Ground water in the southwestern part of the Jemez Mountains volcanic region, New Mexico

Frank W. Trainer, 1974, pp. 337-345

in:

This is one of many related papers that were included in the 1974 NMGS Fall Field Conference Guidebook.

Annual NMGS Fall Field Conference Guidebooks

Every fall since 1950, the New Mexico Geological Society (NMGS) has held an annual Fall Field Conference that explores some region of New Mexico (or surrounding states). Always well attended, these conferences provide a guidebook to participants. Besides detailed road logs, the guidebooks contain many well written, edited, and peer-reviewed geoscience papers. These books have set the national standard for geologic guidebooks and are an essential geologic reference for anyone working in or around New Mexico.

Free Downloads

NMGS has decided to make peer-reviewed papers from our Fall Field Conference guidebooks available for free download. Non-members will have access to guidebook papers two years after publication. Members have access to all papers. This is in keeping with our mission of promoting interest, research, and cooperation regarding geology in New Mexico. However, guidebook sales represent a significant proportion of our operating budget. Therefore, only research papers are available for download. Road logs, mini-papers, maps, stratigraphic charts, and other selected content are available only in the printed guidebooks.

Copyright Information

Publications of the New Mexico Geological Society, printed and electronic, are protected by the copyright laws of the United States. No material from the NMGS website, or printed and electronic publications, may be reprinted or redistributed without NMGS permission. Contact us for permission to reprint portions of any of our publications.

One printed copy of any materials from the NMGS website or our print and electronic publications may be made for individual use without our permission. Teachers and students may make unlimited copies for educational use. Any other use of these materials requires explicit permission.
This page is intentionally left blank to maintain order of facing pages.
GROUND WATER IN THE SOUTHWESTERN PART OF THE JEMEZ MOUNTAINS VOLCANIC REGION, NEW MEXICO*

by

FRANK W. TRAINER
U.S. Geological Survey
Albuquerque, New Mexico

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

The writer gratefully acknowledges the cooperation of landowners and of the U.S. Forest Service in permitting access to lands and sampling of wells, springs, and streams; helpful discussions of local history and development with Thomas Abousleman and Cliff and Harold Hofheins, and of geohydrologic problems with W. D. Purdy and F. G. West of Los Alamos Scientific Laboratory; and assistance with field geochemical studies by Ivan Barnes, J. L. Kunkler, R. M. McBreen, J. E. O'Neill, C. S. Smith, and L. M. Willey of the U.S. Geological Survey.

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 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), Purdy and others (1973), and Purdy 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) (Purdy, 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
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.

WATERBEARING 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 interbedded 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 interlaying 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).
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.
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 Chimene Formation.
11. "Warm Spring" (abandoned gas-test well), northwest of San Ysidro; probably from rocks of Magdalena Group, Abo Formation, and Chimene Formation.
12. Well near village of Jemez Springs; alluvium beside Jemez River.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date of Collection</td>
<td>8-31-49</td>
<td>12-2-72</td>
<td>12-1-72</td>
<td>10-30-73</td>
<td>10-26-73</td>
<td>12-1-72</td>
<td>12-2-72</td>
<td>8-15-73</td>
<td>8-21-73</td>
<td>3-14-64</td>
<td>3-14-64</td>
<td>9-27-73</td>
</tr>
<tr>
<td>Silica (SiO₂)</td>
<td>216</td>
<td>40</td>
<td>100</td>
<td>16</td>
<td>17</td>
<td>50</td>
<td>79</td>
<td>42</td>
<td>44</td>
<td>15</td>
<td>31</td>
<td>59</td>
</tr>
<tr>
<td>Aluminum (Al)</td>
<td>&lt; 0.001</td>
<td>0.025</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.005</td>
<td>0.002</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.6</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>&lt; 0.4</td>
<td>&lt; 0.4</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
<td>-</td>
<td>-</td>
<td>3.9</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>3.3</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
<td>-</td>
<td>-</td>
<td>0.001</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>185</td>
<td>12</td>
<td>6.0</td>
<td>100</td>
<td>12</td>
<td>330</td>
<td>130</td>
<td>130</td>
<td>32</td>
<td>157</td>
<td>345</td>
<td>75</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>52</td>
<td>1.3</td>
<td>1.7</td>
<td>11</td>
<td>10</td>
<td>24</td>
<td>4.8</td>
<td>12</td>
<td>5.7</td>
<td>70</td>
<td>56</td>
<td>13</td>
</tr>
<tr>
<td>Sodium (Na)</td>
<td>6.7</td>
<td>8.3</td>
<td>55</td>
<td>14</td>
<td>860</td>
<td>990</td>
<td>640</td>
<td>250</td>
<td>190</td>
<td>1,760</td>
<td>3,550</td>
<td>120</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>24</td>
<td>2.4</td>
<td>1.8</td>
<td>5.8</td>
<td>8.5</td>
<td>200</td>
<td>82</td>
<td>35</td>
<td>8.2</td>
<td>71</td>
<td>87</td>
<td>19</td>
</tr>
<tr>
<td>Arsenic (As)</td>
<td>&lt; 0.006</td>
<td>&lt; 0.007</td>
<td>&lt; 0.000</td>
<td>&lt; 1.5</td>
<td>&lt; 1.6</td>
<td>&lt; 0.000</td>
<td>&lt; 0.007</td>
<td>&lt; 0.6</td>
<td>0.15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrate (N)</td>
<td>&lt; 0.04</td>
<td>&lt; 0.09</td>
<td>&lt; 0.06</td>
<td>&lt; 13</td>
<td>&lt; 0.7</td>
<td>&lt; 2.4</td>
<td>&lt; 1.4</td>
<td>&lt; 4.4</td>
<td>&lt; 6.4</td>
<td>&lt; 6.9</td>
<td>&lt; 1.4</td>
<td></td>
</tr>
<tr>
<td>Bicarbonate (HCO₃⁻)</td>
<td>0</td>
<td>61.6</td>
<td>144</td>
<td>367</td>
<td>1,640</td>
<td>1,578</td>
<td>732</td>
<td>606</td>
<td>366</td>
<td>1,080</td>
<td>1,450</td>
<td>387</td>
</tr>
<tr>
<td>Carbonate (CO₃⁻)</td>
<td>-</td>
<td>0</td>
<td>1.0</td>
<td>0</td>
<td>0</td>
<td>0.3</td>
<td>1.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sulfate (SO₄⁻)</td>
<td>1,570</td>
<td>5.2</td>
<td>18</td>
<td>21</td>
<td>250</td>
<td>52</td>
<td>53</td>
<td>32</td>
<td>120</td>
<td>1,720</td>
<td>3,260</td>
<td>21</td>
</tr>
<tr>
<td>Chloride (Cl⁻)</td>
<td>3.5</td>
<td>3.8</td>
<td>12</td>
<td>13</td>
<td>200</td>
<td>1,500</td>
<td>920</td>
<td>320</td>
<td>49</td>
<td>1,680</td>
<td>2,990</td>
<td>120</td>
</tr>
<tr>
<td>Fluoride (F⁻)</td>
<td>1.1</td>
<td>4</td>
<td>7</td>
<td>3</td>
<td>2.4</td>
<td>3.3</td>
<td>4.8</td>
<td>2.3</td>
<td>7.6</td>
<td>2.9</td>
<td>2.8</td>
<td>1.6</td>
</tr>
<tr>
<td>Nitrate (NO₃⁻)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Nitrite (NO₂⁻), as N</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.76</td>
</tr>
<tr>
<td>Boron (B)</td>
<td>-</td>
<td>0.02</td>
<td>0.07</td>
<td>0.06</td>
<td>-</td>
<td>12.5</td>
<td>7.4</td>
<td>2.9</td>
<td>3.8</td>
<td>6.8</td>
<td>4.8</td>
<td>1.2</td>
</tr>
<tr>
<td>Dissolved solids</td>
<td>2,160</td>
<td>126</td>
<td>224</td>
<td>365</td>
<td>2,170</td>
<td>3,740</td>
<td>3,500</td>
<td>1,120</td>
<td>638</td>
<td>5,510</td>
<td>11,000</td>
<td>625</td>
</tr>
<tr>
<td>Specific conductance (micromhos at 25°C)</td>
<td>4,570</td>
<td>113</td>
<td>282</td>
<td>640</td>
<td>3,500</td>
<td>6,160</td>
<td>3,930</td>
<td>1,880</td>
<td>1,000</td>
<td>8,560</td>
<td>15,300</td>
<td>925</td>
</tr>
<tr>
<td>pH</td>
<td>1.9</td>
<td>7.0</td>
<td>8.0</td>
<td>7.3</td>
<td>7.4</td>
<td>8.1</td>
<td>6.8</td>
<td>6.3</td>
<td>6.8</td>
<td>7.6</td>
<td>7.6</td>
<td>7.3</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>65</td>
<td>12.0</td>
<td>41.0</td>
<td>10.5</td>
<td>16.0</td>
<td>68.0</td>
<td>75.0</td>
<td>18.0</td>
<td>24.0</td>
<td>54</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

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 H₂S and CO₂. 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$_2$S, 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$_2$S to H$_2$SO$_4$ 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 solfatara areas in San Diego Canyon are expressed as small patches of altered ground near sample site 8, some of which emit H$_2$S. 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 l/s). The water is as warm as 50°C, and it bears H$_2$S.

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 re-establish 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 confined ground water in the surrounding alluvium. The total flow from these springs is estimated to be about 200 gal/min (13 l/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. F10-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 geysers areas in volcanic regions (that is, from hot but accessible environments) that reveal contents of SiO$_2$ 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 geysers 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
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 SiO₂ in these spring waters with those in other waters in the Jemez Mountains and with those in typical volcanic emissions (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 CO₂-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 HCO₃ 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 Purdy 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 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-fraction 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 Río 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 evaportranspira-
tion.

Base runoff of the Rio Guadalupe appears to come prin-
cipally 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 note-
worthy 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 concen-
trated 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 devel-
oped in the Pajarito Plateau (Purpymun 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 con-
tinuously below the caldera rim. Ground water in the allu-
vium, 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 appreci-
able 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. Evapotranspira-
tion 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 enlarge-
ment 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 lime-
stone 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 southwest course
along another canyon and through mountainous country be-
fore 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 artsian 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 Magadalena 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 develop-
ment, are questions requiring further study.

REFERENCES
Bailey, R. A., 1961, Hot springs and solfataric areas in the Valles Cal-
dera, 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

GROUND WATER-SOUTHWESTERN JEMEZ MOUNTAINS

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


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


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.


