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REGIONAL GEOHYDROLOGY OF THE SAN JUAN HYDROLOGIC BASIN
OF NEW MEXICO, COLORADO, ARIZONA, AND UTAH

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REGIONAL GEOHYDROLOGY OF THE SAN JUAN HYDROLOGIC BASIN OF NEW MEXICO, COLORADO, ARIZONA, AND UTAH

"PRELIMINARY, SUBJECT TO REVISION"

By

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U.S. Geological Survey Open-File Report 79-1498

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PREFACE

This is one of a series of reports prepared as part of the San Juan Basin Regional Uranium Study, which is under the leadership of the Bureau of Indian Affairs (BIA). The reports were used as source of material in the preparation of the Regional Study, which is available for public examination at BIA offices in Albuquerque, New Mexico, and Washington, D.C.

The reports listed below are a part of the series that was prepared by the U.S. Geological Survey. These reports have been open filed by the Survey and can be examined by the public at the Survey offices in Denver, Colorado; Albuquerque, New Mexico; and Reston, Virginia.

Water Use in the area of the San Juan Basin Regional Uranium Study, New Mexico, Colorado, Arizona, and Utah--Open File Report 79-1500

Surface-water Environment in the area of the San Juan Basin Regional Uranium Study, New Mexico, Colorado, Arizona, and Utah-------------------------Open File Report 79-1499

Regional Geohydrology of the San Juan Hydrologic Basin of New Mexico, Colorado, Arizona, and Utah--Open File Report 79-1498

Reconnaissance Study of Selected Environmental Impacts on Water Resources due to the Exploration, Mining, and Milling of Uraniferous Ores in the Grants Mineral Belt, Northwest New Mexico--Open File Report 79-1497

Effects of Uranium Development on Erosion and Associated Sedimentation in Southern San Juan Basin, New Mexico------------------------------Open File Report 79-1496

Depths of Channels in the area of the San Juan Basin Regional Uranium Study, New Mexico, Colorado, Arizona, and Utah------------------------------------Open File Report 79-1526

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"PRELIMINARY, SUBJECT TO REVISION"

Conversion of Units

English units used in this report may be converted to metric units by the following conversion factors:

Inch-pound	Multiply by	Metric
foot	0.3048	meter (m)
mile	1.609	kilometer (km)
gallons per minute (gal/min)	3.78543	liters per minute (L/min)
cubic feet per second (ft /sec)	.02832	cubic meters per second (c^3/s)

REGIONAL GEOHYDROLOGY OF THE SAN JUAN HYDROLOGIC BASIN OF NEW MEXICO, COLORADO, ARIZONA, AND UTAH

By Maurice E. Cooley and William G. Weist,

U.S. Geological Survey

ABSTRACT

The San Juan Basin in the southeastern part of the Colorado Plateau, southwest of the San Juan Mountains, broadly includes the Acoma and Gallup Sags in its southern part and the small Chama Basin in its northeastern part. Regionally, the water-yielding strata (aquifers) dip inward toward the center of San Juan Basin or toward the axes of the adjoining structural sags. Aquifers exposed or at shallow depths along the margin of the basin are deeply buried in the center of the basin.

The occurrence and movement of ground water is strongly influenced by the structural configuration of the basin; fractures along joints and faults, particularly the Puerco fault belt; distribution and lithology of the rock strata, and the relationship of the uplands recharge areas of the aquifers to the lowland areas where the most ground-water discharges.

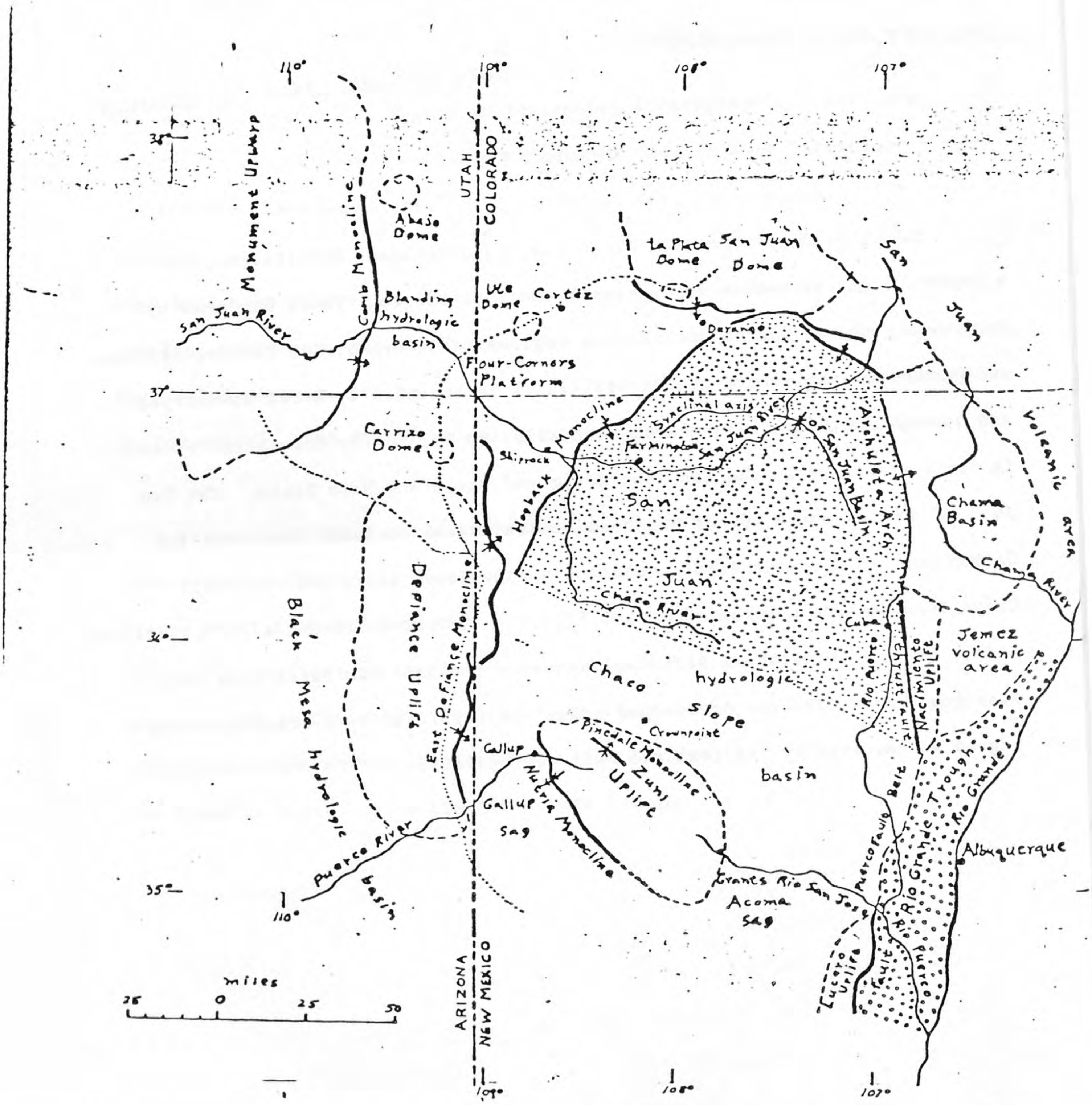
The aggregate thickness of sedimentary rocks is more than 10,000 feet in the deepest part of the basin. In order of decreasing abundance, these rocks consist of mudstone, claystone, siltstone, sandstone, silty sandstone, coal, limestone, conglomerate, and gypsum. The main aquifers consist of sandstone or sandstone containing lenses of conglomerate except for the San Andres Limestone.

The principal aquifers, listed in descending stratigraphic order, are the Tertiary Cuba Mesa and Llaves Members of the San Jose Formation and the Ojo Alamo Sandstone; the Pictured Cliffs, Cliff House, Point Lookout, Gallup, and Dakota Sandstones; the Westwater Canyon and Salt Wash Sandstone Members of the Morrison Formation, the Cow Springs Sandstone, the Zuni Sandstone, and the Entrada Sandstone; and the San Andres Limestone, Glorieta Sandstone, and De Chelly Sandstone. These aquifer are separated by formations, that do not readily transmit water between the aquifers.

Regional movement of ground water is mainly to the San Juan and Chaco Rivers, the Puerco River, the Rio Puerco, and their main tributaries. Ground water from aquifers overlying the Dakota Sandstone discharge within the confines of the San Juan hydrologic basin. Part of the ground water in the Dakota Sandstone, Morrison Formation, and underlying formations moves across the interbasin divide into the Black Mesa, the Blanding Basin, or to the Rio Grande Trough.

INTRODUCTION

The Colorado Plateau, in which the San Juan Basin is situated, is a huge geologic structure of saucer-shaped rock strata. It is bordered by complex structures in the mountainous regions of Colorado, New Mexico, Arizona, and Utah. The continuity of the plateau is interrupted by broad downwarped and upwarped regions. The plateau contains two regionally downwarped areas in its southern part--the San Juan Basin and the Black Mesa Basin. The San Juan Basin lies south of the San Juan Mountains and includes the Acoma and Gallup Sags in its southeastern and and southwestern parts and the small Chama Basin in its northeastern part (fig.1). To the northwest a low structural saddle of the Four-Corners Platform separates the San Juan Basin from the Blanding Basin. The two downwarped areas are separated by a broad uparched region accentuated by the Zuni and Defiance Uplifts.



EXPLANATION

..... Boundary between the San Juan, Black Mesa, and Blanding hydrologic basins.

----- Boundary between main structural elements.

Anticlinal axis.

Synclinal axis.

Monocline.

Area of closed part of San Juan structural basin (after Kelly and Clinton, 1960, fig. 4).

Approximate area of Valley-fill deposits in Rio Grande Trough.

Figure 1.--Chief structural features that influence the occurrence of ground water in the San Juan hydrologic basin and nearby area.

The San Juan hydrologic basin as defined by Cooley and others (1969, fig. 6) is much larger than the San Juan structural basin as defined by Kelly and Clinton (1960, fig. 4). The hydrologic basin includes the San Juan structural basin, the structural crests of the surrounding uplifts and structural saddles, the contiguous Gallup and Acoma Sags, and the shallow Chama Basin.

Ground water in the San Juan hydrologic basin is strongly influenced by: (1) the structural configuration of the basin and its bordering uplifts and structural saddles, (2) openings, fractures along joints, and faults; (3) distribution, lithologic characteristics, facies changes, intertonguing, and wedging-out of the stratigraphic units, and (4) the distribution of uplands (?)- the principal recharge areas for the aquifers, with respect to lowlands or large valleys where ground water is discharged. ?

STRUCTURE IN RELATION TO GROUND-WATER HYDROLOGY

Regionally, the strata of the San Juan Basin dip inward toward the center of the basin or toward the axes of the adjoining structural sags (fig.1). In general, the strata resemble a set of nested mixing bowls. The outcrops of the formation[s] form irregularly shaped concentric rings. Water-yielding formations (aquifers) that are exposed or lie at shallow depths along the margin of the basin generally are under water-table conditions; where the aquifers are deeply buried in the center of the basin they are artesian (fig. 2). ?

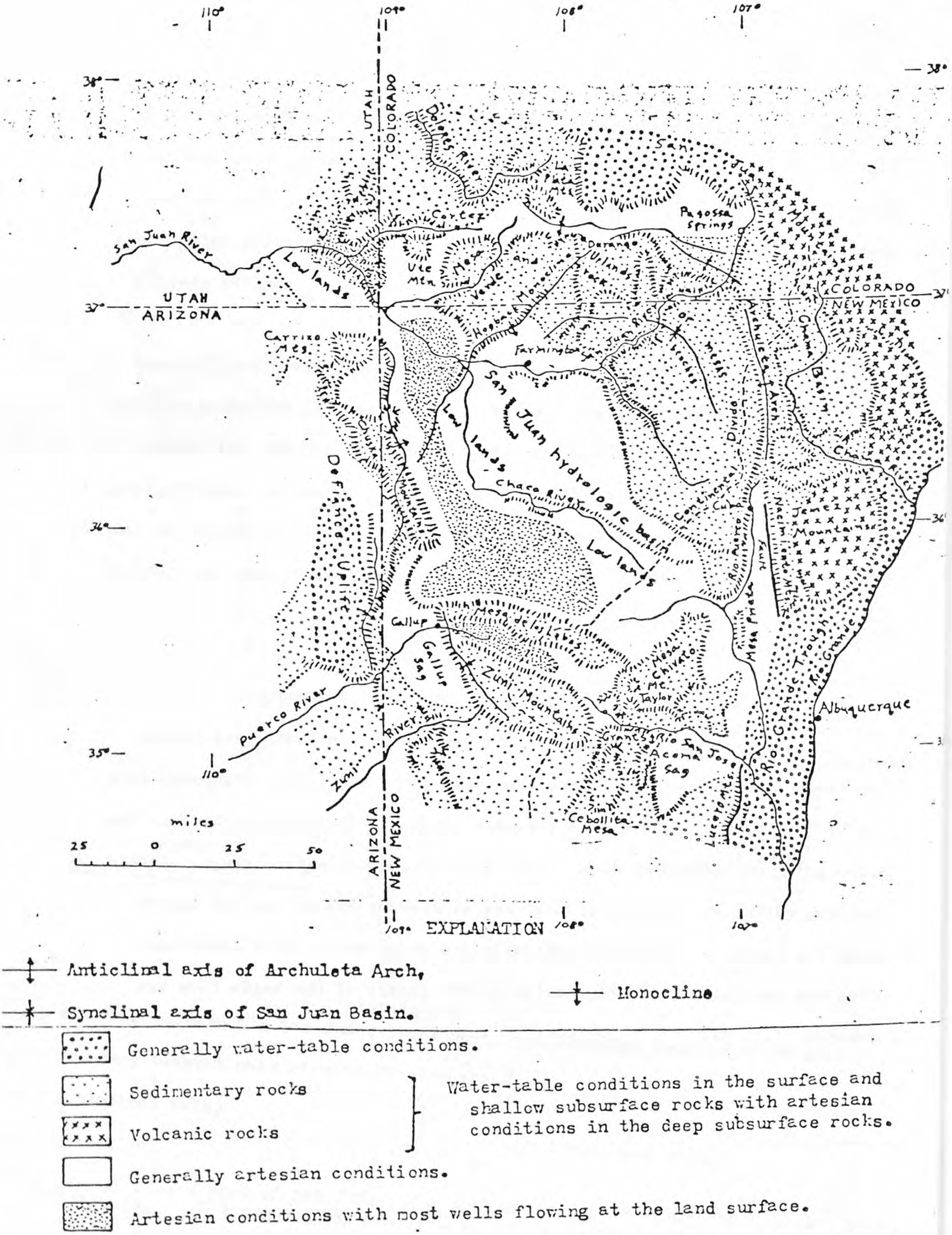


Figure 2.--Physiographic map showing generalized artesian and water-table areas in the San Juan hydrologic basin and nearby areas.

The uplifts or highlands surrounding the San Juan Basin extend to altitudes of more than 7,000 feet above mean sea level. The uplifts are structurally asymmetric and trend northward or northwestward. Sedimentary formations dip steeply eastward from the Defiance Uplift; the East Defiance Monocline is formed where the strata display the steepest dips. The Gallup Sag is between the East Defiance Monocline and the westward-dipping beds of the Nutria Monocline along the steep southwest flank of the Zuni Uplift. The boundary between the San Juan Basin and the Nacimiento Uplift to the east is marked by steeply tilted beds along the north-trending Nacimiento Fault, which is a high-angle reverse fault with at least 10,000 feet of structural relief (Santos, 1975, p.16). Southeast of the San Juan Basin and of the Acoma Sag, the Lucero Uplift is also bounded by a large fault, which is part of the complex fault system along the western boundary of the Rio Grande Trough.

Monoclinal flexures, often indicated by spectacular back ridges, interrupt continuity of the San Juan Basin and nearby uplifts (fig.3). Monoclines commonly form the boundaries of the structural uplifts, platforms, and basins (fig. 1). Displacement along the East Defiance and Hogback Monoclines exceed 3,000 feet. Along others, such as the Pinedale Monoclines, the amount of displacement is only a few hundred feet.

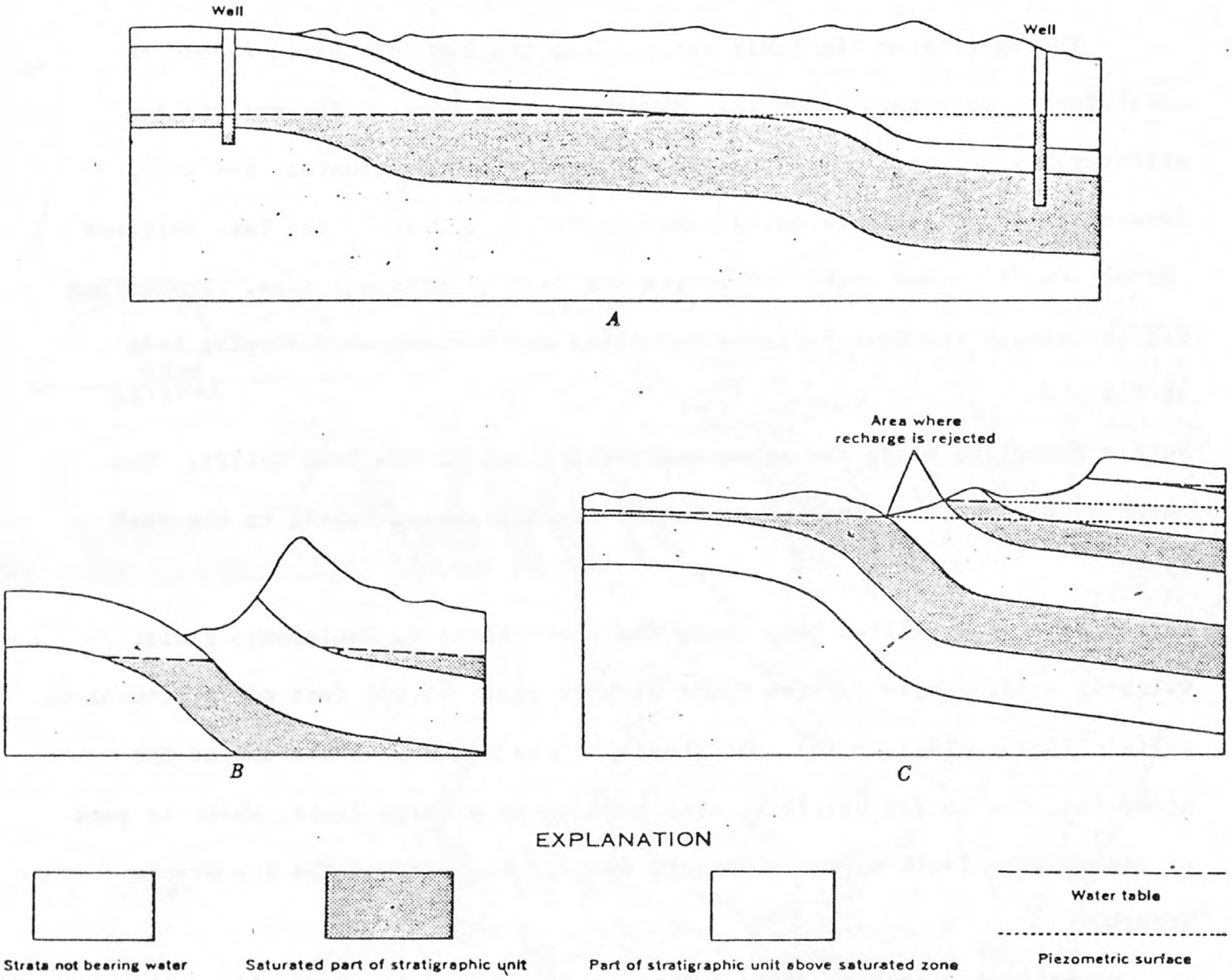


FIGURE 3 —Occurrence of ground water along monoclines.

Many small anticlines and small to large synclines are present in the San Juan Basin and in the adjoining Gallup and Acoma Sags. Rock formations are saturated in synclinal areas. Water wells can be completed along the crests of anticlines, however, formations may be dry on the crests of some anticlines.

INFLUENCE OF FRACTURING ON THE GROUND-WATER HYDROLOGY

Fractures along joints and faults, occur in all types of sedimentary rocks in San Juan Basin. Openings along joints and faults generally impose a strong secondary permeability on the rocks, particularly in limestone and dolomite. Springs commonly issue from such openings in all types of sedimentary rocks. Water seeping from fractures can be seen exposed in uranium mines. Gordon (1961, p. 49-50) described some effects that faults have on the movement of ground water near Grants. The major faults probably strongly influence the movement of ground water.

Charles Pierson (oral communication, 1979), indicated that faults and joints affected localization of uranium deposits. Uranium deposits in the Dakota Sandstone in the Ambrosia Lake area strongly suggest that uranium-bearing fluids have moved upward through openings along joints and faults from the Westwater Canyon Sandstone Member of the Morrison Formation through the Brushy Basin Member of the Morrison into the overlying Dakota Sandstone.

The trends of regional fractures range mainly from northeast to northwest. The generally sparse hydrologic data preclude determining specific relationships of fractures to the occurrence and movement of ground water.

The Puerco Fault Belt (Kelly and Clinton, 1960, p. 52-53) is a strongly fractured area lying between the Nacimiento and Lucero Uplift and separating the southeastern border of the San Juan Basin from the Rio Grande Trough (fig. 1). Much of the ground water that originates in San Juan Basin passes through the Puerco Fault Belt and discharges into the Rio Grande Trough. The highly fractured nature of the rocks in the fault belt facilitates passage of the ground water, although locally the upthrown sides of faults in the fault belt probably impede and cause local diversion of ground water.

AQUIFERS IN THE SEDIMENTARY ROCKS

The sedimentary rocks have a thickness of more than 10,000 feet in the deepest part of the San Juan Basin. Near the margins of the basin their thickness ranges commonly between 3,000 and 6,000 feet. Locally, along the summits of the uplifts, the sedimentary rocks are absent.

The sedimentary rocks consist of, in order of decreasing abundance, mudstone, claystone, siltstone, sandstone, silty sandstone, coal, limestone, conglomereate, and gypsum. The sandstone and most of the silty sandstone are composed of fine-to medium-grained sand. Except for the San Andres Limestone, the main water-yielding unit consists of beds of relatively thin sandstone or sandstone containing lenses of conglomerate or zones of pebbly material. In much of the basin the sedimentary rocks are overlain by thin, relatively permeable, discontinuous deposits of uconsolidated dune sand, alluvium, terrace deposits, and landslide rubble. A description of the hydrologic characteristics of the outcropping rock units, including alluvium, is included in the appendix to this report.

Water-yielding sandstone units in the sequence of rocks from the Pictured Cliffs Sandstone to the Gallup Sandstone conspicuously intertongue with the generally low water-yielding to nonwater-yielding units of the Lewis and Mancos Shales (fig. 4). Another complex intertonguing sequence occurs in the southwestern part of the basin where sandstone tongues of the Cow Springs Sandstone extend northeastward into the Morrison and Summerville Formations.

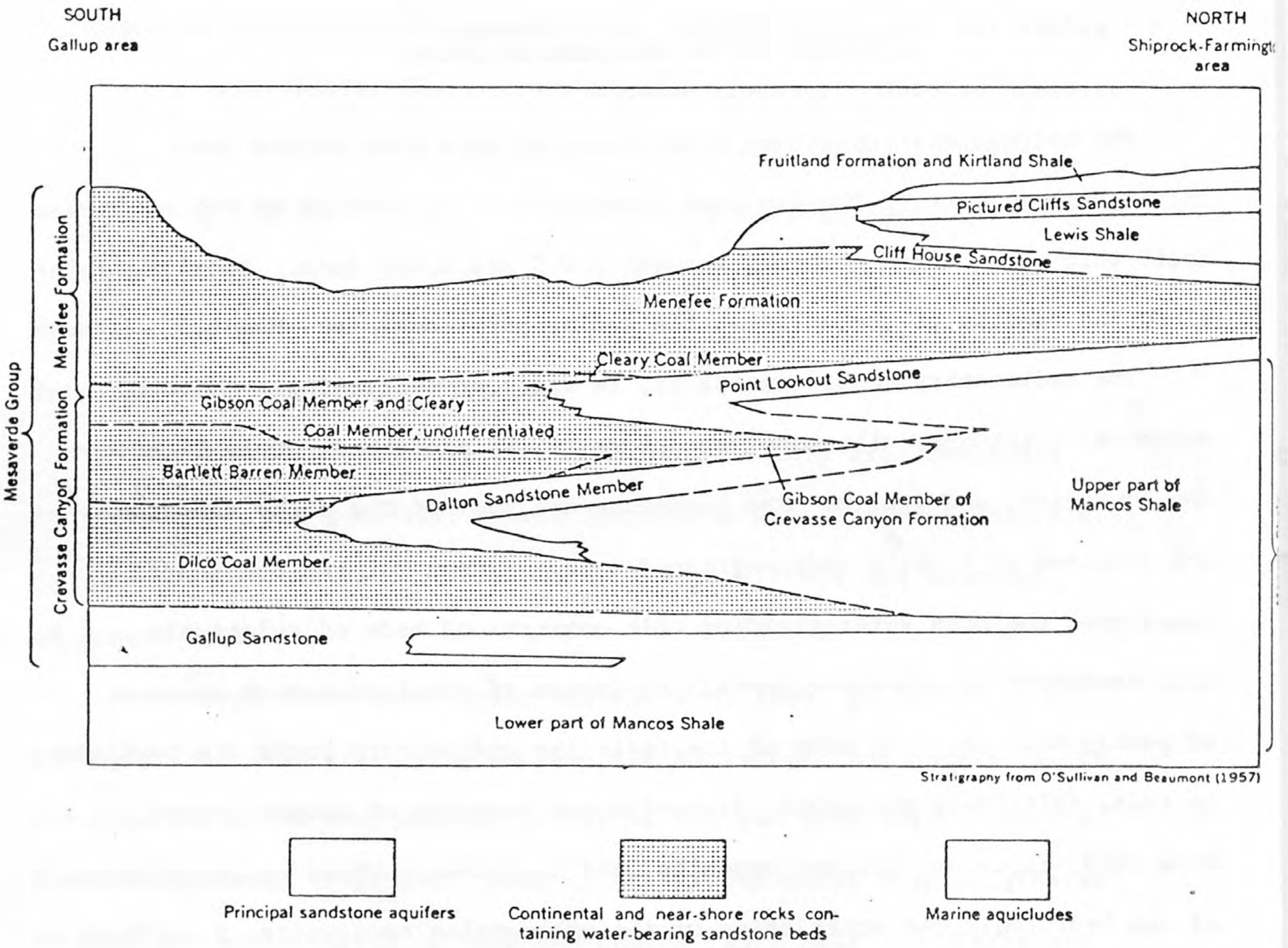


FIGURE 4 —Generalized section of the western San Juan basin, showing the intertonguing of the Upper Cretaceous rock and their water-bearing characteristics.

As a result of intertonguing, the Morrison Formation forms an important aquifer system with the adjacent stratigraphic units (fig. 5). In part of southwestern San Juan Basin where the Recapture Shale Member of the Morrison Formation is thin or not present, the Westwater Canyon Member of the Morrison Formation is hydraulically connected to the Cow Springs, Zuni, and Entrada Sandstones. Where the uppermost Burshy Basin Shale Member of the Morrison is thin or not present beyond its edge of wedge-out, the Dakota Sandstone overlies the Westwater Canyon Member and forms the topmost part of the aquifer system. Generally to the northeast of Gallup, where the Brushy Basin and Recapture Shale Members are present in normal thickness, the aquifer system is imperfectly developed. Elsewhere, the Morrison combines with the Zuni and Dakota Sandstones in the southeastern part of the basin south of Rio San Jose and also with the Bluff or Junction Creek Sandstones in the northwestern part of the basin.

Two other multiple aquifer systems are present in the area. Throughout the southern part of San Juan Basin the San Andres Limestone, Glorieta Sandstone, and De Chelly Sandstone comprise a major aquifer system (Cooley and others, 1969, p. A12) that yields moderate to large amounts of water to wells. In the extreme northwest part of the area, the Navajo Sandstone, Kayenta Formation, and Lukachukai Member of the Wingate Sandstone form the another aquifer system (Cooley and others, 1969, p. A14).

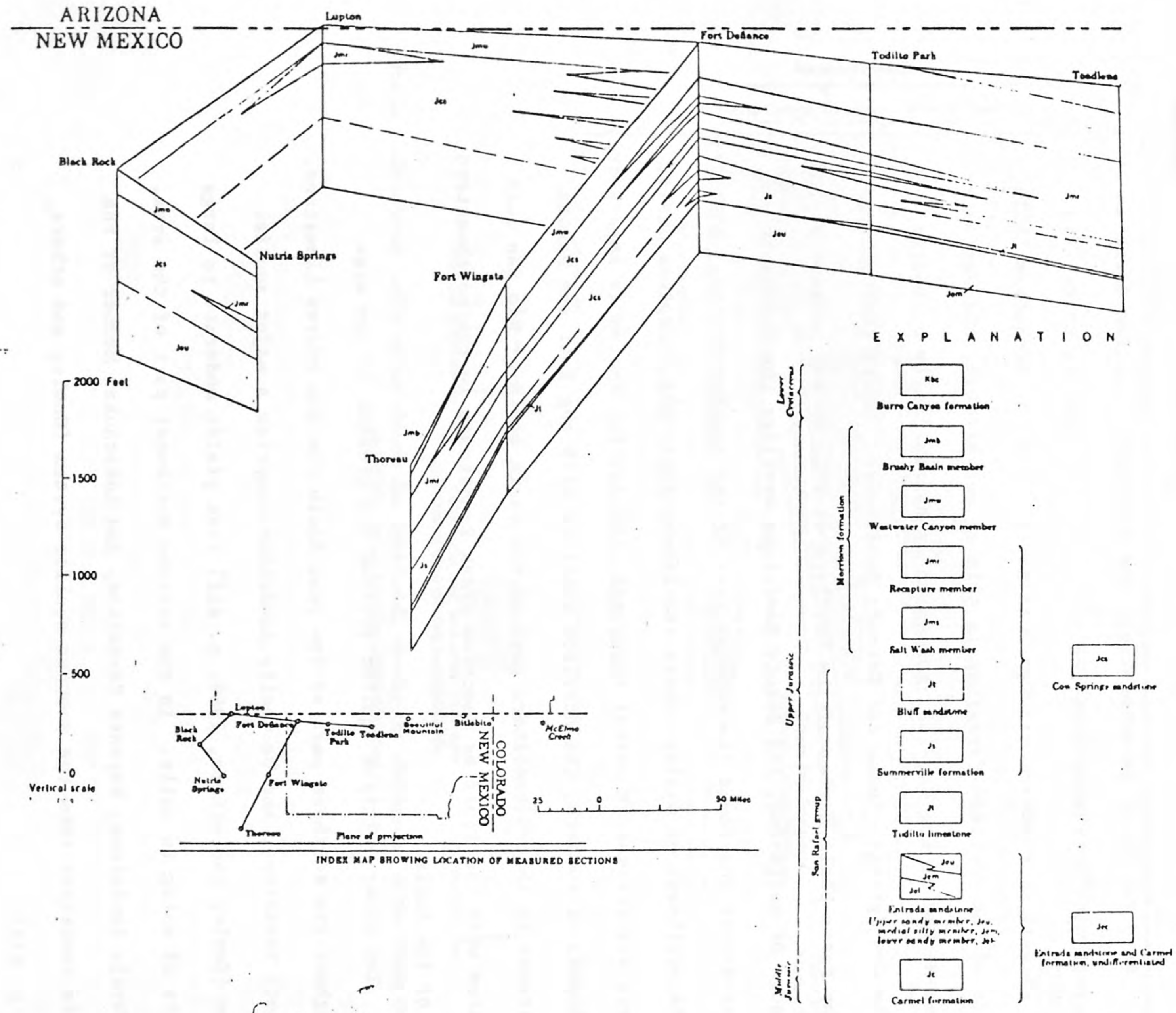


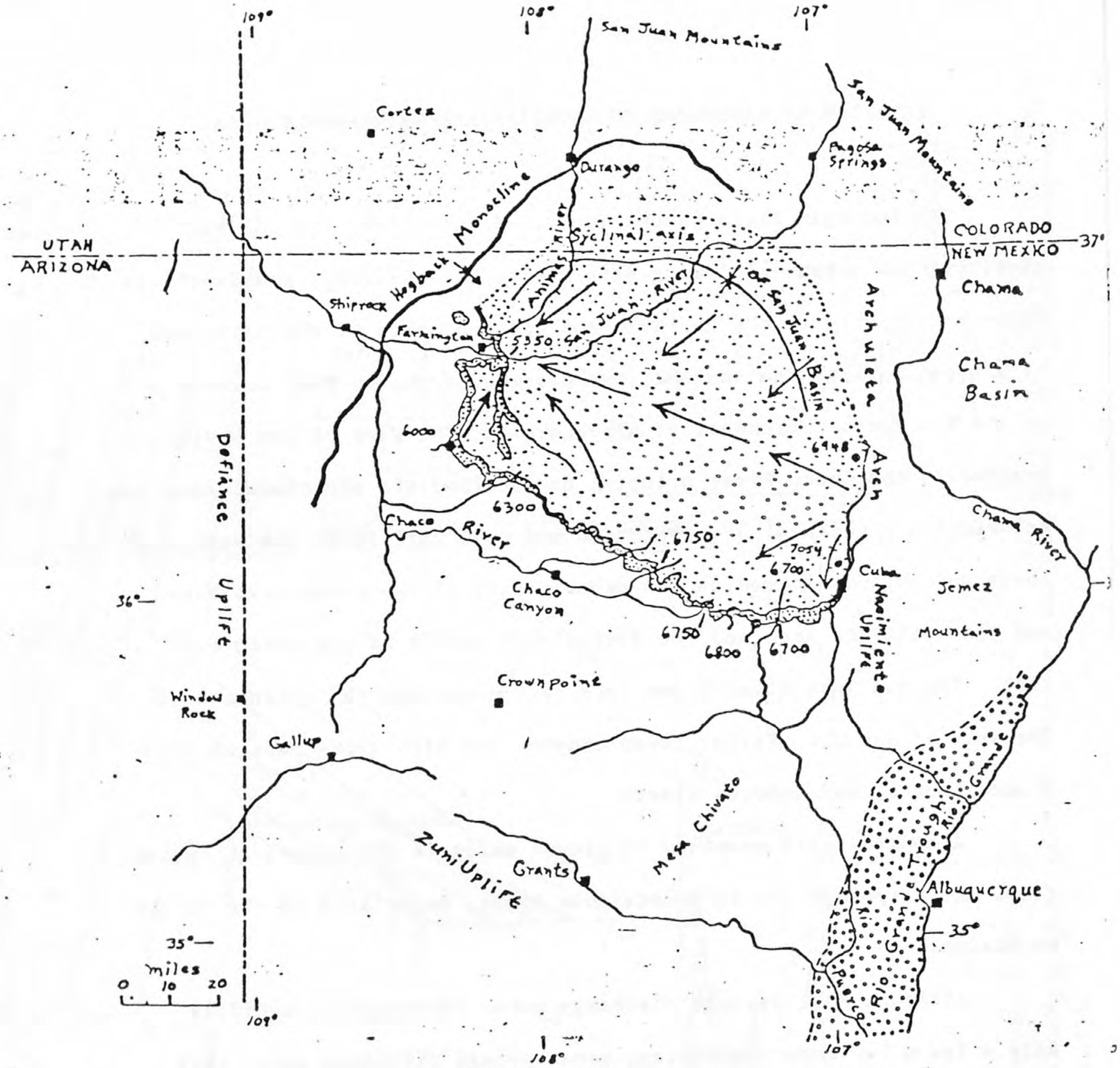
Figure 5. Stratagraphic section showing intertonguing of water-yielding sandstone units in The Morrison Formation and associated formations in the southeastern part of the [illegible]

RELATION OF LANDFORMS TO ARTESIAN AND WATER-TABLE AREAS

The San Juan Basin is characterized by uplands forming rock platforms and mesas--including Mesa Verde, Mesa Chivato, and Cebollita Mesa--principally in the northern and eastern parts of the basin and by a broad lowland that extends southeastward from the Four Corners to the Rio Puerco northwest of Albuquerque. The part of the lowland drained by the Chaco River occupies an intermediate structural position between the structural high Defiance and Zuni Uplifts on the west and south and uplands formed in the deepest part of the structural basin and the Archuleta Arch and the Nacimiento Uplift to the north and east. The San Juan River flows in a canyon through the uplands near the axis of San Juan Basin. Deep canyons are also along part of the Chama, Mancos, and Dolores Rivers.

A considerable quantity of ground water is discharged as spring flow. Most springs are in mountainous areas, especially in the Chuska Mountains.

Although most springs discharge water recharged to aquifers only a few miles from the spring, some springs discharge water that has moved for considerable distances. Among such springs are those in the southern part of the Ojo Alamo Sandstone outcrop (fig. 6), springs that issue mainly from La Ventana Tongue along the Hogback Monocline (fig. 7), and springs that discharge from the Gallup Sandstone near Tocito Dome (fig. 8).



EXPLANATION

←— Generalized direction of ground-water movement.

6800 Spring, figure denotes altitude in feet above mean sea level.

7054 Well, figure denotes altitude in feet of water level.

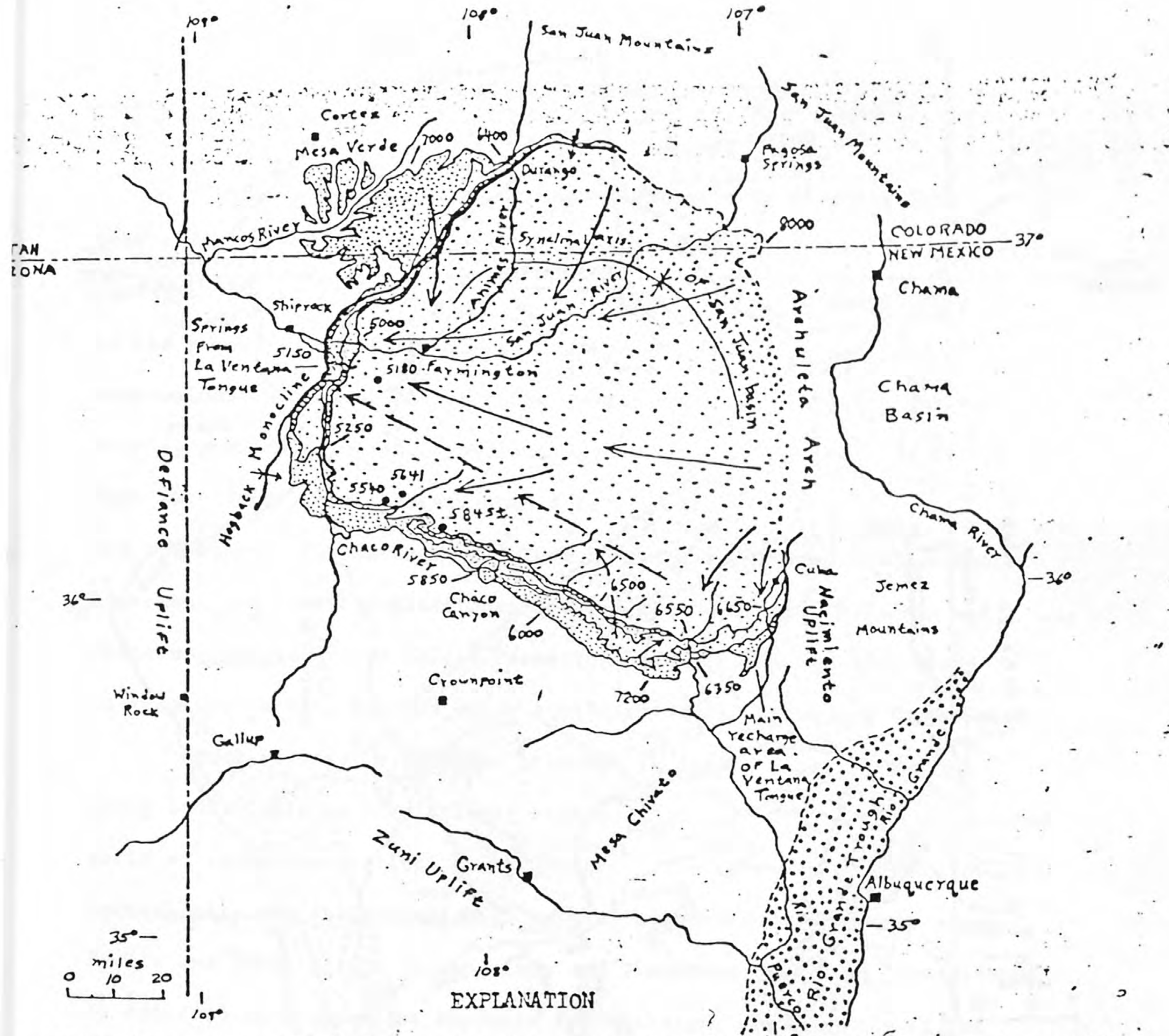
6300 Land-surface altitude in feet of outcrop of Ojo Alamo Sandstone.

Outcrop of Ojo Alamo Sandstone.

Approximate extent of Ojo Alamo Sandstone in the subsurface.

Approximate area of valley-fill deposits in Rio Grande Trough.

Figure 6.--Map of the Ojo Alamo Sandstone showing direction of ground-water movement toward the main places of ground-water discharge.



EXPLANATION

—— Generalized direction of ground-water movement in Pictured Cliffs Sandstone and in much of Cliff House Sandstone.

– – Probable direction of ground-water movement in La Ventana Tongue of Cliff House Sandstone.

5150 Spring, figure denotes altitude in feet above mean sea level.

5641 Well, figure denotes altitude in feet of water level.

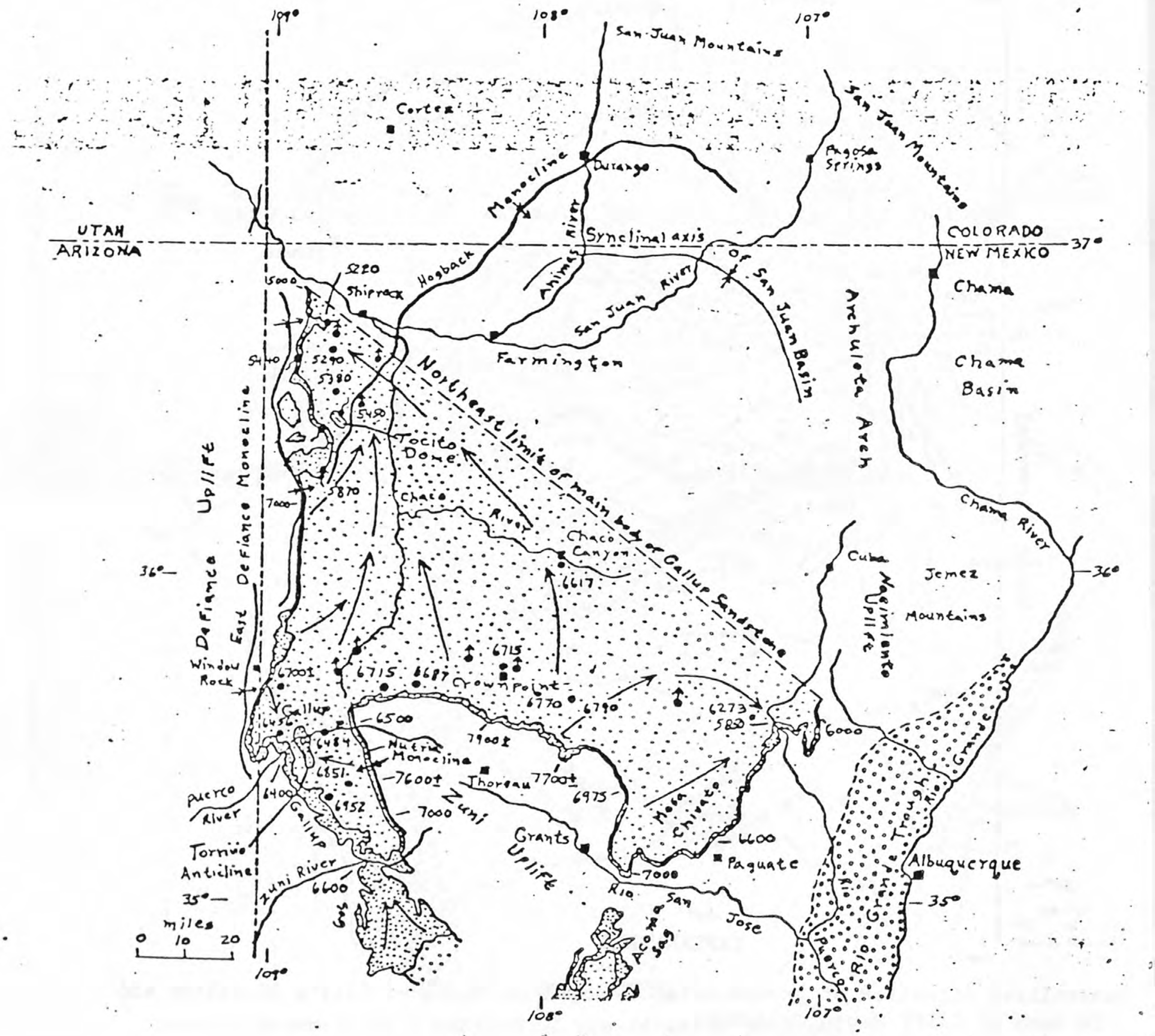
7200 Land surface altitude in feet of Pictured Cliffs or Cliff House Sandstones.

Outcrop of Pictured Cliffs and Cliff House Sandstones.

Extent of Pictured Cliffs and Cliff House Sandstones in the subsurface. Dotted line shows approximent extent of Pictured Cliffs Sandstone in northeastern San Juan basin.

Approximent area of valley-fill deposits in Rio Grande Trough.

Figure 7.--Map of the Pictured Cliffs and Cliff House Sandstones showing direction of ground-water movement toward the main places of ground-water discharge.



EXPLANATION

← Generalized direction of ground-water movement.

5220 Spring, figure denotes altitude in feet above mean sea level.

6715 Well, figure denotes altitude in feet of water level. Flowing well.

7700 Land-surface altitude of outcrop of Gallup Sandstone.

Outcrop of Gallup Sandstone. Extent of Gallup Sandstone in the subsurface

Approximate area of valley-fill deposits in Rio Grande Trough.

Figure 8.--Map of the Gallup Sandstone showing ground-water movement toward the main places of discharge.

RECHARGE TO THE SEDIMENTARY ROCKS

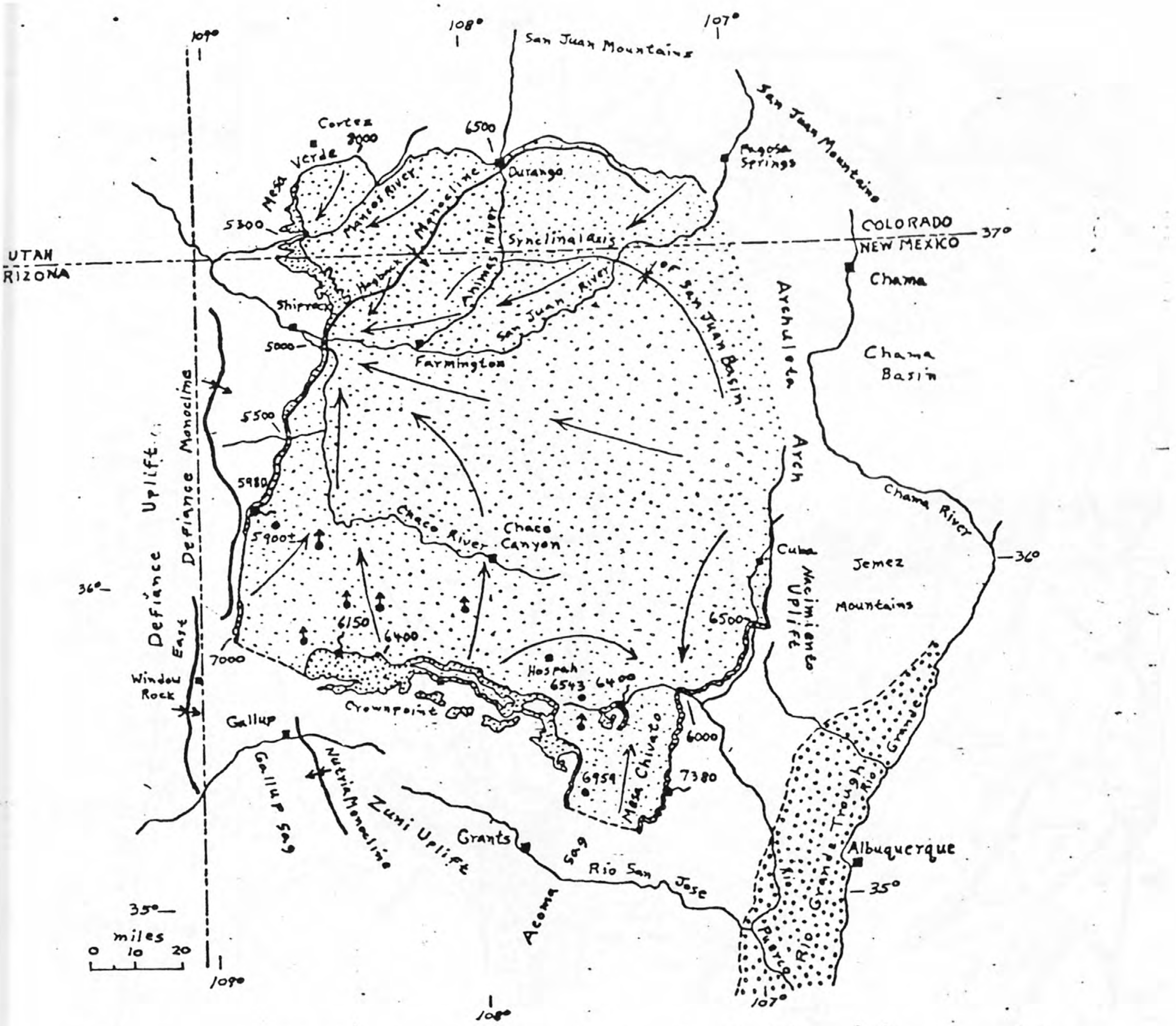
Recharge to aquifers in the San Juan Basin is directly from precipitation and from ephemeral streams or indirectly from interformational leakage. Direct recharge to the aquifers is controlled principally by the permeability of the rocks, the structural and physiographic expression, the amount of fracturing, the altitude of the water-bearing strata, and the duration, type, and amount of precipitation. Recharge from interformational leakage occurs between the Morrison Formation and the Dakota, Cow Springs, and Zuni Sandstones; between the San Andres Limestone and Glorieta Sandstone; between the De Chelly Sandstone and Shinarump Member of the Chinle Formation, and locally, particularly in fractured areas, between other aquifers in the Cretaceous formations.

Water enters the aquifers principally through fractures and along bedding planes. Relatively little water infiltrates the unfractured parts of sandstone aquifers in the outcrop areas because of their low permeability and the general high rate of evaporation. Openings along faults and large joints in sandstone and limestone that have been widened by solution form excellent conduits for recharge, particularly in the San Andres Limestone in the Zuni Uplift. Large open fractures are conspicuous along monoclines and on the more tightly folded anticlines. Other fractures that contribute significantly to recharge are in the shattered zones of laccolithic domes in the Carrizo, Ute, and La Plata

Principal areas of ground-water recharge are in the upturned strata marginal to updomed areas of the Defiance, Zuni, and Nacimiento Uplifts, the San Juan Dome and the La Plata, Ute, and Carrizo Mountains (figs. 1 and 2). However, gently tilted rocks that comprise Mesa Verde, Mesa Chivato, Cebollita Mesa, and the broad upland in the northeastern part of the basin underlain by the thick San Jose Formation receive some recharge. Many small lakes on the summits of the Chuska Mountains and on the basalt-capped Mesa Chivato aid recharge to the underlying sedimentary rocks.

REGIONAL GROUND-WATER MOVEMENT AND DISCHARGE

The distribution and generalized movement of water in the main aquifers of the San Juan hydrologic basin are shown by a series of aquifer maps (figs. 6-11). Regional movement of ground water is mainly to the San Juan, Chaco, and Puerco Rivers and to the Rio Puerco, and to their main tributaries. The ground water that discharges from the aquifers overlying the Dakota Sandstone is within the confines of the San Juan hydrologic basin (figs. 6-9). Water in the Dakota Sandstone and Morrison Formation discharges partly to the San Juan River, and partly to the Rio San Jose and Puerco and Zuni Rivers. Part of the water in these formations moves across the interbasin divide into the Blanding Basin in the Four-Corners area and into the Rio Grande Trough to the southeast (fig. 10). Water in the multiple-aquifer system comprising the San Andres Limestone, Glorieta Sandstone, and De Chelly Sandstone



EXPLANATION

Generalized direction of ground-water movement.

6400 Spring, figure denotes altitude in feet above mean sea level.

6534 Well, figure denotes altitude of water level. Flowing well.

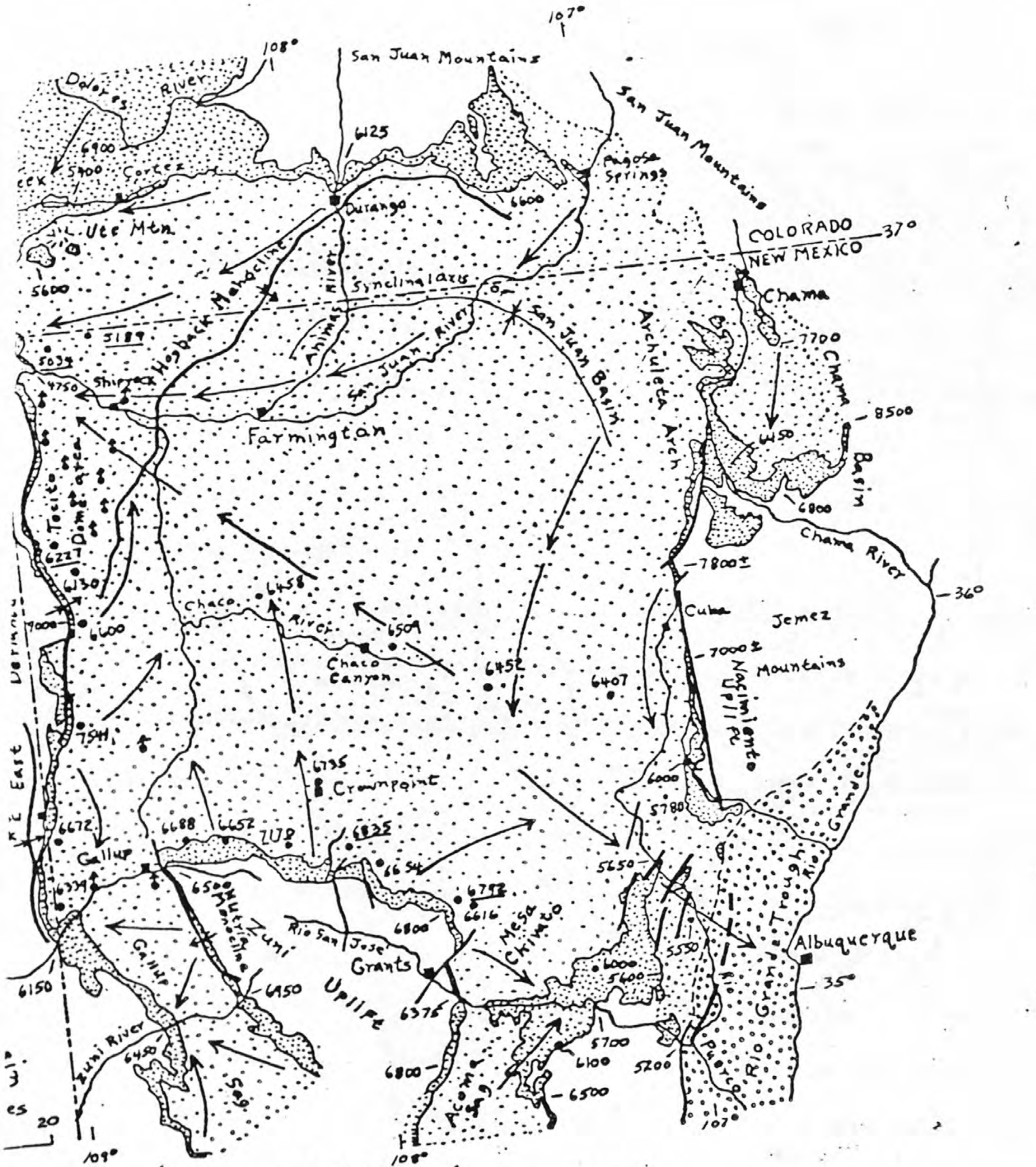
5300 Land-surface altitude of outcrop of Point Lookout Sandstone.

Main outcrop of Point Lookout Sandstone.

Extent of Point Lookout Sandstone in the San Juan basin.

Approximent area of valley-fill deposits in Rio Grande Trough.

Figure 9.--Map of the Point Lookout Sandstone showing ground-water movement toward the main places of ground-water discharge.



EXPLANATION

...ralized direction of ground-water movement.

...ing, figure denotes altitude in feet above mean sea level.

...l completed in Dakota Sandstone

...ll completed in Dakota Sandstone and Morrison Formation

...ll completed in Morrison Formation

} Figure denotes altitude in feet of water level.

...lowing well completed in Dakota Sandstone and/or Morrison Formation.

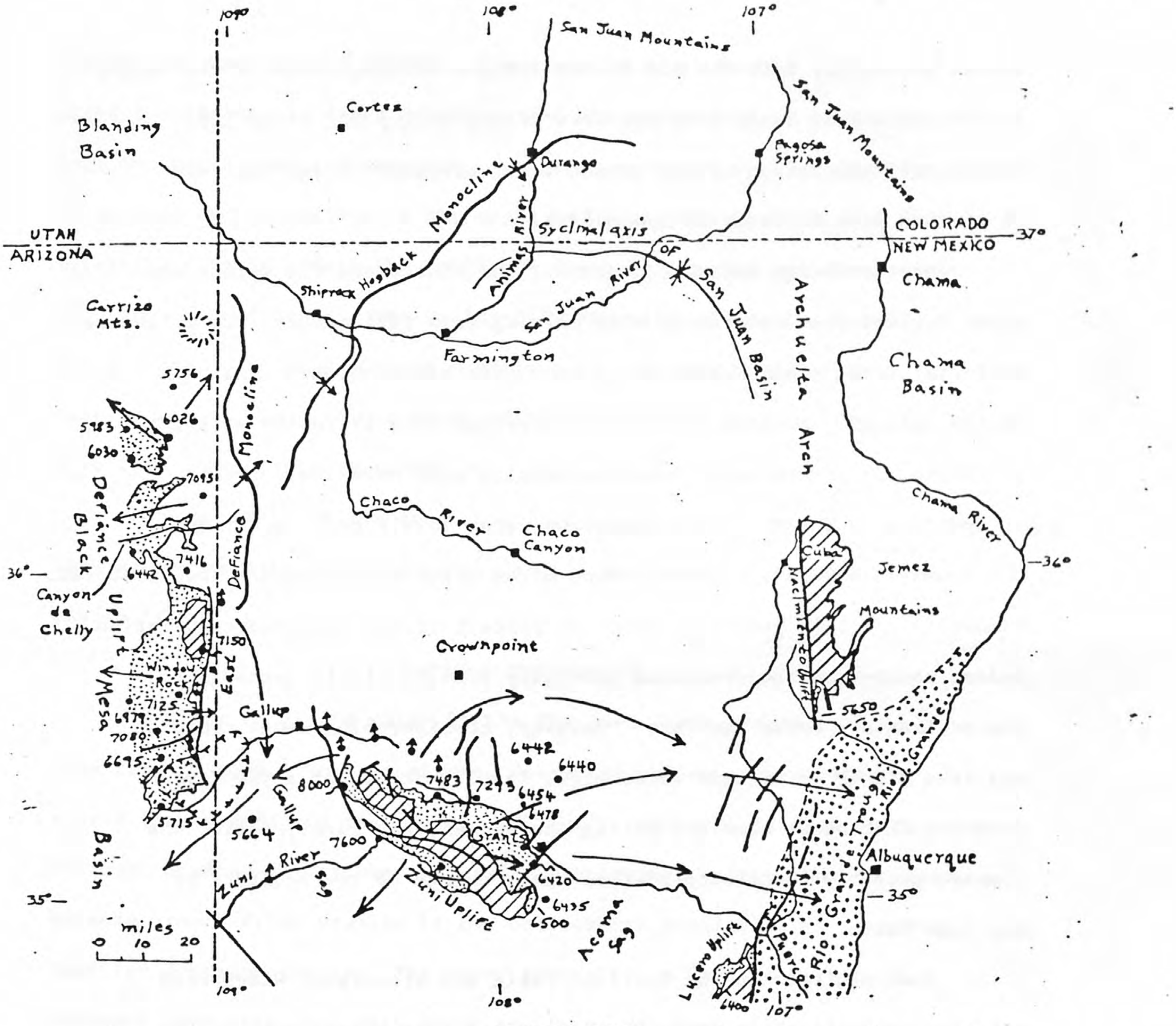
Land-surface altitude in feet of outcrop of Dakota Sandstone, Morrison Formation, Cow Springs Sandstone, or Zuni Sandstone.

Outcrop
Extent in subsurface } of Dakota Sandstone, Morrison Formation, Cow Springs Sandstone and Zuni Sandstone.

Approximent area of valley-fill deposits in Rio Grande Trough.

Fault.

...0.--Map of the Dakota Sandstone, Morrison Formation, and associated formations showing direction of ground-water movement to the main places of ground-



EXPLANATION

Generalized direction of ground-water movement.

7150 Spring, figure denotes altitude in feet above mean sea level.

7483 Well, figure denotes altitude in feet of water level. Flowing well.

5650 Land-surface altitude of outcrop of San Andres Limestone or Glorieta Sandstone.

Area where De Chelly Sandstone is dry. Fault.

Outcrop of San Andres Limestone, Glorieta Sandstone, and De Chelly Sandstone.

Area where San Andres Limestone, Glorieta Sandstone, and De Chelly Sandstone has been eroded off.

Approximent area of valley-fill deposits in Rio Grande Troug

Figure 11.--Map of the San Andres Limestone, Glorieta Sandstone, and De Chelly Sandstone showing ground-water movement toward the main places of ground-water discharge.

discharges mainly into the Rio Grande Trough, although some is discharged to the Black Mesa Basin from the area of the Gallup Sag (fig. 11). Additional description of the ground-water movement in the aquifers of the San Juan Basin is in Appendix 1.

Most recharge takes place during the winter and the spring when water derived from relatively slow melting snow infiltrates into permeable surficial rock. Seasonal recharge from precipitation occurs mainly in the uplands. Maximum discharge of springs also is in the springtime. In the spring ground-water levels generally rise near the outcrops of aquifers. The flow of springs and water levels decline during the summer. However, flash flooding often results from summer thunderstorms. Summer rainfall is generally about 50 percent of the annual precipitation. Sudden short-term thunderstorms generally provide little recharge to the sedimentary rocks aquifers. However, considerable summer recharge may take places in uplands above 6,500 feet. Storms of a few days duration that occur commonly during the winter, but rarely during the summer, probably contribute most of the recharge to the aquifers of San Juan Basin.

Most aquifers in the San Juan Basin are artesian. Widespread artesian conditions are found in the lowland that occupy much of the western and southern parts of the basin and parts of the Gallup and Acoma Sags (fig. 2). In low areas many wells flow at the land surface. Deeply buried artesian aquifers underly the rock platforms and mesas in the basin and along its margins, and in parts of the Defiance, Zuni, Lucero, and Naciemiento Uplifts. Aquifers at depth in the volcanic rocks comprising the Jemez Mountains and the southern part of the San Juan Mountains also are artesian. Water in rocks at shallow depths or exposed at the surface in the mesas and platforms generally is under water-table conditions. The rocks are dry near canyons and along edges of platforms and mesas. The valley-fill deposits of the Rio Grande Trough, in the thick De Chelly Sandstone on the summit of Defiance Uplift, and in the granitic rocks of the San Juan Mountains (fig. 2) also form water-table aquifers.

The aquifers of the area show little relation to surface drainage. They extend across various drainage basins and across the Continental Divide (fig. 2).

GROUND-WATER QUALITY

Quality of ground water in the San Juan Basin generally ranges from fair to poor. In most places, dissolved-solids concentrations exceed the recommended maximum of 1,000 mg/L (National Academy of Sciences, National Academy of Engineering, 1972) for potable water. Nevertheless, because ground water usually is the only source available, it is widely used for domestic supply. The water generally is hard to very hard. Dominant ions vary, not only among aquifers, but from place to place within an aquifer. Calcium or sodium is usually the predominant anion, bicarbonate or sulfate the predominant cation.

Water quality in the bedrock aquifers generally is best near areas of outcrop, where the aquifers are recharged by precipitation and runoff, which have low mineral content. Quality tends to deteriorate with distance from outcrop areas as the water moves down gradient toward the center of the basin. Many of the Cretaceous sandstones pinch-out toward the center of the basin. In or near these pinch-out areas, dissolved-solids concentrations in the water may be as high as 30,000 mg/L.

Generally, water in the alluvium is of better quality than that in adjacent bedrock aquifers, because the water is recharged more directly from precipitation and usually has not been in contact with soluable minerals for long. However, toward the lower end of the major drainages, such as Canon Largo and Chaco River, alluvium is recharged by ground water seeping from bedrock. This water is usually highly mineralized, and, as a result, the water in the alluvium is also high in dissolved solids. Water in the alluvium is high in dissolved solids near some of the ephemeral lakes and ponds, which probably concentrate minerals by evaporation and seepage through evaporite deposits.

Ranges in concentrations of the most common ions in water from the various aquifers are summarized in table 1. Individual analyses of ground-water samples have been published in Baltz and West (1967), Brimhall (1973), Cooper and John (1968), Gordon (1961), Iorns and others (1964), and Mercer and Cooper (1970).

There is considerable interest in the effects of uranium mining and milling activities on water quality in the Grants Mineral Belt. According to Kaufmann and others (1976), ground-water contamination

Table Ranges in chemical and physical properties of ground water in the San Juan Basin (in milligrams per liter, except as noted)

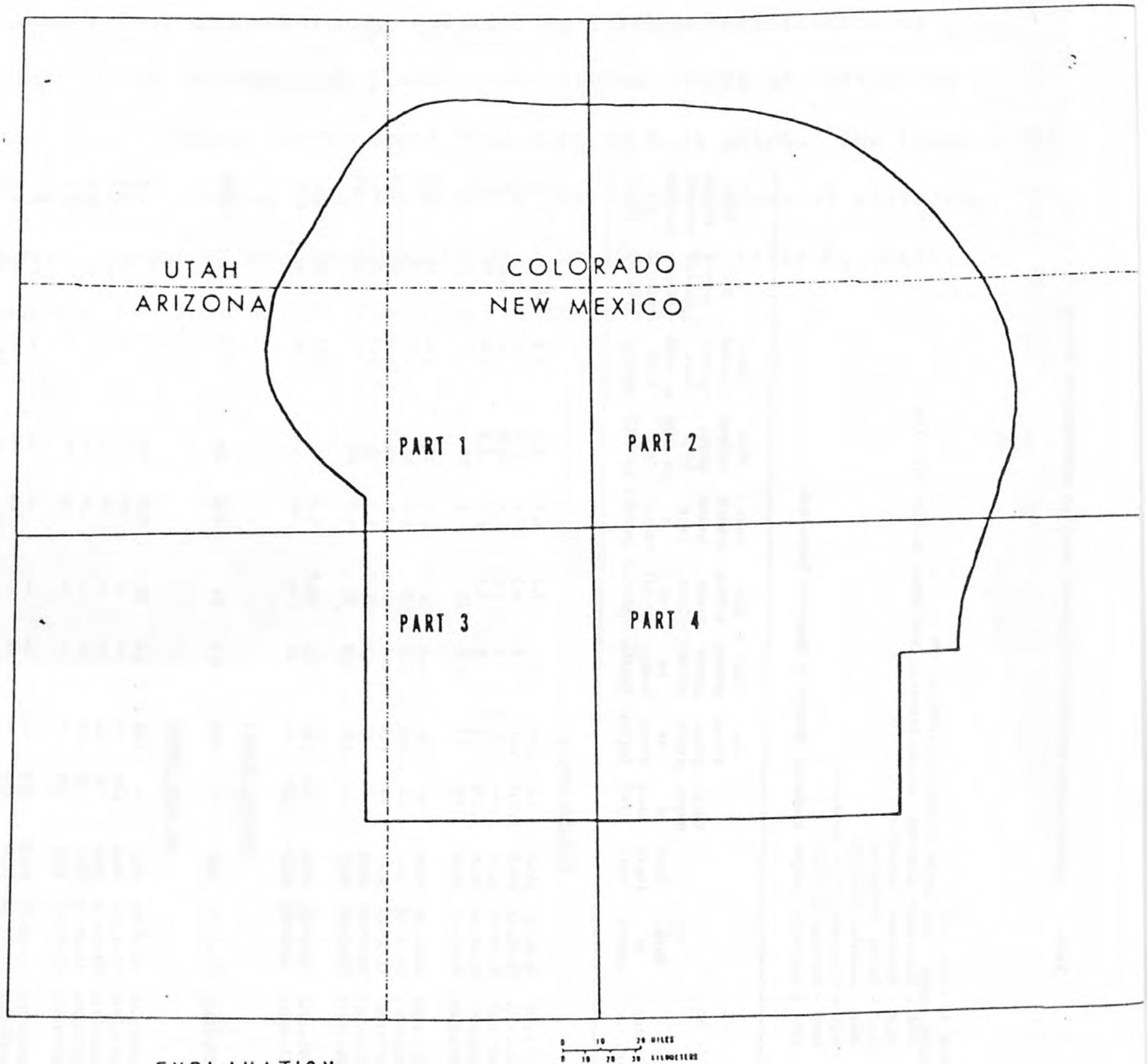
Aquifer	Silica (SiO_2)	Iron (Fe) (µg/L)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness (units)	pH	Temperature (°C)
Alluvium	04.1-63	0-6.6	4-2,870	0.8-2,040	5.5-12,000	34-1,000	2.5-8,890	2-27,500	0-11	0-439	143-47,100	18-15,500	7.3-8.3	4-21
San Jose Formation	7.6-28	0.02-14	1.6-365	0-67	29-745	120-814	71-1,430	3.2-87	0.2-4.0	0-25	323-2,520	4-1,960	6.5-9.2	9-14
Nacimiento Formation	14-22	0.02-0.58	0-385	0-50	3-2,415	0-478	6.2-5,455	1-145	0-4	0.2-5.7	56-14,150	30-966	6.9	12
Ojo Alamo Sandstone	9.6-39	0-2.1	1.6-548	0-126	23-788	0-888	0.4-2,440	0.8-923	0.3-1.8	0-70	275-4,010	4-1,860	6.5-8.9	2-14
Pictured Cliffs Sandstone	11-20	0-0.24	1.9-425	1-217	50-16,600	209-2,400	7.3-4,400	19-26,600	1.2-5.5	0-8.6	383-44,200	11-1,950	7.4-9.1	3-19
Cliff House Sandstone	2.7-19	0-0.01	2.2-280	0.7-170	26-6,140	0-1,250	350-8,230	7-4,210	0-8.1	0.1-2.5	849-3,120	8-1,600	4.3-8.9	13-18
Menefee Formation	5.1-21	0-1.1	1-168	0-34	8-2,620	92-1,890	1.8-3,930	1.5-956	0-12	0-19	129-7,780	4-534	7.4-9.1	12-21
Point Lookout Sandstone	0.05-39	0-0.31	0-684	0.4-267	13-833	116-826	3.8-3,410	2.2-113	0.2-3.7	0.1-14	149-5,080	5-2,800	7.4-10.0	13-21
Crevasse Canyon Formation	5.5-24	0-3.6	1.3-630	0-245	0.9-1,002	122-1,030	9.2-2,980	1.4-94	0-2.0	0-427	243-4,470	4-3,100	6.8-9.1	12-20
Gallup Sandstone	10-38	0.02-15	1-456	0-268	16-1,690	85-763	17-2,854	4-1,940	0-6.8	0-40	285-4,400	4-2,240	7.2-8.8	9-42
Dakota Sandstone	6.5-42	0-7.8	1.5-330	0.9-103	5.8-1,430	130-1,600	7.8-3,540	6-500	0.1-10	0.1-10	165-5,560	9-1,080	7.2-8.4	13-23
Westwater Canyon Member Morrison Formation	6.2-29	0-4	1.2-373	0.2-188	9.2-1,430	60-1,200	11-3,540	0.8-374	0.1-4	0-200	168-5,560	4-1,700	7.2-9.2	14-52
Bluff Sandstone	7.4-18	0-0.39	7.5-221	2.2-106	24-949	168-898	17-2,380	12-118	0.2-5.1	0.1-18	264-3,760	20-988	7.5-8.3	11-24
Entrada Sandstone	9.1-27	0.09	1.2-262	0.2-64	15-543	83-539	5.8-1,930	5-2,230	0.2-1.6	0-33	196-2,870	4-916	9.2	17
Chinle Formation	3.9-45	0-1.2	0.4-304	0.5-587	1.2-5,740	34-1,150	16-4,110	5-9,590	0.1-5.9	0-129	171-6,410	3-3,170	6.8-9.1	12-20
San Andres Limestone	6.7-23	0-1.2	60-266	14-128	1.2-426	161-702	11-1,030	4-254	0-0.8	0-105	272-2,370	72-1,040	6.7-8.2	11-46
Glorieta Sandstone	8.2-13	03.4-4.1	100-183	15-87	9.2-1,330	184-265	230-637	5-1,980	0.1-0.8	0-1.7	567-4,330	412-779	7.2	13-26

can result from uranium mining and milling through infiltration of effluents from ion-exchange plants. Background levels of radium-226 in the Grants Mineral Belt ranged from 0.06 to 0.31 pCi/L. The limit for radium in drinking water is 5 pCi/L (National Academy of Sciences, National Academy of Engineering, 1972). As shown in table 2, water throughout San Juan Basin is well below this limit.

Table . Radiochemical properties of ground water in northwest New Mexico

Map letter: Refer to figs. 7-11
Site identification number: As listed in USGS WATSTORE system
Geologic unit: AVHB - Quaternary alluvium, bolson deposits, and other surface deposits
FRLD - Fruitland Formation
GLLP - Gallup Sandstone
MENF - Menefee Formation
PCCF - Pictured Cliffs Sandstone
ENRD - Entrada Sandstone
WSRC - Westwater Canyon Sandstone Member of Morrison Formation

Map letter	Site identification number	Date of sample	Geo-logic unit	Total depth of well (ft)	Dis-solved gross alpha as U-Nat. (µg/L)	Sus-pended gross alpha as U-Nat. (µg/L)	Dis-solved gross beta as CS-137 (pCi/L)	Sus-pended gross beta as CS-137 (pCi/L)	Dis-solved gross beta as SR90 /Y90 (pCi/L)	Sus-pended gross beta as SR90 /Y90 (pCi/L)	Dis-solved RA-226 (radon method) (pCi/L)	Dis-solved natural uranium (U) (µg/L)
				McKinley County								
A	354145108135501	76-09-17	GLLP	800	<14	15	3.4	4.9	3.0	3.9	0.21	0.10
B	354332108165501	76-09-16	GLLP	1,014	<11	<.4	3.3	<.4	2.7	<.4	.22	.07
C	354345108175001	76-09-16	GLLP	--	7.1	.4	7.5	<.4	6.0	<.4	.42	.20
D	354514108190601	76-09-16	GLLP	1,292	<9.4	.6	3.5	<.4	2.8	<.4	.82	.06
E	355415107252801	76-01-15	MENF	790	54	<.4	25	.8	20	.7	.14	.30
F	355425107314401	76-01-05	PCCF	--	64	<.4	24	<.4	20	<.4	.15	.20
G	355558107293301	75-12-28	--	--	<43	3.6	18	1.5	14	1.2	.25	.20
H	355534107275701	75-12-27	MENF	--	<17	<.4	<7.2	<.4	<5.7	<.4	.05	.05
I	355720107340501	75-12-27	AVHB	--	41	<.4	16	1.1	13	1.1	.07	—
J	355723107312201	75-12-28	FRLD	--	<37	<.4	16	<.4	13	<.4	.21	.09
K	353534108355201	76-10-06	AVHB	90	<18	1.3	<4.4	1.3	2	1.2	.52	2.1
L	354342108184001	77-01-08	GLLP	1,154	--	--	--	--	--	--	--	<.4
				Sandoval County								
M	355302107130501	75-12-27	ENRD	--	260	<.4	94	<.4	76	<.4	1.4	<.01
				San Juan County								
N	360313107473401	76-01-06	WRSC	--	<84	<.4	88	<.4	80	<.4	1.6	<.01
O	361008107543901	77-08-18	FRLD	290	--	--	--	--	--	--	--	.9
P	360941107561601	77-08-16	FRLD	58	--	--	--	--	--	--	--	<.4
Q	360857107531001	77-08-18	FRLD	59	--	--	--	--	--	--	--	<.4
R	360823107544001	77-08-17	FRLD	190	--	--	--	--	--	--	--	1.1
S	360849107561801	77-08-17	FRLD	205	--	--	--	--	--	--	--	2.4
T	360822107561601	77-08-18	PCCF	285	--	--	--	--	--	--	--	3.2
U	361446108090801	76-10-19	FRLD	150	<73	57	21	20	19	17	.24	.4
		77-03-02	FRLD	150	<58	83	<16	28	<14	23	.12	—
V	361446108083701	76-10-19	FRLD	67	310	11	<30	5.1	<26	4.4	.34	2.5
				Valencia County								
W	350232107263701	77-01-27	AVHB	170	<32	2.4	10	2.6	8.2	2.1	.19	7.2
X	350240107291201	77-01-25	AVHB	120	<30	12	8.1	12	6.5	10	.09	7.9
Y	350344107391901	77-01-19	AVHB	135	<46	<.4	<14	.4	<12	<.4	.15	5.5
Z	350349107413401	77-01-21	AVHB	--	<10	<.4	7.3	<.4	5.8	<.4	.06	—



EXPLANATION

- 3795 Partial record surface-water gaging station
- 3722 Daily record surface-water gaging station
- 3555 Daily record surface-water gaging station, with chemical quality data
- 3505 Daily record surface-water gaging station, withchemical quality and radiochemical data
- 2870 Daily record surface-water gaging station, with sediment data
- A Ground-water well, with radiochemical data
- Community with public water-supply system

These various symbols may be combined in different ways. Number is the gaging station identification number, letter refers to well number table.

Map Letter	Well Number
A	354145108135501
B	354332108165501
C	354345108175001
D	354514108190601
E	355415107252801
F	355425107314401
G	355558107293301
H	355534107275701
I	355702107340501
J	355723107312201
K	353534108355201
L	354342108184001
M	355302107130501
N	360313107473401
O	361008107543901
P	360941107561601
Q	360857107531001
R	360823107544001
S	360849107561801
T	360822107561601
U	361446108090801
V	361446108083701
W	350232107263701
X	350240107291201
Y	350344107391901
Z	350349107413401

FIGURE 12 - Index to locations of stream-gaging stations, ground-water wells, and public water-supply systems. This figure and the four that follow are common to three reports supporting the San Juan Basin Regional Uranium Study, and contain more information than needed by any one of the reports.

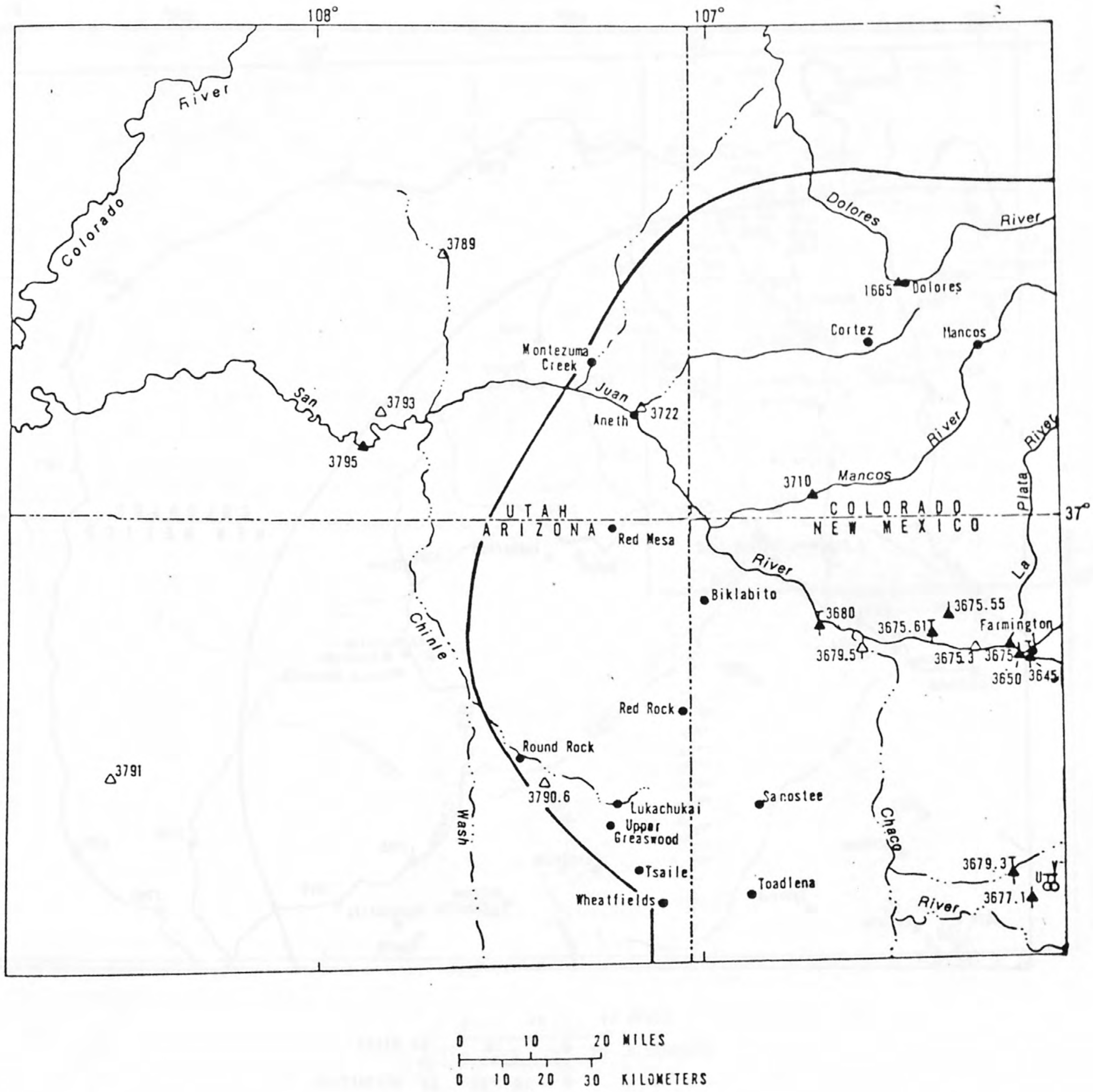


FIGURE 13 –Location of stream-gaging stations, ground-water wells, and public water-supply systems, Part 1

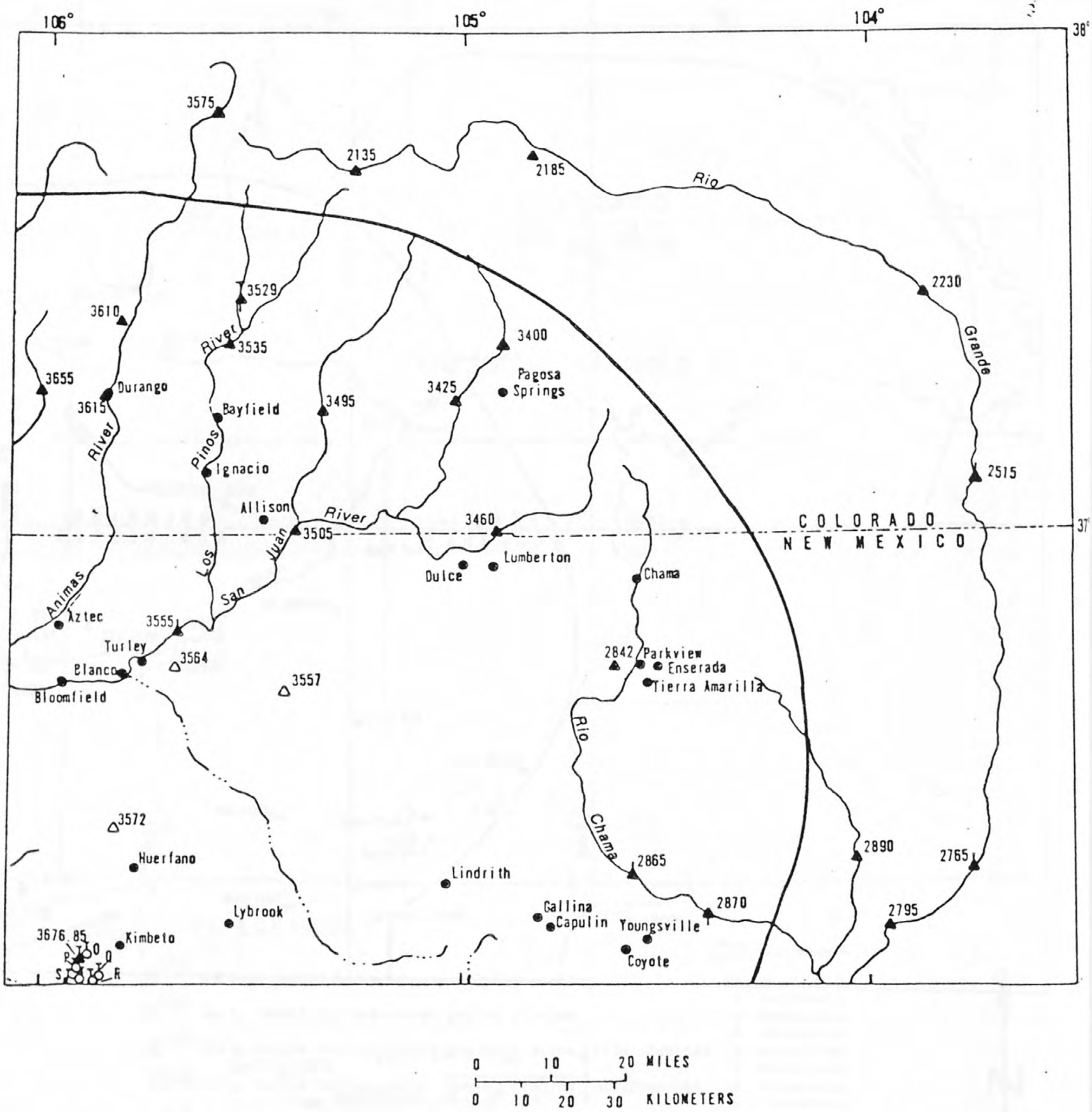


FIGURE 14 –Location of stream-gaging stations, ground-water wells, and public water-supply systems, Part 2

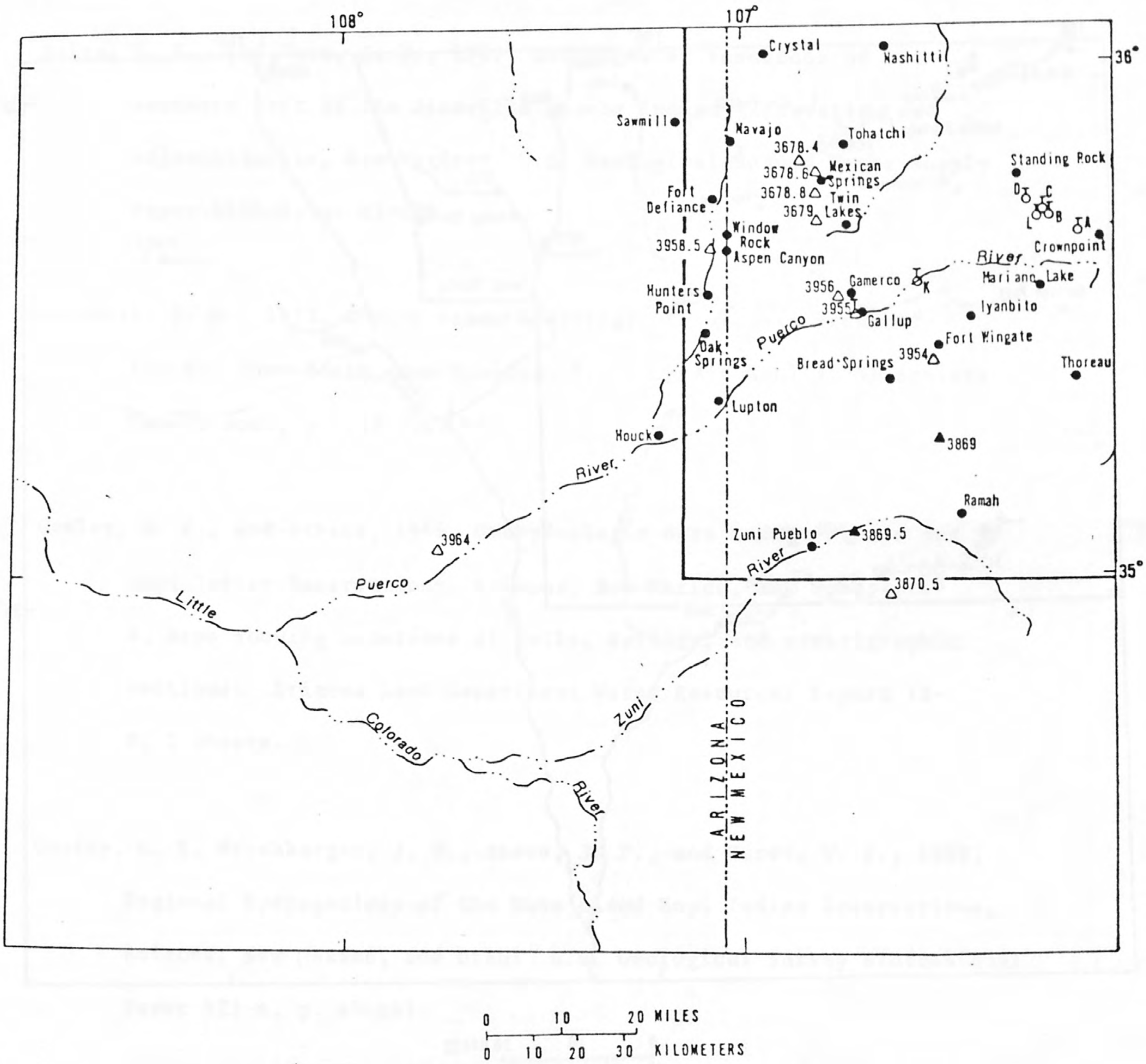


FIGURE 15 —Location of stream-gaging stations, ground-water wells, and public water-supply systems, Part 3

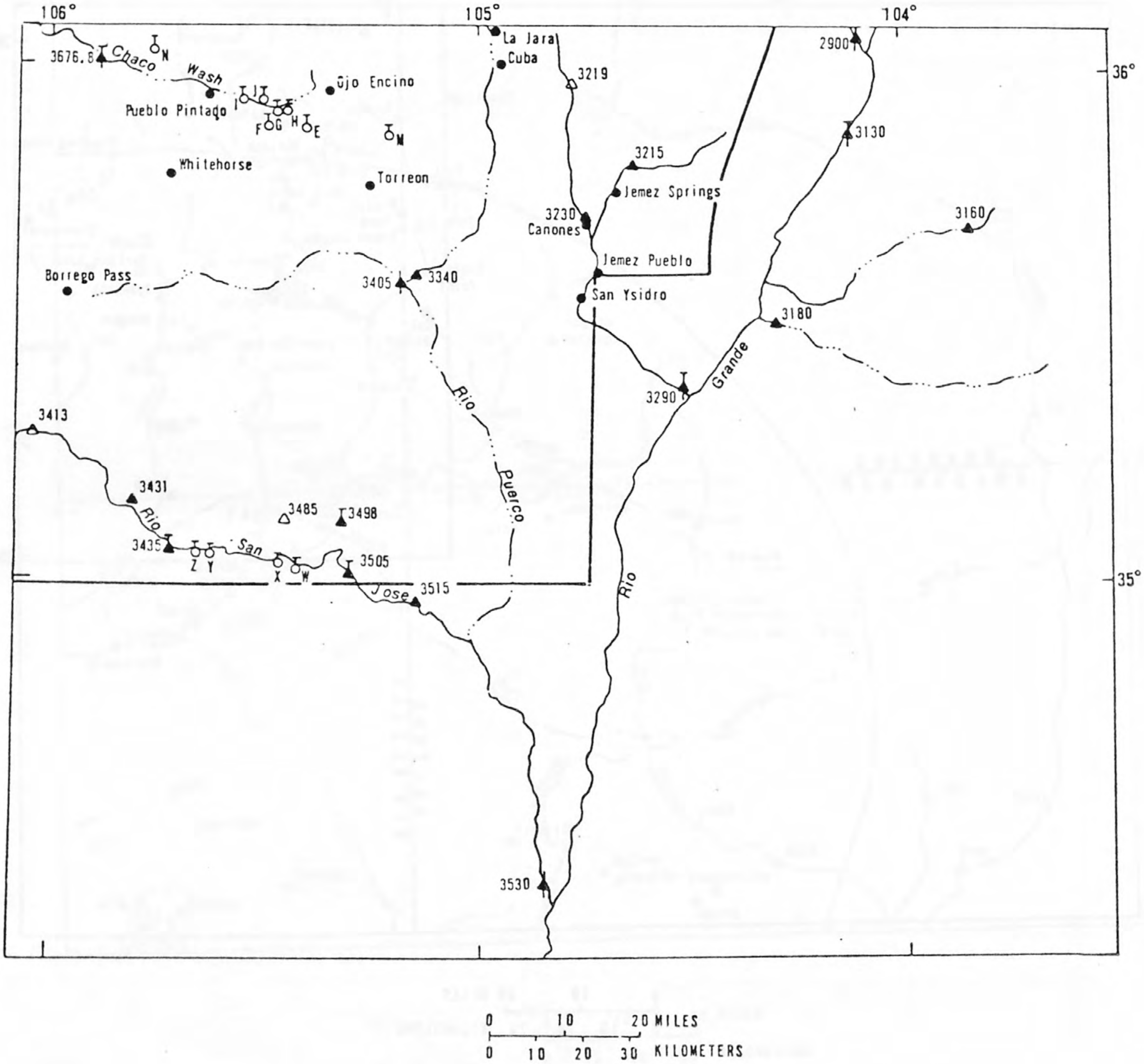


FIGURE 16 –Location of stream-gaging stations, ground-water wells, and public water-supply systems, Part 4

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Appendix A.--Synoptic geohydrologic description of the outcropping rock units in the San Juan Basin of New Mexico, Colorado, Arizona, and Utah.

Alluvium:

Occurs along most of the stream channels in the San Juan Basin. Consists of a heterogeneous mixture of sand, silt, and clay, and, along the larger channels, gravel and boulders. Most wells completed in alluvium yield sufficient quantities of water for stock and domestic use. Generally, alluvium is too thin and limited in extent to support continuous, large withdrawals. However, large yields can be obtained from alluvium along the San Juan River.

Throughout most of basin, water in the alluvium flows toward the nearby major streams. Recharged by runoff from nearby hillsides, by percolation from stream channels, and occasionally, from underlying bedrock aquifers. Discharges through springs and seeps into adjacent streams, and into underlying bedrock aquifers.

Bidahochi Formation:

Is present only in southern part of Gallup Sag and bordering the southern part of Defiance Uplift. Fills ancient valleys that trend southwestward and overlaps part of the adjacent slopes. Thickness of more than 500 feet occur in central part of old valleys. Consists mainly of weakly consolidated sandy siltstone to silty sandstone, some sandstone, and minor pebble-bearing conglomerate.

Yields small amounts of water to wells south of the Puerco River near the New Mexico-Arizona State line. Water occurs mainly in the basal part of the unit in the centers of the filled valleys. Water moves southwestward generally following the trends of the old valleys. Locally, part of the water recharges underlying rocks of Cretaceous to Jurassic age.

Santa Fe Group:

Is present only in the broad alluvial valley or lowland of the Rio Grande Trough. Maximum thickness is more than 2,000 feet. Due to faulting, thickness is variable along western margin of the trough bordering the Puerco Fault Belt.

Ranges from siltstone to conglomerate, includes some volcanics. Siltstone is predominant in the few hundred feet of section exposed in most outcrops. Coarse-grained sediments are present at many places in the subsurface, but their exact distribution is not known.

Forms a large-yielding aquifer. Coarse-grained sediments supply water for irrigation and municipalities. Part of the recharge is from interformational leakage from Morrison Formation and rocks of Cretaceous age that are in contact with the Santa Fe Group in the western part of Rio Grande Trough. Principal area where this recharge occurs is between the Nacimiento and Lucero Uplifts. Ultimate discharge of ground water is to the Rio Grande.

Chuska Sandstone:

Is present mainly as a thick capping layer on the summit of the Chuska Mountains. Thickness is more than 1,000 feet. Nearly horizontal and overlies an erosion surface beveled tilted Cretaceous to Triassic rocks along east flank (East Defiance Monocline) of Defiance Uplift.

Consists chiefly of nearly white cross-stratified fine- to medium-grained sandstone; lower part contains some siltstone and silty sandstone.

Is in a favorable physiographic position (at altitutes generally above 8,000 feet) for recharge from rainfall and snowmelt. Many small, clear lakes occupy depressions on top of the unit. Yields water to many springs and maintains perennial reaches of some of creeks in the Chuska Mountains. Part of water discharging from the unit recharges the Morrison Formation and other sedimentary rocks along the East Defiance Monocline. Water wells have not been completed in the sandstone.

San Jose Formation:

Is present only in the northeastern part of the basin where it is the uppermost formation. Thickness ranges from 200 feet in the south and west to 2,500 feet in the north. Variation in thickness is due primarily to erosion.

Consists in New Mexico of four intergrading lithologic facies that in descending order are: (1) the Tapicitos Member, mainly a variegated white to maroon claystone to siltstone with some lenticular arkosic conglomerate containing some mudstone; (2) the Llaves member; (3) the Regina Member, mainly claystone to siltstone containing numerous beds of sandstone; and (4) the basal Cuba Mesa Member, which is mainly a pebble-bearing conglomeratic arkosic sandstone. Sandstone is more common in the eastern and northern parts of its exposures.

Forms a generally low-yielding aquifer. Well yields are as great as 60 gal/min, although most wells yield less than 10 gal/min. The water quality is generally good to fair. Highest yields are from the Cuba Mesa and Llaves Members. The chief aquifer of the Jicarilla Apache Indian Reservation and nearby area. Water moves generally southward, westward, and northwestward toward Canyon Largo. Many springs issue from the unit in Canyon Largo and nearby canyons.

Blanco Basin Formation:

Is present in the northern part of the basin in Colorado. Maximum thickness is about 750 feet. Consists largely of arkose, arkosic sandstone, mudstone, sandstone, and conglomerate.

Well-yields are similar to those of the San Jose Formation.

Nacimiento Formation:

Is present in the northeastern quarter of the basin. Thickness ranges from 1,750 feet in the eastern part of the basin to 1,000 feet north of Farmington, and 500 feet southwest of Durango. Variations in thickness caused largely by an erosional unconformity between the Nacimiento and the overlying San Jose Formation.

Consists of lenticular layers of claystone, siltstone, and some soft sandstone in the southwest and an alternation of sandstone with claystone and siltstone in the northeast.

Yields small amounts of water to a few wells. Sandstones in the northeastern part of the basin may be a source of water to wells. Generally, the thick shaly sequence in the southwestern part separates the water in the overlying San Jose Formation from the water in the underlying Ojo Alamo Sandstone. Water from many wells tapping the Nacimiento Formation is high in total dissolved solids.

Animas Formation:

Is present principally in the Colorado part of the basin. Thickness ranges from 300 to 2,700 feet; thins generally to the south.

Consists of dark varicolored sandstone, shale, and conglomerate containing abundant volcanic and arkosic detritus. McDermott Member contains igneous detritus derived from La Plata Mountains. Includes tuffaceous sandstone in the western part.

Probably yields only small amounts of water to wells. Water yielding characteristics similar to sandstone beds in the Nacimiento Formation or Ojo Alamo Sandstone.

Ojo Alamo Sandstone:

Is present in the east-central part of the basin. Thickness ranges from 50 to 200 feet.

Consists of cross-bedded fine- to coarse-grained sandstone with interbeds of shale. Locally, as many as three sandstone beds may be present. Contains some lenses of pebble conglomerate and fossil logs. Sandstone beds are moderately cemented by silica, clay, and iron minerals. Cementation is main control on permeability and yield.

Yields small quantities of water to a few wells in different parts of the basin. Small springs issue from sandstone beds. Receives some recharge from water discharging from sandstone beds in the Nacimiento Formation. Water moves in a convergent pattern to the main points of discharge along the San Juan and Animas Rivers near Farmington or to the Rio Puerco near Cuba.

Kirtland Shale:

Is present in the northeastern one-third of the basin. Thickness ranges from less than 200 feet in the eastern part to 700 feet south of Farmington, and to 1,200 feet in Colorado.

Consists of mudstone, siltstone, some silty sandstone and sandstone, and minor beds of coal. Lenses of sandstone of the Farmington Sandstone Member aggregate to a thickness of as much as 350 feet in the middle of the unit.

Yields small amounts of water to wells at only a few places. South of Farmington, the Farmington Sandstone Member contains some water of poor chemical quality. Kirtland Shale in combination with the Fruitland Formation forms a thick confining layer between the Ojo Alamo Sandstone and Pictured Cliffs Sandstone.

Fruitland Formation:

Is present in the northeastern one-third of the basin. Thickness ranges from less than 200 feet in the eastern part to between 250 and 400 feet in Colorado and to about 700 feet in the southwestern part.

Consists chiefly of lenticular beds of mudstone, siltstone, silty sandstone, sandstone, and coal. Coal is mined near the San Juan River.

Locally may yield a little water to wells. Forms a confining layer above the Pictured Cliffs Sandstone.

Pictured Cliffs Sandstone:

Is present in the northeastern one-third of the basin. Thickness generally ranges from 50 feet to 300 feet.

Consists of a very fine to medium-grained sandstone that includes some shale. Unit intertongues with the Fruitland Formation and the underlying Lewis Shale, and coalesces near the Chaco River with the Cliff House Sandstone where the intervening Lewis Shale wedges out.

Forms a thin, low-yielding aquifer that furnishes water to a few stock wells and springs. Water moves generally westward and discharges mainly to the San Juan and Chaco Rivers east and south of Shiprock some water discharges to the Rio Puerco south of Cuba.

Lewis Shale:

Is present in the northeastern one-third of the basin. Thickens progressively eastward from the line where it wedges out near the "big bend" of the Chaco River to about 2,000 feet in the eastern part and to 2,700 feet in Colorado.

Consists of dark gray claystone and siltstone containing some thin, platy beds of fine-grained sandstone and concretionary and shaley limestone. Contains zones of shaley sandstone in the eastern part.

Not known to yield water to wells. Forms a confining bed between the Pictured Cliffs and Cliff House Sandstones.

Cliff House Sandstone:

Is present in the northeastern one-third of the basin. Not including La Ventana Tongue, thickness is about 400 feet near the Chaco River and in the Mesa Verde area, but is generally less than 200 feet in much of the eastern part. Thickness varies locally due to intertonguing with the Lewis Shale above and the Menefee Formation below. The thick La Ventana Tongue trends northwestward and is in the subsurface just north of the outcrops of the Cliff House Sandstone from the Rio Puerco to the Hogback Monocline. Total thickness where La Ventana Tongue is present ranges from about 800 to 1,200 feet.

Consists mainly of fine-grained sandstone that in places contains mudstone and impure sandstone. Near the "big bend" of the Chaco River beyond the western wedge-out of the Lewis Shale, Cliff House Sandstone and the Pictured Cliffs Sandstone form a single sandstone unit. The La Ventana Tongue intertongues chiefly with the Lewis Shale. It contains sandstone and considerable interbeds of siltstone to mudstone.

Forms a persistent generally low yielding aquifer. Yields some water to stock wells south of Farmington and is used as a water supply for the Chaco Canyon National Monument. Generally low permeability limits the amount of water that moves through the sandstone and is yielded by wells. Where the sandstone is well developed, particularly in the La Ventana Tongue, larger yields may be obtained. Water discharges from the Cliff House Sandstone to the San Juan River east of Shiprock and to the Chaco River downstream of the "big bend." Several springs along Hogback Monocline south of the San Juan River discharge water primarily from he La Ventana Tongue. These springs have sufficient flow to reach the Chaco River.

Menefee Formation:

Is present throughout most of the basin. Thins from 3,000 feet near Tohatchi at the south end of the Chuska Mountains to 1,000 feet in Mesa Chivato and 800 feet near the New Mexico-Colorado State line north of Farmington. Eventually wedges out in the northeastern part of the basin.

Consists of alternating beds of mudstone, siltstone, fine to medium-grained sandstone, coal, and coaly shale. Sandstone beds are lenticular and mostly less than 50 feet thick. Coal is concentrated in the upper and lower parts. Near Gallup, the middle noncoal-bearing part is the Allison Me and the lower coal-bearing part is the Cleary Coal Member. The formation intertongues conspicuously with the Cliff House Sandstone.

Yields small, but dependable, quantities of water to many stock wells and for domestic use in the southern part of the basin. Water occurs principally in sandstone beds which are scattered throughout the formation. In the area south of the Chaco River some of the wells flow at the land surface. Many wells tapping the Menefee Formation also tap the underlying Point Lookout Sandstone. The aquifer is recharged in the outcrop area, and ground-water movement is toward the central part of the basin. The Menefee Formation also is recharged through leakage from underlying aquifers.

Point Lookout Sandstone:

Is present throughout most of the basin. Maximum thickness, not including Hosta Tongue, is 450 feet in Colorado, 320 feet in the south-western part, and 200 feet in the southeastern part of the basin. Locally varies in thickness by more than 100 feet. The Hosta Tongue is present only in the southern part of the basin; it grades northeastward into the Mancos Shale near Crownpoint and coalesces with the main mass of the Point Lookout Sandstone at the southern end of the Chuska Mountains and in Mesa de los Lobos. Maximum thickness of Hosta Tongue is about 120 feet.

Consists mainly of fine- to medium-grained sandstone. Lower part contains interbedded mudstone and silty sandstone forming a transitional zone with the underlying Mancos Shale. Locally, some coal is present. Thins abruptly along its southern edge and wedges out near Tohatchi and in Mesa Chivato. Housta Tongue consists of sandstone. Is separated from the main part of the Point Lookout Sandstone by a tongue of the Mancos Shale.

Forms a persistent low-yielding aquifer that yields generally small amounts of water to wells mainly in the area north of Mesa de los Lobos and Mesa Chivato. Many of these wells also tap the Menefee or Crevasse Canyon Formations and flow at the land surface. A few springs discharge from the sandstone. One spring furnishes water to Marguez. Only a few wells are completed in the Hosta Tongue. Much of the water in this formation flows generally northwestward across the basin to discharge into the San Juan or Chaco Rivers. Water in the southeastern part of the basin discharges into the Rio Puerco and its tributaries between Mesa Chivato and Cuba.

Mancos Shale:

Is present throughout the basin and in much of the adjoining area. Thickens progressively from 300 feet in the southern part to about 2,400 feet in Colorado.

Consists mainly of dark gray claystone in mudstone with some silty sandstone. Contains more sandstone in the southern and western parts and some limy shale and impure limestone in the northern and northeastern parts. Southwestward thinning is mainly by intertonguing with the Point Lookout Sandstone, Crevasse Canyon Formation, Gallup Sandstone, and Dakota Sandstone. Tongues of Mancos Shale wedge-out also in a southwesterly direction into these formation.

Does not yield water to wells or springs. Thick shale of the main body of the Mancos and its tongues form confining beds between water-bearing sandstone units.

Crevasse Canyon Formation:

Is present in the southern and southwestern parts of the basin and in the adjacent area to the south. It is 700 to 900 feet thick near Gallup and about 450 feet thick east of Grants. This formation and the Hosta Tongue of the Point Lookout Sandstone form a huge wedge of sediments that thins-out northeastward into the Mancos Shale.

Consists of a highly variable sequence of interbedded mudstone, siltstone, coal, and sandstone. Sandstone is mainly fine grained, but locally is coarse grained. Dalton Sandstone Member, Stray Sandstone, and Terrivio Sandstone are the main sandstone units. Near Gallup, formation is divided in descending order into the Gibson Coal Member, Bartlett Barren Member, Dalton Sandstone Member, and Dilco Coal Member. These members intertongue laterally with each other and also with the Mancos Shale.

Yields small amounts of water to wells usually in combination with the Point Lookout or Gallup Sandstones. The Dalton Sandstone Member, the Stray Sandstone, and the Terrivio Sandstone are the most important water-bearing units.

Gallup Sandstone:

Is present in the southwestern two-fifths of the basin and in the adjoining area to the south. Lenticular tongues extend into the Mancos Shale northeastward beyond the main mass. Thickness decreases northward and eastward from 335 feet near Ramah to 225 feet at Gallup, to about 175 feet near Grants, and to 100 feet near Sanostee.

Consists of cross-bedded, very fine to coarse-grained, partly arkosic sandstone with some coal and mudstone. Near Gallup, the upper part is coarser than the lower part. Some of the sandstone beds tongues out into the Mancos Shale. The different sandstone tongues are conspicuously displayed locally.

Forms a dependable low- to moderate-yielding aquifer. Is the major aquifer in the vicinity of Gallup and supplies most of the city's water. Mercer and Cooper (1970) reported that a test well north of the city was capable of being pumped at 800 gal/min. In 1977, the city of Gallup was pumping about 1 Mgal/d from wells tapping the sandstone, and water levels in nearby wells were declining about 1 ft/yr. Water in the Gallup Sandstone generally is under artesian pressure, and many wells flow. As the sandstone dips under younger rocks to the north, this pressure provides a large range for drawdown, so that several hundred gallons per minute can be pumped from a well, even though the specific capacity is low. Many wells flow at the land surface to the west and south of the Chaco River. Many small springs issue from the aquifer in the western part of the basin. Water moves through the sandstone from near the Zuni Uplift generally northeastward to discharge to the Rio Puerco northeast of Mesa Chivato, southwestward to discharge to the Zuni River between Zuni and Ramah and to the Puerco River near Gallup, and northwestward to discharge as springs in the Tocito Dome area. Some water moves from along the eastern flank of the Defiance Uplift to discharge to the Puerco River and to the Tocito Dome area.

Dakota Sandstone:

Is present throughout the basin and in much of the surrounding area. Thickness generally is about 100 feet, but ranges from 40 to more than 200 feet; mainly thicker in the northern and eastern parts.

Consists of fine- to medium-grained, generally cross-bedded sandstone interbedded with carbonaceous mudstone and siltstone and some coal. In places, contains lenses of pebble-conglomerate. Several sandstone beds intertongue with the Mancos Shale; the Two Wells Sandstone Tongue near Zuni and the Paguate, and the Cubero Sandstone Tongues from the Continental Divide eastward. In the western part, the Dakota Sandstone consists generally of a lower bed of fairly clean sandstone as much as 60 feet thick, a medial fine-grained beds that includes coal, and an upper impure sandstone that occurs in lenticular beds. The Dakota Sandstone was deposited on a widespread erosion surface that truncates the Burro Canyon Formation in the northwest, the Morrison Formation over most of the basin, and the Cow Springs and Zuni Sandstones in the southern part. Local relief along this erosion surface is as much as 30 feet.

Forms a dependable generally low-yielding aquifer throughout the basin and yields water to wells supplying several small communities and many stock wells. Wells having moderately large yields tap the Dakota Sandstone, the Morrison Formation, and the Cow Springs Sandstone. Where the Dakota Sandstone overlies permeable sandstone beds in other formations, it comprises a multiple-aquifer system--with the Burro Canyon Formation in the northwestern part and with the

Morrison Formation (Westwater Canyon Sandstone Member), Cow Springs Sandstone, and Zuni Sandstone in the southern part. Water moves long distances from the principal recharge areas along the Defiance, Zuni, and Nacimiento Uplifts and the southwestern flank of the San Juan Mountains across the basin to points of discharge along the Rio San Jose, Rio Salado, and the San Juan, Puerco, and Zuni Rivers. Water from the Dakota Sandstone also moves into Sandstones of the Santa Fe Group in the western part of the Rio Grande Trough.

Burro Canyon Formation:

Is present only in the northern part of San Juan Basin and in the Chama Basin. It is mainly between 150 and 250 feet thick, and thins southward and generally is not present about 20 miles south of the San Juan River.

Consists of fine- to medium-grained sandstone and conglomeratic sandstone interbedded with mudstone and a few thin beds of limestone.

Yields small quantities of water to wells mainly in Colorado and to springs mainly in Utah.

Morrison Formation:

Is present throughout the basin and in much of the area to the south. Maximum thicknesses are 850 feet in the northwestern part, to about 600 feet near Chama, Nacimiento Uplift, and Gallup, to 500 feet near Mesa Chivato, and to less than 300 feet in the area south of Gallup and Rio San Jose.

Consists of four members, which in decending order are the Brushy Basin Shale, Westwater Canyon Sandstone, Recapture Shale, and Salt Wash Sandstone Members. The Salt Wash Member is present only in the northern and northwestern parts and the Brushy Basin Member is absent only in the southwestern part of the basin. The Westwater Canyon Member underlies most of the basin. The Recapture Member is absent only along the southwestern margin of the basin. The Jackpile Sandstone Bed (an economically important unit) occurs at the top of the Brushy Basin Member in the southeastern part. The Brushy Basin Member consists of varicolored bentonitic mudstone interbedded with siltstone and some sandstone; the sandstone occurs in lenticular beds and ranges from very fine to coarse grained. The Westwater Canyon Member consists of fine- to coarse-grained, locally arkosic, sandstone interbedded with some mudstone and claystone. Is mined extensively for uranium in the Grants Mineral Belt. This mining requires the sandstone to be dewatered in the vicinity of most of the mines. The Recapture Member consists of interbedded fine- to medium-grained sandstone and reddish-brown siltstone, and mudstone, and Shale Sandstone is more common in the Westwater Canyon and Recapture Members in the southwestern and southern parts. The Salt Wash Member consists of lenticular fine- to medium-grained sandstone interbedded with some mudstone. In the southwestern part, the Westwater Canyon and Recapture Members intertongue with the Cow Springs Sandstone (fig. 6). In the northwestern part, the Bluff and Junction Creek Sandstones are closely associated depositionally with the Morrison Formation.

Forms an aquifer that yields moderate to large quantities of water at most places in the basin. The Westwater Canyon Sandstone Member is the principal water-yielding unit of the Morrison. As much as 3,000 gal/min have to be pumped from uranium mines to keep them dewatered. The mines function as long as wells continuously withdraw water from the Morrison. Some of this water is used in milling uranium ores. Yields of wells tapping the Morrison in combination with the Dakota, Cow Springs, or Zuni Sandstones may be as large as a few hundreds of gallons per minute. Locally, yields of wells completed only in part of the Morrison may be small. Is under artesian pressure, except in the outcrop area. The pressure increases as the aquifer extends northward under younger formations, where most wells completed in the aquifer flow. Near Star Lake, the top of the aquifer is about 4,600 feet below land surface, whereas the potentiometric surface is only 188 feet below land surface. Near Chaco Canyon National Monument, where the top of the aquifer is about 4,500 feet below land surface, the potentiometric surface is nearly 160 feet above land surface. Because of the high head, large drawdowns can occur without locally dewatering the aquifer. Even with a low specific capacity of 0.3 (gal/min)/ft of drawdown, yields of several hundred gallons per minute are obtainable before the water level will drawdown to the top of the aquifer. Few wells obtain water from the Westwater Canyon Member because it is so deep below land surface in most of the basin. Wells supply water to Gallup, Crownpoint, and other small outlying communities. At places, the Westwater Canyon and Salt Wash Members and the sandy part of the Recapture Member form a complex multiple-aquifer system with the Zuni, Cow Springs, Entrada, Bluff, and Junction Creek Sandstones, also with the Dakota Sandstone southwest of the wedge-out of the Brushy Basin Member. Throughout most of the basin the Brushy Basin Member separates the water in the Westwater Canyon Member from that in the Dakota Sandstone. The Brushy Basin Member discharges some water to uranium mines in the southeastern part. In general, water originating in uplands adjoining the southeastern part of the basin moves toward and discharges to the Santa Fe Group in western Rio Grande Trough or to the Rio Salado or Rio San Jose. Water generally moves southwestward across the Gallup Sag and discharges to the Puerco River. Water in the larger remainder of the basin flows northwestward and westward to discharge to the San Juan River mainly in Utah. Locally, some water is discharged to McElmo Creek north of Ute Mountains. Much of the water in the Chama Basin moves generally southward to the Chama River and its principal tributaries.

Zuni Sandstone:

Is present only in the southern margin of the area. Maximum thickness is about 700 feet.

Consists of high cross-bedded fine- to medium-grained sandstone. Zuni Sandstone underlies and intertongues northward with, and in part comprises the lateral equivalents of the Morrison Formation, Cow Springs Sandstone, and Entrada Sandstone.

Existing wells probably yield small amounts of water. Wells, penetrating the entire aquifer probably would yield a few hundred gallons per minute. Small springs issue from the unit in the area south of the Rio San Jose. The Zuni Sandstone is part of a sequence of sandstone that forms a multiple-aquifer system with the Dakota Sandstone, Morrison Formation, Cow Springs Sandstone, and Entrada Sandstone.

Cow Springs Sandstone:

Is present only in the southwestern part of the basin. Thickness gnerally ranges from 100 to 450 feet.

Consists of high cross-stratified, mainly fine-grained, white sandstone. Intertongues with the Morrison and Summerville Formations and is laterally equivalent to part of the Zuni Sandstone.

Yields small to moderate amounts of water mainly in combination with the Morrison Formation. Some of the wells flow at the land surface. This sandstone is part of a multiple-aquifer system that includes the Morrison Formation and other beds of sandstone in the southwestern part of the basin.

Bluff or Junction Creek Sandstones:

Called the Junction Creek Sandstone in southwestern Colorado, and Bluff Sandstone in southeastern Utah and northeastern Arizona.

Is present in northwestern part of the area. Thickness decreases from 300 feet in Colorado to less that 100 feet elsewhere.

Consist of fine- to medium-grained partly cross-stratified sandstone. Intertongues with the Morrison and Summerville Formations.

Yields small amounts of water to wells, particularly in Colorado. It is part of a multiple-aquifer system with the Morrison Formation.

Summerville Formation:

Is present in the western, south-central, and southwestern parts of the area. Thickness is generally between 100 and 200 feet.

Consists mainly of interbedded fine-grained silty sandstone and siltstone. Is mostly sandstone in the Defiance Uplift and at other places in the southeastern part of the basin.

Yields little or no water to wells. Sandstone beds yield water to a few small springs in the Chuska Mountains.

Wanakah Formation:

Is present only in the northern part of the area. Thickness is less than 150 feet.

Consists mainly of shale, limestone, and some gypsum. Includes the Junction Creek Sandstone Member, a lateral equivalent of the Junction Creek Sandstone to the west, at the top and the Pony Express Limestone Member at the base. This limestone is partly a lateral equivalent to the Todilto Limestone.

Water-yielding characteristics of the formation are unknown. Junction Creek Sandstone Member locally may yield some water to wells.

Todilto Limestone:

Is present in the west-central, southern, and eastern parts of San Juan Basin and in Chama Basin. Thickness is as much as 125 feet in the southeastern part of the area.

Consists of limestone and sandy limestone in the western part of the basin and of gypsiferous mudstone, gypsum, and siltstone to silty sandstone in the southeastern part of the basin.

Not known to yield water to wells or springs.

Entrada Sandstone:

Is present throughout the basin but absent south of the basin. Thickness ranges from about 200 to 270 feet.

Consists mainly of fine-grained sandstone, fine-grained silty sandstone, and siltstone. Includes the basal Iyanbito Member in the Gallup-Grants area. Contains more sandstone in the western part of the basin. Sandstone generally predominates the upper part and in the Iyanbito Member. Overlies a widespread erosion surface that truncates the Carmel Formation near Four Corners, the Wingate Sandstone in the

Defiance Uplift, and the Chinle Formation in the southeastern part of the area. Hydrologic data for the Entrada Sandstone, although sparse, indicate that transmissivities toward the center of the basin are higher than those near the outcrops on the edge of the basin. Shomaker and Stone (1976) estimated that the water-bearing characteristics of the sandstone were similar to those of the Westwater Canyon Member of the Morrison Formation. Measured transmissivities near Chaco Canyon National Monument of 100 to 300 ft^2/d near the outcrop areas on the south and west slides of the basin.

Water is under artesian pressure and will rise to near land surface, even though the top of the aquifer is as much as 9,500 feet below land surface near the center of the basin. Recharge occurs mainly in or near outcrop areas either by infiltration or leakage from adjacent aquifers. Most of the water moves toward topographically lower outcrops near Four Corners and the Rio Grande Trough. Much of the water may be discharged to other aquifers or the surface before reaching outcrops in the discharge areas. Because the head is so great in this aquifer, large drawdowns are possible without dewatering the aquifer. Yields of as much as several hundred gallons per minute are obtainable from individual wells completed in the Entrada Sandstone.

Carmel Formation:

Is present only in the northwestern part. Is less than 50 feet thick. Consists of fine-grained sandstone, silty sandstone, and siltstone.

Is not waterbearing in the area.

Navajo Sandstone:

Is present only in the extreme northwestern part, northeast of Four Corners. Is less than 350 feet thick, and thickens to the northwest.

Consists of conspicuously cross-stratified, mainly fine-grained sandstone.

Forms a low to moderately yielding aquifer to the west of San Juan Basin, but yields only small amounts of water in the San Juan hydrologic basin. A few of the wells flow in Utah. Forms a multiple-aquifer system with the Kayenta Formation and Lukachukai Member of the Wingate Sandstone. Water moves generally westward and northwestward from the recharge areas near the Carrizo Mountains.

Kayenta Formation:

Is present only in the extreme northwestern part of the area. Thickness is less than 75 feet.

Consists of sandstone and silty sandstone, generally tightly cemented.

Not known to yield water to wells in the area.

Wingate Sandstone:

Is present in the extreme western and in the northwestern parts of the area. Thickness decreases in all directions from 750 feet near Lukachukai to about 400 feet in Utah and to less than 150 feet in the southern part of the Defiance Uplift.

Consists of the upper Lukachukai Member composed of cross-stratified fine-grained sandstone and the lower Rock Point Member composed of flat-bedded, very fine- fine- to fine-grained silty sandstone to siltstone. Lukachukai Member is 300 to 400 feet thick in the north and thins southward. Rock Point Member has a maximum thickness of 460 feet near Lukachukai.

Lukachukai Member forms a low yielding aquifer principally to the west of the area. It yields water to only a few wells north and west of Teec Nos Pos and to many springs near the Carrizo Mountains. The Rock Point Member yields water to a few small springs in the Chuska Mountains. The Lukachukai Member is recharged in the area near the Carrizo Mountains. Water in the member moves mainly northwestward eventually discharging to the San Juan River to the west of the area. Water that enters the member along the east side of the Carrizo Mountains takes a circuitous path around the eastern and northern flanks of the mountains to reach the place of discharge west of the area.

Chinle Formation:

Is present throughout the area except in the extreme northern part. Thickness decreases northward and northeastward from 1,500 feet in the Zuni Mountains to 1,300 feet near Mesa Chivato and to 1,000 feet at the Four-Corners.

Consists of multi-colored mudstone, claystone, and siltstone that contain many lenticular beds of very fine to medium-grained sandstone and silty sandstone, and a few persistent sandstone beds that extend over large areas. In the southwestern part pebble- to small cobble-conglomerate is present in some of the sandstone beds. The sandstone units include the Correo Sandstone Bed at the top of the Petrified Forest Member in the southeastern part, the Sonsela Sandstone Bed of the Petrified Forest Member in the southwestern part, and the Poleo Sandstone Lentil and Agua Zarca Sandstone Member separated by the Salitral Shale Tongue of the Petrified Forest Member in the eastern part. In the southwestern and western parts of the area the formation consists in descending order of siltstone and thin cherty limestone of the Owl Rock Member; the thick Petrified Forest Member, which forms most of the formation, consists of varicolored mudstone and siltstone and includes the medial Sonsela Sandstone bed and various other channel sandstone beds; the Monitor Butte Member, which consists of interbedded sandstone, mudstone, and sandy siltstone; and the conglomeratic Shinarump Member.

Sonsela Sandstone Bed, Shinarump Member, and at places other sandstone beds in the Monitor Butte and Petrified Forest Members yield generally small amounts of water to wells and springs in the southwestern part of the area and along the lower flanks of the Defiance Uplift. Some of the wells flow at the land surface, particularly at Zuni and between Gallup and Grants. Most wells that withdraw water from the Shinarump Member are also completed in the underlying De Chelly Sandstone. At Zuni, the Sonsela Sandstone Bed was tested at 50 gal/min. In combination, the Chinle Formation and the Moenkopi Formation, where present, form a thick confining layer above the De Chelly Sandstone, San Andres Limestone, and Glorieta Sandstone.

Dolores Formation:

Is present only in Colorado. Thickness is about 400 feet.

Consists of reddish-brown shale, siltstone, sandstone, and limestone-pebble conglomerate. Partly a lateral equivalent of the Chinle Formation.

Not known to yield water to wells.

Moenkopi Formation:

Is present only in the Zuni Mountains and Gallup Sag. Thickness is between 30 and 70 feet in the Zuni Mountains and 150 to 200 feet elsewhere.

Consists mainly of siltstone and fine-grained silty sandstone. Contains some arkosic silt-pebble and sand-pebble conglomerate in the Zuni Mountains.

Not known to yield water to wells or springs.

San Andres Limestone:

Is present in the southern part of the area. Thickens regionally to the east and southeast. Thickness is less than 150 feet in the Zuni Mountains, 125 feet near Grants, and about 350 feet near Mesa Chivato.

Consists of thick-bedded dolomitic limestone in the Zuni Mountains. In the southeastern part of the area consists of an upper dolomitic limestone and a lower sequence of alternating dolomitic limestone, gypsum, and silty sandstone. At places the limestone has been deeply weathered with the formation of small cavities.

Forms a moderately to large yielding aquifer. Yields as much as 2,000 gal/min to some industrial and municipal wells near Grants. Some of the wells previously used for irrigation are now utilized by the uranium industry. Springs issue from the limestone in the Zuni Mountains. Other springs situated along faults near Grants discharge water that originated in the San Andres Limestone and the Glorieta Sandstone. Movement of water is mainly eastward and northeastward from the Zuni Uplift. Much of the water funnels into the Rio Grande Trough between the Nacimiento and Lucero Uplifts.

Glorieta Sandstone:

Is present in the southern part of the area. Thickness is between 250 and 300 feet in the Zuni Mountains, 175 to 200 feet near Grants, and about 200 feet in the Nacimiento Uplift.

Consists of generally cross-stratified fine- to medium-grained sandstone. Is partly equivalent to the De Chelly Sandstone in the Defiance Uplift.

Forms generally a moderately yielding aquifer, yielding generally less than 300 gal/min of water to wells. Springs issue from the sandstone in the Zuni Mountains. Forms a widespread multiple-aquifer system with the San Andres Limestone and De Chelly Sandstone. Some of the wells completed in the Glorieta Sandstone and/or San Andres Limestone flow. Water in the aquifer system moves in all directions outward from the Zuni Uplift; it forms a broad arcuate pattern toward the east and the Rio Grande Trough, and also toward the southwest and toward Arizona. The wedging-out of the Glorieta Sandstone and San Andres Limestone to the north restricts movement of water toward the center of the San Juan Basin.

De Chelly Sandstone:

Is present only in the Defiance Uplift area. Regionally it is broadly lens-shaped; from a thickness of 750 feet in Canyon De Chelly it thins to 200 feet in the southern part of the Defiance Uplift, to 600 feet near Shiprock, and to 100 feet near Four Corners.

Consists of two sandstone members. The upper member is present throughout the Defiance Uplift and is mainly cross-stratified fine- to medium-grained sandstone. This member partly the lateral equivalent of the Glorieta Sandstone. The lower member is present only in the central part of the Defiance Uplift and consists of generally flat-bedded fine- to medium-grained sandstone, silty sandstone, and siltstone.

Upper member forms a low to moderately yielding aquifer; well yields are generally less than 150 gal/min. Well yields are small on the summit of the Defiance Uplift where only a small part of the sandstone is saturated. Most wells along the flanks of the Defiance Uplift withdraw water from the upper member in combination with the overlying Shinarump Member of the Chinle Formation. The lower member yields water to only a few small springs. Water in the De Chelly Sandstone moves in all directions outward from the Defiance Uplift. Water that recharges the unit along the eastern flank of the uplift moves generally southward across the southwestern part of the San Juan Basin and the Gallup Sag to join with westward-moving water in the Glorieta Sandstone. Probably little water moves northeastward from the Defiance Uplift into the northwestern part of the basin owing to a gradual increase in the silt content of the De Chelly and to the long distance to places of discharge along the San Juan River to the west of the basin.

Yeso, Abo, Cutler, and Supai Formations:

Are represented in places throughout the San Juan Basin by a combined thickness generally of more than 1,200 feet.

Consists of a sequence of red beds, mostly interbedded siltstone, silty sandstone, and very fine to medium-grained sandstone.

Yields little or no water to wells. Form a thick confining layer below the De Chelly and Glorieta Sandstones.

Rico Formation:

Is present in the northern part of the area. Thickness is about 450 feet near Four Corners and 350 feet in Colorado.

Consists in Colorado of mudstone, siltstone, arkosic sandstone, and limestone. Limestone and siltstone are more common in the Four Corners area.

Not known to yield water to wells.

Hermosa Formation:

Is present in the northern part of the area. Maximum thickness is 2,500 feet in Colorado. Thins southward and southwestward to about 800 feet near Four Corners.

To the east of Los Pinos River consists of mudstone, siltstone, and arkosic sandstone. West of the river it includes limestone and lesser amounts of sandstone. The amount of limestone increases westward and southward.

Not known to yield water to wells. Springs issue from the unit in Colorado.

Other outcropping stratigraphic units--Madera Limestone, Molas Formation, Arroyo Penasco Formation, Leadville Limestone, Ouray Formation, Elbert Formation, and Ignacio Quartzite--are not described because in most of the basin they are buried below many thousands of feet of younger strata.