Chemical quality of ground water in the northern part of the Albuquerque-Belen Basin, Bernalillo and Sandoval Counties, New Mexico

William L. Hiss, Frank W. Trainer, Bruce A. Black, and Douglas R. Posson

1975, pp. 219-235. https://doi.org/10.56577/FFC-26.219

in:

Las Cruces Country, Seager, W. R.; Clemons, R. E.; Callender, J. F.; [eds.], New Mexico Geological Society 26 th Annual Fall Field Conference Guidebook, 376 p. https://doi.org/10.56577/FFC-26

This page is intentionally left blank to maintain order of facing pages.

CHEMICAL QUALITY OF GROUND WATER IN THE NORTHERN PART OF THE ALBUQUERQUE-BELEN BASIN, BERNALILLO AND SANDOVAL COUNTIES, NEW MEXICO*

by
WILLIAM L. HISS[1], FRANK W. TRAINER[1]
BRUCE A. BLACK[2], and DOUGLAS R. POSSON[1]

INTRODUCTION

Aquifers within Cenozoic strata in the Rio Grande rift constitute some of the most important ground-water reservoirs in New Mexico. The Albuquerque-Belen basin, the largest of the south-trending series of grabens that forms the Rio Grande rift, is about 30 mi (48 km) wide and 90 mi (145 km) long (Figs. 1 and 2). Albuquerque, with a population of about 285,000, pumps an average of 68.5 million gallons of water per day (260,000 m^3/day) from wells tapping Cenozoic aquifers (Bureau of Business and Economic Research, 1975; Wombold and Adcock, 1975; and Dan Reddy, Water Department, city of Albuquerque, personal commun., July 8, 1975). This stress on the aquifer system is increased by pumping for the estimated additional 100,000 people living in nearby communities and suburban developments—perhaps as much as 23.5 million gallons of water per day (89,000 m^3/day).

Extrapolation of historic trends in population growth and water use (Reeder, Bjorklund, and Dinwiddie, 1967, p. 9-10) suggests that considerable additional development of the aquifers within the Cenozoic fluvial deposits filling the rift will be required in the future. A knowledge of the quantity and quality of ground water stored in the basin will therefore be an important factor in planning for both orderly economic growth and expansion of the population.

The stratigraphic nomenclature used by the New Mexico Geological Society, followed in this report, does not necessarily conform to that used by the U.S. Geological Survey.

ACKNOWLEDGMENTS

Shell Oil Company cooperated with the U.S. Geological Survey, the New Mexico State Engineer, and the New Mexico State Environmental Improvement Agency in a program to evaluate the yield and quality of water in upper Cenozoic sedimentary rocks in the Shell Oil Company Santa Fe Pacific No. 1 well. In addition, Shell Oil Company (1) computed the salinity of water contained in rocks of several geologic ages from electrical logs of the entire stratigraphic section penetrated in the test well, (2) provided an interpretation of the computed values, and, (3) furnished a description of the type and amount of fluid and chemical data obtained from analyses of water recovered on drill-stem tests of several formations. The assistance of Shell Oil Company has led to a more thorough knowledge of the geohydrology of this area and is gratefully acknowledged.

Messrs. Francis C. Koopman, U.S. Geological Survey, and Michael R. Snavely, New Mexico State Environmental Improvement Agency, made data collected during the testing of the Santa Fe Pacific No. 1 well and analysis of water samples available to the writers. Mr. Dan Reddy, Water Department, city of Albuquerque, privided data and made helpful comments about water development in the Albuqueruqe area. The cooperation of the engineering staff and other personnel associated with communities and industrial plants in the area greatly facilitated the collection of data outside the city.

GEOLOGY

The structural setting of the Albuquerque-Belen basin is illustrated in Figures 1 and 2. To the east, a fault boundary separates the graben of the Albuquerque-Belen basin from the Sandia and Manzano uplifts (Black and Hiss, 1974, pl. 2). Precambrian crystalline rocks and upper Paleozoic sedimentary rocks stand high above the surface of the adjacent valley fill, dominating the landscape of the Albuquerque area. To the west, a series of subparallel faults extends southward from near Jemez Caldera, in the Jemez uplift, south-southwest, separating the graben from the Nacimiento uplift, the Puerco platform, and the Lucero and Ladron uplifts (Kelley, 1954; Slack, 1973). Precambrian, upper Paleozoic, and Mesozoic rocks are exposed in the uplifts west of the basin margin but attain much lower altitudes than rocks of similar age east of the Rio Grande rift. Joesting, Case, and Cordell (1961) estimate that stratigraphic displacement may be as great as 22,000 ft (6,700 m) along the western margin of the Sandia Mountains and about 16,000 ft (4,880 m) along the western margin of the Albuquerque-Belen graben.

Faulting and subsidence, which probably began in late Miocene time (Kelley, 1952, p. 101), were accompanied by deposition of alluvial sediments. The upper Cenozoic strata exposed in the northern part of the Albuquerque-Belen basin and adjacent areas to the north and northeast have been studied by Galusha, 1966; Spiegel, 1961; Stearns, 1943, 1953a, and 1953b; and Black and Hiss, 1974. Smith, Bailey, and Ross (1970) show the areas of exposure of these deposits in the southern Jemez uplift, at the north edge of the basin. Because these rocks have not been studied in detail at the surface farther south along the basin margins, or in the subsurface, they are not subdivided in this report. In general, they consist of the Santa Fe Group (undivided) and the Zia Sand Formation of Galusha (1966). Both units were recognized in the Shell Oil Company Santa Fe Pacific No. 1 well and are termed "valley fill" in this report (Table 1). The upper Cenozoic rocks are buried beneath a relatively thin veneer of Quaternary alluvium along the Rio Grande.

The valley fill consists of gravel, sand, silt, and clay deposited as fans extending into the subsiding trough and, perhaps, in later stages of the history of the trough, as the deposits of a through-flowing stream. The local composition of the valley fill largely reflects the nature of the rocks in adja-

*Publication approved by Director, U.S. Geological Survey.

1. U.S. Geological Survey, Albuquerque, N. Mex.
2. Colorado Plateau Geological Services, Inc., Farmington, N. Mex.

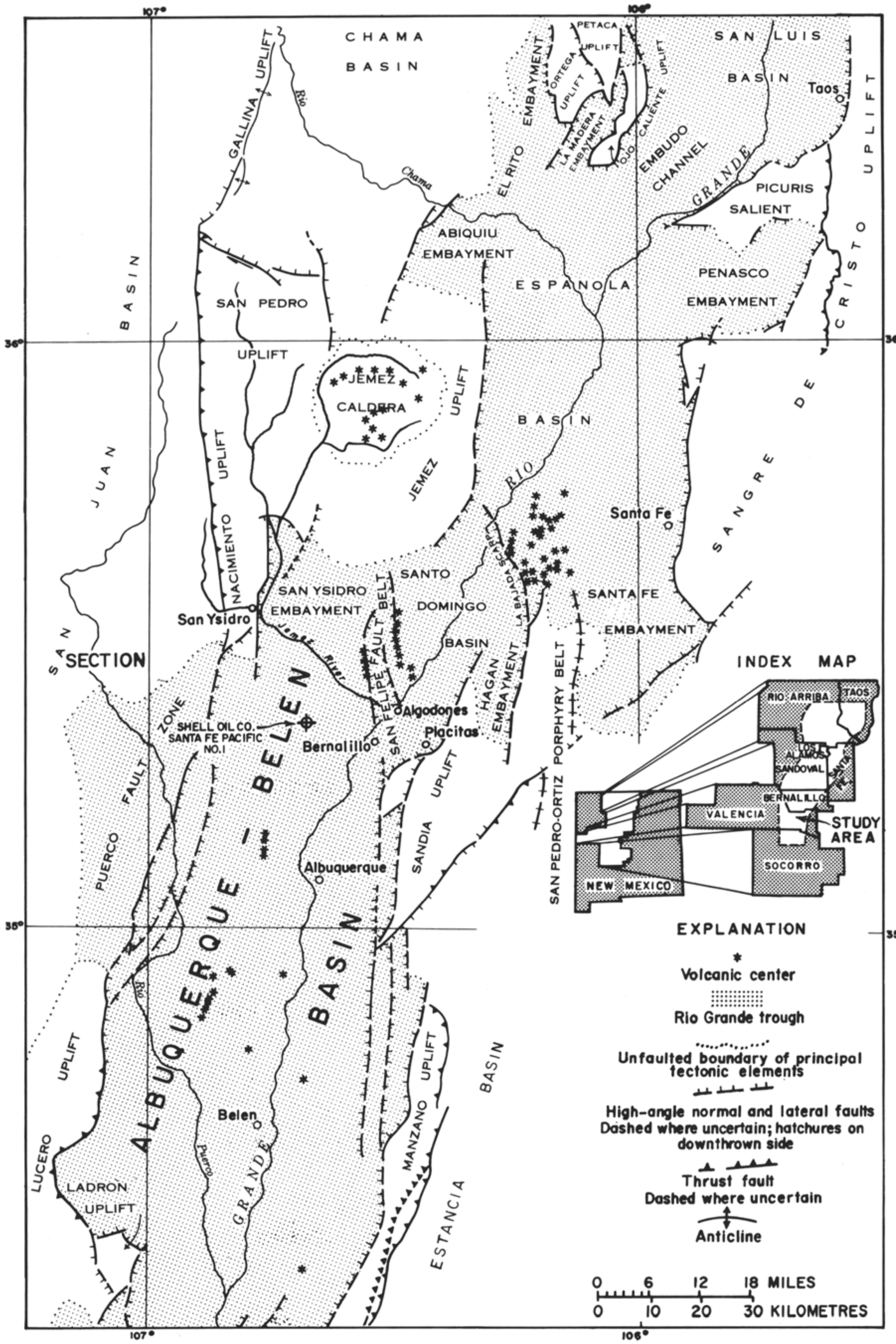

Figure 1. Tectonic diagram of a part of the upper Rio Grande area (adapted from Kelley, 1954 and Dane and Bachman, 1965).

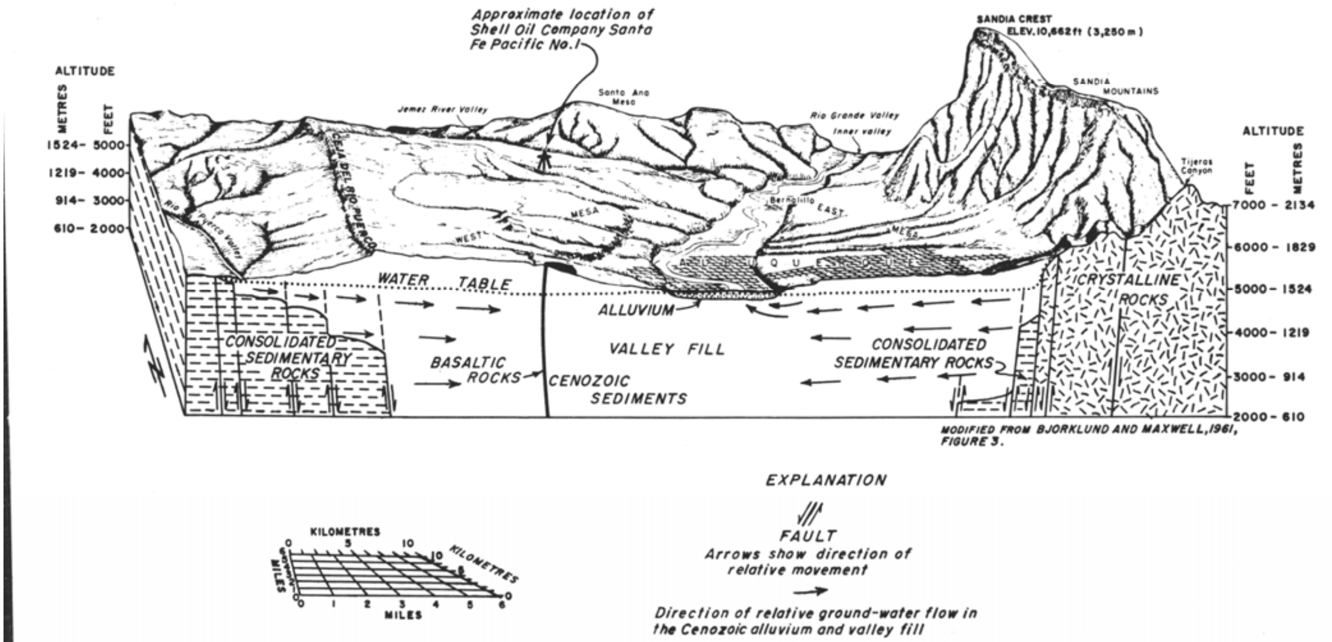

Figure 2. Schematic diagram of the geohydrologic regimen in the Rio Grande rift near Albuquerque, Bernalillo and Sandoval Counties, New Mexico.

cent uplifts (Kelley, 1952, p. 101). Sedimentary rocks largely derived from volcanic rocks are interbedded with igneous flows south of the Jemez uplift. Valley fill derived from the Sandia and Manzano uplifts is largely composed of poorly sorted, coarse granitic, and carbonate rock debris. Erosion of Mesozoic shale, sandstone, and thin limestone and gypsum west of the rift has contributed generally well-sorted, fine-grained sediment to the valley fill.

The sedimentary rock sequence found beneath the valley fill in the northern Albuquerque-Belen basin is shown in data obtained from the Shell Oil Company Santa Fe Pacific No. 1 well (Table 1). The porosity and permeability of the pre-Cenozoic rocks is much lower than that of the overlying valley fill. However, water-bearing zones in these strata are believed o be of potential significance to the hydrology of the Albuquerque-Belen basin because moderately mineralized water ound in these rocks (Table 2; and Berry, 1959) may be in ydraulic communication with flow into the valley fill (Fig. 2).

HYDROLOGY

Ground-Water Sources

Ground water in the Albuquerque-Belen basin is derived from five sources: (1) precipitation within the lowland part of the basin; (2) underflow from the Rio Grande Valley upstream from the basin, and infiltration from the Rio Grande; (3) inflow from the Jemez uplift, to the north; (4) inflow from outside the trough, from the east; and (5) inflow from outside he trough, from the west. The chemical composition of several of these source waters is illustrated by diagrams in figure 3.

Local Precipitation

Water that infiltrates the channels of arroyos during understorms probably provides substantial recharge to the upper part of the saturated zone. This water is of a calcium sodium bicarbonate composition and moderate dissolved-solids concentration, like that of samples collected southeast of Bernalillo (Fig. 3).

Rio Grande, Upstream

Water brought into the basin by underflow is of a calcium sodium bicarbonate composition and some of it also contains appreciable sulfate. Samples collected along the Rio Grande upstream from the Jemez River are typical examples (Fig. 3).

Hydraulic interrelations between the Rio Grande and the aquifers along its course control infiltration from the river. A water-level contour map presented by Titus (1961, Fig. 1) shows the following: For some tens of miles upstream from Bernalillo, the Rio Grande is a gaining stream or it receives ground-water inflow along one bank and loses water by seepage along the other bank. Near Bernalillo and continuing to or near the south end of the Albuquerque-Belen basin, the Rio Grande is a losing stream. The infiltrated water is of relatively good chemical quality, although (as is noted later) the quality of Rio Grande water below the Jemez River reflects the dissolved load brought in from the Jemez uplift.

Inflow from Jemez Uplift

The Jemez River is a losing stream for much or all of its course below San Ysidro. Water with a high content of sodium, chloride, sulfate, and several minor constituents brought from the Jemez and Nacimiento uplifts infiltrates into the ground-water system from the Jemez River (Trainer, 1974). The water from mineral springs, such as those west and north of San Ysidro (Fig. 3), flows into and mixes with the moderately mineralized water of the Jemez River from above San Ysidro. Other inflowing water from valley-fill deposits (as north of Zia Pueblo) is of good quality but of insufficient

Table 1. Depth to and altitude of stratigraphic horizons encountered in the Shell Oil Company Santa Fe Pacific No. 1.[1]

[Altitude of land surface at well is 5,733 ft (1,747.4 m).]

Erathem	System	Series	Stratigraphic unit	Depth from kelly bushing reference datum, 5,753 ft (1,753.5 m) above sea level 2/		Altitude above(+) or below(-) sea level	
				Feet	Metres	Feet	Metres
Cenozoic	Tertiary	Pliocene-Miocene	Santa Fe Group	0	0	+5,733	+1,747
			Zia Sand Formation of Galusha (1966)	2,800	853	+2,953	+ 900
		Eocene	Galisteo-San Jose Formations undivided	2,970	905	+2,783	+ 848
Mesozoic	Cretaceous	Upper	Menefee Formation	3,644	1,111	+2,109	+ 643
			Point Lookout Sandstone	4,378	1,334	+1,375	+ 419
			Mancos Shale	4,520	1,378	+1,233	+ 376
			Crevasse Canyon Formation	4,920	1,500	+ 833	+ 254
			Niobrara Formation (base) 3/	5,695	1,736	+ 58	+ 18
			Sanostee marker 4/	6,095	1,858	- 342	- 104
			Greenhorn Limestone	6,426	1,959	- 673	- 205
			Dakota Sandstone	6,542	1,994	- 789	- 240
			"A" Sandstone Zone 4/	6,542	1,994	- 789	- 240
			"B" Sandstone Zone 4/	6,600	2,012	- 847	- 258
			"C" Sandstone Zone 4/	6,710	2,045	- 957	- 292
		Lower	"D" Sandstone Zone 4/	6,793	2,071	-1,040	- 317
	Jurassic	Upper	Morrison Formation	6,907	2,105	-1,154	- 352
			Todilto Limestone	7,452	2,271	-1,699	- 518
		Lower	Entrada Sandstone	7,528	2,295	-1,775	- 541
	Triassic	Upper	Chinle Formation	7,727	2,355	-2,004	- 611
			Agua Zarca Sandstone Member	8,738	2,663	-2,985	- 910
Paleozoic	Permian	Leonardian	San Andres Limestone	8,875	2,705	-3,122	- 952
			Glorieta Sandstone	8,900	2,713	-3,147	- 959
			Yeso Formation	8,990	2,740	-3,237	- 987
			Meseta Blanca Sandstone Member	9,375	2,858	-3,622	-1,104
		Wolfcampian	Abo Formation	9,500	2,896	-3,747	-1,142
	Pennsylvanian		Madera Limestone	10,376	3,163	-4,623	-1,409
			Sandia Formation	Not Present		-	-
Precambrian	-	-	Precambrian	10,955	3,339	-5,202	-1,586

1/ Depths to several stratigraphic units were released by Shell Oil Company and were confirmed by examination of the electrical logs run in this well. Additional stratigraphic horizons were determined by correlation of the electric logs from the Santa Fe Pacific No. 1 well with similar logs run in other wells in adjacent areas (Black and Hiss, 1974, p. 365).
2/ Reference datum is 20 ft (6.1 m) above land surface. Depths recorded on electrical logs are referenced to this datum.
3/ Correction to data published in Black and Hiss (1974, p. 366, tbl. 1).
4/ Marker beds and zones used locally in northwestern New Mexico.

quantity to have a significant effect on the quality of the stream water.

The effect of the Jemez-Nacimiento water is also expressed indirectly along the Rio Grande south of the mouth of the Jemez River, where water from the Rio Grande that has received the dissolved load of the Jemez River infiltrates into the ground-water system. (In part, the quality of ground water near the Rio Grande south of Bernalillo also reflects the effect of concentration of dissolved solids by evapotranspiration.)

The mineral springs near San Ysidro are representative of many in the fault zone at the west margin of the rift near and up-canyon from this village. They feed into the Jemez River and, at the south end of the Sierra Nacimiento, into Rio Salado. Analyses shown in Figure 3 (in and south of San Ysidro, at the south edge of Zia Pueblo, and along the Jemez River downstream from Zia Pueblo and at Jemez Canyon Dam) illustrate the dissolved load in ground water in alluvium along the Jemez River and are representative of the water which seeps into the streambed.

In addition, mineralized ground water from the Jemez Mountains may flow directly into the valley fill in the rift by way of the marginal fault zone. Trainer (see article in this guidebook) suggests that along some flow paths in consolidated rocks in the fault zone mineralized water has flowed at least as far as Jemez Pueblo (about 20 mi, 32 km, from the rim of Jemez Caldera, and nearly to San Ysidro) without great modification through dilution and dispersion. The absence of springs along the fault zone where it passes into the valley fill near San Ysidro is believed to reflect subsurface discharge into relatively permeable strata in the valley fill.

Table 2. Dissolved solids as sodium chloride expected to be found in strata of several geologic ages penetrated in the Shell Oil Company Santa Fe Pacific No. 1.[1]

Stratigraphic unit	Range in concentration of dissolved solids expected, expressed as sodium chloride, mg/1 2/	Most probable concentration of dissolved solids expected, expressed as sodium chloride, mg/1 2/
Santa Fe Group (total range-in general, salinity gradually increases downward)	400- 8,000	-
Santa Fe Group [average in interval 600-1,500 ft (183-457 m)]	- -	2,000±
Santa Fe Group [850-856 ft (259-261 m)]	- -	500±
Santa Fe Group [1,500-2,970 (457-905 m), salinity gradually increases downward]	1,400- 8,000	-
Galisteo Formation	10,000-15,000	-
Menefee Formation	7,500-13,000	-
Point Lookout Sandstone	9,000-14,000	12,000
Crevasse Canyon Formation	7,000	7,000
"A" Zone of Dakota Sandstone 3/	3,000-10,000	> 3,000
"B" Zone of Dakota Sandstone 3/	3,500-11,000	> 3,500
"C" Zone of Dakota Sandstone 3/	2,300- 3,000	2,300
"D" Zone of Dakota Sandstone 3/	6,000- 8,000	6,800
Morrison Formation	7,000- 9,500	7,000±
Entrada Sandstone	5,000-11,000	7,000±
Agua Zarca Sandstone Member of Chinle Formation	6,000- 8,000	7,000±
San Andres Limestone	13,000- (?)	13,000(?)
Yeso Formation	6,000- 8,000	7,000±
Meseta Blanca Sandstone Member of Yeso Formation	5,500-10,000	5,500±
Abo Sandstone	6,000-10,000	7,000±

1/ Computations made by staff of Shell Oil Company. Data used with permission of Shell Oil Company.

2/ Apparent resistivities of water were determined from electrical logs and then expressed in equivalent total solids as sodium chloride. Geothermal gradient of 1.6°F/100 ft (1.8°C/100 m) was assumed.

3/ Zones used locally in northwestern New Mexico to identify sandstone beds within the Dakota Sandstone.

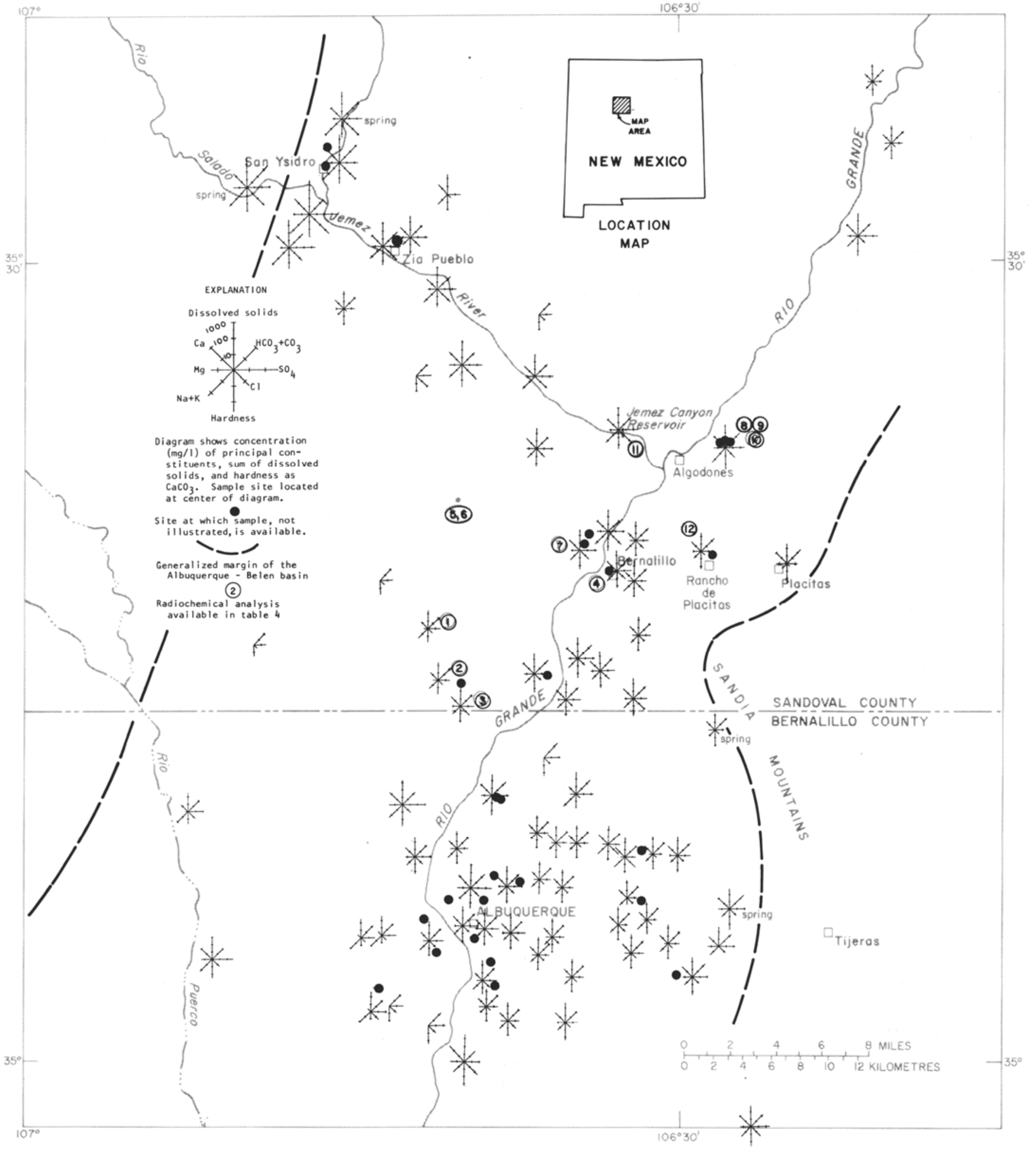

Figure 3. Chemical composition of ground water from selected wells tapping the Santa Fe Group and Quaternary alluvium, and from springs flowing from older rocks, in the Albuquerque-Belen basin.

Preliminary study of geohydrologic data from the Jemez Mountains suggests that mineral-water discharge from that region is principally to the southwest along the margin of the rift. Because of the intricate patterns of the faults, however—many of the known faults extend far into the rift (Smith, Bailey, and Ross, 1970)—this water may enter the valley fill over a front of many miles. The information available thus indicates both the availability of mineralized water in the Jemez Mountains and the presence of routes foP,its subsurface discharge into the rift.

Inflow from Sandia and Manzano Uplifts

Inflow from outside the trough, from the east, as subsurface flow or as surface flow that infiltrates arroyo floors, brings water of good quality to the Albuquerque-Belen basin. Calcium bicarbonate water is derived from carbonate-bearing rocks; see analyses at Placitas (Fig. 3). Water containing calcium, sodium, and bicarbonate ions flows from arkosic rocks as indicated by the analyses east of the graben-margin fault zone, east and northeast of Albuquerque. The shallow ground water in the Albuquerque area east of the Rio Grande appears, on the basis of the chemical analyses, to have been derived from the Sandia Mountains or from precipitation in the local area. Appreciable concentrations of sulfate in water east of the Rio Grande are believed to have been derived from rocks of the Todilto Limestone and associated strata east of the Sandia and Manzano uplifts near Tijeras.

Inflow from the Western Margin of the Basin

Very little was known about the quality of ground water in the deeper aquifers within the Albuquerque-Belen basin until Shell Oil Company drilled the Santa Fe Pacific No. 1 well in sec. 18, T. 13 N., R. 3 E., about 18 mi (30 km) north-northwest of downtown Albuquerque (Fig. 1). A very complete suite of electrical logs was run to determine and evaluate the physical characteristics and the fluids contained in the rocks penetrated in this deep wildcat well (Table 2). Samples of water were collected from several aquifers during drill-stem tests of possible petroleum-bearing zones, and subsequent attempts were made to collect samples of water from aquifers in the valley fill prior to abandonment of the well (Table 3).

Fluid was recovered during tests of potential aquifers in the Santa Fe Group, the Zia Sand Formation, the Dakota Sandstone, the Todilto Limestone and Entrada Sandstone combined, and the Meseta Blanca Sandstone Member of the Yeso Formation. Descriptions and analyses of the recovered fluid are given in Table 3.

Water samples collected from the Dakota Sandstone and the Meseta Blanca Sandstone Member of the Yeso Formation are of a sodium bicarbonate sulfate type and appear to be representative of the waters contained in these aquifers. Water was not recovered during a drill-stem test of the Todilto Limestone and Entrada Sandstone, combined. Therefore, this test was inconclusive. A small amount of water was recovered through casing perforations from the Zia Sand Formation during a brief swabbing test. The representativeness of the water recovered has been questioned (Table 3, samples 35-37). However, supplemental information given below suggests that the water is representative of the Zia Sand Formation. Water recovered during a similar test of the Santa Fe Group is thought not to be representative of the water contained in this aquifer (Table 3, samples 38 and 39).

The salinity of ground water contained in formations of several geologic ages penetrated in the Shell Oil Company Santa Fe Pacific No. 1 well was computed from electrical logs and expressed as sodium chloride (Table 2). Salinities computed for the Dakota Sandstone and Meseta Blanca Sandstone Member of the Yeso Formation agree, in general, with the content of dissolved solids determined from chemical analyses. Computed salinities of the water in the Mesozoic rocks are also in agreement with the dissolved-solids content of the water in Jurassic and Cretaceous rocks mapped by Berry (1959, pls. VIII and X) in the San Juan basin to the west. These compari sons tend to confirm the validity of the computed salinities. By extension, the computed salinities are indicative of deterioration of water quality in the Cenozoic aquifer with increasing depth, assuming effective hydraulic communication between the Paleozoic and Mesozoic rocks and the Cenozoic valley fill.

The salinity of the water from one zone, at a depth of 850 to 856 ft (259 to 261 m), was computed to be approximately 500 mg/l sodium chloride. This thin zone containing fresh water is both over and underlain by rocks containing saline water (Table 2). (For purposes of this report, saline water is defined as water containing more than 1,000 mg/l dissolved solids.)

The radiochemical content of one sample of water swabbed from the Zia Sand Formation was also determined (Table 4). The unexpectedly high alpha and beta activities and dissolved radium and uranium content were initially thought to be indicators of contamination from water entering the aquifer from the drilling mud. However, the alpha and beta activities of the drilling mud, determined for comparison purposes, were much lower than those of the produced water. No other wells are known to tap the Zia Sand Formation in this region, but the radiochemical content of waters from several wells that tap shallower aquifers in the general vicinity was determined. These data (Table 4) suggest that a relatively low radiochemical content is typical of the water in the shallower aquifers in the valley fill.

This interpretation taken with the computed salinities (Table 2), suggests that the water sampled was not entirely mud filtrate and may have been representative of water in the Zia Sand Formation. If so, the altitude of the fresh-saline water interface may be only about 4,500 ft (1,370 m) above sea level. This inference suggests, in turn, that fresh water may be a relatively thin lens only 500 to 800 ft (150 to 245 m) thick in this part of the Albuquerque-Belen basin. Some minor interfingering of fresh and saline water below this depth vary as suggested by the computed water salinities (Table 2).

A comparison of the potentiometric surfaces from the Dakota Sandstone and the Entrada Sandstone in the San Juan basin prepared by Berry (1959, pls. VII and IX) with a similar map compiled for the valley fill in the Rio Grande rift by Titus (1961, Fig. 1, p. 187), supplemented by a general knowledge of the geologic framework of the area suggests that the Rio Grande may drain water from the San Juan basin where the two structural provinces meet along the western margin of the Rio Grande rift (Fig. 1).

Moderately mineralized water of a sodium bicarbonate sulfate type probably moves into the Rio Grande rift from the San Juan basin in a broad zone between the Nacimiento uplift, on the north, and the Ladron uplift, to the south (Fig. 1). Water moving into the Rio Grande rift from the San Juan basin probably also carries uranium and other radioactive elements dissolved from the uranium-bearing rocks found in and on the margins of the San Juan basin (Hilpert, 1969).

Mineralized water moving south-southwestward along faults parallel to the basin margin from the Jemez uplift into the western margin of the Rio Grande rift would be another important source of saline water. An unknown amount of saline water probably was added to the hydrologic regimen by Holocene volcanism in the Albuquerque-Belen basin and vicnity (Fig. 2; and Kelley, 1974, p. 29-35).

A trough in the potentiometric surface from the aquifers in

Table 3. Chemical quality of water recovered during drill-stem and other tests of the Shell Oil Company Santa Fe Pacific No. 1 NW¼SW¼ sec. 18, T. 13 N., R. 3 E., Sandoval County, New Mexico.

Sample sequence number	Sampling method	Aquifer tested	Depth of producing interval or sampling point from kelly bushing reference datum: Top		Bottom		Date (year, month, day)	Amount of fluid recovered during entire test		Type of fluid	Description of fluid
			Feet	Metres	Feet	Metres		Barrels	Cubic Metres		
1	Drill-stem test no. 1 (straddle packer)	Dakota Sandstone ("C" Zone[1/])	6,720	2,048	6,753	2,058	1972-07-10	10.8	1.7	Drilling mud	Water cut
2[8/]	do.	do.	6,720	2,048	6,753	2,058	1972-07-10	85.5	13.6	Water(?)	Water cut mud
3[8/]	do.	do.	6,720	2,048	6,753	2,058	1972-07-10	85.5	13.6	Water	Brackish smelling water
4[8/]	do.	do.	6,720	2,048	6,753	2,058	1972-07-10	85.5	13.6	do.	Fairly clear fluid
5[8/]	do.	do.	6,720	2,048	6,753	2,058	1972-07-10	85.5	13.6	do.	
6[8/]	do.	do.	6,720	2,048	6,753	2,058	1972-07-10	85.5	13.6	do.	
7[8/]	do.	do.	6,720	2,048	6,753	2,058	1972-07-10	85.5	13.6	do.	
8[8/]	do.	do.	6,720	2,048	6,753	2,058	1972-07-10	85.5	13.6	do.	
9[8/]	do.	do.	6,720	2,048	6,753	2,058	1972-07-10	85.5	13.6	do.	
10[8/]	do.	do.	6,720	2,048	6,753	2,058	1972-07-10	85.5	13.6	do.	
11[8/]	do.	do.	6,720	2,048	6,753	2,058	1972-07-10	85.5	13.6	do.	
12[8/]	do.	do.	6,720	2,048	6,753	2,058	1972-07-10	85.5	13.6	do.	Very clear, greenish tint, sand in fluid
13[7/]	do.	do.	6,720	2,048	6,753	2,058	1972-07-10	85.5	13.6	do.	
14[8/]	do.	do.	6,720	2,048	6,753	2,058	1972-07-10	85.5	13.6	do	
15	Drill-stem test no. 2	Todilto Formation and Entrada Sandstone	7,503	2,287	7,535	2,297	1972-07-20	3.7	.6	do.	Slightly mud cut
16	do.	do.	7,503	2,287	7,535	2,297	1972-07-20		.6	Drilling mud	
17	do.	do.	7,503	2,287	7,535	2,297	1972-07-20	3.7	.6	do.	
18	do.	do.	7,503	2,287	7,535	2,297	1972-07-20	3.7	.6	do.	
19	do.	do.	7,503	2,287	7,535	2,297	1972-07-20	3.7	.6	do.	
20	do.	do.	7,503	2,287	7,535	2,297	1972-07-20	3.7	.6	do.	
21	do.	do.	7,503	2,287	7,535	2,297	1972-07-20	3.7	.6	do.	
22	do.	do.	7,503	2,287	7,535	2,297	1972-07-20	3.7	.6	do.	
23	do.	do.	7,503	2,287	7,535	2,297	1972-07-20	3.7	.6	do.	

Table 3—continued.

Sample sequence number	Silica dissolved (SiO_2) mg/l	Iron dissolved (Fe) µg/l	Manganese dissolved (Mn) µg/l	Calcium dissolved (Ca) mg/l	Magnesium dissolved (Mg) mg/l	Sodium dissolved (Na) mg/l	Potassium dissolved (K) mg/l	Bicarbonate dissolved (HCO_3) mg/l	Carbonate dissolved (CO_3) mg/l	Alkalinity as $CaCO_3$, Total mg/l	Sulphate dissolved (SO_4) mg/l	Chloride dissolved (Cl) mg/l	Fluoride dissolved (F) mg/l	Nitrite + Nitrate dissolved as N mg/l
1												2,000[6/]		
2		200[2/]	< 50	43	10	1,200	26	1,610		1,320	1,070	250	3.9	0.8[3/]
3		150[2/]	< 50	43	17	1,200	39	1,470		1,200	1,270	300	3.6	.2[3/]
4		150[2/]	< 750	24	31	1,300	39	1,450		1,190	1,470	330	4.2	.2[3/]
5		350[2/]	100	20	34	1,300	47	1,450		1,190	1,450	330	4.2	.2[3/]
6		800[2/]	1,000	22	36	1,400	55	1,610		1,320	1,470	330	4.1	<.1[3/]
7		1,800[2/]	200	18	36	1,500	45	1,570		1,290	1,550	350	4.4	.7[3/]
8		10,400[2/]	300	16	38	1,400	66	1,420		1,170	1,580	350	4.2	15.0[3/]
9		1,200[2/]	350	76	16	1,400	55	1,460		1,200	1,630	350	5.1	.2[3/]
10		1,400[2/]	600	52	11	1,300	51	1,320		1,090	1,390	360	5.5	.2[3/]
11		850[2/]	750	93	32	1,400	55	1,390		1,140	1,580	360	5.4	1.2[3/]
12		450[2/]	700	21	26	1,400	62	1,350		1,110	1,580	360	5.4	<.1[3/]
13												900[6/]		
14			< 50	12	21	1,300	39	1,360		1,120	1,520	370	5.4	.4[3/]
15												1,350[6/]		
16														
17														
18														
19														
20														
21														
22														
23														

Table 3—continued.

Sample sequence number	Dissolved solids Sum of determined constituents mg/l	Hardness dissolved as $CaCO_3$ (Ca,Mg) mg/l	Specific conductance, micromhos at 25°C	Water resistivity ohm-metres	Temperature water resistivity measured °C	Bottom-hole temperature °C	pH	Water temperature °C	Arsenic dissolved (As) µg/l	Barium dissolved (Ba) µg/l	Beryllium dissolved (Be) µg/l	Boron dissolved (B) µg/l	Cadium dissolved (Cd) µg/l
1				1.20[7/]	70	70							
2	4,390	150	5,250				7.8		10	< 1,000	< 10	2,700	< 10
3	4,140	180	5,800				7.3		4	< 1,000	< 10	4,800	< 10
4	4,720	190	6,090				7.6		2	< 1,000	< 10	4,500	< 10
5	4,650	190	6,090				7.6		< 2	< 1,000	< 10	5,800	< 10
6	4,830	200	6,340				7.0		< 2	< 1,000	< 10	6,000	< 10
7	4,870	190	6,340				7.2		4	< 1,000	< 10	5,900	< 10
8	4,780	200	6,140				7.2		21	< 1,000	< 10	6,700	< 10
9	4,750	190	6,340				7.4		12	< 1,000	< 10	7,200	< 10
10	4,670	180	6,390				7.1		4	< 1,000	< 10	7,200	< 10
11	4,860	180	6,340				7.4		< 2	< 1,000	< 10	6,900	< 10
12	4,730	160	6,440				7.5		21	< 1,000	< 10	7,100	< 10
13				2.28[7/]	25								
14	5,070	120	6,290				8.0		130	< 1,000	< 10	> 7,500	< 10
15				1.20[7/]	35	85							
16				1.53[7/]			10.4						
17				1.47[7/]			8.5						
18				1.34[7/]			8.0						
19				1.25[7/]			7.5						
20				1.19[7/]			7.5						
21				1.19[7/]			7.2						
22				1.19[7/]			7.2						
23				1.20[7/]			7.2						

Table 3—continued.

Sample sequence number	Chromium dissolved (Cr) μg/l	Copper dissolved (Cu) μg/l	Lead dissolved (Pb) μg/l	Nickel dissolved (Ni) μg/l	Selenium dissolved (Se) μg/l	Silver dissolved (Ag) μg/l	Zinc dissolved (Zn) μg/l	Remarks
1								Drilling mud on top of fluid column. Resistivity of drilling mud 1.2 ohm-metres at 70°C bottom-hole temperature. 96.3 barrels (15.3 cubic metres) of fluid recovered.
2	90	< 25	140	120	250	< 20	230	Operator's sample no. 4. Height above bottom of top packer, 5,288 ft (1,612 m).
3	10	< 25	140	100	< 100	< 20	130	do. 7. do. 4,630 ft (1,411 m).
4	< 10	< 25	62	100	250	< 20	20	do. 11. do. 3,878 ft (1,182 m).
5	< 10	< 25	63	< 100	< 100	< 20	50	do. 14. do. 3,314 ft (1,010 m).
6	10	< 25	110	< 100	< 100	< 20	20	do. 17. do. 2,760 ft (841 m).
7	20	< 25	87	100	< 100	< 20	20	do. 21. do. 2,008 ft (612 m).
8	40	620	1,300	< 100	< 100	< 20	260	do. 23. do. 1,632 ft (497 m).
9	30	190	400	< 100	250	< 20	570	do. 26. do. 1,068 ft (326 m).
10	40	240	200	< 100	< 100	< 20	100	do. 29. do. 600 ft (183 m).
11	30	< 25	96	< 100	< 100	< 20	80	do. 32. do. 318 ft (97 m).
12	80	530	990	< 100	< 100	< 20	240	do. 34. do. 140 ft (43 m).
13								do. 24. do. 1,504 ft (458 m). Resistivity of water, 1.87 ohm-metres at 37°C.
14	1,800	1,600	1,400	7,100	150	< 20	2,200	Operator's sample no. 38. Sample chamber contained about 900 cubic centimetres of water. Entrance to chamber plugged by sandstone and shale.
15								--
16								do. 40. Height above tool sample chamber, 580 ft (177 m).
17								do. 41. do. 550 ft (168 m).
18								do. 42. do. 460 ft (140 m).
19								do. 43. do. 370 ft (113 m).
20								do. 44. do. 280 ft (85 m).
21								do. 45. do. 190 ft (58 m).
22								do. 46 do. 100 ft (30 m).
23								do. 47 do. 10 ft (3 m).

Table 3—continued.

Sample sequence number	Sampling method	Aquifer tested	Depth of producing interval or sampling point from kelly bushing reference datum				Date (year, month, day)	Amount of fluid recovered during entire test		Type of fluid	Description of fluid
			Top		Bottom						
			Feet	Metres	Feet	Metres		Barrels	Cubic Metres		
24	Drill-stem test no. 3	Meseta Blanca Sandstone Member of Yeso Formation	9,392	2,863	9,510	2,899	1972-08-23	3.7	.6	Drilling mud	Mud from pit
25	do.	do.	9,392	2,863	9,510	2,899	1972-08-23	50	8.0	Drilling mud and water	
26	do.	do.	9,392	2,863	9,510	2,899	1972-08-23	50	8.0	do.	
27	do.	do.	9,392	2,863	9,510	2,899	1972-08-23	50	8.0	do.	
28	do.	do.	9,392	2,863	9,510	2,899	1972-08-23	50	8.0	Drilling mud	Mud settled out of fluid column
29	do.	do.	9,392	2,863	9,510	2,899	1972-08-23	50	8.0	Water	
30[9/]	do.	do.	9,392	2,863	9,510	2,899	1972-08-23	50	8.0	Water(?)	Mud with dark colored filtrate
31[9/]	do.	do.	9,392	2,863	9,510	2,899	1972-08-23	50	8.0	Water-mud mixture	do.
32[9/]	do.	do.	9,392	2,863	9,510	2,899	1972-08-23	50	8.0	do.	
33[9/]	do.	do.	9,392	2,863	9,510	2,899	1972-08-23	50	8.0	do.	
34[9/]	do.	do.	9,392	2,863	9,510	2,899	1972-08-23			Drilling mud	Mud from pit
35[5/]	Swabbed through tubing. Casing perforated at interval shown	Zia Sand Formation	2,935	895	2,945	898	1972-08-26	4	.6	Water	Mixed with drilling mud
36[8/]	Swabbed through tubing. Casing perforated at interval shown	Zia Sand Formation	2,935	895	2,945	898	1972-08-26	4	.6	Water	
37[8/]	do.	do.	2,935	895	2,945	898	1972-08-26	4	.6	do.	
38[8/]	do.	Santa Fe Group	1,550	472	1,560	475	1972-08-27	12	1.9	do.	
39[8/]	do.	do.	1,550	472	1,560	475	1972-08-27	12	1.9	do.	

Table 3—continued.

Sample sequence number	Silica dissolved (SiO_2) mg/l	Iron dissolved (Fe) µg/l	Manganese dissolved (Mn) µg/l	Calcium dissolved (Ca) mg/l	Magnesium dissolved (Mg) mg/l	Sodium dissolved (Na) mg/l	Potassium dissolved (K) mg/l	Bicarbonate dissolved (HCO_3) mg/l	Carbonate dissolved (CO_3) mg/l	Alkalinity as $CaCO_3$, Total mg/l	Sulphate dissolved (SO_4) mg/l	Chloride dissolved (Cl) mg/l	Fluoride dissolved (F) mg/l	Nitrite + Nitrate dissolved as N mg/l
24												300[6/]		
25												2,000[6/]		
26														
27												2,200[6/]		
28														
29												1,700[6/]		
30				49	9	1,600	44	1,140	220		1,700	500		
31				44	9	1,600	45	1,200	200		1,700	450		
32				25	9	1,200	37	1,100	220		940	350		
33				10	9	1,900	42	1,100	230		2,200	450		
34				Trace	Trace	3,100	451	2,020	440		3,800	700		
35	24	800		1.2	.3	740	22	330	230	650	49	97	3.4	.0
36		1,400[2/]	100	4.0	.6	460	20	653	68	650	230	86	1.5	< .1[3/]
37		6,400[2/]	50	4.0	.2	460	39	716	67	700	200	86	1.6	< .1[3/]
38		1,000[2/]	< 50	33	10	220	3.9	376	0	308	210	33	.7	< .1[3/]
39		5,000[2/]	500	30	3.7	380	20	566	0	460	400	26	.9	< .1[3/]

Table 3—continued.

Sample sequence number	Dissolved solids Sum of determined constituents mg/l	Hardness dissolved as $CaCO_3$ (Ca,Mg) mg/l	Specific conductance micromhos at 25°C	Water resistivity ohm-metres	Temperature water resistivity measured °C	Bottom-hole temperature °C	pH	Water tem-perature °C	Arsenic dissolved (As) µg/l	Barium dissolved (Ba) µg/l	Beryllium dissolved (Be) µg/l	Boron dissolved (B) µg/l	Cadium dissolved (Cd) µg/l
24													
25				2.6[7/]	29	100							
26													
27				2.2[7/]	29								
28				2.6[7/]	28								
29													
30	4,700			1.38	26		8.9						
31	4,660			1.48	26		8.8						
32	3,300			1.86	26		8.8						
33	5,300			1.33	26		8.8						
34	9,680			1.06	26		9.3						
35	1,330[4/]	4	3,140				9.5	32	110			2,200	0.5
36	2,400	13	2,750				9.0						
37	4,970	11	2,750				8.8						
38	868	125	990				9.0						
39	1,570	90	1,430				8.1						

Table 3—continued.

Sample sequence number	Chromium dissolved (Cr) µg/l	Copper dissolved (Cu) µg/l	Lead dissolved (Pb) µg/l	Nickel dissolved (Ni) µg/l	Selenium dissolved (Se) µg/l	Silver dissolved (Ag) µg/l	Zinc dissolved (Zn) µg/l	Remarks
24								Sampled for purpose of comparison to fluid recovered on test.
25								Height above sample chamber, 3,870 ft (1,180 m)-10 percent water, 90 percent drilling mud.
26								Height above sample chamber, 3,200-3,600 ft (975-1,097 m)-40 percent water, 60 percent drilling mud.
27								Height above sample chamber, 150-3,200 (46-975 m)-70 to 90 percent water, 30 to 10 percent drilling mud. Sample taken 2,600 (792 m) above test tool.
28								Height above sample chamber, 50 ft (15 m)-40 percent water, 60 percent drilling mud.
29								Sample chamber of test tool-90 percent water, 10 percent drilling mud.
30								Sample chamber of test tool.
31								Sampled 325 ft (99 m) above test tool.
32								Sampled 1,250 ft (381 m) above production sub.
33								Sampled 1,530 ft (466 m) above production sub.
34								Sampled for purpose of comparison to fluid recovered on test.
35			3,400		0.0			Casing perforated and 17 barrels (2.7 m^3) of water with specific conductance 590 µ-mhos injected into formation under 1,500 psi (1.05 x 10^6 kg/m^2). Tubing with packer set at 2,876 ft (877 m). Swabbed through tubing for 4 hours. Recovered 4 barrels (0.6 m^3) of water representative(?) of fluid in aquifer.
36								Sample of water taken during swab test is described in sample sequence no.35 above. Collected from first swab run after tubing had been evacuated. Appearance-muddy. Turbidity, supernatant-75 Jackson units. Turbidity, total->1,000 Jackson units. Stale odor. Surfactants as LAS-<0.05 mg/l.
37								Sample of water taken during swab test is described in sample sequence no.35 Taken from second swab run after tubing had been evacuated. Appearance-muddy. Turbidity, supernatant-170 Jackson units. Turbidity, total->1,000 Jackson units. Surfactants as LAS-<0.05 mg/l.
38								Sample collected on next to last swab run. Sample is probably not representative of fluid in the aquifer. Appearance-muddy. Turbidity, supernatant-50 Jackson units. Turbidity total->1,000 Jackson units. Odor-stale. Surfactants as LAS-<0.25 mg/l. Casing perforated.
39								Sample collected from last swab run, before pipe was evacuated just before swab cable parted. Subsequently, perforations were plugged by very fine sand and well was abandoned. Sample is probably not representative of fluid in aquifer. Appearance-muddy. Turbidity, supernatant-30 Jackson units. Turbidity, total->1,000 Jackson units. Odor-stale. Surfactants as LAS-<0.05 mg/l.

Footnotes

1/ Zones used locally in northwestern New Mexico to identify beds within the Dakota Sandstone.
2/ Total iron.
3/ Nitrate (NO_3) dissolved.
4/ Residue of dissolved solids on evaporation at 180°C, 2,460 mg/l.
5/ Analyzed by U.S. Geological Survey. Phosphorous, dissolved orthophosphate as P, 0.52 mg/l; Orthophosphate, dissolved as PO_4, 0.17 mg/l; Mercury dissolved as Hg, 0.6 µg/l.
6/ Chloride ion determination by operator by titration in the field.
7/ Determined in the field by the operator.
8/ Analyzed for New Mexico Environmental Improvement Agency by the State Public Health Laboratory.
9/ Analyzed by Chemical and Geological Laboratories, Casper, Wyoming.
10/ Latitude-35°20'58" N, Longitude-106°40'10" W. Data were compiled from several sources including information released by the operator and data extracted from scout records published by Petroleum Information, Inc., Denver, Colorado.

Table 4.--Radiochemical analyses of water from selected wells in Sandoval County, New Mexico[1/]

Table 4. Radiochemical analyses of water from selected wells in Sandoval County, New Mexico.

Sample sequence number	Location of well	Source of sample	Latitude, longitude	Date (year, month, day)	Alpha activity, gross as U natural (μg/l)		Beta activity, gross, as C_S-137 (PC/l)		Beta activity gross as Sr^{90}/Y^{90} (PC/l)		Radium 226 dissolved by radon method (PC/l)	Uranium, natural dissolved (μg/l)	Remarks
					dissolved	suspended	dissolved	suspended	dissolved	suspended			
1	SW¼SE¼ sec.14, T.12 N., R.2 E.[2/]	Rio Rancho, well 6	35°15'46" N, 106°42'05" W	1974-12-12	12	<0.4	6.9	1.4	5.7	1.4	0.09	5.0	--
2	NE¼SE¼ sec.25, T.12 N., R.2 E.[2/]	Rio Rancho, well 3	35°14'22" N, 106°40'42" W	1974-12-12	12	<.4	8.4	<.4	7.3	<.4	.04	2.4	--
3	NE¼NW¼ sec.30, T.12 N., R.3 E.[2/]	Rio Rancho, well 5	35°14'46" N, 106°40'06" W	1974-12-12	7.4	<.4	7.6	1.1	6.6	1.0	.12	4.1	--
4	NW¼NE¼ sec.5, T.12 N., R.4 E.	Town of Bernalillo well	35°18'09" N, 106°32'19" W	1974- 9-25	6.9	<.4	8.2	.7	6.6	.6	.08	1.8	--
5	NW¼SW¼ sec.18, T.13 N., R.3 E.	Shell Oil Co. Santa Fe Pacific 1	35°20'58" N, 106°40'10" W	1972- 8-26	870	1,000	130	870	110	720	2.8	5	Sample no. 35 in table 3. Water from Zia Sand Formation.
6	NW¼SW¼ sec.18, T.13 N., R.3 E.	do.	35°20'58" N, 106°40'10" W	1972- 8-26	99	--	36	--	30	--	--	--	Drilling mud.
7	NE¼NW¼ sec.36 T.13 N., R.3 E.	Price's Valley Gold Dairy, Bernalillo well	35°19'00" N, 106°34'41" W	1975- 2-21	15	<.4	12	.4	9.9	.4	.08	2.4	--
8	SW¼NE¼ sec.1, T.13 N., R.4 E.	Plains Electric plant Algodones, well 2	35°23'06" N, 106°27'58" W	1974- 9-25	31	<.4	15	1.4	12	1.3	.12	7.1	--
9	SE¼NE¼ sec.1, T.13 N., R.4 E.	do. well 3	35°23'03" N, 106°27'46" W	1974- 9-25	12	<.4	14	.7	11	.6	.08	1.5	--
10	NW¼SE¼ sec.1, T.13 N., R.4 E.	do. well 4	35°22'57" N, 106°27'53" W	1974- 9-25	21	<.4	3.8	<.4	3.3	<.4	.07	2.7	--
11	NE¼ sec.5, T.13 N., R.4 E.	Jemez River below Jemez Canyon Dam	35°23'24" N, 106°32'03" W	1974-12-23	25	22	23	14	18	12	.17	4.1	--
12	NW¼NW¼ sec.36, T.18 N., R.4 E.	Ranchos de Placitas, well	35°19'00" N, 106°28'38" W	1974- 2-21	8.3	<.4	2.0	<.4	1.7	<.4	.09	.9	--

1/Analyses by U.S. Geological Survey. Samples were submitted for analysis without filtration or preservation in the field. All wells tap aquifers in the Santa Fe Group unless otherwise indicated.

2/Projected township grid.

the valley fill is shown on a map compiled by Titus (1961, Fig. 1, p. 187). The axis of this trough lies 5 to 10 mi (8 to 16 km) west of the Rio Grande parallel or subparallel to the river. Near Albuquerque, the axis slopes gently southward at an average gradient of 6 ft per mile (1.1 m/km). This gradient is approximately equal to the average downstream gradient of the Rio Grande, the natural linear drain for the Rio Grande trough. Titus (1961, p. 189) suggested that the position of the axis of the trough in the potentiometric surface may be due to an increase in the transmissivity of the Santa Fe Group west of the Rio Grande. However, if saline water of relatively higher density is entering the valley fill from the north and from the west, as is suggested by our interpretation of the data now available, the aquifer head is likely to be low (relative to that in fresh water) in a linear area localized along the numerous faults that parallel the west margin of the Albuquerque-Belen basin (Fig. 2). When more information becomes available, it may be possible to test this hypothesis by constructing a potentiometric surface adjusted for changes in density of the water following methods developed by Lusczynski (1961) and Bond (1972 and 1973).

SUMMARY AND CONCLUSIONS

Extensive chemical data for water from the upper part of the saturated zone in the northern part of the Albuquerque-Belen basin show that the ground water is of relatively good quality-it commonly contains less than 1,000 mg/l dissolved solids. However, data obtained from the Shell Oil Company Santa Fe Pacific No. 1 well, and salinities computed from those data, suggest marked deterioration of water quality with increasing depth. A trough in the potentiometric surface for the valley-fill aquifer in the western part of the basin may reflect the localized occurrence, in a linear area near and parallel to the marginal fault zone, of water of high density. The form and location of the trough suggest fault control of the "pool" of mineralized water and argue for derivation of at least part of the water from the fault zone-and indirectly from the Jemez uplift to the north and (or) from the volcanic field near Albuquerque. Part of the saline water could have migrated into the rift from the San Juan basin to the west.

Our interpretation of these data strongly suggests a need for further, well-planned, deep hydrologic exploration of the Albuquerque-Belen basin. If mineralization of the ground water increases with depth, and the scanty information available suggests that it does, the quantity of potable water stored in the valley fill is but a fraction of the available water. Exploration is therefore a prerequisite for the future ground-water development implied by projections for continued growth of the population and the economy of Albuquerque and the surrounding area. And, because some of the other grabens in the Rio Grande rift may occur in a geohydrologic setting similar to that of the Albuquerque-Belen basin, such a hydrologic study should have considerable transfer value in hydrologic development of other parts of the Rio Grande Valley.

REFERENCES

Bond, D. C., 1972, Hydrodynamics in deep aquifers of the Illinois basin: Illinois Geol. Survey Circ. 470, 69 p.

----, 1973, Deduction of flow patterns in variable-density aquifers from pressure and water-level observations, *in* Underground Waste Management and Artificial Recharge: Am. Assoc. Petroleum Geologists Mem. 18, v. 1, p. 357-377.

Berry, F. A., F., 1959, Hydrodynamics and geochemistry of the Jurassic and Cretaceous Systems in the San Juan Basin, northwestern New Mexico and southwestern Colorado (Ph.D. dissert.): Stanford Univ., California, 192 p.

Bjorklund, L. J., and Maxwell, B. W., 1961, Availability of ground water in the Albuquerque area, Bernalillo and Sandoval Counties, New Mexico: New Mexico State Engineer Tech. Rept. 21, 117 p.

Black, B. A., and Hiss, W. L., 1974, Structure and stratigraphy in the vicinity of the Shell Oil Co. Santa Fe Pacific No. 1 test well, southern Sandoval County, New Mexico, *in* Ghost Ranch-Central northern New Mexico: New Mex. Geol. Soc. Guidebook 25, p. 365-370.

Bureau of Business and Economic Research, 1975, Provisional city population estimates: Inst. Social Research and Devel., Univ. New Mexico, Albuquerque, p. 1.

Dane, C. H., and Bachman, G. 0., 1965, Geologic map of New Mexico: U.S. Geol. Survey, scale 1:500,000.

Galusha, Ted, 1956, The Zia Sand Formation, new early to medial Miocene beds in New Mexico: Am. Mus. Nat. History, Novitates, no. 2271, 12 p.

Hale, W. E., Reiland, L. J., and Beverage, J. P., 1965, Characteristics of the water supply in New Mexico: New Mexico State Engineer Tech. Rept. 31, 131 p.

Hilpert, L. S., 1969, Uranium resources of northwestern New Mexico: U.S. Geol. Survey Prof. Paper 603, 166 p.

Joesting, H. E., Case, J. E., and Cordell, L. E., 1961, The Rio Grande trough near Albuquerque, New Mexico: U.S. Geol. Survey Prof. Paper 424-D, p. 282-286. [Preprinted, *in* Albuquerque Country: New Mexico Geol. Soc. Guidebook 12 (1961), p. 148-150.1

Kelley, V. C., 1952, Tectonics of the Rio Grande depression of central New Mexico, *in* Rio Grande Country, central New Mexico: New Mex. Geol. Soc. Guidebook 3, p. 93-105.

----, 1954, Tectonic map of part of the upper Rio Grande area, New Mexico: U.S. Geol. Survey Oil and Gas Inv. Map 0M-157.

, 1974, Albuquerque-Its mountains, valley, and volcanoes: New Mex. Bur. Mines and Min. Res., Scenic trips to geologic past, no. 9, 106 p.

Kelley, V. C., and Northrop, S. A., 1975, Geology of the Sandia Mountains and vicinity: New Mexico Bur. Mines and Min. Res. Mem. 29, 136 p.

Kelly, T. E., Myers, B. N., and Hershey, L. A., 1974, Reconnaissance investigation of ground water in the Rio Grande drainage basin-with special emphasis on saline ground-water resources: U.S. Geol. Survey Hydrol. Inv. Atlas HA-510.

Lusczynski, N. J., 1961, Head and flow of ground water of variable density: Jour. Geophys. Research, v. 66, p. 4247-4256.

Reeder, H. 0., Bjorklund, L. J., and Dinwiddie, G. A., 1967, Quantitative analysis of water resources in the Albuquerque area, New Mexico: New Mexico State Engineer Tech. Rept. 33, 34 p.

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

Slack, P. B., 1973, Structural geology of the northeast part of the Rio Puerco fault zone, Sandoval County, New Mexico (M.S. thesis): Univ. New Mexico, Albuquerque, 74 p.

Spiegel, Zane, 1961, Late Cenozoic sediments of the lower Jemez River region, *in* Albuquerque Country: New Mex. Geol. Soc. Guidebook 12, p. 132-138.

Stearns, C. E., 1943, The Galisteo Formation in north-central New Mexico: Jour. Geology, v. 51, p. 301-319.

----, 1953a, Early Tertiary volcanism in the Galisteo-Tongue area, north-central New Mexico: Am. Jour. Sci., v. 251, p. 415-452.

– 1953b, Tertiary geology of the Galisteo-Tongue area, New Mexico: Geol. Soc. America Bull., v. 64, p. 459-507.

Titus, F. B., Jr., 1961, Ground-water geology of the Rio Grande trough in north-central New Mexico, *with sections on* the Jemez Caldera and the Lucero uplift, *in* Albuquerque Country: New Mex. Geol. Soc. Guidebook 12, p. 186-192.

Trainer, F. W., 1974, Ground water in the southwestern part of the Jemez Mountains volcanic region, New Mexico, *in* Ghost Ranch-Central northern New Mexico: New Mex. Geol. Soc. Guidebook 25, p. 337-345.

West, S. W., and Broadhurst, W. L., 1975, Summary appraisals of the nation's ground-water resources-Rio Grande region: U.S. Geol. Survey Prof. Paper 813-D, 39 p.

Wombold, L. M., and Adcock, L. D., 1975, Population estimates-July 1974: Bureau of Business and Economic Research, Inst. Social Research and Devel. Business Inf. Ser. no. 56, Univ. New Mexico, Albuquerque, p. 4 [May 19751.