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Geology and Availability of Ground Water on the Ute Mountain Indian Reservation, Colorado and New Mexico

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1576-G

Prepared in cooperation with the Ute Mountain Ute Tribe of Indians

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By JAMES H. IRWIN

WATER SUPPLY OF INDIAN RESERVATIONS

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By JAMES H. IRWIN

ABSTRACT

The geology and availability of ground water on the Ute Mountain Indian Reservation were studied to determine the possibility of developing additional water for domestic and stock purposes. The reservation is in the southwest corner of Colorado and a part of northwestern New Mexico; it has an area of about 900 square miles and includes part of Mesa Verde and the laccolithic Ute Mountains. The climate is semiarid, and the average annual precipitation generally ranges from 10 to 15 inches. The streams are tributary to the San Juan River; the Mancos River is the main tributary.

Most of the rocks exposed are of Cretaceous age. The oldest formation exposed is the Navajo Sandstone of Jurassic and Triassic(?) age. Pre-Cretaceous rocks younger than the Navajo are, in ascending order: the Entrada Sandstone, the Summerville Formation, the Junction Creek Sandstone, and the Morrison Formation. The Cretaceous rocks are: the Burro Canyon Formation, the Dakota Sandstone, the Mancos Shale, the Point Lookout Sandstone, the Menefee Formation, the Cliff House Sandstone, the Lewis Shale, the Pictured Cliffs Sandstone, the Fruitland Formation, the Kirtland Shale, the McDermott Formation, and the Ojo Alamo Sandstone. Some of the pediment deposits are of Tertiary(?) and Quaternary age. Quaternary deposits include: alluvium and terrace, pediment, and talus deposits. Laccoliths, sills, and stocks of Cretaceous or Tertiary age intruded into and between sedimentary rocks form the Ute Mountains. The regional dip is away from the mountains.

There had been little development of water resources before the early 1950's. With the establishment of the Ute Mountain Indian rehabilitation program, ground-water studies were started in an attempt to alleviate shortages of domestic and stock water supplies.

The major factors controlling the occurrence and movement of ground water are climate, lithology, structure, and erosion. The principal occurrence of ground water is in the sandstone formations, although surficial deposits are significant aquifers near the Ute Mountains. Shale, the dominant rock type, inhibits or precludes the movement of ground water. Thus, artesian conditions generally prevail in the sandstone beds confined by the shale.

Most of the wells yield water from artesian sandstone aquifers. The major artesian aquifers are the Dakota Sandstone, the Burro Canyon Formation, the Junction Creek Sandstone, and the Entrada Sandstone.

During this investigation, several stock wells were drilled in the western part of the reservation, and three deep public-supply wells were drilled at Towaoc. Stock wells tapped the Dakota Sandstone; the deep wells at Towaoc tapped the Junction Creek, Entrada, and Navajo Sandstones. Pumping tests at Towaoc indicate that yields of as much as 100 gallons per minute are possible from pumping the three wells.

Water from the bedrock aquifers generally is highly mineralized, and most of it contains one or more constituents that exceed limits recommended by the U.S. Public Health Service. Water from alluvial sources in the mountain area is generally of better quality than that from the deeper aquifers. Shallow supplies are unreliable the year round, and it is necessary to depend on water from the deeper aquifers for a continuous supply.

In general, ground water is not available in large quantities. However, adequate stock supplies are available from the Dakota Sandstone in the western part of the reservation. The Mesa Verde and New Mexico areas are not favorable for extensive ground-water development. Springs are an adequate source of water in the mountains. Public supplies for Towaoc are adequate for the present needs (1962).

INTRODUCTION

PURPOSE AND SCOPE OF INVESTIGATION

This investigation was made to determine the water resources of the Ute Mountain Indian Reservation and to aid in the development of additional water supplies for domestic use in the Towaoc area and for stock use throughout the reservation. The investigation was made by the U.S. Geological Survey in cooperation with the Ute Mountain Ute Tribe of Indians, Towaoc, Colo., and with the approval of the U.S. Bureau of Indian Affairs. The project was established by the Ute Mountain Tribal Council as a part of the Ute Mountain Indian Rehabilitation Program.

The location of water supplies and development of the meager supply to serve the Indian population throughout their semiarid lands have long been critical problems. The investigation included a study of the geology and the ground-water resources to ascertain the occurrence of ground water and to insure its proper development.

The investigation was begun in 1955 and was under the direct supervision of Thad G. McLaughlin and Edward A. Moulder, successive district chiefs, Ground Water Branch, U.S. Geological Survey, in charge of ground-water investigations in Colorado. Details of scope and methods of procedure were established in conferences with Messrs. Robert O. Bennett and James F. Cannon, successive Superintendents of the consolidated Ute Agency, U.S. Bureau of Indian Affairs, Ignacio, Colo., and with the Ute Mountain Tribal Council.

LOCATION AND EXTENT OF THE AREA

The Ute Mountain Indian Reservation includes the southwesternmost part of Colorado and a small part of northwestern New Mexico (fig. 1). The southwest corner is coincident with the "Four Corners,"

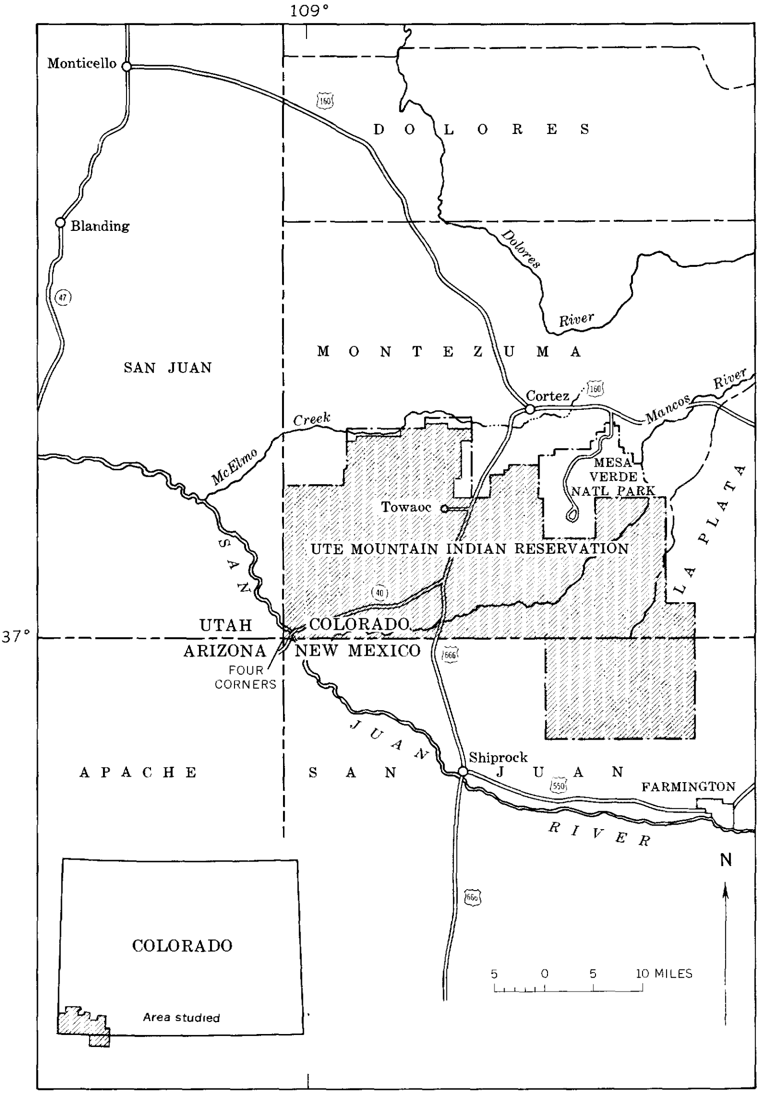

FIGURE 1.—Location of project area.

the only place in the United States where four States (Colorado, New Mexico, Utah, and Arizona) have a common corner. The area, about 900 square miles, includes the southern part of Montezuma and a small part of La Plata Counties, in Colorado, and a part of San Juan County, N. Mex.

PREVIOUS INVESTIGATIONS

The occurrence and the development of the mineral, fuel, and water resources of the Four Corners area, including the Ute Mountain Indian Reservation, have long been of interest to the geologist working in this colorful and scenic region. Until recent years, however, few detailed investigations had been made.

The first ground-water investigation (Waring, 1935) that included the project area was a brief reconnaissance of ground-water supplies in southeastern Utah and southwestern Colorado. Specific studies have been made to obtain public water supplies at Towaoc, Colo., and at the Park headquarters of Mesa Verde National Park just outside the reservation boundary (fig. 1).

In October 1951 a brief reconnaissance was made of the Towaoc area by S. E. Galloway of the U.S. Geological Survey. A more detailed investigation was started in December 1953 by Joseph T. Callahan and completed by William J. Powell in 1954, both members of the U.S. Geological Survey. These investigations were made in cooperation with the Bureau of Indian Affairs. During the 1953–54 investigation, six test holes were drilled in the Towaoc area—five shallow tests in alluvial material and one deep test in sedimentary rocks. Drilling of the deep test hole was stopped at a depth of 960 feet for economic reasons, and the well did not reach its proposed depth. Approximately 25 gpm (gallons per minute) of water was added to the community supply from two of the test wells. Much of the hydrologic data collected by Mr. Powell is included in this report.

Several recent geologic investigations, of the fuel and mineral resources, that include parts of the project area are by: Barnes, Baltz, and Hayes (1954); Hayes and Zapp (1955); Wanek (1954, 1959); Ekren and Houser (1957, 1958, 1959a, b, c, d); and Houser and Ekren (1959a, b). The geologic maps in these reports and additional mapping by the author were used in compiling the geologic map included in this report (pl. 1).

Other recent reports or maps that are concerned with stratigraphic relations and that are important to the understanding of the regional geologic setting were prepared by: Harshbarger, Repenning, and Irwin (1957); Strobell (1956, 1958); Craig and others (1955); Repenning and Irwin (1954a, b); and Irwin, Akers, and Stevens (1954), as well as several of the articles in guidebooks of the Four Corners Geological Society and the Intermountain Association of Petroleum Geologists. Reference to individual articles in these guidebooks is made thoughout the text.

METHODS OF INVESTIGATION

The fieldwork for this report was done in October and November 1955, June to December 1956, and March to December 1957. The writer was assisted in the field in July and August 1956 by William O. Breed and in July and August 1957 by Earl A. Stebbins.

The geology was reviewed in the field, and the parts of the project area where detailed mapping by other members of the Geological Survey had not been completed were mapped by the writer. Field mapping was done on aerial photographs. The base map was prepared by the Topographic Division of the U.S. Geological Survey from Army Map Service maps. Detailed stratigraphic sections were measured in the project area, and outcrops in adjacent areas in Utah, New Mexico, and Arizona were examined. Color terms used to describe rocks are taken from the "Rock-Color Chart" of the National Research Council (Goddard and others, 1948).

Records of the wells and springs were obtained, where possible, from the Bureau of Indian Affairs, Ute Mountain tribal officials, and local drillers. The writer also had access to the published and unpublished geologic and hydrologic data of the Holbrook, Ariz., Salt Lake City, Utah, and Denver, Colo., offices of the Ground Water Branch of the U.S. Geological Survey. Additional information on the geology and hydrology—including electric, gamma-ray, and neutron logs of oil and gas test wells—was examined.

The depths to water were measured in all wells. Samples of water collected from representative wells and springs were analyzed by the Quality of Water Branch of the Geological Survey. Field analyses of water from most wells were made. Additional analyses of water were obtained from the Bureau of Indian Affairs in Gallup, N. Mex., and through Mr. Fred Berry of the Petroleum Research Corp. in Denver.

A water-well-location program was set up early in the investigation to determine the areas most critically in need of water for domestic or stock water supplies. If the geologic conditions were favorable, a test well was drilled, and detailed lithologic logs were prepared from the well cuttings.

Three deep test wells were drilled near Towaoc, and aquifer tests were made at their sites. The tests were made by Edward D. Jenkins, Woodrow W. Wilson, and the writer, all of the U.S. Geological Survey.

ACKNOWLEDGMENTS

The writer thanks the Ute Mountain Tribal Council for the many courtesies extended during the investigation. Special thanks are given Mr. John Kelley, Rehabilitation Director of the tribe during the period of study, Mr. Charles Whitehorn, Resources Director, and many other officials of the tribe for their cooperation. The writer is particularly grateful to E. Bartlett Ekren and Fred N. Houser of the Geological Survey for discussion of the geology in the field and to

Herbert Waite and William Cobban, also of the Geological Survey, for helpful suggestions during visits in the field.

Many officials of the Bureau of Indian Affairs at Ignacio and Towaoc—including Messrs. Lynn Dewey, Falcnor Gifford, Mose Parris, Frank Ferguson, and George Shelhamer—rendered valuable assistance during the drilling program at Towaoc.

Thanks also are given John H. Wesch and Arthur Lawson of the Wesch Drilling Co. for supplying logs of wells and test holes and assistance with the test-drilling program. Other organizations and drillers who graciously supplied records of water wells and oil tests include the Continental Oil Co., the California Co., Honolulu Oil Co., the Rockett Drilling Co., Cowley Brothers Drilling Co., and Vaughey, Vaughey and Blackburn.

GEOGRAPHY

TOPOGRAPHY

The Ute Mountain Indian Reservation is in the southeastern part of the Colorado Plateaus province. In general, the area is characterized by little rainfall, spectacular land forms of rock, and rough terrain. Altitudes range from about 4,500 feet in the San Juan River at Four Corners to 9,977 feet on Ute Peak, a total relief of almost 5,500 feet. The most prominent topographic features are Mesa Verde (fig. 2), which includes most of the eastern part of the reservation, and the laccolithic Ute Mountains, also known as Sleeping Ute Mountain (fig. 3), in the northwestern part.

Mesa Verde is a high, greatly and deeply dissected tableland that at the north side rises about 2,000 feet above a gently southward-sloping plain. The west edge of Mesa Verde rises 800 to 1,000 feet

FIGURE 2.—West face of Mesa Verde looking east from near Towaoc.

above the valley of Navajo Wash. Its surface slopes gently to the south. It ranges in altitude from 6,000 feet in the New Mexico part of the reservation through 8,200 feet at the northern reservation boundary to 8,600 at its north edge a few miles north of the boundary.

The Mancos River and its tributaries have deeply dissected Mesa Verde, leaving many small fingerlike mesas bordered by steep, narrow canyons. In some places headward erosion by streams has reached the north edge of the mesa. These mesas are capped by resistant sandstone ledges that overlie thick sequences of shale. Numerous ruins of ancient cliff dwellings are in the alcoves of the sandstone beds. Mesa Verde National Park, where facilities are provided for the public to view the many interesting ruins, is just north of the Ute Reservation boundaıy on Mesa Verde.

South of Mesa Verde, in the southeast corner of the reservation in New Mexico, the characteristic mesa and butte topography gives way to steeply dipping structural features. Here, the more resistant sandstone beds form ıows of parallel hogbacks with low valleys formed by the less resistant rocks between them. This feature is known as the Hogback.

The Ute Mountains lie west of Mesa Verde and occupy most of the northwestern part of the pıoject area. They are one of several laccolithic mountains in the Colorado Plateaus of Colorado and adjoining States. The Ute Mountains are similar in structure and rock type to the Henry Mountains of southeastern Utah (Ekren and Houser, 1958, p. 74) and are formed by a small group of sills, laccoliths, and stocks intruded into and doming the sedimentary rocks. The highest and most prominent peak is Ute Peak, altitude 9,977 feet.

South of the Ute Mountains is a rough plain cut in soft Cretaceous shale and characterized in general by a barren rolling and irregular surface. The surface is cut by deep gullies that formed rapidly during desert rainstorms. This surface slopes southward from the mountains to the Mancos River, which joins the San Juan River near Four Corners.

FIGURE 3.—Sleeping Ute Mountain (Ute Mountains). To many, the silhouette suggests a reclining Indian.

DRAINAGE

The Ute Mountain Indian Reservation is drained by tributaries of the San Juan River. The river flows a few miles south of the reservation in New Mexico and turns northwestward across the extreme southwest corner (fig. 1) at Four Corners. The Mancos River is the main tributary, entering the area in the northeast corner and flowing to the southwest corner, where it joins the San Juan River just outside the south boundary. The Mancos River and its tributaries, drain all the Colorado part of Mesa Verde, the south half of the Ute Mountains, and areas to the south through Navajo Wash, Spring Creek, and Aztec Wash.

The western part of the area is drained by Cowboy, Mariano, and Marble Washes, which empty directly into the San Juan River to the west.

The north half of the Ute Mountains area is drained by tributaries of McElmo Creek, which flows westward through McElmo Canyon at the reservation boundary north of the Ute Mountains.

The New Mexico and La Plata County, Colo., parts are drained by tributaries flowing southward into the San Juan River.

The discharges of the Mancos River and McElmo Creek are measured at two Geological Survey gaging stations in or near the project area. Records for the water years of 1957 and 1961 are shown in table 1. The station on the Mancos River is 750 feet upstream from the bridge on U.S. Highway 666 about 12 miles south of Towaoc. The average discharge at this station for the past 29 years was 58.8 cfs (cubic feet per second). Maximum recorded flow was 5,300 cfs on October 14, 1941. The stream does not flow at times in most years—particularly during September, October, and November.

TABLE 1.—*Records of discharge of the Mancos River and McElmo Creek from gaging stations in or near the project, 1957 and 1961 water years*

[Discharge, in cubic feet per second. Upper figures, 1957 water year; lower figures, 1961 water year]

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Mancos River	8	39	217	370	1, 062. 4	641. 6
	285. 1	219. 9	141. 5	169. 4	599. 5	1, 320
McElmo Creek	57. 1	419. 3	466. 6	916	1, 303	1, 213
	612. 4	940	673	604	956	1, 026

	Apr.	May	June	July	Aug.	Sept.
Mancos River	1, 880	7, 223	11, 856	3, 725	3, 636. 5	674. 7
	1, 665	652. 2	129. 6	40. 3	471. 5	481. 0
McElmo Creek	2, 037	3, 252	2, 216	4, 088	4, 512	2, 374
	1, 160	1, 707	1, 069	396. 1	731. 8	1, 738

Water is diverted above the station for irrigation of about 100 acres at the Mancos farm, the only land irrigated by surface water in the project area.

The discharge of McElmo Creek is measured at a gaging station 1½ miles east of the Utah State line, a few miles outside the project area. The average discharge at this station for 6 years was 36.2 cfs. Maximum recorded discharge was 1,700 cfs on August 29, 1951, and July 27, 1957. Minimum flows of 0.1 cfs were recorded several days in 1951 and 1957. Water is diverted between the station and the reservation for irrigation of about 1,000 acres of land above the station and 60 acres below it.

CLIMATE

The Ute Mountain Indian Reservation has a semiarid climate. Precipitation ranges from about 8 inches annually in the southwestern part to more than 18 inches on Mesa Verde. Figure 4 shows the distribution of precipitation in the project area and surrounding areas of Colorado. The average annual precipitation at stations in the area ranges from 12.89 inches at Cortez to 18.42 inches at Mesa Verde National Park headquarters. Average monthly precipitation for weather stations at Cortez and Mesa Verde National Park headquarters is shown in table 2. The heaviest precipitation is normally in the late summer from typically sudden violent thundershowers.

Temperatures are relatively moderate. The average monthly temperatures at Cortez and Mesa Verde are shown in table 2. The average annual temperature at Cortez is 48.9° F; the highest mean monthly temperature is 71.3° in July; the lowest is 27.5° in January.

TABLE 2.—*Average monthly precipitation and temperatures at Cortez and Mesa Verde*

	Cortez		Mesa Verde	
	Precipitation (inches)	Temperature (° F)	Precipitation (inches)	Temperature (° F)
January	1. 06	27. 5	1. 93	29. 8
February	1. 10	31. 9	1. 95	33. 0
March	1. 09	38. 5	1. 76	38. 6
April	1. 09	47. 4	1. 32	48. 1
May	. 86	55. 9	1. 05	57. 0
June	. 54	64. 7	. 70	67. 4
July	1. 21	71. 3	1. 68	72. 9
August	1. 51	69. 6	2. 01	70. 8
September	1. 41	62. 2	1. 53	64. 4
October	1. 46	51. 0	1. 66	52. 7
November	. 75	37. 2	. 98	39. 5
December	1. 12	29. 5	1. 71	32. 1
Average annual	13. 20	48. 9	18. 28	50. 5

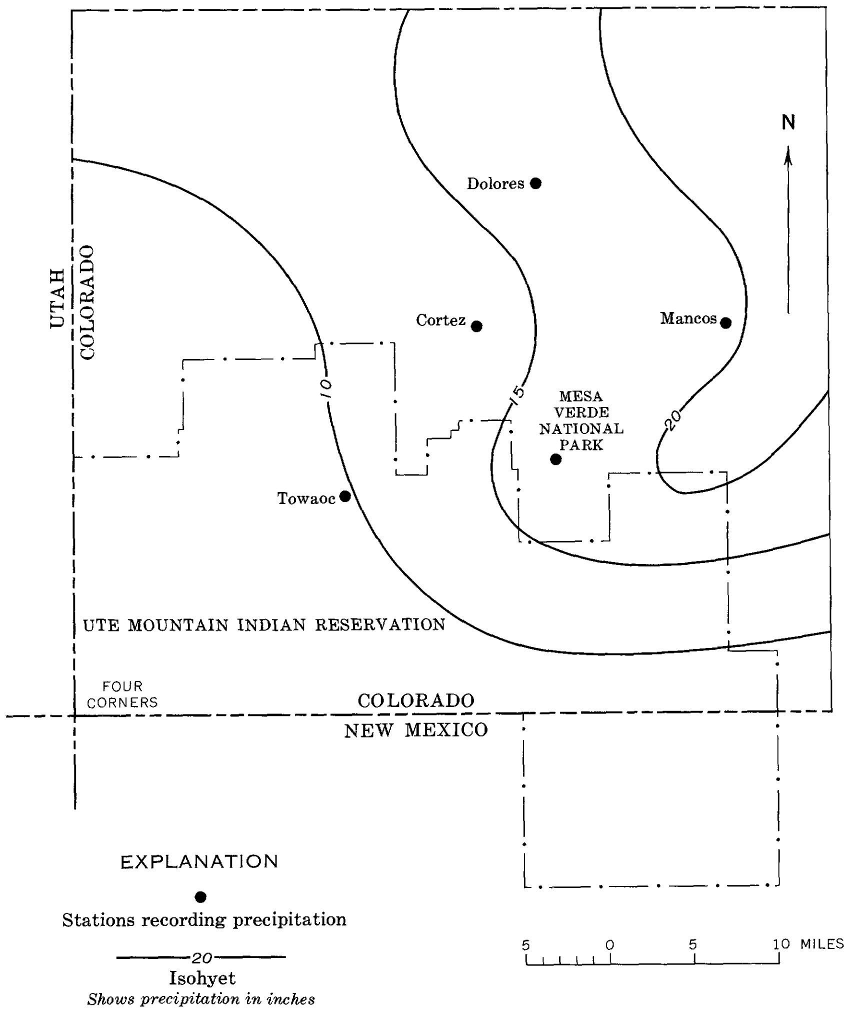

FIGURE 4.—Distribution of average annual precipitation.

Recorded at the Mesa Verde station, the average mean annual temperature is 50.5°; the highest mean monthly temperature is 72.9° in July, and the lowest is 29.8° in January. At Cortez the mean date of the last spring freeze is May 15 (32°, freeze threshold), and the mean date of the first fall freeze is September 29. The lowest temperature recorded in 1961 was −16° on December 12 at Cortez and −4° on December 13 at Mesa Verde National Park headquarters.

Vegetation commonly native to semiarid regions grows in the project area. In the lower altitudes there is a relatively sparse to moderate cover of grass and cactus, sagebrush, and cottonwood. In the higher tableland and the mountains, the vegetation includes piñon and juniper and some piñon and yellow pine.

DEVELOPMENT

The Ute Mountain Indian Reservation is relatively undeveloped. The only settlement is Towaoc, at the foot of the southeastern part of the Ute Mountains (pl. 1). The population of the community is about 650, of which 600 are Ute Mountain Ute Indians. A large percentage of all the Indians now live within a few miles of the town. The tribal headquarters and offices, as well as offices of the Bureau of Indian Affairs, are here. The community also has a school, dormitories, a clinic, a church, a trading post, a cafe and service station, and several houses. Most of the homes that surround the older government compound, approximately 75, have been built in recent years. The community is approximately 13 miles south and west of Cortez, Colo., the county seat of Montezuma County.

The population of the main reservation is a little more than 650, and there are about 200 Indians living in the White Mesa community near Blanding, Utah. All lands are owned by the tribe and are operated as a unit by the tribal council. The Indians are predominantly sheep and cattle ranchers. The only lands under cultivation are a few small vegetable gardens and orchards in the Towaoc area and approximately 100 acres used for raising hay at the Mancos farm.

Much of the reservation is accessible only by poor, unimproved roads. In the Mesa Verde part of the reservation, and in much of the Ute Mountain area, remote areas can be reached only by horse or jeep trails. The area is served by a north-south paved road, U.S. Highway 666, which connects it with Cortez, Colo., to the north and Shiprock and Gallup, N. Mex., to the south. Towaoc may be reached by a paved road from this highway. Several graded roads are maintained by the Bureau of Indian Affairs and the Ute Mountain Tribe.

Colorado State Highway 40, recently completed (1962), connects with U.S. Highway 666 near Chimney Rock. This road gives access to the oil fields, the Four Corners Monument, and other newly paved roads in New Mexico, Arizona, and Utah.

The principal supply center is Cortez (population 6,764, 1960). U.S. Highway 160 connects Cortez with Durango, 45 miles to the east, and Monticello, Utah, 60 miles to the west. Scheduled airline service is available at Cortez. Durango is the nearest rail point, being served by a narrow-gage line of the Denver and Rio Grande-Western Railroad.

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GEOLOGIC FORMATIONS AND THEIR WATER-BEARING PROPERTIES

Most of the rocks that crop out on the reservation are sedimentary, but some are igneous. The igneous rocks are mainly in the mountain area. The exposed sedimentary rocks range in age from Triassic(?) to Quaternary. The areas of outcrop of both types of rocks are shown on plate 1. A brief summary of their physical character and water-bearing properties is given in table 3.

TRIASSIC(?) AND JURASSIC SYSTEMS

GLEN CANYON GROUP

The Glen Canyon Group was named after Glen Canyon of the Colorado River in Kane County, southeastern Utah, where the formations comprising the group are typically exposed. The term was first applied by Gilluly, Reeside, Gregory, and Moore to rocks having a similar lithologic character and areal extent. The first published reference to the name was in a report by Baker, Dobbin, McKnight, and Reeside (1927) and included the Wingate Sandstone (Dutton, 1885), the Todilto Formation (Gregory, 1917), and the Navajo Sandstone (Gregory, 1917). The type Todilto Formation was determined to be younger than the Todilto of the Glen Canyon area, and the name Kayenta Formation (Baker and others, 1931) was introduced to replace what was first considered to be a sandstone facies of the Todilto Formation. The Glen Canyon Group is considered to be both Triassic(?) and Jurassic (Harshbarger and others, 1957; Lewis and others, 1961).

The Navajo Sandstone is the only formation of the group exposed. The Kayenta Formation is present in the subsurface throughout at least the western part of the reservation; it probably pinches out within the project area. The Wingate Sandstone is present in the subsurface throughout the reservation.

NAVAJO SANDSTONE

GENERAL CHARACTER

The Navajo Sandstone, the oldest formation exposed, crops out along the south flank of McElmo dome in McElmo Canyon, just above the north boundary, and in sec. 31, T. 36 N., R. 17 W. (fig. 5). The Navajo Sandstone was named by Gregory (1917, p. 57–59), and the type locality is given as the Navajo country in general, where it is one of the most conspicuous formations. It is recognized over a large part of the Colorado Plateaus and is an important aquifer in many places.

Throughout the McElmo Canyon exposure, the Navajo Sandstone ranges from grayish orange pink (10*R* 8/2) to moderate reddish orange (10*R* 6/6). (For rock color terms, see Goddard and others,

FIGURE 5.—Navajo Sandstone (Jn) in McElmo Canyon. The lower silty unit of the Entrada Sandstone forms the bench above the Navajo. The upper sandstone unit of the Entrada is above the bench. The distant slope is the Summerville Formation, the Junction Creek Sandstone, and the Morrison Formation.

1948.) It is composed of fine-grained subrounded to subangular clear quartz and in most places is bonded with a weak calcareous cement. The lithologic characteristics are fairly consistent throughout. Crossbedding is one of the most characteristic features of the Navajo, particularly in the upper part. The crossbeds occur between horizontal partings on a medium to large scale. The crossbedding is not as distinct and conspicuous in the McElmo Canyon area as it is in the Navajo country in Arizona and Utah, where the large-scale high-angle crossbedding, etched by erosion, is spectacularly exhibited in a considerable outcrop area. The Navajo weathers into rough rounded surfaces, which are commonly pitted, and usually forms cliffs. The outcrop is nearly devoid of soil and vegetation.

The base of the Navajo Sandstone is not exposed in the McElmo Canyon area; so, the total thickness is not known. According to Ekren and Houser (1958, p. 74), the Navajo is about 300 feet thick at Sand Creek, a tributary of McElmo Creek. At Towaoc, 180 feet of Navajo was tapped in water well B–19, drilled in 1957. The Navajo thickens west of the Ute Mountain area and reaches a maximum known thickness of 1,800 feet at Zion National Park in Utah. It probably wedges out in or near Mesa Verde National Park. This thinning is considered to be mainly a depositional phenomenon. A water well drilled at the park headquarters did not penetrate a recognizable section of Navajo. Strobell (1956) indicated a thinning

TABLE 3.—*Generalized section of the geologic formations in the Ute Mountain Indian Reservation*

System	Series	Group	Formation	Member	Thickness (feet)	Physical character	Water supply
Quaternary	Recent and Pleistocene		Alluvium		0–80	Clay, silt, sand, pebbles, and cobbles. The pebbles and cobbles are igneous fragments derived from the intrusive rocks of the Ute Mountains. These deposits occur along major tributaries and include a few low terrace deposits.	Yields small (usually less than 10 gpm) amounts of water to wells.
			Talus deposits			Predominantly igneous pebbles, cobbles, and boulders. Contains some large porphyry blocks up to 10 ft in diameter.	Yields small to large (100 gpm) quantities of water to springs at the base of these deposits.
Quaternary / Tertiary(?)	Recent and Pleistocene		Pediment deposits		1–40	Predominantly pebbles, cobbles, and boulders of igneous origin. In many places the unit is mantled with several feet of windblown silt and very fine sand.	Yields little or no water to wells.
Tertiary and Tertiary or Cretaceous			Igneous rocks			Laccoliths, sills, dikes, and stocks intruded into sedimentary rocks forming the Ute Mountains. Series of porphyries ranging from microgabbro through quartz monzonites.	Yields no water to wells.
Cretaceous	Upper Cretaceous		Ojo Alamo Sandstone and McDermott Formation		0–40	Grayish-brown shale interbedded with soft yellowish-gray sandstone.	Same as unit above.
Cretaceous	Upper Cretaceous		Kirtland Shale		1,160	Olive-gray and yellowish-gray shale and yellowish-gray fine- to coarse-grained sandstone. Lenses of sandstone (Farmington Sandstone Member) 330 ft thick in the middle of the formation. Local thin coal beds near the base.	Sandstone units may yield very small quantities of water to stock wells.
Cretaceous	Upper Cretaceous		Fruitland Formation		250	Shale, brownish-gray sandstone, and coal.	Yields little or no water to wells.
Cretaceous	Upper Cretaceous		Pictured Cliffs Sandstone		230–290	Light-yellow to light-gray very fine- to fine-grained sandstone interbedded with gray shale.	May yield small quantities of water to stock wells.
Cretaceous	Upper Cretaceous		Lewis Shale		735–1,400	Dark-gray to greenish-gray shale and some fine-grained sandstone. Contains thin yellow concretionary layers.	Yields no water to wells.
Cretaceous	Upper Cretaceous	Mesaverde Group	Cliff House Sandstone		400±	Yellowish-orange massive cliff-forming fine-grained sandstone and some shaly sandstone beds.	May yield small quantities of water to stock and domestic wells.
Cretaceous	Upper Cretaceous	Mesaverde Group	Menefee Formation		500–800	Gray to grayish-orange fine- to medium-grained crossbedded sandstone and gray to black carbonaceous shale and coal beds.	Sandstone may yield very small quantities of water to stock wells.
Cretaceous	Upper Cretaceous	Mesaverde Group	Point Lookout Sandstone		300–450	Yellowish-orange to white massive cliff-forming fine-grained sandstone. Lower parts contain interbedded thin sandstone and sandy mudstone.	May yield small quantities of water to stock wells, where the formation is not drained.

			Mancos Shale		1,900–1,975	Gray to dark-gray shale and thin beds of grayish-brown sandy limestone and limestone concretions.	Yields no water to wells except near the Ute Mountains; the limestone interval of Greenhorn age and Juana Lopez Member locally may yield small quantities of water of poor quality.
			Dakota Sandstone		100–160	Light-gray to yellowish-gray fine- to medium-grained sandstone interbedded with carbonaceous shale and some thin coal beds.	Yields small to moderate quantities of water to stock and domestic wells throughout the project area. Principal aquifer of the area.
	Lower Cretaceous		Burro Canyon Formation		0–200	Light-gray to white sandstone and conglomeratic sandstone interbedded with grayish-green and some grayish-red mudstone.	Yields small to moderate quantities of water to wells where unit is present.
Jurassic	Upper Jurassic		Morrison Formation	Brushy Basin Shale Member	150–300	Pinkish-gray to light-greenish-gray (varicolored) bentonitic mudstone interbedded with siltstone and light-greenish-gray to yellowish-gray very fine- to fine-grained sandstone.	Yields little or no water to wells.
				Westwater Canyon Sandstone Member	50–200	Yellowish-gray to greenish-yellow fine- to coarse-grained sandstone interbedded with green and red bentonitic mudstone.	Same as unit above.
				Recapture Shale Member	0–200	Interbedded grayish-pink fine- to medium-grained sandstone and reddish-brown siltstone and mudstone.	Same as unit above.
				Salt Wash Sandstone Member	0–250	Light-greenish-gray to grayish-pink lenticular fine- to medium-grained sandstone interbedded with dusky-red and light-greenish-gray mudstone.	Yields small quantities of water to wells.
		San Rafael Group	Junction Creek Sandstone		230–300	Pale-red to light-brownish-gray fine- to medium-grained sandstone. Bedding ranges from indistinct flat beds to high-angle crossbedding.	Yields small to moderate quantities of water to stock and domestic wells. A major aquifer in the Towaoc-Ute Mountains area. Yields moderate quantities of water of poor quality in the southwestern part of area.
			Summerville Formation		125–150	Reddish-brown silty fine-grained sandstone and pale-red to moderate-brown siltstone.	Yields no water to wells.
			Entrada Sandstone	Upper sandstone member	70–80	Grayish-orange-pink to moderate reddish-orange fine-grained sandstone that forms a characteristic "slick rim" cliff.	Yields small quantities of water to stock and domestic wells.
				Lower silty member	10–20	Pale-reddish-brown to grayish-red very fine-grained silty sandstone and siltstone.	Yields no water to wells.
Triassic(?)		Glen Canyon Group	Navajo Sandstone		0–300	Grayish-orange-pink to reddish-orange fine-grained crossbedded sandstone.	Yields small quantities of water to stock and domestic wells.

eastward and southward—from 200 feet to 0—in the Carrizo Mountain area a few miles southwest of the reservation. Figure 6 shows the approximate limit of the Navajo Sandstone and the Kayenta Formation.

The age of the Navajo Sandstone on the Colorado Plateaus is considered to be Late Triassic(?) and Jurassic by Lewis, Irwin, and Wilson (1961, p. 1439).

WATER SUPPLY

The Navajo Sandstone contributes small amounts of water to the three deep public-supply wells in the Towaoc area. Although the Navajo is a major aquifer on the Navajo Indian Reservation, it is near or at its depositional limit in the project area, and yields are much less than those obtained in parts of the Navajo country. The Navajo is overlain by three major aquifers, and an adequate water supply can generally be obtained without tapping it.

JURASSIC SYSTEM

SAN RAFAEL GROUP

The San Rafael Group was named by Gilluly and Reeside (1928, p. 73), and the type area is in the San Rafael Swell of southeastern Utah. At the type area the group consists of the Carmel Formation, the Entrada Sandstone, the Curtis Formation, and the Summerville Formation. The Junction Creek Sandstone and its equivalent, the Bluff Sandstone, also are now considered to be part of the San Rafael Group in the Four Corners and San Juan Mountain regions (Craig and others, 1955, p. 133, 134). The Todilto Limestone in the Navajo country also is considered by Harshbarger, Repenning, and Irwin (1957, p. 38) to be a part of the San Rafael Group.

In the project area the San Rafael Group is represented by the Entrada Sandstone, the Summerville Formation, and the Junction Creek Sandstone, although the Todilto Limestone may be present in the subsurface in the eastern part. In the San Juan Mountain area, beds equivalent to the Summerville Formation are included in the Wanakah Formation.

ENTRADA SANDSTONE

GENERAL CHARACTER

The Entrada Sandstone was named and described by Gilluly and Reeside (1928, p. 76) for exposures on Entrada Point in the San Rafael Swell, Utah. It is exposed in a small area in the northern part of the reservation (pl. 1) and in the canyons of McElmo Creek and its tributaries (fig. 5). The Entrada is in the subsurface throughout the rest of the reservation. It unconformably overlies the Navajo Sandstone.

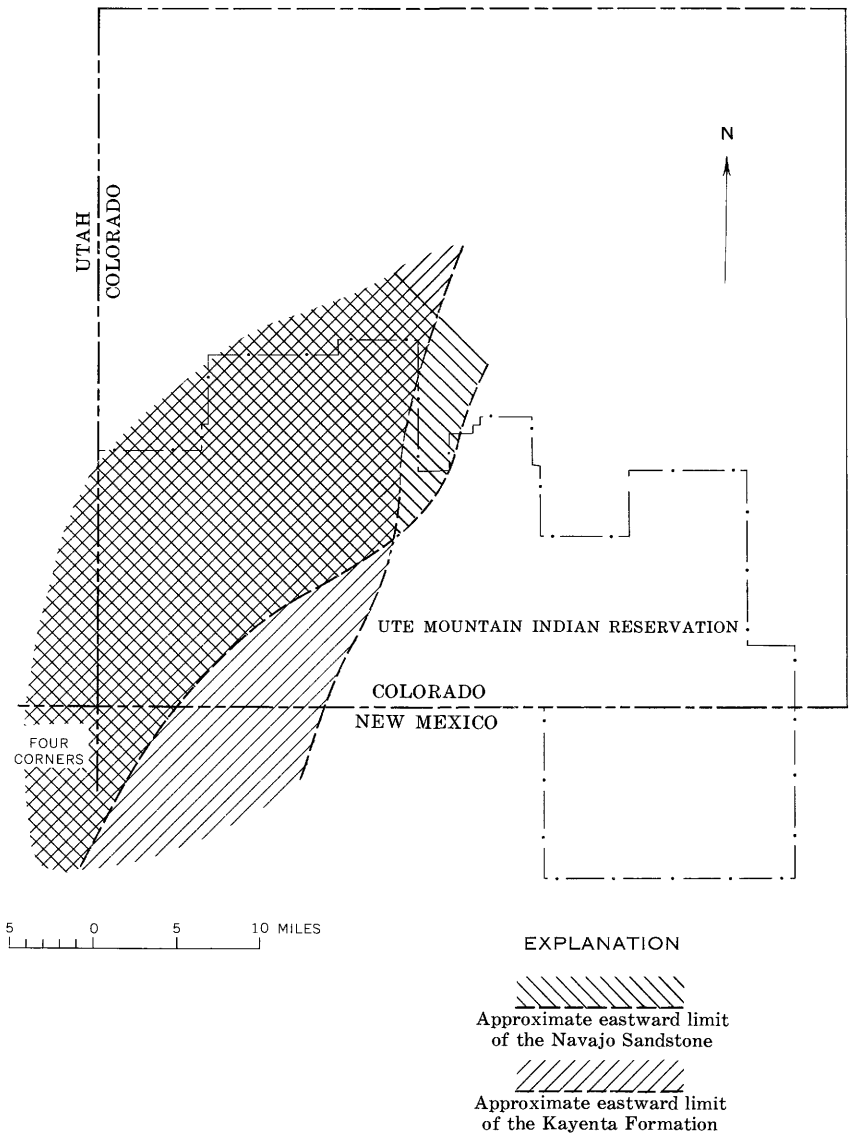

FIGURE 6.—Approximate limit of the Navajo Sandstone and the Kayenta Formation in the Ute Mountain Reservation area.

In the Ute Mountain area, the Entrada Sandstone consists of two units, a lower silty unit and an upper sandstone unit. The lower unit is a very silty pale-reddish-brown (10*R* 5/4) to grayish-red (10*R* 4/2) to moderate-reddish-brown (10*R* 4/6) very fine grained quartz sandstone. It weathers into characteristic rounded forms, commonly called hoodoos, and in places it forms a soft bench between the more massive cliffs of the underlying Navajo Sandstone and the upper sandstone member of the Entrada. This lower unit is correlative with the medial silty member of the Entrada of Harshbarger, Repenning, and Irwin (1957, p. 35–38) in the Navajo country. The lower unit is similar to the red silty facies of the Carmel Formation and has been considered to be the Carmel by some geologists in the area. In this report the unit will be treated as the medial silty member of the Entrada Sandstone.

The medial silty member is about 20 feet thick in the McElmo Canyon area. Three water wells near Towaoc penetrate from 10 to 20 feet of a silty sandstone, which is considered by the writer to be the medial silty member of the Entrada. The member may not be present everywhere in the subsurface in the area.

The upper sandstone unit of the Entrada ranges from white to grayish orange pink (10*R* 8/2) to moderate reddish orange (10*R* 6/6). It is composed of very fine to fine grains, and some subrounded to subangular medium grains, of clear quartz. The unit is highly crossbedded, ranging from small to medium scale, but some beds exhibit horizontal bedding planes. The Entrada weathers to form a prominent characteristic "slick rock" rounded cliff.

According to Ekren and Houser (1958, p. 74), the upper unit of the Entrada is 70 to 80 feet thick in the McElmo Canyon area. The upper sandstone member of the Entrada, determined from cuttings from a well drilled at Towaoc, is approximately 80 feet thick.

No fossils are known from the Entrada other than dinosaur footprints near Moab, Utah. At the type locality, the Entrada is considered to be Late Jurassic from its position between the Middle and Upper Jurassic Carmel Formation and Upper Jurassic Curtis Formation (Gilluly and Reeside, 1928, p. 78).

Wright, Shawe, and Lohman (1962, p. 2057) designated member names for the Entrada in east-central Utah and west-central Colorado. The names Moab Member and Moab Tongue are retained for the upper member; the Moab is called a member in and east of Arches National Monument and is called a tongue west of this point (Lohman, 1965). The middle unit is named the Slick Rock Member, and the lower unit, the Dewey Bridge Member. The upper sandy member and the medial silty member of this report and that of Harshbarger, Repenning, and Irwin (1957) are correlative with the Slick Rock Member and Dewey Bridge Member, respectively.

WATER SUPPLY

The upper sandstone member of the Entrada Sandstone will yield only small (less than 10 gpm) amounts of water to wells because it is fine grained. Development of supplies from the zone should be attempted in places where supplies are needed in addition to those obtainable from the overlying Dakota and Junction Creek Sandstones.

The medial silty member of the Entrada is relatively impermeable and acts as a confining bed. Where the medial silty member is not present, the upper sandy member rests on the Navajo Sandstone, or older rocks where the Navajo has pinched out. Here, the upper sandstone member and the Navajo will act as one aquifer.

The quality of water from the Entrada is not known. In the Towaoc area, the Entrada contributes water to a multiple aquifer system in wells supplying domestic water, and the water is considered to be of acceptable quality for domestic use, at least where mixed with water from the overlying aquifer.

SUMMERVILLE FORMATION

GENERAL CHARACTER

The Summerville Formation conformably overlies the Entrada Sandstone. The Summerville Formation was named for exposures on Summerville Point in the northern part of the San Rafael Swell, Utah, by Gilluly and Reeside (1928, p. 80). The Summerville is exposed only near the northern reservation boundary, where McElmo Creek cuts through the southern part of McElmo Dome.

In general, the unit consists of a sequence of grayish-orange-pink (5*YR* 7/2) to reddish-brown silty sandstone interbedded with grayish-red (5*R* 4/2), pale-red (5*R* 6/2), and moderate-brown (5*YR* 3/4) siltstone or mudstone. The sandstone units are composed of very silty, very fine to fine-grained subrounded clear and frosted quartz. The sorting is usually fair but some is poor. The usually thin-bedded siltstone units are horizontally laminated and commonly are crinkly or wavy. Bedding ranges from a few inches in the siltstone and mudstone to 3 or 4 feet in the sandstone beds. In the McElmo Canyon area the unit becomes more sandy toward the top, and a sandstone bed near the top is 20 feet thick (Ekren and Houser, 1958, p. 74). Here the thick bed forms a prominent ledge, but in other places the formation generally forms a moderate slope with thin sandstone ledges.

The Summerville Formation is approximately 140 feet thick in McElmo Canyon. The thickness penetrated by wells in the Towaoc area ranges from 130 to 150 feet. The Summerville seems to maintain a fairly consistent thickness throughout the reservation. The unit is 148 feet thick at Red Mesa, 20 miles west of Four Corners, and is 126 feet thick at Beclabito Dome, 12 miles south of Four Corners (Strobell, 1956).

The Summerville Formation is considered to be of Late Jurassic age because of its relation with the Late Jurassic Curtis Formation at the type locality. No fossils have been reported from the Summerville. It has been recognized in the project area by many geologists and here has a lithology similar to that of the lower silty member of the Summerville of Harshbarger, Repenning, and Irwin (1957, p. 39–41). South and southwest of the Ute Mountain area in New Mexico and Arizona, the Summerville grades to sandstone. In the southwestern San Juan Mountains region, the rocks considered to be equivalent to the Summerville are called the uppermost member of the Wanakah Formation (Goldman and Spencer, 1941, p. 1759; Imlay, 1952; McKee and others, 1956). In older reports (Coffin, 1921) the Summerville was included in the McElmo Formation.

WATER SUPPLY

The Summerville Formation is not an aquifer. It overlies the Entrada and retards or prevents infiltration of water into the Entrada and acts as a confining layer; hence, water in the Entrada is under artesian pressure.

JUNCTION CREEK SANDSTONE

GENERAL CHARACTER

Overlying the Summerville Formation is a conspicuous sandstone unit called the Junction Creek Sandstone. This is the prominent sandstone unit at the top of the Summerville Formation in the Four Corners area. In Utah this prominent sandstone was named the Bluff Sandstone Member of the Morrison Formation by Gregory (1938, p. 58). Later, geologists, noting intertonguing with the underlying Summerville as well as with the overlying Morrison, treated the Bluff as a separate formation. In southwestern Colorado this unit was defined as the Junction Creek Sandstone Member of the Morrison Formation (Goldman and Spencer, 1941, p. 1750–1751). The Junction Creek in southwestern Colorado is now treated as a separate formation (Eckel and others, 1949, p. 20; Craig and others, 1955, p. 133). The Junction Creek directly correlates with the Bluff Sandstone of Utah and Arizona, but, because the exposures of the Ute Mountain area are in Colorado, the southwestern Colorado nomenclature of Junction Creek Sandstone is used in this report.

The Junction Creek Sandstone is typically exposed opposite Animas City Mountain between Junction Creek and the Animas River north of Durango. It is exposed in McElmo Canyon (fig. 7) and in one small outcrop just south of Sentinel Peak (pl. 1).

The Junction Creek Sandstone in McElmo Canyon ranges from white to pale red (10*R* 6/2) through grayish orange pink (10*R* 8/2) to light brownish gray (5*YR* 6/1). It is composed of fine- to medium-grained poorly sorted subrounded to rounded clear and frosted quartz

FIGURE 7.—Junction Creek Sandstone (J_j) overlain by the Morrison Formation (Jm) near McElmo Creek.

with common light-red, pink, green, and black accessory minerals. Medium to coarse quartz grains are concentrated along the boundary surfaces of the bedding planes (particularly in the crossbedded units) and are disseminated throughout the finer grained material.

The Junction Creek is highly crossbedded, but horizontal bedding is common. The crossbedding is the wedge type and ranges from high to low angle and from medium to large scale. According to Ekren and Houser (1958, p. 74), the formation in McElmo Canyon consists of three vertically gradational units, as follows: "The lower unit (30–60 feet thick) is marked by abundant horizontal bedding planes and low-angle cross-stratification; the middle unit (150–200 feet thick) is cross-stratified at high angles with very few horizontal bedding planes, and the upper unit is a flatbedded argillaceous sandstone that weathers to hoodoos." Where it crops out, it forms a prominent rounded cliff.

The Junction Creek is probably in the subsurface throughout the project area. Reliable subsurface data on its presence in the eastern part, however, are not available. Here, the Junction Creek, if present, would be at depths greater than 2,000 feet.

The thickness of the Junction Creek in the McElmo Canyon area ranges from 230 to 300 feet. Its thickness differs widely, owing to channeling of the formation before Morrison deposition. In the water wells at Towaoc, 230 to 260 feet of the unit was penetrated. It thins abruptly to the south, and, at Beclabito, N. Mex., its direct correlative, the Bluff Sandstone, is 30 feet thick. South of Beclabito, the Bluff grades into the Summerville Formation. The Junction Creek also thins southwestward, where, at Mexican Water, its equivalent, the Bluff, is 47 feet thick (Harshbarger, Repenning, and Irwin, 1957, p. 43). At the type locality of the Bluff Sandstone at Bluff, Utah, the Bluff ranges in thickness from 200 to 350 feet (Gregory, 1938, p. 58).

The Junction Creek is of Late Jurassic age on the basis of its stratigraphic position. The Junction Creek and the Bluff Sandstones have been assigned to the San Rafael Group. Harshbarger, Repenning, and Irwin (1957, p. 42) considered the Bluff to be a tongue of the Cow Springs Sandstone in the Navajo country. Southward from the Four Corners area, the Bluff Sandstone, as well as a large part of the Morrison Formation, grades into the Cow Springs Sandstone.

WATER SUPPLY

Yields of wells tapping the Junction Creek are generally small and the quality of the water is only fair to poor. The unit yields small to moderate quantities of water for domestic and stock use to a few wells in the west half of the project area. It lies at depths ranging from 900 to 2,000 feet below the land surface here, and water can generally be obtained more easily from the overlying Dakota Sandstone. In the Mesa Verde area and the New Mexico part of the reservation, the formation lies at depths greater than 2,000 feet, and no water wells have penetrated it.

Water in the Junction Creek is under artesian pressure except on the outcrop along McElmo Creek and perhaps in the mountains. Water is under sufficient pressure in two wells (B–11, and B–12, pl. 1) to flow at the surface in a structural low. Because only a few water wells penetrate the Junction Creek, data are not sufficient to delineate areas where flowing artesian wells could be developed, but geologic conditions indicate that wells penetrating the formation in the vicinity of the structural and topographic low near Four Corners should flow.

At Towaoc each of three public-supply wells, yielding from 25 to 60 gpm, tap three sandstones—the Junction Creek, Entrada, and Navajo. The Junction Creek probably supplies half these yields.

Three other wells tap or have tapped the Junction Creek. Stock well B–9 in sec. 23, T. 35 N., R. 19 W. (pl. 1) yields approximately 20 gpm. The California Co. well B–12 (pl. 1) flowed 9 gpm before caving. The largest known yield from the Junction Creek was from the Continental Oil Co. test hole B–11 (pl. 1). The casing was perforated opposite a zone at a depth of 1,240 to 1,260 feet. The well flowed approximately 200 gpm, the water rising 50 feet above the land surface. At present (1963), water from the well is used for stock and drilling. Unfortunately, the high mineral content of the water (5,100 parts per million dissolved solids) prohibits its use for domestic supplies. It is possible that highly mineralized water under artesian pressure from formations underlying the Junction Creek may have broken into this well from below and contaminated the Junction Creek water. Water from the Junction Creek at Towaoc, nearer the recharge area, is of better quality and is used for domestic purposes.

MORRISON FORMATION

GENERAL CHARACTER

The Morrison Formation was named by Emmons, Cross, and Eldridge (1896, p. 60) for the exposures near Morrison, Colo., but the name first appeared in print 2 years earlier (Cross, 1894, p. 2). The formation now has been recognized over most of the western interior of the United States and has been the subject of numerous papers. The beds that now make up the Morrison Formation in the McElmo Canyon area were originally assigned to the McElmo Formation by Coffin (1921).

Throughout the Colorado Plateaus the formation has been separated into members on the basis of lithologic similarity. Four members are recognized and are, in ascending order: the Salt Wash Sandstone Member, the Recapture Shale Member, the Westwater Canyon Sandstone Member, and the Brushy Basin Shale Member. For a detailed discussion of the stratigraphy of the Morrison and related formations of the Colorado Plateaus, see the paper by Craig and others (1955).

The Morrison crops out in McElmo Canyon, around the Ute Mountains, in the canyon of the San Juan River at Four Corners, and in places along the Utah State line (pl. 1).

The Morrison Formation seems to overlie the Junction Creek Sandstone conformably in the project area; however, fluvial channeling occurs locally at the contact. Craig and Cadigan (1958, p. 185) considered the contact of the Morrison and the Junction Creek as "characteristically a conspicuous erosion surface suggesting a disconformity between the Morrison formation and the Bluff and Junction Creek sandstones." They noted that where mudstone of the Morrison rests on structureless silty sandstone of the Junction Creek, the sequence appears conformable and in places gradational.

The placement of the upper contact of the unit with the Burro Canyon Formation of Early Cretaceous age is arbitrary, and a break in sedimentation is not noted between the two units. The boundary between the Jurassic and Cretaceous sedimentary rocks is discussed on page G26.

Abundant fossil remains, indicating a Late Jurassic age, have been found in the Morrison in many places.

The Salt Wash Sandstone Member of the Morrison consists of interbedded sandstone and mudstone in the project area. The sandstone units consist of light-greenish-gray (5*GY* 8/1), pinkish-gray (5*YR* 8/1), and yellowish-gray (5*Y* 8/1) lenticular sandstone that commonly contains thin clay stringers. The thickness of the sandstone beds may range from a few feet to 20 feet. In general, the sandstone units are composed of fine- to medium-grained fairly well sorted clear quartz and commonly contain quartz pebbles and green accessory minerals. The mudstone units are predominantly very dusky red (10*R* 2/2) and greenish gray (5*G* 6/1). A few thin beds of gray platey limestone have been noted.

The sandstone is generally crossbedded with small-scale low-angle crossbeds of fluvial origin. The crossbedded units commonly have a channel scour surface at their base. The sandstone units form small ledges between the less resistant mudstone units and, where exposed in McElmo Canyon, form an irregular benchlike steep slope above the more massive vertical cliff of the Junction Creek Sandstone.

The thickness of the Salt Wash differs greatly in the project area, owing to intertonguing and gradation with adjacent units. In the McElmo Canyon area the Salt Wash is 100 to 250 feet thick. In the central part of the Carrizo Mountain area, the unit is 180 to 200 feet thick (Strobell, 1956), and farther south near Toadlena, N. Mex., it can no longer be recognized (Harshbarger and others, 1957, pl. 3).

In at least one outcrop just south of the east toe of the Ute Mountains, the Salt Wash is not present (Ekren and Houser, 1965, p. 14) and the Recapture Member lies directly on the Junction Creek Sandstone. The Salt Wash also is missing 20 miles west of the Ute reservation, and the Recapture Member lies directly on the Bluff Sandstone (Junction Creek Sandstone in Colorado).

The Recapture Shale Member of the Morrison Formation intertongues with and grades into the Salt Wash, and the unit is not everywhere recognizable in the northern part of the reservation. Ekren and Houser (1958, p. 75) reported that it is absent in eastern McElmo Canyon.

The Westwater Canyon intertongues with and grades into the Brushy Basin Member. It is thin in the northern part and is probably not recognizable a short distance north of McElmo Creek.

Where the members can be distinguished, the Recapture Member is typically composed of interbedded sandstone, siltstone, and shaly mudstone. The sandstone is grayish pink (5*R* 8/2) and consists of fine- to medium-grained quartz. The siltstone and mudstone beds are dark reddish brown (10*R* 3/4) and are lenticularly bedded. The member characteristically weathers to a soft steep slope. The Westwater Canyon Member is typically yellowish gray (5*Y* 8/1) to moderate-greenish-yellow (10*Y* 7/4) fine- to coarse-grained sandstone interbedded with green and red bentonitic mudstone.

The Recapture is 0 to 75 feet thick, and the Westwater Canyon is 50 to 125 feet thick in McElmo Canyon. The Recapture and Westwater Canyon Members thicken abruptly south of the McElmo area, and each is about 200 feet thick in the southwestern part of the project area. Strobell (1956) reported 220 feet of Recapture and 150 feet of Westwater Canyon at Beclabito Dome in the Carrizo Mountain area.

The Brushy Basin Shale Member consists of variegated mudstone containing considerable amounts of bentonitic clay interbedded with siltstone and siliceous sandstone. The mudstone and siltstone units are predominately pinkish gray (5*YR* 8/1) to light greenish gray (5*G* 8/1). The bentonitic clay is probably derived from volcanic material and causes the mudstone to weather to a characteristic frothy surface. Ekren and Houser (1959a, p. 192) noted that the "distinctive frothy appearance is a result of swelling and subsequent drying of the contained bentonite. Swelling muds are not present in the lower members of the Morrison or in the Burro Canyon formation."

The sandstone units are white, yellowish gray (5*Y* 8/1), and light greenish gray (5*G* 8/1) and are composed of very fine to fine-grained subrounded to rounded clear and frosted quartz. Ekren and Houser (1959a, p. 192) reported one 20-foot crossbedded conglomeratic sandstone, although conglomerate and conglomeratic sandstone are not common. Where the member is capped by more resistant Burro Canyon and Dakota Formations, it weathers to a steep multicolored slope with small ledges of sandstone.

The Brushy Basin Member ranges in thickness from 150 to 300 feet in the Ute Mountain area. Craig and others (1955, p. 156) said that as much as 450 feet of Brushy Basin has been measured in southwestern Colorado, where the member differs considerably in thickness. The member is 156 feet thick just south of the project area in the Carrizo Mountains (Harshbarger and others, 1957, p. 55).

WATER SUPPLY

Only a few drilled wells have tested the Morrison Formation, and little data are available regarding potential water supplies from the formation. The Westwater Canyon Sandstone Member and the Salt Wash Sandstone Member of the Morrison may yield small quantities of water to wells. However, the members are not major aquifers because of their lenticularity, poor sorting, and differing thickness.

A well drilled at Towaoc in 1954 (well B–16, pl. 1), ending in the basal sandstone units of the Morrison (considered to be the Salt Wash Member), yielded 9 gpm on bail testing but was abandoned in 1956 because its yield had declined to less than 1 gpm. Recent test wells tapping the unit in the Towaoc area also yield small quantities of water.

As the Junction Creek Sandstone is a better source for water than the Salt Wash Sandstone Member, any water well drilled into the Morrison should be deepened to test the underlying Junction Creek.

JURASSIC-CRETACEOUS BOUNDARY

The Jurassic-Cretaceous boundary cannot be precisely located in most of the project area because of intertonguing, lithologic gradation and lack of fossils. Intertonguing and lithologic gradation between the Jurassic Brushy Basin Shale Member of the Morrison Formation and the Cretaceous Burro Canyon Formation has been observed in many areas on the Colorado Plateau. In the Navajo Indian Reservation in Utah, Repenning and Irwin (1954a) mapped the conglomeratic sandstone of the Burro Canyon Formation as lensing into Brushy Basin mudstone to the south. The Burro Canyon is absent or cannot be recognized as a mappable unit south of the San Juan River. Harshbarger, Repenning, and Irwin (1957, p. 57) described the Jurassic-Cretaceous relation on the Navajo Indian Reservation as follows:

> Where the Jurassic rocks are overlain by the Burro Canyon formation, the contact is extremely arbitrary and no indication of a break in sedimentation can be found. Therefore, the upper boundary of the Brushy Basin member of the Morrison is questionable, and the time boundary between the Cretaceous and Jurassic periods cannot be precisely located.

The Burro Canyon is predominantly green mudstone interbedded with lenses of conglomerate and conglomeratic sandstone. Where mudstone of the Burro Canyon overlies mudstone of the Brushy Basin, the contact seems to be conformable, and there is no indication of a break in sedimentation. In places in the Four Corners area, basal sandstone lenses of Burro Canyon intertongue with the Brushy Basin mudstone.

Near Four Corners, the Burro Canyon Formation cannot be recognized as a mappable unit, and the Dakota Sandstone rests on the Brushy Basin. Here, the Brushy Basin may contain some rocks of Cretaceous age. The absence of the Burro Canyon is probably due to erosion before Dakota deposition. Ekren and Houser (1959a, p. 200), however, noted that, in addition to pre-Dakota erosion, this absence may be due to a facies change southward from the Ute Mountains.

In the Carrizo Mountain area, Strobell (1956) did not map the Burro Canyon formation but reported that:

Lenticular strata of conglomeratic sandstone 10 to 20 feet thick occur as much as 100 feet below the top of the Brushy Basin member. These lenses are very pale orange to yellowish gray and are very discontinuous. They are probably equivalent to the basal conglomeratic sandstone of the Burro Canyon formation of southwestern Colorado (Stokes [and Phoenix], 1948), but where they pinch out the overlying sandy claystone beds could not be differentiated from the underlying sandy claystone beds. * * * Hence, in all probability the Brushy Basin member as here mapped locally contains beds of Lower Cretaceous age.

Ekren and Houser (1959a, p. 200) also noted conglomeratic sandstone units in the Carrizo Mountain area, New Mexico—units probably equivalent to the sandstone and conglomerate lenses in the Burro Canyon of southwestern Colorado.

CRETACEOUS SYSTEM

BURRO CANYON FORMATION

GENERAL CHARACTER

The Burro Canyon Formation was named by Stokes and Phoenix (1948, map) for exposures in Burro Canyon, sec. 29, T. 44 N., R. 18 W., San Miguel County, Colo. The unit is described at the type locality as "alternating conglomerate, sandstone, shale, limestone, and chert ranging from 150 to 260 feet in thickness. The sandstones and conglomerates are gray, yellow, and brown, and the shales are faintly varicolored, mainly purple and green * * *. The lower contact is at the base of the lowest, resistant, light-colored, conglomeratic sandstone above the varicolored Brushy Basin shale member of the Morrison * * *."

The Burro Canyon Formation consists of varicolored mudstone and lenticular conglomeratic sandstone on the reservation.

The mudstone units of the Burro Canyon are generally grayish green (5*G* 5/2) with some grayish-red (10*R* 4/2) units and have a characteristic hackly weathered appearance. The mudstone is generally not bentonitic, and thus differs from the bentonitic frothy-weathering mudstone of the Brushy Basin (Ekren and Houser, 1959a, p. 192–195).

The conglomeratic sandstone and sandstone lenses are white to light gray (*N*7) and weather pale brown (5*YR* 6/2). The sansdtone and matrix of the conglomeratic sandstone are composed of fine- to medium-grained subangular clear quartz. The pebbles of the conglomeratic sandstone are principally red, white, green, or gray chert and are as large as 2 inches in diameter. These units are commonly crossbedded. The conglomeratic lenses form rough cliffs or steep ledges, where they are thickest. The lowermost conglomerate in the Burro Canyon was named the Karla Kay Conglomerate Member

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by Ekren and Houser (1959a, p. 195) from an exposure at the Karla Kay mine in McElmo Canyon. They described the member as "part of a system of shoestring channel-filling conglomerate and conglomeratic sandstone lenses * * *. Rarely are the channel-fills more than 2,000 feet wide or more than 65 feet thick; commonly they are 500–800 feet wide."

The conglomeratic sandstone and sandstone lenses are most evident in the northern part of the project area, particularly in McElmo Canyon. South of McElmo Canyon these units are rare and are commonly absent. Where the conglomerate and sandstone are not present, it is difficult to map the contact between the Burro Canyon and the Brushy Basin. In mapping the Ute Mountains area, Ekren and Houser (1959a, p. 193) placed the contact where the rocks change from hackly weathering mudstone of the Burro Canyon to frothy-weathering mudstone of the Brushy Basin Member of the Morrison. Along the San Juan River in the extreme southwestern part of the project area, the Burro Canyon could not be distinguished as a continuous mappable unit. Thin lenses of conglomeratic sandstone similar to the Burro Canyon occur in the upper part of the Brushy Basin Member. Pre-Dakota erosion has probably removed most of the Burro Canyon from the area, and the Dakota rests unconformably on Brushy Basin, which may contain, because of its intertonguing relation, a few lenses of conglomeratic sandstone of Burro Canyon lithology.

The Burro Canyon ranges in thickness from 0 to approximately 200 feet in the McElmo Canyon area. Its occurrence in the east half of the project area is not known, as it does not crop out, and data obtained from well logs are inadequate.

The Burro Canyon Formation is considered to be Early Cretaceous on the basis of fossils. Evidence for this assignment was presented by Brown (1950, p. 50), Stokes (1952, p. 1767), and Simmons (1957, p. 2525–2526). Recent fossil evidence suggesting a Cretaceous age for the basal member of the Burro Canyon, the Karla Kay Conglomerate Member, was presented by O'Sullivan (1962).

WATER SUPPLY

The sandstone units of the Burro Canyon Formation yield water to wells on the reservation. The Burro Canyon is overlain by the Dakota Sandstone, the major aquifer of the reservation. Where the Burro Canyon is present, the two formations are considered a hydrologic unit. As the formations are not everywhere distinguishable in the subsurface, wells completely penetrating the Dakota Sandstone are usually also drilled through the sandstone beds of the

Burro Canyon into the green mudstone of the Burro Canyon or the underlying Morrison Formation.

DAKOTA SANDSTONE

GENERAL CHARACTER

The Dakota Sandstone was named the Dakota Group by Meek and Hayden (1862, p. 419–420) from exposures near Dakota, Nebr. The name is now used throughout an extensive area, including the Colorado Plateaus.

The Dakota in the project area disconformably overlies the Burro Canyon Formation. Where the Burro Canyon is not present or cannot be recognized, the Dakota unconformably overlies the Brushy Basin Member of the Morrison Formation. The Dakota is exposed in the vicinity of the Ute Mountains and along the west boundary of the reservation (pl. 1).

The Dakota crops out or is in the subsurface throughout the project area, except in the relatively few areas where older rocks are exposed (pl. 1). In the eastern part, it lies at considerable depth under an accumulation of several thousand feet of younger Cretaceous rocks. In the western part, the Dakota is at or near enough to the surface so that it can be reached by a drill rig capable of drilling a few hundred feet.

The Dakota is composed of a series of sandstone units interbedded with carbonaceous shaly claystone, mudstone, and some thin coal beds. The basal sandstone unit is commonly conglomeratic. In a general way, the Dakota can be separated into three parts: A lower unit consisting of sandstone or conglomeratic sandstone, a middle unit consisting of carbonaceous black mudstone and silty sandstone, and an upper unit consisting of sandstone.

The sandstone beds are generally light gray to light yellowish gray and weather tan to yellowish brown. They are composed of very fine to medium-grained well-sorted subrounded to subangular frosted quartz.

The sandstone beds of the Dakota generally are weakly cemented with limonite and are moderately porous, friable, and, in some places, sugary. Locally, the cement is firm, and the sandstone is hard and has little porosity. Siliceous, calcareous, and hematitic cement is present locally.

The mudstone beds of the Dakota are medium gray to black and usually contain abundant carbonaceous material. They generally contain abundant fine sand and are commonly interbedded with thin-bedded platy gray sandstone stringers that weather tan.

Thin lenticular beds of low-grade coal occur throughout the unit but are generally more concentrated in the middle and upper parts. The coal beds range from a few inches to a few feet in thickness.

The Dakota of this area was probably deposited under fluvial and lagoonal conditions. The upper sandstone beds may have been beach deposits laid down before the transgression of the Mancos Sea. The marine deposits of the overlying Mancos Shale are conformable upon the Dakota.

The following is a complete measured stratigraphic section of the Dakota.

Kiva section

[Location: SE¼ sec. 8, T. 33½ N., R. 19 W. Measured by J. H. Irwin, F. N. Houser, and E. B. Ekren]

Cretaceous:

Mancos Shale (not measured):

Sandstone, yellow, soft, friable.

Dakota Sandstone:	*Thickness (feet)*
Sandstone, pale-yellowish-gray, weathering tan, fine- to very fine grained, sugary, well-sorted; composed of subrounded frosted quartz and black accessory mineral grains; weak limonite cement; composed mainly of flat beds and some wedge-planar crossbedded units, with concave low-angle small-scale crossbeds; weathers knobby to slabby; forms a ledge; contains limonite stains; base sharp	4. 5
Mudstone and impure coal, medium-gray to black, flat-bedded; weathers hackly; forms an irregular slope; contains limonite pockets; base sharp	4. 0
Sandstone, pale-yellowish-gray, weathering tan, fine-grained, sugary, well-sorted; composed of subrounded quartz; weakly cemented (iron); unit is composed of flat, thin to thick beds and wedge-planar crossbedded units with concave low-angle crossbeds; weathers pitted and slabby; forms a ledge; contains rib and furrow (cuspate) structures and secondary silica overgrowths; base sharp	8. 0
Mudstone, dark-gray, flat-bedded; weathers fissile; contains abundant carbonaceous material and some limonite; base sharp; interval mostly covered	5. 5
Sandstone, gray, weathering light-gray (with abundant yellow limonite staining), carbonaceous, fine-grained to very fine grained, well-sorted; composed of subrounded to subangular quartz; thick bedded; weathers massive and blocky; forms an irregular ledge; contains pitted surface marks, abundant carbonized plant remains, and, at top of unit, a 3-ft bed of impure coaly material and hackly weathering carbonaceous mudstone; base sharp	13. 0
Mudstone, medium-gray to black to yellowish-gray, carbonaceous; weathers hackly; forms a slope; contains limonite stains and beds of impure coal; base sharp	11. 0
Ironstone, dark-red, flat-bedded, cherty; weathers blocky to knobby; forms an irregular ledge; contains abundant hematite and limonite; base sharp	1. 0

Cretaceous—Continued

Dakota Sandstone—Continued

	Thickness (feet)
Mudstone	15.5
Sandstone, light-yellowish-gray, weathering buff, medium-grained, well-sorted; composed of rounded frosted quartz and black accessory mineral grains; weakly cemented by limonite(?); unit contains flat, thin beds and wedge-planar crossbedded units with small-scale crossbeds; weathers smooth to blocky; forms a ledge; contains concretionary masses of rounded medium-grained sandstone firmly cemented with calcite; base gradational	28.0
Conglomerate, pale-yellowish-gray; matrix: fine-grained sandstone; composed of subrounded to subangular frosted quartz; firm cement; pebbles: quartzite and red chert; unit contains flat, thin beds and wedge-planar crossbedded units with low-angle small-scale concave crossbeds; weathers smooth; forms a ledge; unit is short channel or lens; thickness decreases to 6 in. a short distance on either side of the point measured; coarser material concentrated along the bounding surfaces of cross-bedded sets; base irregular and gradational	4.0
Sandstone, pale-yellow, medium-grained, well-sorted, with subrounded frosted quartz and quartz overgrowths; weakly cemented (calcareous and limonitic); wedge- and tabular-planar crossbedding with concave low-angle small-scale crossbeds; weathers blocky to knobby; forms an irregular ledge; thickness differs considerably laterally; base gradational	7.0
Sandstone, gray to brownish-gray, weathering dark-brownish-gray, medium-grained, fairly well to poorly sorted, with rounded quartz, red, orange, and sparse green chert, firm cement (calcareous), flat bedding; weathers blocky; forms an irregular ledge contains calcite overgrowths; unit grades upward into overlying unit; base sharp	3.0
Mudstone (mostly covered), carbonaceous, dark-gray, flat, thinly laminated; weathers fissile, forms a slope; base concealed	4.0
Sandstone with rare short conglomeratic beds, white, weathering light-gray, medium-grained, well-sorted, with subangular quartz and rare black accessory mineral grains, weakly cemented, wedge- and tabular-planar crossbedding with low-angle small-scale crossbeds; weathers rounded to pitty to knobby; forms an irregular ledge; contains abundant limonite at base: flashes in sunlight owing to quartz overgrowths; base gradational	10.0
Sandstone, light-gray, weathering pale-yellowish-gray, medium- to fine-grained, well-sorted, with rounded frosted quartz and rare black accessory mineral grains, firm calcareous(?) cement, flat thin beds, rib and furrow structures; weathers blocky; forms a ledge; contains abundant limonite spots and stains; base sharp	3.0
Mudstone, carbonaceous, dark-gray, flat-bedded; weathers fissile; forms a slope; contains a 6-in. flaggy gray, beige-weathering sandstone about 1 ft from base; composed of angular quartz with abundant limonite and minor iron concretions; base sharp	4.5

	Thickness (feet)
Cretaceous—Continued	
Dakota Sandstone—Continued	
Sandstone, very pale yellow, weathering light-grayish-yellow, fine-grained, sugary, well-sorted, with subangular frosted quartz, weak cement (calcareous); unit is composed of flat, thick-bedded sets and wedge-planar crossbedded sets with low-angle crossbeds; weathers smooth to blocky; forms a ledge; desert varnish on resistant bedding surfaces; contains limonite spots and streaks; quartz flashes in sunlight owing to quartz overgrowths	6. 0
Sandstone with short conglomeratic units, light-gray, coarse- to medium-grained, poorly sorted; rounded to subrounded frosted quartz, pebbles of quartzite, red chert, and clay, firm calcareous(?) cement, wedge-planar crossbedding with concave, low- to medium-angle medium-scale crossbeds; weathers blocky; forms a ledge; contains limonite stains and some clayey material; base gradational	7. 0
Conglomerate, mottled gray and red, weathering light-gray; matrix: coarse-grained, with subrounded frosted quartz; pebbles: quartzite, clay fragments, chert, and siliceous limestone(?); weathers blocky; forms a ledge; contains a 2-in. sandstone bed at the base, which is gray medium grained well sorted and contains abundant carbon and limonite; base is sharp	1. 0
Total Dakota Sandstone	140
Base of section, top of Burro Canyon Formation	

Much of the sandstone is crossbedded, particularly the basal parts. Crossbedding is small scale and low angle. The upper part of the Dakota contains more flat-bedded units and is thinner bedded than the lower sandstone units. Ripple marks and pitting are common on the sandstone surfaces, particularly in the upper parts.

A conspicuous feature is the hard dark-red ironstone beds. The ironstone is generally about a foot thick, and, although it may be anywhere in the Dakota, it is more common in the middle part. It occurs within relatively thick mudstone units as well as within capping sandstone beds. The ironstone is generally well cemented with limonite or hematite and weathers blocky or knobby, forming an irregular ledge. In many places immediately west of the project area, ironstone caps the uppermost sandstone bed of the Dakota.

The Dakota weathers to form steep ledges and cliffs; the mudstone units form several slopes between the steep ledges of the sandstone units. The bedding planes are generally conspicuous, particularly where the unit crops out on gently sloping weathered surfaces in the area surrounding the Ute Mountains. In the McElmo Canyon area, the Dakota caps most of the mesas. Where the exposed Dakota is relatively flat, it is covered with a thin mantle of windblown sand

and soil with knobby sandstone occasionally cropping out in sheltered places or in places cleared by sheet wash from desert rainstorms.

The basal contact of the Dakota with the Burro Canyon is one of erosional disconformity. The relief on this erosional surface ranges from a few inches to several feet in a distance of a few hundred feet. Evidence for the disconformity between the Dakota and the Burro Canyon in western Colorado and eastern Utah is discussed by Carter (1957). In the project area, the basal bed of the Dakota overlying the erosional surface is conglomerate or sandstone that is in part conglomeratic. The uppermost bed of the Burro Canyon at the contact with the Dakota is commonly mudstone but may be sandstone.

The upper contact of the Dakota with the Mancos Shale is conformable, the lagoonal and beach deposits of the Dakota grading into the marine Mancos. The basal Mancos beds commonly consist of reworked Dakota Sandstone.

The thickness of the Dakota ranges from 100 to 160 feet and averages about 135 feet. A thickness of 140 feet was measured in sec. 8, T. 33½ N., R. 19 W., and 110 feet was measured about 3½ miles west of "The Knees" (T. 34 N., R. 18 W.); 100 to 110 feet of Dakota has been measured in McElmo Canyon. Dakota ranging in thickness from 140 to 160 feet was penetrated by several wells drilled in the west half of the reservation. However, it is commonly difficult to distinguish the contact between the Burro Canyon Formation and the Dakota by examination of well cuttings. Commonly, the two formations are logged as the Dakota Sandstone and Burro Canyon Formation, undifferentiated, and the thickness of the two formations ranges from 200 to 230 feet.

The age of the Dakota has not been definitely established because of the lack of conclusive fossil evidence. It is not necessarily the same age everywhere on the Colorado Plateaus, as it was deposited near or at the shores of a transgressing sea. Brown (1950, p. 47) considered it to be Late Cretaceous, on the basis of fossil plants. Katich (1951, p. 2094) reported fossils that indicate an Early Cretaceous age for it in central Utah. Ekren and Houser (1965, p. 20) assigned a Late Cretaceous age to it in the Ute Mountains area, and this age is used in this report.

WATER SUPPLY

The Dakota is the main aquifer for stock water. Although it does not yield large quantities of water to wells, most of the Dakota wells are dependable for small quantities. All the wells tapping the Dakota are in the western half of the project area.

Water in the Dakota is under artesian pressure everywhere except in the outcrop, and, even there, water in the lower part of the formation may be confined by impermeable beds within the unit. Depending on the stratigraphic position of confining beds, artesian pressures may be different at different depths in the Dakota or the Dakota and Burro Canyon sequence.

In some areas along the front of the western edge of Mesa Verde (pl. 1), water in the Dakota is under sufficient pressure to flow at the surface. Few wells have been drilled in this area because the Dakota lies at depths greater than 900 feet; so, little information is available to delineate exact areas where flowing wells are possible. A well drilled to a depth of 1,346 feet near Chimney Rock flows less than 1 gpm and must be pumped to obtain stock supplies. Throughout most of the project area west of Mesa Verde, artesian pressures cause sufficient rise of water in wells to greatly decrease the pumping lifts.

In the areas of outcrop of the Dakota along the Utah State line, sufficient water is difficult to obtain, as canyons dissect and at least partly drain the formation. Several small seeps discharge from it in this area. A test well (B–3) in sec. 10, T. 34 N., R. 20 W., yields approximately 1 gpm from the Dakota. This area is structurally higher than the area to the south and southwest, and water in the Dakota is moving by gravity flow toward the structurally lower areas.

The quantity of water available from wells in the Dakota differs—depending upon the hydrologic characteristics of the sandstone, the thickness of saturated material, construction of the well, and the amount of formation penetrated. A properly developed well completely penetrating the unit could yield 20 gpm, but yields of wells generally range from 2 to 15 gpm. In a few areas, where the yield is only 2 or 3 gpm, the sandstone is very fine grained and firmly cemented. In other areas it is coarser grained, the cementation is less firm, and larger yields are available. Most of the wells are equipped with wind-driven pumps capable of yielding 4 or 5 gpm, and this yield is adequate for stock needs.

The depth of wells tapping the Dakota ranges from approximately 200 feet in the western part of the project area to more than a thousand feet in the eastern part (pl. 2). The depth of most wells is between 500 and 700 feet.

Water from some wells tapping the Dakota is not suitable for domestic use because thin coal beds common throughout the formation may darken the water. A strong sulfur odor also makes the water from some wells objectionable for domestic use.

MANCOS SHALE

GENERAL CHARACTER

The Mancos Shale was named by Cross (1899) for exposures along the Mancos Valley near Mancos, Colo. At the type locality he estimated a thickness of 1,200 feet. The Mancos is 1,900 to 1,955 feet thick in the project area.

The Mancos Shale is exposed extensively in the western half of the reservation (pl. 1). It forms gently rolling hills and low ridges throughout the southwestern part. Where the overlying, more resistant Point Lookout Sandstone is present in the cliffs along the west edge of Mesa Verde, the Mancos forms a steep dissected slope below the caprock.

The Mancos conformably overlies the Dakota Sandstone, and, in many places, reworked Dakota sand was deposited at the base of the Mancos. This transition from beach deposition of the Dakota to marine deposition of the Mancos left deposits of yellow-gray poorly cemented clayey sandstone with indistinct bedding at the base of the Mancos. These deposits are about 35 feet thick. *Gryphaea* has been identified from this unit by W. A. Cobban (written commun., 1956). Houser and Ekren (1959a, p. 150) reported that this weakly consolidated sandstone is absent in and west of the Ute Mountains.

The Mancos Shale consists almost entirely of gray to dark-gray mudstone, but there are many thin sandy limestone lenses and limestone concretions throughout the unit. The following section measured south of the Ute Mountains describes the lower part of the formation.

Mound section

[Location: Secs. 24 and 25, T. 33½ N., R. 19 W., Montezuma County, Colo. On north side of "The Mound." Measured by E. B. Ekren, F. N. Houser, and J. H. Irwin]

	Thickness (feet)
Top of local exposure:	
Pediment gravels	27
Cretaceous Mancos Shale (incomplete):	
Mudstone, pale-yellow-gray, fissile, thin-bedded; weathers hackly; forms a regular slope; base gradational	18
Sandstone, very light gray, weathering buff, very coarse to coarse-grained, poorly sorted; composed of subrounded clear and frosted quartz and abundant glauconite and rounded grains of quartzite(?) and chert(?); medium to thin beds; small-scale low-angle crossbedding; weathers slabby; forms an irregular ledge; interbedded with fissile dark-gray mudstone; contains shark teeth; base sharp	9
Limestone and mudstone, interbedded. Mudstone is dark gray; fissile bedding. Limestone is pale yellow gray, finely crystalline, very fossiliferous; contains pelecypods: *Inoceramus perplexus* Whitfield and *Ostrea luqubris* Conrad; skate tooth, *Ptychodus whipplei* Marcou; thin-bedded (0 to 2 in. thick, average, ½ in.). Six feet above base of unit is fine-grained limy sandstone lens (6 in. thick) with frosted quartz, abundant black accessory mineral grains, and clayey material; weathers rounded to blocky; forms a ledge; base of sandstone lens sharp; unit forms an irregular cliff; base gradational	42

	Thickness (feet)
Cretaceous Mancos Shale (incomplete)—Continued	
Mudstone, dark-gray to black, weathering dark-gray, very thinly laminated; weathers hackly; forms a regular slope; contains carbonaceous material and limestone concretions similar to those described below; base gradational	62
Limestone concretionary zone in shale unit; concretions are dark gray, weather tan to buff and are rounded to blocky; unit forms a ledge; 3- to 6-in. zone at base contains crystalline cone-in-cone structures; limestone not composing this crystalline structure is partly fossiliferous (*Lingula*-like pelecypods); some of upper surfaces of the limestone are rounded and nodular; contains vugs of calcite crystals; basal 3- to 6-in. zone contains some banding; base sharp	2
Mudstone, dark-gray to black, weathering dark-gray	33
Limestone concretionary zone in shale unit; concretions are dark gray, weather brown, are 1 to 5 ft in diameter, are bounded by 4- to 6-in. zone of radiating crystalline structures, like cone-in-cone	2
Mudstone, gray to dark-gray, fissile bedding, calcareous(?); forms a regular slope; contains fossils and in places abundant gypsum; base gradational; interval is mostly covered	266
Limestone, dense, gray, weathering light-gray to white, slightly sandy, flat, thin-bedded, discontinuous and lenticular; intertongues with mudstone above and below; weathers to flat cobbles; forms a thick ledge; has conchoidal fracture	33
Mudstone, gray, silty; contains a few black accessory mineral grains; weathers hackly; forms a regular slope; contains zone, about 1 ft thick, 2 to 3 ft below top of unit, that is full of shells of *Gryphaea newberryi* Stanton	40
Sandstone; same as units described below except includes a 1- to 2-ft thick sandstone bed, 14 ft below top of unit, that is yellow, limonite stained, medium grained, with subrounded quartz, rare green accessory mineral grains, firm cement (calcareous); more resistant than remainder of unit; weathers to rounded ledge or to pebbly soil. Base of unit is gradational	20
Sandstone; same as unit described below except gray and contains no limonite and is firmly cemented (calcareous) in a zone 4 ft from base	10
Sandstone, yellow-gray, fine-grained, with subangular frosted quartz, abundant green accessory mineral grains; poorly cemented (calcareous and ferruginous); indistinct bedding; weathers to soil; forms irregular slope; base sharp	7
Total of incomplete Mancos Shale	544
Dakota Sandstone (incomplete):	
Sandstone, pale-yellow-gray, weathering yellow-gray, medium- to fine-grained, well-sorted, with subrounded frosted quartz, common black and red accessory minerals; firmly cemented (calcareous); thick beds; wedge-planar low-angle small-scale crossbedding; forms rounded ledge; contains abundant calcareous material; limonite stains, streaks, and spots; and a 2-in. thick coal bed about 10 ft below top	15
Total of incomplete Dakota Sandstone	15

Several lithologic zones are present within the lower part of the Mancos. About 75 feet above the base is a persistent interval of thin-bedded dense light-gray limestone that is probably equivalent to the Greenhorn Limestone of eastern Colorado. This limestone interval has been noted in many of the cuttings from wells drilled in the project area. The interval ranges from 10 to 40 feet in thickness and forms low benches covered with flat white to light-gray limestone fragments (fig. 8). The limestone is interbedded with gray to dark-gray mudstone, which is typical of mudstone of the Mancos Shale. Immediately below the limestone is a fossiliferous zone containing abundant *Gryphaea newberryi* Stanton (see measured section). Wanek (1959, p. 681) reported a thin platy limestone containing *Inoceramus labiatus* nearly 50 feet thick and about 100 feet above the Dakota Sandstone in the Mesa Verde area.

An interval of distinctive yellowish-brown sandy fossiliferous limestone and gray to brown shale, called the Juana Lopez Member of the Mancos Shale (Ekren and Houser, 1965, p. 24), has been recognized throughout the project area. Equivalents of this member are present in Upper Cretaceous rocks of several States, including parts of New Mexico, Colorado, and Utah. This interval has been referred to as the Juana Lopez Sandstone Member of the Carlile Shale by Rankin (1944) and as the Sanastee Member of the Carlile Shale or of the Mancos Shale by other geologists working in the San Juan Basin (Bozanic, 1955, p. 91). The interval is probably equivalent to the Codell Sandstone Member of the Carlile Shale of southeastern Colorado.

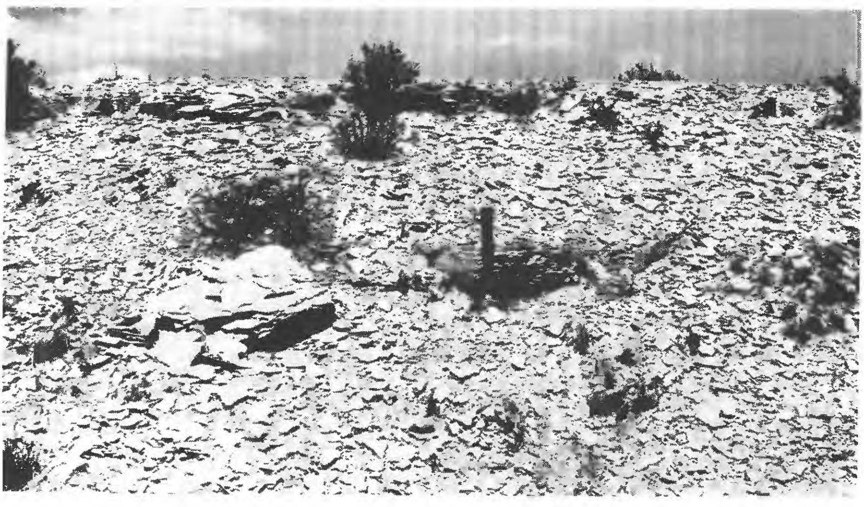

FIGURE 8.—Prominent lithologic zone in the Mancos Shale equivalent to the Greenhorn Limestone of other areas.

The Juana Lopez occurs from 475 to 525 feet above the base of the Mancos. On the flanks of the Ute Mountains, the member is exposed in places in cuestas, such as "The Mound" (fig. 9). Houser and Ekren (1959a, p. 150) stated that the member is present throughout the Ute Mountains, but in many places it is hidden by debris. South of the mountains, the Juana Lopez forms a prominent escarpment that is exposed throughout the southwestern part of the project area (pl. 1 and fig. 9). The unit ranges in thickness from a few feet in parts of the mountains to 50 feet south of the mountains.

In the Ute Mountains area, a light-gray coarse-grained glauconitic sandstone lies on, or a few feet above, beds of the Juana Lopez Member of the Mancos Shale (fig. 9). In the Ute Mountains, Ekren and Houser (1965, p. 24) mapped this sandstone with the Juana Lopez. Dane (1960, p. 53) reported that this sandstone south of Ute Mountain contains *Inoceramus deformis* of Niobrara age and rests on 15 feet of shale above the Juana Lopez. He reported that 3 miles south of the New Mexico State line a glauconitic sandstone bed rests on 60 feet of Carlile Shale above the Juana Lopez. From the Ute Moun-

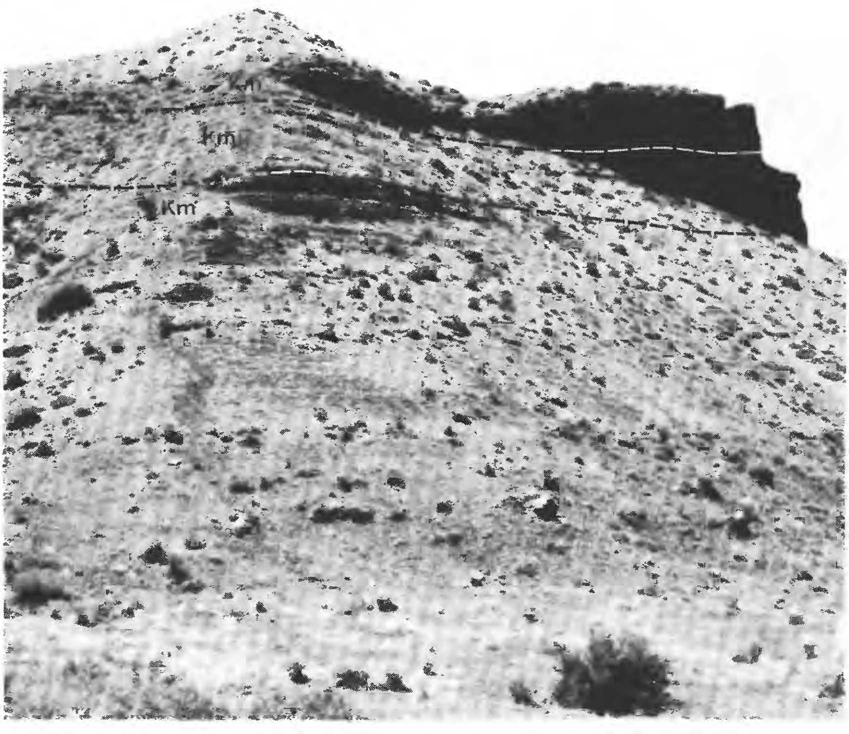

FIGURE 9.—Juana Lopez Member (kmj) of the Mancos Shale (km) of Carlile age at "The Mound." A few feet above the Juana Lopez is a 9-foot glauconitic sandstone of Niobrara age.

tains to the New Mexico State line, a sandstone sequence occurs progressively higher above the Juana Lopez southward. In the Mancos River area, the sequence is about 50 feet above the Juana Lopez. The sequence is probably equivalent to the coarse-grained sandstone units of Dane. Dane (1960, p. 53) concluded that "beds of the *Inoceramus deformis* zone cut down unconformably northward and that 300 feet or more of beds present south of the San Juan River are missing just south of Ute Mountains about 30 miles to the north."

The Mancos is of Late Cretaceous age, according to Pike (1947, p. 20–24); the upper part is of early Montana age, and the lower part is of Colorado age. The reader is referred to Pike's paper for a discussion of age relations of the Mancos and other Upper Cretaceous deposits.

WATER SUPPLY

The Mancos is relatively impermeable and is not a major aquifer. The limestone interval of Greenhorn age in the Mancos locally yields small amounts of highly mineralized water to wells in the vicinity of the Ute Mountains. Here, in wells penetrating this limestone to tap the Dakota Sandstone, it is necessary to case off water of poor quality from this unit.

The Mancos serves as a thick confining layer over the Dakota, and hence, water in the Dakota is under artesian pressure.

MESAVERDE GROUP

The "Mesaverde group" was named by Holmes (1877, p. 244) from exposures at Mesa Verde, Colo. A large part of the reservation lies on the broad dissected mesa (pl. 1) for which this group of rocks is named.

Holmes divided the group into three units—the "Lower Escarpment sandstone," the "Middle Coal Group" and the "Upper Escarpment sandstone." Collier (1919, p. 296) renamed these three divisions, in ascending order: the Point Lookout Sandstone, for Point Lookout on the north rim of Mesa Verde; the Menefee Formation, for exposures on Menefee Mountain near Mancos; and the Cliff House Sandstone, for the ruins of cliff houses in Mesa Verde National Park. These formational names are in use today.

The Mesaverde Group has been studied by Wanek (1959) and Hayes and Zapp (1955); so, a detailed discussion is not included in this report. The group was deposited during Late Cretaceous time, as shallow seas advanced and retreated. The large-scale intertonguing of the marine and continental deposits resulted from the oscillation of the shoreline.

POINT LOOKOUT SANDSTONE

The Point Lookout Sandstone is the basal formation of the Mesaverde Group. It is exposed in the steep sides and canyons of Mesa

Verde, where it forms a cliff above the steep slopes of the Mancos Shale. Several isolated patches of sandstone, which are considered to be Point Lookout, crop out high in the Ute Mountains. One of the larger exposures is on Hermano Peak, known as "The Knees" (pl. 1).

The Point Lookout in the Mesa Verde area was divided informally into two members by Wanek (1959, p. 685); Zapp (1949); and Barnes, Baltz, and Hayes (1954). The lower member is composed of interbedded yellowish-gray (*5Y* 8/1) thin sandstone and medium-gray (*N*6) sandy mudstone. This member is transitional into the underlying Mancos Shale. The intertonguing and gradational relations between the lower part of the Point Lookout and the Mancos are well displayed in the cliff face of Mesa Verde just east of Highway 666 and in the canyon walls carved by the Mancos River, where it emerges through the mesa (fig. 10).[1] The contact between these units is placed arbitrarily at the base of the lowest sandstone bed. The lower member also intertongues with the overlying upper massive sandstone member.

According to Wanek (1959, p. 685), the thickness of the lower member (informally called the sandstone and shale member) ranges from 80 to 125 feet in the Mesa Verde area. In adjacent areas, the lower member is as thick as 250 feet (Zapp, 1949; Barnes and others, 1954).

The upper sandstone member of the Point Lookout is massive yellowish-gray (*5Y* 8/1) to white sandstone. It is composed of fine- to

[1] Due to a printing error, the outcrop of Point Lookout along the Mancos River is shown in the wrong color in the northeastern part of plate 1. However, the areas are properly labelled Kpl.

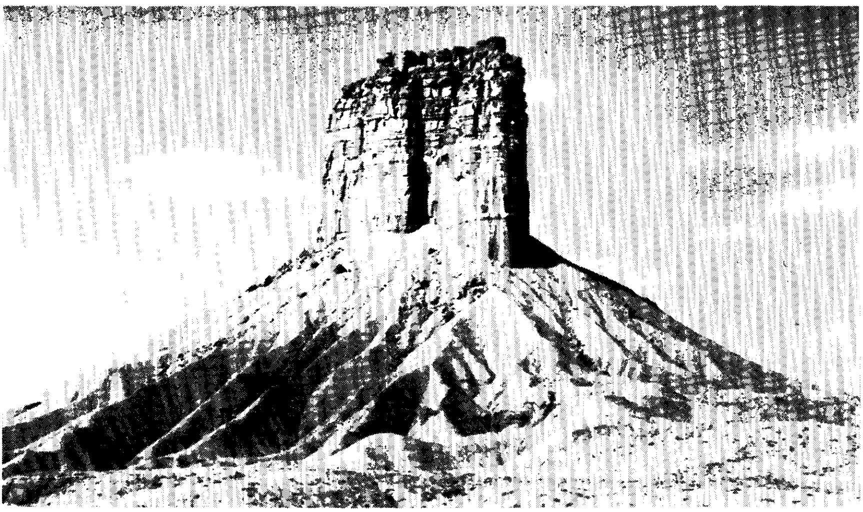

FIGURE 10.—Intertonguing and gradational relation between the lower part of the Point Lookout Sandstone and the Mancos Shale on Chimney Rock.

medium-grained well-sorted quartz. The unit is thick to massive bedded and is crossbedded. It forms the most prominent cliffs in the area, which commonly have overhanging faces. The upper member intertongues with both the lower member and the overlying Menefee Formation. The intertonguing is well exhibited in the Mesa Verde area. At the base, prominent sandstone tongues of the upper member are separated from the main sandstone mass by the shale units of the lower member. These sandstone tongues thin toward the north and grade laterally and vertically into beds of the lower member (Wanek, 1959, p. 686). The sandstone beds of the upper member intertongue with the carbonaceous shale, sandstone, and coal beds of the overlying Menefee Formation.

The upper massive sandstone member is from 200 to 250 feet thick. The entire Point Lookout Sandstone ranges in thickness from 300 to 450 feet.

The Point Lookout Sandstone is of Late Cretaceous age. It has been correlated with the Pierre Shale on the basis of invertebrate fossils (Pike, 1947, p. 21–23). Wanek (1959, p. 687) reported that he found few fossils in the Mesa Verde area other than near the Mesa Verde mine in sec. 33, T. 35 N., R. 16 W., where he collected *Baculites* cf. *B. ovatus*, *Inoceramus* sp., and casts of *Halymenites major*. Consistent with the cyclic deposition of transgressing and regressing seas of Late Cretaceous time, the formation was deposited during a period of northeastward regression of the sea that deposited the underlying Mancos Shale. As the sea retreated, the beach sand and nearshore deposits of the Point Lookout were laid down, and finally, the coastal-swamp deposits of the Menefee Formation were laid down behind the retreating sea.

MENEFEE FORMATION

The middle formation of the Mesaverde Group is the Menefee Formation. It is a sequence of shale, carbonaceous shale, coal, and siltstone beds alternating with lenticular sandstone beds. The sandstone is gray to grayish orange and is primarily composed of fine- to medium-grained quartz. It is thick bedded and forms rounded ledges. Many of the sandstone beds are not continuous and grade laterally into shale and siltstone. The shale is dark gray and generally sandy. The carbonaceous shale is dark brown and is generally associated with the coal beds. The Menefee throughout the Mesa Verde area contains coal beds of commercial significance. The reader is referred to Collier (1919), Hayes and Zapp (1955), and Wanek (1959) for a detailed discussion of the coal deposits. Wanek (1959, p. 689) and Hayes and Zapp (1955), in their reports on the Mesa Verde and Barker Dome areas, subdivided the Menefee into an upper coal member, a middle barren member, and a lower coal member.

The Menefee crops out in steep slopes between the Point Lookout and Cliff House, where all three formations are exposed around the rim of Mesa Verde and in the canyons dissecting the mesa.

In some areas, particularly the lower canyon of the Mancos River, the Menefee contains burned coal beds. These beds are strikingly colored with bright hues of orange and red.

Wanek (1959, p. 688, 689) reported that the Menefee ranges in thickness from about 340 feet in the northern part of Mesa Verde to about 800 feet along the Colorado-New Mexico State line. The formation is wedge-shaped and intertongues considerably with the underlying Point Lookout and the overlying Cliff House. Wanek stated: "Along Mancos Canyon * * *, the top of the Menefee rises stratigraphically more than 400 feet by successive intertonguing with the base of the overlying Cliff House sandstone." These intertonguing relations are shown on the geologic map (pl. 1).

The Menefee was deposited in a coastal swamp, in which existed between the regression of the sea that deposited the Point Lookout and the transgression of the sea southwestward that deposited the Cliff House. The intertonguing between the nonmarine Menefee and the marine Cliff House indicates at least minor oscillations as the sea transgressed.

CLIFF HOUSE SANDSTONE

The Cliff House Sandstone is the uppermost formation of the Meverde Group. It is the surface rock over most of Mesa Verde (pl. 1). The massive sandstone forms vertical cliffs; benches are formed in the more shaly units between the sandstone beds. The upper sandstone has niches and alcoves along the shaly sandstone at the base, and many of the cliff-dweller ruins in the National Park area are in these alcoves.

The sandstone beds of the Cliff House are grayish-orange to pale-yellowish-brown very fine to fine-grained thick-bedded units with large-scale crossbedding. The sandstone weathers to massive cliffs with niches along bedding planes. The thinly bedded shaly sandstone units between massive sandstone beds are interbedded with thin beds of siltstone and coal.

The Cliff House is a sequence of sandstone and shale that is not uniform in thickness or lithologic characteristics throughout the Mesa Verde region. Wanek (1959, p. 694–695) reported that the formation is shaly near Mancos, Colo., and that "The shale interfingers with the sandstone beds and wedges out toward the south." Along Mancos Canyon the unit is composed of relatively thick-bedded sandstone, forming irregular cliffs. Shaly sandstone units lie between the more massive upper and lower sandstone beds. In the New

Mexico part of the project area, the Cliff House consists of two massive sandstone beds separated by approximately 350 feet of shaly sandstone. The upper sandstone thickens and merges with the lower sandstone to the southwest and thins to a sandy unit not differentiated from the overlying Lewis Shale to the northeast (Hayes and Zapp, 1955).

The thickness of the Cliff House differs throughout the project area because of intertonguing. Wanek (1959, p. 695) reported a maximum thickness of about 400 feet in Mesa Verde National Park. Hayes and Zapp (1955) stated that the thickness generally ranges from 200 feet to 400 feet in the New Mexico part of the reservation.

The Cliff House intertongues with the overlying Lewis Shale and the underlying Menefee Formation. Wanek (1959) and Hayes and Zapp (1955) named several of the more prominent tongues and discussed the intertonguing relations in detail.

The Cliff House was deposited as sandstone lenses near shore in a transgressing sea. As the sea transgressed southwestward, it oscillated somewhat, as indicated by intertonguing between the nonmarine Menefee and the marine Cliff House.

WATER SUPPLY

A few wells obtain small amounts of water from the sandstone units of the Mesaverde Group, particularly the Cliff House Sandstone and the upper massive sandstone member of the Point Lookout Sandstone. These wells are in the southeastern part of the reservation.

The sandstone beds of the Mesaverde Group are not considered to be important aquifers for the following reasons: (1) The beds are restricted to Mesa Verde and in many places are overlain by relatively impermeable material; so, they receive a relatively small amount of recharge, all directly from precipitation; (2) Mesa Verde is deeply dissected by the Mancos River and its tributaries, draining the formations through seeps and springs in the canyon walls; (3) although the number of seeps and springs is small, it is not expected that any great amount of water from direct recharge is held in the formations, and therefore obtainable through wells.

In the New Mexico part of the reservation, where the formations have not been as extensively drained, wells tapping the Mesaverde sandstone beds yield 1 to 2 gpm.

LEWIS SHALE

GENERAL CHARACTER

The Lewis Shale overlies the Cliff House Sandstone of the Mesaverde Group. It was named by Cross (1899, p. 4) for exposures near

206-805 O—66——4

Fort Lewis, Colo. The Lewis is present only in the extreme southeast corner of the project area in New Mexico.

The unit consists of dark-gray to greenish-gray sandy shale and some beds of very fine grained sandstone. It contains some limestone and numerous thin yellow concretionary layers.

The Lewis intertongues with the underlying Cliff House, and the contact is transitional. Hayes and Zapp (1955, map) stated that "Almost the entire stratigraphic interval occupied by the Cliff House sandstone at the San Juan River is occupied by Lewis shale at the State line." The Lewis is 735 feet thick near the south boundary of the reservation at Westwater Canyon (Hayes and Zapp, 1955); 475 feet thick at the San Juan River, about 6 miles south of the boundary; and more than 1,400 feet thick near the New Mexico State line and the La Plata River.

The Lewis was deposited during a transgression of the sea from the northeast in middle and late Pierre time (Pike, 1947, p. 97). The large degree of intertonguing with the Cliff House Sandstone indicates an oscillating shoreline as the sea encroached. The Lewis Shale does not yield water to wells.

PICTURED CLIFFS SANDSTONE

GENERAL CHARACTER

Overlying the Lewis Shale is the Pictured Cliffs Sandstone. The unit was named by Holmes (1877, p. 244) for exposures near the San Juan River, west of Fruitland, N. Mex. It is exposed as a narrow band in The Hogback in the extreme southeastern part of the reservation in New Mexico. In the project area the sandstone units form the characteristic hogback topography. The Lewis consists of light-yellow to light-gray very fine to fine-grained sandstone and interbedded gray shale, particularly in the lower part.

The Lewis is 290 feet thick near the southern reservation boundary at Westwater Canyon and is 230 feet thick in the West Fork of Four Mile Canyon (Hayes and Zapp, 1955).

The Pictured Cliffs grades into both the underlying Lewis Shale and overlying Fruitland Formation (Reeside, 1924, p. 19). For a detailed discussion of the transitional relations of these formations, the reader is referred to Hayes and Zapp (1955).

The Pictured Cliffs is probably the last marine deposition in the project area, as the sea regressed northeastward. It is considered to be late Pierre in age.

WATER SUPPLY

The Pictured Cliffs is present in a small area of the reservation but is unimportant as an aquifer. One well (A–14) may yield a small amount of water from this sandstone.

FRUITLAND FORMATION

GENERAL CHARACTER

The Fruitland Formation overlies the Pictured Cliffs Sandstone. It was named by Bauer (1917, p. 274) for Fruitland, N. Mex., and occurs only in the southeast corner of the project area.

Bauer and Reeside (1921, p. 167) described the formation in general as follows: "The formation consists of sandstone, shale, and coal, very irregularly bedded. In constitution the various beds range from shale to sandstone with every conceivable intermediate phase of sandy shale and shaly sandstone * * *. The coal beds are distributed throughout the formation, but are more abundant and generally thicker in its lower portion."

The unit is about 250 feet thick. The basal part of the Fruitland intertongues with the Pictured Cliffs below and is gradational into the Kirtland Shale above. The Fruitland does not yield water to wells on the reservation.

KIRTLAND SHALE

GENERAL CHARACTER

The Kirtland Shale, which overlies the Fruitland Formation, was named by Bauer (1917, p. 274) from exposures near Kirtland, N. Mex. At the type locality the unit has been divided into three members: The lower member, the Farmington Sandstone Member, and the upper member. These members are exposed in a few outcrops in the southeastern part of the project area.

The lower and the upper members consist mainly of gray to grayish-brown shale interbedded with soft yellowish-gray sandstone. Minor amounts of carbonaceous and light sandy shale occur throughout the irregularly bedded units. The middle unit, the Farmington Sandstone Member, is a series of soft olive-gray and brown irregular crossbedded sandstone beds. The sandstone is fine to medium grained. At the New Mexico State line a few miles east of the reservation boundary, Hayes and Zapp (1955) reported the lower member to be 425 feet thick and the upper member to be 405 feet thick—a total thickness of 1,160 feet. Reeside (1924, p. 27) reported the lower member as 271 feet thick, the Farmington Sandstone Member as 459 feet thick, and the upper member as 80 feet thick, on the San Juan River.

The contact between the members is transitional and variable. The formation was deposited under fluviatile conditions.

WATER SUPPLY

The Kirtland is a minor aquifer. Two wells (A–15, A–16) probably yield 1 gpm from the Farmington Sandstone Member. The more permeable sandstone lenses receive some local recharge. However, because of the irregularity and lenticularity of the unit, the Kirtland yields only small amounts of water to wells.

McDERMOTT FORMATION AND OJO ALAMO SANDSTONE

Overlying the Kirtland Formation in the northern San Juan Basin area is a sequence of several hundred feet of sedimentary rocks. As these rocks occur only in the extreme southeast corner of the project area, less then half a square mile, they are mentioned here only for completeness of the stratigraphic column. These rocks are similar to the underlying Kirtland and consist of grayish-brown shale interbedded with soft yellowish-gray sandstone. Owing to the complex stratigraphic relations of the rocks, Hayes and Zapp (1955) referred to them only as undifferentiated Upper Cretaceous rock. Dane and Bachman (1957, map) indicated that these rocks constitute the McDermott Formation and the Ojo Alamo Sandstone.

No wells tap these deposits on the reservation.

CRETACEOUS OR TERTIARY SYSTEMS

IGNEOUS ROCKS

The Ute Mountains are formed by an extensive group of laccoliths, sills, dikes, and stocks. Several small igneous bodies also occur on Mesa Verde. The igneous rocks of the Ute Mountains have been studied in detail by Ekren and Houser (1965) and will not be treated in detail in this report. The following is a brief discussion of their findings in the Ute Mountains area.

The igneous rocks of the Ute Mountains occur as laccoliths, bysmaliths, sills, and dikes that are radially distributed with regard to three stocks—Black Mountain, "The Knees" (Hermano Peak), and a concealed Ute Peak mass (Ekren and Houser, 1965, p. 27). Ekren and Houser (1958, p. 75) stated that these rocks "are a series of porphyries that range from microgabbros through quartz monzonites. Field mapping indicates that the earliest intrusive rocks were microgabbros followed by diorites, granodiorites, and finally quartz monzonites." The igneous bodies were intruded into or between the sedimentary rocks. The bodies were probably intruded about the same time as the other laccolithic mountains on the Colorado Plateaus—from Late Cretaceous to the middle Tertiary.

Several small bodies of igneous rock of Tertiary age crop out in the sedimentary rocks along Mancos Canyon and Rock Canyon (pl. 1). These bodies are small plugs and associated dikes. Wanek (1959, p. 701) reported that the composition of these igneous bodies "generally is identical mineralogically. They have been identified megascopically as minette, a basaltic rock which contains abundant biotite flakes and olivine crystals."

TERTIARY(?) AND QUATERNARY SYSTEMS

PEDIMENT DEPOSITS

GENERAL CHARACTER

Pediment gravel is extensive in the area surrounding the Ute Mountains and in a few places on Mesa Verde. The pediment gravel of the Ute Mountains area is considered to be Quaternary in age. Wanek (1959, p. 698) considered the high-level gravel on Chapin Mesa of Mesa Verde to be Tertiary(?). The high-level gravel along the Montezuma-La Plata county line is considered to be Quaternary by Barnes, Baltz, and Hayes (1954).

The discontinuous pediment gravel of the Ute Mountains area extends radially away from the mountains—in many places for several miles (pl. 1). The surfaces have been formed at various levels probably because of local conditions of load, discharge, and base level. The gravel deposits are more resistant to erosion than the underlying Mancos Shale; thus, later dissection has left isolated low buttes south of the mountains.

The deposits on these surfaces are predominantly composed of pebbles, cobbles, and boulders of igneous origin. The thickness of the pediment gravel ranges from 1 to 40 feet. In many places the gravel is mantled with several feet of windblown silt and very fine sand.

WATER SUPPLY

The pediment deposits are dissected and are generally drained; so, they are not a major source of water. Seeps may occur at a contact with underlying shale deposits.

QUATERNARY SYSTEM

TALUS DEPOSITS

GENERAL CHARACTER

Talus deposits occur extensively in the Ute Mountains and in this report include block rubble and landslide deposits (pl. 1). The talus material consists of igneous pebbles, cobbles, and boulders that lie at the base or on steep slopes below the source rock of the debris. Large talus deposits surround Ute Peak; on the west side there is a particularly impressive rock slide containing large porphyry blocks 8 to 10 feet in diameter.

WATER SUPPLY

The talus deposits are important as a source of water issuing from springs at the base of the deposits. Yields of nearly 100 gpm are obtained from one or two of the springs on the west side of Ute Peak. The amount of flow from the springs is seasonal, depending on precipitation. Some springs dry up completely in the fall and winter.

Several of the larger springs are a potential source of water for domestic use in the Towaoc area; however, as these springs are on the west side of the mountains and drain to the northwest, the water would have to be pumped over the divide south of Ute Peak to be available to the Towaoc area.

ALLUVIUM

GENERAL CHARACTER

Alluvial deposits, including a few low, narrow terrace deposits, occur along major tributaries. The largest deposits of alluvium are along the Mancos River and in the Towaoc area.

The alluvium of Mancos Creek consists of silt, sand, clay, and some gravel. The thickness of the alluvium is not known; however, it is probably more than 80 feet thick in the Mancos farm area.

Near Towaoc the alluvium is composed of clay, silt, fine sand, and gravel. The finer materials were derived from the surrounding Cretaceous shale and sandstone; the coarser pebbles and cobbles are igneous fragments derived from the Ute Mountains intrusive rocks. The thickness differs greatly in this area. The alluvium reaches its maximum thickness in channels cut into the underlying Mancos Shale by older streams that may or may not follow the present drainage patterns. Thickness ranges from 20 to 75 feet. Wells B–17, B–18, and B–19 in the Towaoc area penetrate 40, 40, and 50 feet of alluvium, respectively. Well B–2 southwest of Towaoc tapped 40 feet of alluvium.

Away from the Ute Mountains, the smaller tributaries to the Mancos River have small amounts of alluvium intermittently deposited throughout their reaches.

WATER SUPPLY

Alluvial deposits yield small amounts (usually less than 10 gpm) of water to wells. Several wells and two infiltration galleries yield water from alluvium for domestic use near Towaoc. One well, A–18, at Mancos farm yields water of poor quality from the alluvium along the Mancos River. Water from this well has a salty taste and is used for stock only.

OCCURRENCE OF GROUND WATER

The climate and the physical characteristics of aquifers, both consolidated and unconsolidated, are major factors that greatly limit the occurrence of ground water on the reservation.

The principal source of recharge to aquifers is scanty precipitation as rain or snow on the outcrops either within the area or in nearby areas, particularly to the north. Part of the precipitation precolates downward into the ground to become ground water, but by far the greater part becomes surface runoff, is evaporated or transpired, or is retained by the soil.

Lithologic characteristics of a rock that are important in the occurrence of ground water are grain size, sorting, and cementation. Grain size and the degree of sorting control the amount and distribution of open spaces within the rock and thereby control the amount of water that can move or drain from them. A rock composed of large well-sorted grains can transmit water readily. The amount of cementing material in rocks also influences movement of water. In well-cemented rocks the cement inhibits or prevents movement of water.

Many rocks in this area are fine grained—claystone, mudstone, siltstone, and poorly sorted sandstone. These rocks may hold considerable amounts of water, but, because of their restricted open space, they offer little possibility for the development of water supplies. Other rocks have sufficient grain size and degree of sorting to permit the development of small (6 to 10 gpm) to moderate (10 to 100 gpm) supplies of water.

The occurrence and movement of ground water also is influenced by geologic structure. The Ute Mountains and McElmo Dome immediately to the north are structurally high, and the strata dip away from them. East and southeast of the mountains, the strata dip 2°–3°, forming the west flank of a broad, shallow southward-plunging syncline in the Mesa Verde area. To the southwest, the strata dip into a syncline near Four Corners. Because the major sandstone aquifers are exposed in these structurally and topographically high areas, they are recharge areas. Recharge moves downdip into the structurally low areas toward areas of discharge, which for the most part are outside the project area.

Water wells on the reservation penetrate sedimentary rocks of several types—shale, very fine to medium-grained sandstone, some limestone, igneous debris, and sand and gravel. Because of the fine particle size, most of the rocks do not yield large amounts of water to to wells or springs.

WATER IN SHALE

Shale is not a major water-bearing formation, as it generally has relatively low coefficients of permeability and storage. These and other hydrologic terms are defined in the section on aquifer tests.

Shale is the principal rock type in the project area. The total thickness of the Mancos Shale is about 2,000 feet, and it is at the surface in a large part of the project area and in the subsurface throughout all but a small part. Because of the thickness and extensiveness of the shale, it is difficult to locate water-bearing rocks. Wells must be drilled to depths of several hundred feet and in some places to depths of more than a thousand feet to water-bearing sandstone below the shale.

Shale is important in the area as a confining bed, and the water in the underlying sandstone beds is under artesian pressure. The pressure causes water to rise in a well drilled into the sandstone, thus, greatly reducing the pumping lift. The Mancos Shale and shale beds in the Dakota Sandstone, the Morrison Formation, and the Mesaverde Group are the major confining beds.

WATER IN SANDSTONE

Most of the water from wells on the reservation is obtained from sandstone. Well yields are generally low because these beds are generally fine grained and silty. Yields from wells in these sandstone beds range from a few gallons per minute to approximately 200 gpm from a flowing well in the Junction Creek Sandstone. The principal sandstone aquifers are the Dakota, Burro Canyon, Junction Creek, and Entrada Formations.

WATER IN LIMESTONE

Limestone is not a major aquifer. Only a few thin beds of impure limestone crop out on the reservation. One limestone zone of Greenhorn age in the Mancos Shale yields small amounts of water to wells in places in the vicinity of the Ute Mountains. Here, the unit receives sufficient recharge to yield water to wells near the recharge area. Elsewhere, it seems to be relatively dry. Water from the unit is highly mineralized, and commonly an improperly constructed well tapping the unit permits contamination of water of better quality in aquifers stratigraphically lower.

WATER IN SAND AND GRAVEL

Sand and gravel mixed with clay and silt occurs as Recent alluvium and related terrace deposits. The most widespread alluvial deposits are along the Mancos River and in the areas surrounding the Ute Mountains, particularly the Towaoc area.

Water occurs in these sand and gravel deposits; however, because of the finer particles, they have a relatively low permeability. Wells in these materials yield only small to moderate quantities of water for stock and domestic use.

Pediment gravel is derived from igneous material and occurs most frequently on erosion surfaces surrounding the Ute Mountains. These deposits are dissected and are usually drained; so, they are not a major source of water.

WATER IN IGNEOUS DEBRIS

In many parts of the Ute Mountains, springs issue from igneous debris. Block rubble and talus material at various levels on the mountain slopes serve as catchment areas for snowmelt. Springs are common at the base of slopes overlying relatively impermeable rocks. Seasonal yields from these springs range from a few to nearly 100 gpm; some springs dry up completely during the fall and winter. Many have been developed, and their ponded discharge is used for stock during the summer.

HISTORY OF WATER-RESOURCES DEVELOPMENT

Before the early 1950's, the development of the water resources of the reservation was negligible. A few wells drilled in the 1930's, several developed springs, and a few earthen reservoirs that ponded surface runoff supplied stock and domestic water for the entire area. Waring (1935) reported six wells and developed springs west of the west face of Mesa Verde, where most of the Ute Indians made their homes. Domestic water was often hauled many miles to hogans scattered throughout the reservation. Because of the seasonal fluctuation of water supplies, the Utes moved from place to place seeking better grazing lands and water supplies. In the early 1950's, there were attempts to develop the water resources of the area.

SURFACE-WATER SUPPLIES

Surface water is not plentiful. Precipitation is low and runoff is seasonal. Streams are either intermittent or have relatively small perennial flows. To utilize all possible water resources, development of surface-water supplies has been attempted by (1) using Mancos River water for irrigating small areas, (2) building a canal to transport McElmo Creek water into the reservation near Towaoc, and (3) building numerous reservoirs to catch and store seasonal runoff.

Mancos River water is diverted to irrigate about 100 acres used for raising feed in the Mancos farm area. The lack of irrigable land and dependable amounts of river water has prevented any major development of the Mancos River area. However, the Bureau of Indian Affairs and other Federal agencies have made studies for possible future development along the river.

In 1955 an attempt was made to transport water diverted from McElmo Creek through an extension of a canal entering the reservation in sec. 4, T. 34 N., R. 17 W., and ending near Towaoc (pl. 1). The water was to be stored in the Towaoc reservoir for domestic use. The ditch was unlined, and collapsed along a section dug into the Mancos Shale when water was turned into it. The ditch was abandoned, and the water now is diverted into Navajo Wash at the reservation boundary and at present (1963) is not utilized.

Earthen dams used throughout the reservation are the best means of ponding runoff for use as stock water. Many reservoirs are in low areas and on small intermittent streams that drain the Ute Mountains area. Because of low rainfall, many reservoirs are dry part of the year, and, in years of below-average precipitation, many are dry all year. There are approximately 75 reservoirs throughout the reservation.

GROUND-WATER SUPPLIES

The Ute Mountain Indian rehabilitation program included ground-water investigations, started in the early 1950's, to determine ways of alleviating a critical domestic water shortage at Towaoc and to develop additional stock-water supplies throughout the reservation. The rehabilitation program included the construction of many new Indian homes in the Towaoc area and the reopening of the Government Boarding School at Towaoc in 1953, which had been closed because of lack of sufficient water. The need of an adequate water supply for Towaoc has been a major problem since the town was established in the 1920's.

At the start of the present investigation in October 1955, the shortage of water remained critical, and it was often necessary to haul water from Cortez. During the present investigation, three deep wells were drilled to test several potential aquifers of Jurassic and Triassic age. The results of this and the stock-water drilling program are included in this report. (See section on "Development of water supplies during this investigation," p. G61.)

UTILIZATION OF GROUND WATER

Ground water on the reservation is obtained from drilled wells and from a few developed springs and seeps in the mountains. There are 36 wells, 2 infiltration galleries, and many springs in the area: most are used for stock and (or) domestic purposes; 4 wells and 2 infiltration galleries are used for public supply. At present (1963), none of the wells are used entirely for irrigation. In the Towaoc area, lawns and a few small garden plots are irrigated from the town supply.

Water from few wells, other than from those at Towaoc, is now used for domestic purposes because of the quality of water yielded by many outlying wells and the shift in population to Towaoc. The few Indian families that live out on the reservation usually haul water for cooking and drinking.

Public supplies are available at Towaoc. A detailed discussion of the public supplies of Towaoc is in the section of the report concerning development of water supplies during the present investigation (p. G62).

There are 23 wells throughout the reservation that supply water for livestock, supplementing that available through ponding of surface-water runoff. All the stock wells are west of Mesa Verde in Colorado and in the southern part of the New Mexico part of the reservation (pl. 1).

OBTAINING A GROUND-WATER SUPPLY

SPRINGS

Springs occur principally in the mountains and to a lesser extent in the deeply incised canyons of the Mesa Verde area. These springs long have been the principal source of water and have played an important role throughout the development of the area. Shelters were built by an ancient people at or near springs. The drying up of these springs during prolonged drought may have brought about the departure of these people. Many years later, with the arrival of the Ute Indians, settlement centered near springs. Towaoc was first established at the site of Navajo Spring (pl. 1) and later was moved to its present site.

Today, springs are still a source of water, but, with the increase in population and a higher standard of living, the springs long ago became inadequate. Many springs can be used only a few months after spring runoff, and, because their source of water is entirely dependent on precipitation and snowmelt, many dry up completely in dry years.

Springs are still the principal source of water in the Ute Mountains, where approximately 12 developed springs are used for domestic and stock supplies. They issue from talus, alluvial material, or the Dakota Sandstone. Several reservoirs have been built in the mountains to collect runoff fed by spring flow.

The yields of springs in the mountains vary greatly within the year as well as from year to year. Only a few discharge the entire year. Several springs discharge as much as 80 gpm at the base of a large boulder field on the west side of Ute Peak where the boulders lie on less permeable material, such as the Mancos Shale. Most springs discharge from 1 to 10 gpm from June to September or October. In drought years many springs yield no water at all.

In the Mesa Verde area and in the New Mexico part of the reservation, springs issue mainly from the Point Lookout and Cliff House Sandstones. Yields are small, as a rule barely amounting to more than seeps, and only a few of these springs have been developed.

The more important springs and their yields are listed in table 4.

TABLE 4.—*Records of*

Number on plate 1: Ute Mountain letter and number designation of wells and springs shown on plate 1. A and B indicate a drilled well; S indicates a spring.
Depth of well: Measured depths are given in feet and tenths below land surface; reported depths are given in feet.
Casing diameter: Asterisk indicates iron casing.
Casing perforated interval: 257–420, casing perforated from 257 to 420 ft; OH 276–473, open hole from 276 to 473 ft.
Geologic source: J℞n, Navajo Sandstone; Je, Entrada Sandstone; Jj, Junction Creek Sandstone; Jms Salt Wash Sandstone Member of the Morrison Formation; Kb, Burro Canyon Formation; Kd, Dakota Sandstone; Km, Mancos Shale; Kmg, limestone of Greenhorn age in the Mancos Shale; Kmj, Juana Lopez Member of the Mancos Shale; Kpl, Point Lookout Sandstone; Kch, Cliff House Sandstone; Kkf, Farmington Sandstone Member of the Kirtland Formation; Kpc, Pictured Cliff Sandstone; TKi, igneous rocks;

No. on plate 1	Location	Owner or user	Year completed	Depth of well	Casing		Character of material	Geologic source
					Diameter (inches)	Perforated interval (feet)		
A-1	T. 33 N., R. 18 W.	Ute Mountain Ute Tribe of Indians.	1953	774.7	*6		Sandstone.	Kd
2	T. 33 N., R. 18 W.	do		165.0	(*)		do	Kmj
3	T. 33 N., R. 19 W.	do	1953	695	*6		do	Kd
4	T. 33 N., R. 19 W.	do	1935	665	*6		do	Kd
5	T. 33 N., R. 20 W.	do	1931	250			do	Kd(?)
6	T. 33½ N., R. 20 W., NE¼NW¼ NW¼ sec. 32.	do		271.0	*5		do	Kd
7	T. 35 N., R. 19 W., C, N½ NW¼SW¼ sec. 35.	do			*6		do	Kd
8	T. 34 N., R. 19 W., NW¼SW¼ SW¼ sec. 8.	do		108.6		OH	do	Kd
9	T. 33½ N., R. 17 W., SE¼SE¼ SE¼ sec. 3.	do	1954	1,025	*6		do	Kd
10	T. 31 N., R. 16 W.	do			*8		do	Kpl
11	T. 31 N., R. 16 W.	do	1953	465	*6	257–420	do	Kpl
12	T. 32 N., R. 16 W.	do	1953	296	*6		do	Kpl
13	T. 31 N., R. 14 W.	do	1953	302	*6		do	Kch
14	T. 31 N., R. 14 W.	do						Kpc(?)
15	T. 31 N., R. 14 W.	do		143	*6			Kkf(?)
16	T. 31 N., R. 14 W.	do		330.0	*6			Kkf
17	T. 32 N., R. 14 W.	do	1953	135.0	*6		Sand	Qal
18	T. 32 N., R. 18 W., NE¼SW¼ NW¼ sec. 13.	do		86			Sand and gravel.	Qal
B-1	T. 33½ N., R. 19 W., NW¼NW¼ NW¼ sec. 30.	do	1956	177.0	*4	150–160	Sandstone.	Kd, Kb
2	T. 33½ N., R. 18 W.	do	1956	77.0	*6	25–40	Sand	Qal
3	T. 34 N., R. 20 W., SE¼SE¼ sec. 10.	do	1956	125			Sandstone.	Kd, Kb
4	T. 33½ N., R. 17 W., SE¼SE¼ SE¼ sec. 18.	do	1956	29.5			Sand, clay and gravel.	Qal
5	T. 33½ N, R. 19 W., NW¼NW¼ NE¼ sec. 26.	do	1957	204.0	*4		Limestone.	Kmg
6	T. 33½ N., R. 19 W., NW¼NW¼ NE¼ sec. 26.	do	1957	473.0	*6	OH 276–473	Sandstone.	Kd, Kb
7	T. 33 N., R. 17 W., NW¼NE¼ SE¼ sec. 17.	do	1957	1,346.0	*7	OH 1,246–1,330	do	Kd
9	T. 35 N., R. 19 W., C, SW¼ SW¼ sec. 23.	do	1954	886	*6	OH 580–886	do	Jj

wells and selected springs

Qp, pediment deposits; Qt, talus deposits; Qal, alluvium. For the description of the physical character of the bedrock water-bearing formations, see generalized section of bedrock formation (table 3).
Method of lift and type of power: C, cylinder; E, electric motor; G, gasoline engine; W, wind.
Yield: All quantities given are in gallons per minute (gpm); B, bail test; F, flowing well; P, pumping test; R, reported yield; <, less than.
Altitude: Altitudes of land surfaces were estimated from topographic maps and are given in feet above mean sea level.
Depth to water: Measured depths to water are given in feet and tenths below land surface; reported depths are given in feet below land surface.
Use of water: D, domestic; N, none; S, stock; P, public.
Remarks: A, chemical analyses of water given in table 6; L, log of well given beginning on page G75.

Method of lift, and type of power	Pump setting (in ft below land surface)	Yield		Drawdown		Altitude	Depth to water	Date of measurement	Use of water	Remarks
		Tested	Operating	Feet	Hours					
C, W	360	15 B	3	144	0.5	5,485	225.0	12- 4-57	S	A, L.
C, W	--------	--------	1	--------	--------	5,300	92.0	7-31-57	--------	A. Deepened in 1959.
C, W	485	10 B	2.5	--------	--------	5,330	301.8	6-25-59	S	A, L.
C, W	575	--------	4	--------	--------	5,175	287.3	6-24-59	S	A, L.
C, W	--------	--------	4	--------	--------	4,810	60.9	6-24-59	S	A.
C, W	260	--------	3	--------	--------	5,090	76.9	6-24-59	S	A.
C, W	--------	--------	1.5	--------	--------	5,758	131.0	7-31-56	S	A.
C, W	96	--------	3	--------	--------	5,223	83.9	6- 4-56	S	A.
C, E	--------	12 PR	6	--------	--------	5,775	--------	1954	P	A, L. Well originally flowed less than 1 gpm. No longer flows.
C, W	--------	--------	2	--------	--------	5,660	199.4	6-21-59	S	
C, W	--------	1 PR	1	--------	--------	5,300	285.0	6-21-59	S	L.
C, W	--------	--------	2	--------	--------	5,610	182.3	6-22-59	S	L.
C, W	--------	--------	3	--------	--------	6,000	178.3	6-21-59	S	A, L.
C, W	--------	--------	2	--------	--------	5,720	143.1	6-21-59	S	
C, W	100	--------	3	--------	--------	5,680	131.6	6-21-59	S	
C, W	--------	--------	1	--------	--------	5,670	146.3	6-21-59	S	
C, W	--------	--------	<1	--------	--------	6,200	122.5	6-22-59	S	L. Original depth, 204 ft, plugged back to 135 ft.
C, W	--------	37 B	--------	0	1	4,990	12.0	11-20-57	S	
C, W	151	--------	5	--------	--------	5,104	59.4	7-19-57	S	A, L.
C, G	--------	--------	2	--------	--------	5,690	30.1	9- 3-56	D, S	A, L.
--------	--------	.5B	--------	--------	--------	4,880	89.3	10-30-56	N	Abandoned.
--------	--------	1 B	--------	--------	--------	5,820	25	--------	N	Abandoned, L.
--------	--------	.5F	.5F	--------	--------	5,480	--------	7- 7-57	S	A, L. Not in use.
--------	--------	5 B	--------	--------	4	5,480	84.8	8-14-57	S	L.
C, W	--------	.25F	5	--------	--------	5,360	--------	6- 4-57	S	A, L. Flowing well with windmill installed.
C, W	--------	10 B	5	175	2.5	5,755	599	11-12-57	S	L. Deepened in 1957.

TABLE 4.—*Records of wells and*

No. on plate 1	Location	Owner or user	Year completed	Depth of well	Casing: Diameter (inches)	Casing: Perforated interval (feet)	Character of material	Geologic source
B-10	T 33½ N., R. 17 W., C, SW¼ SW¼ sec. 18.	Ute Mountain, Ute Tribe of Indians.	1958	528.0	*6	OH 335-528	Sandstone.	Kd, Kb
11	T. 33 N., R. 20 W.	do	1956	6,252	*9	1,240-1,260	do	Jj
12	T. 33 N., R. 19 W.	do	1956	1,500	*6	OH 402-1,500	do	Kd, Jj, Je
13	T. 33½ N., R. 17 W, NE¼NW¼ SE¼ sec. 7.	U.S. Bureau of Indian Affairs.	1931	1,750	*8, 6	OH 1,073-1,750	do	Jj, Je J₸n
14	T. 33½ N., R. 17 W., NE¼SE¼ SE¼ sec. 7.	Pyle Trading Co.		98	*6		Sand and gravel.	Qal
15	T. 33½ N., R. 17 W., NE¼SE¼ SE¼ sec. 7.	U.S. Bureau of Indian Affairs.	1954	65.8	*8, 7	32-40	do	Qal
16	T. 33½ N., R. 17 W., SW¼SE¼ SE¼ sec. 7.	do	1954	960.0	*8, 6	804-936	Sandstone.	Jms
17	T. 33½ N., R. 17 W., NE¼NW¼ NE¼ sec. 18.	do	1957	1,769.0	*12, 8, 6	OH 1,264-1,769	do	Jj, Je, J₸n
18	T. 33½ N., R. 17 W., NE¼SW¼ SW¼ sec. 17.	do	1957	2,002.0	*7, 5	1,460-2,000	do	Jj, Je, J₸n
19	T. 33½ N., R. 17 W., NW¼NW¼ SW¼ sec. 8.	do	1957	1,825.0	*7, 5, 4		do	Jj, Je, J₸n
S-1	T. 34 N., R. 17 W., NE¼NE¼ NW¼ sec. 6.	Ute Mountain, Ute Tribe of Indians.						Qp, Kd
2	T. 34 N., R. 17 W., SW¼SW¼ NE¼ sec. 6.	do						Qt, Kd
3	T. 35 N., R. 18 W., SE¼SW¼ NE¼ sec. 35.	do						TKi, Km
4	T. 35 N., R. 18 W., SW¼SW¼ SW¼ sec. 35.	do						TKi, Km
5	T. 35 N., R. 18 W., NW¼SW¼ SW¼ sec. 25.	do						Kmj
6	T. 35 N., R. 18 W., NW¼NW¼ SW¼ sec. 25.	do						TKi
7	T. 35 N., R. 18 W., SW¼SW¼ NW¼ sec. 25.	do						TKi, Km
8	T. 35 N., R. 18 W., NE¼NE¼ SE¼ sec. 27.	do						TKi, Km
9	T. 35 N., R. 18 W., NE¼SW¼ SE¼ sec. 23.	do						Qt
10	T. 35 N., R. 18 W., NW¼SW¼ NW¼ sec. 24.	do						Qt
11	T. 35 N., R. 18 W., SE¼NE¼ NE¼ sec. 23.	do						Qt
12	T. 35 N., R. 17 W., NW¼NW¼ NE¼ sec. 19.	do						Qt
13	T. 35 N., R. 17 W., SE¼SW¼ SE¼ sec. 18.	do						Qt

selected springs—Continued

Method of lift, and type of power	Pump setting (in ft below land surface)	Yield		Drawdown		Altitude	Depth to water	Date of measurement	Use of water	Remarks
		Tested	Operating	Feet	Hours					
C, W	--------	17 B	5	256	1	5,880	73.3	7-17-58	S	A, L.
--------	--------	F	200±	--------	--------	4,985	--------	12-10-57	S	Plugged at 3,000 ft. Abandoned oil test, Continental Oil Co.
--------	--------	--------	--------	--------	--------	5,110	60.0	6-24-59	N	Well originally flowed 4 gpm, caved below 402 ft.
--------	--------	17 BR	--------	--------	48	5,922	60.8	2- 9-54	N	A, L. Abandoned.
C, E	--------	3 R	--------	40	--------	5,880	33.5	2- 7-54	D	A.
C, E	--------	10.3 P	--------	3.5	6.5	5,885	31.1	2- 4-54	N	A, L. Not in use June 1959.
--------	--------	9 B	--------	250	1	5,885	625	4-21-54	N	A, L. Pumping less than 1 gpm Feb. 10, 1956. Abandoned in 1956.
C, E	--------	40	40	412	48	5,877	371.0	2-15-57	P	A, L.
C, E	--------	20	20	920	24	5,739	277.6	9-27-57	P	A, L.
C, E	1,162	20	20	806	27	5,917	349.5	11-10-57	P	A, L.
--------	--------	5.0	--------	--------	--------	6,810	--------	8-13-57	D	A.
--------	--------	.2	--------	--------	--------	6,890	--------	8-13-57	N	Not developed.
--------	--------	20.0	--------	--------	--------	7,800	--------	8-13-57	S	Cement trough and storage tank.
--------	--------	5	--------	--------	--------	8,120	--------	8-13-57	S	Cement troughs.
--------	--------	10.0	--------	--------	--------	7,860	--------	8-22-57	N	Not developed.
--------	--------	<1	--------	--------	--------	7,800	--------	8-22-57	N	Do.
--------	--------	10.0	--------	--------	--------	7,960	--------	8-22-57	N	Do.
--------	--------	20.0	--------	--------	--------	8,600	--------	8-13-57	S	
--------	--------	8.0	--------	--------	--------	8,550	--------	8-14-57	S	Cement troughs and spring house.
--------	--------	50	--------	--------	--------	7,800	--------	8-22-57	N	Not developed, supplies earth reservoir.
--------	--------	75	--------	--------	--------	7,680	--------	7-18-58	N	Not developed.
--------	--------	15.0	--------	--------	--------	7,520	--------	8-13-57	S	Cement basin.
--------	--------	20.0	--------	--------	--------	7,520	--------	8-13-57	S	Do.

TABLE 4.—*Records of wells and*

No. on plate 1	Location	Owner or user	Year completed	Depth of well	Casing: Diameter (inches)	Casing: Perforated interval (feet)	Character of material	Geologic source
S-14	T. 35 N., R. 17 W., NE¼SW¼ SE¼ sec. 20.	Ute Mountain, Ute Tribe of Indians	-------	---------	--------	------------	------------	Qt
15	T. 33½ N., R. 17 W., NE¼NE¼ SE¼ sec. 29.	----do------	-------	---------	--------	------------	------------	Qal, Km
16	T. 33½ N., R. 18 W.	----do------	-------	---------	--------	------------	------------	Qal, Km
17	T. 31 N., R. 15 W.	----do------	-------	---------	--------	------------	------------	Qal, Kch
18	T. 33½ N., R. 19 W., NE¼NE¼ NW¼ sec. 24.	----do------	-------	---------	--------	------------	------------	Kd

WELLS

Most ground water on the reservation is obtained from wells, shown in table 4. Wells in use are all drilled; however, there are several abandoned dug wells.

DUG WELLS

The few dug wells in the area are in the alluvium near Towaoc and the Mancos River. Most have failed during dry years and have not been put back in use. They range in diameter from 3 to 7 feet and are generally not more than 10 feet deep. They are cased with wood and stone. These wells are susceptible to surface contamination.

DRILLED WELLS

Drilled wells are the source of most water supplies on the reservation. Most were drilled by cable tools, which may be time consuming. Cable-tool drilling, however, permits collection of reliable samples for use in interpretation of subsurface geology, and, more important, facilitates the detection of small quantities of water.

The wells range from 30 to more than 2,000 feet in depth, depending on geologic conditions. Throughout most of the reservation, the major aquifer, the Dakota Sandstone, is overlain by the relatively impermeable Mancos Shale. Wells are drilled through the Mancos to the top of the Dakota, and casing is seated and cemented to prevent caving of the overlying shale and contamination of the Dakota water from surface seeps or water of poor quality in the Mancos. The wells generally have wrought-iron or galvanized-iron casings, ranging from 5 to 8 inches in diameter. A smaller diameter hole is then drilled into the Dakota or the underlying Burro Canyon Formation.

selected springs—Continued

Method of lift, and type of power	Pump setting (in ft below land surface)	Yield: Tested	Yield: Operating	Drawdown: Feet	Drawdown: Hours	Altitude	Depth to water	Date of measurement	Use of water	Remarks
--------	--------	3.0	--------	--------	--------	6,800	--------	8-13-57	S	Cement troughs.
--------	--------	5.0	--------	--------	--------	5,400	--------	1-18-54	D, S	A. Navajo spring, dry 1960.
--------	--------	1	--------	--------	--------	5,580	--------	9-10-57	N	Not used.
--------	--------	.25	--------	--------	--------	5,550	--------	6-21-59	D, S	Cement collection basin and trough.
--------	--------	--------	--------	--------	--------	5,720	--------	12- 6-56	S	A. Supplies small earth reservoirs.

Commonly, only the upper sandstone units of the Dakota are penetrated if they yield sufficient water for stock. The Dakota is generally not cased in a stock well, as the sandstone walls usually do not cave.

Wells drilled to Jurassic aquifers are cased and cemented to the top of the Dakota. Then they are cased with a second string of casing into the basal sandstone of the Morrison Formation. The casing in sandstone of the Dakota and Morrison is perforated; formations below the basal sandstone of the Morrison are commonly left uncased.

Wells drilled into unconsolidated alluvial material are generally cased with 4- to 6-inch casing for the entire depth of the well. The casing is usually slot perforated opposite the saturated section.

COLLECTION GALLERIES

Part of the ground-water supplies for the Towaoc area is obtained from two collection galleries—systems of ditches or pipes which extend laterally into the water-bearing materials and through which water flows by gravity to the land surface or into a sump or well. The galleries near Towaoc tap alluvial deposits.

The collection gallery (G–1, pl. 1) 1.7 miles north of Towaoc was the only source of water for Towaoc for several years before 1954. It consists of perforated galvanized-iron pipe, ranging in diameter from 12 to 24 inches, placed on top of the Mancos Shale in a trench in the alluvium and backfilled with 7 to 17 feet of sand and gravel (Powell, 1954, p. 9). The system was constructed in the alluvium of Cottonwood Creek and lies parallel to the stream channel. A plan view of the gallery is given on figure 11. Segments AB and AC were constructed in January and February 1954 to intercept addi-

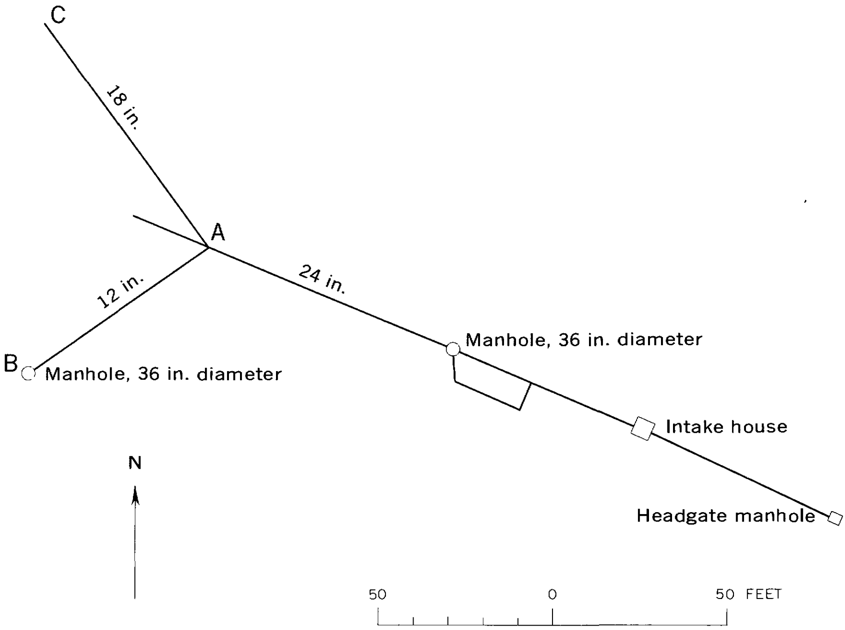

FIGURE 11.—Layout of infiltration gallery, G-1, northwest of Towaoc.

tional water (Powell, 1954, p. 9). Water collected in the system at the intake house is transported 1¼ miles by a 4-inch pipe to a concrete-covered reservoir approximately 120 feet in diameter and 12 feet deep, having a storage capacity of 1,015,000 gallons.

Before 1957 discharge from the gallery ranged from a few gallons per minute during the fall, winter, and early spring to 35 gpm during the summer. In June 1957, yields from the gallery increased to as much as 100 gpm. This increased yield was probably caused by above-normal precipitation in 1957 and by the construction of a reservoir on Cottonwood Creek one-fourth mile upstream from the infiltration gallery. The reservoir is probably recharging the infiltration gallery through seepage into the alluvium of Cottonwood Creek. Cottonwood Creek drains a large area, and this reservoir retains a part of the water from snowmelt and precipitation that normally would run off in Cottonwood Creek. The water in the reservoir then slowly recharges the alluvium and thence the infiltration gallery.

During the construction of a race track a mile south of Towaoc in 1957, the water table in the alluvium was breached, and part of the track was flooded. A collection system of pipe (G-2, pl. 1) was buried in the section where the water table was breached, and the area drained through a sump into Cottonwood Creek. At a later date a pump was installed in the sump, and the water was pumped directly into the Towaoc water system.

Interception of the water table by this network created an artificial point of discharge for water in the alluvium. Within a few years the former natural discharge points, several small seeps and springs a few miles south of Towaoc, dried up. The largest of these, Navajo Spring (S–15, pl. 1), which yielded about 5 gpm throughout its recorded history, was the original site of Towaoc.

Yields from the collection gallery vary with the precipitation. During wet years the gallery has yielded as much as 35 gpm; in 1962, a dry year, the yield was less than 10 gpm.

DEVELOPMENT OF WATER SUPPLIES DURING THIS INVESTIGATION

STOCK SUPPLIES

As the economy of the Ute Mountain Indians advanced under their rehabilitation program, the need for adequate stock-water supplies became acute. Drought years left most of their earthen reservoirs empty and their springs dry. The number of drilled stock wells throughout parts of the potential grazing land was inadequate, and several costly dry wells had been drilled. A stock-water drilling program, therefore, was begun early in the investigation. After a study of the geology and the data available from wells, recommendations were made for several test-drilling sites. Twelve test wells were completed on the reservation and two off the reservation, with several more sites remaining to be tested.

Most of the test drilling was contracted to a private well driller, using cable-tool rigs. Sample cuttings were collected and analyzed, and detailed lithologic logs for each well were compiled. Bail tests were made of each well to estimate potential yield. Water from each well was analyzed for chemical quality in the field, and that from selected wells was analyzed in the laboratory.

Stock wells drilled during the investigation are all in the west half of the reservation. The locations of the wells were coordinated with the geologic conditions and with the availability and condition of grass for grazing as determined by the range-management officers of the Ute Mountain Tribe and the Bureau of Indian Affairs. The distance that livestock will walk to a water supply was assumed to be 2 miles; an attempt was made to make a water supply available (either ground water or surface water) within 2 miles of every part of this western area where grazing was practicable. Surface storage or intermittent stream supplies are not reliable sources of water in most parts of the project area, and, wherever possible or practical, ground-water supplies were developed. Plate 3 shows the areas that are now available to grazing by the development of either permanent ground-water or temporary surface-water supplies. Many of the areas of ground-water supplies shown on this map were developed as a result of the well-drilling phase of the present investigation.

PUBLIC SUPPLIES

In addition to the need for stock water, the need for adequate supplies of water for Towaoc was critical, and special investigations were made to alleviate the water shortage. After a review of the stratigraphy and other available data, it was recommended that a deep test well or wells be drilled at Towaoc to test the Junction Creek, Entrada, and Navajo Sandstones. Wells B–17, B–18, and B–19 were drilled in 1956 and 1957 as a part of this investigation and in cooperation with the Bureau of Indian Affairs at Gallup, N. Mex.

Well B–17, drilled with cable tools, was completed in January 1957 at a depth of 1,769 feet in the Navajo Sandstone.

A 9-inch hole was drilled into the basal sandstone of the Morrison Formation, where 8⅝-inch casing was set and cemented under pressure. The cement rose outside the casing to within 200 feet of the surface. This was done to seal off the black sulfur water in the limestone of Greenhorn age in the Mancos Shale, as well as water of poor quality in the Dakota Sandstone and the Burro Canyon Formation. Wells B–18 and B–19 were cemented similarly.

Wells B–18 and B–19 were drilled in 1957 with a rotary drill. Well B–18 was finished in the Navajo Sandstone at a depth of 2,002 feet, and B–19 was finished in Wingate(?) Sandstone at a depth of 1,825 feet. Logs of these wells are given on pages G95–G102. Methods and results of aquifer tests made at the sites of the wells are discussed on the following pages.

AQUIFER TESTS

By Edward D. Jenkins

Aquifer tests were made to determine the hydraulic properties of the aquifers penetrated by wells B–17, B–18, and B–19. During these tests, the wells were pumped at a nearly uniform rate for 1 to 2 days. The discharge and depth to the water level were measured at periodic intervals. After pumping stopped, water levels were measured periodically until they approached their prepumping level.

Data gathered during the tests were analyzed by nonequilibrium methods, using the equation developed by Theis (1935). The results are summarized in table 5. Terms used to describe the hydraulic properties of the aquifer and well performance are defined as follows:

TABLE 5.—*Summary of results of aquifer tests at the sites of wells B-17, B-18, and B-19, Towaoc, Colo.*

No. on plate 1	Depth of well (feet)	Geologic source	Aquifer interval (feet)	Saturated thickness of sandstone (feet)	Casing: Perforated or open-hole interval	Casing: Diameter (inches)	Altitude of land surface (feet)	Depth to water below land surface (feet)	Date of measurement	Average pumping rate (gpm)	Drawdown (feet)	Specific capacity (gpm per ft of drawdown)	Duration of pumping (hours)	Coefficient of—Transmissibility (gpd per ft)	Coefficient of—Permeability (gpd per sq ft)	Apparent coefficient of storage	Field determinations: Specific conductance, in micromhos at 25° C	Field determinations: Hardness as $CaCO_3$ (ppm)	Field determinations: Water temperature (° F)
B-17 [1]	1,769	Junction Creek Sandstone	1,100-1,360	260															
		Entrada Sandstone	1,510-1,580	70	1,264-1,769	8⅝-6⅝	5,877	371.0	2-15-57	40	412	0.10	48	90	0.2	8×10^{-3}	2,370	22	80
		Navajo Sandstone	1,580-1,769	189															
18 [2]	2,002	Junction Creek Sandstone	1,390-1,620	230															
		Entrada Sandstone	1,770-1,850	80	1,460-2,002	7-5	5,739	277.6	9-27-57	20	920	.02	24	25	.05	1×10^{-3}	2,250	25	88
		Navajo Sandstone	1,850-2,002	152															
19	1,825	Junction Creek Sandstone	1,140-1,380	240															
		Entrada Sandstone	1,510-1,600	90	1,205-1,825	7-4½	5,917	349.5	11-10-57	20	806	.02	27	20	.04	----------	1,900	25	80
		Navajo Sandstone	1,600-1,780	180															
		Wingate(?) Sandstone	1,780-1,825	45															

1 Diameter of drill hole enlarged below 1,100 ft while fishing for tools.
2 Discharge turbid.

Permeability and transmissibility describe the ability of an aquifer to transmit water. The field coefficient of transmissibility may be expressed as the number of gallons of water per day at the prevailing temperature that is transmitted through a mile-wide section for the entire thickness of the water-bearing formation, under a gradient of 1 foot per mile. The coefficient of permeability is a similar measure but for only a thickness of 1 foot of the water-bearing bed and may be expressed as the number of gallons of water per day transmitted through each mile-wide section of the water-bearing bed under a gradient of 1 foot per mile—it is the field coefficient of transmissibility divided by the thickness of the aquifer, in feet.

Coefficient of storage describes the ability of the aquifer to yield water from storage. It is defined as the volume of water an aquifer releases from or takes into storage per unit of surface area of the aquifer per unit change in the component of head normal to that surface.

Specific capacity describes well performance; it is determined by dividing the pumping rate, in gallons per minute, by the drawdown, in feet. Specific capacity differs with the percentage of penetration, construction, and development; quantity and duration of pumping; and the hydraulic properties of the aquifer.

The coefficients of transmissibility determined by the tests ranged from 20 to 90 gpd (gallons per day) per foot and the coefficient of permeability averaged 0.1 gpd per square foot. (See table 5.) All the aquifers tested have a low permeability.

The apparent coefficients of storage as determined by pumping tests ranged from 8×10^{-3} (well B–17) to 1×10^{-3} (well B–18), which approach the storage coefficients for artesian aquifers—1×10^{-5} to 1×10^{-3}.

Logs of wells and the geology indicate that the water in the aquifers is under artesian pressure. Coefficients of storage measured in similar aquifers suggest that the coefficient of storage should be some multiple of 10^{-4}, say about 5×10^{-4}. Although this suggested coefficient of storage is low, the aquifers contain considerable water because of their large areal extent.

The coefficients of storage determined from the tests could be in error because the only available observation wells were beyond the radius of influence of the pumped wells; meaningful measurements, therefore, could be made only in the pumped wells. The assumption was made that the effective radius of the pumped well was equal to the radius of the drill bit; this assumption may be erroneous, but to what degree is not known. Difficulties were encountered in trying to straighten the hole and in fishing for tools in well B–17, which resulted in a drill hole probably several times larger than the drill bit; therefore, the effective radius of well B–17 was assumed to be 1¼ feet. Effective radius for well B–18 was assumed to be 0.3 foot.

Specific capacity ranged from 0.02 to 0.10 gpm per foot of drawdown. Although the combined yield of the three wells was 80 gpm, specific capacities indicate that the combined yield could be as much as 100 gpm.

Table 5 shows the variation in well performance. The aquifers supplying the wells should have similar hydraulic properties, but well B–17 has a higher specific capacity than the others, probably the result of difference in well construction and development.

Well B–17 was pumped continuously for 48 hours at an average of 40 gpm. The pumping level at the end of this period was 783 feet below the land surface, as shown on figure 12. Data from this test indicate that the well could yield 60 gpm continuously for at least 15 days with a pumping level of about 1,200 feet at the end of the period.

Well B–18 was pumped continuously for 24 hours at an average of 20 gpm. The pumping level at the end of this period was 1,200 feet below the land surface. As the well is constructed with only 4-inch casing from 1,390 to 2,002 feet, it might be difficult to install a pump below the 1,390-foot level. Therefore, 20 gpm is the maximum pumping rate that can be expected from this well for periods of 30 days. The water pumped was turbid, indicating that the well may not have completely developed. Further pumping and development might increase the yield.

Well B–19 was pumped continuously for 27 hours at an average of 20 gpm. The pumping level at the end of this period was 1,156 feet below the land surface. The maximum pumping rate that can be expected from this well for periods of 30 days is about 20 gpm.

Water levels in wells B–17 and B–18, at distances of 3,050 and 6,170 feet, respectively, from well B–19 did not decline while well B–19 was being pumped.

Figures 12 and 13 are useful in planning a well field and in predicting its performance. Figure 12 illustrates how data from the test of well B–17 were useful in determining size and setting of the pump and in indicating probable performance of the well with continuous pumping. The projection of the depth to water, after pumping 40 gpm for 21 days, based on the test data in February 1957 was relatively close to the observed depth to water after pumping 40 gpm for 21 days in March 1958. When pumping stops, the water level will rise nearly to the prepumping level. When pumping is resumed, the level will decline again, with time, similarly to the decline shown on the curve on figure 12. This shows that pumping lifts can be reduced by intermittent rather than continuous pumping.

Figure 13 shows the theoretical decline in water level in an aquifer of infinite areal extent, having similar hydraulic properties to those

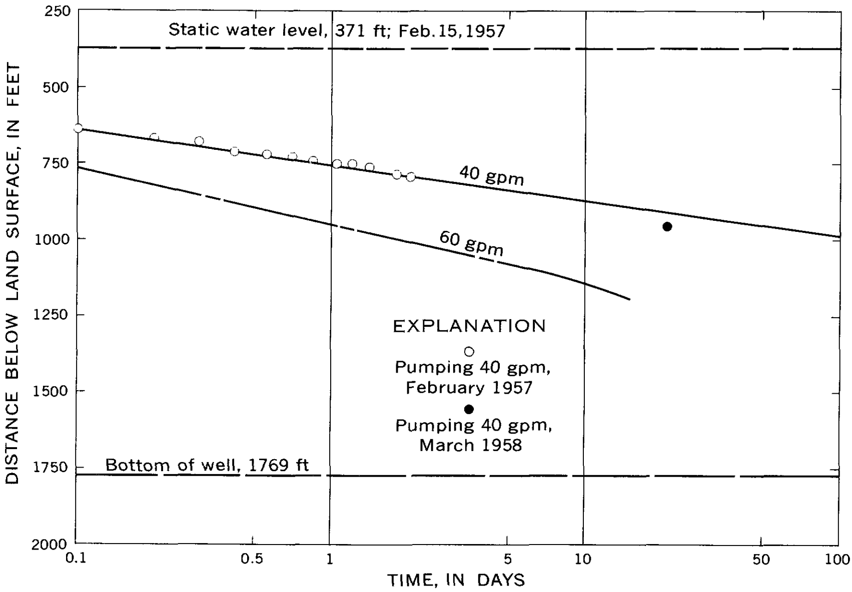

FIGURE 12.—Curves showing depth to water in well B-17 while discharging 40 and 60 gpm for periods ranging from 0.1 to 100 days.

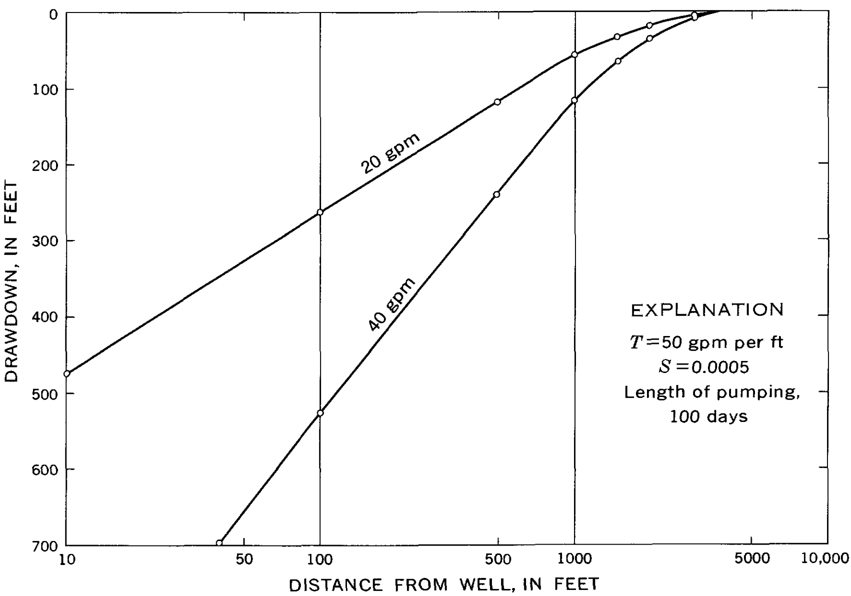

FIGURE 13.—Theoretical declines in water level caused by a well discharging 20 and 40 gpm from the Junction Creek, Entrada, Navajo, and Wingate Sandstones for 100 days at distances ranging from 10 to 10,000 feet from the discharging well. T, coefficient of transmissibility. S, coefficient of storage.

tested. Figure 13 indicates that wells spaced at least a quarter of a mile apart would have little effect on one another when pumped intermittently and, if pumped continuously for long periods, would have little effect if spaced half a mile apart.

The tests show that well B–17 could be pumped 40 to 60 gpm, and wells B–18 and B–19 could be pumped 20 gpm. Records to this time (1963) show that the wells have yielded these amounts for intermittent periods.

QUALITY OF WATER

The chemical quality of ground water is shown by the analyses of water from 38 representative wells and springs (table 6). Samples were analyzed in laboratories of the Geological Survey unless otherwise noted in the table.

The chemical quality of the water generally reflects the chemical composition of rocks with which the water comes in contact. The amount of material in the water dissolved from the rock depends on several factors, including temperature of the water, length of time the water is in contact with the rock, the rate of movement of water through the rock, and the solubility of the rock.

The dissolved-mineral constituents of water are reported in parts per million (ppm). A part per million is a unit weight of a constituent in a million unit weights of water.

Results in parts per million can be converted to grains per gallon by dividing by 17.12. Specific conductance is a measure of the ability of water to conduct an electric current and is expressed in micromhos per centimeter at 25° C. It can be used to estimate the amount of dissolved solids in water. Although no exact relation exists between conductance and dissolved solids in natural water, the conductivity multiplied by 0.7 is a close approximation to the dissolved solids, in parts per million.

Ground water in the project area is used for domestic and stock purposes, and the water-quality requirements differ for these uses. Hardness and the concentrations of dissolved solids, iron, manganese, magnesium, chloride, sulfate, nitrate, and fluoride are important to the domestic users. The concentrations of dissolved solids, nitrate, fluoride, and other constituents are important in stock water supplies.

DOMESTIC USE

Quality standards for potable water were established by the U.S. Public Health Service (1962) for use by interstate carriers. Standards for some of the major chemical constituents are given in table 7.

TABLE 6.—*Chemical*

[Measured depths are given in feet and tenths below land surface; reported depths are given in feet below Wash Sandstone Member of the Morrison Formation; Kb, Burro Canyon Formation; Kd, Dakota Sandstone; Qp, pediment deposits; Qal, alluvium. Results in parts per million except as indicated]

No. on plate 1	Location	Depth (feet)	Geologic source	Date of collection	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)
A-1 [2]	T. 33 N., R. 18 W.	774.7	Kd	12- 5-56	64	-----	-----	-----	------	------	683	4
2 [2]	T. 33 N., R. 18 W.	165.0	Kmj	12- 5-56	58	-----	-----	-----	------	------	1,790	20
3 [2]	T. 33 N., R. 19 W.	699	Kd	12- 5-56	64	-----	-----	-----	------	------	409	2
4 [2]	T. 33 N., R. 19 W.	665	Kd	12- 5-56	64	-----	-----	-----	------	------	719	4
5	T. 33 N., R. 20 W.	250	Kd(?)	6-24-59	60	-----	-----	-----	0.0	0.0	432	1.3
6	T. 33½N., R. 20 W., NE¼ NW¼NW¼ sec. 32.	271.0	Kd	12- 6-56	60	-----	-----	-----	------	------	258	2
7 [2]	T. 35 N., R. 19 W., C, N½ NW¼SW¼ sec. 35.	--------	Kd	12- 6-56	-----	-----	-----	-----	21	23	1,050	16
8 [2]	T. 34 N., R. 19 W., NW¼ SW¼SW¼ sec. 8.	108.6	Kd	12- 7-56	57	-----	-----	-----	60	41	634	9
9 [3]	T. 33½ N., R. 17 W., SE¼ SE¼SE¼ sec. 3.	1,025	Kd	12-13-56	-----	-----	0.7	0	0	0	375	------
9 [2]	T. 33½ N., R. 17 W., SE¼ SE¼SE¼ sec. 3.	1,025	Kd	12- 5-56	68	-----	-----	-----	------	------	373	2
13	T. 31 N., R. 14 W.	302	Kch	6-21-59	66	-----	-----	-----	158	156	168	5.0
B-1 [2]	T. 33½ N., R. 19 W., NW¼ NW¼NW¼ sec. 30.	177.0	Kd, Kb	12- 6-56	-----	-----	-----	-----	36	12	338	6
2 [3]	T. 33½ N., R. 18 W.	77.0	Qal	12- 6-56	56	-----	-----	-----	65	12	45	0
5	T. 33½ N., R. 19 W., NW¼ NW¼NE¼ sec. 26.	204.0	Kmg	6-24-59	62	-----	-----	-----	2.4	.0	635	1.9
7	T. 33 N., R. 17 W., NW¼ NE¼SE¼ sec. 17.	1,346.0	Kd	6-25-59	66	-----	-----	-----	3.2	.5	740	2.2
10 [4]	T. 33½ N., R. 17 W., C, SW¼ SW¼ sec. 18.	528.0	Kd, Kb	7-18-58	63	8.0	0.0	0.00	27	14	260	4.4
11 [2]	T. 33 N., R. 20 W.	6,252	Jj	12- 5-56	71	-----	-----	-----	39	16	1,660	13
11	T. 33 N., R. 20 W.	6,252	Jj	6-24-59	75	-----	-----	-----	22	11	1,590	8.1
13 [5]	T. 33½ N., R. 17 W., NE¼- NW¼SE¼ sec. 7.	1,750	Jj, Je, J₹n	11-10-53	-----	-----	-----	-----	------	------	------	------
13 [5]	T. 33½ N., R. 17 W., NE¼ NW¼SE¼ sec. 7.	1,750	Jj, Je, J₹n	11-10-53	-----	-----	-----	-----	------	------	------	------
13 [5]	T. 33½ N., R. 17 W., NE¼ NW¼SE¼ sec. 7.	1,750	Jj, Je, J₹n	11-10-53	-----	-----	-----	-----	------	------	------	------
13 [5]	T. 33½ N., R. 17 W., NE¼ NW¼SE¼ sec. 7.	1,750	Jj, Je J₹n	--------	-----	-----	-----	-----	------	------	------	------
13 [5]	T. 33½ N., R. 17 W., NE¼ NW¼SE¼ sec. 7.	1,750	Jj, Je, J₹n	11-10-53	-----	-----	-----	-----	------	------	------	------

See footnotes at end of table.

analyses of water

land surface. J̄Rn, Navajo Sandstone; Je, Entrada Sandstone; Jj, Junction Creek Sandstone; Jms, Salt Sandstone; Km, Mancos Shale; Kmg, Limestone of Greenhorn age in the Mancos Shale; Kch, Cliff House

Bicarbonate [1] (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium	Sodium adsorption ratio	Specific conductance (micromhos/cm at 25°C)	pH	Remarks
1,550	10	160	------	------	2,420	14	0	99	80	--------	8.7	
1,120	2,690	190	------	------	6,000	38	0	98	127	--------	8.3	Strong sulfur odor.
957	10	84	------	------	1,470	14	0	98	48	--------	8.6	
1,630	13	162	------	------	1,890	11	0	99	94	--------	8.4	Sulfur odor.
1,030	25	50	4.8	0.0	1,020	0	0	100	------	1,700	8.4	Do.
516	122	17	------	------	920	8	0	98	41	--------	8.7	Do.
1,090	1,360	80	------	------	5,860	147	0	95	38	--------	8.6	
768	990	34	------	------	2,560	317	0	81	16	--------	8.4	
660	0	134	1.0	------	-------	-------	------	100	------	1,540	8.7	Pb-0, As-0, Cr-0, Cu-0, Zn-0.
787	11	136	------	------	1,320	28	0	96	31	--------	8.4	
638	818	40	.4	.0	1,660	1,040	512	26	6.5	2,250	7.4	
634	324	16	------	------	1,380	140	0	83	12	--------	8.7	
237	113	5	------	------	465	210	16	32	1.4	--------	7.9	
1,040	265	188	6.4	.0	1,610	6	0	99	113	2,640	8.2	Sulfur odor.
1,600	6.2	215	10	.0	1,760	10	0	99	104	2,930	8.2	
420	256	57	.3	.0	834	125	0	81	10	1,300	7.7	Al., PO_4.
459	1,940	904	------	------	5,100	160	0	95	57	--------	8.4	
415	1,910	920	3.8	.0	4,670	100	0	97	69	7,240	8.6	
780	-------	5	------	------	-------	-------	------	------	------	1,310	------	Water level 55 ft, water is black.
796	-------	5	------	------	-------	-------	------	------	------	1,290	------	Water level 160 ft, water is black.
692	-------	5	------	------	-------	-------	------	------	------	1,340	------	Water level 369 ft, water is black.
752	-------	8	------	------	-------	-------	------	------	------	1,300	------	Water level 501 ft, water is black.
798	-------	9	------	------	-------	-------	------	------	------	1,300	------	Water level 650 ft, water is black.

See footnotes at end of table.

Table 6.—*Chemical*

No. on plate 1	Location	Depth (feet)	Geologic source	Date of collection	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)
B-13 [5]	T. 33½ N., R. 17 W., NE¼NW¼SE¼ sec. 7.	1,750	Jj, Je JTRn	11-10-53	-----	-----	-----	-----	-----	-----	-----	-----
14	T. 33½ N., R. 17 W., NE¼SE¼ SE¼ sec. 7.	98	Qal	11- 5-53	-----	20	-----	-----	100	48	21	-----
15	T. 33½ N., R. 17 W., NE¼SE¼ SE¼ sec. 7.	65.8	Qal	2- 7-54	56	-----	-----	-----	-----	-----	17	-----
15	T. 33½ N., R. 17 W., NE¼SE¼ SE¼ sec. 7.	65.8	Qal	2- 7-54	56	-----	-----	-----	-----	-----	17	-----
15	T. 33½ N., R. 17 W., NE¼SE¼ SE¼ sec. 7.	65.8	Qal	3-12-54	58	22	-----	-----	122	20	21	-----
16	T. 33½ N., R. 17 W., SW¼SE¼ SE¼ sec. 7.	960.0	Kmg	2-22-54	58	-----	-----	-----	-----	-----	-----	-----
16	T. 33½ N., R. 17 W., SW¼SE¼ SE¼ sec. 7.	960.0	Kd	2-27-54	54	-----	-----	-----	-----	-----	-----	-----
16	T. 33½ N., R. 17 W., SW¼SE¼ SE¼ sec. 7.	960.0	Kd	3- 2-54	58	-----	-----	-----	-----	-----	-----	-----
16	T. 33½ N., R. 17 W., SW¼SE¼ SE¼ sec. 7.	960.0	Kd, Kb	3-15-54	59	6.9	-----	-----	68	34	219	-----
17	T. 33½ N., R. 17 W., NE¼ NW¼NE¼ sec. 18.	1,769.0	Jj	1- 3-57	72	-----	-----	-----	4.8	2.4	-----	539
18	T. 33½ N., R. 17 W., NE¼SW¼ SW¼ sec. 17.	2,002.0	Jj, Je, JTRn	---------	85	15	-----	-----	-----	-----	-----	-----
19	T. 33½ N., R. 17 W., NW¼ NW¼SW¼ sec. 8.	1,825.0	Jj, Je, JTRn	2-13-59	78	-----	-----	-----	2.4	.0	444	2.8
S-1	T. 34 N., R. 17 W., NE¼ NE¼NW¼ sec. 6.	-------	Qp, Kd	10- 3-51	-----	18	-----	-----	155	16	-----	12
15	T. 33½ N., R. 17 W., NE¼ NE¼SE¼ sec. 29.	-------	Qal, Km	10- 3-51	61.5	27	-----	-----	141	39	-----	39
18 [2]	T. 33½ N., R. 19 W., NE¼ NE¼NW¼ sec. 24.	-------	Kd	12- 6-56	40	-----	-----	-----	129	36	67	6
	T. 34 N., R. 17 W., sec. 5.	-------	Qal	7-11-50	50	21	-----	-----	162	28	-----	13
	T. 33½ N., R. 17 W., sec. 18.	-------	Qal	7-11-50	72	19	-----	-----	78	42	-----	114
	Navajo Wash, east of Towaoc infiltration gallery.	-------	---------	3- 1-53	-----	-----	-----	-----	-----	-----	-----	1,100
G-2	T. 33½ N., R. 17 W., SW¼ SW¼SW¼ sec. 17.	-------	Qal	5-24-60	56	25	0.13	0.12	126	54	42	-----

[1] Contains carbonate as bicarbonate when present.
[2] Analysis by Petroleum Research Corp.
[3] Analysis by Colorado State Dept. of Public Health.

analysis of water—Continued

Bicarbonate[1] (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium	Sodium adsorption ratio	Specific conductance (micromhos/cm at 25°C)	pH	Remarks
844	-------	5	------	------	------	------	------	------	------	1,390	------	Water level 900 ft, water is black.
302	223	8	0.2	1.2	[6] 570	447	200	9	0.4	871		
286	161	8	.2	------	[6] 527	376	142	9	.4	754	6.9	Sample collected after pumping 6 min at 10.3 gpm.
290	158	8	.2	------	[6] 538	376	138	9	.4	765	7.0	Sample collected after pumping 6 hrs at 10.3 gpm.
292	169	10	.2	2.3	510	386	147	11	.5	761	------	Sample collected after 25 days of continuous pumping.
197	-------	-------	------	------	------	------	------	------	------	8,900	11.7	Sample collected from depth of 246 ft during drilling.
512	-------	23	------	------	------	------	------	------	------	1,440	8.5	Sample collected from depth of 330 ft during drilling.
496	-------	18	.6	------	------	------	------	------	------	1,430	8.0	Sample collected from depth of 391 ft during drilling.
446	383	15	.2	.6	946	309	0	61	5.4	1,440	------	Sample collected from depth of 477 ft during drilling.
864	379	60	2.8	.1	1,410	22	0	98	50	2,370	8.4	Sample collected from depth of 1,400 ft during drilling.
1,130	860	121	------	------	[6] 2,760	36	------	------	------	-------	8.5	
755	-------	11	3.0	------	------	6	0	99	79	1,900	8.6	
385	151	4	.1	.1	546	452	137	5	.2	833	------	
224	372	18	.3	.6	747	512	329	14	.8	1,050	------	
229	403	13	------	------	875	472	284	43	1.3	-------	7.8	
360	227	10	.1	.4	638	519	224	5	.2	939	------	Seep in Cottonwood Creek.
338	296	20	.2	.4	737	367	90	40	2.6	1,060	------	Do.
901	-------	166	------	------	------	3,530	2,240	40	8.0	7,870	------	Surface water.
300	345	22	.2	.3	812	537	291	14	.8	1,080	7.7	

[4] Beta activity <40 microcuries per liter; Radium 0.7 micro-microcuries per liter; Uranium 3.0 ±0.3 micrograms per liter.
[5] Analysis from Bur. of Indian Affairs.
[6] Residue on evaporation at 180° C.

TABLE 7.—*Quality standards for potable water, established by the U.S. Public Health Service for some chemical constituents*

Constituents	*Concentration (ppm)*
Iron (Fe)	0.3
Manganese (Mn)	.05
Chloride (Cl^{-1})	250
Sulfate (SO^{4-2})	250
Fluoride (F^{-1})	[1]
Nitrate (NO^{3-1})	45
Dissolved solids	[2] 500

[1] Lower, optimum, and upper limits, based on the annual average of maximum daily air temperature of the area, are now used for fluoride. In the project area these limits are 0.7 ppm (lower), 0.9 ppm (optimum), and 1.2 ppm (upper).
[2] 1,000 ppm permitted if no other supply is available.

Dissolved-solids content of water samples ranged from 465 to 6,000 ppm. Although water from surficial deposits is considerably lower in dissolved-solids content than water from bedrock aquifers, most of the water samples collected have greater dissolved-solids content than recommended by the U.S. Public Health standards (1962).

Concentrations of chemical constituents that exceed the recommended limits may make a water undesirable for domestic use. Excess chloride content gives water a salty taste. High magnesium concentrations in combination with sulfate have a laxative effect. Fluoride in concentrations above the upper limits recommended for the area (table 7), may give rise to fluorosis of bone tissue and teeth. This commonly is manifested as mottled teeth in children. However, concentrations of about 0.6 to 1.7 ppm in water has been found to reduce the incidence of dental caries (U.S. Public Health Service, 1962). Nitrate content in excess of 45 ppm (U.S. Public Health Service, 1962) is dangerous to infants, causing methemoglobinemia or cyanosis. Excessive nitrate also may be an indication of contamination from sewage, decaying vegetation, or fertilizers.

Hardness in water is caused mainly by calcium and magnesium, although other constituents contribute to hardness. Hardness is the property of water that is most commonly recognized by its effect on soap (lack of suds, and formation of scum). The hardness-of-water classification used in this report is given in table 8.

TABLE 8.—*Hardness classification used by the U.S. Geological Survey*

Hardness, $CaCO_3$ *(ppm)*	*Classification*
Less than 60	Soft.
61–120	Moderately hard.
121–180	Hard.
More than 181	Very hard.

The ground water sampled ranges from soft to very hard. In general, water from the alluvial aquifers and springs is harder than that from bedrock aquifers.

Ground water in the project area, in general, is highly mineralized, and most contains one or more constituents that exceed the limits recommended by the U.S. Public Health Service (1962). In the Towaoc area, water from the collection galleries in the alluvium is of better quality than that from deeper aquifers. The unrelaibility of the supply from the collection galleries during dry seasons, however, makes it necessary to depend on the more reliable supplies from deeper aquifers. Water from deeper aquifers can be mixed with that from the collection galleries to reduce the dissolved solids and and to increase the fluoride content.

STOCK SUPPLIES

Little data are available on which to establish criteria for rating waters for stock use. Although domestic animals can tolerate water with higher dissolved-solids concentrations than human beings, water that meets the standards for domestic use should be used for maximum production. Water containing 2,500 ppm dissolved solids is acceptable for stock according to the California State Water Pollution Board (1952, p. 155). Prolonged periods of drinking highly mineralized water can cause wasting, gastrointestinal disturbances, and even death of an animal. Certain salts, such as nitrate and fluoride, are toxic to animals.

Several stock supplies contain more dissolved solids than the recommended 2,500 ppm; however, the dissolved-solids content of water that animals can tolerate depends on many factors, particularly the daily water consumption of the animals. In Western Australia, the safe upper limits for stock are reported as follows (Western Australia Department of Agriculture, 1950):

	Salinity limit (ppm)
Poultry	2, 860
Swine	4, 290
Horses	6, 440
Cattle, dairy	7, 150
Cattle, beef	10, 000
Sheep, adult dry	12, 900

Most stock supplies in the project area are probably acceptable, even though some have undesirable chemical properties.

Several stock wells yield water from the Dakota Sandstone that is black and has a strong sulfur odor—probably caused by hydrogen sulfide associated with coal and other carbonaceous material.

POSSIBILITY OF DEVELOPING ADDITIONAL GROUND-WATER SUPPLIES

In general, ground water is not available in large quantities on the reservation, as indicated by the small to moderate yields of the developed supplies and the geology of the area.

For the purpose of discussing available ground water, the project area can be divided into four general provinces (fig. 14): (1) The mountain area, (2) the western area (west of the west face of Mesa Verde), (3) the Mesa Verde area, and (4) the New Mexico area.

In the mountain provinces, water can be obtained from springs and, in a few places, alluvial deposits.

The western province has the greatest development and potential for obtaining ground-water supplies. Here, the major aquifers are at depths easily reached by drilling. The major aquifer, the Dakota Sandstone, underlies most of this area. Plate 2 shows the approximate depth of the top of the Dakota. Below the Dakota, the Junction Creek, Entrada, and Navajo Sandstones are potential sources of additional water.

The Mesa Verde province is the least favorable for the development of ground water; the writer knows of no wells in the area. Alluvial

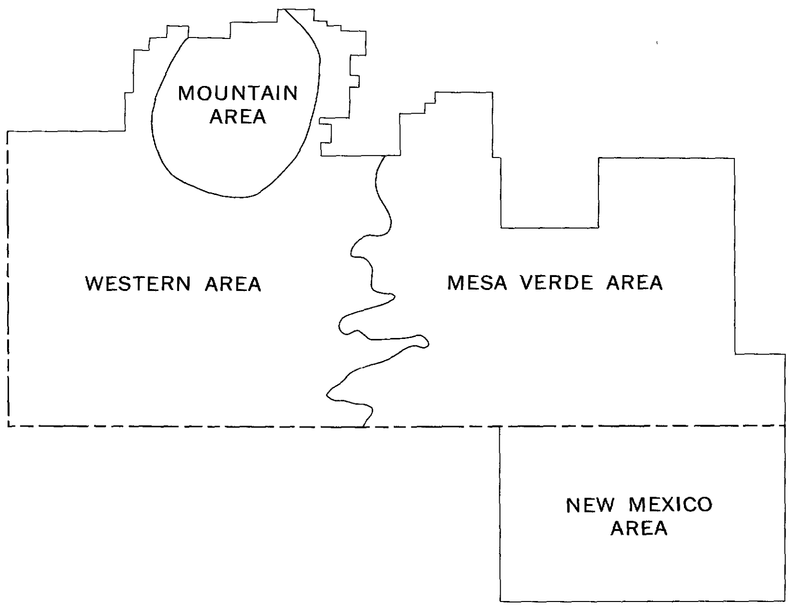

FIGURE 14.—The four general ground-water regions in the project area.

deposits may yield small supplies along the Mancos River. A few springs issue from sandstone beds of the Mesaverde Group, but their discharges are small and are not dependable during dry seasons. The sandstone beds probably are largely drained because of the deep dissection of the canyons. Locally, however, small yields might be obtained from wells penetrating sandstone beds of the Mesaverde Group.

The major aquifers are at considerable depths in the Mesa Verde area. The top of the Dakota lies at depths of more than 2,000 feet. A water well drilled for the Mesa Verde National Park Headquarters in the 1940's was completed in Triassic rocks at a depth of 4,200 feet.

In the New Mexico province small amounts of water can be obtained from wells penetrating the sandstone units of the Mesaverde Group and younger Cretaceous rocks. This area has some potential for obtaining stock supplies from wells.

Domestic and public supplies are adequate for the Towaoc area at present (1963) and for the near future. However, any large growth in population or development requiring even moderate supplies of additional water will necessitate one or more of the following: (1) Drilling additional wells, (2) development of water from the larger springs west of Ute Peak, (3) obtaining a surface-water supply from outside the reservation.

LOGS OF WELLS AND TEST HOLES

Logs of 22 wells and test holes are listed on the following pages. Some of the logs were obtained from the Bureau of Indian Affairs or local drillers. These logs are designated drillers' logs. Logs for which the samples were described by Geological Survey personnel are designated USGS logs. Location of the logged wells are shown on plate 1. Altitudes were estimated from topographic maps and are given in feet above mean sea level. Depths are given in feet below the land surface.

Formational names have been added to the drillers' logs, and the drillers' terms describing the sample have been retained where possible. Drillers' notes concerning drilling conditions and water information are given in parentheses. The abbreviation gpm is used for gallons per minute and gph is used for gallons per hour.

The code number after the color of the sample in the USGS logs refers to the Rock-Color Chart prepared by the National Research Council (Goddard and others, 1948).

206-805 O—66——6

	Thickness (feet)	Depth below land surface (feet)
A-1, T. 33 N., R. 18 W. [Driller's log. Alt 5,485 ft]		
Cretaceous:		
Mancos Shale:		
Clay, yellow	52	52
Shale, gray	134	186
Shale, sandy, gray	24	210
Shale, gray	14	224
Sandstone, gray (Juana Lopez Member) (very small amount of water, 10 gph)	16	240
Shale	278	518
Shale, gray; contains very thin streak of sandy lime at 557 ft	111	629
Shale, gray	93	722
Dakota Sandstone:		
Shale, sandy, gray	12	734
Shale, white	4	738
Shale, sandy, gray	23	761
Sandstone, gray (water, yields 10 gpm, estimated)	11	772
A-3, T. 33 N., R. 19 W. [Driller's log. Alt 5,330 ft]		
Quaternary:		
Alluvium:		
Surface soil	3	3
Clay, sandy, yellow	19	22
Cretaceous:		
Mancos Shale:		
Shale, gray	74	96
Shale, sandy, gray	12	108
Shale, gray; contains hard shells at 138 and 141 ft	269	377
Shale	282	659
Dakota Sandstone:		
Sandstone, gray to white (water, yields 10 gpm)	36	695
A-4, T. 33 N., R. 19 W. [Driller's log. Alt 5,175 ft]		
Cretaceous:		
Mancos Shale:		
Shale and sandstone, yellow (Juana Lopez Member)	23	23
Clay, yellow	12	35
Shale, blue	451	486
Limestone, hard (Greenhorn(?) age)	2	488
Shale, blue	58	546
Dakota Sandstone:		
Sandstone, gray	11	557
Shale, sandy, gray	13	570
Shale, brown	20	590
Limestone, gray, hard	4	594
Coal	6	600
Shale, sandy, gray	38	638
Sandstone (water)	16	654
Shale, blue	11	665

	Thickness (feet)	Depth below land surface (feet)
A-9, SE¼SE¼SE¼ sec. 3 T. 33½ N., R. 17 W. [Driller's log. Alt 5,775 ft]		
Cretaceous:		
Mancos Shale:		
Clay	63	63
Shale, firm	617	680
Shale (caving)	290	970
Shale, sandy	16	986
Dakota Sandstone:		
Sandstone (water)	23	1,009
Shale	2	1,011
Sandstone (water, yields 12 gpm)	14	1,025
A-11, T. 31 N., R. 16 W. [Driller's log. Alt 5,300 ft]		
Cretaceous:		
Menefee Formation:		
Shale	2	2
Point Lookout Sandstone:		
Sandstone, buff; contains streaks of shale	119	121
Shale, blue	6	127
Sandstone, gray; contains streaks of shale	35	162
Sandstone, gray, bentonitic	78	240
Sandstone, gray, very hard	6	246
Sandstone, gray, and broken shale (very small quantity of water at 250 ft)	39	285
Sandstone, gray, and streaks of shale (water, yields 20 gph at 330 ft)	88	373
Sandstone, gray, limy, very hard (water yields 1 gpm at 374 ft)	2	375
Sandstone, gray	23	398
Limestone, sandy, gray, very hard	5	403
Sandstone, gray; contains streaks of shale	12	415
Mancos Shale:		
Shale; contains few thin streaks of sandstone (water, yields 1 gpm)	50	465
A-12, T. 32 N., R. 16 W. [Driller's log. Alt 5,610 ft]		
Quaternary:		
Alluvium:		
Surface	16	16
Cretaceous:		
Point Lookout Sandstone:		
Shale; contains streaks of sandstone	33	49
Sandstone, gray	42	91
Shale and coal	3	94
Sandstone, gray	63	157
Clay, red	2	159
Sandstone, gray, very hard	36	195
Sandstone, gray; contains streaks of shale (small quantity of water at 195 ft, yields as much as 1 gpm at 260 ft)	65	260
Sandstone and shale (water yields 2 gpm at 290 ft)	30	290
Sandstone, gray (sand taking water, cemented hole with two sacks of cement to 290 ft; water, yields 2 gpm)	6	296

	Thickness (feet)	Depth below land surface (feet)
A-13, T. 31 N., R. 14 W. [Driller's log. Alt 6,000 ft]		
Quaternary:		
Alluvium:		
Surface	2	2
Cretaceous:		
Cliff House Sandstone:		
Sand and shale, buff	40	42
Shale, blue	146	188
Sandstone, gray; contains streaks of shale	30	218
Sandstone, gray; contains streaks of shale (water, yields 2 gpm at 300 ft)	82	300
A-17, T. 32 N., R. 14 W. [Driller's log. Alt 6,200 ft]		
Quaternary:		
Alluvium:		
Surface clay	3	3
Sandstone boulders	2	5
Cretaceous:		
Menefee Formation:		
Shale, sandy	10	15
Sandstone, hard	22	37
Shale	18	55
Sandstone, gray, hard	27	82
Shale; contains some coal and sandstone (water, yields 1 gpm)	53	135
Shale, some coal, and sandstone	5	140
Point Lookout Sandstone:		
Sandstone, gray	28	168
Limestone, gray, sandy	6	174
Sandstone, gray (well plugged back to 135 ft)	30	204
B-1, NW¼NW¼NW¼ sec. 30 T. 33½ N., R. 19 W. [Driller's log. Alt. 5,104 ft]		
Cretaceous:		
Dakota Sandstone and Burro Canyon Formation, undifferentiated:		
Sandstone; contains streaks of shale	177	177
B-2, T. 33½ N., R. 18 W. [USGS log. Alt 5,690 ft]		
Quaternary:		
Alluvium:		
Gravel, sandstone, and dark-gray (*N*3) mudstone	10	10
Gravel, dark-gray (*N*3) mudstone, and a few boulders	10	20
Gravel and yellowish-gray (5*Y* 8/1) and medium-dark-gray (*N*4) mudstone; contains some olive-gray (5*Y* 4/1) sandstone	20	40
Cretaceous:		
Mancos Shale:		
Mudstone, medium-dark-gray (*N*4) to dark-gray (*N*3)	37	77

	Thickness (feet)	Depth below land surface (feet)
B-4, SE¼SE¼SE¼ Sec. 18, T. 33½ N., R. 17 W. [Driller's log. Alt 5,820 ft]		
Quaternary:		
Alluvium:		
Sand, clay, and gravel; contains considerable amount of reworked Mancos Shale	29	29
B-5, NW¼NW¼NE¼ sec. 26 T. 33½ N., R. 19 W. [Driller's log. Alt 5,480 ft]		
Cretaceous:		
Mancos Shale:		
Mudstone, dark-gray	180	180
Mudstone, dark-gray; contains fragments of limestone (limestone of Greenhorn(?) age)	24	204
B-6, NW¼NW¼NE¼ sec. 26 T. 33½ N., R. 19 W. [USGS log. Alt 5,480 ft]		
Quaternary:		
Alluvium:		
Sand, silt, and pebbles	10	10
Cretaceous:		
Mancos Shale:		
Mudstone, medium-dark-gray (*N*4); some pebbles	20	30
Mudstone, medium-dark-gray (*N*4); abundant gypsum	10	40
Mudstone, medium-dark-gray (*N*4); minor amounts of medium-light-gray (*N*6) siltstone and limestone, and limonite-stained particles	90	130
Mudstone, medium-dark-gray (*N*4); some gypsum and a few sand grains	70	200
(Limestone of Greenhorn(?) age, interval 200 to 240 ft)		
Mudstone, medium-dark-gray (*N*4); some limestone	20	220
Limestone and mudstone, medium-dark-gray (*N*4); some pyrite	20	240
Mudstone, medium-dark-gray (*N*4); some gypsum and minor limestone particles	15	255
Mudstone, medium-dark-gray (*N*4); some light-colored claystone	5	260
Mudstone, medium-dark-gray (*N*4); minor limestone	5	265
Mudstone, medium-dark-gray (*N*4); abundant bentonitic clay	10	275
Dakota Sandstone and Burro Canyon Formation, undifferentiated:		
Sandstone, light-gray (*N*7), fine- to medium-grained; rounded to subrounded poorly sorted frosted-quartz grains; some limonite-stained grains and a few white chalklike particles	57	332
Sandstone, light-gray (*N*7), fine- to medium-grained; rounded to subrounded poorly sorted frosted-quartz grains; contains abundant dark-gray (*N*3) carbonaceous material	6	338

	Thickness (feet)	Depth below land surface (feet)
B-6, NW¼NW¼NE¼ sec. 26 T. 33½ N., R. 19 W.—Continued		
Cretaceous—Continued		
Dakota Sandstone, etc.—Continued		
Mudstone, carbonaceous, black (*N*1); some light-gray (*N*7) sandstone	14	352
Sandstone, white (*N*9), fine-grained; rounded well-sorted frosted-quartz grains; some coal	38	390
Sandstone, white (*N*9), fine- to medium-grained; rounded poorly sorted frosted-quartz grains	10	400
Sandstone, white (*N*9), medium-grained; rounded poorly sorted frosted-quartz grains; minor amounts of coal	10	410
Sandstone, white (*N*9), very fine to fine-grained; rounded frosted-quartz grains; contains abundant dark-gray (*N*3) mudstone and some carbonaceous material	21	431
Mudstone, medium-dark-gray (*N*4); some carbonaceous material	19	450
Sandstone, light-gray (*N*7), fine-grained; considerable medium-dark-gray (*N*4) mudstone	10	460
Sandstone, very light gray (*N*8), medium-grained; rounded frosted-quartz grains; some mudstone and chert particles	7	467
Jurassic:		
Morrison Formation:		
Brushy Basin Shale Member:		
Mudstone, greenish-gray (5*G* 6/1) to light-bluish-gray (5*B* 7/1); some sandstone and chert	3	470
Siltstone, greenish-gray (5*G* 7/1); some fine-grained sandstone and medium-gray (*N*5) mudstone	3	473
B-7, NW¼NE¼SE¼ sec. 17 T. 33 N., R. 17 W. [USGS log. Alt 5,360 ft]		
Quaternary:		
Alluvium:		
Sandstone, pebbles, and siltstone, grayish-orange (10*YR* 7/4)	10	10
Siltstone, pale-yellowish-brown (10*YR* 6/2); some sandstone, medium to coarse grained; abundant gypsum particles	20	30
Cretaceous:		
Mancos Shale:		
Mudstone, medium-dark-gray (*N*4); minor amounts of sand and silt	14	44
Mudstone, medium-dark-gray (*N*4); abundant gypsum	11	55
Mudstone, medium-dark-gray (*N*4); minor gypsum	30	85
Mudstone, medium-dark-gray (*N*4); some buff sand grains; slight amount of gypsum	31	116
Mudstone, medium-dark-gray (*N*4); some iron stains and gypsum	22	138
Mudstone, medium-dark-gray (*N*4); some particles of fine buff sand	33	171
Mudstone, dark-gray (*N*3); some gypsum	9	180

	Thickness (feet)	Depth below land surface (feet)
B-7, NW¼NE¼SE¼ sec. 17 T. 33 N., R. 17 W.—Continued		
Cretaceous—Continued		
Mancos Shale—Continued		
Mudstone, medium-dark-gray (*N*4); some particles of fine buff sand	16	196
Mudstone, medium-dark-gray (*N*4); contains as much as 20 percent light-gray (*N*7) limestone particles	49	245
Mudstone, medium-dark-gray (*N*4); with abundant light-gray (*N*7) limestone and some very fine grained particles of buff sandstone	29	274
Mudstone, medium-dark-gray (*N*4); slight amount of light-gray (*N*7) limestone and gypsum	50	324
Mudstone, medium-dark-gray (*N*4) some light-gray (*N*7) limestone and small amounts of buff sand	61	385
Mudstone, medium-dark-gray (*N*4); abundant gypsum	10	395
Mudstone, medium-dark-gray (*N*4); some light-gray (*N*7) limestone	40	435
Mudstone, medium-dark-gray (*N*4), paper-thin; some gypsum	20	455
Mudstone, medium-dark-gray (*N*4)	50	505
Mudstone, dark-gray (*N*3), paper-thin; some gypsum	10	515
Mudstone, medium-dark-gray (*N*4)	60	575
Mudstone, medium-dark-gray (*N*4); minor amounts of light- to medium-light-gray (*N*6) limestone and gypsum	20	595
Mudstone, dark-gray (*N*3), paper-thin; some light-gray (*N*7) limestone	30	625
Mudstone, medium-dark-gray (*N*4); small amounts of limestone and gypsum	50	675
Mudstone, dark-gray (*N*3), paper-thin; some gypsum	10	685
Mudstone, medium-dark-gray (*N*4); some gypsum	20	705
Mudstone, dark-gray (*N*3), paper-thin; some gypsum	30	735
Mudstone, medium-dark-gray (*N*4); some gypsum	20	755
Mudstone, dark-gray (*N*3)	15	770
Juana Lopez Member (770 to 807 ft):		
Sandstone, light-gray (*N*7), medium-grained; subrounded clear quartz grains; contains abundant green accessory minerals, pyrite, and abundant dark-gray (*N*3) mudstone	28	798
Sandstone, light-gray (*N*7), fine- to medium-grained; subrounded fairly well to poorly sorted clear-quartz grains; abundant mudstone	4	802
Sandstone, light-gray (*N*7), medium-grained; subrounded poorly sorted frosted-quartz-grains; and medium-dark-gray (*N*4) mudstone; contains some gypsum	5	807
Mudstone, dark-gray (*N*3); minor amount of sand	5	812
Mudstone, dark-gray (*N*3); minor gypsum, limestone, and sand grains	38	850

	Thickness (feet)	Depth below land surface (feet)
B-7, NW¼NE¼SE¼ sec. 17 T. 33 N., R. 17 W.—Continued		
Cretaceous—Continued		
Mancos Shale—Continued		
Mudstone, dark-gray (*N*3); some pyrite	15	865
Mudstone, dark-gray (*N*3); contains a few chalk-like particles	18	883
Mudstone, medium-dark-gray (*N*4)	15	898
Mudstone, dark-gray (*N*3), paper-thin	18	916
Mudstone, grayish-black (*N*2)	82	998
Mudstone, medium-dark-gray (*N*4)	39	1, 037
Mudstone, dark-gray (*N*3), and some minor light-gray (*N*7) limestone	68	1, 105
Mudstone, medium-dark-gray (*N*4); some limestone	50	1, 155
Mudstone, dark-gray (*N*3), paper-thin	5	1, 160
Mudstone, medium-dark-gray (*N*4) to dark-gray (*N*3), paper-thin; some light-gray (*N*7) limestone	13	1, 173
Mudstone, medium-dark-gray (*N*4); minor limestone	45	1, 218
Limestone of Greenhorn(?) age, interval 1,218 to 1,227 ft:		
Limestone, medium-gray (*N*5) noncrystalline; 35 percent black mudstone	4	1, 222
Mudstone, dark-gray (*N*3), and some limestone	5	1, 227
Mudstone, dark-gray (*N*3) to medium-dark-gray (*N*4)	17	1, 244
Mudstone, medium-dark-gray (*N*4); some light-gray (*N*7) claystone	4	1, 248
Mudstone, dark-gray (*N*3), paper-thin; contains some light-gray (*N*7) claystone	10	1, 258
Dakota Sandstone:		
Sandstone, grayish-orange (10*YR* 7/4), fine- to medium-grained; subrounded to rounded fairly well to poorly sorted frosted-quartz grains; some limonite-stained grains	22	1, 280
Sandstone, yellowish-gray (5*Y* 7/2), fine- to medium-grained; subrounded to angular fairly well sorted frosted- and minor clear-quartz grains	4	1, 284
Sandstone, yellowish-gray (5*Y* 7/2), fine-grained; subrounded fairly well sorted frosted-quartz grains	20	1, 304
Sandstone, light-brown (5*YR* 6/4), fine-grained; subrounded fairly well sorted frosted-quartz grains; abundant limonite-stained grains	5	1, 309
Sandstone, light-gray (*N*7), fine-grained; fairly well sorted frosted-quartz grains; limonite specks and some gray mudstone	8	1, 317
Sandstone, grayish-orange-pink (5*YR* 7/2), fine-grained, well-sorted frosted-quartz grains	4	1, 321
Sandstone, yellowish-gray (5*Y* 7/2), fine-grained; well-sorted frosted-quartz grains	9	1, 330
Sandstone, light-olive-gray (5*Y* 5/2), fine-grained; well-sorted frosted-quartz grains; 5 percent mudstone	10	1, 340
Sandstone, yellowish-gray (5*Y* 7/2), fine-grained; well-sorted frosted-quartz grains	3	1, 343
Mudstone, dark-gray (*N*3), and coal	3	1, 346

	Thickness (feet)	Depth below land surface (feet)
B-9 C, SW¼SW¼ sec. 23 T. 35 N., R. 19 W. [Driller's log. Alt 5,755 ft]		
Quaternary:		
Alluvium:		
Surface	2	2
Cretaceous:		
Burro Canyon Formation:		
Sandstone, gray	41	43
Jurassic:		
Morrison Formation:		
Shale, green and gray; contains gray limestone shells	47	90
Limestone, sandy and very hard	3	93
Shale, light-blue; contains limestone shells	72	165
Limestone, gray, sandy	13	178
Sandstone, white, coarse to fine-grained; contains limestone shells (dry)	32	210
Shale, sandy, and limestone	21	231
Sandstone, gray	10	241
Shale, sandy; contains limestone shells	9	250
Sandstone, gray; contains limestone shells	24	274
Limestone and shale, gray	28	302
Sandstone, gray to buff; contains limestone shells	35	337
Shale, pink, and limestone	21	358
Sandstone, gray; contains limestone shells	22	380
Shale, brown and green; contains broken limestone shells	12	392
Sandstone, gray	44	436
Sandstone, buff, and red shale	49	485
Limestone, sandy, very hard	2	487
Sandstone; buff to red	21	508
Shale, red and green, sandy; contains limestone shells	20	528
Sandstone, gray; contains limestone shells	7	535
Shale, red and green, sandy	45	580
Limestone, gray to pink, sandy, very hard	4	584
Shale, red, sandy	10	594
Limestone shell, sandy	4	598
Shale, red and green, sandy; contains limestone shells	62	660
Junction Creek Sandstone:		
Sandstone, pink, shaly	67	727
Sandstone, pink; contains streaks of red and green shale (water at 730 ft, yields ¼ gpm)	32	759
Quartzite, white	1	760
Sandstone, pink	10	770
Sandstone, pink (water yield increased to 10 gpm)	116	886
B-10 C, SW¼SW¼ sec. 18 T. 33½ N., R. 17 W. [USGS log. Alt 5,880 ft]		
Quaternary:		
Alluvium:		
Soil, light-olive-gray (5*Y* 6/1), sandy mudstone with minor amounts of gypsum; abundant limonite stains	15	15
Cretaceous:		
Mancos Shale:		
Mudstone, medium-light-gray (*N*6); abundant limonite-stained grains; abundant gypsum	20	35
Mudstone, medium-light-gray (*N*6) to medium-dark-gray (*N*4); abundant limonite stains and gypsum	15	50

	Thickness (feet)	Depth below land surface (feet)
B-10 C, SW¼SW¼ sec. 18 T. 33½ N., R. 17 W.—Continued		
Cretaceous—Continued		
Mancos Shale—Continued		
Mudstone, medium-dark-gray (*N*4)	10	60
Mudstone, medium-gray (*N*5)	40	100
Mudstone, medium-dark-gray (*N*4)	184	284
Limestone of Greenhorn(?) age, interval 280 to 300 ft:		
Mudstone, medium-dark-gray (*N*4); limestone fragments and some pyrite; minor amounts of fine-grained sandstone	4	288
Mudstone, medium-dark-gray (*N*4)	4	292
Limestone, light-gray (*N*7), hard, crystalline; abundant medium-dark-gray (*N*4) mudstone	8	300
Mudstone, medium-light-gray (*N*6); some bentonite	28	328
Dakota Sandstone and Burro Canyon Formation, undifferentiated:		
Sandstone, yellowish-gray (5*Y* 8/1), medium-grained; subangular to subrounded well-sorted frosted-quartz grains	13	341
Sandstone, yellowish-gray (5*Y* 8/1), fine-grained; subangular to subrounded fairly well sorted frosted-quartz grains; common limonite-stained grains	29	370
Sandstone, light-greenish-gray (5*GY* 8/1), very fine to fine-grained; subangular fairly well sorted frosted-quartz grains	20	390
Sandstone, yellowish-gray (5*Y* 8/1), very fine grained; subangular well-sorted frosted-quartz grains	10	400
Sandstone, yellowish-gray (5*Y* 8/1), fine-grained; subangular fairly well sorted frosted-quartz grains; abundant carbonaceous material and pyrite; some gray mudstone	20	420
Sandstone, yellowish-gray (5*Y* 8/1), fine-grained; subangular fairly well sorted frosted-quartz grains; limonite-stained grains	10	430
Sandstone, pinkish-gray (5*YR* 8/1), fine-to medium-grained; subangular fairly well sorted clear- and frosted-quartz grains	14	444
Sandstone, pinkish-gray (5*YR* 8/1), fine-grained; subangular to subrounded well sorted frosted-quartz grains	21	465
Coal, black (*N*1), low-grade	2	467
Sandstone, light-brownish-gray (5*YR* 6/1) to light-gray (*N*7), fine-grained; subangular fairly well sorted frosted-quartz grains; pyrite, considerable coal particles, and some white siltstone	13	480
Sandstone, pinkish-gray (5*YR* 8/1), fine-grained; subangular poorly sorted frosted-quartz grains; limonite-stained; abundant pyrite	48	528

	Thickness (feet)	Depth below land surface (feet)
B-13, NE¼NW¼SE¼ sec. 7 T. 33½ N., R. 17 W. [Driller's log. Alt. 5,922 ft]		
Quaternary:		
Alluvium:		
Dirt, brown	9	9
Shale or mud, brown	18	27
Sediment, brown	18	45
Granite boulders and gravel (water)	3	48
Sediment, black	12	60
Boulders and gravel (water)	5	65
Cretaceous:		
Mancos Shale:		
Shale, dark	25	90
Shale	88	178
Limestone of Greenhorn(?) age, 178 to 182 ft:		
Shell	2	180
Broken formation (water)	2	182
Shale	38	220
Dakota Sandstone and Burro Canyon Formation, undifferentiated:		
Sand	10	230
Shale	5	235
Sand	30	265
Shale	5	270
Sand (Driller's note: "All of this sand is hard, and most of it is dry.")	10	280
Coal	3	283
Sand (Driller's note: "All of this sand is hard, and most of it probably is dry.")	7	290
Sand	50	340
Shale, sandy	25	365
Sand	45	410
Jurassic:		
Morrison Formation and Junction Creek Sandstone, undifferentiated:		
Sand and shale, green	10	420
Shale, green, and gray lime shells	50	470
Shale, gray and green, containing hard lime shells	45	515
Shale, gray and green, containing hard lime shells (Driller's note: "Unit is about 50 percent lime.")	35	550
Shale, green and gray, alternating with shells of hard lime	120	670
Shale, sandy, gray and green (water, bail test indicates yield about 1 gpm)	5	675
Shale, gray and green	35	710
Sand, gray (some water between 735 and 750 ft)	45	755
Shale, green, interbedded with layers of gray sand (water, bail test indicates yield 2.7 gpm)	110	865
Shale and sand, pink	325	1, 190
Sand, pink (water)	60	1, 250
Jurassic and Triassic(?):		
Summerville Formation, Entrada Sandstone, and Navajo Sandstone, undifferentiated:		
Shale, pink	15	1, 265
Shale, sandy, pink (Driller's note: "Water level raised 75 ft at 1,610 ft, but no appreciable sand was found at this depth. Well was pumped continuously for 48 hr between 16.7 and 18.7 gpm.")	485	1, 750

	Thickness (feet)	Depth below land surface (feet)
B-15 NE¼SE¼SE¼ sec. 7 T. 33½ N., R. 17 W. [USGS log. Alt 5,885 ft]		
Quaternary:		
Alluvium:		
Clay, silty to sandy, brown to gray, very fine grained; contains fine to very coarse gravel at 6.5 ft	9	9
Sand, very fine, to gravel, very coarse; unit is mixed with yellowish soft clay; below 16 ft unit contains rounded fragments of blue clay	23	32
Gravel, very fine to very coarse; contains fine to very coarse sand and some large boulders	12	44
Cretaceous:		
Mancos Shale:		
Shale, dark-blue, silty, firm	21.8	65.8

	Thickness (feet)	Depth below land surface (feet)
B-16, SW¼SE¼SE¼ sec. 7 T. 33½ N., R. 17 W. [USGS log. Alt 5,885 ft]		
Quaternary:		
Alluvium:		
Clay, brown, silty to sandy; contains some very fine to very coarse gravel	24	24
Clay, yellow, silty to sandy; contains fine to coarse gravel	3	27
Sand, very fine to coarse; contains some fine to coarse gravel interbedded with silty to sandy gray and bluish-gray clay	13	40
Sand, very fine to very coarse; contains gray to grayish-blue clay and angular to subrounded fragments of blue silty shale. (Water at about 40 ft)	2	42
Cretaceous:		
Mancos Shale:		
Shale, dark-blue, silty, firm	139	181
Bentonite, light-gray	4	185
Shale, limy, firm; contains thin layers of very fine sand	16	201
Shale, dark-gray, silty, firm; interbedded with dark-bluish-gray slightly sandy shale	12	223
Shale, silty, firm; interbedded with thin beds of limestone; pyrite below 227 ft. (Drilling hard between 226–229 ft)	11	234
Limestone, light- to dark-gray, dense, hard, badly broken. (Water at 234 ft, water level after 48 hr was 53.7 ft below top of casing.)	3	237
Shale, dark-blue, silty to sandy	4	241
Shale, silty, blocky; interbedded with thin layers of bentonite	4	245
Shale, dark-bluish-gray, silty to sandy, firm	13	258
Shale, silty to slightly sandy, firm; interbedded with thin layers of bentonite	7	265
Shale, dark-bluish-gray, silty to sandy; sand is very fine	8	273
Dakota Sandstone:		
Sandstone, dark-gray, very fine to fine-grained, slightly clayey, hard; contains thin layers of sandy shale	16	289

	Thickness (feet)	Depth below land surface (feet)
B-16, SW¼SE¼SE¼ sec. 7 T. 33½ N., R. 17 W.—Continued		
Cretaceous—Continued		
Dakota Sandstone—Continued		
Shale, bluish-gray, silty to sandy, firm to soft; interbedded with layers of very fine sand	5	294
Sandstone, dark-gray, silty, very fine grained; interbedded with dark-gray sandy shale	5	299
Sandstone, very fine to fine-grained; rounded to angular fragments of quartz; well-cemented; hard	4	303
Sandstone, dark-gray, silty, very fine grained, hard; contains thin layers of dark-brown to bluish-black shale	4	307
Sandstone, light-gray, silty, very fine grained; contains rounded fragments of brown ironstone and thin layers of brown carbonaceous clay	26	333
Sandstone, gray, silty, very fine grained; contains thin layers of dark-gray to brown carbonaceous clay (water has a strong odor)	7	340
Sandstone, gray, silty, fine-grained; contains thin layers of dark-gray to brown carbonaceous shale	6	346
Coal, black, soft	3	349
Sandstone, gray, silty, very fine grained; contains thin layers of dark-gray to brown carbonaceous shale	5	354
Shale, dark-gray, silty to slightly sandy, blocky	4	358
Sandstone, silty, very fine grained, hard; interbedded with thin layers of silty blue shale	3	361
Burro Canyon Formation:		
Shale, dark-gray to brown, silty to sandy, blocky; interbedded with thin layers of very fine grained silty light-gray sandstone	24	385
Shale, slightly sandy, hard to soft, blocky	5	390
Shale, brown to black, silty to sandy, blocky, carbonaceous	4	394
Sandstone and shale, silty, very fine grained, hard to soft	7	401
Shale, dark-bluish-gray, silty to sandy; interbedded with thin layers of carbonaceous shale	7	408
Sandstone, light-gray to tan, silty, very fine grained, hard; contains fragments of dark-brown silty shale	10	418
Shale, dark-gray to black, silty to sandy carbonaceous	7	425
Sandstone, light-gray to tan, very fine to fine-grained, hard (water has strong sulfur odor)	6	431
Sandstone, light-tan, silty, fine-grained, soft; contains some very fine gravel	16	447
Sandstone, silty, fine-grained, poorly sorted; contains some medium sand and some very fine gravel	3	452
Sandstone, light-tan very fine to fine-grained, well-sorted; contains some very fine gravel	6	458
Sandstone, light-gray to tan, very fine to fine-grained, hard; contains some medium sand	13	471
Sandstone, silty, fine-grained, contains some blue and green shale and abundant pyrite crystals	1	472
Shale, bluish-green, silty to slightly sandy	6	478

	Thickness (feet)	Depth below land surface (feet)
B-16, SW¼SE¼SE¼ sec. 7 T. 33½ N., R. 17 W.—Continued		
Jurassic:		
Morrison Formation:		
Brushy Basin Shale Member:		
Siltstone and mudstone, bluish-white (5*B* 9/1) to bluish-gray (5*B* 8/1); contains some fine to coarse subrounded to rounded poorly sorted sand composed of clear and frosted quartz; contains rare to common gypsum and rare pyrite, limonite and dark accessory minerals; weak calcareous and clayey cement	119	597
Sandstone, white (*N*9) to medium-gray (*N*5) very fine to coarse-grained; angular to subrounded poorly sorted quartz grains; contains siltstone, claystone, mudstone, jasper, and siliceous limestone; weak calcareous cement	3	600
Siltstone, light-bluish-gray (5*B* 7/1) to light-greenish-gray (5*G* 8/1); contains jasper, siliceous limestone, and some quartz; weak calcareous cement	5	605
Siltstone and mudstone, light-bluish-gray (5*B* 7/1) to light-greenish-gray (5*G* 8/1); contains jasper, siliceous limestone, and rare pyrite and dark accessory minerals; weak calcareous cement	14	619
Limestone, light-bluish-gray (5*B* 7/1) to light-greenish-gray (5*G* 8/1); contains siltstone, mudstone, and rare mica and pyrite; weak calcareous cement	10	629
Siltstone, bluish-pyrite (5*B* 9/1); contains siliceous limestone, mudstone, and rare mica and pyrite; weak calcareous cement	9	638
Limestone, light-bluish-gray (5*B* 7/1) to light-greenish-gray (5*G* 8/1); contains siltstone, mudstone, and rare mica and pyrite; weak calcareous cement	2	640
Sandstone, very pale blue (5*B* 8/2) to pale-blue-green (5*BG* 7/2), fine- to very coarse-grained; angular to subrounded poorly sorted clear- and frosted-quartz grains; contains siltstone, mudstone, siliceous limestone, limonite, and rare pyrite and chert; weak calcareous cement	30	670
Siltstone and mudstone, very light gray (*N*8); contains chert and siliceous limestone; weak calcareous cement	4	674
Sandstone, very pale blue (5*B* 8/2) to pale-blue-green (5*BG* 7/2), fine- to very coarse grained; angular to subrounded poorly sorted clear-, amber-, and frosted-quartz grains; contains siliceous limestone, rare chert and pyrite; weak calcareous cement	3	677
Limestone, light-bluish-gray (5*B* 7/1) to light-greenish-gray (5*G* 8/1), siliceous; contains siltstone and mudstone, rare mica and pyrite; weak calcareous cement	3	680

	Thickness (feet)	Depth below land surface (feet)
B-16, SW¼SE¼SE¼ sec. 7 T. 33½ N., R. 17 W.—Continued		
Jurassic—Continued		
Morrison Formation—Continued		
Brushy Basin Shale Member—Continued		
Siltstone and mudstone, very light gray (*N*8); contains chert and siliceous limestone; weak calcareous cement	6	686
Sandstone, very pale blue (5*B* 8/2) to pale-blue-green (5*BG* 7/2), fine- to very coarse grained; angular to subrounded poorly sorted clear-, amber-, and frosted-quartz grains; contains siliceous limestone and rare pyrite and chert; weak calcareous cement	4	690
Sandstone, light-bluish-gray (5*B* 7/1) to light-greenish-gray (5*G* 8/1), fine- to very coarse grained; angular to subrounded poorly sorted clear-, frosted-, and amber-quartz grains; contains chert, jasper, siliceous limestone, mudstone, siltstone, rare pyrite and mica; weak calcareous cement	16	706
Siltstone and mudstone, very light gray (*N*8); contains rare mica, pyrite, and dark accessory minerals; weak calcareous cement	3	709
Sandstone, light-bluish-gray (5*B* 7/1) to light-greenish-gray (5*G* 8/1); fine- to very coarse grained; angular to subrounded poorly sorted grains; predominantly chert, jasper, and siliceous limestone with some clear-, frosted-, and amber-quartz grains; contains siltstone and mudstone; weak calcareous cement	3	712
Sandstone, very light gray (*N*8), silty, very fine to medium-grained; angular to subrounded clear-, frosted-, and amber-quartz grains; contains rare pyrite and mica; weak calcareous cement	5	717
Sandstone, light-bluish-gray (5*B* 7/1) to light-greenish-gray (5*G* 8/1), fine- to very coarse-grained; angular to subrounded poorly sorted clear-, frosted-, and amber-quartz grains; contains chert, jasper, siliceous limestone, and rare pyrite and mica; weak calcareous cement	15	732
Limestone, light-bluish-gray (5*B* 7/1) siliceous, silty; contains rare mica and pyrite; weak calcareous cement	13	745
Siltstone and mudstone, very light gray (*N*8); contains rare mica, pyrite, and dark accessory minerals; weak calcareous cement	5	750
Sandstone, very light gray (*N*8), silty, very fine to medium-grained; angular to subrounded poorly sorted clear-, frosted-, and amber-quartz grains; contains rare pyrite and mica; weak calcareous cement	4	754
Siltstone and mudstone, very light gray (*N*8); contains rare mica, pyrite, and dark accessory minerals; weak calcareous cement	6	760

	Thickness (feet)	Depth below land surface (feet)
B-16, SW¼SE¼SE¼ sec. 7 T. 33½ N., R. 17 W.—Continued		
Jurassic—Continued		
Morrison Formation—Continued		
Brushy Basin Shale Member—Continued		
Sandstone, light-bluish-gray (5*B* 7/1) to light-greenish-gray (5*G* 8/1), fine- to very coarse-grained; rounded to subangular poorly sorted clear-, frosted-, and amber-quartz grains; siliceous limestone, chert, and jasper; contains mudstone, siltstone, rare pyrite and mica; weak calcareous cement	1	761
Siltstone and mudstone, very light gray (*N*8); contains limestone and rare mica, pyrite, and limonite; weak calcareous cement	4	765
Sandstone, very light gray (*N*8) to medium-light-gray (*N*6), very fine to coarse-grained; angular to subrounded poorly sorted clear-, amber-, and frosted-quartz grains; contains rare pyrite, limonite, and dark accessory minerals; firm calcareous cement	2	767
Siltstone and mudstone, very light gray (*N*8) to medium-light-gray (*N*6); contains rare limonite, pyrite, and dark accessory minerals; weak calcareous cement	8	775
Sandstone, very light gray (*N*8) and medium-light-gray (*N*6) to light-bluish-gray (5*B* 7/1), very fine- to coarse-grained; angular to subrounded poorly sorted clear-, amber-, and frosted-quartz grains; contains siltstone, rare pyrite, limonite, and dark accessory minerals; calcareous cement	30	805
Salt Wash Sandstone Member:		
Sandstone, yellowish-gray (5*Y* 8/1), fine- to medium-grained; angular to subrounded poorly sorted clear-, frosted-, and amber-quartz grains; contains some siltstone and mudstone, common limonite, and rare pyrite and dark accessory minerals; weak calcareous cement	46	851
Sandstone, white (*N*9) to bluish-white (5*B* 9/1) fine- to coarse-grained; angular to subrounded poorly sorted clear-, frosted-, and amber-quartz grains; contains some siltstone and mudstone, common limonite, and rare pyrite and dark accessory minerals; weak calcareous cement	24	875
Mudstone, light-greenish-gray (5*G* 8/1) to light-bluish-gray (5*B* 7/1), calcareous; contains some fine to coarse angular to subrounded clear- and stained-quartz sand; contains rare pyrite, limonite, and dark accessory minerals; calcareous cement	9	884
Sandstone, pinkish-gray (5*YR* 8/1), fine- to medium-grained; angular to subrounded poorly sorted clear-, stained- and frosted-quartz grains; contains siltstone, common limonite, and rare feldspar; weak calcareous cement	4	888

	Thickness (feet)	Depth below land surface (feet)
B-16, SW¼SE¼SE¼ sec. 7 T. 33½ N., R. 16 W.—Continued		
Jurassic—Continued		
Morrison Formation—Continued		
Salt Wash Sandstone Member—Continued		
Mudstone, light-greenish-gray (5*G* 8/1) to light-bluish-gray (5*B* 7/1); contains some fine to coarse angular to subrounded clear- and stained-quartz sand; contains rare pyrite, limonite, and dark accessory minerals; calcareous cement	5	893
Sandstone, very pale orange (10*YR* 8/2) to light-olive-gray (5*Y* 6/1); fine- to coarse-grained; angular to subangular poorly sorted clear-, frosted-, and stained-quartz grains; contains siltstone, chert, limonite, and rare feldspar, pyrite, and dark accessory minerals; weak calcareous cement	15	908
Sandstone, pinkish-gray (5*YR* 8/1), very fine to fine-grained, silty; angular to subrounded fairly well sorted clear-, frosted-, amber-, and stained-quartz grains; calcareous cement	4	912
Sandstone, white (*N*9) to medium-gray (*N*5), very fine to coarse-grained; angular to subrounded poorly sorted clear-, frosted-, and stained-quartz grains; contains siltstone, mudstone, common limonite, rare pyrite and dark accessory minerals; weak calcareous cement	11	923
Sandstone, white (*N*9) to pinkish-gray (5*YR* 8/1), very fine to medium-grained; angular to subrounded fairly well sorted clear-, frosted-, and stained-quartz grains; contains siltstone and rare limonite, limestone and dark accessory minerals, weak calcareous cement	35	958
Sandstone, white (*N*9) to light-brownish-gray (5*YR* 6/1), fine to very coarse grained; subrounded to subangular poorly sorted clear-, amber-, frosted-, and stained-quartz grains; contains siltstone, limestone, claystone, common limonite, and rare feldspar, pyrite, mica, and dark accessory minerals; weak calcareous and ferruginous cement	2	960
B-17, NE¼NW¼NE¼ sec. 18 T. 33½ N., R. 17 W. [USGS log. Alt 5,877 ft]		
Quaternary:		
Alluvium:		
Soil and mudstone, grayish-yellow-green (5*GY* 7/2)	20	20
Mudstone, pebbles, and silt, medium-gray	20	40
Cretaceous:		
Mancos Shale:		
Mudstone, medium-dark-gray (*N*4)	60	100
Mudstone, medium-dark-gray (*N*4); contains some buff sand grains	10	110

	Thickness (feet)	Depth below land surface (feet)
B-17, NE¼NW¼NE¼ sec. 18 T. 33½ N., R. 17 W.—Continued		
Cretaceous—Continued		
Mancos Shale—Continued		
Mudstone, medium-dark-gray (*N*4)	60	170
Mudstone, medium-light-gray (*N*6); contains some buff sand grains	20	190
Mudstone, medium-gray (*N*5); contains some buff sand grains	30	220
Mudstone, medium-light-gray (*N*6); contains sand grains	10	230
Mudstone, medium-gray (*N*5); contains sand grains and iron-stained particles and pyrite	10	240
Mudstone, medium-gray (*N*5); contains some sand grains, abundant pyrite, ironstone particles, dense impure limestone, and white chalk-like particles	10	250
Mudstone, medium-light-gray (*N*6), iron stains, some pyrite and minor limestone particles	10	260
Dakota Sandstone and Burro Canyon Formation, undifferentiated:		
Sandstone, brownish-gray (5*YR* 4/1), medium-grained; subrounded poorly sorted frosted-quartz grains; contains rare white accessories and abundant mudstone	10	270
Mudstone, medium-gray (*N*5); contains a considerable amount of sand grains	10	280
No sample	10	290
Siltstone and mudstone, medium-light-gray (*N*6); contains fine- to medium-grained sandstone and abundant pyrite	10	300
Sandstone, light-gray (*N*7), to light-brownish-gray (5*YR* 6/1), fine-grained; subrounded fairly well sorted frosted-quartz grains; contains some mudstone cavings	10	310
Sandstone, very light gray (*N*8), fine-grained; subrounded fairly well sorted frosted-quartz grains; common black accessory minerals and abundant pyrite	30	340
Sandstone and mudstone—poor samples	30	370
Sandstone, very light gray (*N*8), fine-grained; subrounded fairly well sorted frosted-quartz grains; common black accessory minerals	10	380
Mudstone, medium-light-gray (*N*6), sandy	20	400
Sandstone, pinkish-gray (5*YR* 8/1), fine-grained; subrounded fairly well sorted frosted-quartz grains; rare black and red accessory minerals	40	440
Sandstone, yellowish-gray (5*Y* 8/1), medium-grained; subrounded fairly well sorted frosted-quartz grains; common black accessory minerals	20	460
Sandstone, yellowish-gray (5*Y* 8/1), medium- to coarse-grained; subangular to rounded poorly sorted quartz grains; some chert and common red and black particles	20	480
Sandstone, pinkish-gray (5*YR* 8/1), fine- to medium-grained; fairly well sorted frosted-quartz grains; iron stains common, and some black accessory minerals	10	490

	Thickness (feet)	Depth below land surface (feet)
B-17, NE¼NW¼NE¼ sec. 18 T. 33½ N., R. 17 W.—Continued		
Jurassic:		
Morrison Formation:		
Sandstone, pinkish-gray (5*YR* 8/1), and light-greenish-gray (5*G* 8/1) mudstone	10	500
Mudstone, light-greenish-gray (5*G* 8/1)	20	520
Mudstone, grayish-red (5*R* 4/2)	10	530
Mudstone, light-greenish-gray (5*G* 8/1) and grayish-red (5*R* 4/2)	20	550
Mudstone, light-greenish-gray (5*G* 8/1)	30	580
Sandstone, very pale orange (10*YR* 8/2), medium-grained; rounded to subrounded fairly well sorted frosted-quartz grains	10	590
Mudstone, light-greenish-gray (5*G* 8/1)	10	600
Sandstone, light-greenish-gray (5*G* 8/1)	10	610
Mudstone, light-greenish-gray (5*GY* 8/1)	20	630
Sandstone, greenish-gray (5*G* 6/1), fine-grained; subrounded clear- and frosted-quartz grains	10	640
Mudstone, light-greenish-gray (5*G* 8/1)	50	690
Mudstone and siltstone, light-greenish-gray (5*G* 8/1), some limonite	40	730
Sandstone, pinkish-gray (5*YR* 8/1) silty, very fine to fine-grained; subangular poorly sorted frosted-quartz grains	10	740
Mudstone, light-greenish-gray (5*G* 8/1), some fine sand, and some limonite from 760 to 770 ft	30	770
Sandstone, pinkish-gray (5*YR* 8/1), fine-grained; subrounded poorly sorted frosted-quartz grains	20	790
Sandstone, pinkish-gray (5*YR* 8/1), fine-grained, subrounded; some pale-red (5*R* 6/2) mudstone	20	810
Mudstone, light-greenish-gray (5*G* 8/1); minor sand	20	830
Sandstone and mudstone, light-greenish-gray (5*G* 8/1)	10	840
Sandstone, light-greenish-gray (5*GY* 8/1), fine- to medium-grained; subangular fairly well sorted frosted-quartz grains; some green mud and silt	30	870
Sandstone, pinkish-gray (5*YR* 8/1), fine-grained; subangular frosted-quartz grains; some green mudstone	20	890
Sandstone, light-greenish-gray (5*GY* 8/1), fine-grained; subrounded fairly well sorted quartz grains; common black and green accessory minerals, and limonite stains	80	970
Sandstone, light-brownish-gray (5*YR* 7/1), fine-grained; subrounded fairly well sorted quartz grains; silty; contains yellow, black, and green accessory minerals	30	1,000
Sandstone, pinkish-gray (5*YR* 8/1), very fine grained; subangular quartz grains; silty	20	1,020
Sandstone, yellowish-gray (5*Y* 8/1), fine- to medium-grained; subangular quartz grains; silty	20	1,040
Sandstone, pinkish-gray (5*YR* 8/1), very fine grained; subangular quartz grains; silty	30	1,070
Mudstone, red and green	10	1,080
Sandstone, light-brownish-gray (5*YR* 6/1), very silty, fine-grained to silt; subrounded to subangular quartz grains; common green accessory minerals; contains red claystone particles	20	1,100

	Thickness (feet)	Depth below land surface (feet)
B-17, NE¼NW¼NE¼ sec. 18 T. 33½ N., R. 17 W.—Continued		
Jurassic—Continued		
Junction Creek Sandstone:		
Sandstone, very pale orange (10*YR* 8/2), fine- to medium-grained, and dark-red (5*R* 5/6) and grayish-green (5*G* 6/1) mudstone; contains abundant limonite (hole is caving badly for next 100 ft, samples are poor)	10	1,110
Sandstone, light-brownish-gray (5*YR* 6/1), very silty, and abundant red and green mudstone	20	1,130
Samples are mainly cavings; siltstone, mudstone, and some sandstone—red, green, grayish-red (5*R* 4/2), and brownish-gray (5*YR* 4/1); some pyrite and abundant limonite	70	1,200
Sandstone, very pale orange (10*YR* 8/2), fine-grained; clear- and frosted-quartz grains and red and green mudstone; contains pyrite and abundant limonite	40	1,240
Sandstone, grayish-orange-pink (10*R* 8/2), very fine to fine-grained; subrounded to subangular poorly sorted frosted-quartz grains; red mudstone cavings; rare bright red accessory minerals 1,250 to 1,260 ft	30	1,270
Sandstone, moderate-orange-pink (10*R* 7/4), very fine to fine-grained; subrounded to subangular poorly sorted frosted-quartz grains	10	1,280
Sandstone, very pale orange (10*YR* 8/2), fine-grained; rounded to subrounded fairly well sorted frosted-quartz grains; green, red, and black accessory minerals common	20	1,300
Sandstone, very pale orange (10*YR* 8/2), to grayish-orange (10*YR* 7/2), fine- to medium-grained; subrounded frosted-quartz grains; rare red and dark accessory minerals	60	1,360
Summerville Formation:		
Sandstone, moderate-reddish-orange (10*R* 6/6), to light-brown (5*YR* 6/4), fine-grained; subrounded poorly sorted frosted-quartz grains	60	1,420
Sandstone, grayish-orange-pink (10*R* 8/2), fine-grained; subrounded fairly well sorted frosted-quartz grains; minor red and dark accessory minerals	20	1,440
Sandstone, moderate-orange-pink (5*YR* 8/4), very fine to fine-grained; subrounded fairly well sorted frosted-quartz grains; limonite stains	30	1,470
Sandstone, light-brown (5*YR* 6/4), very fine to fine-grained; subrounded fairly well sorted frosted-quartz grains; abundant limonite stains, black accessory minerals common	20	1,490
Sandstone, very silty, light-brown (5*YR* 6/4), very fine grained to silt; angular fairly well sorted frosted- and stained-quartz grains; black and yellow accessory minerals common	20	1,510
Entrada Sandstone:		
Sandstone, grayish-orange (10*YR* 7/4) to light-brown (5*YR* 6/4), very fine to fine-grained; angular poorly sorted clear- and frosted-quartz grains; considerable limonite stains, black accessory minerals	20	1,530

	Thickness (feet)	Depth below land surface (feet)
B-17, NE¼NW¼NE¼ sec. 18 T. 33½ N., R. 17 W.—Continued		
Jurassic—Continued		
Entrada Sandstone—Continued		
Sandstone, grayish-orange-pink (10*R* 8/2), fine-grained; subrounded poorly sorted clear- and frosted-quartz grains; limonite stains	10	1, 540
Sandstone, silty, moderate-orange-pink (10*R* 7/4), very fine to fine-grained; subrounded poorly to fairly well sorted clear- and frosted-quartz grains	10	1, 550
No samples	20	1, 570
Sandstone, grayish-orange-pink (10*R* 8/2) to moderate-orange-pink (10*R* 7/4), very fine grained	10	1, 580
Navajo Sandstones:		
Sandstone, moderate-reddish-orange (10*R* 5/6), very fine grained; subrounded fairly well sorted quartz grains	10	1, 590
Sandstone, moderate-orange-pink (10*R* 8/4), very fine grained; subrounded fairly well sorted quartz grains	20	1, 610
Sandstone, moderate-reddish-orange (10*R* 5/6), fine- to very fine-grained; subrounded fairly well sorted quartz grains	135	1, 745
Sandstone, grayish-orange-pink (10*R* 8/2), fine-grained; subrounded quartz grains (some white and pink sand grains)	5	1, 750
No samples	16	1, 769
B-18, NE¼SW¼SW¼ sec. 17 T. 33½ N., R. 17 W. [USGS log. Alt 5,739 ft]		
Quaternary:		
Alluvium:		
Surface material, including white, red, and brown sandstone; gray shale; and some pebbles and cobbles	40	40
Cretaceous:		
Mancos Shale:		
Mudstone, medium-dark-gray (*N*4), and 25 to 30 percent coarse sand	20	60
Mudstone, medium-dark-gray (*N*4), and some coarse sand	60	120
Mudstone, dark-gray (*N*3), and some sandstone	30	150
Mudstone, dark-gray (*N*3), and some dark-yellowish-orange (10*YR* 6/6), very fine grained well-sorted sandstone	10	160
Mudstone, dark-gray (*N*3), and some marcasite	30	190
Mudstone, dark-gray (*N*3); slight bit of light-brown (5*YR* 5/6) sand	10	200
Mudstone, dark-gray (*N*3), and very pale orange (10*YR* 8/2) very fine grained sandstone; contains some bentonite at 250 ft	60	260
Mudstone, dark-gray (*N*3)	70	330
Mudstone, grayish-black (*N*2)	20	350
Mudstone, dark-gray (*N*3); bentonite	10	360
No sample	10	370
Mudstone, dark-gray (*N*3)	90	460
Mudstone, dark-gray (*N*3), and some light-brown (5*YR* 5/6) fine well-sorted sand	10	470

	Thickness (feet)	Depth below land surface (feet)
B-18, NE¼SW¼SW¼ sec. 17 T. 33½ N., R. 17 W.—Continued		
Cretaceous—Continued		
Mancos Shale—Continued		
Mudstone, dark-gray (*N*3)	30	500
Mudstone, medium-dark-gray (*N*4)	20	520
Mudstone and 10 to 15 percent medium-light-gray (*N*6) limestone	10	530
Mudstone, medium-dark-gray (*N*4), and some limestone cavings	30	560
Dakota Sandstone and Burro Canyon Formation, undifferentiated:		
Sandstone, light-gray (*N*7), fine- to medium-grained; subrounded frosted-quartz grains; light-gray mudstone	10	570
Sandstone, light-gray (*N*7), fine- to medium-grained, 50 percent; mudstone 50 percent	30	600
Sandstone, very light gray (*N*8), fine- to medium-grained, well-rounded to subrounded frosted-quartz grains; gray mudstone	80	680
Mudstone, medium-dark-gray (*N*4), and some grayish-orange-pink (5*YR* 7/2) clay particles; contains slight amount of sand	10	690
Mudstone, medium-dark-gray (*N*4), and very light gray (*N*8) sandstone; very fine grained; rounded well-sorted frosted-quartz grains; contains some bentonite	30	720
Sandstone, very light gray (*N*8), fine-grained; well-sorted rounded to subrounded quartz grains; 25 to 50 percent mudstone	40	760
Sandstone, light-gray (*N*7), fine- to medium-grained; subrounded poorly sorted frosted-quartz grains; 10 percent mudstone	20	780
Jurassic:		
Morrison Formation:		
Sandstone, light-gray (*N*7), fine- to medium-grained; poorly sorted quartz grains; abundant limonite-stained grains, and slight amount of greenish mudstone	10	790
Sandstone, light-gray (*N*7), very fine grained, and greenish-gray (5*G* 6/1) sandy siltstone	10	800
Mudstone, light-bluish-gray (5*B* 7/1) to dark-gray (*N*3); some sandstone	10	810
Sandstone, light-bluish-gray (5*B* 7/1), fine-grained, well-sorted quartz grains; contains green accessory minerals, dark-gray (*N*3) and greenish-gray (5*G* 6/1) mudstone	30	840
Mudstone, greenish-gray (5*G* 6/1) to dark-gray (*N*3); some sandstone	20	860
Mudstone, greenish-gray (5*GY* 6/1), and light-bluish-gray (5*B* 7/1) fine-grained; rounded quartz grains; green and dark-colored accessory minerals	20	880
Sandstone, light-bluish-gray (5*B* 7/1), and greenish-gray (5*G* 6/1) to gray mudstone	10	890
Mudstone, light-bluish-gray (5*B* 7/1), and medium-bluish-gray (5*B* 5/1) siltstone; some sandstone	40	930
Sandstone, very light bluish gray (5*B* 8/1), and 40 percent medium-bluish-gray (5*B* 5/1) mudstone	40	97

	Thickness (feet)	Depth below land surface (feet)
B-18, NE¼SW¼SW¼sec. 17 T. 33½ N., R. 17 W.—Continued		
Jurassic—Continued		
Morrison Formation—Continued		
Mudstone, brownish-gray (5*YR* 5/1)	10	980
Mudstone, brownish-gray (5*YR* 5/1), very sandy; fine- to medium-grained; rounded fairly well sorted frosted- and clear-quartz grains	10	990
Sandstone, brownish-gray (5*YR* 5/1), fine- to medium-grained; rounded well-sorted frosted- and clear-quartz grains	20	1,010
Mudstone, medium-bluish-gray (5*B* 5/1); some sandstone	20	1,030
Sandstone, very light gray (*N*8), fine-grained; rounded poorly sorted clear- and frosted-quartz grains; gray and green mudstone, 10 percent; and white chalky particles at 1,070 and 1,160 ft	150	1,180
Mudstone, greenish-gray (5*G* 6/1), and very light gray (*N*7) sandstone, 40 percent	10	1,190
Sandstone, light-gray (*N*7), fine-grained; subrounded fairly well sorted frosted-quartz grains; some greenish-gray (5*G* 6/1) and brown mudstone	70	1,260
Sandstone, light-gray (*N*7), fine-grained; subrounded quartz grains; dark-greenish-gray (5*G* 4/1) mudstone	20	1,280
Sandstone, light-gray (*N*7), fine-grained, and brownish-gray (5*YR* 5/1) mudstone	10	1,290
Sandstone, very light gray (*N*8) to white, fine- to medium-grained; subrounded fairly well sorted clear-quartz grains; contains some blue-green and gray mudstone; and a few reddish-orange sand grains from 1,320 to 1,330 ft	40	1,330
Sandstone, very light gray (*N*8) to white (*N*9), fine- to medium-grained; subrounded fairly well sorted clear-quartz grains, 50 percent; gray and green mudstone, 50 percent	10	1,340
Sandstone, very light gray (*N*8) to white, fine- to medium-grained; subrounded fairly well sorted clear-quartz grains; a few reddish-orange grains and some gray-green mudstone	10	1,350
Sandstone, very light gray (*N*8) to white, fine- to medium-grained; subrounded fairly well sorted clear-quartz grains, 50 percent; red and green mudstone, 50 percent; some sandy siltstone	30	1,380
Mudstone, red and green, 80 percent; some white sandstone and green sandy siltstone, 20 percent	10	1,390
Junction Creek Sandstone:		
Sandstone, slightly pink, fine-grained; rounded well-sorted frosted-quartz grains; contains reddish grains	10	1,400
Sandstone, silty, light-brownish-gray (5*YR* 6/1), very fine grained; well-sorted frosted-quartz grains; (considerable cement from cementing operation)	30	1,430
Sandstone—poor samples—large amount of cement	30	1,460
Mudstone, brownish-gray (5*YR* 4/1)	10	1,470
Sandstone, light-brownish-gray (5*YR* 6/1), silty, very fine grained; some brownish-gray (5*YR* 4/1) and grayish-green (10*G* 4/2) mudstone	10	1,480

	Thickness (feet)	Depth below land surface (feet)
B-18, NE¼SW¼SW¼ sec. 17 T. 33½ N., R. 17 W.—Continued		
Jurassic—Continued		
Junction Creek Sandstone—Continued		
Sandstone, light-brownish-gray (5*YR* 6/1), fine-grained; subrounded poorly sorted clear- and frosted-quartz grains; 10 percent brown mudstone	10	1, 490
Sandstone, pale-red (10*R* 6/2), fine-grained; subrounded poorly sorted clear- and frosted-quartz grains; contains some brown mudstone, a few pieces of white clay, and some bright-red grains	20	1, 510
Sandstone, grayish-orange-pink (5*YR* 7/2), fine-grained; subrounded poorly sorted clear- and frosted-quartz grains	70	1, 580
Sandstone, light-brown (5*YR* 6/4), fine-grained; rounded poorly sorted frosted-quartz grains; limonite common	30	1, 610
Sandstone, pale-red (10*R* 6/2), fine-grained; subrounded poorly sorted clear- and frosted-quartz grains	10	1, 620
Summerville Formation:		
Sandstone, orange-pale-red (10*R* 7/2), very fine to fine-grained; subrounded fairly well sorted clear- and frosted-quartz grains; contains brown mudstone	50	1, 670
Sandstone, very pale orange (10*YR* 8/2), fine-grained; subrounded fairly well sorted clear- and frosted-quartz grains; contains small amount of white chalk	20	1, 690
Sandstone, orange-pale-red (10*R* 7/2), very fine to fine-grained; subrounded fairly well sorted clear- and frosted-quartz grains; 15 percent moderate-brown (5*YR* 3/4) mudstone	10	1, 700
Mudstone, moderate-brown (5*YR* 3/4), 50 percent, and orangish-pale-red (10*R* 7/2) very fine to fine-grained subrounded, clear- and frosted-quartz sandstone, 50 percent	10	1, 710
Sandstone, grayish-orange-pink (10*R* 8/2), fine-grained, and grayish-red (10*R* 4/2) mudstone; contains some white fine sand	40	1, 750
Sandstone, grayish-orange-pink (10*R* 8/2), fine-grained and moderate-brown (5*YR* 3/4) mudstone	20	1, 770
Entrada Sandstone:		
Sandstone, light-grayish-orange-pink (5*YR* 7/2), fine-grained; subrounded poorly sorted frosted-quartz grains	10	1, 780
Sandstone, white, very fine grained, and grayish-red (10*R* 4/2) siltstone and mudstone (1,788 ft—lost 120 ft of drill stem in hole; drilling continued along side of drill stem in new hole—poor samples next 50 ft)	10	1, 790
Siltstone, grayish-red (10*R* 4/2), and as much as 20 percent white very fine grained sandstone	20	1, 810
Sandstone, moderate-orange-pink (10*R* 7/4), very fine to fine-grained; subrounded to subangular clear- and frosted-quartz grains	20	1, 830
Siltstone, grayish-red (10*R* 4/2), and white to grayish-orange-pink (10*R* 8/2) sandstone (medial silty member)	20	1, 850

	Thickness (feet)	Depth below land surface (feet)
B-18, NE¼SW¼SW¼ sec. 17 T. 33½ N., R. 17 W.—Continued		
Jurassic and Triassic(?):		
Navajo Sandstone:		
Sandstone, white to moderate-orange-pink (10*R* 7/4), very fine grained, and some grayish-red (10*R* 4/2) siltstone	40	1, 890
Sandstone, moderate-reddish-orange (10*R* 6/6), fine-grained; subrounded to subangular clear- and frosted-quartz grains	10	1, 900
Sandstone, moderate-orange-pink (10*R* 7/4), fine-grained; subrounded to subangular clear- and frosted-quartz grains	100	2, 000
No sample	2	2, 002
B-19, NW¼NW¼SW¼ sec. 8 T. 33½ N., R. 17 W. [USGS log. Alt 5,917 ft]		
Quaternary:		
Alluvium:		
Sandstone, fine- to very coarse grained, and gravel	30	30
Sandstone, cobbles, pebbles, a few boulders, some gray mudstone, and siltstone	20	50
Cretaceous:		
Mancos Shale:		
Mudstone and siltstone, medium-dark-gray (*N*4); contains considerable surface material	20	70
Mudstone, medium-dark-gray (*N*4)	130	200
Mudstone, medium-gray (*N*4), calcareous; contains minor sand grains	20	220
Mudstone, medium-dark-gray (*N*4)	10	230
Mudstone, medium-gray (*N*5), calcareous	40	270
Mudstone, medium-dark-gray (*N*4), and gray limestone particles	20	290
Mudstone, medium-dark-gray (*N*4), calcareous	30	320
Dakota Sandstone and Burro Canyon Formations, undifferentiated:		
Sandstone, yellowish-gray (5*Y* 8/1), fine-grained; subrounded fairly well sorted frosted-quartz grains; considerable circulating Mancos Shale material	160	480
Sandstone, pinkish-gray (5*YR* 8/1), and yellowish-gray (5*Y* 7/2), fine- to medium-grained; subrounded fairly well sorted frosted-quartz grains; abundant coal particles	20	500
No sample	10	510
Sandstone, yellowish-gray (5*GY* 8/1), medium-grained; subrounded fairly well sorted frosted-quartz grains; rare coal particles and considerable cavings	20	530
Jurassic:		
Morrison Formation:		
Sandstone, yellowish-gray (5*Y* 7/2), and light-greenish-gray (5*G* 8/1) mudstone	10	540
Mudstone, light-greenish-gray (5*G* 8/1); contains common dark-green accessory minerals from 600 to 610 ft	100	640
Mudstone, greenish-gray (5*GY* 6/1)	60	700

	Thickness (feet)	Depth below land surface (feet)
B-19, NW¼NW¼SW¼ sec. 8 T. 33½ N., R. 17 W.—Continued		
Jurassic—Continued		
Morrison Formation--Continued		
Mudstone, greenish-gray (5*GY* 6/1), and light-greenish-gray (5*G* 8/1), fine-grained; subrounded frosted-quartz sandstone	10	710
Sandstone, light-greenish-gray (5*G* 8/1), fine-grained; subrounded frosted-quartz grains	10	720
Mudstone and sandstone, light-greenish-gray (5*G* 8/1); sandstone is very fine to fine-grained	40	760
Sandstone, yellowish-gray (5*Y* 8/1), fine-grained; subrounded clear- and frosted-quartz grains; siliceous cement; contains some greenish-gray (5*G* 6/1) mudstone	10	770
Sandstone, yellowish-gray (5*Y* 8/1), fine-grained; subrounded clear- and frosted-quartz grains; black accessory minerals common, and very dusky-red (10*R* 2/2) mudstone; abundant limonitic mudstone balls and some gray-green mudstone particles	20	790
Sandstone, yellowish-gray (5*Y* 8/1), fine-grained; subrounded clear- and frosted-quartz grains	10	800
Sandstone, light-greenish-gray (5*GY* 8/1), fine-grained; subrounded fairly well sorted frosted-quartz grains; calcareous cement; some gray-green mudstone	60	860
Sandstone, yellowish-gray (5*Y* 8/1), medium-grained; subrounded fairly well sorted frosted-quartz grains	20	880
Sandstone, light-greenish-gray (5*GY* 8/1); very fine- to fine-grained; subrounded frosted-quartz grains; contains some gray-green mudstone	10	890
Sandstone, yellowish-gray (5*Y* 8/1), medium-grained; subrounded fairly well sorted frosted-quartz grains; some gray-green mudstone	90	980
Sandstone, pinkish-gray (5*YR* 8/1), fine-grained; subrounded frosted-quartz grains	20	1,000
Sandstone, pinkish-gray (5*YR* 8/1), fine-grained, 50 percent; and 50 percent very dusky red (10*R* 2/2), and greenish-gray (5*G* 6/1) mudstone	30	1,030
Sandstone, pinkish-gray (5*YR* 8/1), fine-grained; subrounded clear-quartz grains; 15 percent red and green mudstone	30	1,060
Sandstone, pinkish-gray (5*YR* 8/1), fine-grained; subrounded quartz grains, 50 percent; and 50 percent red and green mudstone	30	1,090
Sandstone, pinkish-gray (5*Y* 8/1), fine- to medium-grained; subrounded clear-quartz grains	40	1,130
Sandstone, yellowish-gray (5*Y* 8/1), fine-grained; frosted-quartz grains; 25 percent red and green mudstone	10	1,140
Junction Creek Sandstone:		
Sandstone, pinkish-gray (5*YR* 8/1), fine- to medium-grained; frosted-quartz grains; red and green mudstone	30	1,170
Claystone, grayish-red (10*R* 4/2)	10	1,180
Claystone, grayish-red (10*R* 4/2), 50 percent; light-greenish-gray (5*G* 8/1) mudstone, 15 percent; and fine-grained sandstone, 35 percent	20	1,200

	Thickness (feet)	Depth below land surface (feet)
B-19, NW¼NW¼SW¼ sec. 8 T. 33½ N., R. 17 W.—Continued		
Jurassic—Continued		
Junction Creek Sandstone—Continued		
Mudstone, brownish-gray (5*YR* 4/1); contains a considerable amount of sandstone and green mudstone	30	1, 230
Sandstone, moderate-orange-pink (5*YR* 8/4), fine-grained; subrounded well-sorted frosted-quartz grains	30	1, 260
Sandstone, very pale orange (10*YR* 8/2), fine- to medium-grained; subrounded fairly well sorted frosted-quartz grains	10	1, 270
Sandstone, pale-red (10*R* 6/2), medium-grained; subrounded well-sorted clear- and frosted-quartz grains	60	1, 330
Sandstone, pale-red (10*R* 6/2), fine-grained; subrounded fairly well sorted clear- and frosted-quartz grains; calcareous	10	1, 340
Sandstone, grayish-orange-pink (10*R* 8/2), fine-grained; subrounded fairly well sorted clear- and frosted-quartz grains	10	1, 350
Sandstone, grayish-orange-pink (10*R* 8/2) to pale-red (10*R* 6/2), very fine to fine-grained; subrounded, fairly well sorted clear- and frosted-quartz grains	30	1, 380
Summerville Formation:		
Sandstone, pale-red (10*R* 7/2), fine- to medium-grained; subrounded fairly well sorted frosted-quartz grains	10	1, 390
Sandstone, pale-red (10*R* 7/2), medium-grained; subrounded fairly well sorted frosted-quartz grains	10	1, 400
Sandstone, moderate-orange-pink (10*R* 7/4), fine- to medium-grained; subrounded fairly well sorted frosted-quartz grains	10	1, 410
Siltstone, grayish-red (10*R* 4/2); contains some sand grains; limonite stains	20	1, 430
Sandstone, grayish-orange-pink (10*R* 8/2), medium-grained; fairly well sorted frosted-quartz grains; 30 percent grayish-red (10*R* 4/2) mudstone	20	1, 450
Sandstone, grayish-orange-pink (10*R* 8/2), silty, fine-grained; fairly well sorted frosted-quartz grains	40	1, 490
Siltstone, grayish-red (10R 4/2); contains a small amount of moderate-reddish-orange (10*R* 6/6) sandstone	10	1, 500
Siltstone, grayish-red (10*R* 4/2)	10	1, 510
Entrada Sandstone:		
Sandstone, white to grayish-orange-pink (10*R* 8/2), very fine to fine-grained; subangular to subrounded clear- and frosted-quartz grains	20	1, 530
Sandstone, grayish-orange-pink (10*R* 8/2), very fine to fine-grained; subangular to subrounded poorly sorted clear- and frosted-quartz grains	30	1, 560
Sandstone, white to grayish-orange-pink (10*R* 8/2) to moderate-orange-pink (10*R* 7/4), fine- to medium-grained; subrounded poorly sorted clear- and frosted-quartz grains	10	1, 570

	Thickness (feet)	Depth below land surface (feet)
B-19, NW¼NW¼SW¼ sec. 8 T. 33½ N., R. 17 W.—Continued		
Jurassic—Continued		
Entrada Sandstone—Continued		
Sandstone, grayish-orange-pink (10*R* 8/2), very fine to fine-grained; subrounded to rounded poorly sorted clear- and frosted-quartz grains; contains minor amounts of medium-grained quartz	10	1, 580
Sandstone, moderate-orange-pink (10*R* 7/4), fine-grained; and grayish-red (10*R* 4/2) mudstone (medial silty member)	20	1, 600
Jurassic and Triassic(?):		
Navajo Sandstone:		
Sandstone, moderate-orange-pink (10*R* 7/4) to moderate-reddish-orange (10*R* 6/6), fine- to medium-grained; subrounded to rounded fairly well sorted frosted-quartz grains; contains a few white grains	10	1, 610
Sandstone, moderate-orange-pink (10*R* 7/4) to moderate-reddish-orange (10*R* 6/6), very fine to fine-grained, subrounded to rounded poorly sorted frosted-quartz grains	30	1, 640
Sandstone, moderate-reddish-orange (10*R* 6/6), very fine grained, subrounded frosted-quartz grains	20	1, 660
Sandstone, white and moderate-orange-pink (10*R* 7/4), very fine to fine-grained, subrounded frosted-quartz grains	10	1, 670
Sandstone, moderate-reddish-orange (10*R* 6/6), very fine to fine-grained, subrounded fairly well sorted clear- and frosted-quartz grains	10	1, 680
Sandstone, moderate-orange-pink (10*R* 7/4), very fine to fine-grained; contains some fine-grained white and greenish-white frosted-quartz grains	10	1, 690
Sandstone, moderate-reddish-orange (10*R* 6/6), to grayish-orange (10*R* 7/4), fine- to very fine grained; subrounded to rounded fairly well sorted clear- and frosted-quartz grains; 25 percent grayish-red (10*R* 4/2) siltstone	30	1, 720
Siltstone, grayish-red (5*R* 4/2), 60 percent; and 40 percent moderate-reddish-orange (10*R* 6/6) very fine to fine-grained frosted-quartz sandstone	20	1, 740
Siltstone, grayish-red (5*R* 4/2); some sand	20	1, 760
Sandstone, moderate-reddish-orange (10*R* 6/6) to pale-reddish-brown (10*R* 5/4), very fine to fine-grained; subangular to subrounded frosted-quartz grains, 50 percent; and 50 percent grayish brown (5*YR* 3/2) mudstone	20	1, 780
Triassic		
Wingate(?) Sandstone:		
Sandstone, moderate-reddish-orange (10*R* 6/6), very fine to fine-grained; frosted-quartz grains, contains a considerable amount of white sandstone	20	1, 800
No samples	25	1, 825

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