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GROUND-WATER GEOLOGY OF THE RIO GRANDE TROUGH IN NORTH-CENTRAL NEW MEXICO, WITH SECTIONS ON THE JEMEZ CALDERA AND THE LUCERO UPLIFT[1]

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INTRODUCTION

The Rio Grande structural trough in north-central New Mexico contains a thick section of Tertiary and Quaternary rocks that serves as an underground reservoir for an immense volume of water. This paper briefly describes the interrelationship between geology and the occurrence of ground water in that part of the trough extending from Espanola southward to the Valencia County line a few miles south of Belen. The Ground Water Branch of the U. S. Geological Survey has been studying, since about 1949, the hydrologic conditions and the related geology in this area in cooperation with the New Mexico State Engineer Office, the State Bureau of Mines and Mineral Resources Division of the New Mexico Institute of Mining and Technology, the City of Albuquerque, and the Atomic Energy Commission at Los Alamos. This report is essentially a compilation of the published and publishable data and conclusions arrived at as a result of these projects. The area described in each of the several reports is shown on the source map for Figure 1. Bjorklund and Maxwell's report (1961) is the only one of the group to have been published to date. The work by Spiegel and Baldwin in the Santa Fe area (1958), Theis and Conover in the Los Alamos area (1961), and Theis, Conover, and Griggs in the Valle Grande and Valle Toledo area (1961) is presently available only in open-file reports of the Geological Survey, but each is in the process of publication. A report on eastern Valencia County is in preparation by the writer. In the remainder of the area, mostly in eastern Sandoval County, limited data on file in the Ground Water Branch office in Albuquerque were compiled to obtain the contours on the water-table and artesian-pressure surface shown on Figure 1.

AQUIFERS—THEIR GEOLOGY AND HYDROLOGY

All of the sedimentary rocks and some of the igneous rocks that crop out in the Rio Grande trough yield water to wells at one place or another. Generally, however, the sedimentary rocks of early and middle Tertiary age, which include the Galisteo formation, and the Espinaso volcanics and Cieneguilla limburgite of Stearns (1953), have low permeabilities and are capable of yielding only very small quantities of water. Ground water is obtained from these rocks locally where they crop out south and southwest of Santa Fe. The intrusive and extrusive rocks in this part of the area also produce small quantities of ground water locally. The important water-bearing and water-yielding stratigraphic units in the Rio Grande trough are the Santa Fe group and the Quaternary alluvium. These units have hydrologic characteristics that differ sharply from the early and middle Tertiary rocks upon which they rest and from the pre-Tertiary rocks that bound the trough on both sides. The relatively high porosity, permeability, and great combined thickness of the units result in the Rio Grande structural trough being a huge conduit through which ground water moves with relative ease.

Santa Fe Group

The Santa Fe group consists of several thousand feet of terrestrial sediments that were deposited in the subsiding Rio Grande trough between middle(?) Miocene time and Pleistocene(?) time. The group is composed mainly of interbedded silt, sand, and gravel. In general it is poorly indurated. However, the beds range from noncoherent to tightly cemented and highly compacted. Clay is present only in minor amounts in most of the Santa Fe. Terrace deposits in the incised valley occupied by the Rio Grande and elsewhere in the trough, which are sometimes lumped with the Santa Fe, often contain large amounts of this constituent. Spiegel and Baldwin (1958, p. 71-81), working in the Santa Fe area, recognized an underlying Tesuque formation consisting principally of pinkish tan silty sandstone, which forms the bulk of the Santa Fe group, and an overlying Ancha formation which consists of sand and gravel. They estimated the maximum thickness of the Ancha formation to be at least 300 feet. Most of the Santa Fe throughout its area of occurrence is lithologically similar to the Tesuque formation; gravel beds are subordinate constituents.

The thickness of the Santa Fe group has been reported at only a few locations. Spiegel and Baldwin estimated a thickness of several thousand feet in the vicinity of Santa Fe. Stearns (1953, p. 475) concluded from the driller's log of a deep test hole that the Santa Fe was about 2,150 feet thick at a point 9 miles northeast of Albuquerque. R. L. Bates (in Reiche, 1949, p. 1204), after studying the samples from an oil test located about 6 miles east of Belen, concluded that the thickness of the Santa Fe here was 4,550 feet. The maximum thickness of the Santa Fe recorded by Bjorklund and Maxwell (1961, p. 21) is 6,100 feet at a location about 12 miles west of Albuquerque.

Ground water has been obtained from the Santa Fe group wherever the unit has been tested within the Rio Grande trough. Pumping yields reported from the aquifer range from a few gallons per minute to several thousand gallons per minute. Care must be taken in interpreting these data, however, because the yields depend to a large extent upon the total thickness of saturated permeable beds penetrated by the well, and upon the construction of the well itself. Large-diameter wells, and wells that have been subjected to adequate well-completion procedures, remove water from the aquifer with relatively low pumping drawdown. Recognizing the limitations, it is still interesting to note some of the yields from the Santa Fe. In the vicinity of the city of Santa Fe and to the west of the city, maximum yields recorded by Spiegel (in Spiegel and Baldwin, 1958, figs. 38A, 38B) are on the order of 500 to 700 gpm (gallons per minute). The wells penetrate a few hundred feet of saturated Tesuque formation. A small

[1] Publication authorized by the Director, U. S. Geological Survey.

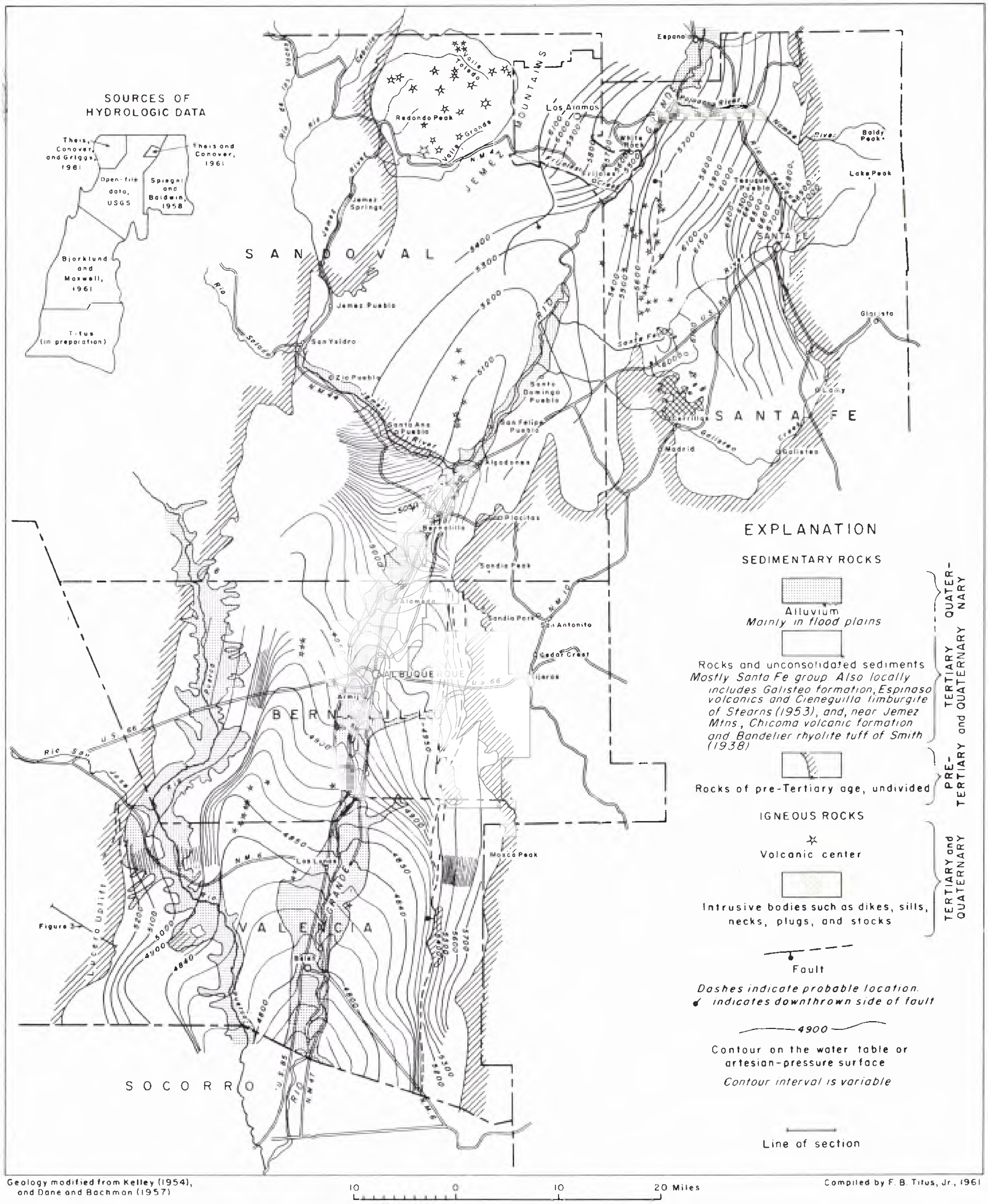

Figure 1. -- Water-table and artesian-pressure-surface contours for ground water in the Rio Grande trough in Santa Fe, Sandoval, Bernalillo, and Valencia Counties, New Mexico.

part of the discharge may come from the lower part of the Ancha formation. In the city of Albuquerque well fields the maximum yield is 3,360 gpm from a municipal well in the Rio Grande valley. The well penetrates almost 950 feet of saturated aquifer. Part of the discharge may come from the Quaternary alluvium. A well located about 5½ miles northeast of downtown Albuquerque produces 2,475 gpm from about 680 feet of saturated Santa Fe. The city of Belen pumps nearly 900 gpm from a well penetrating about 400 feet of saturated Santa Fe.

Very few data are available that would indicate potential pumping yields outside of populated areas in the Rio Grande trough. Water requirements here are not large, and most of the wells are pumped with windmills. The few available data suggest that, with aquifer penetration of a few hundred feet, only a few 10's of gallons per minute may be expected from wells in the Santa Fe a few miles or more west of the Rio Grande valley in Valencia, Bernalillo, and southern Sandoval Counties. Between the valley and the normal faults several miles east of the valley in Bernalillo County (Fig. 1) large potential yields are indicated by existing wells in the Albuquerque area. To the south in Valencia County potential yields may be somewhat lower.

The average temperature of ground water in the Albuquerque area is 64°F. Ground water pumped in 1960 from a new 1,180-foot municipal well 5 miles west of downtown Albuquerque had a temperature of 90°F. The unusually warm water may be the result of the volcanism that formed the Albuquerque volcanoes located about 4 miles northwest of the well.

Artesian conditions in the Santa Fe occur in parts of Sandoval and Santa Fe Counties. Wells in the Los Alamos Canyon well field, lying from 1 mile to about 4 miles west of the Rio Grande along New Mexico Highway 4 near Los Alamos, obtain water from an artesian aquifer, and in 1950 were pumped at rates ranging from about 250 to 650 gpm. A few miles north of Santa Ana Pueblo, water was reported to have risen 45 feet during drilling of a new well after the confining bed over the aquifer was penetrated. Across the Rio Grande from White Rock, in the northeast corner of Santa Fe County, two "artesian" wells are shown on the Geological Survey's 7½' topographic map. Artesian conditions would not be surprising in the area northwest of the city of Santa Fe. Spiegel has stated that, "As the Tesuque formation dips westward and northwestward to areas of discharge along the Rio Grande, more steeply than the slope of the piezometric surface, water must move across the dipping beds in order to discharge, even though the permeability across beds of the Tesuque formation is low" (Spiegel and Baldwin, 1958, p. 222).

Alluvium

Unconsolidated alluvium of Recent age underlies the floodplains of the major streams in the area. The alluvium consists mainly of thin to medium beds of clay, silt, sand, and fine gravel. In the Rio Grande valley in Valencia County, and possibly elsewhere, gravel is most common in the lower part of the unit. The alluvium under the valley floor of the Rio Grande resembles the Santa Fe because of the predominance of silt in both units and because of similarities in bedding and color; but it differs from the Santa Fe in that it contains larger amounts of gravel, clay, and organic material. Terrace deposits along the sides of the Rio Grande valley south of the mouth of the Jemez River closely resemble the alluvium. The maximum thickness of the alluvium in the Rio Grande valley is about 120 feet. The thickness of the alluvium in the Rio Puerco valley is not known. It is greater, however, than the approximate 40 feet that the Rio Puerco has been incised within historic time.

The alluvium in the Rio Grande valley is the most prolific aquifer in the area because of its high permeability and because in most places nearly the entire thickness is saturated. The depth of the water table almost everywhere in the valley is less than 10 feet. The maximum reported yield from the alluvium is about 3,000 gpm. Irrigation wells with capacities ranging from 200 to 2,000 gpm number about 200 in Valencia, Bernalillo, and southern Sandoval Counties. These wells mostly supplement the surface water that is the main source of supply for irrigation. Bjorklund and Maxwell (1961, p. 34) estimate that there are between 1,000 and 2,000 small-yield wells also used for irrigation. The number of wells supplying domestic water is of the same order of magnitude.

SHAPE OF THE WATER TABLE AND DEPTH TO WATER

The contour lines on Figure 1 are drawn on the water table or on the artesian-pressure surface where the groundwater body is confined. (The artesian-pressure surface indicates the altitude to which pressure in a confined aquifer at any location would raise water if the confining bed were penetrated by a well.) The general slope of the water table and artesian-pressure surface in the Tertiary and Quaternary aquifers is southward at an average angle equal to the slope of the Rio Grande. Superimposed on the over-all southward slope is a component of slope toward the central part of the aquifer from either side. The result is a trough in the water table or artesian-pressure surface, the axis of which, as seen from Figure 1, is coincident with the alignment of the Rio Grande in some places and in other places is roughly parallel to the alignment but situated to one side.

A sloping water table or artesian-pressure surface indicates the existence of a pressure gradient in the groundwater body and, therefore, implies movement of the ground water. The movement at any point must be normal to the contour lines and down the slope of the surface.

The continued existence of a natural ground-water trough depends upon water being transmitted more readily down the central part of the trough than toward the axis from both sides. Ground-water movement parallel to the trough axis is in response to a lower pressure gradient than is movement toward the axis from the sides. In addition, the volume of water moving parallel to the axis is the sum of the volume already in the central part of the trough and that being added from the sides. Thus, a ground-water trough indicates a lineal drain for the ground-water body. In the northern and southern parts of the map area (Fig. 1), where the axis of the groundwater trough coincides with the Rio Grande valley, draining is due to the combined effect of the Quaternary alluvium, which is more permeable than the Santa Fe, and to the Rio Grande and a system of drainage ditches, which remove ground water from the alluvium and carry it off as surface flow.

Where the ground-water trough lies to the west of the Rio Grande valley and the water table is at great depth, as in much of the central part of the area, the necessary lineal drain results either from anomalously high permeability of the Santa Fe along the axis or from greater thickness of the Santa Fe along the axis than on either side. The few wells along the ground-water trough in Bernalillo and Valencia Counties do not show an anomalously high permeability in the upper part of the saturated zone of the Santa Fe. Numerous small volcanic centers lying in a discontinuous line along the axis of the trough might be related to fractures which could increase the transmissibility of the aquifer. (Transmissibility is the transmitting capacity of the entire thickness of the aquifer.) The trough in Sandoval County also has volcanic centers nearby, although they lie to the west of the trough axis. Several small faults which could increase transmissibility have been mapped along this axis (Dane and Bachman, 1957). There is some evidence that the Santa Fe is relatively thick in the vicinity of the Bernalillo County trough. Thus, great aquifer thickness and high permeability may both be factors in the existence of the ground-water troughs. The steep slope on the west side of the Bernalillo County trough suggests that the Santa Fe thins rapidly to the west of the trough axis.

The depth of water below land surface in the Rio Grande structural trough ranges from zero at springs to more than a thousand feet under the upland west of Albuquerque and under the plateaus and mesas northeast of the Jemez River. At Santa Fe, the depth to water is a few 10's of feet. Locally there are perched bodies of water at very shallow depths. West and northwest of Santa Fe the depth to water is generally between 200 and 600 feet. In the Los Alamos Canyon well field, though the artesian-pressure surface is shallow, the wells are 870 to more than 1,900 feet deep, suggesting that the water-yielding beds are well below the artesian-pressure surface.

In the alluvium of the Rio Grande valley the water table generally is less than 10 feet below the surface. On either side of the valley the land surface rises at a steeper angle than the water table. East of the Rio Grande in Bernalillo and Valencia Counties the maximum depth to the water table is 400 to 500 feet immediately west of the faults shown on Figure 1. In Valencia County ground water moving toward the fault from the east flows through the Santa Fe on top of an uplifted block of pre-Tertiary rocks. At the fault it cascades several hundred feet to a lower level in the thick Santa Fe on the downthrown western block. Several springs occur along the fault.

RECHARGE

Some recharge to the Santa Fe must take place along both the east and west margins of the structural trough since the water-table contours invariably show movement toward the center of the trough from either side. The mountains that bound the trough on both sides throughout most of the area generally have higher precipitation rates than the lowlands in the structural trough. Recharge to the Santa Fe probably occurs both from ground water percolating through interstices and fractures in the pre-Tertiary rocks and from surface runoff to the lowlands, most of which infiltrates in the alluvial fans at the foot of the mountains.

In the vicinity of Los Alamos the thick Bandelier rhyolite tuff of Smith (1938) overlies the Santa Fe above the zone of saturation. Little information is available on hydrologic characteristics of the Bandelier. Since the artesian-pressure surface slopes toward the Rio Grande, there must be recharge to the aquifer from the Jemez Mountains. The welded tuff of the Bandelier might prevent or reduce recharge to the Santa Fe in the area between the Jemez Mountains and the canyon through which the Rio Grande flows in the vicinity of White Rock.

The amount of recharge to the Santa Fe from infiltration of precipitation and infiltration of arroyo flow has not been determined. When conditions are such that this water percolates to a depth below the zone of root interception and the zone in which circulation of air can evaporate water in the interstices of the rock, even where the water table lies considerably below the bases of these zones, the water may ultimately recharge the aquifer. The time interval between infiltration and recharge is much shorter than that required for a given drop of water to move the distance from the land surface to the water table. One drop of water infiltrating below the zone of evapotranspiration may quickly release one drop of water to the water table by a sort of chain reaction. The frequency with which water infiltrates below the zone of evapotranspiration needs investigation.

THE EFFECT OF THE RIO GRANDE

The depth of the water table under the floodplain of the Rio Grande south of Algodones is in most places 7 to 10 feet. A depression in the water table under downtown Albuquerque, developed by extensive pumping and lack of natural recharge, has a maximum depth of almost 30 feet. Under most of the floodplain the depth to water is maintained at a minimum of about 5 feet by a system of drainage ditches incised in the floodplain. The drains intercept shallow ground water, carry it off as surface flow, and eventually dump it into the river. Prior to the construction of the drainage-ditch system, which took place about 1930, the water table stood several feet higher than at present, and a large part of the floodplain was a marsh.

The elevation of the bed of the Rio Grande is in many places slightly above the elevation of the natural floodplain outside of the main levees. This has been caused by alluviation in the channel since the channel was confined by levees. Because the bed of the river is generally several feet above the level of the water table, seepage loss from the river is a potential source of recharge to the alluvium. Riverside drains on each side of the river immediately outside of the levees are designed to pick up this seepage to prevent its raising the water table under the floodplain on either side of the river channel.

Surface water diverted from the Rio Grande into a complex network of distribution ditches is used extensively for irrigation purposes during the growing season. A significant portion of this water seeps to the water table, and this recharge tends to raise the water table. Interior drains, which follow natural low places in the valley floor, are designed to remove excess ground water recharged from irrigation, as well as from precipitation and subsurface inflow from the Santa Fe.

The elevation of the water table throughout most of the valley is thus fixed rather closely by the discharging effect of the drainage ditches and the recharging effect of the river and irrigation.

Transpiration by plants and direct evaporation cause large losses from the combined ground- and surface-water reservoir in the Rio Grande valley and elsewhere where the water table is shallow. The shallow water table is conducive to the growth of a group of plants called phreatophytes which will thrive when their roots are below the water table or within the capillary fringe immediately above the water table. Included in this group are willows, cottonwoods, saltcedar, and alfalfa. Bjorklund and Maxwell (1961, p. 56) estimate that where the valley is covered by dense growth of cottonwood, willow, and saltcedar, the amount of water transpired annually is about

4 acre-feet per acre. Transpiration by alfalfa where the plant is cultivated and irrigated might be greater than this.

CHEMICAL QUALITY OF WATER

The chemical quality of ground water throughout most of the area considered in this report is such that the water may be used for drinking purposes. This applies to the part of Santa Fe County for which water-table contours are shown on Figure 1, Sandoval County north of the Jemez River and west of the Rio Grande, Bernalillo County east of the valley of the Rio Puerco, and Valencia County east of the axis of the ground-water trough. Recharge from storm runoff in the Jemez River and the Rio Puerco generally contains large amounts of dissolved material. Wells located near these two rivers usually produce water too high in dissolved solids, particularly in sulfate, to be potable. In Valencia County a significant amount of recharge to the Santa Fe comes from springs and seeps along the fault zone on the east side of the Lucero uplift. Water from the springs contains a maximum recorded dissolved-solids content of 33,900 ppm (parts per million), with a chloride content of more than 9,000 ppm. This water moves generally southeastward in the subsurface to the axis of the ground-water trough which, south of Belen, is coincident with the alignment of the Rio Grande. The dissolved-solids content of the water in the Santa Fe east of the fault zone generally decreases with distance from the faults, which suggests some recharge from precipitation. The concentration of dissolved solids does not decrease to the point of potability until the water reaches the Rio Grande valley.

Ground water from the alluvial aquifer in the Rio Grande valley is somewhat more highly mineralized than water in the adjacent Santa Fe aquifer, but chemically potable water can be obtained from the alluvium throughout the valley. The concentration of dissolved solids appears to be highest at the water table, diminishes rapidly in the uppermost few feet of aquifer, and then diminishes slowly to the base of the aquifer, where it is about the same as water in the Santa Fe. It is inferred from ground-water relationships in Valencia County that the high concentration of dissolved material near the water table is caused by phreatophyte transpiration. These plants remove water from the top of the ground-water body leaving the dissolved solids behind. This process has resulted in high concentrations within the root zone, and, because of periodic flushing by irrigation and floods, has probably contributed to the content of dissolved solids lower in the alluvium.

GEOLOGY AND HYDROLOGY OF VALLE GRANDE AND VALLE TOLEDO, SANDOVAL COUNTY[2]

A large volcanic depression [Valles or Jemez caldera] in the Jemez Mountains of north-central New Mexico was studied for its potential as a source of water for the town of Los Alamos, New Mexico. The depression is bowl shaped and is roughly 12 miles in diameter. The floor of the depression is divided into a network of valleys by numerous domes of rhyolite. Two valleys in the eastern half of the depression, Valle Grande and Valle Toledo, comprise the area investigated.

[2] This section is taken entirely from the open-file report by Theis, Conover, and Griggs (1961), and consists of a condensation of the abstract with a few additional notations from the text of the report.

The Jemez Mountains primarily consist of a volcanic caldera and an encircling apron of consolidated volcanic ash and pumice. Rhyolite domes were extruded in the caldera, and the lowland area remaining between the rhyolite domes and the caldera rim was, for a time, a lake. The lake gradually filled with debris derived largely from the rhyolite domes and, in part, from rocks of the caldera rim.

The rocks that crop out in the area are volcanic and sedimentary. An older sequence of flow rocks (Chicoma volcanic formation of Smith, 1938) is of probable Pliocene and Pleistocene age; a younger series of extrusive domes and tuff (Bandelier rhyolite tuff of Smith, 1938) is of probable Pleistocene age. The sedimentary rocks are lacustrine deposits of Pleistocene age and surface alluvium consisting of terrace, fan, and channel deposits, all younger than the volcanic rocks.

The Chicoma volcanic formation of Smith (1938) and the Bandelier rhyolite tuff of Smith (1938) do not contain important aquifers in the area. The same is true of the rhyolite domes, but the blocky crust and the porous rhyolite of the domes make them important as areas of recharge for the sedimentary rocks of the caldera fill (Fig. 2). Probably little if any water flows off the domes; it percolates downward through the porous rhyolite and into the porous strata in the lake beds and perhaps the alluvial fan material on the edges of the valleys.

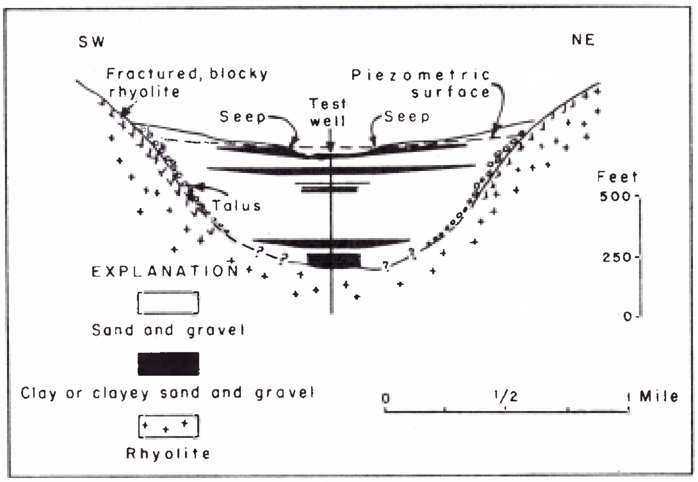

Figure 2.—Generalized section across Valle Toledo, Sandoval County, New Mexico. Modified from Theis, Conover, and Griggs (1961, fig. 4).

Several clayey members interfinger with the pumiceous sand and gravel of the caldera fill. Test drilling indicated that individual clay members are as much as 20 feet thick in the Valle Toledo; however, at places in that valley, the clayey members unite to form a clayey zone as much as 80 feet thick. In the Valle Grande, a thick zone of clay overlies a thicker zone of pumiceous sand and gravel. The maximum known thickness of the upper clay and underlying sand and gravel are 295 feet and 880 feet, respectively. The underlying sand and gravel unit was not completely penetrated by the well in which this thickness was measured. The pumiceous sand and gravel of the lake sediments form the principal aquifers in the Valle Toledo and Valle Grande, and ground water in these aquifers is confined under pressure by clay zones.

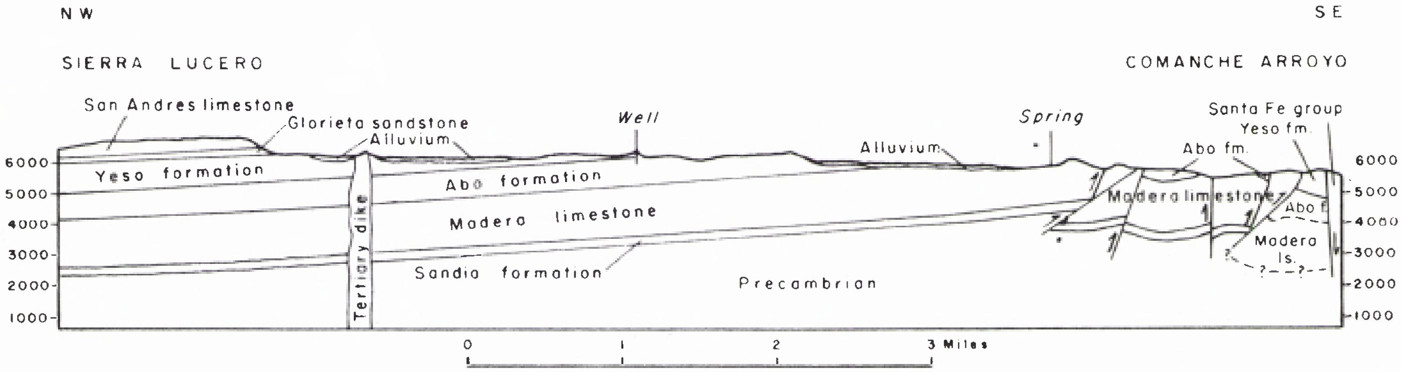

Figure 3. — Generalized section across the Lucero uplift in Valencia County, New Mexico, showing well and spring locations discussed in text. Modified from Kelley and Wood (1946, section E - E').

Properly constructed wells in the lake deposits might be expected to yield more than 1,000 gpm each. Large-discharge wells should be spaced far enough apart to avoid undue interference among the wells.

Considerable water could be pumped from storage, but the amount of water perennially available to wells in each valley would be the amount of water issuing from springs in their respective valleys — about 2,200 acre-feet in the Valle Grande and about 1,600 acre-feet in the Valle Toledo. Pumping from wells would deplete the flow of the springs, some of which now flow nearly 1,000 gpm, and thereby interfere with surface-water rights downstream.

Water from the lake deposits is high in silica content but low in total dissolved solids. The water is soft. Water in the Valle Toledo is relatively high in fluoride content and would have to be mixed with low-fluoride water before using in a municipal system.

GROUND-WATER CONDITIONS ON THE EAST SIDE OF THE LUCERO UPLIFT, VALENCIA COUNTY

Numerous springs discharge highly mineralized water to the surface along the fault zone on the east side of the Lucero uplift. In the northern part of the fault zone the water comes from rocks ranging in age from Pennsylvanian to Cretaceous that crop out on the sloping east side of the uplift. In the southern part of the fault zone, in southern Valencia County and northern Socorro County, the springs are restricted to water gaps through a hogback formed by tilted strata of the Madera limestone of Pennsylvanian age (Fig. 3; the well and spring locations in Figure 3 have been projected to the line of the cross section from nearby arroyos). The water discharging from the several springs contains from 15,000 to nearly 34,000 ppm dissolved solids, yet the ratios between individual chemical constituents strongly suggest a common source for all of the water. Apparently, dilution with water low in dissolved solids takes place locally near some of the springs. The water is very salty, having a high concentration of sodium and chloride ions, and it has a moderately high concentration of sulfate ions.

In the southern part of the area, erosion has produced strike valleys west of the fault zone. Several stock wells tap water in sandstones in the upper part of the Abo and the lower part of the Yeso formation. This water differs considerably from water discharging at the springs. It has a dissolved-solids content of roughly 4,000 to 5,000 ppm, and is predominantly a calcium-sulfate water with a low concentration of chloride ions. Water contained in this aquifer was probably recharged on the nearby Sierra Lucero and in the strike valleys, and the calcium sulfate was dissolved from gypsum beds in the San Andres limestone, the Glorieta sandstone, and the Yeso formation.

The two bodies of ground water having distinctly different chemical characteristics are separated by shales in the lower part of the Abo formation. Since both surface and subsurface drainage from the strike valleys must be eastward across the fault zone, and the only path across the hogback is through the gaps, water discharged at the southern springs is potentially a mixture from both ground-water bodies. Water from the upper aquifer is inferred to move across the Abo outcrop to the springs as underflow through arroyo channels. The underflow in the arroyos probably also includes water low in dissolved solids that is derived from local runoff.

Ground water discharging from the springs in the northern part of the Lucero fault zone on the average has a slightly higher ratio of sulfate to chloride than the water from the springs to the south. This suggests that more water is contributed to the springs from aquifers in the Abo and Yeso formations in the north. The Abo and Yeso here are mostly in the subsurface and are cut by faults.

Persistent reports have been heard from oldtimers in the area that some of the springs in gaps across the hogback yielded potable water "many years ago." Extended periods of high rainfall should increase the amount of water contributed to the springs by the upper aquifer but should not affect the contribution from the lower aquifer.

Furthermore, during these periods, ground water should be flushed more rapidly through the upper aquifer and thus have less time to pick up dissolved solids from the rock. Even so, it is a reasonable guess that what these old-time cowboys and sheepherders considered to be potable water might not meet the recommendations of the U. S. Public Health Service (1946).

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