Spring near mouth of Rio Guadalupe; probably from limestone in Magdalena Group, but water issues from fractured granite.*
10. *Spring near San Ysidro; sandstone in Chinle Formation.*
11. *"Warm Spring" (abandoned gas-test well), northwest of San Ysidro; probably from rocks of Magdalena Group, Abo Formation, and Chinle Formation.*
12. *Well near village of Jemez Springs; alluvium beside Jemez River.*

Sample Number	1	2	3	4	5	6	7	8	9	10	11	12
Date of Collection	8-31-49	12-2-72	12-1-72	10-30-73	10-26-73	12-1-72	12-2-72	8-15-73	8-21-73	3-14-64	3-14-64	9-27-73
Silica (SiO_2)...........	216	40	100	16	17	50	79	42	44	15	31	59
Aluminum (Al)...........	56	< 0.001	0.025	-	-	0.005	0.002	-	-	-	2.6	-
Iron (Fe)...............	33	< .04	< .04	0.01	0.03	.04	< .04	0.06	0.14	0.00	3.9	0.03
Manganese (Mn)..........	3.3	< .01	< .01	.01	.06	.55	.175	.02	.08	-	.01	.000
Calcium (Ca)............	185	11	6.0	100	12	330	130	130	32	157	345	75
Magnesium (Mg)..........	52	1.3	1.7	11	10	24	4.8	12	5.7	70	56	13
Sodium (Na).............	6.7	8.5	55	14	860	990	640	250	190	1,760	3,550	120
Potassium (K)...........	24	2.4	1.8	5.8	8.5	200	82	35	8.2	71	87	19
Arsenic (As)............	-	.006	.072	.000	-	1.5	.66	.000	.067	-	.60	.15
Lithium (Li)............	-	< .04	.69	.06	-	13	8.7	3.6[1/]	.43	6.4	6.9	1.4
Bicarbonate (HCO_3)......	0	61.6	144	367	1,640	1,578	732	606	366	1,080	1,450	387
Carbonate (CO_3)........	-	0	1.0	0	0	0.3	1.5	0	0	0	0	0
Sulfate (SO_4)...........	1,570	5.2	18	21	250	52	53	32	120	1,220	3,260	21
Chloride (Cl)...........	3.5	3.8	12	13	200	1,500	920	320	49	1,680	2,990	120
Fluoride (F)............	1.1	.4	.7	.3	2.4	3.3	4.8	2.3	7.6	2.9	2.8	1.6
Nitrate (NO_3) plus nitrite (NO_2), as N....	0	-	-	.56	.03	-	-	.11	.00	-	-	.76
Boron (B)...............	-	.02	.07	.06	-	12.5	7.4	2.9	.38	6.8	4.8	1.2
Dissolved solids.........	2,160	126	224	365	2,170	3,740	3,500	1,120	638	5,510	11,000	625
Specific conductance (micromhos at 25°C)....	4,570	113	282	640	3,500	6,160	3,930	1,880	1,000	8,560	15,300	925
pH......................	1.9	7.0	8.0	7.3	7.4	6.1	6.3	6.8	7.6	7.6	7.3	7.3
Temperature (°C)........	65±	12.0	41.0	10.5	16.0	48.0	75.0	18.0	18.5	24.0	54	-

Sulphur Springs and the Solfataric Areas

Tracts of altered ground and numerous solfataras occur within an area of several square miles in canyons on the northwest side of the resurgent dome in Valles Caldera (Bailey, 1961). Sulphur Springs, a group of a dozen or more hot springs and solfataras, is the most conspicuous expression of hydrothermal features in this part of the Jemez Mountains.

Rocks in the area immediately surrounding Sulphur Springs have been extensively altered, with the formation of clay and the deposition of native sulfur and other minerals. Sulfur was once mined here (Kelly and Anspach, 1913, p. 10). A variety of springs is present, including a bubbling mud pit. The springs discharge small quantities of acidic sulfate water at temperatures as high as 75°C, along with gas containing H_2S and CO_2. Temperatures in the ground, a few feet beneath the land surface, have been reported to be as high as 93°C (Summers, 1965b, p. 7). Chemical analyses of water or gas are given by Kelly and Anspach (1913, p. 36-42), Renick (1931, p. 79-79, 89), White and others (1963, p. F46, F58), Summers (1965a, p. 22-23; 1965b, p. 12), and Purtymun and others (1974, p. 20). The analysis published by White and others (1963) is given as no. 1 in Table 1 of this report. Summers (1965b, p. 19) presents a sketch map of the Sulphur Springs area.

A tentative model of a vapor-dominated geothermal reservoir described by White and others (1971, p. 90-91) explains the relationships observed at Sulphur Springs. In the model, steam from boiling water at the water table rises through the zone of aeration. As it approaches the land surface part of the steam condenses to liquid water, releasing heat; part of this water percolates back toward the water table, but part of it may be carried on to the surface with the rising vapor, which is also carrying CO_2, H_2S, and other gases. The aggressive water and steam attack the wall rocks and form clay minerals. Only a small quantity of water is involved, and it may be sufficient to supply only small springs. Because of the oxidation of part of the H_2S to H_2SO_4 near the land surface, the spring water is of acidic and sulfate character; because of the low volatility of chlorides, the water has a very low content of Cl even though the parent fluid beneath the water table may be a brine. As applied to the Sulphur Springs area, this hypothesis implies the presence, at some depth, of a reservoir that is vapor dominated at least in the region beneath the springs and altered ground.

The solfataric areas in San Diego Canyon are expressed as small patches of altered ground near sample site 8, some of which emit H_2S. Explanation of this altered ground by the hypothesis of White and others (1971) implies that the canyon floor here is also underlain by a reservoir that contains water at or above the boiling point, and separated from the land surface by an unsaturated zone. This explanation is reasonable because the canyon lies along the major Jemez fault zone that extends up-canyon toward or into the caldera, because warm springs occur farther down the canyon, and because an unsaturated zone has been found in wells.

Warm Springs at Soda Dam and Jemez Springs

Fault-controlled warm springs issue from fractured rock at Soda Dam and from alluvium at the village of Jemez Springs (Fig. 2). Their water, moderately mineralized, is believed to have been derived from the geothermal reservoir beneath the caldera but to have been modified along its flow path through solution of country rock and through dilution.

Soda Dam is a low ridge of travertine built across the floor of San Diego Canyon by water from the warm springs. The Jemez River has maintained an opening through which it flows beneath one end of the dam. Building of the dam practically ceased after the spring flow was diverted by the construction of a highway cut through the west end of the dam. Remnants of a higher travertine ridge stand above the ends of the modern dam, and the high ridge south of the dam is mantled by still older travertine. The dam and older deposits mark a fault zone along which rocks of Precambrian age have been brought to the surface against Pennsylvanian limestone. Spring water issues from the main part of the fault zone, which is concealed by travertine and travertine debris, from fractures in the granite, and from alluvial deposits in and near the stream channel. A total of 50 to 75 gal/min (3.2 to 4.7 l/s) is discharged from openings in the highway cut; the total flow from the springs at Soda Dam is estimated from a study of the streamflow to be about 300 gal/min (19 1/s). The water is as warm as 50°C, and it bears H_2S.

The warm springs at Jemez Springs issue from 10 or more vents in alluvium in and near Jemez River near the southernmost limit of exposures of limestone in the canyon. The chemical composition of the water (considered in the next paragraphs) and the areal distribution of many of the springs along a linear trend subparallel to the canyon indicate fault control and suggest flow through the limestone. Two other observations are consistent with a nearby bedrock source beneath the alluvium: although some springs are submerged each year by the snowmelt flood, they maintain their vents or reestablish themselves after the flood; and the temperature of the water-as high as 75°C, the highest observed in the southwestern Jemez Mountains outside the Sulphur Springs area-is much higher than would be expected where water has followed a long flow path through alluvium. Possibly the rising mineral water has lined its conduits through the alluvium with travertine, so that it remains somewhat isolated from unconfined ground water in the surrounding alluvium. The total flow from these springs is estimated to be about 200 gal/min (13 1/s).

The mineral content of the spring waters at Soda Dam and Jemez Springs has long been of interest; two public baths were maintained for many years at Jemez Springs, and one of them is still in use. Analyses are given by Kelly and Anspach (1913, p. 31-35), Renick (1931, p. 78-79), White and others (1963, p. F42), Summers (1965a, p. 20-21; 1965b, p. 11), and Purtymun and others (1974, p. 20-21). Woltz (1972) reviewed and interpreted the analyses in a study of the source of the water.

White and others (1963, p. FI0-F11, F40-F43) describe the chemical character of volcanic waters, which typically have high contents of SiO_2, Cl, F, and several minor constituents. They (1963, p. F40) list fourteen analyses for thermal waters from geyser areas in volcanic regions (that is, from hot but accessible environments) that reveal contents of $S10_2$ that range from 150 to 609 mg/l. The samples from Soda Dam and Jemez Springs contained 50 and 79 mg/l, respectively (Table 1). These values are not unusual for the Jemez Mountains. Sample 2 (Table 1), from Bandelier Tuff several miles outside the caldera, contained 40 mg/l SiO_2. Conover and others (1963, p. Y36) and Griggs (1964, p. 88) list samples from Valles Caldera (chiefly from unconsolidated deposits of rhyolite detritus in which the water probably did not travel to great depths); SiO_2 ranges from 39 to 75 mg/l, and the median value is about 60 mg/l. However, the waters at Soda Dam and Jemez Springs appear to have been diluted along their flow paths, so that their SiO_2 may originally have been considerably higher than the observed values.

White and others (1963, p. F40) list concentrations of Cl in 13 samples of thermal water from geyser areas. The values range from 30 to 3,410 mg/l, and the median concentration is 744 mg/l. (A fourteenth sample containing 27,400 mg/l Cl may represent nonvolcanic water.) Samples from Soda Dam and Jemez Springs (nos. 6 and 7, Table 1) contained 1,500 and 920 mg/l Cl, respectively; expressed in terms of the ratio Cl/dissolved solids, these values are 0.40 and 0.26, respectively-proportions much larger than those in samples from rhyolite and from limestone outside the caldera and outside San Diego Canyon (see nos. 2, 4, 6, and 7, Table 2).

Water from Soda Dam and Jemez Springs contained 3.3 and

Table 2. Ratios of selected constituents in ground water from the southwestern Jemez Mountains, New Mexico. Sample numbers as in Table 1.

Sample Number	2	3	4	6	7	8	9	10	11
Brief Name	Calaveras Canyon	Spence Spring	Well, limestone	Soda Dam	Jemez Springs	Spring, limestone	Spring, lime-stone, granite	Spring nr. San Ysidro	"Warm Spring"
Ratios, by weight:									
Cl/diss.solids	0.030	0.054	0.036	0.40	0.26	0.29	0.08	0.30	0.27
Li/Na	<.0047	.012	.0043	.013	.014	.014	.0023	.0036	.0019
B/Cl	.0053	.0058	.0046	.0083	.0080	.0091	.0078	.0040	.0016

4.8 mg/l F, respectively—values somewhat larger to much larger than the concentrations found in most samples from either volcanic or sedimentary rocks in the Jemez Mountains. Fluoride content in the samples from rhyolite detritus in Valles Caldera (Conover and others, 1963, p. Y36; Griggs, 1964, p. 88) ranges from 0.2 to 3.6 mg/l; in 19 samples the median concentration is 2.0 mg/l.

The ratios of certain constituents are typical of geyser waters in volcanic areas; thus, Li/Na and B/Cl are commonly greater in these waters than in many others (White and others, 1963, p. F10). Relatively few data on lithium and boron in water are available from the Jemez Mountains region, but Table 2 lists the ratios Li/Na and B/Cl for several of the samples in Table 1. The ratio Li/Na is much higher at Soda Dam and Jemez Springs than in volcanic rock at Calaveras Canyon (sample 2), and the ratio B/Cl is somewhat higher. These relationships are consistent with the interpretation that the warm-spring waters came in part from the geothermal reservoir at depth within the caldera.

Woltz (1972) used ion concentrations in the spring water to infer provenance of the water, and concluded (1972, p. 42, 45-47), after comparing the contents of F, Cl, Na, Ca, and Si02 in these spring waters with those in other waters in the Jemez Mountains and with those in typical volcanic emanations (White and Waring, 1963), that the spring waters at Soda Dam and Jemez Springs contain magmatic material.

The chemical data, together with the occurrence of these springs in a fault-controlled canyon that heads in the caldera, indicate that part of the water is probably derived from the geothermal reservoir. Smith and others (1970, section BB') suggest the presence of limestone beneath the volcanic rocks in the sunken block within the caldera. If limestone is present there, it should play a significant role in the development of porosity in the reservoir because of its susceptibility to attack by hot CO_2-rich volcanic water. Water escaping through the subsurface down San Diego Canyon no doubt erodes additional limestone along its flow path. Travertine at and near Soda Dam reflects an enormous volume of carbonate rock removed, and the high content of HCO_3 in the spring water shows that carbonate material is still being carried away in the escaping water. We do not know, however, what proportion of this dissolved load may be derived from the caldera rocks and what proportion comes from rocks outside the caldera.

Nonthermal Mineral Springs

Samples 8-10 (Table 1) represent cold mineral springs believed to contain geothermal water that has been diluted in different degrees through mixing with other waters. All the cold mineral waters are of broadly similar composition. The analyses in Table 1 are representative; additional data are given by Clark (1929), Renick (1931), Summers (1965a, 1965b), and Purtymun and others (1974). Woltz (1972) discusses the composition of these spring waters and concludes that they contain magmatic material. The chemical content and geologic occurrence of these waters appear consistent with a hypothesis of flow through the subsurface from the caldera (see next section of this report).

THE GROUND WATER FLOW SYSTEM

The ground-water flow system in the southwestern Jemez Mountains can be considered in a preliminary way by noting the sources of base runoff of the Jemez River. In San Diego Canyon at the edge of the caldera, the base runoff consists of water provided by (1) ground-water runoff from near-surface deposits—the crust of broken rock on rhyolite domes, and valley fill—in the caldera (Conover and others, 1963; Griggs, 1964), mostly outside the area considered in this report, (2) flow from warm springs that drain deeper aquifers within the young volcanoes in the ring-fracture zone, (3) discharge from perched aquifers that form ground-water mounds in volcanic and sedimentary rocks in interstream plateaus (West, 1973), and (4) flow of mineralized ground water, from depth, through seeps in the floor of San Diego Canyon inside the caldera. Preliminary estimates suggest that most of this ground-water runoff is derived from the near-surface deposits, a small part of it from the warm springs and interstream ground-water mounds, and only a very small part from the deep sources.

Between the caldera rim and the confluence of the Jemez River and Rio Guadalupe (Fig. 2), the principal addition to base flow of the Jemez River is the discharge of Warm springs at Soda Dam and Jemez Springs. Perched aquifers that form ground-water mounds in the volcanic rocks on the plateaus flanking the canyon, and in the underlying Abo Formation, are drained through contact springs along the canyon walls. Part of this water reaches the Jemez River in small surface streams or by subsurface flow through surficial deposits, but most of it is discharged to the atmosphere by evapotranspiration.

Base runoff of the Rio Guadalupe appears to come principally from perched aquifers that discharge on the canyon walls and from seeps in the canyon floors. Several small springs flow from fault zones. A large group of springs that drains an extensive zone of densely fractured Bandelier Tuff in Calaveras and Cebolla Canyons near their confluence (Fig. 2) is noteworthy because of its bearing on ground-water recharge. Observations in Calaveras Canyon during the high snowmelt flood of 1973 indicate that much of the water must have entered the aquifer up-canyon, at places where the fractured zone intersects the canyon floor. It seems likely that much of the recharge of ground water in the fractured rocks occurs where stream courses cross faults and other fracture zones. So far as can be judged from chemical analyses of the stream water, little if any mineralized water similar to that of the springs at Soda Dam and Jemez Springs flows into the Rio Guadalupe.

Several springs that yield moderately mineralized water, and several mineral springs whose dissolved load is more concentrated than that of the springs at Soda Dam and Jemez Springs, flow into the Jemez River between Rio Guadalupe and San Ysidro. A large area underlain by Tertiary valley fill, east and northeast of San Ysidro, also contributes ground-water runoff to the Jemez River. Little information is available regarding this valley fill, however, and we do not know to what degree its hydrologic character and water yield resemble those of similar deposits that have been explored and developed in the Pajarito Plateau (Purtymun and Johansen, this Guidebook). Several springs issue from sedimentary rocks in or near fault zones along the south and west front of the Sierra Nacimiento. Some of these springs yield slightly mineralized water, but others discharge the most highly mineralized water of springs in the region (see analysis 10, Table 1).

An important aspect of the shallow ground-water flow system is underflow through alluvium in the canyon bottoms. In San Diego Canyon alluvial deposits floor the canyon continuously below the caldera rim. Ground water in the alluvium, like the stream water, is slightly mineralized above Soda Dam. Below Soda Dam and Jemez Springs the ground water is more highly mineralized (no. 12, Table 1), and it has an appreciable content of minor elements, such as As, B, F, and Li, believed to be characteristic of water from the geothermal reservoir. The dissolved load in ground water in the Jemez River alluvium increases near San Ysidro, and below that village it increases still further as a result of the contribution of the Rio Salado, which joins the Jemez River and brings drainage from the west front of the Sierra Nacimiento and from part of the sedimentary basin west of the mountains. Near San Ysidro the alluvium is thick enough and permeable enough to draw off much of the streamflow. Evapotranspiration also robs the stream, and in many years the Jemez River channel is dry or practically dry below San Ysidro during late summer and autumn.

The distribution of thermal and cold mineral springs in San Diego Canyon and near San Ysidro coincides with the pattern of fault zones (Wood and Northrop, 1946; Smith and others, 1970), and is believed to indicate a route for subsurface drainage from the geothermal reservoir beneath the caldera. Preliminary study suggests a consistent decrease in head along the Jemez fault zone, from the caldera rim to San Ysidro, and analyses from several springs (nos. 6-10, Table 1) show a similarity of water composition that is thought to reflect dilution of a single source water by different proportions of native ground waters along the route of flow. Other mineralized waters at the west foot of the Sierra Nacimiento have a similar gross chemical composition but different head relations, and if they also originate in the Valles Caldera they must have followed a substantially different flow path. Whether Valles Caldera water flows through the granitic rock of the Sierra Nacimiento is a question requiring further study, but the presence of a network of intersecting faults in the southern part of the range (Wood and Northrop, 1946; Woodward and others, 1972, p. 2385) justifies that flow pattern as a hypothesis for consideration.

The presence of thick limestone in the stratigraphic section cut by the Jemez fault zone facilitates the flow of geothermal water down San Diego Canyon because it favors the enlargement of openings in the faulted rocks. Data (not presented in this report) from a limestone spring near the caldera rim (no. 8, Table 1) and from several nearby wells show that the hydrology of the limestone in this part of the fault zone is complex—not only does the presumed geothermal water reach the land surface here, but river water is flowing into the limestone at some point a short distance upstream from the caldera rim. The difference in dissolved load in the waters of the springs at Soda Dam and Jemez Springs may reflect differing degrees of dilution and mixing that result from such inflow of river water. No warm mineral springs are known in San Diego Canyon below Jemez Springs, at the southernmost exposure of the limestone in the bottom of the canyon; but all the mineral springs known, as far south as San Ysidro, yield water that has flowed through limestone. The Jemez fault zone swings to the west at Soda Dam and continues its general southward course along another canyon and through mountainous country before it returns and marks the west side of the main canyon near San Ysidro. Cold mineral springs occur along that reach of the fault zone. Two gas-test wells drilled northwest of San Ysidro in the 1920's tapped warm artesian water near the west front of the Sierra Nacimiento (Clark, 1929, p. 12-14; Renick, 1931, p. 82-83). One well was plugged shortly after drilling; the other (no. 11, Table 1), still flowing, yields water having a temperature of 52-54°C at the land surface. This well ends in the Magdalena Group at 2,008 feet. The fact that all the mineral-spring waters near San Ysidro are cold is thought to reflect deep occurrence of the limestone and slow migration of the water to the land surface along fractures. Whether the water is hotter than normal for a given depth, this far from the caldera, and whether it is hot enough at economical depth anywhere outside the caldera to support geothermal development, are questions requiring further study.

REFERENCES

Bailey, R. A., 1961, Hot springs and solfataric areas in the Valles Caldera, Jemez Mountains, N. Mex.: U.S. Geol. Survey open-file map, scale 1:62,500.

Clark, J. D., 1929, The saline springs of the Rio Salado, Sandoval

County, New Mexico: Univ. New Mexico Bull., Chemistry Ser., v. 1, no. 3,29 p.

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.

Fournier, R. 0., and Rowe, J. J., 1966, Estimation of underground temperatures from the silica content of water from hot springs and wet-steam wells: Amer. Jour. Science, v. 264, p. 685-697.

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

Kelly, Clyde, and Anspach, E. V., 1913, A preliminary study of the waters of the Jemez Plateau, New Mexico: Univ. New Mexico Bull., Chemistry Ser., v. 1, no. 1,43 p.

Kudo, A. M., 1974, Outline of the igneous geology of the Jemez Mountains volcanic field: this Guidebook.

Purtymun, W. D., 1973, Geology of the Jemez Plateau west of Valles Caldera: Univ. California, Los Alamos Scientific Laboratory, Pub. LA-5124-MS, 13 p.

Purtymun, W. D., and Johansen, S., 1974, General geohydrology of the Pajarito Plateau: this Guidebook.

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 Scientific Laboratory, Pub. LA-5595-M5, 26 p.

Renick, B. C., 1931, Geology and ground-water resources of western Sandoval County, New Mexico: U.S. Geol. Survey 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, *in* New Mexico Geol. Soc. Guidebook, 12th Field Conf., The Albuquerque Country, p. 139-143.

Smith, R. L., and Bailey, R. A., 1968, Resurgent cauldrons,in Coats, R. R., and others, eds., Studies in volcanology: Geol. Soc. America Mem. 116, p. 613-662.

Smith, R. L., Bailey, R. A., and Ross, C. S., 1970, Geologic map of the Jemez Mountains, New Mexico: U.S. Geol. Survey Miscel. Geol. Inv., Map 1-571.

Summers, W. K., 1965a, A preliminary report on New Mexico's geothermal energy resources: New Mexico Bur. Mines and Mineral Resources, Cir. 80,41 p.

Summers, W. K., 1965b, Chemical characteristics of New Mexico's thermal waters-a critique: New Mexico Bur. Mines and Mineral Resources, Cir. 83,27 p.

West, F. G., 1973, Geohydrology of the Jemez Plateau (abs.): EOS, Amer. Geophysical Union Trans., v.54, no. 11, p. 1214-1215.

West, F. G., 1974, Dry hot rock project: this Guidebook.

White, D. E., Hem, J. D., and Waring, G. A., 1963, Chemical composition of subsurface waters: *chapter F in* Data of geochemistry, 6th ed.: U.S. Geol. Survey Prof. Paper 440-F, 67 p.

White, D. E., and Waring, G. A., 1963, Volcanic emanations: *chapter K in* Data of geochemistry, 6th ed.: U.S. Geol. Survey Prof. Paper 440-K, 29 p.

White, D. E., Muffler, L. J. P., and Truesdell, A. H., 1971, Vapor-dominated hydrothermal systems compared with hot-water systems: Econ. Geology, v. 66, no. 1, p. 75-97.

Woltz, David, 1972, The chemistry of groundwaters in the Jemez area and a magnetic survey of a potential source of magmatic fluids: Univ. New Mexico, unpub. MS thesis, 90 p.

Wood, G. H., and Northrop, S. A., 1946, Geology of the Nacimiento Mountains, San Pedro Mountain, and adjacent plateaus in parts of Sandoval and Rio Arriba Counties, New Mexico: U.S. Geol. Survey Oil and Gas Inv., Map 0M-57.

Woodward, L. A., Kaufman, W. H., and Anderson, J. B., 1972, Nacimiento fault and related structures, northern New Mexico: Geol. Soc. America Bull., v. 83, no. 8, p. 2383-2396.