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Surface Geology of the Nash Draw Quadrangle Eddy County New Mexico

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GEOLOGICAL SURVEY BULLETIN 1141-B

Prepared on behalf of the U.S. Atomic Energy Commission

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

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Surface Geology of the Nash Draw Quadrangle Eddy County New Mexico

By JAMES D. VINE

CONTRIBUTIONS TO GENERAL GEOLOGY

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STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

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CONTENTS

ILLUSTRATIONS

CONTRIBUTIONS TO GENERAL GEOLOGY

SURFACE GEOLOGY OF THE NASH DRAW QUADRANGLE, EDDY COUNTY, NEW MEXICO

By JAMES D. VINE

ABSTRACT

Outcropping rocks and surficial deposits of the Nash Draw quadrangle were mapped to provide geologic information for the U.S. Atomic Energy Commission's Plowshare program. The quadrangle is near the north margin of the Delaware basin and about 15 miles east of Carlsbad, N. Mex. The region is sparsely inhabited and has an arid climate.

As much as 4,000 feet of salt and anhydrite of Permian age is present below the surface, but does not crop out in normal thickness in this area or elsewhere because of their high solubility. These rocks have been divided into the Castile formation below and the Salado formation above. Rocks exposed at the surface overlie these soluble rocks and include the Rustler formation of Late Permian age, the Pierce Canyon redbeds of Permian or Triassic age, the Santa Rosa sandstone of Late Triassic age, and the Gatuna formation, caliche, and a variety of unconsolidated deposits of late Cenozoic age.

The Rustler formation of Late Permian age is subdivided into four easily distinguishable members, excluding about 120 feet of the lower part, which is not exposed at the surface in this area. The oldest member exposed is the Culebra dolomite member, about 30 feet thick, identified only in erratically distributed outcrops in collapse areas. The Culebra consists of microcrystalline gray dolomite or dolomitic limestone characterized by numerous spherical cavities 1 to 10 mm in diameter. It is conformably overlain by the Tamarisk member, named herein for exposures directly east of Tamarisk Flat. It consists of about 115 feet of massive gypsum at the surface, changing to anhydrite in the subsurface, and a bed, 5 feet thick, of siltstone near the base. Surficial deformation caused by hydration and solution are characteristic of all the outcrops. The Tamarisk member is conformably overlain by the Magenta member, about 20 feet thick and consisting of alternating wavy laminae of pale-red dolomite and pale yellowish-green anhydrite or gypsum. The top member of the Rustler formation conformably overlies the Magenta and is here named the Forty-niner member after Forty-niner Ridge, where it crops out. In surface exposures it consists of about 40 to 65 feet of broken and slumped massive gypsum and a bed of siltstone in the lower part. The siltstone beds in the Tamarisk and Forty-niner members probably represent the insoluble residue of salt beds reported from the subsurface to the east.

Overlying the Rustler formation with apparent conformity are the Pierce Canyon redbeds of Permian or Triassic age. These rocks consist of about 200 to 250 feet of laminated or minutely cross-laminated moderate reddish-brown siltstone. The contact between the Pierce Canyon redbeds and the overlying Santa Rosa sandstone is a disconformity, at least locally.

The Santa Rosa sandstone of Late Triassic age consists of pale-red sandstone and conglomerate lenses crossbedded in sets 3 to 15 feet thick separated locally by moderate reddish-brown siltstone and claystone. Only the lower 50 to 70 feet of Santa Rosa was recognized in the area.

The Gatuna formation of Pleistocene(?) age unconformably overlies all older rocks. In much of the area it consists of 3 to 5 feet of moderate reddish-orange sandstone, siltstone, and conglomerate. Locally, in karst depressions, the Gatuna attains a thickness of at least 100 feet. In some areas the lithology closely resembles the Pierce Canyon redbeds or the Santa Rosa sandstone.

Caliche forms a resistant layer at the ground surface, 5 to 10 feet thick, that protects older rocks from erosion in many areas. The caliche consists of calcareous material with a variable amount of imbedded sand grains, pebbles, and rock fragments. Caliche mounds and broken flexture ridges, 10 to 15 feet high, have formed narrow zones 50 to several hundred feet long.

Quaternary alluvium has been deposited along the sides of depressions. It is overlain by playa lake deposits, which are in turn overlain by conspicuous sand dunes as much as 100 feet high.

The regional structure is relatively simple and consists of a dip of a few feet per mile to the east and southeast.

Normally flat-lying strata are tilted, warped, and locally distorted at the surface by hydration and solution of the evaporite rocks in the subsurface. Nash Draw, a depression 4 to 6 miles wide and about 18 miles long, has resulted from the solution of salt in the Rustler and Salado formations and collapse of the overlying relatively insoluble rocks. Topography and surface structure conform in some areas with the configuration of the underlying solution surface at the top of the massive salt in the Salado formation; however, locally there is an inverse correspondence. Many circular karst features 1/10 to 1/2 mile in diameter are in the area. Some of these features are structural domes, but they contain a core of tilted or brecciated rock. These karst features result from the formation and collapse of sinkholes, differential solution at the top of the massive salt, and hydration of the anhydrite beds.

INTRODUCTION

The surface geology of the Nash Draw quadrangle, New Mexico (pl. 1), was mapped between October 1958 and March 1959 to provide the U.S. Atomic Energy Commission with geologic data on the area surrounding the site of the proposed Gnome experiment, part of the Plowshare program for the development of peaceful uses of atomic energy. Selection of the Gnome site in sec. 34, T. 23 S., R. 30 E., was based in part on geologic requirements relating to thickness of overburden and of the salt bed in which the detonation of a nuclear device is planned. Adequate geologic data on the surrounding area are essential to the success of the experiment. The investigation was on behalf of the Office of Test Operations, Albuquerque Operations Office, U.S. Atomic Energy Commission.

This report describes the surface geologic features of the area. An intensive investigation of the subsurface geology over a period of about 10 years was completed by C. L. Jones and others in connection with the U.S. Geological Survey's commodity study of the potash deposits, and preliminary reports have been prepared by Jones (1954, 1959, and 1960), Jones and Madsen (1959), and Jones, Bowles, and Bell (1960).

The Nash Draw quadrangle is located in southeastern New Mexico in eastern Eddy County (fig. 1). The city of Carlsbad lies about 14 miles due west of the northern part of the quadrangle. The only dwellings within the quadrangle are three ranchhouses. Nash Draw is a topographic depression 4 to 6 miles wide, and extends the entire length of the quadrangle. An escarpment on the north side of Nash Draw is called Maroon Cliffs; one on the east is called Livingston Ridge, and one on the west is Quahada Ridge. An escarpment on the south side is not named. Nash Draw has no external surface drainage. Several lakes, including Salt Lake in the southwestern part of the depression, have no surface outlet. A semiarid to arid climate and infertile, saline, rocky, or sandy soils combine to make agriculture impractical. Grazing is the only use made of the land surface. In contrast to poor agricultural conditions, a great wealth of potash lies underground; it is localized chiefly in the northwestern part of the

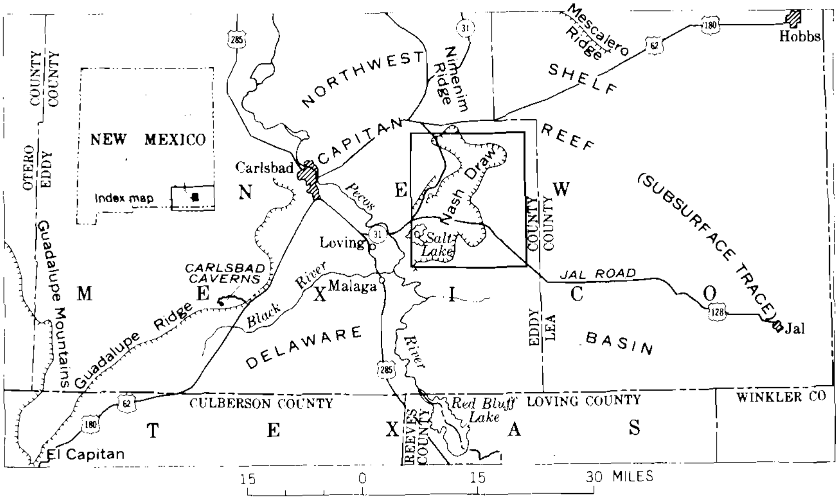

FIGURE 1.—Southeastern New Mexico and adjacent part of Texas showing location of the Nash Draw quadrangle (heavy line). Hachures show position of scarp.

quadrangle and extends beyond the quadrangle to the north and northeast. Within the quadrangle the U.S. Potash Co.'s principal mine entry is located in sec. 12, T. 21 S., R. 29 E., and the International Minerals and Chemical Corp.'s principal mine entry and refinery are located in secs. 1 and 12, T. 22 S., R. 29 E. The U.S. Potash Co.'s refinery is located on the west side of Salt Lake about 2 miles west of the quadrangle (fig. 2). Together these potash mines and four others a few miles north of the quadrangle comprise the principal source of potash available within the United States and represent the principal industrial employment and income within the Carlsbad region.

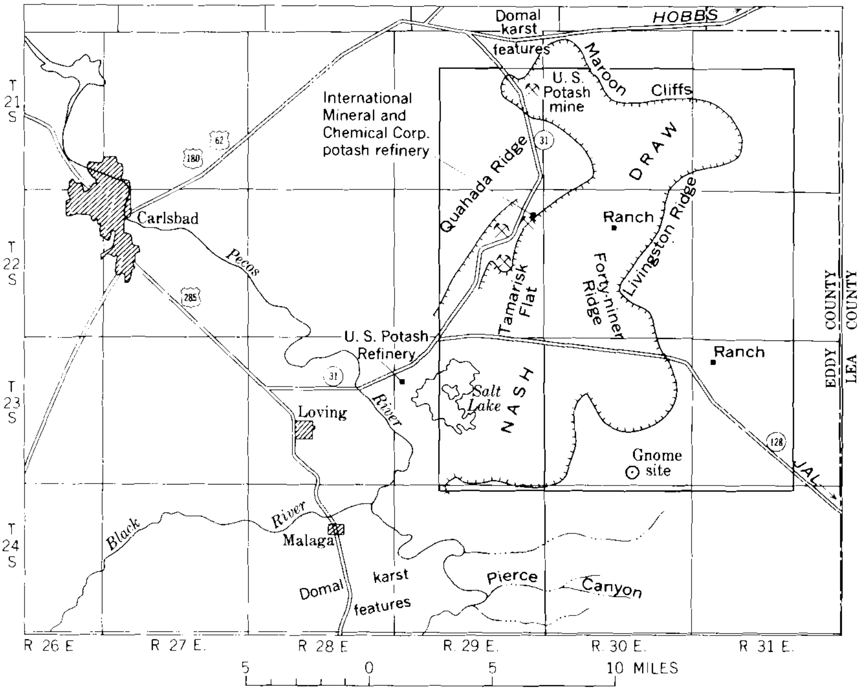

FIGURE 2.—Map showing geographic features in the Nash Draw quadrangle and adjacent areas. Hachures show position of scarp.

Access to the Nash Draw quadrangle is provided by two improved roads. New Mexico State Route 31 crosses the northwestern part of the area. It joins U.S. Highway 285 about 8 miles west of the quadrangle and about 2 miles northwest of Loving, N. Mex. About 2 miles beyond the north boundary New Mexico State Route 31 joins U.S. Highway 62 and 180. An unnumbered highway from Jal, N. Mex., in the extreme southeast corner of the State, crosses the southern part of the Nash Draw quadrangle and joins New Mexico State Route 31 about an eighth of a mile west of the quadrangle boundary. An access road, 5 miles long, to the Gnome site was constructed from a point on the Jal road about 7½ miles east of the junction with New Mexico State Route. 31.

The writer was aided in the fieldwork and the interpretation of the field relations by other geologists and engineers in the area, especially George W. Moore and Charles B. Read, who accompained the writer in the field on several occasions. Robert Fulton and Bruno R. Alto cooperated by making available the records of wells drilled on Government lands. The writer is especially indebted to Mr. William H. Atkinson, work unit conservationist U.S. Soil Conservation Service in Carlsbad, for the loan of large-scale aerial photographs of the Nash Draw quadrangle and adjacent areas. Robert E. Miller, U.S. Atomic Energy Commission, Albuquerque Operations Office, provided office space and vehicles for field use. Ray Harbert, Phillip D. Pack, and Michael S. Bickers, Holmes and Narver, Inc.; Thomas Pearce, the U.S. Coast and Geodetic Survey; Charles E. Violet, Lawrence Radiation Laboratory, Livermore, Calif.; and William R. Perret, Sandia Corp., Albuquerque, N. Mex., provided technical discussion of specific geologic features that might be of interest in connection with the Gnome experiment. E. G. Patton, Reynolds Electrical & Engineering Co., Inc., provided necessary administrative services.

REGIONAL STRATIGRAPHIC SETTING

The Nash Draw quadrangle lies in the Delaware basin, a region of sedimentary rocks that is well known to geologists from exposures in the Guadalupe Mountains southwest of the quadrangle and from exploratory bore holes drilled for petroleum and potash. A summary of the Late Permian and younger strata and surficial deposits is presented in the table below. In addition to the rocks that have been studied in surface exposures as a part of the present investigation, two older rock formations, the Castile and the Salado, are listed in the table and briefly described below because of their importance in understanding the outcropping rocks. As much as 10,000 feet of still older Paleozoic strata has been penetrated by drilling but is not described in this report.

The eastern escarpment of the Guadalupe Ridge southwest of the Nash Draw quadrangle is formed by a massive limestone, the Capitan limestone, which has long been considered to be an ancient barrier reef (Lloyd, 1929; Crandall, 1929). The limestone is as much as 2,000 feet thick and can be traced for many miles; but it is very narrow, as it is generally only a few thousand feet to a few miles wide. The reef

Summary of Late Permian and younger strata and deposits, Nash Draw quadrangle, New Mexico

Age		Formation	Member or zone	Description
Quaternary	Recent	Sand		Windblown sand deposits and conspicuous dunes as much as 100 ft high.
		Playa lake deposits.		Sand and silt; includes gypsum sand deposited in shallow intermittent lakes.
		Alluvium		Sand and silt, locally conglomeratic, deposited on slopes and in depressions.
		Caliche		Limestone, ranging from dense to travertinelike; includes sand grains and rock fragments; 2 to 15 ft thick.
	Pleistocene(?)	Gatuna		Gravel, sand, silt, clay, and locally gypsum, deposited as alluvium; poorly consolidated; dominantly reddish orange, grading to pink, gray, or yellow; as much as 100 ft thick.
Triassic	Late Triassic	Santa Rosa sandstone.		Sandstone, conglomeratic, pale-red, very poorly sorted; crossbedded in sets 3 to 15 ft thick; interbedded locally with moderate reddish-brown claystone and siltstone; 50 to 70 ft thick.
Permian or Triassic		Pierce Canyon redbeds.		Siltstone, moderate reddish-orange; conspicuous laminae 1 to 5 mm thick; poorly sorted; locally sandy or clayey; 200 to 250 ft thick.
Permian	Late Permian	Rustler	Forty-niner	Gypsum, white, massive, and siltstone; 40 to 65 ft thick.
			Magenta	Dolomite, pink, interlaminated with pale-green anhydrite; 20 ft thick.
			Tamarisk	Gypsum, white, massive, and siltstone; 115 ft thick.
			Culebra dolomite.	Dolomite, light-gray, silty, thin-bedded to massive; contains spherical vugs 1 to 10 mm in diameter; 30 ft thick.
			Unnamed	Siltstone, gypsum, and very fine grained gray sandstone 120 ft thick.
		Salado	Upper leached zone.	Gypsum, siltstone, and anhydrite, brecciated; 50 to 200 ft thick.
			Zone of massive salt.	Halite, anhydrite, siltstone, and polyhalite; soluble potash minerals locally; as much as 2,000 ft thick.
		Castile		Anhydrite, halite, anhydrite interlaminated with limestone; as much as 2,000 ft thick.

passes underground in the vicinity of Carlsbad and from there it has been traced eastward in the subsurface to the vicinity of Hobbs and from Hobbs southward into Texas. In plan, the Capitan limestone is shaped like a horseshoe more than 60 miles wide (fig. 1). The area within the horseshoe-shaped outline is known as the Delaware basin and the area north of the reef as the Northwest shelf. The Nash Draw quadrangle lies at the north margin of the Delaware basin. According to the barrier reef hypothesis as it has been described in more recent years (Adams, 1944, p. 1598; King, 1942, p. 617–622; King, 1948; Newell and others, 1953), the Capitan limestone reef enclosed a deep basin of water and was surrounded by a shallow shelf. The deep basin was separated from the open sea, and presumably facilitated the accumulation and gravity separation of heavy brines and the chemical precipitation of the evaporite rocks that comprise the Castile formation. The basin eventually filled, but the deposition of evaporites continued and spread across the shelf area, at least to the north and east, where the Salado formation is still preserved under cover of less soluble rocks. Rocks of the Rustler formation represent continued deposition of evaporite rocks with some interruptions. The interval of evaporite deposition was terminated finally when the clastic rocks of the Pierce Canyon redbeds were laid down.

The term Castile, as first used by Richardson (1904, p. 43) was applied to the several hundred feet of cracked and cavernous gypsum that underlies the Rustler formation and overlies the Delaware Mountain group at the surface in west Texas and southeastern New Mexico. Drilling indicates that the interval represented by gypsum at the surface consists of a thick sequence of highly soluble evaporite rocks in the subsurface, including mostly anhydrite, $CaSO_4$, in the lower part of the sequence and mostly halite, NaCl, in the upper part. Wells that have penetrated the evaporite rocks in the Nash Draw quadrangle are listed in the table below. Lang (1935) restricted the term Castile to the lower part of this thick evaporite sequence and applied the name Salado halite to the upper part. Each of the two formations is about 2,000 feet thick.

The Castile formation, as much as 2,000 feet thick in the subsurface in the vicinity of the Nash Draw quadrangle, is composed chiefly of massive anhydrite, limestone interlaminated with anhydrite, and halite in beds as much as several hundred feet thick. The Castile formation overlies the Lamar limestone member of the Bell Canyon formation of the Delaware Mountain group, also of Permian age. Exposures of the less soluble portions of the Castile formation may be viewed in roadcuts on U.S. Highway 62 and 180 south of Carlsbad Caverns near the Texas border. The Castile formation is laterally bounded by the reef of Capitan limestone, which is generally interpreted as being largely older than the Castile.

The Salado formation consists of thick beds of halite and anhydrite and thin beds of siltstone and polyhalite, $K_2MgCa_2(SO_4)_4 \cdot 2H_2O$. Beds locally rich in sylvite, KCl, and other soluble potassium minerals constitute the valuable potash ores. The upper part of the Salado is characterized by a leached zone that consists largely of unconsolidated reddish-gray to brown silt and clay with varying amounts of brecciated gray or red gypsum. It is estimated that the thickness of the leached zone is roughly one-third to one-tenth the thickness of the original rock that was present. Because the halite has been removed, some geologists have included the leached zone with the Rustler formation for convenience; but the zone is most appropriately included with the Salado formation, if not regarded as a separate unit. The zone has variable thickness and lithology, and is of significance because it may be saturated with brine and is locally a prolific aquifer. Because it is incompetent and has a tendency to slump or flow into cavities, special precautions are advisable where this zone is encountered in shaft sinking or other engineering works.

Wells drilled below Permian evaporite rocks

[Elevations from various sources, including Government records and industry reports. A query following an elevation indicates that it is not consistent with the form contours on pl. 1]

Name of operator and lease	Location	Elevation (feet)			Total depth drilled (feet)
		Ground surface	Permian massive salt		
			Top	Base	
Ralph Nix, No. 1 Hall	C SE¼SE¼ sec. 21, T. 21 S., R. 29 E.	3,420	2,870	[1] 345	3,334
Richardson and Bass, No. 1 Fidel-Federal (oil well).	C SW¼SW¼ sec. 27, T. 21 S., R. 29 E.	3,433	2,943?	[2] 180	10,425
Stanolind Oil & Gas Co., No. 1 Duncan.	C SE¼SW¼ sec. 30, T. 21 S., R. 30 E.	3,320	2,977	[3] −139	3,658
I. W. Bosworth, No. 1	SE¼SE¼ sec. 8, T. 21 S., R. 31 E.	3,407	2,672?	[2] −531	4,505
M. D. Bryant, and others, No. 1 Williamson.	C NW¼NW¼ sec. 10, T. 21 S., R. 31 E.	3,615	2,665	[2] −320	4,287
Richardson and Bass, No. 1 Legg (oil well).	NW¼NW¼ sec. 27, T. 22 S., R. 30 E.	3,309	2,779	[3] −443	15,854
Ohio Oil Co., No. 1 Workman	SW¼SW¼SW¼ sec. 13, T. 22 S., R. 29 E.	3,050	2,730	[3] −105	3,260
H and W Drilling Co., No. 1 Danford.	C SE¼SE¼ sec. 9, T. 22 S., R. 29 E.	3,246	2,957	[3] −124	3,322
Shell Oil Co., No. 1 James Ranch (gas well).	SW¼SE¼ sec. 36 T. 22 S., R. 30 E.	3,326	2,596?	[2] −504	17,555
Hall and Wills Drilling Co., No. 1-X Fogarty.	C SW¼SW¼ sec. 14, T. 23 S., R. 29 E.	3,003	2,731	[3] −52	3,144
Wills, and others, No. 1 Montgomery.	SW¼SW¼ NE¼ sec. 10 T. 23 S., R. 30 E.	3,129	2,769	[3] −444	3,715
Continental Oil Co., No. 1 Gardner.	NE¼NE¼SW¼ sec. 34, T. 23 S., R. 31 E.	3,455	2,500	[3] −865	4,410

[1] Top of the "Delaware sand."
[2] Top of the "Delaware lime."
[3] Top of the "Bell Canyon."

DESCRIPTION OF OUTCROPPING ROCKS AND DEPOSITS

Rock exposures in the Nash Draw quadrangle are relatively abundant, but contrary to what might be expected, they are poor for stratigraphic study. This is partly because of the low relief, partly because of the slumping and warping that has accompanied the formation of a karst topography, and partly because of the widespread nature of the late Cenozoic deposits. For these reasons it is nearly impossible to piece together suitable stratigraphic sections from surface exposures alone. Drill data are therefore an important supplement to a study of these outcropping rocks.

In connection with the selection of a site for the Gnome project, the U.S. Atomic Energy Commission drilled a test hole to a depth of 1,500 feet near the center of sec. 34, T. 23 S., R. 30 E. The core recovered from this hole was described by Moore, 1958. The description of the upper 725 feet of this core was used as a standard of reference for many of the stratigraphic units as they were mapped in the field. The core log is therefore reproduced below with minor modifications and shown graphically in figure 3.

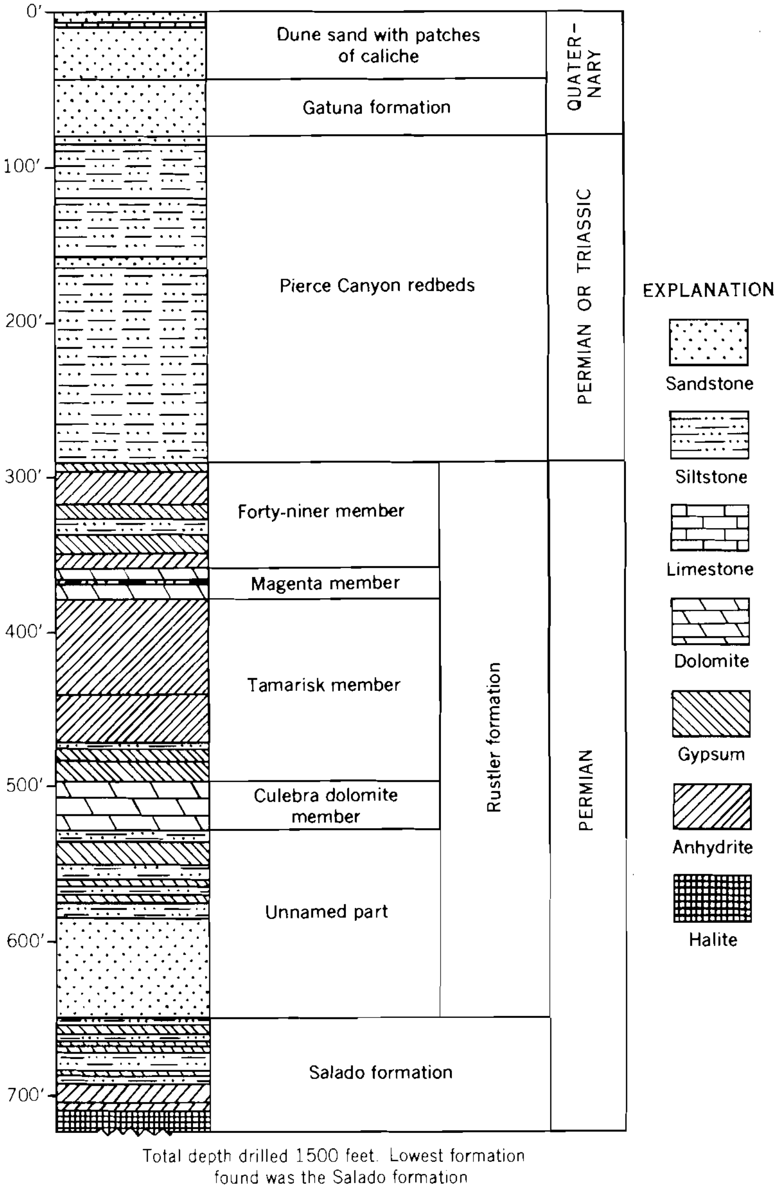

FIGURE 3.—Lithologic log of core from AEC drill hole 1, sec. 34, T. 23 S., R. 30 E.

Log of the upper part of the core from U.S. Atomic Energy Commission drill hole 1, center sec. 34, T. 23 S., R. 30 E., Eddy County, N. Mex.

[Description modified after G. W. Moore. See complete log in Moore (1958). Only 3 ft of core were recovered from the top 85 ft of hole. Descriptions of that part are interpreted mostly from cuttings and drilling speeds]

	Depth (feet)
Surficial sand and caliche:	
Sand, fine-grained, light-brown, well-rounded, unconsolidated	7.0
Limestone, white; contains fine-grained quartz sand; well indurated	10.0
Sand, fine-grained, light-brown, fairly well rounded, very friable	43.0
Gatuna formation of Pleistocene(?) age:	
Sandstone, medium-grained, pale reddish-brown; scattered pebbles 3 mm long; calcite cement; yields water	45.2
Conglomerate, pebble, pale-red; pebbles 5 mm long of limestone, siltstone, quartzite; matrix of coarse-grained well-indurated sandstone; calcite cement	45.7
Sandstone, medium- to coarse-grained, pale-red; scattered pebbles 3 mm long; friable; yields water	53.0
Sandstone, medium- to coarse-grained, moderate-brown, friable	80.0
Pierce Canyon redbeds of Permian or Triassic age:	
Sandstone, very fine grained, moderate reddish-brown; has light greenish-gray spots 2 mm long and about 1 cm apart; calcite veins 0.5 mm thick; poorly indurated except basal 0.5 ft, which is fairly well indurated; calcareous cement	84.5
Siltstone, sandy, moderate reddish-brown; light greenish-gray spots 1 to 5 mm long and about 1 cm apart; rare calcite veins 0.5 mm thick; fairly well indurated, slightly fissile, some calcareous cement	120.6
Claystone, silty, moderate reddish-brown; light greenish-gray spots 2 mm long; poorly indurated; plastic	120.8
Siltstone, sandy, moderate reddish-brown; light greenish-gray spots 1 to 5 mm long and about 1 cm apart, several light-green layers 0.1 ft thick; rare calcite veins 0.5 mm thick; fairly well indurated; slightly fissile; some calcareous cement	159.0
Sandstone, medium-grained, moderate reddish-brown with light greenish-gray patches 5 cm long; sand grains are well rounded, well sorted; a few calcite veins 0.5 mm thick; fairly well indurated to very friable; yields water	166.5
Siltstone, sandy, moderate reddish-brown; light greenish-gray spots 1 to 10 mm long and about 5 cm apart; some calcite veins 1 mm thick; fairly well indurated, slightly fissile, calcite cement; below 217 ft are blebs, 0.5 to 1 mm long, of gypsum about 5 mm apart	291.5
Rustler formation of Permian age:	
Forty-niner member:	
Gypsum, olive-gray, crystals 1 cm long; massively bedded; masses of anhydrite, 5 cm thick in basal 2 ft; upper contact irregular because of solution	297.7
Anhydrite, olive-gray; crystals 1 mm long; some gypsum crystals throughout especially near top and bottom; massively bedded; contacts are gradational	318.0

Log of the upper part of the core from U.S. Atomic Energy Commission drill hole 1—Continued

	Depth (feet)
Rustler formation of Permian age—Continued	
Forty-niner member—Continued	
Gypsum, olive-gray; crystals 1 cm long; masses, 5 cm thick, of anhydrite in top foot; massive	327.5
Siltstone, greenish-gray, friable	327.6
Siltstone, sandy, moderate reddish-brown, brecciated; contains breccia fragments of gypsum rock 5 mm long; fairly well indurated	328.0
Siltstone, sandy, moderate reddish-brown with light greenish-gray spots 1 mm long and 5 mm apart; upper 3 ft fairly well indurated, basal part very friable; some calcareous cement	337.5
Siltstone breccia, moderate reddish-brown with irregular light greenish-gray spots 3 mm long; fragments of siltstone 10 mm long, some gypsum fragments; fairly well indurated; calcareous cement	338.4
Gypsum breccia, grayish-purple; fragments of gypsum and claystone laminae 1 to 2 cm long; well indurated; calcareous cement	339.8
Gypsum, grayish-red; crystals 5 cm long; abundant patches of anhydrite 5 cm long; grayish-red stylolites with amplitudes of 1 mm about 1 cm apart	350.0
Anhydrite, olive-gray; gradational with unit above; lower 6 ft has thick 1 cm fibrous veins of gypsum, approximately parallel to the bedding and 5 cm apart; lower 6 ft has alternating grayish-red and greenish-gray bands 5 cm thick; gradational with unit below	360.2
Magenta member:	
Dolomite, greenish-gray with some grayish red-purple layers 1 cm thick; very fine grained; basal part has wavy lenticular or crossbedded texture; basal 1.5 ft porous with solution cavities 1 mm long	367.7
Siltstone, dolomitic; upper 0.6 ft greenish gray, lower part grayish red-purple; slightly fissile	369.5
Dolomite, silty, grayish red-purple with some greenish-gray layers 1 cm thick; has wavy lenticular bedding; fibrous gypsum veins, 1 cm thick, parallel to bedding, average 10 cm apart	380.3
Tamarisk member:	
Anhydrite, grayish-red to greenish-gray; has a few veins of gypsum, 1 cm thick, parallel to bedding and some masses of gypsum, 5 cm thick; solution cavity 1 cm long at 432.9 ft; massive, microcrystalline	441.5
Claystone, brownish-black; some fragments of gypsum 5 mm long; plastic; slickensided	441.7
Anhydrite, greenish-gray; masses of gypsum, 5 cm thick, abundant in upper 2 ft and lower 9 ft; massive	472.0
Siltstone, greenish-gray; contains breccia fragments of gypsum and claystone 1 to 5 cm long; fairly well indurated; some calcareous cement	473.4
Siltstone, grayish-red; has brecciated gypsum beds, 1 cm thick, about 5 cm apart; poorly indurated; plastic	477.2

Log of the upper part of the core from U.S. Atomic Energy Commission drill hole 1—Continued

	Depth (feet)
Rustler formation of Permian age—Continued	
Forty-niner member—Continued	
Gypsum, greenish-gray; crystals mostly 2 mm long; some clay-filled fractures; massive	482.6
Claystone, olive-gray, slickensided; contains breccia fragments of gypsum 2 mm long	482.8
Gypsum, olive-gray; crystals 1 mm long; massive; some anhydrite layers 10 cm thick; basal 0.4 ft. has clay-filled solution cavities	497.4
Culebra dolomite member:	
Dolomite, light olive-gray, microcrystalline; cavities 3 mm long and 5 mm apart; solution cavities; brecciated; yields water	529.0
Unnamed lower member:	
Siltstone, clayey; upper 0.9 ft. dark greenish gray, lower part grayish red; abundant breccia fragments of gypsum 1 cm long; poorly consolidated; plastic	537.2
Gypsum, olive-gray; mostly crystals 1 mm long but some patches have crystals 10 cm long; massive	550.4
Gypsum breccia, olive-gray; angular fragments of gypsum 2 cm long in a matrix of greenish-gray clay	551.5
Siltstone, clayey, moderate reddish-brown; a few light greenish-gray spots 1 cm long; abundant gypsum and siltstone breccia fragments 2 cm long; poorly consolidated; plastic	561.5
Gypsum, olive-gray; crystals 0.5 mm long; a few stylolites; massive	565.1
Siltstone, clayey, moderate reddish-brown; fragments of gypsum 1 cm long; poorly consolidated; plastic	570.8
Gypsum, silty; alternating layers of olive-gray gypsum and grayish-red siltstone 5 cm thick; fairly well indurated	576.2
Siltstone, sandy, grayish-red to greenish-gray; fairly well indurated in part; some dolomite cement; gradational with unit below	586.0
Sandstone, very fine grained, silty, greenish-gray, brecciated; fragments average 5 cm long, friable; basal 3 ft. well indurated with dolomite cement	649.9
Salado formation of Permian age:	
Upper leached zone:	
Siltstone, grayish-red; abundant breccia fragments of gypsum 1 cm long; gypsum veins 1 mm thick; poorly consolidated; plastic	652.3
Gypsum, olive-gray; crystals 2 mm long; massive	652.5
Siltstone, grayish-red; abundant gypsum fragments 2 mm long	652.8
Gypsum, pale reddish-brown; crystals 1 mm long; massive; probably altered from polyhalite	653.4
Siltstone, grayish-red; some pale reddish-brown gypsum fragments 2 cm long	654.1
Gypsum, pale reddish-brown	654.3
Siltstone, clayey, grayish-red; abundant gypsum fragments 1 cm long; very poorly indurated; plastic	660.1

Log of the upper part of the core from U.S. Atomic Energy Commission drill hole 1—Continued

	Depth (feet)
Salado formation of Permian age—Continued	
Upper leached zone—Continued	
Gypsum, pale reddish-brown; crystals 1 cm long	660.4
Siltstone, grayish-red; abundant fragments of gypsum and sandstone 1 to 5 cm long; poorly indurated; plastic	664.2
Gypsum, moderate-red; bedding dips 30° in core	664.4
Siltstone, clayey, grayish-red; scattered fragments of moderate-red gypsum 1 cm long; poorly indurated; plastic	667.7
Gypsum, moderate-red; crystals 1 cm long, brecciated in part	668.5
Siltstone, clayey, grayish-red; some fragments of moderate-red gypsum 3 cm long; plastic	670.2
Sandstone, very fine grained, pale reddish-brown to greenish-gray, massive; friable except basal 0.4 ft, which is fairly well indurated	672.6
Siltstone, clayey, grayish-red; abundant fragments of gypsum and sandstone 1 to 5 cm long; highly contorted; poorly indurated; plastic	684.5
Gypsum, olive-gray; crystals 2 mm long; bedding contorted; altered from anhydrite	685.2
Gypsum, moderate-red; crystals 1 mm long; probably altered from polyhalite	685.8
Siltstone, clayey, grayish-red	686.0
Gypsum, olive-gray with grayish-red stains	687.3
Siltstone, clayey, grayish-red; contacts contorted	687.8
Gypsum, olive-gray, massive	688.6
Siltstone, clayey, grayish-red; fragments 1 to 5 cm long and broken beds of sandstone and gypsum; poorly indurated; plastic	694.0
Gypsum, olive-gray; crystals 1 mm long; massive	694.9
Anhydrite, greenish-grey, microcrystalline; basal 0.6 ft silty; massive	706.8
Siltstone, clayey, dark greenish-grey, poorly indurated, plastic; basal 0.2 ft grayish-red	708.1
Anhydrite; upper 0.4 ft grayish red-purple, lower part greenish-gray; massive	709.7
Massive salt and sulphate zone, unleached:	
Halite, pale yellowish-brown; crystals 1 cm long; 2 percent polyhalite in blebs 1 to 10 mm long	725.0
Interbedded halite, anhydrite, polyhalite, and siltstone. See detailed description in Moore (1958)	1,500

RUSTLER FORMATION OF PERMIAN AGE

The Rustler formation was named by Richardson (1904, p. 44) for exposures on the Rustler Hills in eastern Culberson County, Tex., and it was described as consisting of 150 to 200 feet of calcareous buff sandstone overlain by fine-textured white magnesian limestone. These units are thought to represent only the lower part of the formation as the name is now used in southeastern New Mexico. In the Nash Draw quadrangle, the Rustler formation probably ranges from about 200 to 400 feet thick, depending in large part on how much of the formation has been removed by solution at depth and by erosion at the surface. It consists chiefly of gypsum (or anhydrite in the subsurface) interbedded with dolomitic limestone, interlaminated dolomite and anhydrite, siltstone, and, in the subsurface, halite. The base of the Rustler as it was originally deposited is now separated from the top of the massive salt in the Salado formation by a leached zone (about 60 ft thick in AEC drill hole 1) that represents the insoluble residue left after removal of halite in the Salado by ground water.

The lower part of the Rustler formation, consisting of about 120 feet of siltstone and very fine grained sandstone with several interbeds of gypsum or anhydrite, was not recognized in outcrops of the Nash Draw area but was penetrated in the AEC drill hole 1. Overlying the lower part is the Culebra dolomite member, consisting of about 30 feet of uniformly fine textured microcrystalline gray dolomite or dolomitic limestone. Adams (1944, p. 1614) credits W. B. Lang with naming the Culebra for Culebra Bluff on the east side of the Pecos River, about 4 miles northeast of Loving. The rock is characterized by numerous small nearly spherical cavities that range from about 1 to 10 mm in diameter. These cavities are present both in surface exposures of the Culebra and in core taken from the AEC drill hole 1 and therefore are presumed to be either a primary or a diagenetic phenomenon and not related to surface weathering. Some of the cavities are parly filled with secondary gypsum and calcite, but most are open. There seems to be little or no tendency for the cavities to be connected, as might be expected if they were formed by solution in a homogeneous rock. These features suggest that they were formed by the solution of a highly soluble mineral aggregate or by the inclusion of a gas or liquid at the time the sediment was soft. Locally, the Culebra is finely oolitic, and the individual oolites are less than 0.5 mm in diameter.

Exposures of the Culebra dolomite member are in the southern part of the Nash Draw quadrangle, east of Salt Lake where the rocks are locally deformed by solution collapse, which has caused the outcrop pattern to be irregular. The Culebra outcrops are brecciated locally. For this reason the Culebra was not seen in normal stratigraphic sequence with the underlying and overlying rocks in the Nash Draw quadrangle.

Overlying the Culebra dolomite member is the Tamarisk member of the Rustler formation. The Tamarisk consists of about 115 feet of massive gypsum in exposures but is chiefly anhydrite and locally gypsum in the subsurface, except for a bed 5 feet thick, of siltstone about 20 feet above the base. The siltstone is thought to represent the insoluble residue from a halite bed in the subsurface (Jones and others, 1960, fig. 1). This member forms a broad expanse of barren outcrop 2 to 3 miles wide and about 7 miles long east of Tamarisk Flat, from which the name is here taken.

Typically the Tamarisk member is massive and coarsely crystalline in outcrop. Massive beds consist of gypsum crystals that are 0.5 to 1.5 cm wide and are a whitish-gray color locally tinted reddish or greenish. However, in many exposures where the slope is gentle, massive gypsum has been altered at the surface to a softer textured light-gray gypsum rock composed of loosely packed gypsum grains about 1 mm across. This surficially altered gypsum grades almost imperceptibly into alluvial gypsum or gypsite in which the individual grains have been reworked by wind and runoff water into an alluvial sand composed chiefly of gypsum. No surface sections of the Tamarisk member were measured because of the universal distortion in outcrop. Surficial deformation has caused the member to be draped into large irregular folds and tilted blocks with dips as great as 45°. (See fig. 4.) In general, the dips are toward surface depressions or dry lakes. Locally, the member has been removed by solution, and the overlying and underlying parts of the formation are in contact. Hollow blisters

FIGURE 4.—Steeply tilted Tamarisk member of the Rustler formation. View looking south from a point on the ridge in the SW¼ sec. 6, T. 23 S., R. 30 E.

2 to 10 feet in diameter with a shell as much as 1 foot thick have formed locally, perhaps the result of the volume increase that accompanies the hydration of anhydrite to gypsum.

Overlying the Tamarisk member of the Rustler formation is the Magenta member, about 20 feet thick. Adams (1944, p. 1614) states that Lang named the Magenta member after Magenta Point, which is the bluff north of Salt Lake. One of the best exposures in this area is in a small canyon that has cut back into the bluff about 1 mile south of the plant site of the International Mineral and Chemical Corp. The Magenta is characterized by alternating laminae of dolomite and anhydrite (or gypsum) arranged in wavy or lenticular laminae 0.2 to 5 cm thick (fig. 5). Bedding surfaces have a botryoidal appearance. Laminae of dolomite are pale red to grayish orange pink, and laminae of anhydrite or gypsum are pale yellowish green. Microscopic examination shows dolomite and anhydrite crystals intergrown in varying proportions. The dolomite being more resistant to weathering than the anhydrite or gypsum, stands out in high relief. The lithology is so distinctive that it is possible to recognize the Magenta member from weathered fragments in the soil. Where subjected to intense leaching as in some collapse areas, the rock has become brecci-

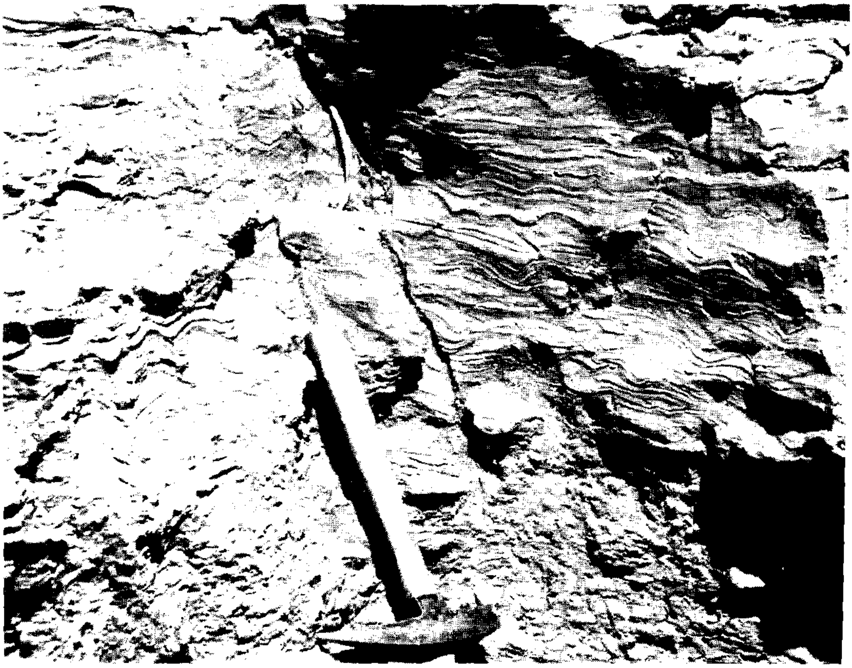

FIGURE 5.—Magenta member of the Rustler formation showing characteristic wavy lamination of dolomite and gypsum. View in narrow canyon in sec. 13, T. 22 S., R. 29 E.

ated, and the gypsum partly dissolved away or recrystallized; but the wavy laminae of pale-red dolomite (or dolomitic limestone) still permit a positive identification of the Magenta member.

Core from AEC drill hole 1 contains about 2 feet of dolomitic siltstone near the middle of the Magenta member, but this bed was not recognized in the surface exposures.

The Forty-niner member of the Rustler formation as named herein overlies the Magenta member and forms the youngest unit of the Rustler in the Nash Draw quadrangle. The name is taken from Forty-niner Ridge on the east side of Nash Draw where the member is exposed on a minor bluff below Livingston Ridge. In outcrop the Forty-niner member consists of about 40 to 65 feet of broken and slumped gypsum and a bed of massive siltstone near the base. The bed of siltstone, about 5 to 10 feet thick, is separated from the Magenta member by about 22 feet of gypsum and anhydrite in the AEC drill hole 1. In some outcrops the gypsum has been almost entirely dissolved away. The siltstone is especially conspicuous because it is moderate reddish-orange with light-gray circular spots 1 to 5 mm in diameter, and because it is friable and weathers more easily than the dolomite and gypsum above and below. This bed is nearly indistinguishable from some Quaternary alluvial material, except where the normal stratigraphic succession is visible. This bed is thought to represent the insoluble residue from a bed of halite that has been reported from the subsurface to the east (Jones and others, 1960, fig. 1).

A bed of gypsum about 35 feet thick overlies the bed of massive siltstone just described and forms the top of the Forty-niner member of the Rustler formation. Except for the thickness and stratigraphic position, this gypsum bed is difficult to distinguish in outcrop from the Tamarisk member. In outcrop it consists of massive and coarsely crystalline gypsum with a whitish-gray color locally tinted reddish and greenish, but on gentle slopes the gypsum becomes altered to soft friable loose-textured gypsum sand or gypsite that grades into alluvial gypsum which has been reworked from the outcrop. In the subsurface, anhydrite is commonly present instead of gypsum.

Surficial deformation characterizes exposures of the gypsum and stratification is obscured or obliterated (fig. 6). Small caverns, solution-enlarged joints, and sinkholes (fig. 13) or playas commonly dot the surface underlain by the Forty-niner member and make travel hazardous. In places, large circular depressions as much as several hundred feet across, partly filled with playa deposits, attest to the amount of rock that has been removed by solution.

The contact of the Forty-niner member of the Rustler formation and the overlying Pierce Canyon redbeds is obscured by swelling and

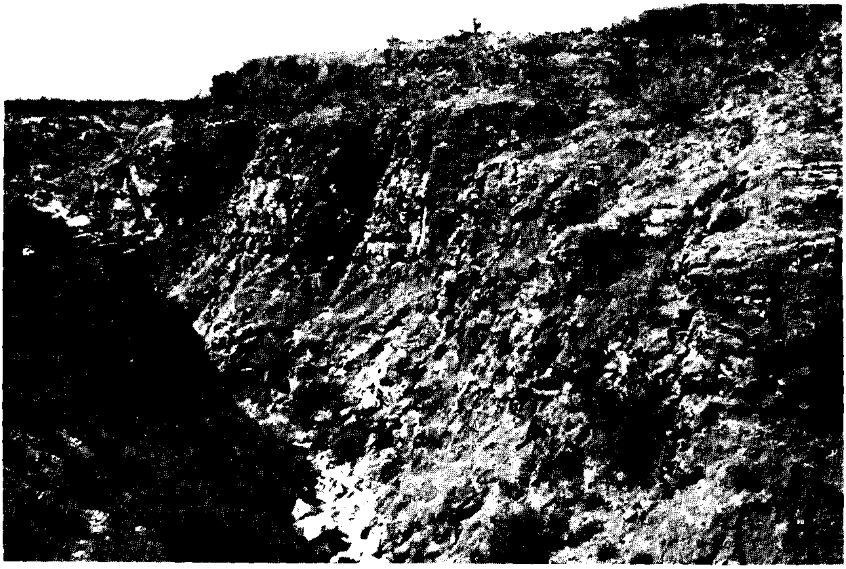

FIGURE 6.— Broken and slumped outcrop of gypsum in the Forty-niner member of the Rustler formation. Note that bedding and attitude are obscured. View looking northwest across narrow canyon in sec. 13, T. 22 S., R. 29 E.

deformation of the gypsum in nearly all exposures throughout the Nash Draw quadrangle. In a typical outcrop of the contact, such as in the SE¼ sec. 20, T. 23 S., R. 30 E., mounds of gypsum 3 to 10 feet high and from 10 to several hundred feet across project upward into the Pierce Canyon redbeds. Except for this deformation, however, no evidence was seen to suggest an unconformity at the base of the Pierce Canyon redbeds. Core from AEC drill hole 1 shows a sharp horizontal break at the contact from white gypsum below to moderate reddish-brown siltstone above.

No fossils were found in the Rustler formation during this investigation, and none have been reported from the formation in New Mexico. In Culberson County, Tex., fossils have been reported from the lower part of the Rustler in and below rocks equivalent to the Culebra dolomite member (Walter, 1953). The fauna consists of 35 species of mollusks that lived in abnormally saline water. The fauna is thought to be the youngest of Permian age so far found in North America (Walter, 1953). The upper unfossiliferous part of the Rustler might be Permian or Triassic.

PIERCE CANYON REDBEDS OF PERMIAN OR TRIASSIC AGE

The Pierce Canyon redbeds were first described by Lang (1935, p. 264) from a drill core taken from the Means No. 1 well in Loving County, Tex., as "fine sandy to earthy redbeds, polka-dotted with green reduction spots and usually irregularly veined with thin secondary selenite fillings." He further states that "a fair outcrop is present in the vicinity of Pierce Canyon," a small tributary to the Pecos River about 5 miles south of the Nash Draw quadrangle. In a memorandum to George V. Cohee, dated April 29, 1959, Lang states: "This canyon was the only significant and suitable geographic feature then available for giving name to the formation, although better exposures were known to exist along unnamed ridges (Livingston, for example)." Indeed, excellent exposures are present at many places along Livingston Ridge and Maroon Cliffs in the Nash Draw quadrangle, and if these names had been available, would have been much more suitable type localities because the exposures along Pierce Canyon are nearly all in the Gatuna formation of Pleistocene(?) age, part of which is red, and might easily be mistaken for the Pierce Canyon redbeds of Permian or Triassic age.

The Pierce Canyon redbeds are probably about 200 to 250 feet thick in the Nash Draw quadrangle, though this thickness was not measured in surface exposures. Except for a few places in the northern part of the area, the upper part of the formation is eroded back from the face of a scarp that forms the eastern margin of Nash Draw. The contact of the Pierce Canyon redbeds with the overlying Santa Rosa sandstone is mantled by a cover of caliche and sand.

The Pierce Canyon redbeds are characteristically moderate reddish-orange to moderate reddish-brown sandstone and siltstone that is thinly (0.5 to 1.5 mm) laminated and has very small scale cross laminae with sets ranging from about 0.5 to 2 cm thick (fig. 7). The grain size of the coarser particles is 0.03 to 0.3 mm; the particles are set in an abundant clay matrix. In some samples the laminae are formed by alternating bands of silt (0.03 to 0.06 mm) and fine sand (0.1 to 0.3 mm). In other samples, hematite stained clay laminae alternate with lighter colored silt laminae. Small current and oscillation ripple marks are present in some laminae in the upper part of the formation (fig. 8). Subangular to subrounded clear quartz is the most abundant single mineral grain and chert and feldspar the next most abundant. Muscovite, biotite, rock fragments, and opaque minerals together generally make up less than 10 percent of the mineral grains. Clay, amounting to about 15 to 25 percent of the rock, is stained red and forms the principal rock cement though calcite and gypsum are locally abundant. D. N. Miller, Jr.,[1] gives further details regarding the texture, mineralogy, and petrology of the Pierce Canyon redbeds. Miller (1955) notes zones of hollow sanidine grains in the sandstone

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[1] Miller, D. N., Jr., 1955, Petrology of the Pierce Canyon redbeds, Texas and New Mexico: Ph.D. dissertation, Texas Univ.

which he regards as possible stratigraphic markers. These were not observed in the present investigation. Miller and Folk (1955) suggest that magnetite and ilmenite are the source of the red color in other redbeds similar to the Pierce Canyon.

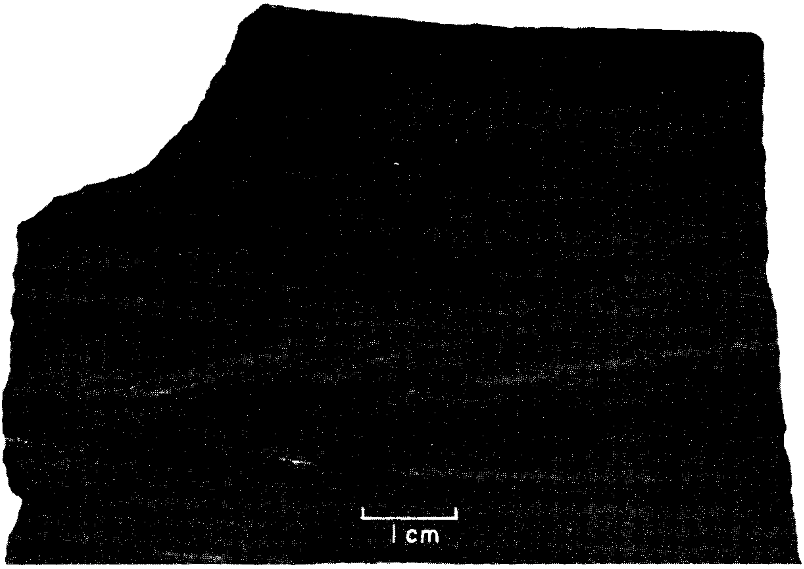

FIGURE 7.—Minute trough-type cross-lamination in red siltstone about 40 feet below the top of the Pierce Canyon redbeds, sec. 5, T. 21 S., R. 30 E.

FIGURE 8.—Small-scale oscillation ripple marks in a light-gray siltstone lamina about 20 feet below the top of the Pierce Canyon redbeds, sec. 5, T. 21 S., R. 30 E.

The Pierce Canyon redbeds crop out chiefly around the north and east margins of Nash Draw. The best exposures are on the west tip of Livingston Ridge; near the boundary between secs. 28 and 29, T. 22 S., R. 30 E.; near the boundary between secs. 14 and 15 of that same township; and along Maroon Cliffs, across the northern half of T. 21 S., R. 30 E., and extending for about 2 miles into the north half of T. 21 S., R. 31 E. The formation is well exposed in sec.10, T. 22 S., R. 29 E., and outcrops occur in secs. 3, 10, 16, 17, 20, 21, 27, 28, and 29, T. 23 S., R. 30 E., and in secs. 11, 12, and 14, T. 21 S., R. 29 E. An excellent exposure showing the disconformity between the Pierce Canyon redbeds and the overlying Santa Rosa sandstone is in the railroad cut in the SE¼SE¼SW¼ sec. 35, T. 20 S., R. 30 7. (fig. 9). In some of the smaller outcrops difficulty was encountered in trying to distinguish between the Pierce Canyon redbeds and red silt reworked from the Pierce Canyon into the Gatuna formation of Pleistocene(?) age and identification is not everywhere certain. On the west tip of Livingston Ridge, about 75 feet of the lower part of the Pierce Canyon redbeds is exposed. The formation consists of uniform moderate reddish-brown to moderate reddish-orange siltstone with numerous pale greenish-gray spots about 1 to 10 mm in diameter. The weathered exposure has a distinctly papery appearance when viewed from a distance of several feet, but the laminae are difficult to see at close range. The rock weathers into chips generally less than 1 inch across, but

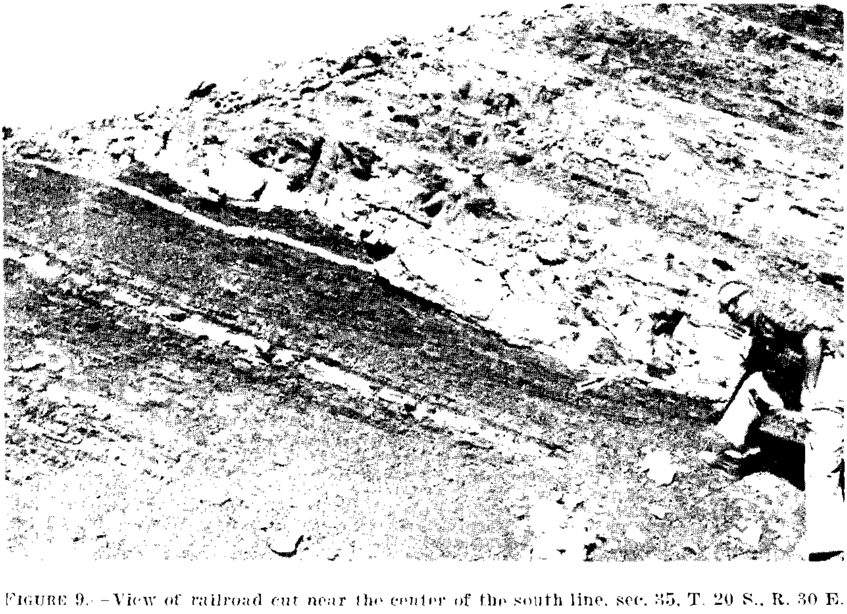

FIGURE 9.—View of railroad cut near the center of the south line, sec. 35, T. 20 S., R. 30 E. Arrow indicates disconformable contact between the Pierce Canyon redbeds, below, and the Santa Rose sandstone, above.

some beds break into fragments 6 inches or more across. Along Maroon Cliffs as much as 100 feet of the Pierce Canylon is exposed. The following stratigraphic section of the upper part of the Pierce Canyon redbeds, measured about half a mile north of the Nash Draw quadrangle in sec. 5, T. 21 S., R. 30 E., is typical of most of the exposures along Maroon Cliffs.

Stratigraphic section of the upper part of the Pierce Canyon redbeds exposed in the E½ sec. 5, T. 21 S., R. 30 E., Eddy County, N. Mex.

	Thickness (feet)
Santa Rosa sandstone:	
Sandstone, fine- to coarse-grained, pale red, crossbedded; contains silty dolomite pebbles.	
Unconformity.	
Pierce Canyon redbeds:	
Siltstone, sandy, moderate reddish-orange; alternating laminae composed of silt and fine-grained sand; individual laminae generally less than 1 mm thick; some strata characterized by oscillation and current ripple marks ranging from ⅜ to 1 in. from crest to crest; light-gray spots as much as 10 mm across are abundant, and some thin strata are light gray throughout	35
Siltstone, moderate reddish-orange and moderate reddish-brown in alternating laminae; different colors due to differences in amount of hematitic staining in the clay-sized fraction; minute trough-type cross-lamination with individual cross lamina generally 0.5 to 10 cm in length; forms ledge. A lenticular set of medium-scale cross-laminated fine-grained pale-red sandstone present locally about 3 to 5 ft. above base	15
Claystone, silty, moderate reddish-brown, nonfissile	1
Siltstone, sandy, moderate reddish-orange, friable; weathers to slope covered with chips less than ½ in. across	18
Siltstone, sandy, moderate reddish-orange, horizontally laminated and locally cross laminated in sets as much as 1 in. thick; weathers into blocks as much as 2 ft. across and 6 in. thick	5
Sandstone, very fine grained, silty, moderate reddish-orange; laminated and interstratified with siltstone the same color; light-gray spots as much as 10 mm across abundant; forms slope; weathers to blocks as much as 10 inches across and 1½ in. thick	16
Siltstone, sandy, moderate reddish-orange; horizontally laminated and locally cross laminated in sets as much as 1 in. thick; weathers to blocks as much as 2 ft. across and 6 in. thick	3
Siltstone, moderate reddish-brown, laminated; and very fine grained moderate reddish-orange sandstone; in beds as much as 1 in. thick; light-gray spots as much as 10 mm across abundant; weathers to papery chips as much as 4 in. across	7
Siltstone, sandy, moderate reddish-orange; forms minor ledge; weathers to blocks as much as 4 in. thick and 10 in. across	3
Siltstone, moderate reddish-brown, laminated, locally ripple-marked; pale greenish-gray spots as much as 10 mm across abundant; weathers to paper chips as much as 4 in. across; base covered	10
	113

Interval to top of Rustler formation not exposed.

The Pierce Canyon redbeds represent the beginning of continuous deposition of detrital sediment following the long period of predominantly evaporite deposition in the Delaware basin and adjacent shelf areas of southeastern New Mexico. However, the abrupt change in lithology does not necessarily signify a sudden tectonic or eustatic movement, but only a gradual decrease in the salinity or depth of the water plus a new source for the detrital sediments which were deposited. Certain general features of the Pierce Canyon are especially noteworthy. The lithology and color appear to be remarkably uniform. Viewed from the distance of a few feet, the stratification nearly always appears to be parallel even though small-scale cross-lamination may be seen on close inspection. The small grain size, together with the minute scale of primary sedimentary structures, such as cross-lamination in sets less than 1 cm thick and oscillation ripple marks less than 1 inch from crest to crest, suggests that the silt was deposited in extremely shallow water extending over a broad flat. Lenses of medium-scale cross-laminated fine-grained sandstone or siltstone in the upper part of the Pierce Canyon (fig. 10) probably indicate a gradual change toward fluvial deposition near the end of Pierce Canyon time. The deposit undoubtedly blanketed the Delaware basin and part of the shelf area to the north, but the source of the sediment is unknown. The paleogeologic setting is imperfectly known because

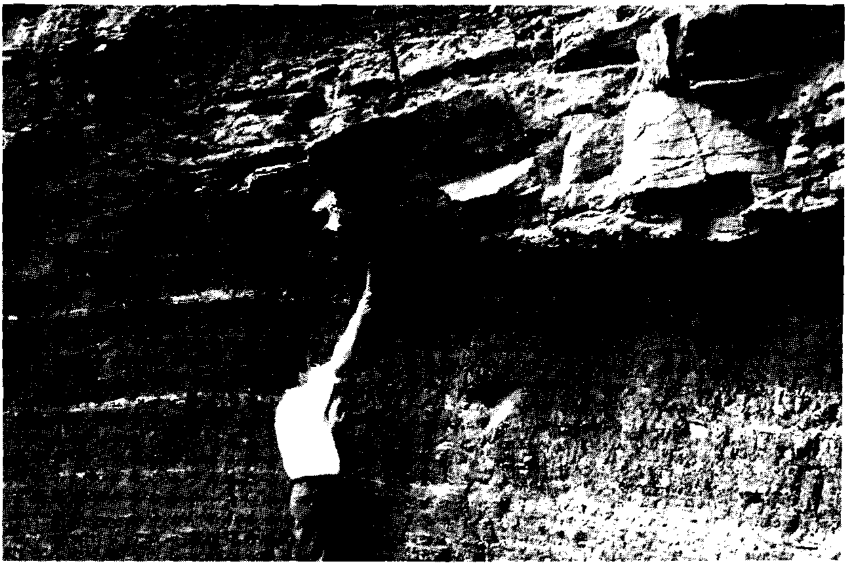

FIGURE 10.—View of the upper part of the Pierce Canyon redbeds showing a lens of ledge-forming sandy siltstone interstratified with typical laminated siltstone. Photograph of canyon wall, NW¼ sec. 12, T. 21 S., R. 30 E.

the correlation with rocks in other areas has not been determined. To the west of the Delaware basin, erosion has removed the formation. To the east, the rocks may be continuous with similar red siltstones in the Midland basin of Texas, but the correlation is uncertain.

A few water wells in the area obtain sufficient water from the Pierce Canyon redbeds for local domestic and stock use, but in some areas the quality is very low because of dissolved salts.

Exposures of the Pierce Canyon redbeds are commonly tilted or draped into simple structures as a result of the collapse and swelling that accompanies solution and hydration of the underlying evaporite rocks. Some exposures of the Pierce Canyon along the margin of Nash Draw show a downwarping into the topographic depression that is presumably the result of removal of soluble rocks (fig. 11). For this reason, strike and dip readings, even on the very apparent parallel stratification of the Pierce Canyon redbeds, do not necessarily reflect the structure of older rocks.

FIGURE 11.—Downwarping of the Pierce Canyon redbeds and a thin cap of caliche along the north margin of Nash Draw. Deformation is attributed to solution and removal of soluble rocks, chiefly salt, in the subsurface. View of Maroon Cliffs looking southeast from a point in the northern part of sec. 8, T. 21 S., R. 30 E.

The age and correlation of the Pierce Canyon redbeds are uncertain. In the first published reference to the formation, Lang (1935) designated the rocks as Permian in age. Two years later (Lang, 1937, footnote p. 876) the designation was changed to Triassic, because, according to Lang (1947), the Pierce Canyon redbeds grade into, and are in part contemporaneous with, the overlying Santa Rosa sandstone in the Dockum group of Late Triassic age. This interpretation is believed to result from the fact that lenses of cross-laminated sandstone, apparently of fluvial origin, are present locally in the upper part of the Pierce Canyon redbeds (fig. 10). These lenses are finer grained than typical lenses in the Santa Rosa sandstone. Moreover, the Santa Rosa disconformably overlies the Pierce Canyon as shown in figure 9, so that Lang's correlation does not seem well substantiated. In this report the formation is regarded as either Permian or Triassic in age.

Among petroleum geologists the name Dewey Lake redbeds is commonly applied to the rocks here designated the Pierce Canyon redbeds. The name Dewey Lake was first used by Page and Adams (1940) for rocks penetrated by drilling in the Midland basin of Texas that occupy about the same stratigraphic position as the Pierce Canyon redbeds in the Delaware basin of southeastern New Mexico. The Dewey Lake redbeds were assigned a Permian age because they were thought to lie conformably on the Rustler formation and to be more closely related in appearance and mineral content with the underlying Permian rocks than with the overlying Triassic rocks. The Pierce Canyon and Dewey Lake redbeds may possibly be equivalent.[2]

SANTA ROSA SANDSTONE OF TRIASSIC AGE

The Santa Rosa sandstone disconformably overlies the Pierce Canyon redbeds. Only the lower 50 to 70 feet of the Santa Rosa sandstone is present in the northern and northeastern part of the Nash Draw quadrangle and therefore the total thickness of the formation could not be determined. In general, the Santa Rosa consists of large-scale trough-type crossbedded pale-red sandstone and conglomerate lenses, 3 to 15 feet thick, separated by thin partings of moderate reddish-brown siltstone and silty claystone (fig. 12). The conglomerate lenses contain both silty dolomite pebbles and chert or quartz pebbles. The sandstone is characteristically poorly sorted. The formation differs from the underlying Pierce Canyon redbeds by being coarser grained, less well sorted, and by having beds that are thicker and more lenticular.

The name Santa Rosa sandstone was first used for rocks of Triassic age in east-central New Mexico along the Pecos River near the town of Santa Rosa (Rich, 1921; Darton, 1922, p. 183). In the Nash Draw quadrangle and adjacent areas to the north and east, the Santa Rosa sandstone is mostly pale red to pale reddish brown, and locally pale red purple to pale blue green. Secondary alteration has locally

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[2] Subsequent to the preparation of this report, the U.S. Geological Survey decided in favor of using the name Dewey Lake redbeds of Permian age in place of the name Pierce Canyon redbeds of Permian or Triassic age.

bleached the rocks to light gray, grayish pink, and light greenish gray. Bleaching is especially common near the base, in some of the coarser sandstones, and in places where the rocks have been recently deformed. The disconformity between the Santa Rosa sandstone and the underlying Pierce Canyon is shown in figure 9.

FIGURE 12.—Santa Rosa sandstone showing large-scale trough-type crossbedding. View of bluff, northeast corner sec. 1, T. 21 S., R. 30 E.

Sand grains in the Santa Rosa mostly range from silt to medium-grained sand; the fine sand (0.125 to 0.25 mm) is most abundant. Quartz and chert are the most abundant mineral grains and generally amount to more than 60 percent of the rock. Plagioclase and microcline or perthite are moderately abundant and may constitute 15 or 20 percent of the rock. Grains, granules, and locally pebbles of quartz and chert as much as several centimeters in diameter and light-gray silty dolomite pebbles ranging from a few millimeters to several centimeters across are also common. Locally, some beds are made up almost entirely of mottled reddish and bluish-green silty dolomite granules and pebbles. The larger fragments tend to be well rounded; the fine- and medium-sand particles are angular. Locally, some grains are crushed and fractured. Many grains are embayed and interlocked with adjacent grains. Authigenic quartz overgrowths are fairly common. Accessory minerals include biotite, muscovite, magnetite, ilmenite, pink garnet, and zircon. The accessory minerals comprise less than about 5 percent of the rock. Fossil plant impressions, carbonaceous plant fragments, and fossil reptile bones and teeth thought to be from phytosaurs characterize some of the beds. Clay is a relatively minor constituent in most of the Santa Rosa sandstone. Secondary dolomite was identified by B. M. Madson (oral communication, January 1960) as the most abundant cement, and it probably constitutes at least 10 percent of the rock.

The Santa Rosa sandstone represents a change in the environment of deposition as compared with the Pierce Canyon redbeds. The large-scale through-type crossbedding probably indicates a fluvial environment. The lack of sorting, arkosic composition, and angularity of the grains suggests rapid deposition by streams descending from a predominantly crystalline terrain.

Outcrops of the Santa Rosa sandstone in normal stratigraphic position are found only in the extreme northeastern corner of the Nash Draw quadrangle, and the exposures there are poor. More favorable exposures are found within a mile or two of the north boundary of the quadrangle south of U.S. Highway 62 and 180. There the Santa Rosa sandstone forms a conspicuous south-facing escarpment (fig. 12) that extends from sec. 4, T. 21, S., R. 31 E., almost continuously to the Maroon Cliffs in sec. 6, T. 21 S., R. 30 E. The Santa Rosa sandstone is also preserved on the flanks and in brecciated downdropped cores of several domal karst features near the north boundary of the quadrangle. Tower Hill, on the north boundary of the quadrangle, has a tilted block of Santa Rosa sandstone exposed on the south side of the hill that probably represents part of a downdropped core.

The Santa Rosa sandstone probably contains water locally in areas north and east of the Nash Draw quadrangle, but most of the records of water wells are inadequate to distinguish between the various red beds that may be present.

On the basis of the remains of phytosaurs (Case, 1914), the formation is assigned to the Late Triassic and is commonly regarded as the basal formation of the Dockum group of Late Triassic age.

GATUNA FORMATION OF PLEISTOCENE(?) AGE

The Gatuna formation unconformably overlies the Permian and Triassic rocks in the quadrangle, except where it has been removed by erosion. In most of the area the Gatuna formation is only about 3 to 5 feet thick and is directly overlain by Recent caliche that is more resistant than the Gatuna and masks the underlying rocks. Therefore, except where the Gatuna is thick or forms a broad enough exposure to map separately, it is shown together with the caliche on the geologic map (pl. 1). In general, the Gatuna formation consists of moderate reddish-orange friable sandstone, siltstone, and conglomerate, but locally includes gypsum, gray shale, and claystone. The Gatuna is as much as 100 feet thick locally.

The formation takes its name from Gatuna Canyon, about 7 miles north of the Nash Draw quadrangle (Robinson and Lang, 1938, p. 84–85). Some of the best exposures in Gatuna Canyon are in the S½ sec. 35, T. 19 S., R. 30 E., directly south of the point where New Mexico State Route 31 crosses the escarpment of Nimenim Ridge. The Gatuna is at least 80 feet thick in a gravel pit at this locality; it consists of pale-red conglomeratic sandstone in the lower part, grading upward into moderate reddish-orange massive sandstone and siltstone at the top, where it is overlain by caliche. The base is not exposed because of slumping and landsliding along the steep slope.

South of Salt Lake in the extreme southwest corner of the Nash Draw quadrangle, the Gatuna formation forms a north-facing escarpment 60 to 100 feet high, covered at the top by a cap of caliche. The color and lithology are quite variable locally. The rock is chiefly moderate orangish-red friable fine-grained sandstone and siltstone, but contains some lenses of gray to yellowish-gray laminated clay and silt interbedded with ledges of pale-red sandstone and conglomeratic sandstone 6 inches to 2 feet thick. Three stratigraphic sections of the Gatuna were measured in Pierce Canyon, one of a series of eastern tributary canyons to the Pecos River, about 4 miles south of Nash Draw quadrangle, to show the range and variability of the lithology locally.

Stratigraphic section of a part of the Gatuna formation near the west end of the north bluff of Pierce Canyon in SW¼ sec. 22, T. 24 S., R. 29 E.

	Thickness (feet)
Gatuna formation (part):	
Siltstone, moderate reddish-orange, crossbedded, massive-weathering	5
Sandstone, pale-red, medium-grained; forms ledge	2
Sandstone, moderate-pink to gray, medium-grained, friable	8
Sandstone, pale-red, conglomeratic crossbedded	5–10
Siltstone, moderate reddish-orange, crossbedded, massive-weathering: base covered by alluvium	15
	35–40

The next section was measured about half a mile east of the first. At the base of the slope on which the section was measured is a tilted block of bedded rock at least 20 feet thick and several times as long surrounded by alluvium. The block shows the characteristic color and wavy lamination of dolomite of the Magenta member, but it has been fractured, recrystallized, and most of the gypsum leached away. Several large erratic blocks from the Magenta member of the Rustler formation and the Pierce Canyon redbeds are imbedded in the Gatuna within a mile to the east, and it seems likely that this block was also incorporated in the Gatuna.

Stratigraphic section of a part of the Gatuna formation exposed along the north bluff of Pierce Canyon in SE¼ sec 22, T. 24 S., R. 29 E.

	Thickness (feet)
Caliche.	
Gatuna formation (part):	
Sandstone, pale-red to moderate reddish-orange, medium-grained; locally contains granules and pebbles; becomes calcareous at the top, grading upward into the caliche	40
Conglomerate, grayish-pink to pale-red, crossbedded; contains variously colored rounded quartz and chert pebbles and rounded to angular siltstone pebbles	22
Siltstone, moderate reddish-orange, and pale-red conglomerate containing rounded quartz and chert pebbles and angular fragments of pink dolomite apparently derived from the Magenta member of the Rustler formation. Base covered by alluvium	10
	72

The third section, as shown below, was measured on the west point of a prominent reentrant into the north bluff of Pierce Canyon about 500 feet east of the second section.

Stratigraphic section of a part of the Gatuna formation exposed along the north bluff of Pierce Canyon in SW¼ sec. 23, T. 24 S., R. 29 E.

	Thickness (feet)
Caliche.	
Gatuna formation:	
Siltstone, pinkish-gray, sandy, friable; no visible bedding; upper part grades into overlying caliche	22
Siltstone, and very fine grained sandstone, moderate orange-pink; some thin laminae locally; weathers massive, except for a few ledges of sandstone 3 to 6 in. thick	25
Siltstone and claystone, grayish-yellow to yellowish-gray, possibly tuffaceous; contains sparse plant fragments. Base covered by alluvium	33
	80

Several sinkholes and domal karst features contain thick fillings of Gatuna in the Nash Draw quadrangle and adjacent areas. Good examples of such fillings associated with karst features are (1) a prominent bluff of red siltstone about a quarter of a mile north of the Jal road on the section line between secs. 33 and 34, T. 22 S., R. 29 E.; (2) red siltstone about a quarter of a mile southeast of New Mexico State Route 31 near the center of the SE¼ sec. 15, T. 22 S., R. 29 E.; (3) red siltstone near the center of the large island in Salt Lake at the northeast corner sec. 16, T. 23 S., R. 29 E.; and (4) a red siltstone knob near the north end of the prominent hill in the SE¼ sec. 24, T. 23 S., R. 29 E. A hill about half a mile west of the quadrangle near the intersection of New Mexico State Route 31 and the Jal road is cut by the U.S. Potash Co.'s narrow-gauge railroad to the mill and contains an unusually good exposure of red beds thought to be part of the Gatuna formation. The lower 30 feet of this outcrop consists of poorly bedded moderate reddish-brown siltstone with light-gray spots, several beds, 3 to 6 inches thick, of medium- to coarse-grained sandstone, and large angular erratically distributed blocks of laminated siltstone probably derived from the Pierce Canyon redbeds. This unit is overlain with slight angular unconformity by 8 to 15 feet of conglomeratic moderate reddish-orange mudstone containing chert and quartz pebbles as much as 4 inches across. The upper unit apparently has no bedding and weathers into a nearly vertical cavernous ledge. Rocks at the top of the outcrop grade in color and texture into caliche, which forms a resistant cap 5 to 10 feet thick at the top of the hill. The examples of Gatuna core-filling mentioned earlier are mostly similar to the lower siltstone unit.

In some areas where the exposures are small or partly covered, it is difficult to distinguish the Gatuna formation from the Pierce Canyon redbeds and the Santa Rosa sandstone. In other places where much gypsum is present, the Gatuna resembles the Rustler formation. In general, however, the bedding or lamination is more obscure in the Gatuna than in the older rocks, and many outcrops of Gatuna have veinlets of gypsum of carbonate minerals not so common in the older rocks. A chert- and quartz-pebble conglomerate lens overlying the Pierce Canyon redbeds in sec. 10, T. 22 S., R. 29 E., is too friable and has too many pebbles to be regarded as Santa Rosa and therefore is indicated as Gatuna. Similar reasoning was used to designate other outcrops shown as Gatuna on the geologic map (pl. 1) in the NE¼ sec. 32, T. 23 S., R. 30 E., and several outcrops of Gatuna along Livingston Ridge. An outcrop of gypsum on the large island in Salt Lake is shown on the map (pl. 1) as Gatuna formation, but it is possible that some of the gypsum represents the Rustler formation.

Quahada Ridge in the northwestern part of the Nash Draw quadrangle is covered by windblown sands, but well records show that the sand is underlain by red beds. In his description of the Fletcher potash core test in sec. 1, T. 21 S., R. 28 E., Lang (1942) suggests that the Santa Rosa sandstone may be 55 feet thick, the Pierce Canyon redbeds 505 feet thick, the Rustler formation 320 feet thick, and the Salado formation 490 feet thick. He further states that the Rustler formation lacks about 100 feet of its top beds and that it lies on truncated Salado formation of which the upper half has been removed by solution. Considering the abnormally thick unit assigned to the Pierce Canyon redbeds, the evidence for solution, and the history in adjacent areas, it seems reasonable to assign at least 300 feet of the 560 feet of red beds in this well to the Gatuna formation. It then follows that Quahada Ridge was formerly the site of a depression, not unlike the present Nash Draw depression, that became filled with alluvial material in Gatuna time (pl. 1).

It seems likely from a consideration of the local variation and rapid changes in thickness of the Gatuna formation that its deposition followed immediately after, or in part accompanied, a period of active solution in the Rustler and Salado formations. Either the Pecos River or a major tributary of the Pecos probably flowed across the area in a position nearly parallel to the present Pecos River but offset several miles farther east, which caused both the underground solution of the older rocks and the filling of the resulting depressions and sinkholes with locally derived sediments.

The Gatuna formation was orginally indicated as being simply Quaternary in age (Robinson and Lang, 1938), but is now considered Pleistocene(?) by the U.S. Geological Survey. Fossils bearing on the age of the Gatuna formation have not been reported. Physiographic relations would seem to indicate that the Gatuna is deposited on a surface of erosion that is younger than the Ogallala formation of Pliocene age on the High Plains farther to the east, because the pre-Gatuna surface lies at a lower level. However, the pre-Gatuna surface has been warped by solution of the underlying soluble rocks and gradual sinking of the ground surface as much as hundreds of feet so that the usual methods of correlating physiographic surfaces by their elevations is not necessarily valid. As much as 2,000 feet of salt has been removed from the formations of Late Permian age throughout large areas west of the Pecos River, but it is not known how much of this solution and sinking had taken place by the time the Gatuna was deposited, and how much took place in post-Gatuna time. If much of the solution was post-Gatuna, then the Gatuna might actually represent rocks equivalent in part to the Ogallala formation of Pliocene age.

PLEISTOCENE AND RECENT DEPOSITS

CALICHE

In the Nash Draw quadrangle, a fairly continuous mantle of caliche was deposited uncomformably on the Gatuna formation and older rocks. This caliche has been overlain, in turn, by younger deposits and is therefore thought to have stratigraphic significance. Though generally less than 10 feet thick, its resistance to weathering in the dry climate has allowed it to form extensive surfaces that can be mapped in definite stratigraphic sequence with other rocks and deposits.

Caliche is a near-surface accumulation of calcareous and clastic material that forms a resistant mantle. It is characterized by an excess of calcareous material over that required to cement the clastic grains, with the result that the grains appear to float in the matrix. In many areas the caliche is characteristically brecciated and recemented. In addition to sand and calcareous material, pebbles are locally abundant, and silica in the form of chalcedony or opal also forms part of the cementing matrix. Other soluble minerals, including gypsum, are probably locally present. Where the top surface of caliche has long been exposed to weathering, it almost invariably has a very hard dense limestone surface that could easily be misinterpreted as an outcrop of massive limestone similar to those in some older formations. Close inspection, however, generally reveals sand grains, chalcedony, and brecciation. Commonly the dense layer at the top is only 1 or 2 feet thick, and the rock becomes more friable and shows a greater proportion of sand grains to matrix within a few feet of the surface. The less calcareous zone in turn grades downward within 5 or 10 feet into the underlying bedrock, which generally is broken into angular fragments recemented with calcareous material. In many areas caliche has concentric lamination or colloform structure suggesting calcareous algal structures. The widespread mantle of caliche has much the same composition throughout the area regardless of whether the underlying bedrock is red sandstone and siltstone from the Gatuna formation, Santa Rosa sandstone, and Pierce Canyon redbeds, or gypsum from the Rustler formation.

Locally, younger caliche occurs as small irregular masses within the younger deposits, but these patches of caliche are too small to be mapped and are not stratigraphically significant.

Most of the caliche is thought by Brown (1956, p. 12) to have formed during the Quaternary period, probably from subsurface evaporation of soil moisture in an eolian aggrading soil profile. According to Brown, both the sand and the calcareous material were deposited by wind. In many areas erosion and solution are destroying the caliche. Sinkholes, including both small cavernous openings enlarged by small animals and shallow circular depressions or wallows up to several hundred feet in diameter, are common in areas where caliche is exposed on broad flats. In some areas where these features are most conspicuous, the caliche is underlain by gypsum that is locally dissolved away, as shown by figure 13.

Mounds and broken flexure ridges of caliche where the surface of the caliche has been buckled upwards 10 to 15 feet high along narrow zones for distances of 50 to several hundred feet are common locally. These features were noted especially in the southwestern part of the quadrangle within a distance of 3 miles east of Salt Lake (fig. 14). Broken flexure ridges differ from mounds in having open tension fractures that extend parallel to the axis of the structure. Many caliche mounds and broken flexure ridges protrude through alluvial material, but are too small to distinguish individually from the alluvium at the scale of the geologic map.

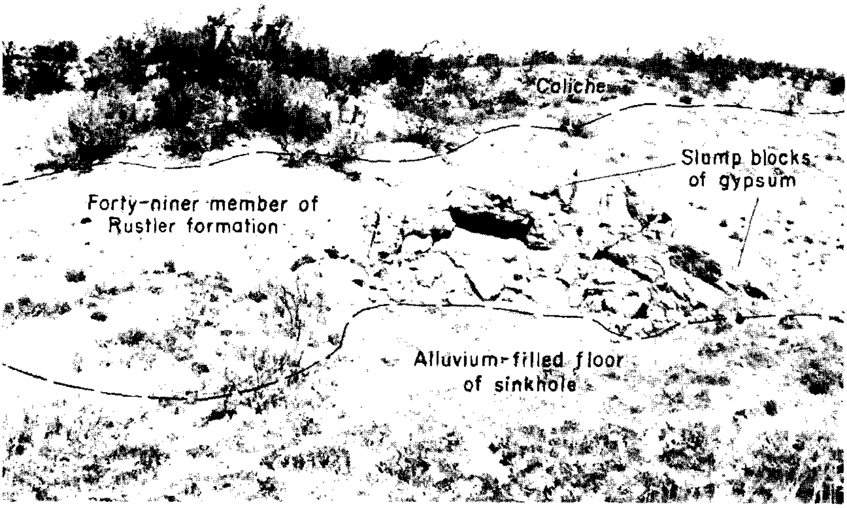

FIGURE 13.—Sinkhole in the Forty-niner member of the Rustler formation. Gypsum and overlying caliche have collapsed along the margin of the depression which occupies the foreground. View in SW¼ sec. 3, T. 23 S., R. 30 E.

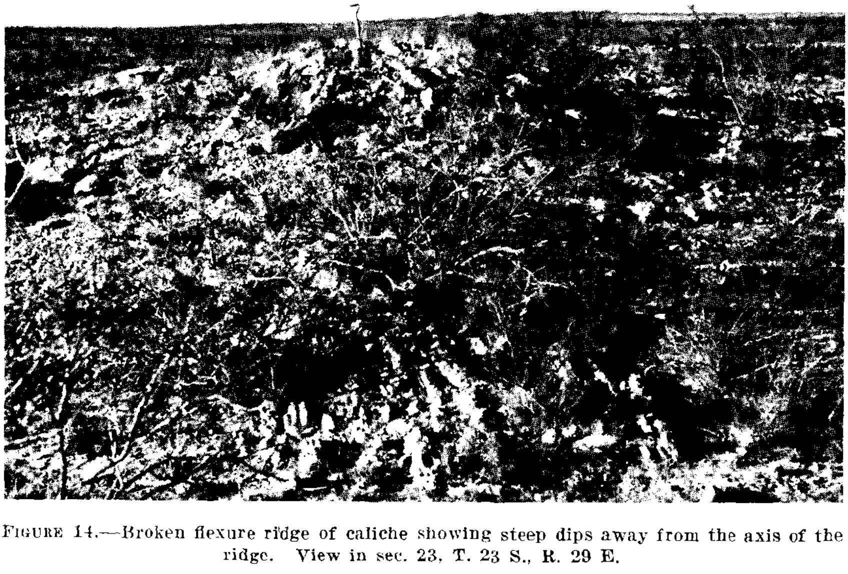

FIGURE 14.—Broken flexure ridge of caliche showing steep dips away from the axis of the ridge. View in sec. 23, T. 23 S., R. 29 E.

The origin and significance of the caliche mounds and ridges is uncertain. They may be similar to the pseudoanticlines described by Price (1925) from central Tamaulipas, Mexico, which he attributes to the accretion of caliche at shallow depth in the joints of slabby bedrock. The pressure of crystal growth was considered by Mortensen (1930, p. 487) to explain the origin of similar ridges in the salt deposits of Chile. Consideration might also be given to thermal expansion and contraction with deposition of material in open fissures. This process is regarded as important in the formation of polygons and similar patterned ground in polar regions (Washburn, 1956, p. 851). The expansion of anhydrite as it alters to gypsum is a further process that should be considered because of the occurrence of these ridges in areas where caliche directly overlies the Rustler formation. Probably a combination of more than one process is involved in the formation of caliche mounds and broken flexure ridges in this area. The present mapping was insufficiently detailed to determine whether the ridges and mounds form a regular areal pattern.

Bretz and Horberg (1949, p. 492) recognize four surfaces on which caliche is developed. They are, from oldest and highest to youngest and lowest: (1) the High Plains of the Llano Estacado in extreme eastern New Mexico; (2) the Mescalero plain, which extends westward from the High Plains to the rim of Nash Draw and includes areas east of Livingston Ridge and Maroon Cliffs, east of Nash Draw, and the top of Quahada Ridge, west of Nash Draw; (3) the Blackdom plain; and (4) the Orchard Park plain. The two lowest surfaces are west of the Pecos River. According to this classification, most of the broad areas of caliche in the Nash Draw quadrangle are formed on the Mescalero plain. Possible exceptions would be the areas of caliche within Nash Draw which are lower than the surrounding ridges, but these might represent parts of the Mescalero plain that have been let down by solution. Differences of relief of as much as 400 feet of caliche on sloping surfaces and caliche-covered slopes as steep as 10° apparently have resulted from tilting caused by recent solution.

Although the relative age of these surfaces is generally accepted, correlation of their ages with late Tertiary and Quaternary events elsewhere is difficult to establish. The Mescalero plain is developed largely on the Gatuna formation. The age of the Gatuna is uncertain, however, and may be as old as Pliocene. The caliche, accordingly, may be Pliocene, Pleistocene, or Recent, but it is carried as Recent on the accompanying geologic map.

ALLUVIUM

Because there are no throughgoing streams in the Nash Draw quadrangle, there are no alluvial stream deposits of the kind familiar to most geologists. Instead, alluvium that has been mapped over large parts of the Nash Draw quadrangle is locally derived material deposited by sheet wash on the slopes of depressions and by intermittent streams that discharge their load into the depressions as alluvial fans during rare periods of flash flooding. Many of these deposits might logically be termed "pediment" or "bolson" deposits. The kind and size of material varies greatly, depending on the local source. Alluvium along the base of Maroon Cliffs consists mostly of reworked red sand and silt and rock fragments from the Pierce Canyon redbeds and Santa Rosa sandstone mixed with limestone fragments from the caliche. In the southwestern part of the area the alluvium includes considerable gypsum and dolomite derived from the Rustler formation mixed with sand and silt that is probably of eolian origin. As mapped, the contact of the alluvium commonly merges against bedrock from which it was derived. Alluvium commonly also grades into, or intertongues with, playa deposits near the center of the depressions or bolsons.

PLAYA DEPOSITS

Playa deposits consists of alluvium and eolian sands reworked by shallow-lake waters. Normally, lakes form in depressions after periods of heavy runoff and evaporate soon thereafter. Parts of some depressions are occupied by more or less perennial lakes, of which the largest is Salt Lake (also called Laguna Grande de la Sal on many maps). The level of some of the lakes is maintained, at least in part, by the discharge into them of water and brine from potash refineries in the area. The playa deposits were not examined in detail, for there are no natural cuts through them. The surface of some at the time they were seen was a water-saturated mudflat. Examples of this sort are Remunda Basin in sec. 30, T. 23 S., R. 30 E., and the depression in sec. 28 of the same township where the margin of the depression has been built up to increase its capacity as a water tank for cattle. Playa deposits at higher elevations are drained by sinkholes and are apparently dry most of the year because they support a growth of grass. Examples of this type are in secs. 7, 17, and 18, T. 23 S., R. 30 E. Others that are damp most of the time support a dense growth of salt cedar (*Tamarix*). Examples of this sort are Tamarisk Flat, in secs. 26 and 35, T. 22 S., R. 29 E., and the intermittent lakes in secs. 12 and 13, T. 23 S., R. 29 E. Playa deposits along the margins of Salt Lake consist locally of gray mud with local concentrations of carbonate minerals, probably derived from the Rustler formation, and saline minerals, including both chlorides and sulfates, derived from the evaporation of brine from the lake. Some of these deposits are consolidated into a hard rock similar to caliche but with a more coarsely granular texture.

WINDBLOWN SAND

More than half the Nash Draw quadrangle is covered by surficial deposits of sand. Similar deposits extent westward from Mescalero Ridge (the west-facing escarpment of the High Plains) for 20 to 30 miles to the Pecos River and for many tens of miles north of the Texas boundary. The sand is locally known as the Mescalero sands. Though widespread, the sand is very erratic in its distribution and thickness. It is blown about continuously and forms dune ridges and hummocky dune areas separated by broad flats. On the flats the sand is stabilized by mesquite, bunchgrass, and other vegetation. The most pronounced dune ridges and hummocky dunes occupy areas where the sand is shifting, and they are clearly shown on the aerial photographs by their relief and by the absence of vegetation. Dune ridges and hummocky dune areas were mapped separately from the broad flats (pl. 1). In general, the areas outlined as dunes are also underlain by the greatest thickness of sand, probably as much as 100 feet locally. The areas mapped simply as sand, probably are underlain by only 10 to 15 feet of sand on the average and the deposits feather out at their margins. The long dimension of the dune ridges appears to parallel the prevailing direction of the strongest winds at the time the dunes were formed. It is interesting to note that the orientation of the ridges is not uniform throughout the area.

No petrographic study was made of the sand; however, from field observation it appears to be fairly uniformly fine grained light-brown to pale reddish-brown quartz. Many of the grains are rounded and frosted. In deflated areas or "blowouts" among the dunes one sees many small pockets where polished chert and quartz pebbles up to several inches across are concentrated at the surface. Rarely, Indian artifacts occur among the pebbles, indicating an artificial source for some. It is otherwise difficult to visualize how these pebbles could become mixed with the eolian sand. Perhaps some pebbles were reworked and let down from a once higher formation, such as the Ogallala, and perhaps the sand also was derived from the Ogallala formation, hoving been reworked, winnowed, and let down as the Mescalero Ridge retreated to its present position several miles to the east.

Sand may be derived from deposits of different ages in different parts of the area. Locally, alluvial and playa deposits may make contributions to the eolian sand during dry periods. Sand deposits at the northwest end of Tamarisk Flat in secs. 23 and 27, T. 22 S.,

R. 29 E., are intermediate in position between alluvium and playa deposits, and most of the sand is stabilized in nearly circular mounds, each centered about a clump of mesquite and other vegetation, rather than in dune ridges or hummocky dune areas. This suggests that the sand is currently being derived from the adjacent deposits and held in place by the vegetation. Patches of sand similar to this are present east of Salt Lake. Sands at the base of a dune may remain stationary for many years locally before being uncovered and reworked, while the upper layers shift about with each change in the wind. There seems to be little justification in the Nash Draw quadrangle for subdividing and naming different units within the sand, as has been done on a part of the High Plains of western Texas (Huffington and Albritton, 1941) because the various layers have not been observed to have regional significance.

STRUCTURE

The tectonic structure of the Nash Draw quadrangle is thought to be a relatively simple homoclinal dip to the east. This interpretation is based chiefly on subsurface data in, and adjacent to, the quadrangle and to a lesser extent on the outcrop. In general, the outcrop data are not regarded as sufficiently reliable for the determination of specific structural features other than surficial because of the widespread warping and subsidence. The surficial structure is described under "Geomorphology."

Structure contours on the Precambrian-Paleozoic contact of southeastern New Mexico (Flawn, 1956) show the deepest part of the Delaware basin 13,000 feet below sea level in the northeast corner of the Nash Draw quadrangle. Evidence for the —13,000-foot contour shown on this map is based on a single drill hole that penetrated Precambrian rocks at 12,881 feet below sea level about 4 miles north of the quadrangle. Northwest from this point the basement is shown to rise at a rate slightly less than 200 feet per mile. The gradient to the east of this drill hole is nearly the same as to the northwest, but is somewhat irregular. More recently, within the Nash Draw quadrangle, the Shell Oil Co. No. 1 James Ranch gas well in sec. 36, T. 22 S., R. 30 E., was drilled to a depth of more than 14,000 feet below sea level without penetrating Precambrian rocks. Structure contours drawn on top of the "Yates sand" (Stipp and Haigler, 1956), which underlies the Salado formation in the shelf area north and east of the Capitan limestone, show a decrease in elevation from about 3,000 feet in the area north of Carlsbad to about 500 feet 70 miles to the east near the east boundary of New Mexico. Superimposed on this average dip of about 35 feet per mile to the east are a number of gentle domes with a relief of 100 to 300 feet. Except for surficial deformation, the structure south of the surface trace of the Capitan limestone, including nearly all the Nash Draw quadrangle, is generally believed to be similarly gentle on the basis of relatively sparse drill information available below the Permian evaporite rocks in the northern Delaware basin.

GEOMORPHOLOGY

Nash Draw is the principal surface structure and geomorphic feature in the area. In very general outline the outcrop pattern is that of a large anticline gently plunging to the north with the oldest rocks, the Rustler formation, exposed in the center and the younger Pierce Canyon redbeds and Santa Rosa sandstone exposed on the flanks. At least locally, the rocks exposed along the margins of Nash Draw exhibit dips in toward the center of the topographic depression, contrary to a structural picture consistent with an anticline (fig. 11). The structure of the marker beds within the Salado formation as revealed by well records indicates a gentle homoclinal structure (pl. 1). The anomalous dips seen in surface exposures are interpreted to represent surficial deformation later than the tectonic structure as a result of collapse into the Nash Draw depression. Nash Draw is, therefore, thought to be an undrained physiographic depression superimposed over a gentle homoclinal structure. The depression probably resulted from regional differential solution of beds in the upper part of the Salado formation. Nash Draw is separated by a gentle divide area from a similar large depression to the north called Clayton Basin. These depressions are probably similar in origin to the solution-subsidence troughs of the Gypsum Plain in southern Eddy County, N. Mex., and adjacent parts of Texas, described by Olive (1957). However, the solution-subsidence troughs of Olive are more regular in outline, smaller, and are formed in the Castile formation.

In the northern part of Nash Draw, bedrock is largely covered by a mantle of windblown sand, dunes, caliche, and alluvium. In the central and southern part of Nash Draw however, the Rustler formation is highly deformed in outcrops. The deformation is thought to be due primarily to large-scale collapse of the Rustler formation as a result of solution within the anhydrite, gypsum, and halite beds of the Rustler, and at the top of the Salado formation. Evidence for solution within the Rustler can be found almost everywhere that it is exposed. Sinkholes of all sizes abound in the Rustler formation, ranging from small cavernous joints that trap unwary livestock to large shallow depressions, partly filled with alluvial or playa deposits but commonly with identifiable sinks within the depressed area (fig. 13). Where dips in the Rustler can be determined, they are generally in the direction of the larger depressions. In plan, these depressions range from small circular features a few tens or hundreds of feet across to large irregular, or arcuate, features more than a mile across. Many of the larger depressions, including the basin that holds Salt Lake, are probably formed by the coalescing of smaller ones. Some of the depressions tend to line up. These may indicate the probable location of subterranean cavernous water courses.

Contour lines drawn at the top of the massive salt in the Salado formation (pl. 1) help show the degree of correspondence between topography, surficial structure, and solution at the top of the salt. Data for the contour lines were compiled by Bruno R. Alto, U.S. Geological Survey from Government records of oil and gas wells and potash test wells.[3] Surficial structural features correspond with the attitude of the surface of the massive salt in some areas, but the surface structure is quite different from what would be expected if it were caused only by solution at this one zone. Salt Lake basin is a closed depression on the top of the Salado formation. However, a larger and more pronounced closed depression on the surface of the salt comprising several square miles that center on the NE¼ sec. 36, T. 22 S., R. 29 E., corresponds in general to the largest continuous outcrop of the Tamarisk member of the Rustler formation. This large outcrop is for the most part surrounded by playa depressions, some of which correspond closely to the margin of the depression in the salt; but the center of the outcrop is topographically and, judging from the surface dips, structurally higher than the playas that surround it. A similar disagreement in surface and subsurface structure is found along the southeast margin of Quahada Ridge, which is separated from the main escarpment of Nash Draw by a slight topographic depression. The topographic depression overlies a ridge on the surface of the salt, and Quahada Ridge overlies a trough on the surface of the salt (pl. 1). In its broader outlines; Nash Draw is not very clearly defined by the structure contours on the top of the salt, though the contour lines, in general, tend to parallel the outline of the topographic depression.

From this discussion it may be inferred that, although solution on the top of the massive salt in the Salado formation resulted in rather uniform lowering of the land surface, surficial structural features are greatly modified in detail by differential solution of the more soluble portions of the Rustler formation. Appreciable local solution in the Rustler formation is shown in secs. 15 and 22, T. 23 S., R. 29 E., where the Magenta member and Culebra dolomite member are in contact, whereas in normal stratigraphic succession they are separated by about 120 feet of gypsum in the Tamarisk member.

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[3] The well records include those listed in the table on page 8 plus many others, especially potash test wells that are closely spaced and quite numerous in some areas.

Areas of rock deformation that are circular or semicircular in plan and range from a few hundred to a few thousand feet in diameter are a common form of solution or karst feature in this area. Sedimentary strata including caliche are well exposed on the flanks of some of these features and dip away from the center giving them the appearance of structural domes. Generally, such domes contain a core of brecciated or randomly rotated rock that has been displaced downward with respect to the flanking rock. Typically the brecciated rock in the core is overlain by a greater thickness of the Gatuna formation than is present in the adjacent areas. The core of brecciated rock and Gatuna is overlain by an unbroken arch of caliche on several of these features, which suggests that the brecciation predates the deposition and doming of the caliche. The breccia probably formed as a result of collapse into a sinkhole. Examples of several well-exposed domes directly north of the Nash Draw quadrangle have been described in a separate report (Vine, 1960).

The depth and type of deformation are not generally known for the circular and semicircular surficial karst features in the Nash Draw quadrangle. Of two such surficial features noted near the potash workings north of the Nash Draw quadrangle, one is represented by a dome and the other by a depression of the marker beds in the Salado formation at depth.

A semicircular domal karst feature occupies the center of sec. 18, T. 23 S., R. 30 E. The west flank of the dome is down faulted so as to place the Forty-niner member of the Rustler formation where it forms the flank of the dome opposite to the Tamarisk member on the side away from the dome. The otherwise circular plan of the dome is interrupted on the east side by a large depression in which the structure is masked by the accumulation of surficial deposits.

A hill in the SE¼ sec. 24, T. 23 S., R. 29 E., consists chiefly of an anomalously located outcrop of recrystallized and highly contorted Magenta member of the Rustler formation. The general structure of the hill appears to be a dome on which many minor folds are superimposed. Near the north end of the hill an outcrop of massive red siltstone, thought to be part of the Gatuna formation, is probably a sinkhole filling. Near the center of the hill an outcrop of the Tamarisk member of the Rustler formation is about 100 feet structurally higher than in the surounding areas. If a cavernous opening in the lower part of the Rustler formation became filled with silt from the Gatuna formation, the sinkhole filling may have remained stationary while all the surrounding area collapsed by later solution. The sinkhole filling would then hold up a hill such as the one described above.

An isolated outcrop of red siltstone thought to be part of the Pierce Canyon redbeds (but conceivably from the Gatuna formation) lies against the Forty-niner member of the Rustler formation along a vertical contact in the SE¼ sec. 29, T. 23 S., R. 30 E. This appears to be a simple example of the younger rock having been let down into a sinkhole. The conclusion is the same regardless of the stratigraphic interpretation of the red siltstone.

A circular hill on the large island in Salt Lake contains an exposure of interbedded red siltstone and sandstone believed to be the Gatuna formation surrounded by massive gypsite that is separately mapped as an informal gypsum member of the Gatuna formation. The hill is anomalously located in the middle of a lake that is a large playa and is surrounded by alluvial and playa deposits. As there is little to suggest a domal karst feature, the hill probably represents the exposed residual core of a sinkhole in the Salado formation, left standing when the surrounding more soluble rocks were removed.

On the west side of Nash Draw are several circular and semicircular karst features that contain exposed cores of red siltstone or sandstone from the Gatuna formation, Pierce Canyon redbeds, or Santa Rosa sandstone. These include a dome that forms a prominent red hill about half a mile west of the quadrangle near the junction of New Mexico State Route 31 and the Jal road; an elongated domal structure on the line between secs. 33 and 34, T. 22 S., R. 29 E.; a dome in the SE¼ sec. 15 of that same township; a small dome near the center of sec. 11, T. 21 S., R. 29 E., another at Tower Hill; a karst feature on the line between secs. 11 and 12 of the same township; and an elongate dome on the east line of sec. 12 of the same township. Others may form some nearby smooth rounded hills, but caliche masks the bedrock.

These domal karst features show deformation of the Recent caliche, but the exposures are not adequate to determine the extent of deformation in older rock. Like the domes to the north, however, all are probably superimposed over sinkholes or depressions that formed before the deposition of the Gatuna formation and before the formation of the extensive caliche. Perhaps they are not all formed by a single process. Probably differential solution and collapse surrounding a sinkhole core is most important in some, plastic flow of salt important in others, and hydration of anhydrite to form a gypsum a factor in all.

Horberg (1949, p. 475) recognized solution as an important factor in the late Cenozoic history and geomorphology of the Pecos Valley; Maley and Huffington (1953) emphasized that as much as 1,900 feet of Cenozoic fill in some parts of the Delaware basin has been localized by solution, especially of salt. The large number of individual features where solution or hydration has deformed rocks as young as caliche indicates that Recent solution of salt and gypsum is of primary importance in the geomorphic history of the Nash Draw quadrangle. Local warping and depression of the caliche where the bedding remains parallel with the underlying Gatuna and older formations amounts to 100 to 150 feet in many parts of the Nash Draw quadrangle. On a larger scale within the quadrangle, the caliche appears to be warped as much as 300 or 400 feet, though it may be argued that such differences in altitude are due to initial differences in the altitude at which the caliche was deposited. If the caliche formed chiefly on the Mescalero plain as suggested by Bretz and Horberg (1949), then there has been at least 100 to 150 feet of warping and depression in relatively recent time.

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INDEX

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