DEPARTMENT OF THE INTERIOR
Roy O. West, Secretary

U. S. GEOLOGICAL SURVEY
George Otis Smith, Director

Bulletin 794

"RED BEDS" AND ASSOCIATED FORMATIONS IN NEW MEXICO

WITH AN OUTLINE OF THE GEOLOGY OF THE STATE

BY
N. H. DARTON

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Shading by J. H. Renshawe, based on topographic map by N. H. Darton, 1925

"RED BEDS" AND ASSOCIATED FORMATIONS IN NEW MEXICO

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By N. H. Darton

INTRODUCTION

This report presents the results of reconnaissance investigations covering a large part of New Mexico, made at intervals from 1912 to 1925, together with an outline of the geology of the State made up in part from the observations of others. The main economic purpose of the investigations was to determine the stratigraphic succession of the red beds and gypsum deposits in order to ascertain the prospects for potassium salts. Incidentally many data were obtained as to the relations of associated formations. Finally the reconnaissance was extended into several areas to complete a geologic map of the State, which was published late in 1928. Some of the data, especially as to the structure of the sedimentary rocks, have been presented in a preliminary report,[1] mainly to afford information to persons interested in the prospecting for oil and gas that has been so actively in progress in New Mexico since 1919. Prior to this brief papers on other results of the work were published.[2] (See fig. 1.)

GEOGRAPHY

New Mexico extends from about longitude 103° 03′ on the Texas State line and 103° on the Oklahoma State line to longitude 109° 02′ 56.82″ and from about latitude 37° to latitude 32° in its eastern part and 31° 19′ 56.35″ in its southwestern part, covering an area of 122,634 square miles, or 317,622 square kilometers. The greatest width from east to west is nearly 352 miles (567 kilometers) and the greatest length from north to south a little more than 390½ miles (628½ kilometers). The State is traversed from north to south by the Rio Grande and includes the headwaters of Pecos, Canadian, and Gila Rivers, of some tributaries of San Juan River, and of several branches of Little Colorado River. The altitude

[1] Darton, N. H., Geologic structure of parts of New Mexico: U. S. Geol. Survey Bull. 726, pp. 173–275, 1922.

[2] Darton, N. H., A reconnaissance of parts of northwestern New Mexico and northern Arizona: U. S. Geol. Survey Bull. 435, 88 pp., 1910; A comparison of Paleozoic sections in southern New Mexico: U. S. Geol. Survey Prof. Paper 108, pp. 29–54, 1917; Permian salt deposits of the south-central United States: U. S. Geol. Survey Bull. 715, pp. 203–223, 1921.

ranges from about 2,850 feet on Pecos River at the Texas State line to 13,306 feet in the Truchas Peaks, northeast of Santa Fe.

One of the principal topographic features in New Mexico is the southern extension of the Rocky Mountains, which reaches latitude 35°. They are continued southward, structurally at least, in a zone of high detached ridges extending to the Franklin Mountains at El Paso. The Rio Grande flows through this region in a valley which

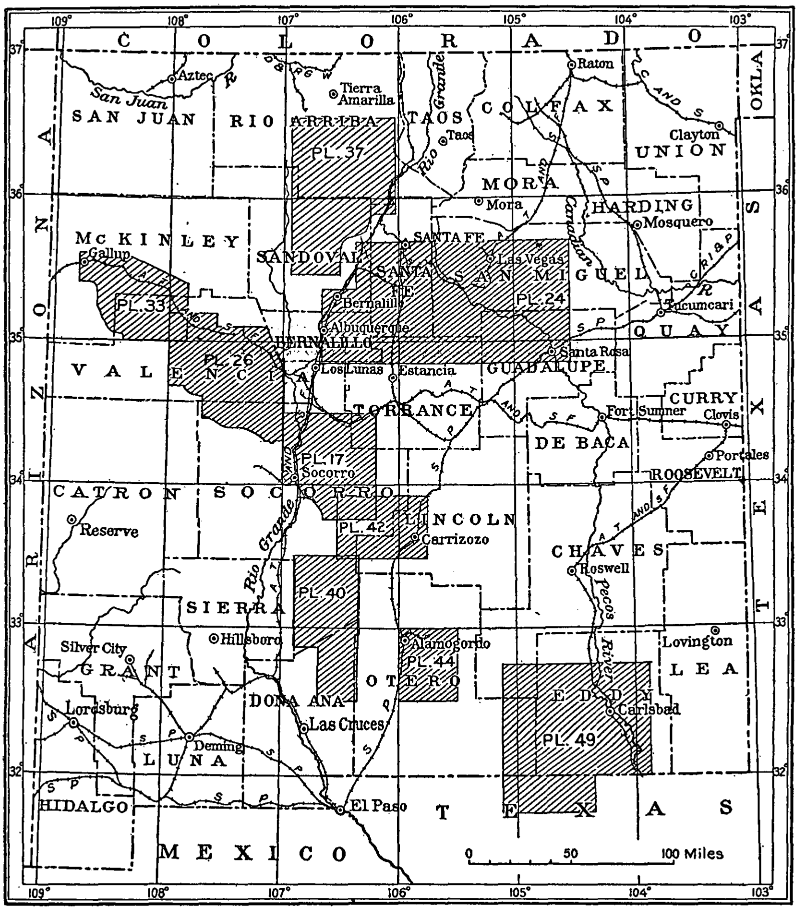

FIGURE 1.—Map of New Mexico showing areas covered by detailed maps in this report

is mostly wide and filled with sand and gravel but which toward the north contains a sheet of lava that flowed in part from great craters in Colorado. West of Santa Fe this lava sheet is surmounted by the remains of the great Valle Grande volcanic cone and a widespread sheet of tuff ejected from it. East of the Rocky Mountains are high rocky plateaus that on the north are occupied in places by cones and elevated masses of volcanic rocks and on the south merge into the Great Plains, which to the east and in the Llano Estacado to the south are covered by a mantle of sand.

This plateau district is deeply trenched by Canadian River, and its northern division terminates to the south in a long sinuous line of high cliffs known as the Canadian Escarpment.

Most of the northwest quarter of New Mexico lies in the Colorado Plateaus, a physiographic province of the central southwestern United States. A large part of this plateau province has an average altitude between 6,000 and 7,000 feet, and although tabular surfaces predominate the province shows great diversity of configuration. The volcanic pile of Mount Taylor, the outlying mass of Tertiary rocks of the Chuska Mountains, and the uplift of the Zuni Mountains are the most notable features. To the south for some distance are plateaus and ridges consisting of thick and widespread accumulations of Tertiary volcanic rocks, beyond which the Colorado Plateaus give place to the Basin and Range province, a succession of wide desert valleys interspersed with long ridges that are composed in part of accumulations of volcanic rocks and in part of uplifted Paleozoic and associated strata. This province extends eastward across the southern part of the State as far as the Pecos Valley and includes the isolated ranges of the Mimbres, San Andres, Franklin, and Sacramento Mountains, which structurally are in the southward continuation of the Rocky Mountain zone.

DESCRIPTIVE GEOLOGY

GENERAL CHARACTER OF THE ROCKS

There are in New Mexico many kinds of metamorphic, sedimentary, and igneous rocks. The metamorphic rocks, which are mostly of pre-Cambrian age, comprise schist, quartzite, and a very small amount of marble. They are revealed by uplifts of the earth's crust and consequent removal of overlying sedimentary strata. The sedimentary series, extending from Cambrian to Quaternary in the southern part of the State and from Pennsylvanian to Quaternary in the northern part comprises limestone, sandstone, shale, sand, and gravel. These strata have a combined thickness of about 16,000 feet, but no place is known where the entire column is present to this amount. In the deepest part of the San Juan Basin there may be 15,000 feet of beds, and borings in the central eastern part of the State have found about 4,000 feet. The igneous rocks include granite, amphibolite, and some other rocks of pre-Cambrian age, many intrusive rocks of post-Cretaceous age, and eruptive rocks of late Cretaceous, Tertiary, and Quaternary age.

PRE-CAMBRIAN ROCKS

The pre-Cambrian rocks are bared in the southern prolongation of the Rocky Mountains, in the Sandia, Manzano, Nacimiento, Burro, Mimbres, Cooks, Lemitar, Ladrones, Oscura, San Andres, Magdalena, Fra Cristobal, and Sierra Caballo uplifts, in the region between Ojo Caliente and Brazos Peak, and in small areas in the west front of the Sacramento Mountains, in the Hatchet Mountains, in the hills east of Socorro, in the Klondike Hills, in the ridge northwest of Silver City, in Lone Mountain, and near Hanover. There are also exposures in the Hills of Pedernal and the Zuni Mountains, which are parts of old ridges that survived far into Permian time.

Very little detailed study has been made of the pre-Cambrian rocks, which consist mainly of granite, gneiss, mica schist, and quartzite. Most of the granite cuts the schist and quartzite, but some of it may be older than these metamorphic rocks, and there are also granitic rocks of post-Cambrian age. Many facts regarding the pre-Cambrian rocks are given by Lindgren and Graton,[3] who describe briefly the gneiss, granite, mica schist, and quartzite at mining localities in the Sangre de Cristo Mountains in Taos, Santa Fe, and Mora Counties, supplementing the earlier statements by Stevenson [4] and Keyes.[5]

Near Picuris, southwest of Taos, and on the Rio Grande near Glenwoody is granite or granite gneiss with basic intrusive rocks and a series of metamorphosed conglomerate, quartzite, and schist with many secondary minerals. The pre-Cambrian rocks of the mountains east of Taos have been described by Gruner.[6] In the Hopewell and Bromide districts in the pre-Cambrian area in the eastern part of Rio Arriba County Graton [7] observed gneissic granite cutting dark dioritic gneiss and cut in turn by porphyry of several kinds. Many ridges and knobs of quartzite also occur, and in the eastern part of the district there is some biotite-chlorite schist.

According to Schrader [8] the principal pre-Cambrian rock of the Nacimiento and Zuni Mountains is massive red granite, but schist also occurs. The pre-Cambrian rocks in the Silver City region have been described by Paige,[9] who found that granite occupies a considerable area in the Burro Mountains and the western flanks of the Little Burro Mountains. Small outcrops of granite appear in other uplifts in the region and minor masses of schistose and quartzitic rocks are included in places. The pre-Cambrian rocks of Luna County [10] consist mostly of coarse red to gray granite, and the largest

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3 Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, 1910.

4 Stevenson, J. J., Report upon geological examinations in southern Colorado and northern New Mexico during the years 1878 and 1879: U. S. Geog. Surveys W. 100th Mer. Rept., vol. 3, Suppl., 1881.

5 Keyes, C. R., The fundamental complex beyond the southern end of the Rocky Mountains: Am. Geologist, vol. 36, pp. 112–122, 1905.

6 Gruner, J. W., Geologic reconnaissance of the southern part of the Taos Range, New Mexico: Jour. Geology, vol. 28, pp. 731–742, 1920.

7 Graton, L. C., op. cit. (Prof. Paper 68), pp. 124–128.

8 Idem, pp. 141–146.

9 Paige, Sidney, U. S. Geol. Survey Geol. Atlas, Silver City folio (No. 199), p. 3, 1916.

10 Darton, N. H., Geology and underground water of Luna County, N. Mex.: U. S. Geol. Survey Bull. 618, pp. 19–23, 1916; U. S. Geol. Survey Geol. Atlas, Deming folio (No. 207), pp. 3–4, 1917.

exposure is in the Florida Mountains. Some small dikes of diorite amphibolite also occur. Gneiss is exposed in the Klondike Hills, and schist occurs in a breccia in Fluorite Ridge, north of Deming. Granite is exposed in the Hatchet Mountains,[11] in the northern part of Cooks Range, and in places along the east foot of the Mimbres Mountains. The Hills of Pedernal and Cerrito del Lobo, in Torrance County, consist of white quartzite, but the southern extension of this old range is gneiss, except Chameleon Hill, which is granite. Much quartzite appears in the Sandia Mountains.

SEDIMENTARY ROCKS

GENERAL SUCCESSION

The sedimentary rocks in New Mexico range in age from Algonkian to Recent, but portions of several geologic periods are not represented by strata and some of the formations present do not occur in all parts of the State. The classification of the earlier Paleozoic strata has been treated in a previous publication,[12] and some modifications of the terminology and grouping of the later Paleozoic "Red Beds" have been given in a description of structural features of the State.[13] (See fig. 2.) A review of the Permian stratigraphy has also been presented.[14]

The following lists of formations show the principal features of stratigraphy and the classifications that have been adopted. It is not practicable to present all the formations in one list because in the great area of the State there are many regional differences that are difficult to combine.

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[11] Darton, N. H., Geologic structure of part of New Mexico: U. S. Geol. Survey Bull. 726, p. 274, 1922.

[12] Darton, N. H., A comparison of Paleozoic sections in southern New Mexico: U. S. Geol. Survey Prof Paper 108, pp. 31-55, 1918.

[13] Darton, N. H., op. cit. (Bull. 726), pp. 181-183.

[14] Darton, N. H., The Permian of Arizona and New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 10, pp. 819-852, 1926.

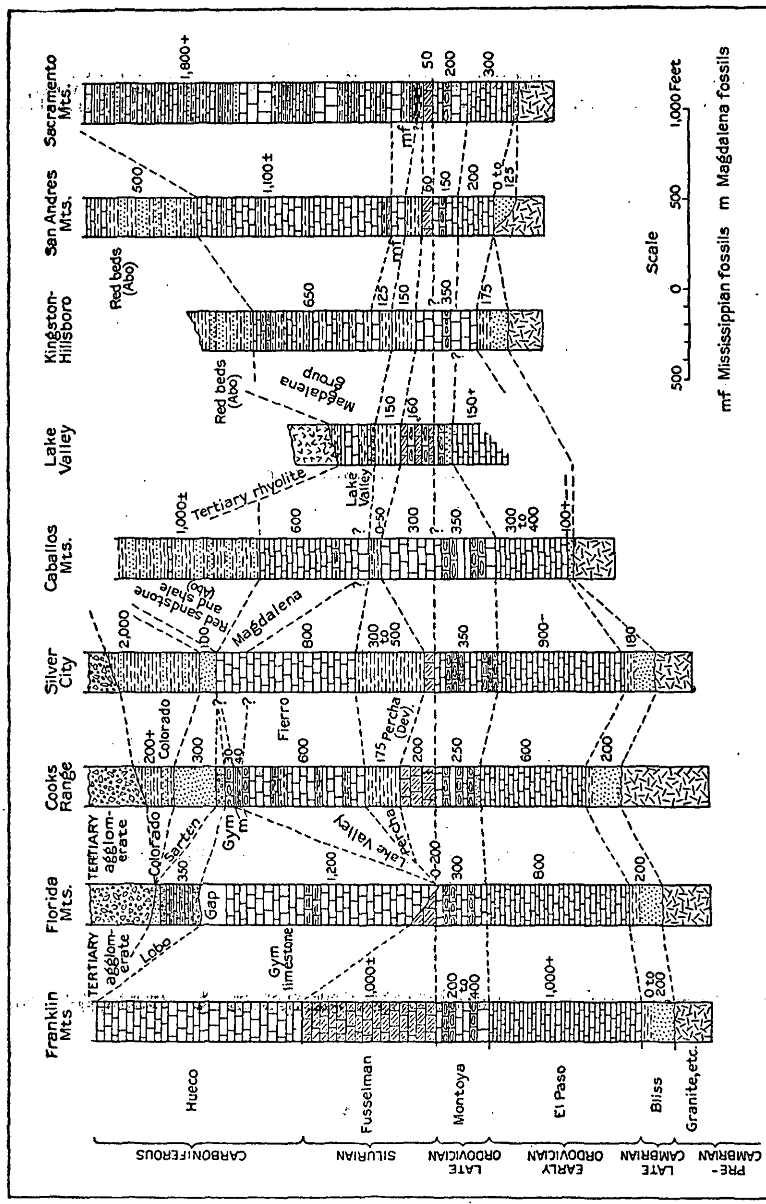


FIGURE 2.—Columnar sections showing stratigraphic relations of Paleozoic rocks in southern New Mexico

Formations in northeastern New Mexico

Age	Group and formation		Character and general relations		Average thickness (feet)
Recent.	Alluvium.		Sand, gravel, and clay.		50±
Pliocene and Miocene.	Santa Fe formation.		Sand, silt, gravel, and conglomerate.		150+
Eocene.	Raton formation.		Conglomerate and sandstone; local coal beds.		1,200-1,600
Eocene (?).	Galisteo sandstone.		Sandstone and conglomerate. Relations to Raton formation unknown.		700+
Upper Cretaceous.	Montana group.	Vermejo formation.	Sandstone and shale, with coal beds.		0-375
		Trinidad sandstone.	Sandstone, gray to buff.		0-100
		Pierre shale.	Shale, mostly dark colored; upper beds sandy.		(?)
	Colorado group.	Apishapa shale.	Shale, in part limy.	Niobrara formation where not differentiated.	500
		Timpas limestone.	Limestone, mostly impure.		50
		Carlile shale.	Shale, with concretions.	Benton shale where not differentiated.	250
		Greenhorn limestone.	Limestone, slabby, and dark shale.		60
		Graneros shale.	Shale, dark.		150+
	Dakota sandstone.		Sandstone, gray to buff, hard.		100
Lower Cretaceous.	Purgatoire formation.		Sandstone, overlain by shale.		140
Cretaceous (?).	Morrison formation.		Shale, massive, mostly greenish gray, and intercalated sandstones.		150
Jurassic (?).	Todilto limestone.		Limestone; weathers thin bedded; locally overlain by 60 feet of gypsum.		0-85
	Wingate sandstone.		Sandstone, massive, light gray.		100
Triassic.	Dockum group.		Shales and sandstones, mostly red, containing locally, near the lower part, the Santa Rosa sandstone.		100-800+
Permian.	Manzano group.	Chupadera formation.	Limestone, sandstone, and gypsum.		0-600
		Abo sandstone.	Sandstone, mostly hard, slabby, brownish red.		600-800
Pennsylvanian.	Magdalena group.		Limestone, some shale, and sandstone.		600-1,200+
Pre-Cambrian.			Granite, schist, quartzite, etc.		

Formations in northwestern New Mexico

Age	Group and formation	Character and general relations	Average thickness (feet)
Recent.	Alluvium.	Sand, gravel, and silt of river bottoms, desert floors, and fans.	0–50
Pliocene and Miocene.	Santa Fe formation.	Sand, gravel, silt, sandstone, and conglomerate.	450±
Eocene.	Wasatch formation.	Conglomerate, sandstone, and shale.	2,000+
	Torrejon formation.	Clay, sandy shale, and sandstones, hard and soft.	400
	Puerco formation.	Clay, sandy shale, and sandstones, hard and soft.	
Upper Cretaceous.	Ojo Alamo sandstone.	Sandstone, conglomeratic, with two conglomerate beds and shale lenses.	65–110
	Kirkland shale.	Shale. Includes Farmington sandstone member.	800–1,180
	Fruitland formation.	Sandstone and shale, with coal, sandy shales, and concretions.	190–290
	Pictured Cliffs sandstone.	Sandstone, copper-colored, also yellowish to light gray or brown.	50–275
	Lewis shale.	Shale, greenish gray, sandy, with local streaks of yellowish calcareous shale.	200–1,200
	Mesaverde group. Cliff House sandstone.	Sandstone, with some shale beds.	400+
	Mesaverde group. Menefee formation.	Shale, with sandstone and coal beds.	600–1,200
	Mesaverde group. Point Lookout sandstone.	Sandstone, with some shale beds.	300
	Mancos shale.	Shale, with sandstone members.	1,000–2,000
	Dakota (?) sandstone.	Sandstone, gray to buff, hard, massive.	75–125
Cretaceous (?).	Morrison formation.	Shale, light-colored, and sandstone.	200
Jurassic (?).	Navajo sandstone.	Sandstone, massive, pink to gray.	600
	Todilto limestone.	Limestone, mostly very thin-bedded and 15 feet thick; locally at top a gypsum bed 80 feet thick.	0–95
	Wingate sandstone.	Sandstone, massive, pink.	80–400
Triassic.	Chinle formation.	Shale, largely red, some gray.	850
	Shinarump conglomerate to west; Poleo sandstone in Nacimiento uplift.	Sandstone, mostly coarse (Shinarump conglomerate, 50–100 feet); in Nacimiento uplift sandstone, massive gray, hard (Poleo sandstone, 120 feet).	50–120
	Moenkopi formation.	Shale, in part sandy, mostly red.	400–800
Permian.	Manzano group. Chupadera formation.	Limestone, gray sandstone, gypsum, and soft red sandstone.	600+
	Manzano group. Abo sandstone.	Sandstone, hard, slabby, brownish red; limestone near base.	700+
Pennsylvanian.	Magdalena group.	Limestone; some shale and sandstone.	0–200+
Pre-Cambrian.		Granite and schist.	

Formations in southern New Mexico

Age	Group and formation	Character and general relations	Average thickness (feet)
Recent.	Alluvium.	Sand, gravel, and silt of river bottoms, desert floors, and fans.	0-1,000
Pleistocene.	Palomas gravel.	Sand, gravel, and conglomerate.	450
Eocene (?).		Conglomerate.	120+
Upper Cretaceous.	Mesaverde (?) formation.	Sandstone, with coal beds.	600
	Mancos shale(?).	Shale, with sandstone layers.	940-2,000
Upper Cretaceous(?)	Beartooth quartzite.	Quartzite, with some shale.	90-125
Lower Cretaceous.	Sarten sandstone.	Sandstone.	0-300
		Limestones, shales, and sandstones.	800+
Triassic (?).	Lobo formation.	Shales, conglomerate, and limestone.	0-350
Triassic.	Dockum group.	Red shales and sandstones.	0-600
Permian (?).	Rustler limestone.	Red shale; limestone layer.	400±
	Castile gypsum.	Gypsum mainly.	2,100+
Permian.	Manzano group. Chupadera formation.	Limestone, gypsum, and gray and red sandstone. Gym l'mestone of Deming quadrangle is equivalent to part of Chupadera.	1,200-3,000+
	Manzano group. Abo sandstone.	Sandstone, slabby, brown-red. Thins out near Hueco Mountains and to southwest.	0-900
Pennsylvanian.	Magdalena group.	Limestone, with some shale and sandstone, especially in lower part.	1,000-2,500
Mississippian.	Lake Valley limestone.	Limestone. Absent north of latitude 34° 30′. (Combined with Magdalena as Fierro limestone in Silver City region.)	0-80
Devonian.	Percha shale.	Shale. Absent north of latitude 33° 30′.	0-300+
Silurian.	Fusselman limestone.	Limestone, massive. Absent north of latitude 33° 30′.	0-1,000
Ordovician.	Montoya limestone.	Limestone, with cherty members above, dark and massive below. Absent north of latitude 33° 40′.	0-250
	El Paso limestone.	Limestone, slabby; weathers light gray. Absent north of latitude 33° 40′.	0-1,000
Cambrian.	Bliss sandstone.	Sandstone, massive to slabby, glauconitic. Absent north of latitude 33° 40′.	0-300
Pre-Cambrian.		Granite, schist, etc.	

CAMBRIAN SYSTEM

Bliss sandstone.—The basal sandstone of the Paleozoic succession in southern New Mexico is known as the Bliss sandstone. Its age is Upper Cambrian. It is a prominent feature in the type locality in the Franklin Mountains of Texas, which extend into New Mexico, and in other ranges in south-central and southwestern New Mexico. It thins out together with the overlying Ordovician strata just north of the San Andres Mountains and probably does not extend north of latitude 33° 30′ in the western part of the State. It is well exposed at the base of the sedimentary section in the Hatchet Mountains.

At all places it lies unconformably on granite or schist and apparently it grades up into the El Paso limestone, although the evidence of continuity is not conclusive.

In outcrops along the eastern base of the Franklin Mountains the Bliss sandstone consists mainly of small grains of quartz. The basal beds are mostly quartzitic and locally conglomeratic; the higher beds are softer and finer grained. The prevailing color is brown, but some portions have lighter tints. The thickness is 300 feet in places, but locally the formation thins out and the overlying limestone rests on the pre-Cambrian rocks. Annelid borings are abundant, and a few brachiopods in the lower beds comprise *Lingulepis acuminata, Obolus matinalis,* and *Lingulella.* In the Florida Mountains, Cooks Range, Mimbres Mountains, and Silver City region, where the thickness was not observed to exceed 180 feet, the formation consists of gray to brownish sandstone, in part quartzitic, with upper slabby members in part glauconitic. The thickness and local features vary from place to place. Beds of this character crop out all along the east side of the San Andres Mountains with thicknesses averaging about 100 feet to the south, as shown in Plate 2, 30 to 40 feet near latitude 33°, and 6 feet in the northern part of the range. In the Sierra Caballo the average thickness of the Bliss sandstone is about 100 feet, and the upper members consist largely of green sandy shale which has yielded *Obolus* (*Westonia*) *stoneanus, Obolus sinoe?, Eoorthis desmopleura,* and *Lingulella acutangulata?.* The small exposure of Bliss sandstone in the west face of the Sacramento Mountains, just south of the mouth of Agua Chiquita Canyon, shows only a few feet of sandstone separating dark granite from El Paso limestone.

ORDOVICIAN SYSTEM

General features.—The strata of Ordovician age in New Mexico comprise the Lower Ordovician El Paso limestone and the Upper Ordovician Montoya limestone. Both formations appear extensively in the mountains and ridges of southeastern New Mexico, but they thin out near latitude 34°. The El Paso limestone appears to grade down into the Bliss sandstone, but it is separated from the Montoya limestone by a break in sedimentation representing part of Ordovician time, and the Montoya limestone is limited above by a break representing an interval of unknown duration.

El Paso limestone.—In the type locality in the Franklin Mountains, north of El Paso, Tex., the El Paso limestone consists of about 1,000 feet of somewhat magnesian gray limestone, in part slabby and in part massive, and containing locally in the lower part considerable sand. The surface of many layers is covered by thin reticulating brown deposits of silica, and most of the rock weathers to a pale-gray tint—two features which are distinctive throughout southwestern

New Mexico. The El Paso limestone is very conspicuous in the outcrop zone along the east front of the San Andres Mountains (see pl. 3), where its thickness is 300 feet at the south but gradually diminishes to about half that amount in the northern part of the range; the last exposure to the north is seen in the southwestern ridge of the Oscura Mountains. In the west face of the Sacramento Mountains, southeast of Alamogordo, its thickness is 250 feet at the place where its base is exposed near the mouth of Agua Chiquita Canyon, as shown in Plate 45, *B*. It is about 300 to 400 feet thick in the west face of the Sierra Caballo, but only about half as thick in the Lake Valley district and the Mimbres Mountains and 600 feet in the Cooks Range. About Silver City and Hanover and in the Florida Mountains, where the total thickness is about 800 feet, there are extensive exposures of the characteristic limestone. In the Klondike Hills and Victorio Mountains the thickness is 640 feet, and in the Hatchet Mountains it is about 500 feet. The east end of the Snake Hills, which rise out of the plain a few miles southwest of Deming, consists of the medial and upper beds of the formation, and upper strata appear in a small outcrop in the Peloncillo Mountains, north of Granite Gap.

Fossils are not numerous in the El Paso limestone, and most of those obtained came from the medial and upper beds. A small coiled shell, *Ophileta*, is the most common. In the Franklin Mountains forms related to *Piloceras* and *Cameroceras* occur. Higher beds near Deming yielded *Orthis pogonipensis* Hall and Whitfield, *Strophomena* cf. *S. nemea* Hall and Whitfield, *Hormotoma* sp., and *Trochonema*. Near Silver City were collected *Calathium anstedi* Billings, *Dalmanella* cf. *D. wempli* Cleland, *Sinuites* cf. *S. rossi* (Collie), *Bucanella nana* Meek?, *Lophospira* sp., *Polygyrata trochiscus* (Meek), *Eccyliopterus* sp., *Maclurites* cf. *M. oceanus* (Billings); *Holopea* sp., *Piloceras* cf. *P. wortheni* Billings, *Cameroceras*, and the usual *Ophileta*. In the Sierra Caballo *Ophileta* cf. *O. complanata* Vanuxem and *Hormotoma* cf. *H. artemesia* (Billings) were obtained. In the San Andres Mountains were collected *Calathium* cf. *C. anstedi* Billings and *Polygyrata trochiscus* (Meek), and in Alamo Canyon near Alamogordo *Calathium* cf. *C. anstedi* Billings and *Orthis pogonipensis* Hall and Whitfield. *Ophileta* and *Maclurites?* were found in the Hatchet Mountains.

These fossils were determined by E. O. Ulrich and Edwin Kirk, who regard them as representing late Beekmantown time and who suggest that in some areas the El Paso may include strata of Chazy age. Evidence obtained in southeastern Arizona suggests that the uppermost Upper Cambrian may be represented in the lowest El Paso beds in New Mexico, which have not proved fossiliferous.

Montoya limestone.—The Montoya limestone, of latest Ordovician (Richmond) age, underlies the portion of New Mexico south of latitude 33° and in places may extend farther north under overlapping beds. The thickness ranges from 200 to 300 feet at most outcrops, with local diminution due to erosion of the top; to the north the formation thins out rather rapidly. The formation comprises a lower member of dark-colored massive limestone, in places sandy, and an upper member of slabby beds with many thin layers of chert. The strata are all hard, and at most places the outcrop is a dark cliff in the mountain side. Along the east slope of the Franklin Mountains the formation is 250 feet thick. In the Cooks Range there is a top member of 60 feet of light-colored slabby limestone with a 6-foot very fossiliferous layer at the base, underlain by 150 feet of limestone containing numerous cherty layers, and a basal member of 40 feet of dark massive limestone or sandstone. In the Snake Hills, a few miles west of Deming, the greater part of the formation, 300 feet in all, is exposed lying on the El Paso limestone. At the base is dark massive limestone; next above very cherty limestone with alternating layers of purer limestone; 30 feet of dark-gray sandy limestone grading upward into purer, partly massive limestone that weathers to an olive tint; then a 60-foot member of alternating layers of chert and limestone, with fossils; and at the top a thick mass of highly cherty rock constituting the crest of the ridge. In the Klondike Hills the basal member is a dark-gray sandstone 6 to 8 feet thick, lying on the slightly irregular surface of the El Paso limestone. It is overlain by 30 or 40 feet of dark massive sandy limestone, capped as in other areas by a succession of alternating layers of chert and very fossiliferous limestone. In the Silver City region, where the formation is about 300 feet thick, it contains many chert layers, except at the top, where there is a member that consists of alternating thin beds of smooth white limestone and blue limestone with cherty beds at intervals. In the Sierra Caballo and the Mimbres Mountains the formation is extensively developed with its usual characteristics. At Lake Valley there is 20 feet of gray hard sandstone at the base, overlain by 25 feet or more of cherty limestone of strong Montoya aspect. The Montoya limestone is a prominent feature all along the great eastward-facing escarpment of the San Andres Mountains, as shown in Plate 3, but it thins out in the south end of the Oscura Mountains. It consists of an upper member of alternating thin beds of limestone and chert, from 30 to 75 feet thick, and a lower member of very massive dark limestone, 100 feet thick near latitude 33° and southward but thinning to the north. Locally there is a basal deposit of sandstone which attains a thickness of 15 feet near San Andres Peak. In the southwestern portion of the Oscura Mountains the lower member of dark massive limestone, 35 feet thick, grades up into 6 feet of beds with cherty layers, overlain by red shale probably representing the Percha. In the west front of the Sacramento

Mountains, southeast of Alamogordo, the Montoya limestone consists of the usual two members—the upper one 60 feet thick, of alternating thin beds of chert and fossiliferous limestone, and the lower one 75 to 120 feet thick, of dark massive limestone with local gray sandstone at the base, lying on the slightly channeled surface of the El Paso limestone. In the Hatchet Mountains the upper member is about 120 feet thick and the lower member about 30 feet.

Fossils of the Richmond fauna occur throughout the Montoya limestone at nearly all exposures, but they are relatively scarce in the lower member, especially in Luna County. The following species from the upper beds have been identified by Ulrich and Kirk:

Bythopora gracilis (Nicholson).
Bythopora striata Ulrich.
Dicranopora cf. D. fragilis (Billings).
Eurydictya cf. E. montifera Ulrich.
Hemiphragma imperfectum (Ulrich).
Rhombotrypa quadrata (Rominger).
Stromatocerium huronense (Billings).
Calapoecia anticostiensis Billings.
Columnaria alveolata Goldfuss var.
Columnaria (Paleophyllum) thomi (Hall).
Paleofavosites asper D'Orbigny.
Streptelasma rusticum (Billings).
Dalmanella cf. D. corpulenta (Sardeson).
Dalmanella cf. D. meeki (Miller).
Dalmanella tersa (Sardeson)?
Dalmanella testudinaria (Dalman) var.
Dinorthis subquadrata (Hall).
Hebertella occidentalis (Hall).
Hebertella occidentalis var. sinuata (Hall).
Leptaena unicostata (Meek and Worthen).
Parastrophia divergens Hall and Clarke.
Platystrophia acutilirata (Conrad).
Plectambonites saxeus (Sardeson).
Plectorthis cf. P. kankakensis (McChesney).
Plectorthis whitfieldi (Winchell).
Rafinesquina cf. R. kingi (Whitfield).
Rhynchotrema argenturbicum (White).
Rhynchotrema capax (Conrad).
Rhynchotrema neenah (Whitfield).
Rhynchotrema perlamellosum (Whitfield).
Strophomena fluctuosa (Billings).
Strophomena cf. S. subtenta Conrad.
Zygospira recurvirostris (Hall).
Ctenodonta sp.
Lophospira medialis Ulrich and Scofield.
Lophospira perangulata (Hall).

The principal forms collected from the basal beds are *Halysites gracilis* (Hall), *Rhynchotrema capax* (Conrad), *Eridotrypa* sp., *Batostoma* cf. *B. varium* Ulrich, *Dalmanella testudinaria* (Dalman) var., and *Zygospira recurvirostris* (Hall). In the Hatchet Mountains were collected *Dalmanella testudinaria* (Dalman), *Dinorthis subquadrata* (Hall), *Rhynchotrema capax* (Conrad), and *Rhynchotrema argenturbicum* (White).

SILURIAN SYSTEM

Fusselman limestone.—Only a small portion of Silurian time is represented by the Fusselman limestone, which is confined to the part of New Mexico south of latitude 33°, though in that part it is of general occurrence. It carries abundant fossils of Niagara age. At the type locality in the Franklin Mountains, north of El Paso, Tex., its thickness is 1,000 feet and it is of considerable topographic prominence. In the Cooks Range near Lake Valley it is about 200 feet thick, in the Sacramento Mountains 100 to 130 feet (see pl. 45), near Silver City 40 feet, in the Hatchet and Victorio Mountains 100 feet or more, and in the San Andres Mountains it ranges from 220 to 120 feet but thins out rapidly a short distance north of latitude 33°.

The formation everywhere lies on the Montoya limestone on a plane of erosional unconformity, in places marked by conglomerate consisting of pebbles of the underlying formation. Generally it is overlain abruptly by dark shale of the Percha (Devonian), but in the Franklin Mountains it is overlain by limestone apparently of Pennsylvanian age, and in the Florida Mountains is overlapped by the Gym limestone (Permian). It is the ore-bearing rock in the Cooks Peak and Victorio mining districts. In most regions two members are present—an upper one about 50 feet thick, of hard dark massive limestone with fossils and a lower one 85 feet thick (southeast of Alamogordo), of compact fine-grained gray limestone that weathers nearly white.

In general, fossils are rare in the Fusselman limestone; the most common and characteristic form is a *Pentamerus*, but many corals occur in places, notably in a knoll on the south side of Mine Hill, in the Victorio Mountains, where the following were obtained: *Heliolites megastoma*, *Favosites* cf. *F. venustus*, *Cyathophyllum* cf. *C. radiculum*, *Halysites catenulatus* (large and small varieties), *Syringopora* sp., and an orthoid suggesting *Rhipidomella hybrida*. These forms were determined by E. O. Ulrich, who regards them as probably of late Niagara age, similar to a coral fauna in the Laketown dolomite in northeastern Utah. At Lake Valley fossils were collected from several strata above the 80-foot basal member, which weathers to a light color. Not far above this member occur *Monomerella* n. sp. and *Zaphrentis* sp. In cherty layers 100 feet higher *Monomerella* was very abundant, and near the top, about 30 feet below the Percha shale, were collected *Zaphrentis* sp., *Amplexus* sp., and a variety of *Pentamerus oblongatus* that is characteristic of the upper beds in other areas.

DEVONIAN SYSTEM

Percha shale.—The Devonian system is represented in southern New Mexico by a widespread deposit of black shale named the Percha shale, from Percha Creek, near Kingston. It represents a portion of later Devonian time, and although accordant in attitude with overlying and underlying formations it is separated from them by breaks of sedimentation. It is absent in the Franklin Mountains and apparently also in the Permian overlap in the Florida and Victorio Mountains. It attains a thickness of nearly 500 feet in part of the Silver City region but is less than half as thick in the Cooks Range, the Sierra Caballo, and the Mimbres and Hatchet Mountains, 160 feet at Lake Valley, and about 100 feet in the San Andres and Sacramento Mountains. It thins out in the northern part of the San Andres Mountains but probably is represented by some red shale overlying Montoya strata in the southern part of the Oscura Mountains. It is absent in the Magdalena Mountains and other ranges in central and northern New Mexico. In most places the lower beds are fissile shales and the upper beds of gray shale contain layers of slabby and nodular limestone.

Many fossils occur in the Percha shale, especially in the limy beds of its upper member. The principal collections were obtained near Kingston, Hillsboro, and Silver City and in the San Andres Mountains. According to identifications by G. H. Girty, E. M. Kindle, and Edwin Kirk the following species are included:

Athyris coloradoensis Girty.
Atrypa hystrix Hall.
Atrypa reticularis (Linnaeus).
Camarotoechia contracta Hall.
Camarotoechia (Plethorhyncha) endlichi (Meek).
Leptaena rhomboidalis (Wilckens).
Meristella barrisi Hall?
Productella coloradensis Kindle.
Productella coloradensis var. plicatus Kindle.
Productella hallana Walcott.
Productella hillsboroensis Kindle.
Productella laminatus Kindle.
Productella spinigera Kindle.
Pugnax pugnus (Martin).
Reticularia spinosa Kindle.
Reticularia undifera Roemer var.
Schizophoria striatula var. australis Kindle.
Spirifer notabilis Kindle.
Spirifer cf. S. utahensis Meek.
Spirifer whitneyi Hall.
Spirifer whitneyi var. animasensis Girty.
Stropheodonta near S. arcuata Hall.
Syringospira prima Kindle.
Tropidoleptus carinatus (Conrad) var.
Euomphalus eurekensis Walcott?

These fossils are regarded as late Devonian, equivalent to the lower part of the Ouray limestone, the upper part of the Martin limestone of eastern Arizona, and the upper 2,000 feet of the Nevada limestone of the Eureka district, Nevada. As no fossils have been found in the lower beds, these strata may represent a somewhat greater stratigraphic range than is indicated by the fossils above listed.

CARBONIFEROUS SYSTEM

Rocks of the Carboniferous system occupy all parts of New Mexico except the higher portions of some of the uplifts, where they have been removed by erosion. Representatives of the lower Mississippian occupy most of the southwestern part of the State and probably are present under some of the southeastern part, but they appear to be absent in the Franklin, Florida, and Victorio Mountains. The Pennsylvanian series, represented by the Magdalena group, is widespread, but it is absent about Pedernal Mountain, in the east-central area, in the Zuni Mountain region, and in part of Luna County. The Permian series,[14a] represented by the Abo sandstone, Chupadera formation, and Gym limestone, is still more widespread and becomes very thick under the eastern third of the State, especially to the southeast, where the Chupadera formation merges into the Guadalupe group.[14b] In the Pedernal and Zuni Mountain regions the lower beds of the Permian series abut against slopes of a pre-Permian land surface, which, however, may have been entirely buried by later Carboniferous deposits. It is not unlikely also that originally the Permian strata may have extended over the southwest corner of the State, where the Lower Cretaceous and Pennsylvanian are now in contact.

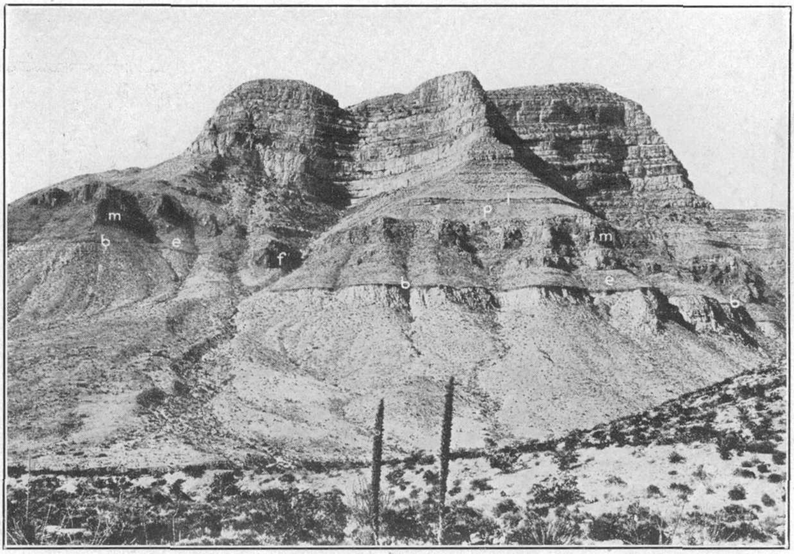
Lake Valley limestone and other limestones of Mississippian age.—The Lake Valley limestone is conspicuous in the Sacramento, San Andres, Robledo, Caballo, Cooks, and Mimbres Mountains, where it generally consists of 100 to 200 feet of massive to slabby, mostly coarse-grained light-colored limestone. In the Cooks Range locally its thickness reaches 500 feet. In the Magdalena Mountains it is apparently 243 feet thick. This horizon is represented by the lower part of the Fierro limestone in the Silver City region and by limestone which has not yet been classified in the Hatchet Mountains and Ladron Peak and probably in the Peloncillo Mountains. In the Magdalena Mountains and Sierra Ladrones this limestone lies on pre-Cambrian granite, but elsewhere it overlies the Percha shale without discordance in attitude. It is overlain by limestones of Pennsylvanian age (Magdalena group) without notable difference in attitude but separated by a break representing a long interval of late Mississippian time.

[14a] See footnote 21a, p. 25.

[14b] Darton, N. H., and Reeside, J. B., jr., Guadalupe group: Geol. Soc. America Bull., vol. 37, pp. 413–428, pls. 12–16, 1927. Darton, N. H., The Permian of Arizona and New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 10, pp. 819–852, 1926.

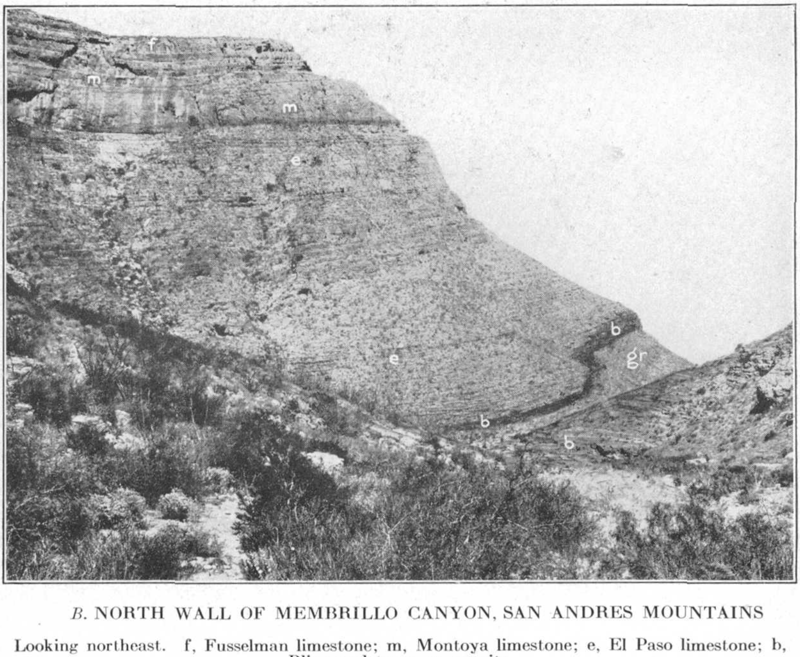
BLISS SANDSTONE AND OVERLYING FORMATIONS IN NORTH WALL OF BENNETT CANYON, SAN ANDRES MOUNTAINS, 25 MILES NORTHEAST OF LAS CRUCES

Looking northwest. Bliss sandstone overlain at a by El Paso limestone m Montoya limestone; f. Fusselman limestone



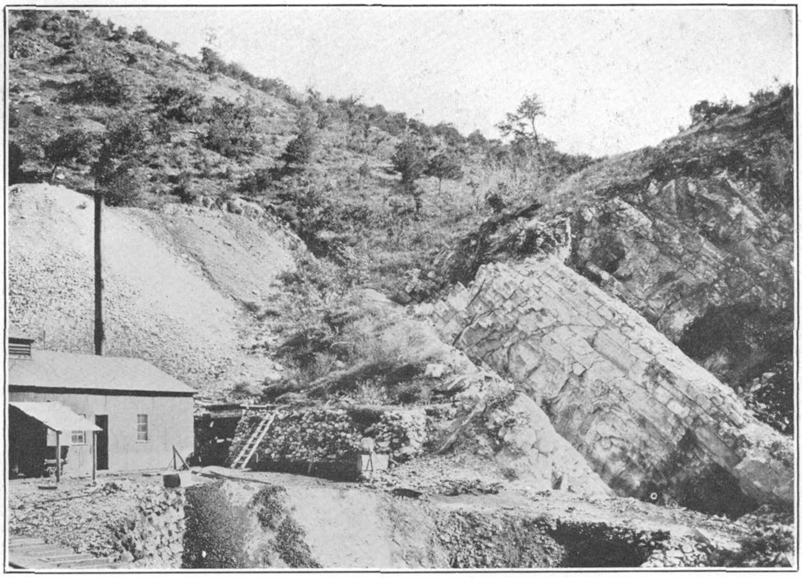
A. NORTH END OF SHEEP MOUNTAIN AT LAVA GAP, SAN ANDRES MOUNTAINS

Looking south. b, Bliss sandstone on granite; e, El Paso limestone; m, Montoya limestone; p, Percha shale; l, Lake Valley limestone overlain by limestone of Magdalena group; f, fault



B. NORTH WALL OF MEMBRILLO CANYON, SAN ANDRES MOUNTAINS

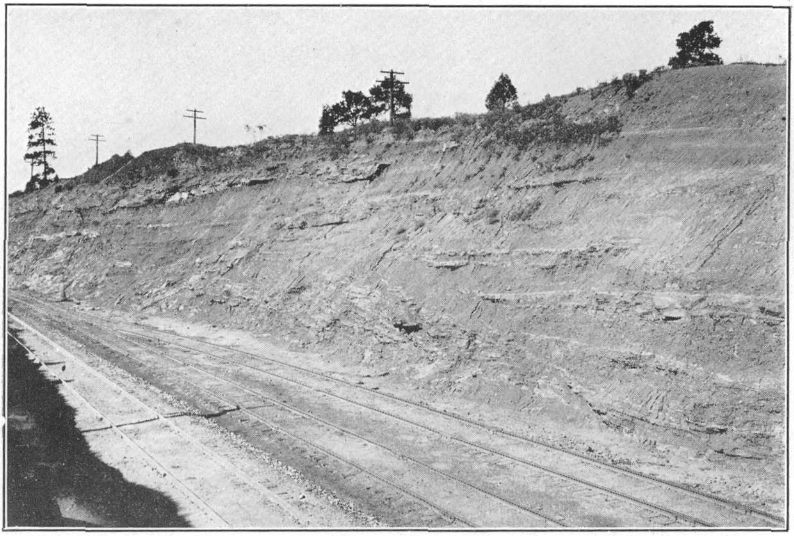
Looking northeast. f, Fusselman limestone; m, Montoya limestone; e, El Paso limestone; b, Bliss sandstone; gr, granite



A. LAKE VALLEY LIMESTONE AT GRAPHIC MINE, NEAR MAGDALENA

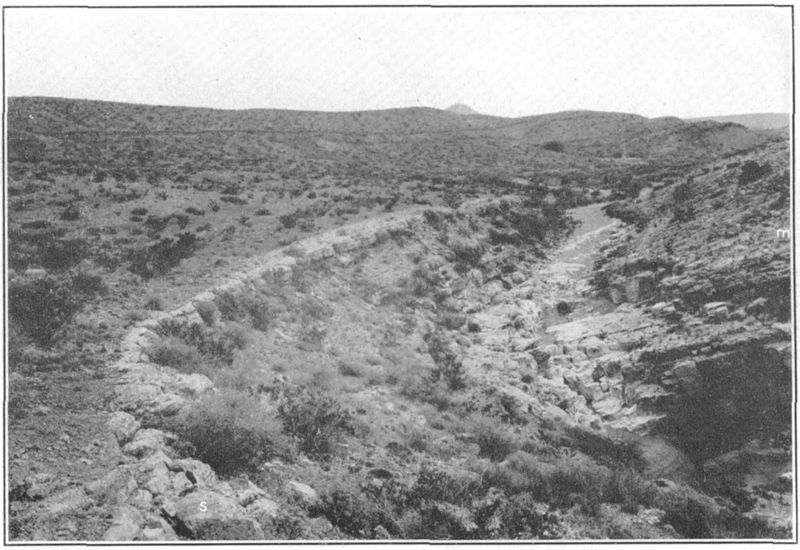
B. LIMESTONE OF MAGDALENA GROUP IN CANYON OF RIO SALADO AT SOUTH END OF LADRONES MOUNTAINS, 8 MILES EAST OF RILEY

Looking west



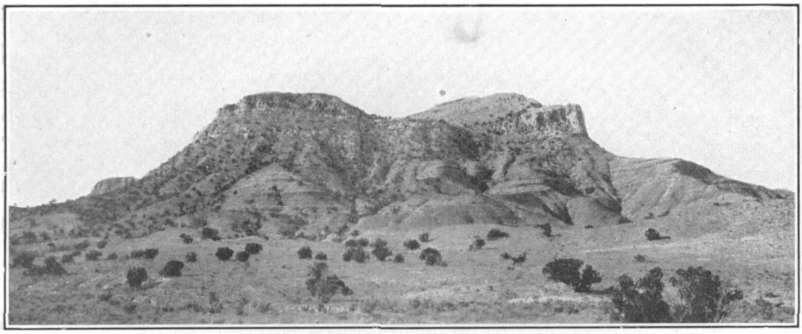
A. ABO SANDSTONE IN CUT OF ATCHISON, TOPEKA & SANTA FE RAILWAY AT GLORIETA

Looking northwest



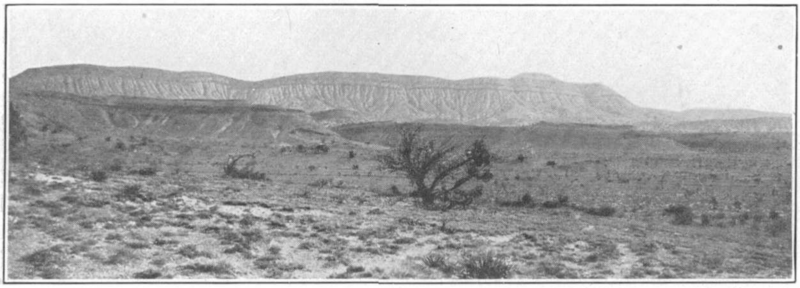
B. CONTACT OF ABO SANDSTONE AND LIMESTONE OF MAGDALENA GROUP, ARROYO DE LOS PINOS, 6 MILES NORTHEAST OF SOCORRO

Looking northeast. m, top ledge of limestone. Red cliffs of Abo sandstone in middle ground. Top of Coyote Butte in distance



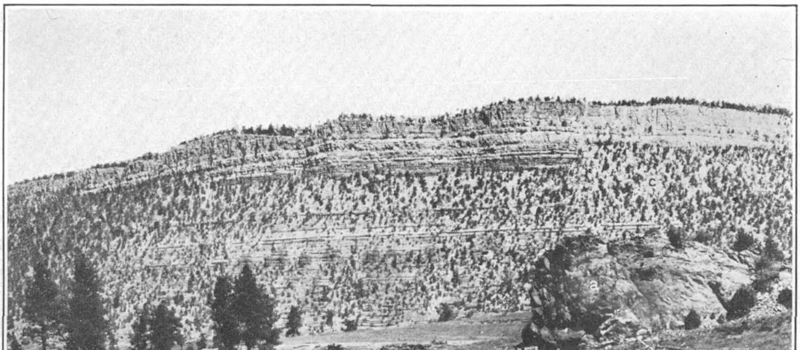
A. CIBOLA CONE, 17 MILES NORTHEAST OF SOCORRO

Red beds and gypsum of Chupadera formation capped by an outlying mass of gray sandstone and limestone. Looking south



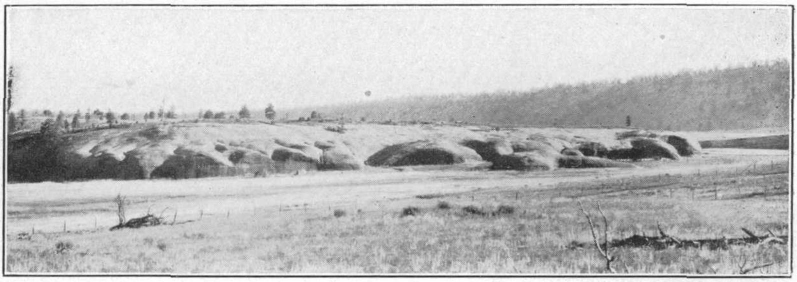
B. CHUPADERA FORMATION IN WEST FACE OF SOUTH END OF CHUPADERA MESA, IN EASTERN PART OF T. 7 S., R. 8 E., 17 MILES WEST BY NORTH OF CARRIZOZO

Looking southeast. Red beds with limestone members, capped by sandstone, gypsum, and limestone. Lower limestone members cap benches and mesas in foreground



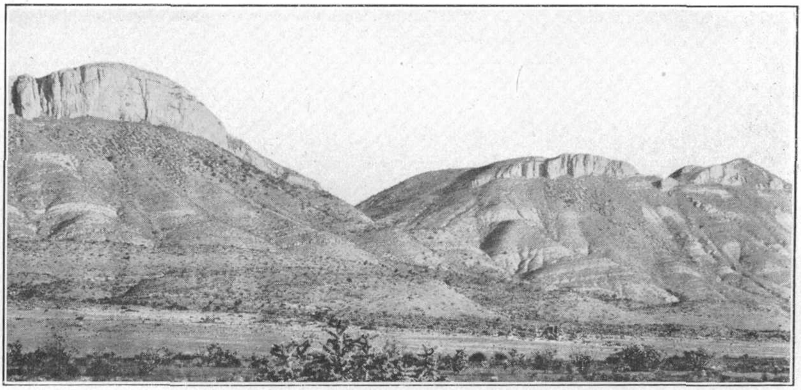
C. ESCARPMENT ON NORTH SIDE OF BLUEWATER CREEK, 7 MILES EAST OF SAWYER, ZUNI MOUNTAINS

Looking north. Limestone and sandstone of Chupadera formation on Abo sandstone at *c*. Massive member in lower part of Abo at *a* to right



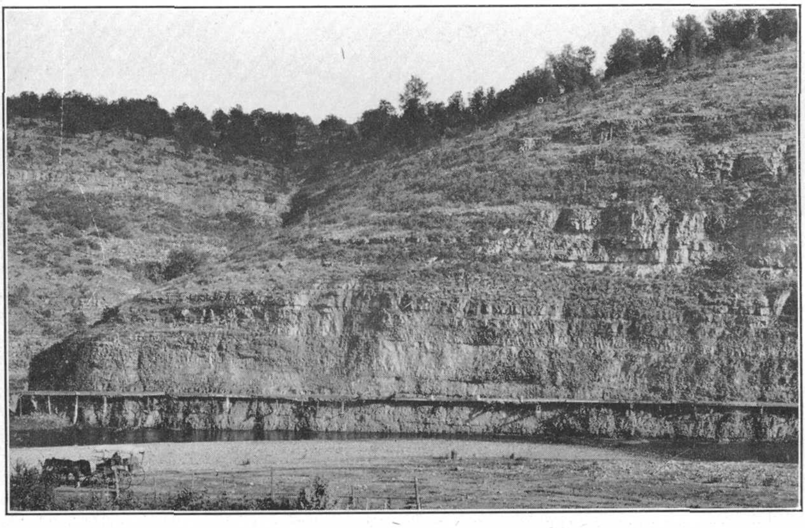
A. MASSIVE RED SANDSTONE IN ABO FORMATION, ZUNI MOUNTAINS, 7 MILES SOUTHWEST OF THOREAU

Cliff of limestone of Chupadera formation in distance. Looking north



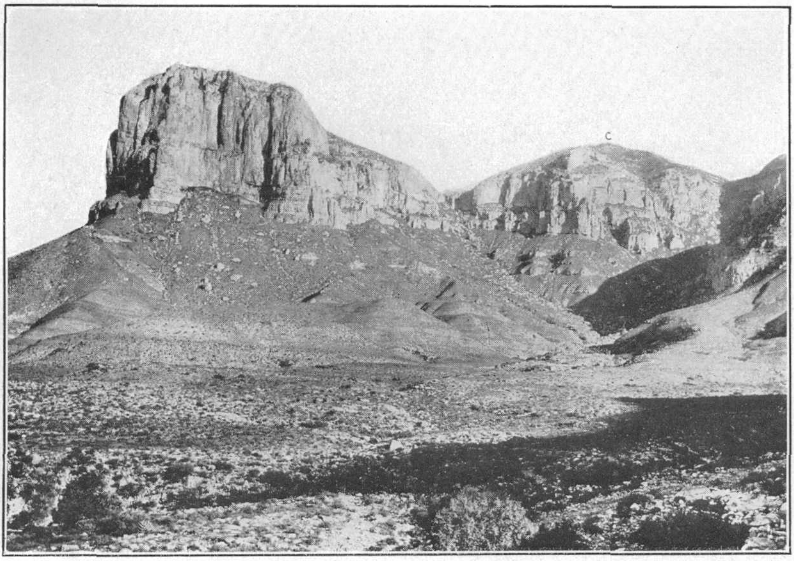
B. CHUPADERA FORMATION IN WESTERN RIDGE OF SAN ANDRES MOUNTAINS EAST OF ENGLE

Heavy cap of massive limestone above gypsum, sandstone, limestone, and red sandy shale. Looking west from point near old Rhodes ranch



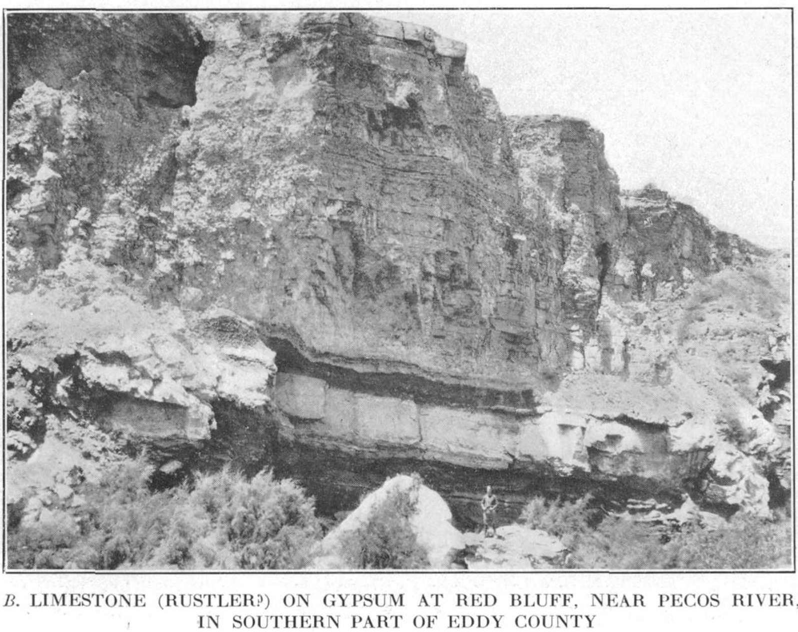
C. LIMESTONE OF CHUPADERA FORMATION ON SOUTH SIDE OF PENASCO CREEK 18 MILES SOUTHEAST OF CLOUDCROFT

Looking south

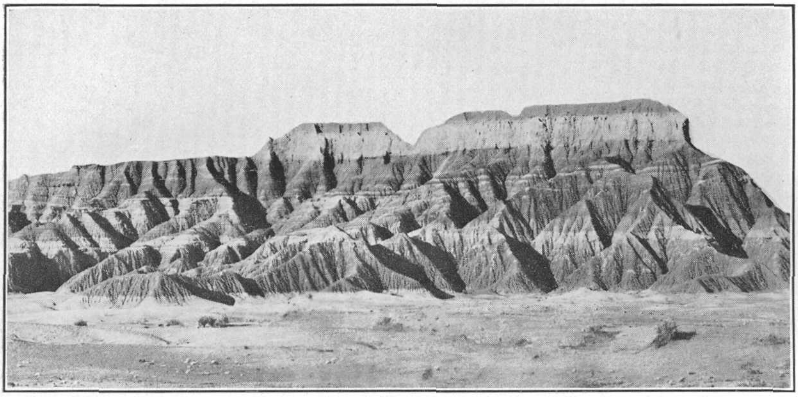


A. CAPITAN LIMESTONE AND DELAWARE MOUNTAIN FORMATION (GUADALUPE GROUP) AT GUADALUPE POINT, CULBERSON COUNTY, TEX.

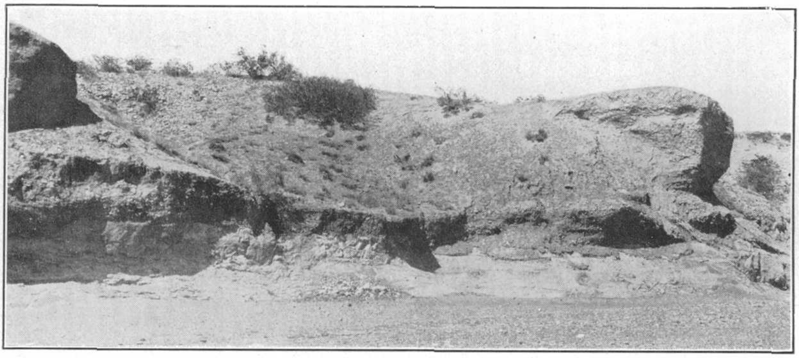
c. El Capitan Peak, highest point in Texas



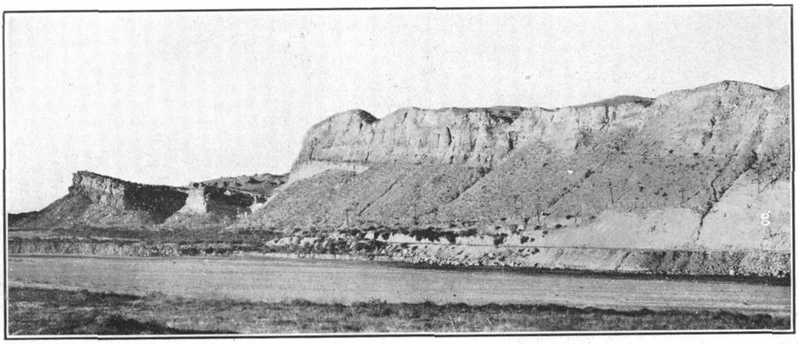
B. LIMESTONE (RUSTLER?) ON GYPSUM AT RED BLUFF, NEAR PECOS RIVER, IN SOUTHERN PART OF EDDY COUNTY



A. BADLANDS IN DOCKUM GROUP 10 MILES EAST OF TUCUMCARI



B. BONE-BEARING CONGLOMERATE OF PROBABLE TRIASSIC AGE LYING UNCONFORMABLY ON SANDSTONE AND SHALE AT TOP OF CHUPADERA FORMATION NEAR OJO DE LA PARTIDA, 8 MILES NORTHEAST OF SOCORRO



C. GYPSUM, WINGATE SANDSTONE, AND ASSOCIATED ROCKS ON NORTH SIDE OF GALISTEO RIVER NEAR ROSARIO SIDING, 8 MILES WEST OF CERRILLOS

Looking northwest. g, Gypsum

At the type locality near Lake Valley, where the top of the formation is eroded and in part overlain by Tertiary igneous rocks, the thickness is about 210 feet, including a lower member 50 feet thick of compact massive gray limestone with nodular chert which may possibly be Devonian. The other members of the Lake Valley limestone at this place consist of an upper light-colored, highly fossiliferous subcrystalline limestone 60 feet thick; blue shale with thin layers of bluish limestone, 25 feet; grayish-blue limestone, more or less siliceous, called "blue limestone" in the mines, 20 feet; and at the base coarse crystalline yellowish-white limestone, 5 feet. There are many exposures in the cliffs near Cooks Peak and in canyons north of Kingston, near Hermosa and along the steep escarpments of the Sacramento and San Andres Mountains, and in slopes northwest of Silver City and east of Hanover. In the northern part of the east front of the San Andres Mountains the Lake Valley is a massive bed of limestone 100 feet thick to the south, but thinning to 25 feet near the north end of the range. In the mountain slope southeast of Alamogordo it consists of 150 feet of limestone, mostly coarse grained and light colored, and limy shale, both containing numerous crinoid stems and other fossils.

The Kelly limestone,[15] the ore-bearing formation in the silver-lead mines in the Magdalena Mountains (see pl. 4, *A*), has yielded crinoids and other fossils which indicate its early Mississippian age. The thickness given by Gordon is 193 feet, not including 50 feet of a nonfossiliferous shale which extends to a pebbly quartzite 60 feet thick supposed to be the base of the Magdalena group. The northernmost exposure of limestone of Mississippian age is on the southwest slope of the Sierra Ladrones, where the formation thins out to the north. According to Keyes[16] it also appears in the Oscura Mountains.

The principal fossils collected in the Lake Valley limestone at Lake Valley and in the Mimbres Mountains near Kingston are listed below. The crinoids were mostly identified by Frank Springer and the other forms by G. H. Girty.

Favosites aff. F. valmeyerensis.
Amplexus aff. A. fragilis.
Platycrinus peculiaris.
Platycrinus parvinodus.
Platycrinus pileiformis.
Platycrinus subspinosa.
Periechocrinus whitei.
Megistocrinus evansi?
Cactocrinus multibrachiatus.
Cactocrinus proboscidialis.
Dorycrinus unicornis.
Physetocrinus lobatus.
Physetocrinus copei.
Physetocrinus planus.
Rhodocrinus wortheni var. urceolatus.
Steganocrinus sculptus.
Steganocrinus pentagonus.
Fistulipora americana.
Crania aff. C. missouriensis.
Schizophoria aff. S. swallowi.
Rhipidomella dalyana.
Leptaena analoga.

[15] Gordon, C. H., Mississippian formations in the Rio Grande Valley, N. Mex.: Am. Jour. Sci., 4th ser. vol. 24, pp. 62–63, 1906; U. S. Geol. Survey Prof. Paper 68, pp. 229–231, 244–245, 1910.

[16] Keyes, C. R., op. cit.

Productus aff. P. burlingtonensis.
Productus aff. P. arcuatus.
Productus aff. P. sampsoni.
Productus aff. P. mesialis.
Productus ovatus.
Productus aff. P. wortheni.
Rhynchopora occidentalis.
Camarotoechia metallica.
Spirifer aff. S. grimesi.
Spirifer aff. S. vernonensis.
Brachythyris aff. B. suborbicularis.
Delthyris novimexicana.
Reticularia aff. R. cooperensis.
Pseudosyrinx aff. P. gigas.
Athyris lamellosa.
Composita humilis.
Cliothyridina temeraria.
Cliothyridina aff. C. obmaxima.
Cliothyridina aff. C. incrassata.
Cliothyridina aff. C. glenparkensis.
Platyceras aff. P. equilaterum.
Phillipsia aff. P. peroccidens.
Proteus aff. P. loganensis.

The principal forms obtained in the Cooks Peak region as determined by Mr. Girty were *Cystodictya* aff. *C. pustulosa*, *Leptaena analoga*, *Rhipidomella pulchella?*, *Productus semireticulatus*, *P. ovatus*, *P.* aff. *P. burlingtonensis*, *P.* aff. *P. wortheni*, *Brachythyris suborbicularis?*, *Spirifer centronatus*, and *Composita humilis;* from the lower division of the Fierro limestone near Silver City, *Actinocrinus copei?*, *Dorycrinus lineatus*, *Leptaena analoga*, *Rhipidomella* aff. *R. oweni*, *Productus mesialis*, *Spirifer* aff. *S. imbrex*, and *Reticularia cooperensis;* on the south side of Ladron Peak, *Rhipidomella* aff. *R. dubia*, *Spirifer* aff. *S. logani*, *Spiriferella* aff. *S. neglecta*, *Athyris lamellosa*, *Cliothyridina* aff. *C. obmaxima*, *Phillipsia* sp., and various crinoids; on the west front of the Sacramento Mountains, *Schizoblastus* aff. *S. roemeri*, *Leptaena analoga*, *Schuchertella chemungensis*, *Rhipidomella diminutiva?*, *R. dalyana*, *Schizophoria poststriatula*, *Spirifer rowleyi*, *S. centronatus*, *S.* aff. *S. grimesi*, *Productus gallatinensis*, *Productella* n. sp., aff. *P. pyxidata*, *Shumardella* aff. *S. missouriensis*, *Delthyris novimexicana*, *Composita humilis?*, *Cliothyridina prouti?*, *Platyceras* aff. *P. fissurellum*, *P.* aff. *P. paralium*, and *P.* aff. *P. equilaterum*.

Magdalena group (Pennsylvanian).—The thick limestone succession of the Magdalena group is a prominent feature in the Sacramento, San Andres, Oscura, Franklin, Caballo, Los Pinos, Sandia, and Manzano Mountains, and it constitutes a large part of the Sangre de Cristo Mountains. It also appears in the Magdalena, Ladron, Robledo, Lemitar, Lone, Hatchet, Cooks, Peloncillo, and Mimbres Mountains and the ridges east and west of Socorro, south and west of Hatchet, and west and north of Silver City, and in the uplift of Santa Rita and Hanover. A characteristic exposure is shown in Plate 4, *B*. It underlies a part of the eastern third of the State, where, however, its limits are not known, as it has not yet been definitely recognized in the deep borings. It is absent in the Zuni Mountains, in parts of Grant County, in the Pedernal region, and in most of northeastern New Mexico, where deep borings find granite below probable Chupadera or Abo beds.

Limestone is the predominant rock in the Magdalena group, but interbedded sandstone and shale occur in all sections, and along the east side of the Sangre de Cristo Mountains, in the northern part of the State, gray and red sandstone preponderates.

The group ranges in thickness from 900 to nearly 2,500 feet and attains the maximum in parts of the Rocky Mountains. Gardner measured 1,237 feet near Pecos. In the San Andres Mountains the thickness is near 2,000 feet. In the Sandia and Manzano Mountains it is from 900 to 950 feet, and there is local thickening to 1,200 feet in the Los Pinos Mountains. In the Magdalena Mountains Gordon [17] measured about 1,100 feet. In the Sacramento Mountains the thickness is fully 1,500 feet. In part of the Nacimiento Mountains the maximum thickness is 500 feet, and in places the group thins out. It is thin where present locally in Grant County.

In the ridges near the Rio Grande, especially in the Sandia Mountains, the Magdalena group has been divided into the Sandia formation below and the Madera limestone above, but the plane of division appears not to be constant. The stratigraphic position of the sandstone beds and the transitions from one member to the other differ in different localities. Locally the group can be divided into several formations, some of them separated by apparent unconformities, but no notable faunal distinctions have yet been found in these formations.

Fossils occur abundantly in most parts of the Magdalena group at nearly all localities. The following are the principal forms as determined by G. H. Girty:

Fusulina secalica.
Campophyllum torquium?
Lophophyllum profundum?
Monilipora prosseri.
Chaetetes milleporaceus.
Stenopora carbonaria.
Pinnatopora sp.
Septopora sp.
Cyclopora sp.
Polypora sp.
Rhombopora lepidodendroides.
Lingula carbonaria.
Lingulidiscina missouriensis.
Rhipidomella pecosi.
Schizophoria aff. S. altirostris.
Enteletes hemiplicatus.
Derbya crassa.
Derbya robusta.
Meekella striaticostata.
Chonetes granulifer.
Chonetes verneuilianus.
Productus semireticulatus.
Productus walkeri.
Productus coloradoensis, var.
Productus aff. P. gallatinensis.
Productus cora.
Pustula nebraskensis.
Pustula semipunctata.
Marginifera wabashensis.
Marginifera muricata?
Marginifera splendens.
Marginifera lasallensis.
Pugnax osagensis.
Dielasma bovidens.
Spirifer triplicatus.
Spirifer boonensis?
Spirifer rockymontanus.
Spiriferina kentuckyensis.
Spiriferina campestris?
Squamularia perplexa.
Ambocoelia planiconvexa.
Composita subtilita.

[17] Gordon, C. H., op. cit. (Prof. Paper 68), p. 246.

Cliothyridina orbicularis.
Hustedia mormoni.
Edmondia nebraskensis.
Parallelodon carbonarius.
Deltopecten occidentalis.
Acanthopecten carboniferus.
Aviculipinna nebraskensis.
Aviculipinna peracuta.
Myalina subquadrata.
Anthracomya elongata.
Pleurophorella costata.
Anomphalus rotulus.
Schizostoma sp.
Platyceras nebraskense.
Metacoceras aff. M. walcotii.
Gonioloboceras goniolobus.
Phillipsia aff. P. scitula.
Phillipsia major.

Hueco limestone.—The limestone of Carboniferous age in the Franklin and Hueco Mountains in Texas, which extend into the southern part of New Mexico, has been classed as Hueco limestone. In the northern extension of the Franklin Mountains the limestone has so far yielded only a Magdalena fauna, but the limestones constituting the northern extension of the Hueco Mountains apparently comprise not only the southern extension of the Magdalena group but also the Chupadera formation, both containing characteristic fossils. The Abo sandstone, which intervenes in the Sacramento Mountains, thins out at a point southeast of Oro Grande.

Abo sandstone (Permian).—The red strata of the Abo sandstone, the basal formation of the Manzano group, appear in many uplifts in central New Mexico, notably in the Sandia, Manzano, Sacramento, San Andres, Oscura, Nacimiento, Zuni, and Lucero Mountains, the south end and east side of the Sangre de Cristo Mountains, and the ridges east of Socorro, and there are small outcrops in the Magdalena and Mimbres Mountains and the ridge east of Fairview. The Abo thins out in the southern part of the southward continuation of the Sacramento cuesta, in the south-central part of Otero County, so that the Chupadera and Magdalena formations join to form the greater part of the limestone succession in the Hueco Mountains. The Abo is absent in the southwest corner of the State and in part of the Pedernal region, where its edge lies against the old ridge of pre-Cambrian rock. An extensive exposure in the railroad cut at Glorieta is shown in Plate 5, *A*. In most places the Abo formation appears to lie unconformably on the Magdalena group, but the nature, duration, and extent of the hiatus are not known. An interesting exposure of contact is shown in Plate 5, *B*.

The thickness of the Abo sandstone ranges from 600 to 1,000 feet, and the formation thins rapidly near its southern termination southeast of Oro Grande. Although most of the rock is a slabby sandstone of strong red-brown color, with one notable massive member in the Zuni Mountains (see pl. 7, *A*), considerable sandy red shale is included, and in the western part of the State one or more thin limestone members occur near the base. These limestones have yielded fossils that were identified by G. H. Girty as follows and indicate Permian age:

Basal beds in the axis of the Lucero anticline, in sec. 36, T. 6 N., R. 3 W.; collected in 1902:[18]

Myalina permiana.
Myalina perattenuata.
Aviculipecten cf. A. whitei.
Bakewellia? sp.
Bulimorphia near B. nitidula.
Spirorbis sp.

Limestone 30 feet above base of Abo sandstone near Sawyer, Zuni Mountains; collected in 1919:

Composita subtilita.
Myalina aff. M. permiana.
Schizodus? sp.
Pleurophorus?
Bellerophon? sp.
Goniospira? sp.
Naticopsis? sp.
Bulimorphia aff. B. chrysalis.

Fossil plants collected from Abo beds near Canyoncito, Glorieta, and Kelly and from equivalent Supai beds in Arizona have been determined by David White and classed as Permian.

Bones from red beds now regarded as representing the Abo sandstone near Coyote, in Rio Arriba County, were classed as Permian by Marsh and Cope and later by Williston and Case.[19]

The following list is given by Williston and Case:

Eryops (?) reticulatus Cope.
Eryops grandis Marsh.
Aspidosaurus novomexicanus Williston.
Platyhystrix rugosus Case.
Chenoprosopus milleri Mehl.
Diadectes (Neothodon) lentus Marsh.
Animasaurus carinatus Case and Williston.
Diasparactus zenos (from Cobre Canyon).
Elcobresaurus baldwini Case.
Arribasaurus (Dimetrodon) navajovicus Case.
Ophiacodon mirus Marsh.
Sphenacodon ferox Marsh.
Edaphosaurus novomexicanus Williston and Case.
Scoliomus puercensis Williston and Case.
Limnoscelis paludis Williston.

Chupadera formation (Permian).—The Chupadera, the upper formation of the Manzano group, named from Chupadera Mesa,[20] in eastern Socorro County, comprises the San Andres limestone above and the Yeso formation below. These divisions are not separable in

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[18] Darton, N. H., Reconnaissance of parts of northwestern New Mexico and northern Arizona: U. S. Geol. Survey Bull. 435, p. 37, 1910.

[19] Williston, S. W., and Case, E. C., The Permo-Carboniferous of northern New Mexico: Jour. Geology, vol. 20, pp. 1-12, 1912. Case, E. C., The Permo-Carboniferous red beds of North America and their vertebrate fauna: Carnegie Inst. Washington Pub. 207, 176 pp., 1915; also Pub. 181, p. 6, 1913.

[20] Darton, N. H., op. cit. (Bull. 726), p. 181.

all localities, however, or at least not at the same plane, and moreover the upper division consists not only of limestone but includes gray sandstone and to the south deposits of gypsum, anhydrite, and salt, which become very thick in the south-central and southeastern parts of the State. The lower division (Yeso) consists mainly of soft red sandstone with gypsum beds. To the north, where the Chupadera formation thins greatly, the anhydrite and salt disappear and gray sandstone predominates. A hard sandstone member prominent in Glorieta Mesa is the principal feature of the formation north of latitude 35°, where it is at or near the base, but it is not certainly represented in the Nacimiento uplift, and it apparently thins out north of latitude 36° in the Sangre de Cristo Mountains. In the Zuni Mountains both the gray sandstone and the massive limestone are present capping the Abo sandstone, and locally some gypsum is included in the lower red sandy members. The upper limestone member, with Manzano fossils, is exposed in the uplift of Ojo Caliente, southwest of Zuni. In Valencia County the formation comprises a thick succession of sandstone, limestone, and gypsum. In the southwestern part of the State the formation is represented in whole or in part by the Gym limestone, which is prominent in the Florida and Victorio Mountains, Cooks Range, and Tres Hermanas. In Figure 3 are given columnar sections showing the stratigraphy of the formation at intervals from west to east and from north to south across New Mexico.

The limestone beds with thick interbedded deposits of gypsum and anhydrite attain a thickness of 2,500 feet in the east slope of the cuesta of the Sacramento Mountains (see pl. 7, *C*), and the thickness is still greater to the south, where the limestone develops into the Delaware Mountain formation and Capitan limestone (Guadalupe group) of Texas.[20a] The thick deposits of gypsum and associated red beds which overlie the Capitan limestone in the Pecos Valley south of Carlsbad in southern New Mexico are the northern extension of the Castile gypsum and Rustler limestone. They also are believed to be of Permian age, but they are not included in the Chupadera formation, as they were not included in the Manzano group as defined by Lee. The Chupadera formation thickens underground in eastern New Mexico, where thick beds of salt and anhydrite develop, as shown by records of numerous drill holes. One of these holes, 3,120 feet deep, 13 miles northeast of Roswell (see log, p. 235), appears to have been in Chupadera beds to 3,025 feet, where probably it entered the Abo sandstone. A boring 5,800 feet deep at Carlsbad in 1925 revealed 2,925 feet of limestone (Chupadera) and 2,000 feet of sandstone believed to be the northeastern extension of

[20a] Darton, N. H., and Reeside, J. B., jr., Guadalupe group: Geol. Soc. America Bull., vol. 37, pp. 413-428, pls. 12-16, 1927.

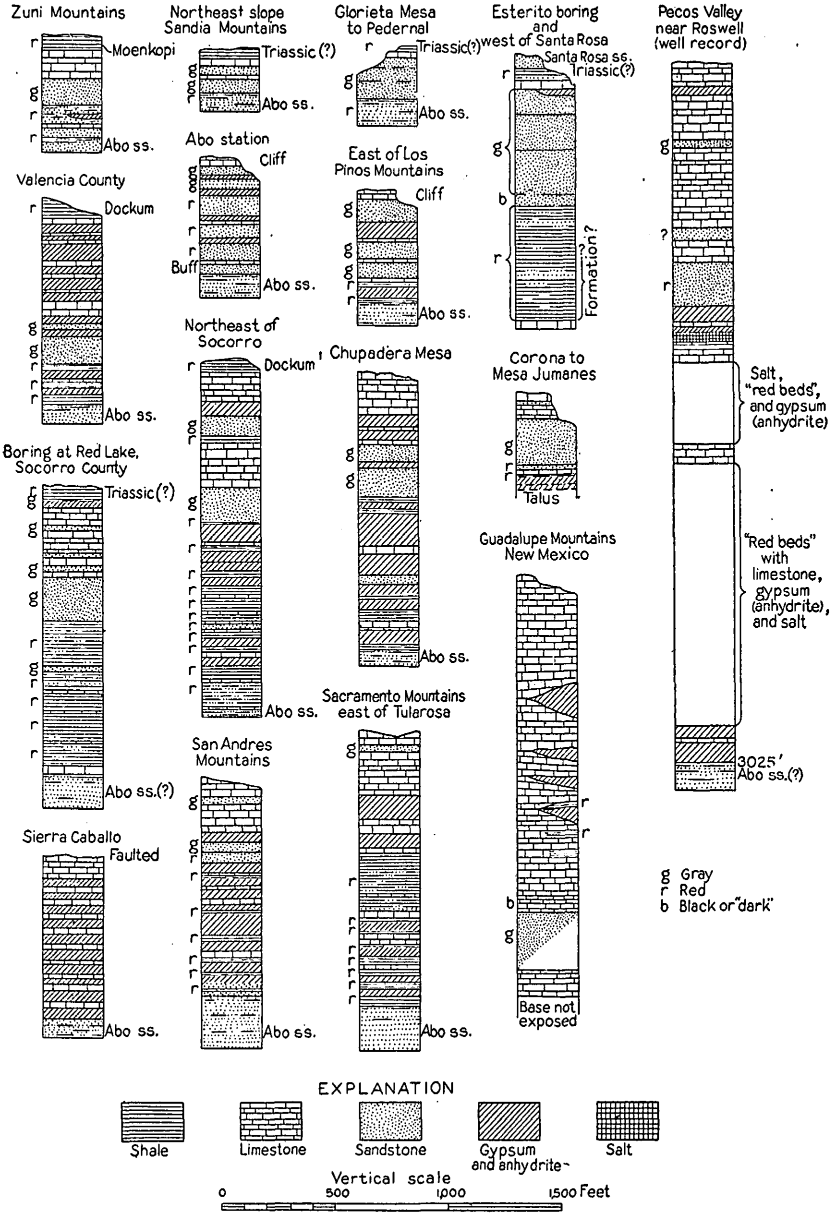


FIGURE 3.—Columnar sections of Chupadera formation

the sandstone of the Delaware Mountain formation with more limestone below. Details regarding the relations of these formations are given on pages 222 to 227.

The sandstone member of the Chupadera formation, which is so prominent in Glorieta Mesa, is bared by the erosion of anticlines west of Santa Rosa, notably in Esterito Butte, and near San Ignacio, and it is extensively exposed along Pecos River in the canyon above Anton Chico. In all these places it is overlain by limestone containing distinctive fossils, which extends north over most of Glorieta Mesa. The thinning of the limestone toward the northwest is visible near Tejon and San Antonito, and this member is absent in the steeply dipping succession west of Las Vegas. The sandstone was not traced far north of Las Vegas and is absent in the region north of Mora. It appears to extend far to the south in central New Mexico, where, however, other similar sandstones are included at various horizons in the formations. The Chupadera formation is well developed along the west slope of the San Andres Mountains (see pl. 7, *B*), in the Lucero anticline 40 miles southwest of Albuquerque, the ridges east of Socorro, the eastern foothills of the Sierra Caballo, the Fra Cristobal Range, the ridge east of Fairview, Jarilla Hills, and several knobs in Tularosa Valley. Some characteristic exposures are shown in Plates 6 and 7. The following sections show the typical succession of Chupadera strata in the San Andres Mountains and the region west of the Rio Grande:

Section of Chupadera formation near Rhodes Canyon, in the central part of the San Andres Mountains

	Feet
Limestone, gray, hard	200
Gypsum	18
Sandstone, buff or red	45
Gypsum with some red sandstone and thin limestones	200
Limestone	20
Gypsum	100
Limestone, gypsum, and red sandstone	45
Gypsum	35
Limestone	18
Red shale and gypsum	70
Buff sandy shale on Abo sandstone	50
	801

Section of Chupadera formation near Santa Rita (Riley post office)

	Feet
Limestone under red shale (Triassic)	25
Gypsum	30
Limestone and gypsum	35
Gypsum	80
Limestone	25
Gypsum	25
Limestone and gypsum	25
Gypsum with thin limestone layers	100
Limestone	60+
Gypsum	30
Sandstone, gray	35+
Gypsum with limestone	20
Sandstone, gray	125+
Sandy shale and sandstone, red, with some gypsum and limestone layers	140+
Red-brown sandstone and shale (Abo sandstone).	

In the northern part of the Nacimiento uplift and the Chama Basin the Chupadera formation is absent unless some of the massive Poleo sandstone capping the red beds of the Abo formation represents a portion of it. A supposed northern extension of the Poleo sandstone, however, is believed from evidence of fossil plants and animals to be of Triassic age, possibly in places lying on a representative of the Moenkopi formation (Lower Triassic). Bones of Permian animals occur in Abo beds a short distance below the Poleo sandstone near Coyote, and remains of Triassic animals have been collected not far above the Poleo sandstone in the same vicinity.

Throughout central and southern New Mexico the limestones of the Chupadera formation carry many fossils of the well-known Manzano fauna described by Girty,[21] originally regarded as late Pennsylvanian but now classed as Permian.[21a] This formation overlies the Abo sandstone, which, as shown above, is of Permian age, and I have traced it continuously southward into the Capitan and Delaware Mountain formations of the Guadalupe Mountains of Texas (see pl. 8, *A*), which are unquestionably Permian.

[21] Lee, W. T., and Girty, G. H., The Manzano group of the Rio Grande Valley, N. Mex.: U. S. Geol. Survey Bull. 389, 1909.

[21a] Lee, W. T., General stratigraphic break between Pennsylvanian and Permian in western America: Geol. Soc. America Bull., vol. 28, pp. 169–170, 1917; Notes on Manzano group: Am. Jour. Sci., 5th ser. vol. 4, p. 325, 1920, in which he refers to "a definite decision of the United States Geological Survey approving N. H. Darton's reference of the Manzano group to the Permian in a report on the Red Beds now in preparation."

Among the more distinctive molluscan species collected from the limestones of the Chupadera formation are the following, according to determinations by Girty:

Lophophyllum sp.
Echinocrinus sp.
Stenopora sp.
Derbya sp.
Chonetes aff. C. geinitzianus.
Productus ivesi.
Productus leei?
Productus mexicanus?
Productus occidentalis.
Pustula subhorrida?
Marginifera cristobalensis.
Marginifera manzanica.
Pugnax osagensis var. pusilla.
Composita subtilita.
Composita mexicana.
Nucula levatiformis.
Euphemus subpapillosus.
Manzanella elliptica.
Aviculipecten aff. A. vanvleeti.
Acanthopecten carboniferus?
Modiola sp.
Myalina aff. M. meliniformis.
Myalina aff. M. perniformis.
Pleurophorella gilberti?
Cleidophorus aff. C. pallasi.
Pleurophorus mexicanus?
Pleurophorus aff. P. occidentalis.
Schizodus wheeleri?
Bucanopsis modesta.
Sedgwickia sp.
Plagioglypta canna.
Bellerophon majusculus.
Pleurotomaria sp.
Murchisonia aff. M. terebra.
Euomphalus n. sp.
Naticopsis deformis?
Orthoceras sp.
Coloceras globulare?
Metacoceras aff. M. inconspicuum.
Domatoceras highlandense?
Nautilus sp.
Anisopyge inornata.
Griffithides sp.

But few of these are known to occur in the Guadalupian fauna, which comprises more than 300 species,[22] a fact which Girty and Richardson ascribe to differences in local life conditions in the areas of pure limestone deposition near the Texas-New Mexico line and in the wide area of limestone, gypsum, and red-bed deposition represented by the Chupadera formation in central-southern and central New Mexico.

Case [23] discovered bones of Permian age in conglomerate 8 miles northeast of Socorro (shown in pl. 9, *B*), but this deposit may be Triassic or younger, the bones having been derived by erosion from underlying upper members of the Chupadera formation. These remains, which are described more in detail on page 71, comprise representatives of *Eryops*, *Sphenacodon*, and possibly other genera.

Gym limestone (Permian).—The Chupadera formation is represented in southwestern New Mexico by the Gym limestone, a light-gray massive limestone, which crops out extensively in the Florida Mountains, the type locality, in the Victorio Mountains, and in the Tres Hermanas and some small buttes in the southern part of Luna County. In the Florida Mountains it lies unconformably on formations from the El Paso to the Fusselman, for the Percha shale,

[22] For list see Girty, G. H., The Guadalupian fauna: U. S. Geol. Survey Prof. Paper 58, pp. 51-55, 1908.
[23] Case, E. C., Further evidence bearing on the age of the red beds in the Rio Grande valley: Science, new ser., vol. 44, p. 709, 1916.

Lake Valley limestone, and limestones of the Magdalena group are absent. In the Cooks Range about 50 feet of Gym limestone lies in part on Lake Valley limestone and in part on shale of Magdalena age. In the Tres Hermanas the formation is uplifted and much altered by porphyry and includes 50 to 60 feet of gray to reddish quartzite. In the Florida Mountains the Gym limestone is about 1,000 feet thick, but, as shown in the sections of Figure 160, it is greatly faulted and the uppermost beds have been removed by erosion. In the Silver City-Hanover district and in Grant County the Permian strata are absent and strata of Lower Cretaceous age lie directly on Pennsylvanian limestone. It is not unlikely that the Gym limestone was deposited in that region and was removed by erosion in Triassic or Jurassic time. It appears to be represented in the upper part of the Naco limestone of southeastern Arizona.

Fossils collected at several horizons in the Gym limestone, mostly in the Florida Mountains, have been determined as follows by G. H. Girty:

Echinocrinus ornatus.
Meekella mexicana?
Chonetes platynotus?
Productus semireticulatus.
Productus occidentalis.
Productus cora.
Marginifera splendens?
Pugnax utah.
Squamularia perplexa.
Composita subtilita.
Composita mexicana?
Nucula levatiformis.
Nucula levatiformis var. obliqua.
Manzanella elliptica.
Parallelodon politum?
Pinna peracuta.
Monopteria marian?
Plagioglypta canna?
Bellerophon crassus.
Bellerophon majusculus?
Bucanopsis modesta.
Pleurotomaria texana.
Rhynchomphalus obtusispira.
Euomphalus aff. E. pernodosus.
Orthonema socorroense?
Sphaerodoma aff. S. humilis.
Sphaerodoma aff. S. primigenia.
Bulimorpha inornata.

In the Victorio Mountains the Gym limestone yielded the following fossils:

Solenomya? sp.
Nucula levatiformis var. obliqua.
Manzanella elliptica.
Edmondia sp.
Monopteria marian?
Myalina sp.
Schizodus sp.
Pleurophorus sp.
Astartella n. sp.
Plagioglypta canna?
Murchisonia n. sp.
Euomphalus? sp.
Cyclonema? sp.
Sphaerodoma? aff. S. fusiformis.

Castile gypsum and Rustler limestone.—The two formations defined by Richardson[24] as the Castile gypsum and Rustler limestone extend northward from the type locality in Texas into Eddy County, N. Mex., and pass under the overlap of the Dockum group toward the east. The gypsum is extensively exposed in places, notably

[24] Richardson, G. B., Report of a reconnaissance in trans-Pecos Texas north of the Texas & Pacific Railway: Texas Univ. Min. Survey Bull. 9, pp. 43-45, 1904.

along the valley of Black River, along Pecos River (see pl. 8, *B*), and near Carlsbad, and the deep boring (see pl. 53) 8 miles east of Carlsbad revealed alternations of anhydrite and salt[25] which began under red shale at a depth of 300 feet and continued considerably below 2,380 feet, showing a thickness of more than 2,100 feet, presumably all Castile.

Limestone and red shale that extend into Eddy County near Red Bluff and cap the gypsum there and at intervals to the north and northeast are an extension of the Rustler limestone. (See pl. 8, *B*.)

As neither the Castile nor the Rustler formation was studied in detail, no definite statements can be made in regard to their distribution, character, and relations. The formations have been provisionally assigned to the Permian because they lie in apparent conformable succession on the Guadalupian rocks in New Mexico, although in northwestern Texas the Castile lies unconformably on the upper limestone of the Delaware Mountain formation. A few fossils obtained from the Rustler limestone are not decisive as to age. There is a general overlap of Dockum beds to the northeast. It is possible that these formations represent the Lower Triassic Moenkopi formation, but it is much more likely that they represent the western extension of the Blaine gypsum of north-central Texas and Oklahoma.

TRIASSIC SYSTEM

General relations.—Triassic rocks occupy a large proportion of New Mexico, but they have been extensively removed by post-Cretaceous erosion in the central part of the State, notably in the wide cuestas and plateaus of the Chupadera formation. They are absent in the southwestern part of the State, owing either to nondeposition or to removal by erosion in late Triassic or Jurassic time, but it is possible that a portion of the Triassic period is represented by the Lobo formation in Luna County. In most areas west of the Rio Grande in central New Mexico, especially in the Zuni Mountain uplift, three Triassic formations are recognized—the Moenkopi formation (Lower Triassic) at the base, the Shinarump conglomerate (Upper? Triassic) in the middle, and the Chinle formation (Upper Triassic) at the top—but the recognition of these divisions to the east has not been satisfactory so far. East of the Rio Grande the Chinle formation (Upper Triassic) is represented in the Dockum group, which occupies most of the eastern third of the State. Near or at its base is a conspicuous sandstone which I have named the Santa Rosa sandstone[26] and which crops out across the eastern part of the State and may possibly be an eastern extension of the Shinarump conglomerate. In the Nacimiento uplift and Chama Basin a local

[25] Darton, N. H., Permian salt deposits of the south-central United States: U. S. Geol. Survey Bull. 715, p. 221, 1921.
[26] Darton, N. H., op. cit. (Bull. 726), p. 183.

sandstone, the Poleo,[27] occupies approximately the same horizon as the Shinarump, but it appears to lie directly on the Abo sandstone. A portion of it, if not all, however, strongly suggests the sandstone of Glorieta Mesa, which is the basal member of the Chupadera formation in that region, but apparently it is the formation that contains Triassic plants at the old Cobre copper mine, near Abiquiu, and bones of Triassic animals have been collected just above it near Coyote. In some places the upper part of the Chupadera formation includes red beds that contain bones of Permian animals, but the great mass of overlying red beds is of Triassic age. The extent to which the Moenkopi formation, or Lower Triassic, is represented east of the Rio Grande is not yet ascertained. Although the red rocks of the Pecos Valley in southern New Mexico are probably of Permian age, it is possible that strata of Lower Triassic age are also present. The overlap of the western edge of the Dockum group is now believed to be marked by the sandstone outcrop which extends along the foot of the western slope of the escarpment of the Llano Estacado, crosses the Pecos Valley near latitude 34°, and extends northwestward to the western margin of Guadalupe County. The southern limit of the Triassic rocks in south-central New Mexico is not known; they have been traced southward nearly to Tularosa but are absent under the Cretaceous rocks in exposures 10 miles north of Organ.

Most of the evidence as to the age of the Triassic rocks in New Mexico is derived from the occurrence of fossil bones. The western extension of the Moenkopi formation in Arizona and Utah has yielded characteristic molluscan remains of Lower Triassic age. In the Zuni uplift a few fossil plants were found by Newberry and some bones were collected by Cope; these are of Triassic age, but they came from the Chinle horizon. The Poleo sandstone and associated strata in the Chama Basin yielded Triassic plants and bone fragments. Bones of Triassic animals have been collected by Case[28] and others in various parts of the Dockum group in eastern New Mexico, and in red beds of Chinle character and position near Carthage.[29] A few unios and other shells have been collected from the Dockum group at several localities. The Santa Rosa sandstone has yielded a few fragments of bones believed to be of Triassic age.[28] In the "Gallina Mountains," presumably near Gallina, N. Mex., Cope[30] collected teeth and bones which he identified as *Laelaps*, *Palaeoctonus*, a crocodile, *Typothorax coccinarium*, and five species of *Unio*.

[27] Huene, F. von, Kurze Mitteilung über Perm, Trias, und Jura in New Mexico: Neues Jahrb., Beilage-Band 32, p. 736, 1911.

[28] Case, E. C., The red beds between Wichita Falls, Tex., and Las Vegas, N. Mex., in relation to their vertebrate fauna: Jour. Geology, vol. 22, pp. 243-259, 1914.

[29] Case, E. C., personal letter; also Science, new ser., vol. 44, pp. 708-709, 1916.

[30] Cope, E. D., The geology of New Mexico: Acad. Nat. Sci. Philadelphia Proc., 1875, p. 265.

Moenkopi formation.—The lowest formation of the Triassic system in the Colorado Plateau province extends eastward for some distance into western New Mexico, but its eastern limits and representatives have not been recognized. The formation is well exhibited in the Zuni uplift, where it crops out along the lower slopes on all sides of the Zuni Mountains, except to the east, where lava covers a wide area. On the south slope north of Ramah the formation extends far up the flanks of the southern limestone ridge. Here the thickness is about 1,000 feet, but along the north slope of the mountains it appears to be somewhat less. The formation is also exposed in the uplift at Ojo Caliente, overlain by Shinarump conglomerate. The rocks consist mainly of shale of maroon, dark purplish-red, and chocolate-brown colors, alternating with dark ash-gray or lavender. At the base, especially to the east in the Bluewater region, is a thin mass of brown-red conglomeratic sandstone overlying the top limestone of the Chupadera formation. This is overlain by about 500 feet of soft shale of gray, buff, reddish, and purplish tints containing beds of sandstone from a few inches to several feet thick. This sandstone is mostly red in the lower beds, but higher beds are of lighter color and largely cross-bedded. A peculiar limestone conglomerate about 3 feet thick occurs in the shale about 50 feet above the base and is traceable from a point near Bluewater to a point beyond Fort Wingate. The strata vary in character from place to place, especially in the color of the shale and the thickness and character of the included sandstones. In many exposures to the west there is a basal shale of dark-red, maroon, and purple colors. The exposures south of Guam have at the base from 30 to 40 feet of gray sandstone, followed by 50 to 70 feet of red shale, 30 feet of the peculiar conglomerate with limestone pebbles, and 120 feet of maroon to gray massive shale with three gray sandstone members in its upper half.

Red shale similar to that of the Moenkopi formation appears extensively in the uplift zone extending through Lucero Mesa and reaching the Rio Salado valley near Puertecito. As the Shinarump conglomerate does not show its characteristic features in this area and as no paleontologic evidence has been obtained, the classification and the limits of the Moenkopi strata are uncertain, but the formation may have a thickness of 400 feet or more.

Shinarump conglomerate.—The Shinarump conglomerate crops out along the north and west sides of the Zuni uplift, where however, most of the rock is light-colored sandstone, from 30 to 100 feet thick, constituting the crest and upper slope of a hogback ridge of considerable prominence. It also appears in the uplift at Ojo Caliente, where much of the material is conglomeratic. Coarse sandstone in the middle of the "Red Beds" succession in the Lucero uplift strongly suggests the Shinarump conglomerate in character and position, but its equivalence is not positively determined. The Shinarump may also be present in some of the uplifts in the central part of the State and probably is represented by the Poleo sandstone in the Nacimiento uplift and Chama Basin and by the Santa Rosa sandstone in eastern New Mexico.

Poleo sandstone.—The bed of massive sandstone extending along the Nacimiento uplift and extensively exposed in the Chama Basin has been classed as Triassic by Huene[31] and Case.[32] It constitutes the Poleo Mesa, north of Coyote, and the west rim of the Cobre Basin, northwest of Abiquiu. At the latter place it appears to be the bed from which plant remains identified by Newberry and Knowlton[33] were obtained. At this place and throughout the northern part of the Nacimiento uplift, it lies on red slabby sandstone believed to be the Abo sandstone, the Moenkopi and Chupadera formations being absent. The formation strongly resembles the basal sandstone of the Chupadera formation constituting Glorieta Mesa and the Coconino sandstone of Arizona, but the paleontologic evidence appears to indicate Triassic age. It is probable, however, that both Poleo and Chupadera sandstones are present in the southern part of the Nacimiento uplift.

Chinle formation.—The upper red shale of Triassic age in the Zuni uplift is undoubtedly an extension of the Chinle formation of eastern Arizona. The Atchison, Topeka & Santa Fe Railway follows a valley excavated in the shale of this formation from a point west of Bluewater to and beyond Wingate, and the outcrop extends just north of Ramah and makes the valley between Inscription Rock and Tinajas. It also appears extensively in the valley of Zuni River between Zuni and Ojo Caliente and southward from Ojo Caliente to Atarque. Its thickness averages about 850 feet, but precise measurements are difficult to make on account of the softness of the beds. The principal material is red shale, but a few thin beds of purplish-brown slabby sandstone are included, and in places at the top there is a member of purple to gray calcareous pebbly sandstone and sandy shale, with scattered bone fragments. Rocks of this same character appear extensively in the Lucero uplift, in which they reach the valley of the Rio Salado at Puertecito. They are also present, overlying the Poleo sandstone, along the west side of the Nacimiento uplift and throughout the Chama Basin from the mouth of the Rio Cebolla nearly to Abiquiu. Presumably the red shale overlying the Chupadera formation in the northern part of the Sandia uplift and in the ridges east of Socorro is an extension of the same formation.

[31] Huene, F. von, op. cit., p. 737.

[32] Williston, S. W., and Case, E. C., The Permo-Carboniferous of northern New Mexico: Jour. Geology, vol. 20, pp. 8-11, 1912; Permo-Carboniferous vertebrates from New Mexico: Carnegie Inst. Pub. 181, 81 pp., 1913.

[33] Fontaine, W. M., and Knowlton, F. H., Notes on Triassic plants from New Mexico: U. S. Nat. Mus. Proc., vol. 13, pp. 281-285, pls. 22-26, 1890.

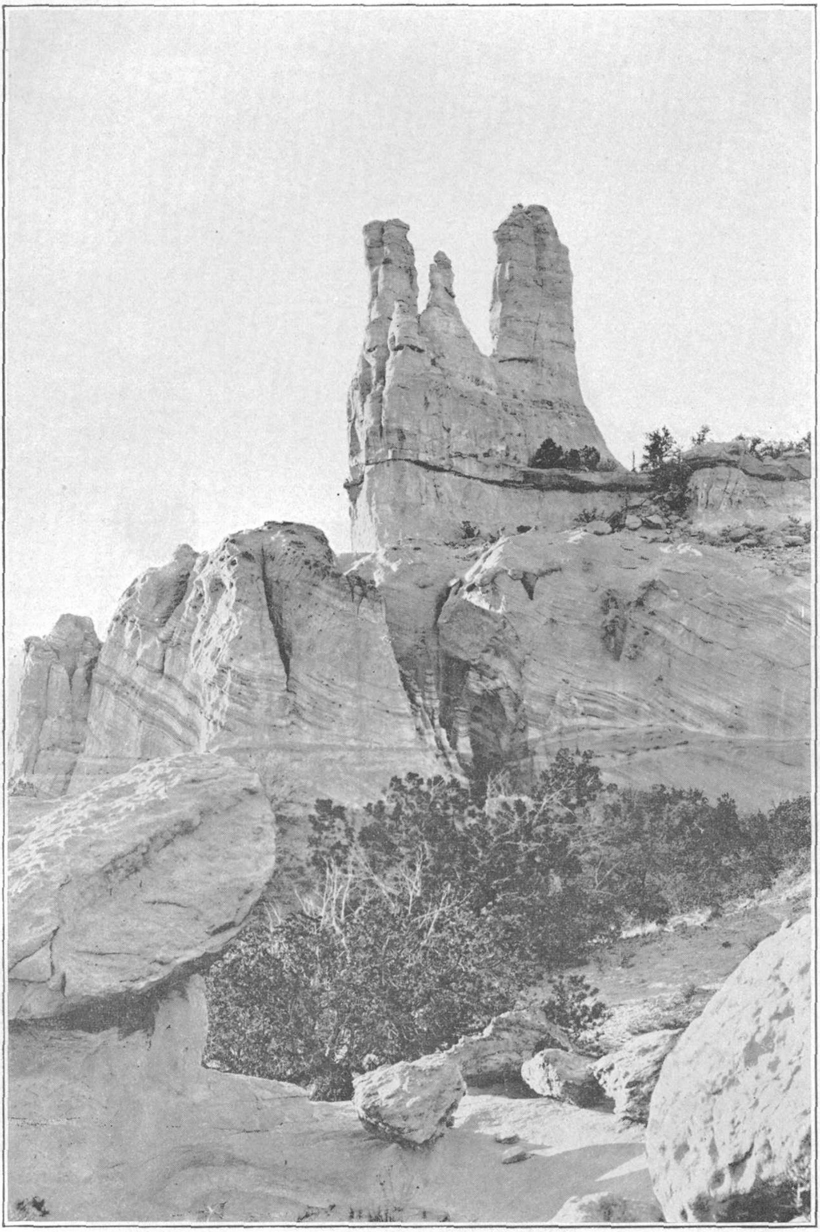
Farther east it is represented in the Dockum group, but the limits of its representatives in that group have not been ascertained.

Dockum group.—Most of northeastern New Mexico east of the Rocky Mountain front ridge and all of southeastern New Mexico east of Pecos River is underlain by a thick succession of red beds which are continuous with the Dockum group of western Texas and Oklahoma. The maximum thickness is about 1,000 feet. Although red shale and red sandstone predominate, some of the rocks are gray to brown. Near the base of the group in the northern part of the area is a prominent dark-gray sandstone, the Santa Rosa sandstone, about 100 feet thick, which has considerable prominence in the topography of that area. It is underlain by red shale, which lies on the top limestone member of the Chupadera formation and attains a thickness of 200 feet northwest of Santa Rosa. This shale thins toward the south and apparently disappears near latitude 34° 30′, south of which the supposed southern extension of the Santa Rosa sandstone constitutes the base of the group. The rocks of the Dockum group are, however, mostly covered by sand in Chaves, Eddy, and Lee Counties, where outcrops are widely scattered. In the Santa Rosa region and northward the strata above the Santa Rosa sandstone consist of red shale and a succession of red, brown, and gray sandstones having in all a thickness of about 500 feet. These rocks are extensively exposed along Concho and Canadian Rivers (see pl. 58), north of which they are overlain by the Wingate sandstone. The stratigraphy has not been fully determined, and the beds change in character from place to place in the area. Farther south the upper strata are covered by the sand and gravel of the Llano Estacado.

Fossil bones obtained by Case [34] and others in the Dockum group at several localities in eastern New Mexico, mainly in the vicinity of the Canadian and Concho Valleys, and collected by Case [35] in red beds of Chinle character and position near Carthage are regarded by Case [35a] as Upper Triassic. A few fresh-water shells have also been collected, notably at a locality a few miles north of Santa Rosa, and Lee [36] found similar remains on the Rio Concho at a point 30 miles southeast of Las Vegas.

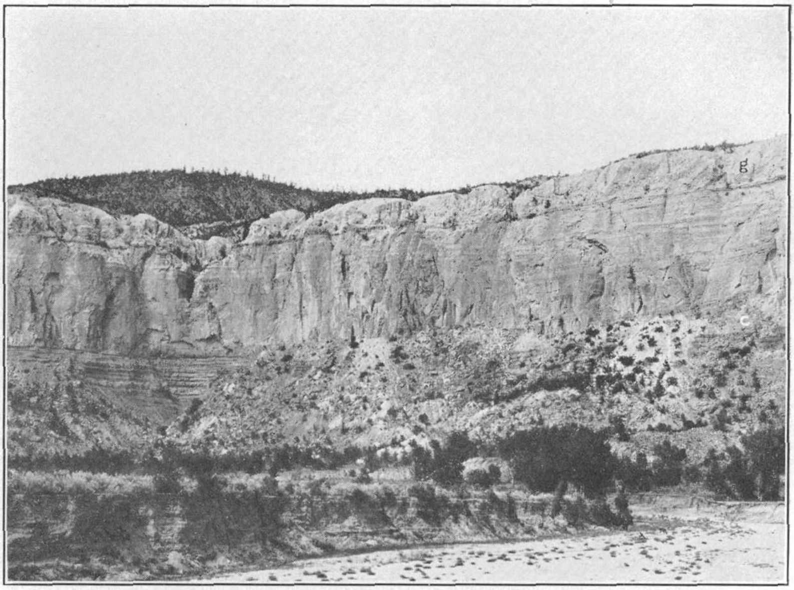
Lobo formation (Triassic?).—Some red strata in Luna County have been separated as the Lobo formation and tentatively classed as Triassic (?) on account of their character and their position between the Gym limestone (Permian) and the Sarten sandstone (Lower Cretaceous). The formation occurs mostly in the Florida Mountains and southern spurs and outliers of the Cooks Range.

[34] Case, E. C., Jour. Geology, vol. 22, pp. 257–258, 1914.
[35] Case, E. C., Science, new ser., vol. 44, pp. 708–709, 1916.
[35a] Case, E. C., personal letter, June 23, 1927.
[36] Lee, W. T., Note on the red beds of the Rio Grande region in central New Mexico: Jour. Geology, vol. 15, pp. 55–56, 1907.



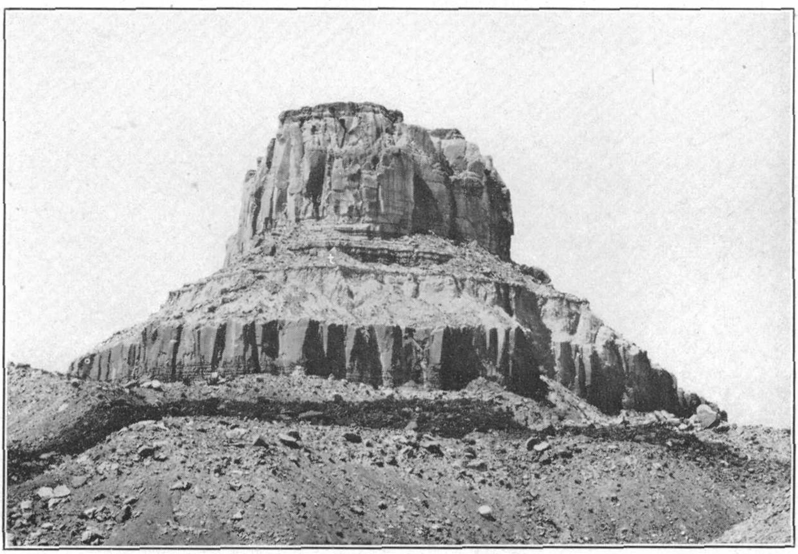
NAVAJO CHURCH, NORTH OF WINGATE

An erosion feature in Navajo sandstone



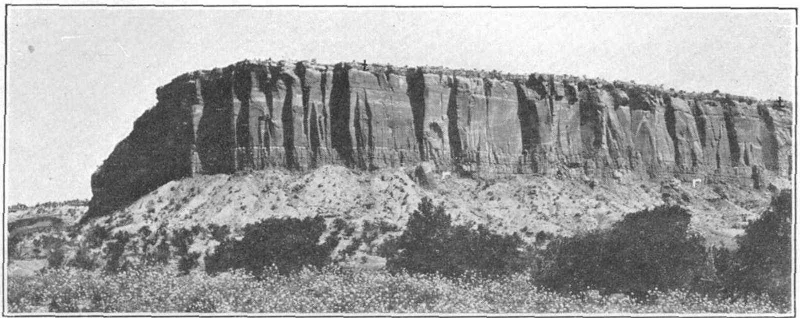
A. WINGATE SANDSTONE, GYPSUM MEMBER OF TODILTO FORMATION, AND ASSOCIATED ROCKS, NORTH WALL OF VALLEY OF GALLINA RIVER 2 MILES ABOVE ITS MOUTH, RIO ARRIBA COUNTY

Looking northwest. c, Contact of Wingate sandstone on red shale (Chinle?); g, gypsum. Plateau in distance capped by Dakota sandstone



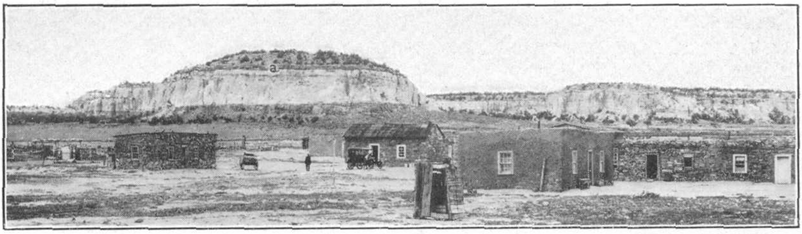
B. PETOCH BUTTE, AN OUTLIER OF THE HIGH MESA 14 MILES SOUTHWEST OF LAGUNA

Looking west. Cap, Dakota sandstone; upper cliff, Navajo sandstone to ledges of Todilto limestone at t; white slope and red cliff next below, Wingate sandstone; slopes to base, Chinle red shale



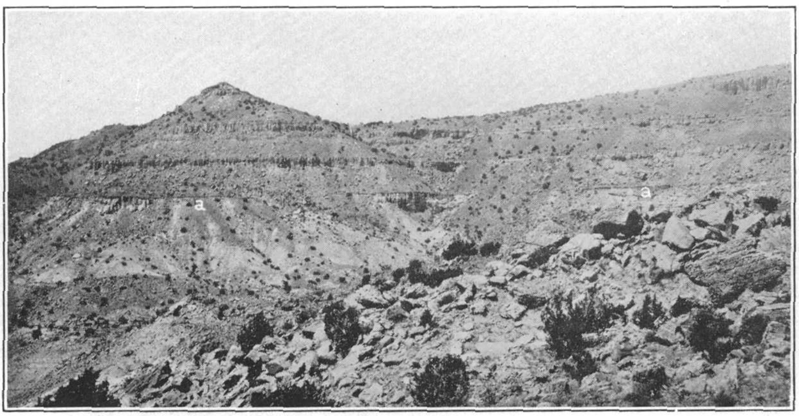
A. RED CLIFF OF WINGATE SANDSTONE NEAR CONTINENTAL DIVIDE NORTH OF THOREAU

Looking north. t, Cap of Todilto limestone; r contact of Chinle red shale



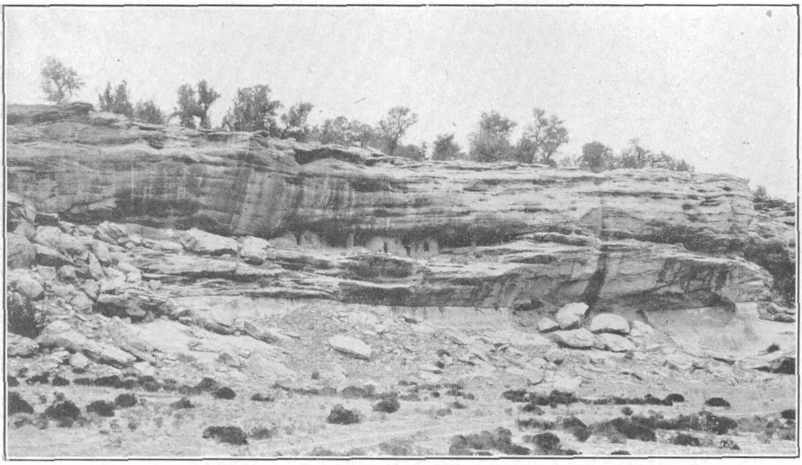
B. NAVAJO SANDSTONE CAPPED BY DAKOTA SANDSTONE (a), HALF A MILE NORTH OF GARCIA'S RANCH, ATARQUE, VALENCIA COUNTY

Looking north. Wingate sandstone underlies the Navajo sandstone. The butte is just east of a fault



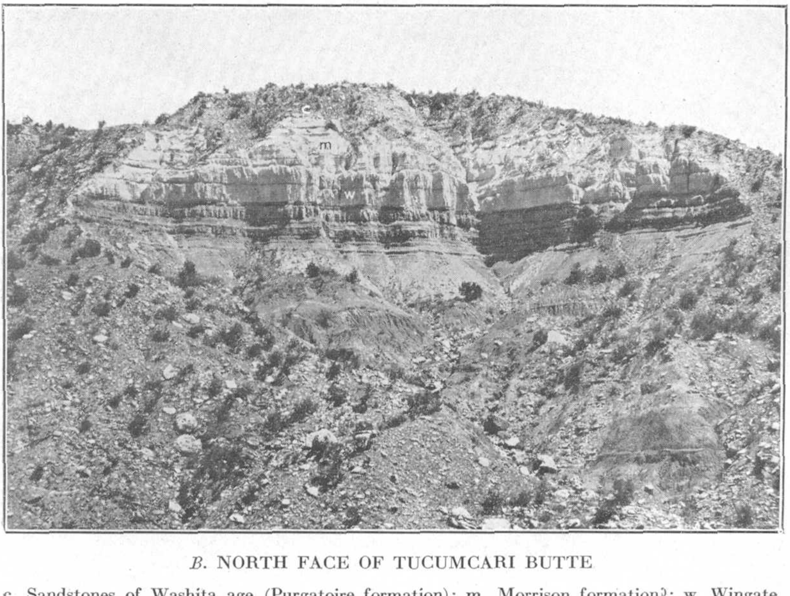
C. MORRISON SHALE OVERLAIN BY DAKOTA SANDSTONE AND HIGHER CRETACEOUS SHALES AND SANDSTONES IN BLUFF EAST OF LAGUNA

a, Contact between Morrison shale and Dakota sandstone



A. DAKOTA SANDSTONE LYING UNCONFORMABLY ON NAVAJO SANDSTONE IN CANYON 1 MILE SOUTHEAST OF RAMAH

Looking north. Cliff dwellings in middle of Dakota ledge



B. NORTH FACE OF TUCUMCARI BUTTE

c, Sandstones of Washita age (Purgatoire formation); m, Morrison formation?; w, Wingate sandstone on red shale of Dockum group. The summit, not shown in the view, is capped by Dakota sandstone, sand, and caliche

The rocks are mainly reddish and gray shale and gray to pinkish impure limestone, but considerable conglomerate is present in the basal strata. In an exposure in the north end of the Florida Mountains 318 feet of beds lie across a fault, which, as shown in section A, Figure 160, lifts granite into juxtaposition with the Montoya and El Paso limestones. At the type locality in Lobo Draw in the Florida Mountains, the formation consists largely of buff and red shale and massive very fine grained sandstone and limestone. (See section, p. 337.) In the Cooks Range, where the greatest thickness is about 100 feet, the reddish-brown sandstone, shale, and conglomerate lie unconformably on the Gym limestone. At one place the top member is 50 feet of conglomerate with a limestone matrix. In the Victorio Mountains the Gym limestone is overlain unconformably by about 700 feet of shale and sandstone, largely reddish, which resemble the Lobo formation but may be Cretaceous or Tertiary. The Tertiary assignment is suggested by the presence of andesite boulders in the basal conglomerate.

As no fossils were found in the Lobo formation, its age is not determined. In the central part of the Cooks Range it lies unconformably on the Gym limestone, of Permian age, and is also separated from the overlying Sarten sandstone (Lower Cretaceous) by an unconformity; hence its age may be Permian, Triassic, or even earliest Cretaceous. Because of its unconformable relations with the overlying and underlying formations, however, the Lobo is tentatively classified as Triassic (?).

JURASSIC (?) SYSTEM

Wingate sandstone.—The outcrop of the Wingate sandstone extends into the western margin of New Mexico in the Zuni region, and the formation is extensively exhibited in the Zuni uplift. It also is conspicuous in the Nacimiento uplift and the Chama Valley, in the Cobre uplift, in the Lucero anticline, on the east side and at the north end of the Sandia uplift, in the monoclinal ridge west of Cerrillos, in the east front of the Rocky Mountain uplift in the Las Vegas region, and thence continuously southward to and along the southern front of the Canadian Escarpment to the vicinity of longitude 103° 30′, where it thins out. It is present in the outliers of the Canadian Escarpment south and west of Tucumcari, including Cuervo Hill and Mesa Rica, but appears to be absent in the canyon of the Cimarron in Union County. In all the exposures it is a massive, compact, but only moderately hard pale-red to buff sandstone, generally giving rise to a prominent cliff in which the entire thickness of the formation is exhibited. (See pls. 11, 12, *A*, 28, 35, *A*, and 38.) In a large part of the area the upper portion of the sandstone is white, buff, or yellowish. It is conformably capped by the Todilto limestone

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throughout nearly its entire area of outcrop. The lower contact, on the red shale of the Chinle formation or Dockum group, is very abrupt, owing mainly to difference in the character of the materials, but it shows very little evidence of channeling or coarse deposits, and there is no notable difference in attitude. In the northeastern part of the State the Wingate lies on a thick succession of Dockum strata. The thickness of the Wingate sandstone is about 300 feet at the maximum north of Thoreau, but 150 feet in most other portions of the Zuni uplift and in the Nacimiento and Lucero uplifts, 80 feet in the Canadian Escarpment, and still less in the vicinity of Tucumcari, and the sandstone thins out rather abruptly east of Ute Creek and in the northern edge of the Great Plains. It also thins out rapidly in the southern part of Valencia County near longitude 107° 30′. No fossils have been found in the Wingate sandstone, and it was regarded as Triassic by Newberry,[37] Gilbert,[38] Howell,[39] Dutton,[40] and Darton.[41] Later it was thought to be an extension of the lower part of the La Plata sandstone and was classed as Jurassic,[42] but still later observations by Paige,[43] Lee,[44] and others appear to show that it is older than the La Plata of Cross.

Todilto formation.—The thin-bedded limestone that caps the Wingate sandstone in most of northeastern Arizona has been traced southward from its type locality in Todilto Park,[45] in western New Mexico, and found to be present in the north slopes of the Zuni and Lucero uplifts, near Suwanee and Acoma, throughout the Nacimiento uplift, the Chama Basin, and the northern part of the Sandia uplift, in the Cerrillos Basin, near Lamy, and in the Las Vegas region, and it extends along the southern front of the Canadian Escarpment eastward nearly to longitude 104°, not quite as far east as the underlying Wingate sandstone. The southern margin of the limestone is a few miles south of Acoma. Its northern limit has not been ascertained, but the formation is not present in Mora and Colfax Counties. It appears to thin out northwest of Tucumcari but is well exhibited in Cuervo Hill, 18 miles northeast of Santa Rosa. The maximum thickness ordinarily is not more than 10 feet, and the limestone is in thin layers. Locally it becomes sandy, and at a point 20 miles south of Grant it may be represented by white conglomerate at the base of the Navajo sandstone.

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37 Newberry, J. S., Report upon the Colorado River of the West explored in 1858–59, by Lieut. J. C. Ives, pt. 3, p. 89, 1861.

38 Gilbert, G. K., U. S. Geol. Surveys W. 100th Mer. Rept., vol. 3, pp. 551–553, 1875.

39 Howell, E. E., idem, p. 290.

40 Dutton, C. E., Mount Taylor and the Zuni Plateau: U. S. Geol. Survey Sixth Ann. Rept., pp. 135 et seq., 1885.

41 Darton, N. H., op. cit. (Bull. 435), pp. 45–53.

42 Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, pp. 52–55, 1917.

43 Paige, Sidney, communication to section E, Am. Assoc. Adv. Sci., December, 1924.

44 Lee, W. T., personal communication.

45 Gregory, H. E., op. cit., p. 55.

In the Nacimiento and Sandia uplifts, the northern part of the Lucero uplift, and the Cerrillos Basin the limestone is overlain by a bed of pure-white gypsum, which attains a thickness of 60 feet and which is regarded as a local upper member of the Todilto formation. This gypsum is conspicuous in cliffs along the Santa Fe Railway near El Rito, a few miles east of Laguna, as shown in Plate 27, and also at a point halfway between Domingo and Cerrillos (pl. 9, *C*), and throughout the Nacimiento uplift and Chama Basin (pls. 11, *A*, 36, and 38). No fossils have been found in the limestone or gypsum in New Mexico, but the formation is believed to be an eastern extension of Jurassic strata of southern Utah. Limestones in the same general succession in that State contain abundant Jurassic fauna, but apparently they are at a much higher horizon than that of the Todilto.

Navajo sandstone.—In the portion of New Mexico west of longitude 107° the Todilto formation is overlain by a thick bed of sandstone, in part white or gray and in part red, that is believed to be a southern extension of the basal part of the La Plata sandstone (Jurassic) of southwestern Colorado. It is extensively exposed in the vicinity of Zuni and in the Zuni uplift, and its outcrop extends eastward to the eastern slope of the Lucero anticline west of Rio Puerco station. To the south it thins out at a point about 15 miles south of Acoma. In parts of the Nacimiento uplift and Chama Basin it may possibly be represented by sandstone overlying the gypsum member of the Todilto formation, but this sandstone more probably is a sandy portion of the Morrison formation. The thickness of the Navajo sandstone is about 400 feet at the west but not more than half this amount at the east and south. The formation reaches the surface on the west side of the Zuni Basin, where it crops out in high cliffs that extend from a point near Manuelito past Zuni to Atarque (pl. 12, *B*), where the formation is cut off by a fault and a wide lava flow. It appears extensively in the cliffs south of Grant and about Acoma and Laguna, where the thickness is 150 to 200 feet and the rock is a massive fine-grained gray sandstone of moderate hardness. At Rito siding there is a red lower member and a massive gray upper member. Some characteristic outcrops are shown in Plates 12, 29, 31, 34, *C*, and 35, *A*, *C*.

COMPARISON OF "RED BEDS" OF NEW MEXICO WITH THOSE OF SOUTHERN COLORADO

Very little evidence has been obtained as to the existence of Permian strata along the east slope of the Rocky Mountain Front Range in Colorado. Carboniferous limestone and sandstone with Mississippian and Pennsylvanian fossils are present in places, and the red beds between these strata and the Morrison formation probably contain representatives of the Permian series and the

Triassic and Jurassic systems. I have correlated some of these formations with stratigraphic units defined by me[45a] and others in Wyoming and the Black Hills, but with considerable uncertainty as to their ages.

One of the most notable sections lies west of Colorado Springs, where the Millsap limestone, of Mississippian age, is overlain by the Fountain formation, classed as Pennsylvanian, and the Lykins formation (Triassic? and probably Permian), which extend to the unconformity at the base of the Morrison.[45b] The medial and lower portions of the Fountain formation contain Pennsylvanian fossils, but in places in the lower part of the upper member of massive red sandstone 800 feet thick, which makes the Gateway of the Garden of the Gods, there is conglomerate carrying pre- ambrian crystalline rocks and pebbles from the underlying red beds. This member is strongly suggestive of a northern extensio : of the Abo sandstone, and the overlying striped red and gray softer sandstone and 150 feet of "creamy-white" sandstone at the top of the formation resemble Chupadera and Coconino deposits. This light sandstone is also like the Wingate sandstone (Jurassic?) in northern New Mexico.

The Lykins formation, next above, is a thin-bedded red sandstone and shale with a thick be of gypsum at its top; in all, less than 200 feet thick. The shale contains thin-bedded limestones suggesting the Todilto, from a southern point of view, or perhaps part of the Chugwater formation (Triassic and Permian) of Wyoming, with which I correlated it in previous years. The thick bed of gypsum, although local, is strongly suggestive of the similar bed constituting the upper part of the Todilto formation in New Mexico, as indicated by Lee,[45c] quoting from the manuscript of this report. It may also be noted that the limestone, shale, and gypsum succession at Colorado Springs is paralleled by the Chupadera succession in central New Mexico and southward, which would also be in regular order overlying Abo sandstone if that is represented by the upper part of the Fountain formation. However, it seems more likely that strata of Chupadera, Moenkopi, and Navajo-Wingate (Jurassic) age are absent in this section, because they thin out in northern New Mexico. Lee[45d] has suggested that the Sundance formation (marine Jurassic) from the north may also be represented at this horizon by nonmarine beds, in which case the gypsum may be the product of a succeeding epoch of

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[45a] Darton, N. H., Comparison of the stratigraphy of the Black Hills, Bighorn Mountain, and Rocky Mountain Front Range: Geol. Soc. America Bull., vol. 15, pp. 379–448, 1903; Geology and underground waters of the Arkansas Valley in eastern Colorado: U. S. Geol. Survey Prof. Paper 52, 1906.

[45b] Finlay, G. I., U. S. Geol. Survey Geol. Atlas, Colorado Springs folio (No. 203). He regarded the upper beds of the Fountain formation as Lyons sandstone, but Lee states that this sandstone does not extend so far south. (Lee, W. T., Correlation of geologic formations between east central Colorado, central Wyoming, and southern Montana U. S. Geol. Survey Prof. Paper 149, pl. 1, 1927.)

[45c] Lee, W. T., Early Mesozoic physiography of the southern Rocky Mountains: Smithsonian Misc. Coll., vol. 69, pp. 20, 22, 1918.

[45d] Lee, W. T., Type section of the Morrison formation: Am. Jour. Sci., 4th ser., vol. 49, pp. 183–188, 1920.

marine incursion, doubtless Todilto. The Dockum group may also be present at this horizon or lower, for in the basin of Purgatoire River farther east I found a bone of a bolodont (Upper Triassic) in red beds under a thick bed of gypsum.[45e]

CRETACEOUS SYSTEM

General relations.—Rocks of Cretaceous age occur extensively in New Mexico, but in most places the succession is incomplete, and in the southern part of the State the areas of later Cretaceous strata are very widely separated, a condition possibly resulting from extensive removal by erosion in post-Cretaceous time. The earliest formation that may belong in the system is the Morrison, which is classed as Cretaceous (?) because of lack of evidence as to the precise age of the mammalian remains it carries. Next in age are the shale and sandstone of the Purgatoire formation in the northeastern part of the State and the Sarten and other sandstones and limestones of Comanche age in the southern part; these, however, represent only a small portion of Comanche time. The Upper Cretaceous consists of the Dakota sandstone and the shales and sandstones of the Colorado and Montana groups, which are divided into formations that bear different names and differ in range in the eastern and western parts of the State. It is probable that some of the volcanic rocks in southwestern New Mexico are of Cretaceous age, but evidence as to their equivalence is lacking.

Morrison formation (Cretaceous?).—The Morrison formation occurs throughout northern New Mexico and appears to be well represented in part of the structural basin about the Sierra Blanca, in the western part of Lincoln County. It consists chiefly of pale greenish-gray clay or massive shale, with maroon portions at most localities, and includes more or less light-colored sandstone, some of which is greenish. Thin beds of limestone, mostly concretionary, and some reddish chalcedony concretions also occur in the northeastern part of the State. The chalcedony concretions may possibly indicate the presence of the Sundance formation (Jurassic) at some localities. The average thickness of the formation is near 150 feet, but the amount varies considerably from place to place. The formation crops out extensively in the high plateaus of northeastern New Mexico, the Canadian Escarpment, the Cimarron and Ute Valleys (Union County), and the Las Vegas region, and apparently it is also present in the outlying buttes south and west of Tucumcari and in the basin of the Sierra Blanca. In the Sandia uplift and Cerrillos Basin it crops out at intervals from the vicinity of Tijeras to Rosario, and it appears near Lamy and farther south. It is exposed near Suwanee, Laguna, and Rito siding but thins out to the south

[45e] Darton, N. H., op. cit. (Prof. Paper 52), p. 20.

in the ridges between Laguna and Acoma. Extensive exposures, part of which are shown in Plate 12, *C*, occur north of Laguna station. In the Zuni uplift the Morrison formation appears in the vicinity of Horace and Grant and high along the slopes extending north of Thoreau, Guam, and Wingate, but it is absent in the southern part of the uplift. North of Wingate the beds become very sandy and appear to merge laterally on the west into sandstone which has been classed as "McElmo formation" by Gregory,[46] although it is possible that at this place there is an overlap onto a remnant of an older sandstone. It thins out near the railroad 3 miles east of Gallup. This sandstone comes to the surface again at Manuelito, where according to Gregory it is in seven beds, in all 340 feet thick.

The only fossils so far reported from the Morrison beds in New Mexico are scattered bones of saurians of various kinds, which have not yet been studied. Remains of many of these animals have been collected from the formation in Colorado and Wyoming. Some paleontologists regard this fauna as early Cretaceous, but others regard it as late Jurassic or possibly as representing a transition from one period to the other.

Sarten sandstone and associated limestones (*Comanche*).—In southern and southwestern New Mexico the Lower Cretaceous is represented by the Sarten sandstone, which I have separated in Luna County[47] and found to extend northward into the Silver City-Hanover region, where it has been called the "Beartooth quartzite"[48] and classed as Upper Cretaceous (?). In the southern extension of the Cooks Range the Sarten sandstone yielded the following Comanche fossils, which are regarded as Washita: *Cardita belviderensis*, *Cardium kansasense*, *Protocardia texana*, *P. quadrans*, *Tapes belviderensis*, *Turritella* aff. *T. seriatimgranulata*, *Ostrea* sp., *Nucula* sp., *Trigonia* sp., *Lunatia* sp., *Leptosolen* sp., *Homomya* sp., *Turritella* sp., *Cyprimeria* sp., and *Anchura* sp., similar to the fauna near Tucumcari. Farther south in New Mexico the Comanche strata are limestones, which are extensively developed about El Paso, Tex., where they are quarried for the manufacture of cement. They have yielded fossils of Fredericksburg and Washita age. Similar limestone constitutes the Cornudas Mountains, the Potrillo Mountains, the Sierra Rica, and parts of the Hatchet Mountain and adjoining ridges, in the southwestern part of the State. The limestones in the Hatchet Mountain region closely resemble the Mural limestone of the Bisbee and Douglas region, Arizona, to which doubtless they are equivalent. Fossils from this region determined by T. W. Stanton comprise forms characteristic of both Washita and Trinity groups of the

[46] Gregory, H. E., op. cit., map.

[47] Darton, N. H., op. cit. (Bull. 618), pp. 43-44. See also U. S. Geol. Survey Geol. Atlas, Deming folio (No. 207), p. 6, 1917.

[48] Paige, Sidney, U. S. Geol. Survey Geol. Atlas, Silver City folio (No. 199), pp. 5-6, 1916.

Comanche series. The most abundant form is a large *Exogyra* related to *E. quitmanensis*. A small terebratuloid apparently closely related to *Kingena wacoensis* is also abundant. There also occur the Foraminifera *Orbitolina texana, Ostrea* sp., *Corbula* sp., *Anchura*, and *Turritella* sp. At the south end of the Hatchet Mountains were collected *Hemiaster comanchi, Enallaster* sp., *Ostrea* sp., and *Requienia texana*, and at exposures 31 miles southwest of Hachita *Exogyra quitmanensis, Limopsis?, Tapes* sp., and *Tylostoma* sp.

In the Potrillo Mountains south of Afton, Lee[49] collected fossils determined by T. W. Stanton as *Caprina occidentalis, Trigonia* sp., *Cyprina* sp., and *Actaeonella dolium*, a Fredericksburg fauna.

Purgatoire formation (Comanche).—The plateaus of northeastern New Mexico are underlain by shale and sandstone of Lower Cretaceous age which are extensively exposed in many canyons, in the southern face of the Canadian Escarpment, and in several outliers of that escarpment in the region south and west of Tucumcari. In most areas they are overlain by the Dakota sandstone, which constitutes the floor of the plateaus, and they lie on the clays of the Morrison formation. In many places there is a lower member of sandstone and an upper member of dark sandy shale, in all about 100 feet thick, but the local sections are variable. The sandstones are mostly gray and massive, similar to the overlying Dakota sandstone. The Purgatoire formation has not been observed west of the Rocky Mountains and in the central part of the State, where the Dakota sandstone lies on the Morrison or older formations. Possibly there are also breaks in the continuity of the Purgatoire formation in the northeastern part of the State. Fossil shells that have been collected in the shale of the formation by T. W. Stanton and W. T. Lee in the valley of the Cimarron (Union County) and also in Colorado indicate its Comanche age, and abundant fossils of that age occur in buttes in the Tucumcari region (see pl. 13, *B*), including Cuervo Hill, to which, however, the name Purgatoire has not yet been applied. The fossils reported by Stanton, Hill,[50] and others from the vicinity of Tucumcari are as follows:

Turbinolia texana?
Ostrea marshi.
Ostrea quadriplicata.
Gryphaea dilatata var. tucumcarii.
Gryphaea pitcheri.
Exogyra texana.
Plicatula sp.
Neithea occidentalis.
Trigonia emoryii.
Protocardia multistriata.
Protocardia texana.
Cytherea leonensis.
Pinna comancheana.
Cardita belviderensis.
Tapes belviderensis.
Cyprimeria sp.
Turritella seriatimgranulata.
Ammonites leonensis.

W. B. Lang recently found outcrops containing Comanche fossils 13 miles southeast of Portales, rising as an island in the Staked Plains.

[49] Lee, W. T., personal communication.

[50] Hill, R. T., On outlying areas of the Comanche series in Kansas, Oklahoma, and New Mexico: Am. Jour. Sci., 3d ser., vol. 50, pp. 229–231, 1895; Tucumcari: Science, vol. 22, pp. 23–25, 1893.

Dakota sandstone.—Throughout northeastern New Mexico the basal formation of the Upper Cretaceous succession is a hard gray massive sandstone supposed to be a southern extension of the Dakota sandstone. It constitutes much of the surface of the Canadian Plateau in Union and Mora Counties, which extends southward to the Canadian Escarpment. Outliers of this plateau south and west of Tucumcari are capped by this sandstone (see pls. 13, *B*, 57), and a small area of it remains in the northern face of the Llano Estacado, in Quay County. It is well exhibited also in the basin of the Sierra Blanca region, in the western part of Lincoln County. It constitutes the surface of the plateaus on both sides of the Chama Valley, in the central part of Rio Arriba County, and is conspicuous in the Lucero and Zuni uplifts. Its supposed representative crops out in a broad belt extending from Manuelito to Atarque, on the west side of the Zuni Basin, and it is also exposed in the valley of the San Juan in the northwest corner of the State. The thickness of the Dakota sandstone ranges in general from 80 to 100 feet. In Mora and Colfax Counties the sandstone passes beneath the shale of the Colorado group but is uplifted and exposed at intervals along the foot of the Rocky Mountain front range. In the western part of the State the Dakota (?) sandstone is immediately overlain by the Mancos shale. East of Gallup it overlaps from the Morrison formation directly onto the Navajo sandstone, which it caps in the areas from Zuni to Atarque and Ramah to El Moro, as shown in Plate 13, *A*. Farther south it lies on Chinle shale as shown in Plate 14, *A*. Locally the Dakota sandstone contains conglomerate, especially at its base. In some places in the western part of the State this sandstone contains fossil *Exogyra*, which probably indicates either that the sandstone here is the basal member of the Mancos or that marine conditions began in Dakota time in that region. There is also some doubt as to the identity of the formation in the Carthage region and the ridges east and northeast of Socorro.

Colorado group.—In northeastern New Mexico the subdivisions of the Colorado group that have been recognized in eastern Colorado extend southward to the Las Vegas region, and they are also more or less evident in the Upper Cretaceous succession in the north-central and northwestern parts of the State, where they are grouped in the Mancos shale. The basal formation is the Graneros shale, a dark shale 150 to 160 feet thick, and next is the Greenhorn limestone, 50 to 80 feet thick, which is overlain by the Carlile shale, 150 to 250 feet thick. The Niobrara formation, consisting of the Timpas limestone, 50 feet thick, and the Apishapa shale, 500 feet thick, is also present. The Graneros shale is extensively exposed in the region east of Springer and Wagon Mound, where its base lies on the Dakota sandstone in the slopes near the edge of the canyon of Canadian River.

The Greenhorn consists of a succession of thin beds of limestone separated by black shale, and many layers contain large numbers of the highly characteristic fossil *Inoceramus labiatus*. It is exposed along Cimarron River (Colfax County) a few miles southeast of Springer and thence extends southward along the west side of the Canadian Valley and is well exposed in the eastern part of Las Vegas, as shown in Plate 14, *B*. The overlying Carlile shale is a dark-gray shale containing numerous biscuit-shaped concretions carrying many characteristic fossils, including *Camptonectes symmetricus*, *Inoceramus fragilis*, *Exogyra columbella*, *Liopistha* (*Psilomya*) *concentrica*, *Ostrea lugubris*, *Pinna petrina*, *Prionocyclus wyomingensis*, and *Prionotropis woolgari*, determined by T. W. Stanton.

The Timpas limestone was formerly quarried near Springer, Colfax County, on the banks of Cimarron River, and it crops out on Ocate Creek a short distance east of Colmor. Next above the limestone is the Apishapa shale, which crops out along the Canadian Valley and is well exposed about Dorsey and southwest of Springer. The upper boundary of the Apishapa is very indefinite, as it appears to grade into the Pierre shale.

The strata of Colorado age in the Cerrillos coal field and east of Galisteo are a nearly uniform succession of the dark shale about 2,000 feet thick. The Greenhorn limestone, with numerous *Inoceramus labiatus*, is well defined in the lower part of this succession. It is also conspicuous in the Nacimiento uplift and extends southward through the outcrop zone in the western parts of Bernalillo and Valencia Counties. Shale containing colonies of *Inoceramus labiatus* appears in the western part of El Paso, Tex., and on the east side of Cerro Mulato in Mexico opposite El Paso. Near the base of the Colorado succession in the Cerrillos Basin is a prominent bed of hard gray sandstone, possibly the Tres Hermanos sandstone member of Lee.

Mancos shale.—The Mancos shale comprises shale of the Colorado group as above described and probably also the lower part of the Pierre shale. Its outcrop skirts both sides of the Zuni uplift, occupies a broad area in the San Juan Valley in the northwest corner of San Juan County, and extends along the western margin of the Gallup coal basin. The formation is also exposed in the valley of Carrizo Creek in the Salt Lake region, Catron County. It underlies the Sierra Blanca, Cerrillos, and Tijeras coal basins and crops out along the east slope of the Sierra Caballo. There are small outcrops in the ridges east of Socorro, in the region north and northeast of Silver City, and on the south and east sides of the Cooks Range, north of Deming. The locality in El Paso is referred to above.

The thickness of the Mancos shale ranges from 900 to 1,300 feet in most parts of the area above described, except where the upper beds have been removed by erosion. In the Tijeras region Lee [51] measured 1,550 feet. In places the formation includes sandstone associated with coal deposits, and where these occur it is difficult to separate the Mancos from the overlying Mesaverde formation. A notable occurrence of this sort is found in the basin south of La Joya. In north-central New Mexico two included sandstones are the Punta de la Mesa and Tres Hermanos sandstone members. In the Puertecito region, where much of the Mancos shale has been separated by Winchester [52] as the Miguel formation, there are two included sandstones, known as the Bell Mountain and Gallego sandstone members. In the Tijeras coal field a 145-foot sandstone member 60 feet above the base has been regarded by Lee [53] as the Tres Hermanos member. An included sandstone in the northwestern part of the State has been called the Tocito sandstone lentil; [54] it attains a thickness of 35 feet near Tocito.

In the Gallup-Zuñi Basin Sears [55] found that the Mancos shale is from 700 to 950 feet thick, placing the upper limit at the bottom of the massive sandstone (Gallup sandstone member of the Mesaverde formation) that forms the west ridge of the hogback east of Gallup. The rocks are mainly dark-gray, somewhat sandy marine shale with sandy shale and slabby to shaly sandstone near and at the top. Near the base is a 10-foot bed of impure limestone which contains many *Gryphaea* and *Ostrea*. Sears states that in the Zuni Reservation there is only 425 feet of gray marine shale that can be assigned to the Mancos.

It is the opinion of Lee [56] that the coal measures at the north end of the Sierra Caballo (Engle field) are of Benton age. They are largely sandstones of gray to buff tint with beds of shale and shaly sandstones overlain unconformably by Tertiary deposits.

The Mancos and associated strata in the Chama Valley have been described by Lee,[57] who found the Mancos shale well developed, with a sandstone near the base regarded as a representative of the Tres Hermanos sandstone member. Lee states that Schrader collected from medial beds of the formation 2 miles northwest of El Vado the upper Benton fossils *Inoceramus fragilis*, *Scaphites warreni*, and *Prionocyclus wyomingensis*. The Mancos strata extend to a massive sandstone regarded as the base of the Mesaverde, which forms a high ridge and walls of a deep canyon just east of Monero.

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[51] Lee, W. T., The Tijeras coal field, Bernalillo County, N. Mex.: U. S. Geol. Survey Bull. 471, p. 575, 1912.

[52] Winchester, D. E., Geology of Alamosa Creek valley, Socorro County, N. Mex.: U. S. Geol. Survey Bull. 716, pp. 6–8, 1921.

[53] Lee, W. T., U. S. Geol. Survey Bull. 471, p. 571, 1912; Prof. Paper 101, p. 199, 1917; Stratigraphy of the coal fields of north-central New Mexico: Geol. Soc. America Bull., vol. 23, p. 631, 1912.

[54] Reeside, J. B., jr., Upper Cretaceous and Tertiary formations of the western part of the San Juan Basin, Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 134, p. 9, 1924.

[55] Sears, J. D., Geology and coal resources of the Gallup-Zuni Basin, New Mexico: U. S. Geol. Survey Bull. 767, pp. 14–15, 1925.

[56] Lee, W. T., The Engle coal field, N. Mex.: U. S. Geol. Survey Bull. 285, p. 240, 1906. See also Prof. Paper 95, p. 41, 1916; Prof. Paper 101, p. 33, 1917.

[57] Lee, W. T., op. cit. (Prof. Paper 101), p. 189.

The Mancos shale in the region east of Mount Taylor has been described in detail by Shimer and Blodgett [58] and by Lee, and exposures in the San Juan Basin have been described by Reeside [59] and Gardner,[60] in the Cerrillos and Tijeras coal basins by Lee,[61] in the Sierra Blanca Basin by Campbell [62] and Wegemann [63] and in the Alamosa Valley by Winchester.[64]

Pierre shale.—The upper half of the thick succession of shales of Upper Cretaceous age in north-central New Mexico is the Pierre shale, which extends southward from Colorado. It is considerably more than 2,000 feet thick in the Raton region and may be 1,800 feet thick in the vicinity of Las Vegas. It consists of dark shale with a few thin sandstone layers in its upper part and limy beds toward the base. Farther south and in the region west of the Sangre de Cristo Mountains, where the formation includes thick beds of sandstone, it is represented by the Mesaverde group, the Lewis shale, and probably the top of the Mancos shale.

From the Pierre shale in eastern New Mexico Lee [65] reports the following species, determined by T. W. Stanton:

Ancyloceras sp.
Anisomyon sp.
Anomia sp.
Avicula sp.
Avicula linguiformis.
Baculites ovatus.
Baculites compressus.
Cardium sp.
Crassatellites cimarronensis.
Crenella sp.
Dentalium sp.
Fasciolaria sp.
Heteroceras sp.
Heteroceras cheyennense.
Inoceramus barabini.
Inoceramus oblongus.
Inoceramus sagensis.
Inoceramus vanuxemi.
Leda sp.
Leda scitula.
Lima sp.
Liopistha (Cymella) undata.
Lucina sp.
Lucina occidentalis.
Lunatia sp.
Mactra sp.
Margarita nebrascensis.
Martesia? sp.
Nautilus dekayi.
Nemodon sp.
Nucula planimarginata.
Odontobasis? sp.
Ostrea pellucida.
Ostrea patina.
Pinna sp.
Placenticeras sp.
Placenticeras intercalare.
Placenticeras whitfieldi.
Ptychoceras sp.
Pyrifusus? sp.
Scaphites nodosus.
Syncyclonema sp.
Syncyclonema rigida.
Tancredia americana.
Mososaurus sp.

[58] Shimer, H. W., and Blodgett, M. E., The stratigraphy of the Mount Taylor region, New Mexico: Am. Jour. Sci., 4th ser., vol. 25, pp. 53–67, 1908.

[59] Reeside, J. B., jr., op. cit., pp. 9–13.

[60] Gardner, J. H., The coal field between Gallina and Raton Spring, N. Mex.: U. S. Geol. Survey Bull, 341, p. 338, 1909.

[61] Lee, W. T., op. cit. (Bull. 471), p. 575. See also Bull. 531, p. 287, 1913; Prof. Paper 101, pp. 198, 210–217. 1918.

[62] Campbell, M. R., Coal in the vicinity of Fort Stanton Reservation, Lincoln County, N. Mex.: U. S. Geol. Survey Bull. 316, p. 434, 1907.

[63] Wegemann, C. H., Geology and coal resources of the Sierra Blanca coal field, Lincoln and Otero Counties, N. Mex.: U. S. Geol. Survey Bull. 541, pp. 430–431, 1914.

[64] Winchester, D. E., op. cit. (Bull. 716), pp. 6–8.

[65] Lee, W. T., Geology of the Raton Mesa and other regions in Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 101, pp. 45–46, 1917.

Trinidad sandstone.—The Trinidad sandstone extends from the type locality in southern Colorado into New Mexico as part of the rim of the Raton coal basin. According to Lee [66] it is a moderately hard massive light-colored rock, appearing as a cliff above slopes of the Pierre shale. In most places it is about 100 feet thick, but locally the thickness diminishes to 50 feet or less. South of Dawson a lower sandstone member appears in the upper part of the Pierre shale, and thence southward it is the more conspicuous cliff-maker above the shale slope. A characteristic fossil plant (*Halymenites major*) occurs in both sandstones. The molluscan fossils from the Trinidad sandstone and underlying transitional beds identified by T. W. Stanton are as follows:

Avicula nebrascana.
Chlamys nebrascensis.
Inoceramus barabini.
Inoceramus sagensis.
Mactra warrenana.
Ostrea pellucida.
Tancredia americana.
Tellina scitula.

The age of the Trinidad is regarded as upper Montana, possibly equivalent to that of the lower part of the Fox Hills of the Rocky Mountain region.

Vermejo formation.—Conformably above the Trinidad sandstone in the Raton coal field is the Vermejo formation, which consists of coal-bearing shale and sandstone. According to Lee [67] it has a maximum thickness of about 75 feet in and near Raton and thickens locally in the Koehler region to a maximum of about 200 feet. It thins out by erosion to the east at a point about 2 miles northeast of Raton. It is absent locally near Red River Peak and some other points. Its top is more or less eroded throughout the area. In the southern and western part of the coal basin it thickens to a maximum of nearly 400 feet, having a thickness of about 375 feet at Vermejo Park, the type locality. The principal material of the Vermejo formation is shale, most of it carbonaceous, and it contains several widespread coal beds, some of which attain a thickness of 15 feet. Irregular sandstone deposits are included at many places. Many fossil plants have been collected in the Vermejo formation, and according to Knowlton,[68] represent 108 species belonging to the Montana flora. In Colorado it includes a member containing mollusks, which suggests correlation with the Fox Hills sandstone.

Mesaverde group.—In most of New Mexico the upper part of the Upper Cretaceous consists of a succession of sandstone and shale with coal measures, but as the base of these sandy sediments is not at the same horizon throughout it is not possible to establish a uniform plane

[66] Lee, W. T., op. cit. (Prof. Paper 101), pp. 48–50. See also U. S. Geol. Survey Geol. Atlas, Raton-Brilliant-Koehler folio (No. 214), p. 6, 1922.

[67] Lee, W. T., op. cit. (Prof. Paper 101), pp. 51–56. See also Folio 214, pp. 6–7, 1922.

[68] Knowlton, F. H., Fossil floras of the Vermejo and Raton formations of Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 101, pp. 227–230, 1917.

of separation. The sandstones that overlie the Mancos shale in the central and northwestern parts of the State are known as the Mesaverde group. According to Reeside,[69] in the western part of the San Juan Basin the group consists of the three formations into which it has been divided in southwestern Colorado. At the base is the Point Lookout sandstone, about 200 feet thick, capping slopes of the Mancos shale. Next above is the Menefee formation, consisting of 700 to 1,100 feet of gray to brown shale with lenticular sandstone members and coal beds. Some beds of this formation are of marine origin, and others were deposited in fresh water. At the top is the Cliff House sandstone, 300 to 750 feet thick, consisting of a thick yellow to brown massive sandstone underlain and overlain by thin sandstone and shale, all of marine origin. According to Gardner,[70] on Arroyo Torrejon, on the eastern margin of the San Juan Basin, the Mesaverde group is 1,328 feet thick. The lower 70 feet may represent the Point Lookout sandstone, the middle 938 feet the Menefee formation, and the upper 320 feet the Cliff House sandstone.

The fossils listed below are among those reported by T. W. Stanton from the marine formations of the Mesaverde group of the San Juan Basin. They are of Montana age.

Micrabacia americana.
Yoldia evansi.
Inoceramus barabini.
Pteria nebrascana.
Liopistha undata.
Sphaeriola cf. S. endotrachys.
Tancredia americana.
Callista deweyi.
Tellina equilateralis.
Mactra formosa.
Mactra warrenana.
Chemnitzia cerithiformis.
Lunatia occidentalis.
Lunatia concinna?
Lunatia subcrassa?
Gyrodes aff. G. petrosa.
Anchura nebrascensis?
Fusus cf. F. newberryi.
Actaeon attenuatus.
Haminea subcylindrica.
Anisomyon cf. A. shumardi.
Baculites anceps var. obtusus.
Placenticeras intercalare.

According to Lee [71] the coal at Monero occurs above a westward-dipping sandstone classed as Mesaverde. Just above the coal a few fossil plants were found, and both above and below this horizon were collected the marine fossils *Ostrea* sp., *Pecten* sp., *Inoceramus barabini*, and *Baculites anceps* var. *obtusus*. The Mesaverde sandstones and shales crop out southward from this place along the east rim of the San Juan Basin, and their features and relations in that area have been described by Gardner.[72] There is much hard sandstone, which makes a prominent hogback ridge, and more or less coal is included. The thickness of the formation ranges from 214 to 719 feet in the

[69] Reeside, J. B., jr., op. cit., pp. 13-16.

[70] Gardner, J. H., The coal field between San Mateo and Cuba, N. Mex.: U. S. Geol. Survey Bull. 381, pp. 470-471, 1910.

[71] Lee, W. T., op. cit. (Prof. Paper 101), p. 189.

[72] Gardner, J. H., op. cit. (Bull. 341), pp. 338-339, 342-347.

sections measured, and in places the strata are covered by an overlap of Wasatch beds. Lee [73] has examined the outcrops farther south near Cabezon and Casa Salazar and recorded various details of their stratigraphy.

The wide area of Mesaverde strata in the Gallup-Zuni coal basin was studied by Shaler [74] in 1906 and in greater detail by Sears [75] in 1919 and 1920. The thickness of 1,800 feet comprises alternating beds of gray sandstone and drab clay shale, with coal beds that are extensively mined. There are three persistent massive beds of sandstone near the base and other sandstones higher up which vary greatly from place to place. The top of the formation is eroded, so that the section is not complete. The following members are recorded by Sears:

Strata of the Mesaverde formation in the Gallup-Zuni Basin

	Feet
Allison barren member: Light-colored sandstone and shale, with thin irregular coal beds of no commercial importance	800+
Gibson coal member: Light-colored sandstone and shale with coal beds	150–175
Bartlett barren member: Light-colored sandstone and shale with thin coal beds of no commercial importance	330–400
Dilco coal member: Light-colored sandstone and shale with valuable widespread coal beds	240–300
Gallup sandstone member: Three thick beds of hard gray to pink sandstone, the upper one locally very coarse and arkosic, separated by shale containing coal beds, of which those in the upper shale are of commercial importance in most places	180–250

The lowest sandstone is the hardest. Along the hogback ridge the upper and lower sandstones are pink and the middle bed light gray. The anticline at Gallup exposes the upper sandstone, and it is also exposed in the arch at Defiance switch, where, however, all the beds are light gray. The formation extends southward to the Hagan or Uña del Gato field, where Lee [76] measured 1,854 feet of Mesaverde beds consisting of sandstone, sandy shale, and shale.

In the Tijeras coal field, a few miles east of Albuquerque, Lee [77] found Montana fossils in the coal-bearing rocks, which are classed as Mesaverde. The thickness of this formation is stated to be 1,197 feet, with a 115-foot bed of sandstone at the base, resting on 1,550 feet of the Mancos shale. Some shale above the coal measures suggests the presence of the Lewis shale.

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73 Lee, W. T., op. cit. (Prof. Paper 101), pp. 192–195.

74 Shaler, M. K., A reconnaissance survey of the western part of the Durango-Gallup coal field of Colorado and New Mexico: U. S. Geol. Survey Bull. 316, pp. 379, 380, 1907.

75 Sears, J. D., op. cit. (Bull. 767), pp. 15–18.

76 Lee, W. T., op. cit. (Prof. Paper 101), pp. 201–202.

77 Idem, pp. 198–200; Bull. 471, pp. 10–14, pl. 59, 1912.

According to Gardner [78] the uppermost member of the Cretaceous succession with coal measures at Carthage is regarded as Mesaverde. The coal measures of the Sierra Blanca Basin studied by Campbell [79] and Wegemann [80] are regarded as Mesaverde.

Lewis shale.—Overlying the Mesaverde group in northern and western New Mexico is a thick body of shale of Montana age, named the Lewis shale, from Fort Lewis, in La Plata County, Colo. Its outcrop zone extends around the San Juan Basin, varying in width from 1 to 5 miles in greater part. It forms a broad valley between Monero and Dulce. Although it consists essentially of shale, a few layers of limestone and sandy and concretionary beds occur in it. According to Reeside [81] its thickness is 1,100 feet at Navajo Springs, north of Kirtland, 475 feet on San Juan River, and 76 feet at Coal Creek. It is about 100 to 150 feet thick on the south side of the San Juan Basin, and according to Gardner [82] it is over 2,000 feet thick north of Gallina and only 250 feet at Arroyo Torrejon, 30 miles southwest of Cuba. The upper and lower contacts are indefinite, and probably where the formation is thick it is in part equivalent to upper Mesaverde strata. The principal fossils from the west side of the San Juan Basin have been identified by T. W. Stanton as follows:

Ostrea inornata.
Inoceramus barabini.
Liopistha undata.
Lunatia sp.
Baculites sp.
Placenticeras intercalare.

About half a mile north of Dulce Lee [83] collected the following species:

Ostrea pellucida.
Syncyclonema rigida.
Inoceramus sagensis.
Inoceramus oblongus.
Cardium speciosum.
Pinna lakesi.
Trigonarca (Breviarca) exigua.
Lucina occidentalis.
Thetis circularis.
Pyrifusus sp.
Liopistha undata.
Lunatia sp.
Anisomyon patelliformis.
Actaeon sp.
Haminea sp.
Baculites ovatus.
Baculites compressus.
Ancyloceras sp.
Scaphites nodosus.
Placenticeras whitfieldi.
Placenticeras intercalare.

The Lewis shale is believed to be equivalent to the upper and perhaps also the middle part of the Pierre shale east of the Rocky Mountains.

Pictured Cliffs sandstone.—The sandstone overlying the Lewis shale in the San Juan Basin consists mainly of sandstone with inter-

78 Gardner, J. H., The Carthage coal field, N. Mex.: U. S. Geol. Survey Bull. 381, p. 453, 1910.
79 Campbell, M. R., op. cit. (Bull. 316), pp. 431–434.
80 Wegemann, C. H., Geology and coal resources of the Sierra Blanca coal field, Lincoln and Otero Counties, N. Mex.: U. S. Geol. Survey Bull. 541, pp. 419–452, 1914.
81 Reeside, J. B., jr., op. cit., p. 17.
82 Gardner, J. H., op. cit. (Bull. 341), p. 339.
83 Lee, W. T., op. cit. (Prof. Paper 101), p. 189.

bedded gray sandy shale, all of marine origin. According to Reeside,[84] it is 281 feet thick on San Juan River, but it thins to the south, measuring only about 50 feet near the big bend to the north in Chaco River and thence eastward for some distance, finally thinning out near longitude 107°. Lee [85] suggests, however, that it may be represented in the 225 feet of sandstone and shale overlying the Lewis shale near Dulce. In the San Juan Basin it merges into adjoining formations. The fucoid *Halymenites major* is abundant at all exposures. The principal fossils reported in New Mexico, as determined by T. W. Stanton, are as follows:

Inoceramus barabini.
Modiola cf. M. meeki.
Cardium aff. C. speciosum.
Tellina scitula.
Mactra gracilis.
Chemnitzia cerithiformis.
Lunatia occidentalis.
Haminea subcylindrica.
Cinulia n. sp.

This fauna is regarded as high Montana, and the sandstone appears to be at a constant horizon over a wide area.

Fruitland formation.—The Upper Cretaceous Fruitland formation is extensively exposed on the west side of the San Juan Basin except in a small area where it is overlapped by Tertiary formations. It is not recognized in the eastern rim of the basin or in other areas. According to Reeside [86] it consists of sandstones, shale, and coal deposits of brackish and fresh water origin, in a succession that varies somewhat from place to place. It is 240 feet thick on San Juan River, 425 feet near La Plata, and 530 feet at the Colorado State line. In the southeastern part of San Juan County its thickness ranges from 194 to 328 feet. The formation has yielded many vertebrates,[87] invertebrates, and fossil plants. The invertebrate fauna determined by Stanton [88] includes the following species:

Ostrea glabra.
Anomia gryphorhynchus.
Anomia gryphaeiformis.
Modiola laticostata.
Unio holmesianus.
Unio amarillensis.
Unio gardneri.
Unio reesidei.
Unio brachyopisthus.
Unio neomexicanus.
Unio brimhallensis.
Unio sp. cf. U. primaevus.
Corbicula cytheriformis.
Corbula chacoensis.
Panopaea simulatrix.
Teredina neomexicana.
Neritina baueri.
Campeloma amarillensis.
Tulotoma thompsoni.
Melania insculpta.
Goniobasis? subtortuosa.
Physa reesidei.
Planorbis (Bathyomphalus) chacoensis.

84 Reeside, J. B., jr., op. cit., p. 18.
85 Lee, W. T., op. cit. (Prof. Paper 101), p. 183.
86 Reeside, J. B. jr., op. cit., pp. 20–21.
87 Gilmore, C. W., Reptilian faunas of the Torrejon, Puerco, and underlying Upper Cretaceous formations of San Juan County, N. Mex.: U. S. Geol. Survey Prof. Paper 119, p. 8, 1919.
88 Stanton, T. W., Nonmarine Cretaceous invertebrates of the San Juan Basin: U. S. Geol. Survey Prof. Paper 98, p. 310, 1917.

The following plants have been identified by Knowlton:[89]

Asplenium neomexicanum.
Anemia hesperia.
Sequoia reichenbachi.
Sequoia obovata?
Geinitzia formosa.
Sabal montana.
Myrica torreyi.
Salix baueri.
Quercus baueri.
Laurus baueri.
Laurus coloradoensis.
Nelumbo sp.
Ficus baueri.
Ficus curta?
Ficus praetrinervis.
Ficus leei.
Ficus praelatifolia.
Ficus rhamnoides.
Ficus squarrosa.
Ficus eucalyptifolia?
Heteranthera cretacea.
Pistia corrugata.
Pterospermites undulatus.
Pterospermites neomexicanus.
Ribes neomexicana.
Carpites baueri.
Phyllites petiolatus.
Phyllites neomexicanus.

This flora together with that from the Kirtland formation is regarded by Knowlton as of Montana age. Reeside[90] regards these two formations as late Montana, possibly equivalent to the latest part of the Pierre shale and part of the Fox Hills sandstone.

Kirtland shale.—The Kirtland shale crops out in a wide belt around the western and southern margins of the San Juan Basin but has not been recognized east of longitude 107°. According to Reeside[91] it consists of three members, all of fresh-water origin. The lower member is mainly gray shale with dark layers and soft light-colored irregularly bedded sandstones. The middle part, the Farmington sandstone member, consists of many irregular lenses of sandstone, soft and light colored below but darker and harder above. The top member consists of shale and soft sandstone. The Farmington sandstone member thins out near the southeast corner of San Juan County but is conspicuous in the vicinity of San Juan River and northward, where its thickness is 480 feet. The total thickness of the formation varies considerably, being 1,065 feet at the Colorado State line, 800 feet on San Juan River, 1,180 feet on Hunter Wash, 700 feet on Escavado Wash, and 390 feet in the southwestern margin of Sandoval County, not far east of which it is overlapped by later formations. At its base the Kirtland shale grades into the Fruitland formation. The fossils collected from the Kirtland shale by Gilmore,[92] Stanton,[93] and Knowlton[94] indicate a fluviatile origin. The invertebrates listed by Stanton are *Unio pyramidatoides* and *Unio baueri*. Among the plants described by Knowlton are *Geinitzia formosa, Salix* sp., *Ficus*

[89] Knowlton, F. H., Flora of the Fruitland and Kirtland formations: U. S. Geol. Survey Prof. Paper 98, p. 330, 1917.

[90] Reeside, J. B., jr., op. cit., pp. 20–21.

[91] Idem, pp. 21–24.

[92] Gilmore, C. A., op. cit. (Prof. Paper 119), p. 8.

[93] Stanton, T. W., op. cit. (Prof. Paper 98), p. 310.

[94] Knowlton, F. H., op. cit. (Prof. Paper 98), p. 330.

praetrinervis?, and *Ficus leei*. The age of this formation, as mentioned above under Fruitland formation, is late Montana.

McDermott formation (Cretaceous?).—In the San Juan Basin the Kirtland shale is succeeded by the McDermott formation, which is provisionally regarded as Cretaceous, according to Reeside,[95] because it seems to have much closer relations to the underlying strata than to the overlying Tertiary deposits. It is included in the uppermost part of the Kirtland shale as described by Bauer, Gilmore, Stanton, and Knowlton. Its outcrop extends some distance along the western margin of the San Juan Basin, but it passes under the Ojo Alamo sandstone at a point about 12 miles due north of Pueblo Bonito (Putnam). In Colorado the formation consists of soft sandstone, tuffaceous shale, and coarse conglomerate in which some of the pebbles are andesite. Nearly all the finer-grained parts of the formation contain some volcanic débris, but the amount of this material is greatly diminished in its extension in New Mexico. At the Colorado State line the formation is 245 feet thick; at San Juan River 30 feet; and thence southward and eastward to the point where it disappears it ranges from 30 to 50 feet in greater part. South of San Juan River the formation is a thin assemblage of brown sandstone, grit, gray-white sandstone, and purple and gray shale. At San Juan River it is represented by thin irregular lenses of fine purple and green tuffaceous sandstone, coarse white sandstone with clay pellets, and purple and gray shale, in all 30 feet thick. The formation has yielded a few vertebrate remains, which have been regarded by Gilmore[96] as of Montana age, and the following plants from New Mexico collections have been reported by Knowlton:[97]

Pistia corrugata.
Ficus leei?
Onoclea neomexicana.
Asplenium neomexicanum.
Myrica? neomexicana.
Leguminosites? neomexicana.

According to Knowlton these plants indicate Cretaceous age, but they are not conclusive.

TERTIARY SYSTEM

Several sedimentary formations of Tertiary age occupy different parts of New Mexico, and probably there are deposits of that age buried under the volcanic rocks and valley fill of some of the deserts in the southwestern part of the State. One of the most extensive outcrop areas is the wide, shallow basin in western Rio Arriba County and eastern San Juan County, where there is a well-known succession of lower Eocene strata, including the Wasatch, Torrejon, and Puerco formations, about 2,000 feet thick. The underlying Ojo Alamo sandstone and the Animas formation, at the base of this succession, are

[95] Reeside, J. B., jr., op. cit., pp. 27–28.
[96] Gilmore, C. W., op. cit. (Prof. Paper 119), p. 7.
[97] Knowlton, F. H., op. cit. (Prof. Paper 98), p. 330. Reeside, J. B., jr., op. cit., p. 27.

probably of early Tertiary (Eocene) age, together with the Galisteo sandstone in the region near Cerrillos, the Raton formation of the Raton coal basin, and some other similar beds farther south. These all lie unconformably on Upper Cretaceous formations, generally with a basal conglomerate and more or less irregularity of overlap. The Tohachi shale and Chuska sandstone of the Chuska Mountains probably represent the Wasatch and possibly some underlying beds. Later Tertiary strata are represented by the Santa Fe formation and remnants of sand and gravel on high plateaus in both the western and eastern parts of the State. The sand mantle of the Llano Estacado and outliers of the same formation farther west are a southern extension of the Ogallala formation, which caps the High Plains of the Nebraska, Kansas, and Colorado region. Doubtless these later Tertiary formations underlie parts of some of the desert valleys of the south-central and southwestern parts of New Mexico and are also included in the succession of volcanic rocks in the west-central and southwestern parts. This great succession of volcanic products is mostly of Tertiary age and may represent a large part of that period. It comprises thick and widespread flows of lava of various kinds with interbedded volcanic tuff and ash, as well as gravel and sands, some of them separated by unconformities representing considerable erosion intervals.

Ojo Alamo sandstone (Tertiary?).—Outcropping along the western margin of the Tertiary deposits in the San Juan Basin is the Ojo Alamo sandstone, provisionally regarded as lower Tertiary (Eocene?), though the precise age is still under discussion. According to Reeside,[98] the sandstone includes considerable conglomerate, in which the pebbles are in part silica of various kinds but many are of rhyolite, andesite, and other igneous rocks. Most of them range from 1 to 3 inches in diameter, but some are larger. Nothing of this kind has been found in the underlying Cretaceous formations. Near the type locality the formation is from 60 to 80 feet thick. To the south it increases somewhat in thickness, reaching 125 feet on Escavada Wash. It has been traced eastward through Sandoval County, where, together with the overlying Torrejon formation, it overlaps the Kirtland, Fruitland, Pictured Cliffs, and Lewis formations. In the triangular area between Animas and San Juan Rivers the sandstone with its included shale layers is 400 feet thick. At a point about 9 miles north of Farmington it disappears under the Torrejon formation, but possibly its disappearance here is due to erosion prior to Torrejon deposition.

Many fragmentary remains of reptiles and a few poorly preserved remains of plants have been obtained from this sandstone, all of them from the vicinity of the type locality. Many silicified logs occur in

[98] Reeside, J. B., jr., op. cit., p. 29.

places. Gilmore[99] has given a list of the animal remains, but it is believed that the paleontologic data now available are inconclusive as to the age of the beds. However, the beds are separated from preceding deposits by a pronounced and widespread erosional unconformity, which very strongly suggests that the formation is later than Montana. It is also stated by Reeside[1] that there is a great difference between the fauna of the Ojo Alamo formation and that of the Puerco formation, which follows, and some deformation attended by considerable erosion intervened between the two periods of deposition. Apparently the Puerco is absent in a wide area in which the Ojo Alamo beds are directly overlain by the Torrejon deposits.

Galisteo sandstone (Tertiary?).—Overlying the Mesaverde formation unconformably in the Galisteo Valley, in central New Mexico, is a thick succession of sandstone and shale which has been separated as the Galisteo sandstone and classed as probably early Tertiary. At the base are coarse deposits, in large part conglomeratic, and evidently a considerable time break is represented in the unconformity. Lee[2] has described the character of these rocks at several places in the Cerrillos Basin as far south as the Uña del Gato (Hagan) coal field, where he measured the following section:

Section of Galisteo (?) sandstone in Hagan coal field

	Feet
Shale and friable sandstone, purple, blue, green, yellow, etc.	2, 500
Sandstone, conglomeratic, with red shale partings; Conglomerate, coarse	195
Shale, sandy in places, gypsiferous, highly colored like upper shale member	750
Sandstone, yellow, coarse, conglomeratic base, many petrified logs	345
Unconformity on shale of Mesaverde formation.	
	3, 790

These beds are extensively exposed in the Cerrillos coal field and are penetrated by drill holes east of Madrid. The formation is largely covered by sand and gravel of the Santa Fe formation and by talus from the mountain slopes. The formation extends across the Atchison, Topeka & Santa Fe Railway a short distance east of Cerrillos, where it exhibits many petrified logs—a characteristic component of the formation.

Raton formation (Eocene).—The Raton formation occupies an area of about 800 square miles in the portion of the Raton coal field that lies in New Mexico. According to detailed descriptions by Lee[3]

[1] Reeside, J. B., jr., op. cit., p. 32.

[2] Lee, W. T., The Cerrillos coal field, Santa Fe County, N. Mex.: U. S. Geol. Survey Bull. 531, pp. 286–297, 1913. See also Prof. Paper 101, pp. 201–217, 1917.

[3] Lee, W. T., op. cit. (Prof. Paper 101), pp. 56–61. See also Folio 214, pp. 7–8, 1922.

[99] Gilmore, C. W., op. cit. (Prof. Paper 119), p. 9.

the rocks are mainly sandstone with shale partings, but shale preponderates in the upper part. The total thickness is 1,150 feet in the central and southern part of the area, but the amount increases somewhat to the southwest. The basal member is conglomerate, 10 to 40 feet thick in the eastern outcrops, which thickens and becomes coarser to the south and west. The pebbles and boulders are of various rocks of older formations, including material from the Vermejo formation. The conglomerate lies on an irregularly eroded surface which in places descends to the Trinidad sandstone, and in the southwestern part of the Raton Mesa area it rests on Pierre shale. Next above the conglomerate are coal-bearing shale and sandstone about 100 feet thick, best developed to the north, where the principal coal bed is known as the "Sugarite coal," but the coal merges into coarse sediments to the southwest. This member is overlain by a "barren" series of sandstones, which weather yellowish brown and make conspicuous cliffs. The thickness of this series is 300 feet east of Raton and about 600 feet a few miles west of Raton. Next above is the "upper coal group," consisting of shale and friable sandstone with several coal beds, which are mined to some extent.

The principal fossils in the Raton formation are plants which have been studied by Knowlton.[4] The number of species is 148, and they afford evidence for classing the formation as older Eocene.

Puerco formation.—According to Reeside [5] the Puerco formation as defined by its characteristic fauna is known only in an area about 35 miles long in the southeastern part of San Juan County. It is possible, however, that the formation is represented by the lower members of the Eocene deposits in other portions of the San Juan Basin, but the beds at this horizon appear to be barren of fossils in most of the great area in which they may possibly outcrop. It is suggested by Reeside that the Torrejon formation extensively overlaps and conceals the Puerco formation. On Escavado Wash and its branches the lower 250 feet of the series of beds that includes the Puerco and Torrejon formations consists of shale of various tints with interbedded soft light-colored sandstone. Puerco fossils occur in the lower 50 feet of these beds. The overlying 500 feet consists of light-colored sandstone separated by gray shale; these beds have yielded no fossils but have been arbitrarily placed in the Puerco formation by Sinclair and Granger.[6] The lowest Torrejon fossils are about 500 feet still higher. Near Ojo Alamo Puerco fossils occur in the lower 90 feet of a series of dark shale and soft sandstone. These strata are overlain by shale and sandstone of various colors, the proved Puerco beds being succeeded by an interval without fossils of about 110 feet.

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[4] Knowlton, F. H., op. cit. (Prof. Paper 101), pp. 235-241, 284-349.

[5] Reeside, J. B., jr., op. cit., pp. 35-39.

[6] Sinclair, W. J., and Granger, Walter, Paleocene deposits of the San Juan Basin: Am. Mus. Nat. Hist. Bull., vol. 33, pp. 305-308, 1914.

The beds regarded as Puerco show erosional unconformity, without discordance of dip at the contact with the Ojo Alamo sandstone, and an abrupt change of fauna.

The Puerco formation has yielded a large number of vertebrate remains, which have been listed by Matthew [7] and Gilmore.[8] A condensed list may be found in Reeside's report on the San Juan Basin.[9] Matthew states that the Puerco fauna is wholly unknown elsewhere and is one in which archaic placentals predominate. There are no dinosaurs, but the crocodiles, rhynchocephalians, and turtles are of the same group as those of the Judith River and Lance formations and not perceptibly more advanced. Plants collected on Barrel Spring Arroyo were studied by Knowlton,[9] who identified the following forms:

Ficus occidentalis.
Artocarpus sp. undet.
Paliurus zizyphoides.
Viburnum lakesii?
Platanus cf. P. haydenii.
Populus cf. P. cuneata.

These suggest the age as "Denver or perhaps as late as Fort Union."

Torrejon formation.—According to Reeside [10] the Torrejon formation as defined by its fauna extends from Arroyo Torrejon, in Sandoval County, across the southern and western parts of the San Juan Basin almost to the Colorado State line. Eastward from Arroyo Torrejon the formation has been followed by Sinclair and Granger [11] to and beyond Puerco River. At the type locality, as described by Gardner,[12] the Torrejon formation consists of drab-gray, reddish, and black shale and gray and tan soft sandstone. The fossiliferous beds are 240 feet thick, and a barren zone 110 feet thick lies on the Ojo Alamo sandstone. On Puerco River the lowest fossil zone is overlain by shale and sandstone 660 feet thick with a barren zone 179 feet thick which Reeside includes in the Torrejon. In the Escavada Basin the Torrejon beds are 450 feet thick, including 25 feet of barren beds under the lowest fossil-bearing stratum. They are overlain by 250 feet of light-colored shale and sandstone, which Reeside provisionally regards as Torrejon. Near Ojo Alamo there is a barren interval of 110 feet of shale and sandstone between beds carrying Puerco and Torrejon fossils. The upper 50 feet of this interval is regarded as Torrejon, together with an additional 190 feet of shale and sandstone and 186 feet of overlying light-colored beds of uncertain age. On San Juan and Animas Rivers the Ojo Alamo sandstone is

[7] Matthew, W. D., Faunal lists of the Tertiary Mammalia of the West: U. S. Geol. Survey Bull. 361, pp. 91-92, 1909.
[8] Gilmore, C. W., op. cit. (Prof. Paper 119), pp. 9-10.
[9] Reeside, J. B., jr., op. cit., p. 38.
[10] Idem, p. 39.
[11] Sinclair, W. J., and Granger, Walter, op. cit., p. 312.
[12] Gardner, J. H., The Puerco and Torrejon formations of the Nacimiento group: Jour. Geology, vol. 18, pp. 714-719, 1910.

overlain by gray, olive-green, and brown shales, succeeded by 600 to 700 feet of sandstone, mostly light colored, and an equal thickness of beds in which hard brown lenticular sandstones are abundant. Torrejon fossils have been found about 150 feet above the base of this formation, all of which is regarded as Torrejon. Near Cedar Hill the fossiliferous beds are in the uppermost 300 feet of the Torrejon formation and consist of brown lenticular sandstone and variegated shale.

Matthew [13] has given a long list of mammals and Gilmore [14] a long list of reptiles from this formation, which need not be repeated here. In a later paper [15] Matthew states that the Torrejon overlies the Puerco conformably and that although many of the archaic mammals are common to both, some additional ones appear in the Puerco. A few fresh-water invertebrates and poorly preserved plants are reported by Reeside from the Torrejon beds, but they throw no light on the precise stratigraphic position of the formation.

Wasatch formation.—The central area of the San Juan Basin is occupied by light-colored sandstone and shale of the Wasatch formation. The thickness has been estimated as 1,000 feet by Granger,[16] who recognized two faunal divisions—a lower one called the "Almagre beds," containing *Eohippus* and *Anacodon,* and consisting of red, gray, and ocherous shale and sandstone, and an upper one called the "Largo beds," containing *Eohippus, Meniscotherium,* and *Ambloctonus* and consisting of material similar to that of the lower division but with more red coloring.. According to Reeside [17] the Wasatch beds in eastern San Juan County consist of a basal massive cliff-forming coarse pebbly copper-red sandstone, 50 feet thick, overlain by 150 feet of light-gray and red shale and soft white sandstone, overlain in turn by a sandstone similar to the basal member. Still higher are other shales and sandstones. There are excellent exposures in Blanco Canyon and lower Largo Canyon. Locally the basal 300 feet or more appears to be a continuous sandstone, but elsewhere beds of shale appear in it. On the divide between San Juan and Animas Rivers the Wasatch is a succession of coarse white to red sandstone, variegated purple to gray shale, and soft white sandstone. Near Cedar Hill the lower 700 feet of the formation is exposed, and on the highlands to the east higher beds appear.

In southern San Juan County there is a sharp lithologic break between the Torrejon and Wasatch formations, but to the north there appears to be conformity. Near the Nacimiento Mountains the Wasatch overlaps other formations with angular discordance.

13 Matthew, W. D., op. cit., pp. 91–92.

14 Gilmore, C. W., op. cit. (Prof. Paper 119), p. 10.

15 Matthew, W. D., Evidence of the Paleocene vertebrate fauna on the Cretaceous-Tertiary problem: Geol. Soc. America Bull., vol. 25, p. 382, 1914.

16 Granger, Walter, On the names of lower Eocene faunal horizons of New Mexico and Wyoming: Am. Mus. Nat. Hist. Bull., vol. 33, p. 205, 1914; Notes on Paleocene and lower Eocene mammal horizons of northern New Mexico and southern Colorado: Idem, vol. 37, p. 824, 1917.

17 Reeside, J. B., jr., op. cit., pp. 44–45.

Matthew [18] has given a long list of fossil animals obtained from the Wasatch formation in the San Juan Basin.

Tohachi shale and Chuska sandstone.—The Chuska Mountains, south of Gallup, consist of shale and sandstone (Tohachi shale), 200 to 1,100 feet thick, overlain by the Chuska sandstone, 700 to 900 feet thick, all lying nearly horizontal. These formations have been described by Gregory,[19] who suggests that they represent the Puerco, Torrejon, and Wasatch formations of the San Juan Basin, but no basis for precise correlation was obtained. The Tohachi strata consist mainly of black, drab, blue, yellow, brown, and red shale, with interbedded sandstone and a few carbonaceous layers. They lie unconformably across several Mesozoic formations. As mapped by Gregory, Beautiful Mountain consists of an outlier of these formations capped by lava.

Unclassified early Tertiary deposits.—In the ridges east of Socorro the coal measures of the Upper Cretaceous are overlain unconformably by conglomerate and sandstone that are probably of early Tertiary age. In the Carthage coal field Gardner [20] found similar deposits and relations with the following succession of strata:

Section of Tertiary strata near Carthage, N. Mex.

	Feet
Shale and sandstone, variegated	700
Conglomerate, very coarse, boulders of granite, Carboniferous limestone, etc	200
Shale, red; some sandstone	70
Sandstone, red, very coarse	30
Conglomerate; quartz, sandstone, granite, and chert in matrix of granite débris	3
Sandstone, red; some shale	10
Conglomerate, small quartz pebbles	5
Shale, red and drab	5
	1,023

Some bones and a tooth were collected in the lower part of the succession. The tooth is regarded by Gidley as possibly belonging to *Palaeosyops*, which would indicate an age later than Wasatch, probably Bridger, but the evidence is indefinite. A small deposit of conglomerate unconformably overlying Upper Cretaceous coal measures at the southwest end of the San Andres uplift, 23 miles northeast of Las Cruces, is regarded as Tertiary.

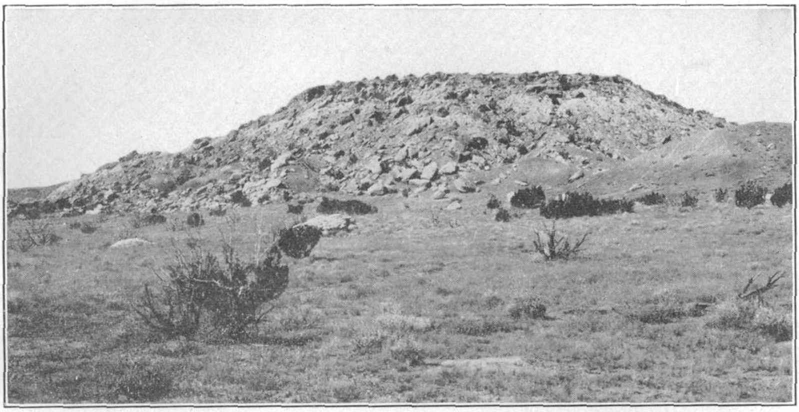
In the western part of New Mexico there are extensive outliers of sand on the plateaus, south of Gallup and Zuni, which are doubtless of Tertiary age, but no data are available as to their correlation. An outcrop in the western part of Catron County is shown in Plate 15, *B*.

In the Elephant Butte region, between the Sierra Caballo and the Fra Cristobal Range, the coal-bearing Mesaverde beds are overlain by sandstone, shale, and conglomerate that carry *Tricera-*

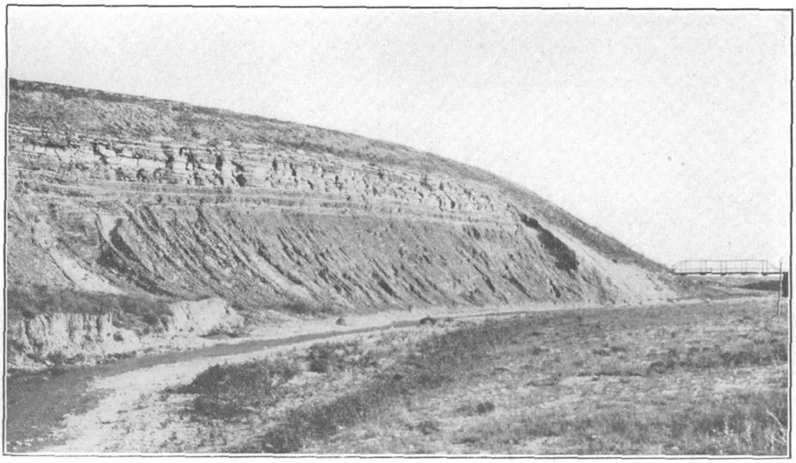
[18] Matthew, W. D., op. cit. (Bull. 361), pp. 92–95.

[19] Gregory, H. E., op. cit. (Prof. Paper 93), pp. 79–81.

[20] Gardner, J. H., op. cit. (Bull. 381), p. 454.

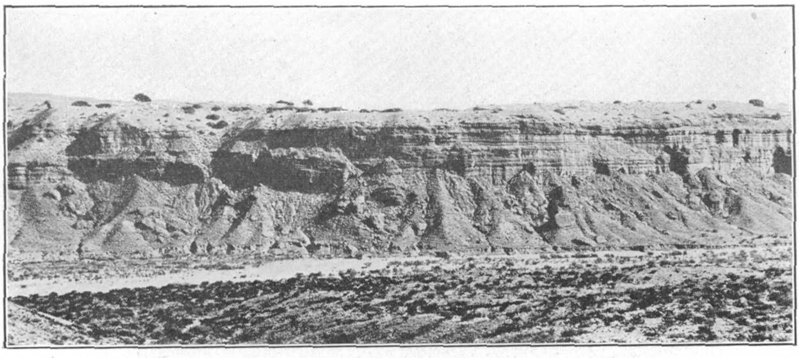


A. DAKOTA SANDSTONE ON RED SHALE OF CHINLE FORMATION 50 MILES SOUTHWEST OF ZUNI, NEAR NEW MEXICO-ARIZONA STATE LINE



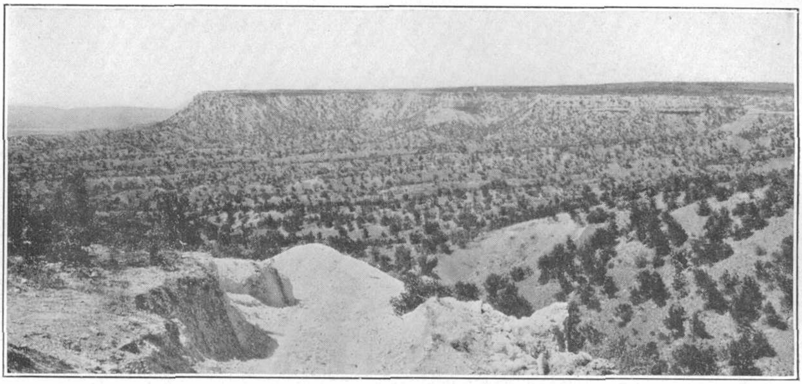
B. GREENHORN LIMESTONE ON BANK OF NORTH BRANCH OF GALLINA CREEK AT EAST LAS VEGAS

Looking southwest



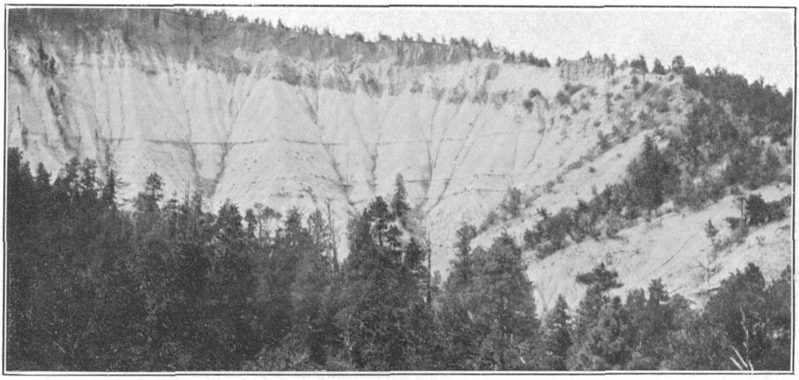
C. RED CONGLOMERATE OF SANTA FE FORMATION IN SOUTH BANK OF ARROYO DE LA PARTIDA, 6 MILES NORTHEAST OF SOCORRO

Looking south from old automobile road to Albuquerque



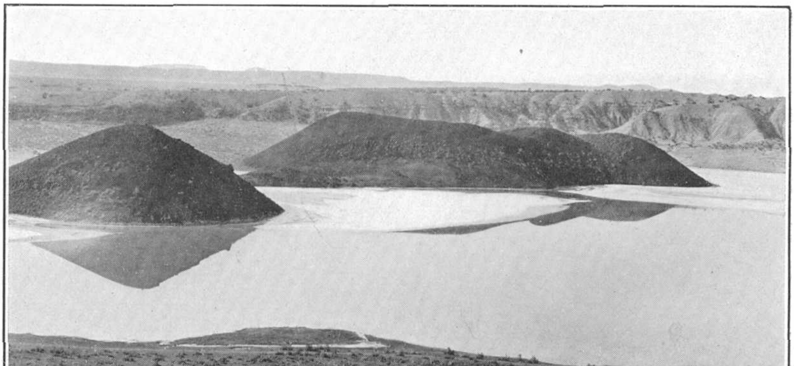
A. NORTHERN EDGE OF LLANO ESTACADO NEAR RAGLAND, 25 MILES SOUTH OF TUCUMCARI

Capping of sand, gravel, and grit of late Tertiary age



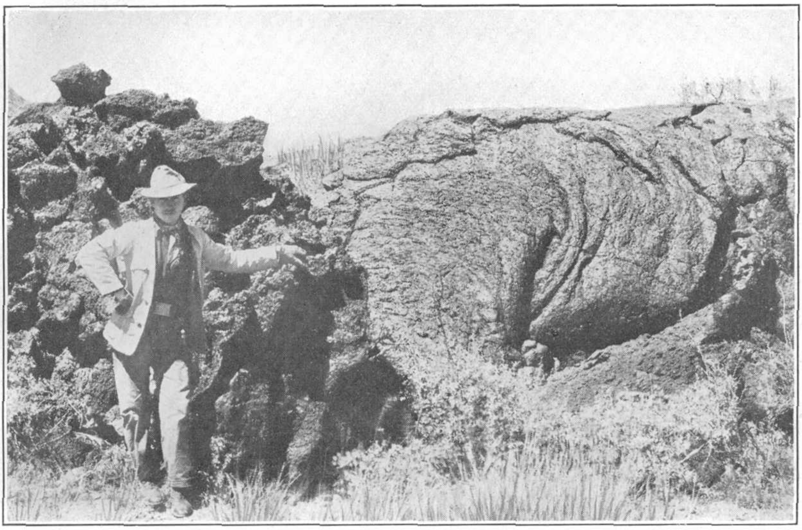
B. TERTIARY BEDS ON EAST SIDE OF COYOTE CREEK, 18 MILES NORTH-NORTHWEST OF LUNA, CATRON COUNTY

Looking east

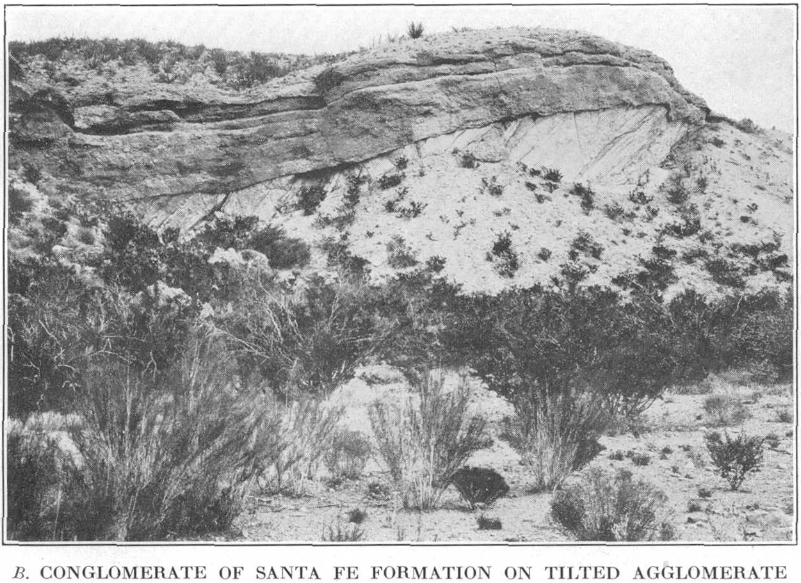


C. ZUNI SALT LAKE, AN EXPLOSION CRATER 43 MILES SOUTH OF ZUNI

Volcanic cone and crater and rim of Cretaceous sandstone surmounted by deposits of ejected materials, including fragments of Kaibab limestone. Looking east



A. EDGE OF THE MALPAÍS, A RECENT LAVA FLOW IN TULAROSA VALLEY



B. CONGLOMERATE OF SANTA FE FORMATION ON TILTED AGGLOMERATE ONE-EIGHTH MILE WEST OF OJO DEL AMADO, 5 MILES NORTHEAST OF SOCORRO

Looking north

tops and according to Lee[21] closely resemble the Galisteo sandstone and are probably of early Eocene age. The upper beds are in large part chocolate-brown to red, and the lower beds are white, brown, and reddish, with some greenish layers.

Santa Fe formation (Miocene and Pliocene).—The wide basin traversed by the Rio Grande from the Colorado State line southward to and beyond the center of New Mexico is occupied by a succession of sand, soft sandstone, and conglomerate which represents a portion of later Tertiary time. These beds are overlain locally by sand and alluvium of Quaternary age and by extensive lava flows. They have long been known as the Santa Fe marl or formation, the former a name proposed by Hayden in 1869. In most places the beds lie horizontal or nearly so, and in some of the deep valleys northwest of Santa Fe a thickness of 200 feet or more is exposed. Many fossil bones have been obtained in this region, some of which are regarded as upper Miocene and others as Pliocene. It is probable that this formation extends southward along the Rio Grande Valley under Albuquerque, for in that region there are exposed two separate formations of valley fill lying nearly horizontal; and a third older one of conglomerate is well exhibited east of Socorro (see pl. 14, *C*) and also on Rio Salado, where its beds are steeply tilted in the vicinity of the Lemitar and Ladrones uplifts. In Taos County the Santa Fe formation is widely overlain by the great lava flow of the Rio Grande Valley, but it is revealed in the deep trench cut by the river, and its relations are particularly well exposed in the slopes of Black Mesa and on the east side of the Rio Grande near Embudo. There is also an extensive lava cap on Santa Fe beds west of Santa Fe, which covers them to the south to points within a few miles of Cerrillos and Domingo. East of the Cerrillos Hills the formation lies on the Galisteo sandstone, and possibly some of the deposits of its southern margin abut against the igneous core of Ortiz Mountain.

According to Matthew[22] the principal fossils reported from the Santa Fe formation in the upper Rio Grande Valley in New Mexico are as follows:

Aelurodon wheelerianus (Cope).
?Dinocyon ursinus (Cope).
Putorius nambianus (Cope).
Hesperomys (=Peromyscus) loxodon (Cope).
Panolax sanctaefidei Cope.
Trilophodon (=Gomphotherium) productus Cope.
?Aphelops jemezanus Cope.
Merychippus calamarius (Cope).
Neohipparion calamarium (Cope).
Procamelus gracilis Leidy.
Pliauchenia humphreysiana Cope.
Palaeomeryx teres (Cope).
Palaeomeryx trilateralis (Cope).
?Merycodus tehuanus (Cope).

[21] Lee, W. T., op. cit. (Prof. Paper 101), p. 33.
[22] Matthew, W. D., op. cit. (Bull. 361), pp. 115-118.

It is possible that the beds from which Cope[22a] obtained *Aphelops fossiger* near the mouth of Dry Creek in the valley of Gila River may represent the Santa Fe formation. He states also that in the valley of the San Francisco these beds reach a thickness of 500 feet and consist of sand, soft sandstone, and conglomerate that contains pebbles of eruptive rocks.

Ogallala formation (*Miocene and Pliocene*).—The mantle of gravel and sand that constitutes the surface of the High Plains over a vast extent of western Nebraska and Kansas, eastern Colorado, and northwestern Texas extends a long distance into New Mexico. It appears to be part of the Ogallala formation, of Pliocene and Miocene age, although probably in most areas only the upper (Pliocene) part is represented, and some of the surface sands may be of Quaternary age. On the Llano Estacado it forms a thick covering in most places. This high plain presents on the north a steep escarpment (see pl. 15, *A*) descending to the Canadian Valley and on the west a line of cliffs forming the eastern margin of the Pecos Valley but diminishing in altitude and distinctness toward the south in Lee County. In some parts of northwestern Texas not far east of the New Mexico line the formations of the Llano Estacado are underlain by sand and gravel which have yielded bones of Miocene and Pliocene age. Outliers of the Ogallala formation cover an extensive area of the plateau west of Fort Sumner and northwest of Elvira, and deposits supposed to belong to this formation extend along the east slope of the Hills of Pedernal and occupy several plateaus in the southwest corner of Santa Fe County. Small areas of sand and gravel also occur on the Canadian Plateau about Roy and east of Vernon, and possibly the high terrace remnant just north of Sapello is an outlier of this formation. In general the Ogallala formation is believed to be equivalent to part of the Santa Fe formation of the Rio Grande Basin at Santa Fe and westward.

QUATERNARY SYSTEM

Bolson deposits.—The products of Quaternary time in New Mexico are mainly sand, gravel, and clay, which constitute the thick and extensive valley fills. There are also lavas and other igneous materials derived from volcanic eruptions. Wide valleys, such as those of the Tularosa Desert, the Jornada del Muerto, the Rio Grande, and the Florida Plains contain a vast amount of detrital material, largely of Quaternary age but possibly in part late Tertiary. Deep borings have shown that in places these deposits of sand, gravel, and clay have a thickness of more than 1,500 feet, but the amount is probably variable, and in some of the valleys the deposit is thin and even discontinuous. Thick deposits of Quaternary sand crop out in high

[22a] Cope, E. D., The Loup Fork beds on the Gila River: Am. Naturalist ,vol. 18, pp. 58-59, 1884.

banks along the west side of the valley of the Rio Grande opposite Las Cruces and farther south. In the slopes northwest of El Paso 200 feet of this material is exposed, underlying the wide plain that extends westward to and beyond Deming.[22b] There are also notable exposures of similar beds in the slopes west and northwest of Rincon, but it seems probable that some of the lower strata in these thick deposits may be of late Tertiary age. Alluvial deposits occur along most of the streams all over the State except where rock canyons are being cut, and large amounts of wash and talus accumulate on the slopes.

Saline deposits.—There are many inclosed basins in New Mexico, in several of which saline deposits have been in the course of accumulation for a long time. Some of the most notable of these are in Estancia and Tularosa Valleys, which have been described by Meinzer.[23] The deposits in the valleys of Hidalgo County have been described by Schwennesen.[24]

Dune sands.—On the east side of the Pecos Valley in southern New Mexico there are very extensive sand hills formed of deposits known as the "Mescalero Sands," which are doubtless of Quaternary age and may represent deposits of an early stage of Pecos River that have been more or less rearranged by the wind.

A most remarkable accumulation of dune sand is the large deposit of gypsum sand that constitutes the "White Sands" west of Alamogordo. These sands occupy an irregular area about 27 miles long by 10 to 13 miles wide, and at the ends of this area they merge into dune sands consisting mainly of quartz grains. The gypsum has been brought to the surface by a seepage of water, probably from underlying Chupadera beds, and deposited on the surface in crusts,which have crumbled to sand and in the course of many centuries have been piled by wind into great dunes covering many square miles.

Glacial deposits.—Deposits of rock débris on some of the higher parts of the Sangre de Cristo Mountains are probably glacial moraines. They have not been mapped. One of the most notable deposits, according to Stevenson,[25] covers the pass between Vermejo and Costilla Creeks at an altitude of about 10,150 feet. Its surface is hummocky, with many irregular depressions, some of which are occupied by ponds. Distinct moraines occur along the east side of Costilla Park on the headwaters of Costilla Creek.

[22b] In this deposit at El Paso Richardson has collected teeth identified by J. W. Gidley as *Elephas columbi*, *Equus complicatus*, and probable *Tapirus haysii* (El Paso folio, No. 166).

[23] Meinzer, O. E., Geology and ground-water resources of Estancia Valley, N. Mex.: U. S. Geol. Survey Water-Supply Paper 275, 1911; Geology and water resources of the Tularosa Basin, N. Mex.: U. S. Geol. Survey Water-Supply Paper 343, 1915.

[24] Schwennesen, A. T., Ground water in the Animas, Playas, Hachita, and San Luis Basins, N. Mex.: U. S. Geol. Survey Water-Supply Paper 422, 1918.

[25] Stevenson, J. J., Report upon geological examinations in southern Colorado and northern New Mexico during the years 1878 and 1879: U. S. Geog. Surveys W. 100th Mer. Rept., vol. 3, Suppl., pp. 177-178, 1881.

Gila conglomerate.—In many of the deeper valleys of southwestern New Mexico there are exposures of conglomerate believed to be the eastern extension of the Gila conglomerate of eastern Arizona. It is most extensively exposed along Gila River and its branches, but similar material appears in the valley of the Mimbres and in the valley of the Rio Grande in the vicinity of Socorro and to the south. Rocks of this kind in a portion of this valley near the Sierra Caballo have been classed as Palomas gravel by Gordon [26] and regarded as Pleistocene.

IGNEOUS ROCKS

There are extensive masses of igneous rocks in most parts of New Mexico, comprising intrusive dikes, sills, and stocks, mostly of pre-Cambrian, late Cretaceous, Tertiary, and Quaternary age, and volcanic rocks of late Cretaceous, Tertiary, and Quaternary age. Most of these rocks have not been studied or mapped in detail, but many scattered facts regarding them, especially in certain mining districts, are on record.

Intrusive rocks.—The pre-Cambrian granites are intrusive and in many places they are exposed cutting gneiss, schist, quartzite, and other pre-Cambrian rocks, and there are also syenite, amphibolite, porphyry, and other pre-Cambrian intrusive rocks, some of which cut granite. In many districts sedimentary rocks ranging from Cambrian to Cretaceous are cut by porphyry and other intrusive rocks of various kinds in stocks, dikes, or sills. No intrusive rocks of Paleozoic age have been observed. In all parts of the State there are dikes of diabase and other similar rocks such as the one shown in Plate 19, *A*, some of them cutting Tertiary strata and Quaternary gravel and sand. Most of these dikes are feeders of Quaternary lava flows.

Many descriptions of the intrusive rocks in mining regions of New Mexico are given by Lindgren.[27] The principal localities referred to are the Organ Mountains, the Tres Hermanas, the Jarilla Mountains, parts of the Sangre de Cristo Range, the Cochiti district, the Cerrillos Hills, the Nogal, White Oaks, and Jicarilla districts in the Sierra Blanca region, the Little Hatchet and Pyramid Mountains, and several mining districts in the southwestern part of the State.

The igneous rocks in the Silver City quadrangle have been described in detail by Paige.[28] They comprise porphyries of several kinds, including quartz monzonite, diorite, and granodiorite, regarded as probably late Cretaceous, and intrusive stocks or dikes of rhyolite, andesite, latite, and diabase of Tertiary age. There are also pre-Cambrian granite, syenite, and porphyry. The intrusive rocks of Luna County [29] comprise the large masses of quartz monzonite and granodiorite porphyries of the Cooks Range and Fluorite Ridge, the

[26] Gordon, C. H., op. cit. (Prof. Paper 68), p. 237.
[27] Lindgren, Waldemar, op. cit. (Prof. Paper 68).
[28] Paige, Sidney, op. cit. (Folio 199), pp. 7-10.
[29] Darton, N. H., op. cit. (Bull. 618), pp. 19-23, 51-68. See also Folio 207, pp. 3-4, 7-10.

granite porphyry of the Tres Hermanas, and dikes of diabase, keratophyre, andesite, and rhyolite.

Salinas Peak, in the San Andres Mountains, is a large mass of porphyry intruded mostly in the limestones of the Magdalena group. Gallinas Mountain consists of another large intrusive mass of porphyry in the Chupadera formation.

The Cerrillos Hills, in Santa Fe County, consist of large intrusive bodies of monzonite porphyry of various kinds, the character and relations of which have been described by Johnson [30] and Lindgren.[31] Similar intrusions in the Ortiz and San Pedro districts, southeast of Cerrillos, have been described by Lindgren.[32]

Ferguson [33] found that most of the rocks in the Mogollon mining district were volcanic, but there are dikes of basalt and rhyolite and some intrusive andesite.

The intrusive rocks of the Raton coal basin have been described by Mertie.[34] They occur in dikes, plugs, and sills that cut and invade nearly all the Cretaceous rocks and also the Raton formation. They are mostly basaltic rocks similar to the basalt lava flows of the region, but dikes and sills of sodic vogesite also occur.

Ogilvie [35] has found that a dike cutting the Cretaceous shale 4 miles east of Las Vegas is an analcite-bearing camptonite. She also studied intrusive rocks of the Ortiz Mountains [36] and found that the main laccolithic mass is andesite and the rocks on the flanks are dacite with more or less gradation through diorite.

Dikes cut red beds 20 miles northeast of Socorro and Cretaceous strata 15 miles south of Quemado.

A long dike of olivine gabbro, described by Fisher,[37] which cuts the red beds northeast of Roswell, has been studied by Semmes,[38] together with another similar dike a few miles north which is regarded as augite andesite. Semmes also describes a sill of diorite cutting Chupadera strata southwest of Dunlap and gives data regarding the character of the intrusive rocks near Capitan. In 1925 I found a dike cutting the Castile gypsum in sec. 10, T. 26 S., R. 29 E., 30 miles south-southwest of Carlsbad. An examination by C. S. Ross shows that although considerably decomposed, it is a lamprophyre of basaltic habit. A long dike cuts Chupadera strata at the Jones iron mine, west of Carrizozo.

30 Johnson, D. W., The geology of the Cerrillos Hills, N. Mex.: School of Mines Quart., vol. 25, pp. 175-203, 1904.

31 Lindgren, Waldemar, op. cit., pp. 165-166.

32 Idem, pp. 168-171.

33 Ferguson, H. G., The Mogollon district, N. Mex.: U. S. Geol. Survey Bull. 715, p. 174, 1921.

34 Mertie, J. B., jr., U. S. Geol. Survey Geol. Atlas, Raton-Brilliant-Koehler folio (No. 214), pp. 11-12, 1922.

35 Ogilvie, I. H., An analcite-bearing camptonite from New Mexico: Jour. Geology, vol. 10, pp. 500-507, 1902.

36 Ogilvie, I. H., Some igneous rocks from the Ortiz Mountains: Jour. Geology, vol. 16, pp. 230-238, 1908.

37 Fisher, C. A., Preliminary report on the geology and underground waters of the Roswell artesian area, N. Mex.: U. S. Geol. Survey Water-Supply Paper 158, p. 8, 1906.

38 Semmes, D. R., Notes on the Tertiary intrusives of the lower Pecos Valley, N. Mex.: Am. Jour. Sci., 4th ser., vol. 50, pp. 415-430, 1920.

Twin Cones, a prominent butte near the railroad 6 miles west of Gallup, consists of a dike or neck of an intrusive rock between minette and vogesite, which is flanked by a large amount of breccia.[39]

Gregory [40] found several igneous masses in the western part of the San Juan, notably the Ship Rock, Mitten Rock, and prominent dikes in Todilto Park. Some of the latter are probably remains of volcanic plugs and consist in part of agglomerate. The petrology of these rocks which are mostly monchiquite, has been studied by L. V. Pirsson.[41]

Volcanic rocks.—A large area in New Mexico is covered by products of volcanic eruptions that occurred mainly in Tertiary and Quaternary time. There were, however, flows of considerable extent in late Cretaceous time in the southwestern part of the State, but it is difficult to separate the lavas of that period from later ones. In Tertiary time many different lavas were erupted and much volcanic fragmental material was deposited between the flows, together with sand and gravel in some areas. No widespread regularity in the sequence of eruptions has yet been established, and outflows of similar lava appear to have taken place at different times. In general it has not been possible to separate the later Tertiary outflows from those of earlier Quaternary time, especially the basalts capping high mesas. Most of the tilted flows are regarded as pre-Quaternary.

The largest areas of volcanic rocks are in the west-central part of the State, where the Tertiary lava flows cover many thousands of square miles and probably have great aggregate thickness. They present considerable variety, including latite, andesite, rhyolite, basalt, and various fragmental volcanic products such as agglomerate, tuff, and ash. In places they have been uplifted and faulted extensively. In most areas the succession and relations of these volcanic rocks have not been studied in detail.

Ferguson [42] has studied these rocks in the Mogollon district, where the succession exposed has a maximum thickness of 8,000 feet, of which 6,400 feet represents lava flows and fragmental volcanic deposits and the remainder sedimentary deposits laid down by streams. The lava sheets in this region are very irregular in thickness and extent. The following list gives the order and the maximum thickness observed:

	Feet
Andesite with dacite flows	600
Rhyolite tuff	400
Andesite	600
Rhyolite, coarsely spherulitic	1, 200
Andesite and basalt	800
Sandstone	100
Rhyolite with quartz phenocrysts	700
Sandstone with andesite flow in lower part	400
Rhyolite and rhyolite tuff	1, 400
Rhyolite, minutely spherulitic	700

[39] Darton, N. H., op. cit. (Bull. 435), p. 63.

[40] Gregory, H. E., op cit. (Prof. Paper 93), pp. 83-107.

[41] Idem, pp. 107-108.

[42] Ferguson, H. G., The Mogollon district, N. Mex.: U. S. Geol. Survey Bull. 715, pp. 174-183, 1921.

Many facts regarding the character and relations of the eruptive rocks in the mining districts of the State have been given by Lindgren,[43] from observations by himself, L. C. Graton, and C. H. Gordon. These relate mainly to the Mogollon, Cochiti, Socorro, Magdalena, Rosedale, Mimbres, Steeple Rock, and Lordsburg districts.

The lavas and associated deposits in the northern margin of the great central western volcanic area have been studied by Winchester,[44] who has proposed for them the name Datil formation. A representative section of the succession is as follows:

Section of Datil formation at north end of Bear Mountains, 6 miles southeast of Puertecito, Socorro County, N. Mex.

	Feet
Quartz rhyolite	120
Conglomerate and sandstone, reddish, friable; conglomerate contains angular fragments of igneous rock	40
Sandstone	35
Conglomerate with pebbles as large as 1 foot in diameter	50
Sandstone and conglomerate in alternating beds	25
Sandstone, argillaceous	4
Tuff, conglomeratic, with pebbles and angular fragments as much as 18 inches in diameter	60
Rhyolite, vitreous, light colored	4
Andesite, light purple, vesicular	8
Agglomerate with igneous pebbles as much as 1 foot in diameter	17
Tuff, similar in composition to 65-foot bed below but gray and rather porous and slightly more basic	105
Tuff, red, compact, with groundmass of glass, iron ore, feldspar, and secondary calcite; inclusions of glassy material containing phenocrysts of feldspar, biotite, and iron ore	65
Sandstone, friable, containing earthy material	127
Covered	60
Tuff, conglomeratic, dark, slate-colored; angular fragments of igneous rock; maximum diameter of rounded pebbles 18 inches	420
Sandstone, red, argillaceous; contains streaks of gypsum	210
Covered but contains some yellow sand	190
Conglomerate like 4-foot bed below	5
Sandstone, thin bedded, with clay	1½
Clay, red, with sand and mica	12
Conglomerate, reddish, pebbles as much as 4 inches in diameter in matrix of clay, feldspar, and quartz	4
Clay, red, with sand and mica specks	15
Not exposed	175
Conglomerate, reddish gray, with well-rounded fragments of igneous and sedimentary rocks, including limestone	8
Conglomerate, white, well-rounded pebbles, maximum diameter 6 inches, of granite, obsidian, feldspar, and quartz	64
	1,824½

[43] Lindgren, Waldemar, op. cit. (Prof. Paper 68).
[44] Winchester, D. E., op. cit. (Bull. 716), pp. 9-10.

The eruptive rocks of the Silver City quadrangle have been differentiated by Paige.[45] The flows of probable late Cretaceous age consist of rocks of the diorite-andesite group with agglomerate or flow breccias. The Tertiary lavas, which cover highland areas in different parts of the quadrangle, consist of rhyolite, andesite, quartz latite, and breccia, with interbedded deposits of ash tuff and gravel. Quaternary flows of basalt mostly less than 100 feet thick occur interbedded with gravel and sand.

In Luna County [46] the succession of volcanic rocks varies considerably from place to place and includes large bodies of agglomerate and other fragmental deposits. The thickest and most extensive sheets are rhyolite, latite, and andesite of various kinds and minor amounts of quartz basalt, keratophyre, and quartz diorite. These are mostly of Tertiary age. There are also basalt flows of Quaternary age.

Some of the volcanic rocks collected by Mearns along the Mexican boundary have been described by Lord.[47] They comprise basalt, andesite, and rhyolite and were collected in the vicinity of boundary monuments 15, 19, 20, 35, 40, and 55.

Iddings [48] has described in detail the petrography of rhyolite, tuff, andesite, and basalt (some of it quartz-bearing), collected by J. W. Powell in the Valle Grande ("Tewan") Mountain region, and Henderson [49] has given an account of some features of the great tuff deposits of this region.

The volcanic rocks of Mount Taylor and the Zuni Mountain region have been described by Dutton [50] and Johnson.[51] Herrick [52] has described relations in the Albuquerque region and about Socorro. Volcanic rocks on the Chuska Mountains, in the western part of San Juan County, have been described by Gregory.[53]

The volcanic rocks in the Raton coal field have been described by Mertie.[54] The oldest flows are mostly on the higher mesas, and nearly all the younger lavas are on the lower lands, as there was

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45 Paige, Sidney, op. cit. (Folio 199), pp. 9-10.

46 Darton, N. H., op. cit. (Bull. 618), pp. 51-68. See also Folio 207, pp. 7-9.

47 Lord, E. C. E., Petrographic report on rocks of the United States-Mexico boundary: U. S. Nat. Mus. Proc., vol. 21, pp. 773-782, 1899.

48 Iddings, J. P., On a group of volcanic rocks from the Tewan Mountains, N. Mex.: U. S. Geol. Survey Bull. 66, 1890.

49 Henderson, Junius, Geology and topography of the Rio Grande region in New Mexico: Bur. Am. Ethnology Bull. 54, pp. 23-39, 1913.

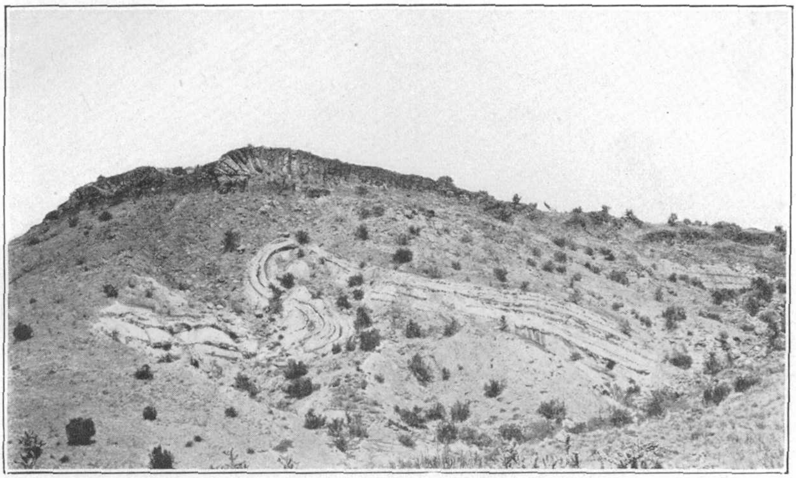
50 Dutton, C. E., Mount Taylor and the Zuni Plateau: U. S. Geol. Survey Sixth Ann. Rept., pp. 105-198, 1886.

51 Johnson, D. W., Volcanic necks of the Mount Taylor region, N. Mex.: Geol. Soc. America Bull., vol. 18, pp. 303-324, 1907.

52 Herrick, C. L., The geology of the environs of Albuquerque, N. Mex.: Am. Geologist, vol. 22, pp. 23-43, 1898.

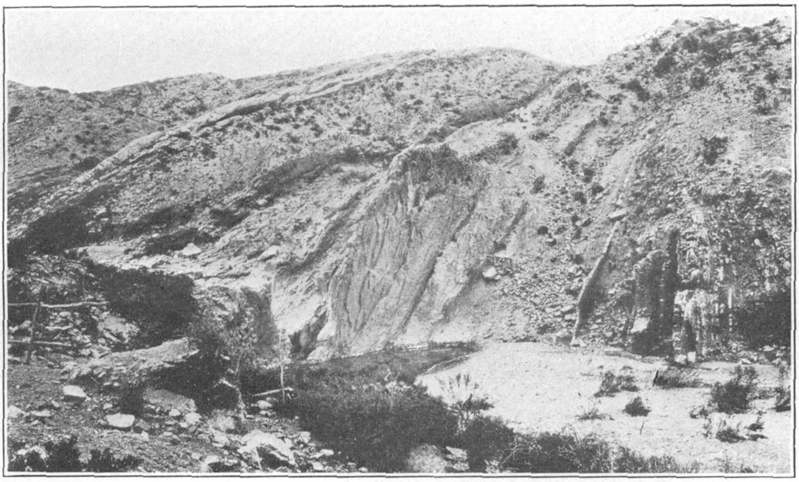
53 Gregory, H. E., op. cit. (Prof. Paper 93), pp. 98-100.

54 Mertie, J. B., jr., op. cit. (Folio 214), pp. 9-11.



A. TWIST IN GYPSUM AND ASSOCIATED RED BEDS OF LOWER PART OF CHUPADERA FORMATION UNDER BASALT NEAR PYRAMID CONE, 25 MILES NORTHEAST OF SOCORRO

Looking north



B. LIMESTONE OF MAGDALENA GROUP LOCALLY UPTURNED AT OJO DEL AMADO, 5½ MILES NORTHEAST OF SOCORRO

Looking south

considerable erosion of the surface between the several eruptions. Some of the thicker masses consist of a succession of flows separated by scoriaceous material. The oldest lavas, which are on Barilla Mesa and the west end of Johnson Mesa, are from 100 to 500 feet thick and are classed as olivine basalt. The lavas of the second period of eruption are closely similar to the older flows, but those of the later flows comprise basalt, dacite, and andesite, constituting Towndrow Peak, Hunter Mesa, Meloche Mesa, and Cunningham Butte. It is stated by Mertie that the lava flow of Mount Capulin is vesicular and glassy olivine basalt. Its cone, which is about 1,500 feet high and 1½ miles in diameter, consists of fresh cinders and is the product of a very recent eruption on a gigantic scale. The walls of the crater in its top are 75 to 275 feet high.

The volcanic rocks of northeastern New Mexico were mapped many years ago by Prentiss Baldwin, and data from his manuscript map have been used in preparing the geologic map of New Mexico recently published by the United States Geological Survey. Some of the flows in this region are relatively young, for they extend down the bottoms of recent valleys, notably the Cimarron Valley near Folsom, Union County. The lava from the Maxson crater, north of Shoemaker, flowed down the canyon of Mora River and the valley of Canadian River, but these streams have since cut a trench through the basalt, as shown in Figure 137.

The crater-like depression holding Zuni Salt Lake, southwest of Zuni,[55] is rimmed in part by Cretaceous sandstone and in part by lava. It has two cinder cones near its center and a rim of rock fragments, some of them Carboniferous, and is believed to be an explosion crater. Some of its features are shown in Plate 15, *C*. Other craters probably caused by volcanic explosions are the Afton and Kilbourne craters, described by Lee,[56] in the southwestern part of Dona Ana County, northwest of El Paso, Tex.

There are several recent lava flows in the region adjacent to the Zuni Mountains, where numerous fresh craters remain from which flows have run down the bottoms of valleys. The lava of the "malpais" strip in the Tularosa Valley, near Carrizozo, as shown in Plate 16, *A*, and the flows on the plain northeast of Engle, about the Potrillo Mountains, in the valley near Pratt, in the valley near San Jose from Horace to Cubero, and from Cerro Verde south of Suwanee are all products of recent eruptions.

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[55] Darton, N. H., The Zuni Salt Lake: Jour. Geology, vol. 13, pp. 185–193, 1905; Explosion craters: Sci. Monthly, vol. 3, pp. 417–430, 1916.

[56] Lee, W. T., Afton craters of southwestern New Mexico: Geol. Soc. America Bull., vol. 18 pp. 211–220, 1907.

LOCAL GEOLOGY

SOCORRO REGION

GENERAL RELATIONS

The distribution of formations about Socorro and eastward to Chupadera Mesa is shown in Plate 17, which covers an area extending from the south end of the Manzano Mountains to the north end of the Oscura Mountains. The salient structural features are shown in the sections of Figure 4. On the basement of granite rest limestone and sandstone of the Magdalena group; the red Abo sandstone; the succession of red beds, limestone, and gypsum composing the Chupadera formation; the upper series of "Red Beds" (Dockum? group, Triassic); the Upper Cretaceous sandstone and shale representing the Dakota (?), Mancos, and possibly later beds; beds of conglomerate, gravel, and sand of probable Eocene age; a thick succession of tuffs and lavas of late Tertiary age; gravel, sand, and red conglomerate of the Santa Fe formation (upper Miocene and lower Pliocene); and Quaternary alluvium and wash. The following table sets forth the principal features:

Formations in the Socorro region

Age	Formation	Principal features	Thickness (feet)
Quaternary.	Alluvium and wash.	Sand and gravel; local overflows of basalt.	100±
Unconformity			
Upper Miocene and lower Pliocene.	Santa Fe formation.	Sandstone and conglomerate.	500
Unconformity			
Late Tertiary.		Agglomerate, tuff, andesite, latite, etc.	600
Eocene (?)		Shale, sandstone, and conglomerate.	0-1,020
Unconformity			
Upper Cretaceous.	Mancos shale and possibly later beds.	Shale and sandstone.	1,150?
	Dakota (?) sandstone.	Massive gray sandstone.	120?
Unconformity			
Triassic.	Dockum (?) group.	Red shale and sandstone and local conglomerate.	200-300
Unconformity			
Permian.	Manzano group. Chupadera formation.	Limestone, gypsum, and gray and red sandstone.	1,100
	Manzano group. Abo sandstone.	Brown-red slabby sandstone.	800
Pennsylvanian.	Magdalena group.	Limestone, shale, and sandstone.	800-1,000
Unconformity			
Pre-Cambrian.		Light-colored massive granite; some schist and quartzite.	

FORMATIONS

GRANITE

Granite crops out on both sides of the Rio Grande Valley not far from Socorro. One zone extends along the east slope of the Lemitar Mountains, another constitutes the west slope of the Los Pinos Mountains, and a third appears in the central ridge of the Joyita Hills, 6 miles northeast of Alamillo. Granite also rises in great prominence in Ladron Peak, northwest of Socorro, and in the Magdalena Mountains, southwest of Socorro. There are also outcrops in two small anticlines 6 miles east of Socorro, and a small exposure of schist on the east slope of Socorro Peak. The granite is mostly a massive light-colored coarsely granular rock consisting of quartz, feldspar, and more or less mica. Schist and dioritic rocks are included in the complex at some places. These rocks are all similar to those which underlie the Cambrian strata farther south and therefore are believed to be of pre-Cambrian age. Their smooth surface is overlain by sandy sediments at the base of the Magdalena group, with unmistakable evidence of shore conditions and no suggestion of igneous intrusion.

MAGDALENA GROUP (PENNSYLVANIAN)

There are extensive exposures of rocks of the Magdalena group on both sides of the Rio Grande in the vicinity of Socorro. The average thickness is about 800 feet, and the rocks are mostly limestone, with more or less shale and sandstone interbedded in the lower portion. Complete sections are exhibited in the several anticlinal uplifts 6 miles east of Socorro, where the outcrop extends from underlying granite to the overlying Abo sandstone. A portion of one of these exposures is shown in Plate 19, *C*. The greater part of the group appears also in the eastern slope of the Socorro and Lemitar Mountains, lying on granite and overlain unconformably by the late Tertiary igneous succession. In the Joyita Hills uplift the group is broken by faults and overlain by younger formations, so that the section is not complete.

The larger features of the stratigraphy of the Magdalena group are uniform throughout, but there are local variations in the occurrence of sandstone and shale members. In the slopes west of Socorro the basal bed consists of 25 feet of gray to white quartzite, which is overlain by fossiliferous limestone, of which 400 feet is exposed. In Arroyo del Tajo the following strata are exposed:

Section of basal beds of Magdalena group on Arroyo del Tajo, 5 miles east of Socorro

	Feet
Limestone	Many.
Quartzite, gray, grading up to brown sandstone	50
Shale, gray, hard	5
Limestone, buff, sandy, very fossiliferous	6
Quartzite, in places conglomeratic; shale near the middle	8
Granite.	

A complete section of the Magdalena group in or near Arroyo de la Presilla, above the old fire-clay pits, is as follows:

Section of Magdalena group on Arroyo de la Presilla, 6 miles east of Socorro

	Feet
Abo sandstone.	
Limestone, slabby to medium bedded	50
Limestone, light colored, massive, high cliff	45
Limestone, gray, medium bedded	60
Sandstone, buff, cross-bedded	10
Shale, dark, and slabby layers, especially near top	65
Sandstone, dark	7
Shale and limestone	17
Limestone, blue and buff, massive, ridge maker	30
Shale, gray, with limestone layers	70
Limestone, gray, slabby to massive	45
Sandstone, gray, cross-bedded	7
Limestone and shale; weather brown, many fossils	50
Limestone, dark, massive	6
Shale	65
Limestone, slabby to medium bedded	205
Limestone with interbedded sandy shale and rusty sandstone	70
Limestone, brown, very fossiliferous	30
Sandstone, gray	40
Limestone, hard, very fossiliferous	20
Sandstone, very compact	10
Shale, siliceous, buff	20
Fire clay	11
Sandstone, very compact, locally conglomeratic	8
Granite.	
	941

The lower beds of the Magdalena on Arroyo del Tajo, 1 mile southwest of the fire-clay pits, are as follows:

Section of lowest beds of Magdalena group on Arroyo del Tajo, southeast of Socorro

	Feet
Limestone.	
Sandstone, brown	10
Sandstone, hard, gray, silicified	40
Shale, hard, gray	5
Limestone, buff, sandy, very fossiliferous	6
Sandstone, hard, grayish brown with deposit of green shale in middle. Local conglomerate at base	8
Granite.	

Impressions of the bark of a large plant, *Lepidodendron obovatum* (Sternberg), accompany the fire clay. This species, identified by David White, indicates a Pottsville (basal Pennsylvanian) age for the lowest Pennsylvanian in this region.

Fossils are abundant in the Magdalena strata, representing a well-known fauna of Pennsylvanian age. The following species were identified by G. H. Girty:

Lower bed of limestone not far above granite near the fire-clay pits 6 miles east of Socorro:

Lophophyllum profundum?
Derbya crassa.
Productus cora.
Productus walkeri.
Spirifer rockymontanus.

Limestone about 300 feet higher, or about midway in the Magdalena:

Pustula nebraskensis.
Dielasma bovidens.
Spirifer cameratus.
Composita subtilita.
Cliothyridina orbicularis.

Lower limestone on the east slope of Socorro Peak, about 100 feet above the base of the Magdalena beds:

Campophyllum torquium?
Marginifera aff. M. wabashensis.
Spirifer rockymontanus.

A short distance northeast of Polvadera Mountain, in the Lemitar Mountains:

Productus cora.
Marginifera n. sp.
Spirifer rockymontanus.
Composita subtilita.
Cliothyridina orbicularia.

Ledges of semicrystalline granular limestone 6 feet above the granite on the same slope:

Abundant crinoid stems.
Cystodictya sp.
Productus aff. P. gallatinensis.
Spirifer rockymontanus.
Composita subtilita.
Hustedia mormoni.
Acanthopecten carboniferus.

MANZANO GROUP (PERMIAN)

Abo sandstone.—The thick series of red sandstones constituting the basal formation of the Manzano group of Lee is prominent in the region east of Socorro. A broad outcrop extends north from the Loma de las Cañas and passes along the east side of the Los Pinos Mountains to the type locality in Abo Valley. Smaller exposures extend along the west side of the uplift of the Joyita Hills. The formation consists entirely of slabby sandstone and hard sandy shale of dark brownish-red color, dissimilar to the other rocks of the region. The thickness is near 800 feet, with slight local variations. In places the outcrops may be repeated by faults which doubtless traverse the formation east of Socorro, especially in the broad areas northwest of Cibolo Cone.

Chupadera formation.—The thick series of sandstone, gypsum, and limestone of the Chupadera formation constitutes the surface of a large area in the region east of Socorro. Smaller exposures occur in the ridges extending north from the vicinity of Carthage, on the

Lomo de las Cañas, Cerrillos del Coyote, Joyita Hills, and the ridges of Cerro Venado, Cibolo Cone, and Mesa del Yeso. The total thickness is about 1,100 feet. The stratigraphy varies considerably from place to place, but in general there is at the base an alternation of soft reddish sandstones and thin limestones not easily separated from the top of the Abo formation. Several beds of gypsum are conspicuous in the upper part of the basal member. The medial beds are largely massive gray sandstone with interbedded limestone, and the top member in this region as elsewhere is a thick body of hard light-gray limestone. (See pl. 20.) Lee[56a] found many fossils of the Manzano fauna in limestone near Mesa del Yeso.

The peak half a mile north of Mesa del Yeso consists of the thick gypsum member ("big bed") overlain by red sandstone and massive gray sandstone with a small remnantal cap of limestone. In the ridge next north, which parallels on the east the old automobile road for some distance, there is a large deposit of gypsum in the lower part of the Chupadera formation. The following beds are exposed:

Partial section of Chupadera formation in north-central part of T. 1 S., R. 2 E., 18 miles northeast of Socorro

	Feet
Sandstone, gray, massive (probably Chupadera but possibly Dakota separated by a fault)	60
Sandstone, brown-red, slabby	40
Sandstone, soft red	3
Gypsum ("big bed")	60
Limestone	6
Sandstone, pale buff, soft to hard	50
Gypsum	20±
Limestone	8
Gypsum parted by layers of limestone and soft pale-red sandstone	240
Sandstone, bright red	30
Shale, red, sandy	50±
Limestone lying on Abo sandstone	12

The 60-foot bed of gypsum on the above section is a conspicuous feature in a wide area of the region east of Socorro as far south as Lomo de las Cañas and beyond, notably about the Armijo ranch and Ojo Trementina. It is overlain by red sandstone and massive hard gray sandstone 100 feet or more thick. The gray sandstone is capped by massive limestone constituting many ridges and cuestas. A sample of this limestone, tested by Chase Palmer in the laboratory of the United States Geological Survey, was found to consist of 52 per cent of calcium carbonate, 38 per cent of magnesium carbonate, and 10 per cent of insoluble material.

In the buttes 2 to 3 miles south of the Armijo ranch, in the north-central part of T. 3 S., R. 2 E., where much of the upper part of the

[56a] Lee, W. T., and Girty, G. H., The Manzano group of the Rio Grande Valley, N. Mex.: U. S. Geol. Survey Bull. 389, p. 23, 1909.

formation has been removed by erosion, there remains a thick body of limestone containing near the middle a 3-foot bed of gray sandstone. Next below this limestone is about 100 feet of massive gray sandstone, in part moderately soft, which gives place abruptly to soft red sandstone containing the thick bed of gypsum which is conspicuous throughout the region south of Socorro. This gypsum member is 60 feet thick in the canyon of Arroyo de las Cañas (see section D, pl. 21) and nearly 100 feet in the ridge 4 miles southeast of Pyramid Crater, where it is parted by several thin beds of limestone.

In the high bare butte 2 miles east of Mesa del Yeso the 60-foot gypsum bed is separated from the 100-foot massive light-colored sandstone above by 10 feet of soft red sandstone, and a similar rock 45 feet thick with a thin limestone member near the top separates it from a 20-foot bed of hard massive limestone below that forms extensive terraces and cliffs on the adjoining slopes. This massive limestone is separated from the thin basal limestone by about 150 feet of pale-red soft sandstone with a few thin beds of limestone and gypsum.

Northwest of the Cerrillos del Coyote, notably near Ojo de la Parida, the upper massive limestone dips under a 40-foot member of speckled light-red shale locally overlain by conglomerate.

On my suggestion Case examined these strata and found in them bones of "Permo-Carboniferous" age similar to those collected by Case and Williston in Rio Arriba County. The bones were mainly in a conglomerate of dark-red pebbles, lying on green, blue, and drab shales in the bank of Arroyo de la Parida at a point not far below the mouth of Canyoncito Colorado, about 8 miles northeast of Socorro. (See pl. 9, *B*.) The following were obtained:[57]

A complete femur of *Eryops* sp.
The distal end of a clavicle of *Eryops* sp.
The distal end of a neural spine of *Eryops* sp.
A femur of *Sphenacodon*.
A fragment of the jaw, with four teeth of *Sphenacodon*.
The distal end of a scapula of a *Sphenacodon* or *Ophiacodon*.
The distal end of a large scapula, possibly *Sphenacodon*.
Fragments of a large pelvis, possibly *Sphenacodon*.
In the bluish shale in the bank of the arroyo, the proximal end of a rib of a diadectic type associated with poorly preserved plant remains.
In the drab shale below the blue, several invertebrates.

These beds overlie the thick body of limestone of the upper part of the Chupadera formation, which rises on a west dip in the adjoining slopes to the east and is prominent in the Cerrillos del Coyote. The aspect and relations of this bone-bearing conglomerate strongly suggest that it is of Triassic age or even a late valley filling, and if this is so the bones were washed out from underlying strata, such as the drab shale member of the Chupadera formation, and redeposited.

[57] Case, E. C., Science, new ser., vol. 44, p. 709, 1916.

TRIASSIC ROCKS (DOCKUM ? GROUP)

Red shale and sandstone of Triassic age and probably belonging to the Dockum group lie above the Chupadera formation throughout the area east of Socorro. They are of Chinle aspect. In part of the area, however, it has not been practicable to separate them from red shale and other beds which at some places may constitute the top of the Chupadera formation; possibly some Lower Triassic also is present. The thickness of the Triassic beds ranges from 200 to 300 feet. The most extensive exposures are in the faulted blocks north of Carthage, the long outcrop zone extending northwest from Prairie Spring, the southern part of the Valle del Ojo de la Parida, and the areas southeast of La Joya. There are small outcrops 2 miles south of the Armijo ranch, in a small syncline 2 miles southwest of the ranch, and in a narrow zone 2 miles east of the ranch, all in the southeastern part of T. 3 S., R. 2 E. In these localities there is dark brownish-red shale with layers of limy concretions and more or less red sandstone. These beds have the same attitude as the Chupadera formation and the overlying Dakota (?) sandstone, but they are separated from each of these formations by a long time hiatus. Some of the upper red shale in places may possibly represent the Morrison formation, but it probably does not.

In the extensive exposures north of Carthage all the beds are exhibited. Possibly there is a small amount of Permian red shale at the base here, but the principal rocks are red and purple shales with minor members of nodular concretionary gray limestone.

In the vicinity of Ojo de la Parida the 40-foot member of light-red shale, locally overlain by conglomerate, at the top of the Chupadera formation is overlain by 40 to 50 feet of brown-red slabby sandstone with some coarse and moderately massive layers, 65 feet of red shale, 50 feet of dirty-gray to purplish shale with several thin layers of limestone in nodular slabby form, and 30 feet of red sandstone, mostly slabby. The red sandstone is overlain by gray pebbly sandstone probably of Tertiary age.

In the slopes north of Carthage the outcrop of the Dockum (?) group is a mile wide at one place, and the strata dip about 5° E., but some of the beds are repeated by faulting. At the top, but separated from the Dakota (?) sandstone in places by 4 feet or more of light-buff clay, is a succession of 30 feet of purple shale; 100 feet of mostly red-brown shale with many beds of purplish-gray sandstone, some coarse; about 120 feet of shale and thin-bedded sandstone, mostly purplish to brown-red; 30 feet of pink shale; and at the base 50 feet of bright-red sandy shale. Near the middle of these beds several layers of nodular dark-gray limestone are included—a feature distinctive at all localities.

There are numerous exposures of the Dockum (?) rocks near the Cox ranch, in the southwestern part of T. 2 S., R. 3 E. The thickness is about 450 feet, and the dip is in places 20°. Red shale and brown sandstone predominate. Some of the sandstone members are 20 feet thick. Several beds of nodular limestone or limestone conglomerate are included. At the base is 20 feet of purplish-gray massive sandstone lying on limestone of the Chupadera formation. Next above are blue-gray shale with limestone nodules, thin to slabby brown sandstone and red shale with nodules, and conglomerate of limestone pebbles. In this area as at other localities the precise lower limit of the formation is in doubt.

In the east face of the ridge in sec. 1, T. 2 S., R. 1 E., there is an exposure of light-red clay with intercalated layers of coarse sandstone. All the beds are capped by a mantle of granite boulders resulting from the disintegration of a deposit of Tertiary age.

Case examined the Triassic rocks in the slopes north of Carthage and obtained several fossil bones, on which he makes the following report:[58]

The red beds above the limestone are faulted down against it at the old limekiln and can be traced up the valley for several miles. Close to the limekiln and about halfway up to the base of the Cretaceous there was found a small bed of conglomerate containing an abundance of lamellibranchs not yet identified. A few fragments of bone occur in the same bed, while farther up the valley but in slightly lower beds the following fragments were found:

1. A section, about 4 inches long, of the snout of a slender-jawed phytosaur suggesting *Angistorhinus* or *Mystriosuchus*, with teeth diverging at an angle of 15° to 20°. This was on a concretion of dark-brown impure limestone occurring as a lens in the red shale.
2. Three vertebrae found at different places, apparently phytosaurian.
3. The proximal and distal ends of a large limb bone, too badly worn to be identified but certainly not from any of the known forms of Permo-Carboniferous vertebrates.
4. Two small dorsal plates, one with a median dorsal ridge and the others regularly hexagonal and with a ventral rugosity, evidently for attachment to the dorsal spine of a vertebra.
5. Several imperfect and large limb bones; two suggesting the ends of a tibia and a radius respectively.
6. Two fragments of thoracic plates, one from a large plate with deep radial flutings and the other smaller with similar markings. Both are evidently stegocephalian.
7. A large vertebral centrum, evidently from a stereospondylous stegocephalian.

Most of these bones were found in conglomerate, but some of them were in lenses of impure limestone in the red beds. Case regards this fauna as certainly Triassic.

[58] Case, E. C., Science, new ser., vol. 44, pp. 708, 709, 1916.

CRETACEOUS ROCKS

Sandstone and shale of Upper Cretaceous age crop out in several areas in the region east of Socorro. At the south is the well-known coal basin at Carthage, and at the north is the succession of exposures in the Valle del Ojo de la Parida and on Agua Torres east of La Joya. There is also a wedge-shaped area of considerable extent in the valley of Taylor Creek and near Prairie Spring, which probably extends southward under part of the Jornada del Muerto. It is not unlikely that rocks of this age occupy the basin traversed by the Rio Grande in the Socorro region.

The rocks comprise a basal sandstone supposed to represent the Dakota sandstone and possibly also the Purgatoire formation and shale and sandstone representing the Mancos shale, and possibly also some beds of later age, but the identity of these supposed later beds is not established. Coal beds are included in the medial and upper members, notably about Carthage, where they have been extensively mined for many years. These beds also occur and have been worked to a small extent in the Taylor Creek area, in the Valle del Ojo de la Parida, and on Arroyo Cibolo. The stratigraphy of the beds in the Carthage region has been described by Gardner,[59] who gives the following section of Upper Cretaceous strata:

Section of Cretaceous rocks in Carthage coal field

	Feet
Montana:	
Sandstone, tan-colored, and drab shale with traces of coal	600
Shale and thin beds of sandstone. Top contains *Ostrea* sp., *Anomia micronema* Meek?, *Modiola* related to *M. regularis* (White), *Corbicula?* sp., *Corbula* sp., *Melania* sp., and *Admetopsis?* sp.	40
Coal (Carthage mines)	5
Shale, drab	20
Sandstone, massive, brown	20
	685
Colorado:	
Shale, drab, with yellowish lime concretions	120
Shale, yellowish, with brown sandstone	45
Sandstone, massive, soft, brown, fossiliferous, containing *Ostrea* sp., *Ostrea lugubris* var. *belliplicata* Shumard, *Pinna* sp., *Pholadomya* sp., *Fasciolaria?* sp., *Prionotropis woolgari* (Mantell)?, and *Coilopoceras colleti* Hyatt	15
Shale, drab	40
Shale, drab, with thin brown sandstone	135
Sandstone, massive, gray	10
Sandstone and shale; in center a sandstone layer containing *Inoceramus labiatus*, *Cardium* sp., *Cyprimeria* sp., *Psilomya* sp., *Gyrodes* sp., *Fasciolaria?* sp., and *Volutoderma* sp	30
Shale, drab	500
	895
Dakota (?): Sandstone, hard, gray, in bold hogback; some thin shale	200

[59] Gardner, J. H., The Carthage coal field, N. Mex.: U. S. Geol. Survey Bull. 381, p. 455, 1910.

The Dakota (?) sandstone lies on dark-red sandstone with red and drab shale 1,300 feet thick, regarded as Triassic. The lower fossiliferous bed 500 feet above the Dakota (?) sandstone strongly suggests the Greenhorn limestone underlain by Graneros shale, and the upper fossiliferous bed with concretions is closely similar to the Carlile shale in the northern part of the State.

The lower members of the Mancos shale exposed in the northeast corner of the Socorro region are as follows:

Section of lower part of Upper Cretaceous rocks exposed in the north-central part of T. 1 S., R. 2 E.

	Feet
Mancos shale:	
Gravel cap	20
Dark shale with oval concretions	60
Sandstone, light brownish buff	6
Shale, dark, with concretions	60
Sandstone, light brown-buff	15
Shale, light and dark	100
Shale, very limy (suggests Greenhorn limestone)	10
Shale, light and dark	100
Sandstone, hard, massive, gray-buff, in three ledges	60
Probably Dakota sandstone but possibly Triassic: Slabby sandstone, dirty gray-brown; part exposed	30
Probable Triassic.	

The several buttes southeast of Mesa del Yeso consist largely of yellow sandstone and dark shale with concretions. One thin bed of highly carbonaceous shale which dips 5° S. is included.

Fossils were collected from Upper Cretaceous rocks at several points in the region east of Socorro and identified by T. W. Stanton as follows:

30 feet above coal at Garcia y Goebel mine northeast of Socorro:
- Ostrea elegantula.
- Camptonectes symmetrica.
- Cardium sp.
- Liopistha (Psilomya)? sp.
- Lunatia? sp.

Upper Cretaceous, most probably of Colorado age.

40 feet above coal at Garcia y Goebel mine, northeast of Socorro:
- Ostrea elegantula.

50 feet above coal at new Herring coal mine, 20 miles north of Socorro:
- Ostrea elegantula.
- Ostrea sannionis?
- Cardium sp.
- Cyprimeria? sp.

Probably of Colorado age.

40 feet above coal 1¼ miles south of Perry Cox place, 11 miles north of Carthage:

Ostrea elegantula.
Anomia sp.
Avicula sp.
Leda sp.
Cardium sp.
Isocardia sp.
Cyprimeria? sp.
Pyropsis sp.
Volutoderma.
Probably of Colorado age.

1 mile southeast of Mesa del Yeso:

Ostrea sp.
Anomia sp.
Cardium curtum.
Mactra sp.
Pugnellus fusiformis.
Of Colorado age; probably corresponding to late Benton.

TERTIARY ROCKS

There are extensive deposits of Tertiary rocks in the Socorro area, but very little attention was given to them in this investigation. In the Rio Grande Valley are deposits of sand and gravel believed to belong to the Santa Fe formation, and on the ridges on each side of the valley are several areas of the igneous succession of agglomerate and tuff and stocks and flows of andesite, latite, and other lavas. The Socorro and Lemitar Mountains and their extensions to the north and south are conspicuous examples of these igneous masses, and a long outcrop zone extends along the ridge between the Valle del Ojo de la Parida and the Rio Grande. Outlying areas occur west of Taylor Creek, 12 miles east by south of Socorro, and in Cerro Colorado, south of Carthage.

In the Carthage coal area, according to Gardner,[60] the coal-bearing beds of Upper Cretaceous age and the underlying beds are overlain unconformably by 1,023 feet of shale, sandstone, and conglomerate, in which was found a tooth identified by J. W. Gidley as possibly *Palaeosyops*. This tooth is regarded by Gidley as certainly of later than Wasatch and probably of about Bridger age. This series is penetrated and overlain by later Tertiary igneous rocks, which rise conspicuously as the Cerro Colorado, a group of prominent peaks a few miles south of Carthage.

In the region east of Socorro, as in some other parts of New Mexico, a conglomerate lies between the Cretaceous beds and the Tertiary igneous series. It may not be in a continuous sheet and apparently does not attain a thickness greater than 50 or 60 feet, but it is a conspicuous feature in many exposures. Some of the most notable of

[60] Gardner, J. H., op. cit. (Bull. 381), p. 454.

these are in the Valle del Ojo de la Parida, where there is a long continuous outcrop and many detached exposures. At the coal mine of Garcia y Goebel on Arroyo Cibolo this conglomerate is not far above the coal bed. In the ridge in the southwestern and southern part of sec. 1, T. 2 S., R. 1 E., it caps Triassic "Red Beds." In the ridge in the northeastern part of sec. 2 it caps the Cretaceous shale, and at the north end of this ridge it is overlain by agglomerate and scoria under solid rhyolite at the base of the Tertiary igneous series.

Buttes in the east side of the Valle del Ojo de la Parida are also capped by this conglomerate. One butte half a mile southeast of Mesa del Yeso, at an altitude of 5,350 feet, has a thin cap probably of a disintegrated bed with many boulders of granite and red sandstone. A smaller butte half a mile to the southwest, in the NE. ¼ sec. 31, T. 1 S., R. 2 E., has a heavy cap of this material dipping south at a low angle. In sec. 32 are two small bouldery knobs, and in sec. 6, T. 2 S., R. 2 E., there is a ridge that exhibits a large amount of the conglomerate, evidently overlapping onto the downfaulted Chupadera and Abo rocks just to the east.

STRUCTURE

As shown in the sections in Figure 4 the principal general structural features near Socorro comprise an anticline near the Rio Grande Valley which extends north to Ladron Peak, a zone of faulted anticlines extending south from the anticline of the Los Pinos and Manzano Mountains; and the broad syncline of the valley of Chupadera Arroyo, of which the east limb rises on the western slope of a prolongation of the anticline of the Oscura Mountains.

There are many variations in pitch, with minor anticlines and synclines, and faults cut the strata in several directions. In the higher anticlines the pre-Cambrian granite is exposed, notably in the Lemitar Mountains, the Joyita Hills, the uplift 6 miles east of Socorro, and the Los Pinos Mountains, and a small exposure appears low in the east flank of Socorro Peak. Cretaceous rocks occupy the deeper basins, in part overlain by the Tertiary volcanic series. The Santa Fe formation occupies part of the Rio Grande Valley, but it is largely overlain by later sand and gravel, especially in the lowlands near the river and in the wide talus slope west of the Los Pinos Mountains.

PRAIRIE SPRING-CERRO VENADO ANTICLINE

As shown in section *B–B′*, Figure 4, the Cerro Venado Ridge is on an anticline of considerable prominence. The axis extends north in the slopes east of Pyramid Crater, but it flattens greatly in that direction, although it is well defined in the ridges east of Rayo. To the south of section *B–B′* the arch pitches downward, and at Prairie Spring the limestone and sandstone of the Chupadera formation, which are so prominent in the Cerro Venado, pass beneath Triassic

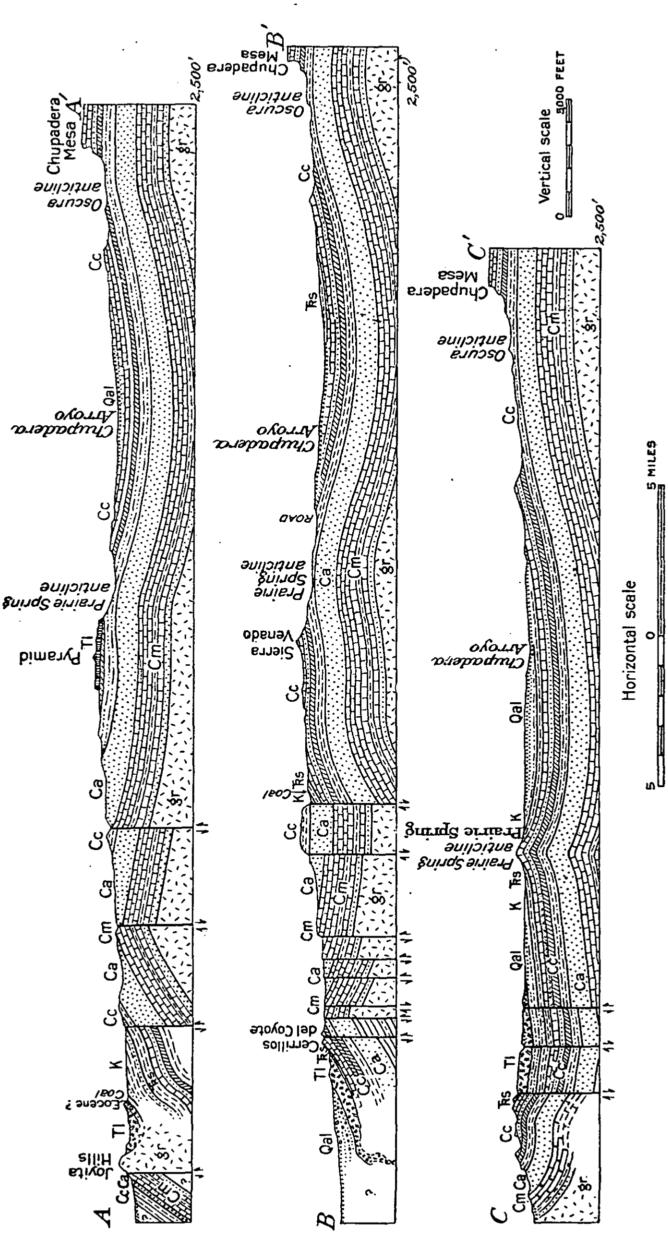


FIGURE 4.—Sections across eastern Socorro County. Qal, Alluvium; Tl, Tertiary lavas; K, Cretaceous rocks; Trs, Triassic "Red Beds"; Cc, Chupadera formation; Ca, Abo sandstone; Cm, Magdalena group; gr, granite. A-A', From Joyita Hills to Chupadera Mesa; B-B', from east of Lemitar through Sierra Venado; C-C', from southeast of Socorro through Prairie Spring

"Red Beds." The outcrop of these "Red Beds" extends northward along the west slope of the anticline to sec. 19, T. 2 S., R. 2 E., where the strata are cut off by the north-south fault, as shown in section *B–B′*. These "Red Beds" and the overlying Cretaceous rocks also extend northward up the basin east of the anticline under the wide valley of Arroyo Chupadera. The dips in this uplift are in general at very low angles. In the high ridge of the Cerro Venado, which is capped by limestone and gray sandstone of the Chupadera formation, the beds dip gently to the west, and the same strata constitute the less prominent ridge in the east side of T. 2 S., R. 4 E., in which the beds show a pronounced eastward dip into the basin of Arroyo Chupadera. Between these two ridges is a wide rolling area of red beds and gypsum of the lower part of the Chupadera formation, and a deep arroyo in the center of T. 2 S., R. 4 E., cuts through to the Abo sandstone for an area of about 1 square mile. A short distance north of this place there is exposed under the southwest face of the cap of lava from Pyramid Crater a peculiar local contortion in the lower members of the Chupadera formation, as shown in Plate 18, *A*. Evidently this flexing was effected before the extrusion of the lava, for the lava lies on a smooth erosion plane.

Just west of Prairie Spring is a small local anticline or elongated dome on the west slope of the main anticline. It is marked by a small ridge of the upper limestone of the Chupadera formation dipping under red shale on all sides. The spring is at the southwest end of this dome. Two samples of the water from this spring and one from Trementina Spring, a few miles west, tested by W. B. Hicks in the laboratory of the United States Geological Survey, showed 0.32 and 0.45 per cent of total solids, mainly calcium sulphate with only a very small amount of potassium.

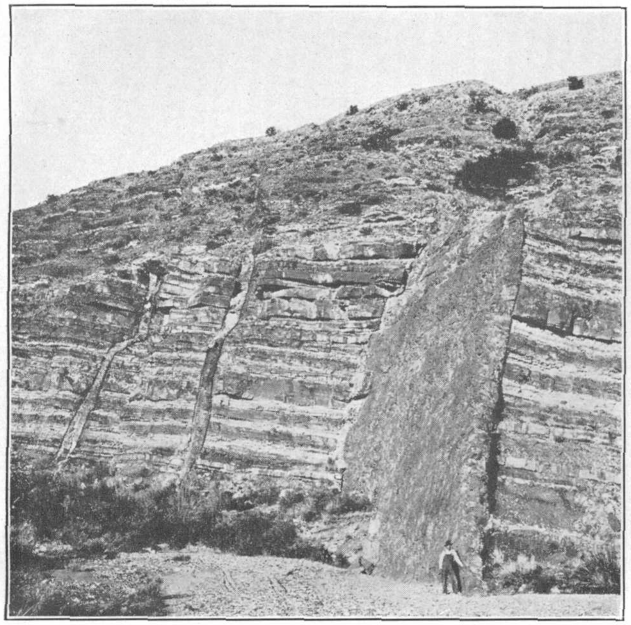
CERRILLOS DEL COYOTE TO CARTHAGE

The high limestone ridges beginning about 5 miles east of Socorro occupy a narrow belt about 18 miles long extending from the Cerrillos del Coyote nearly to Carthage. They are in greater part in Rs. 1 and 2 E. Some of the higher ridges, such as the Lomo de las Cañas, Cerro del Viboro, and Cerrillos del Coyote, are conspicuous topographic features. The structure is in the main anticlinal, being a continuation of the Sandia-Manzano-Los Pinos uplift. There are many faults and minor flexures, most of them longitudinal to the main line of uplift—that is trending nearly north. Some of the faults, however, are transverse to this course, and the flexures have much pitch. Some general features are shown in the section in Figure 4. The formations present are the Magdalena group, Abo sandstone, Chupadera formation, Dockum (?) group, and Mancos shale, with more or less overlap of Tertiary and Quaternary deposits and of Tertiary igneous rocks. The underlying pre-Cambrian granite is exposed in the axis of two small uplifts about 6 miles east of Socorro. Some details of the stratigraphy of the sedimentary rocks in this area are given on page 67. The more important details as to structure and relations are shown on sections A to F, Plate 21.

The Cerrillos del Coyote consist of a small group of buttes capped by limestone lying on massive gray sandstone with soft red sandstone, gypsum, and thin limestone on the lower slope, all Chupadera formation. The beds dip west and are traversed by faults, as shown in section A, Plate 21. To the south the underlying Abo beds appear; to the north the limestone passes under "Red Beds" of Triassic age, and in places some Tertiary agglomerate abuts against it. On the east side is uplifted Magdalena limestone. A mile south of Ojo del Amado 1,000 feet of the agglomerate dips 30° W. and to the east abuts against a fault, bringing up limestone of the Magdalena group. The Magdalena also constitutes an extensive series of limestone ridges to the south, where its outcrop continues to Arroyo de las Cañas. The Magdalena outcrop is wide on Arroyo de los Pinos, where, as shown in section B, Plate 21, it presents an anticline, a syncline, and a broad anticline. On the east side of the anticline lies a basin of Abo sandstone along the west side of R. 2 E., east of which the limestone of the Magdalena group is brought up again by a fault of considerable throw.

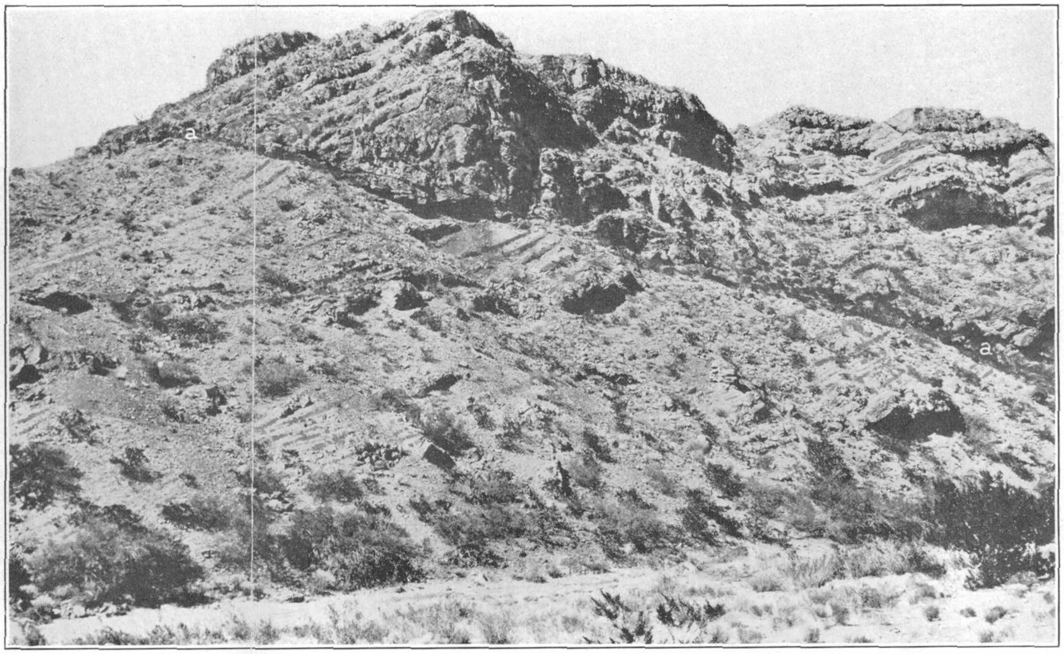
South of Arroyo de los Pinos the anticline in the Magdalena beds rises gradually, and in the northeastern part of T. 3 S., R. 1 E., the underlying granite appears, as shown in section C. A parallel exposure of granite occurs in another anticline lying a short distance to the west. The axis of this anticline passes just east of Ojo del Amado, where the uplifted rocks are mostly buried under Tertiary and later deposits. The granite appears in several other arroyos in this vicinity. The rocks in the syncline between the two axes are exposed on Arroyo de Tio Bartolo, as shown in the section in Figure 5. The relations along the eastern axis are well exposed on Arroyo de la Presilla near the old fire-clay pits, 6 miles east of Socorro. Here, as shown in Figure 6, and Plate 19, *C*, there is a fault which repeats the outcrop of granite and overlying quartzite and fire clay. To the east, up the arroyo, there is a regular monocline exposing a complete section of beds of the Magdalena group (see p. 68), all the overlying Abo beds, and the lower members of the Chupadera formation, which extend to the foot of Lomo de las Cañas. Some of these features are shown in Plate 19, *C*.

The ridges in the eastern part of T. 3 S., R. 1 E., consist of an eastward-dipping succession of limestone on gray massive sandstone, the upper members of the Chupadera formation, repeated somewhat by faulting, as shown in section D, Plate 21. To the east of these ridges the upper limestone passes beneath Triassic "Red Beds,"



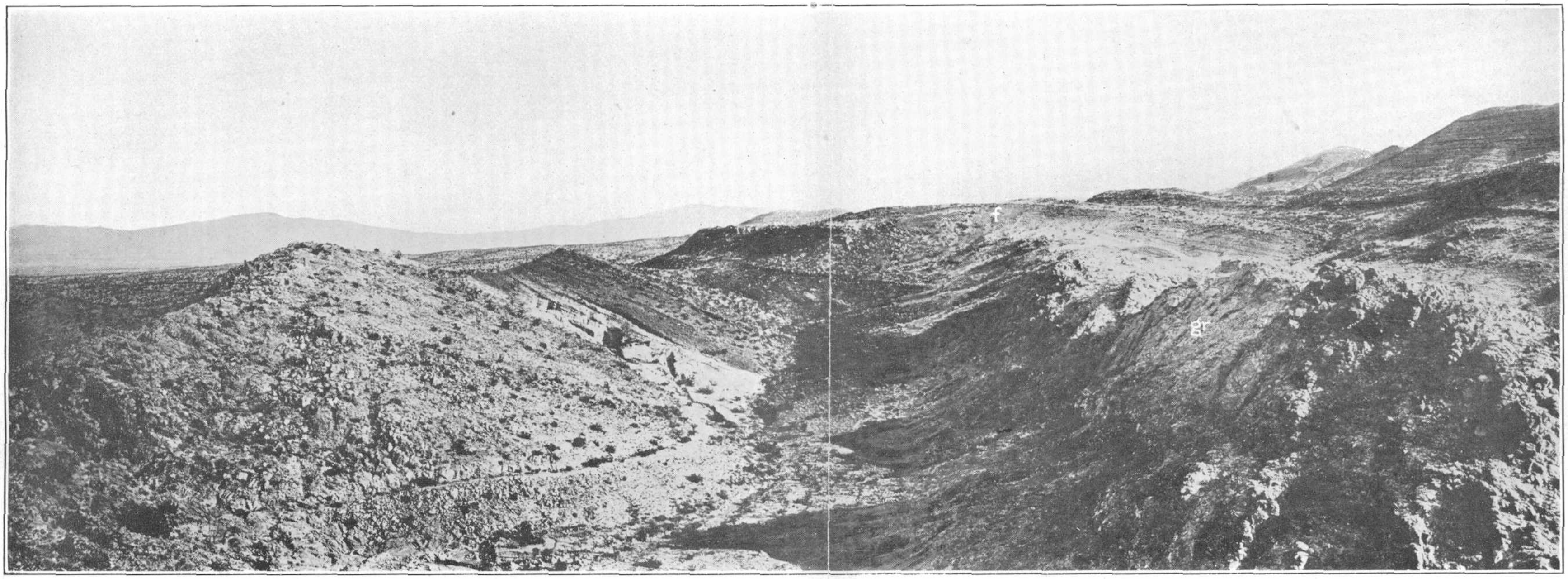
A. DIKES CUTTING ABO SANDSTONE IN ALAMILLO CREEK 18 MILES NORTHEAST OF SOCORRO

Looking southwest



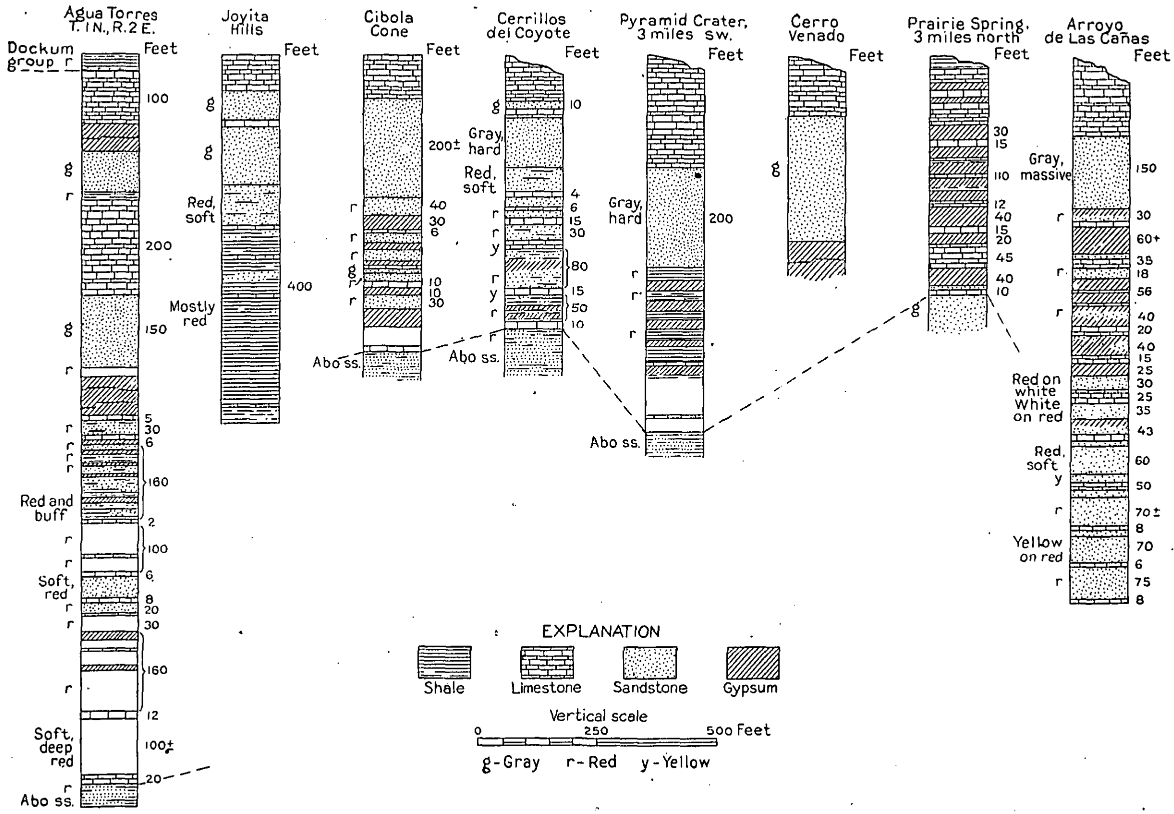
B. OVERTHRUST OF MAGDALENA LIMESTONE ONTO ABO SANDSTONE, JOYITA HILLS, SOUTHEAST OF LA JOYA

North wall of canyon crossing uplift. Looking north. a-a, Fault plane

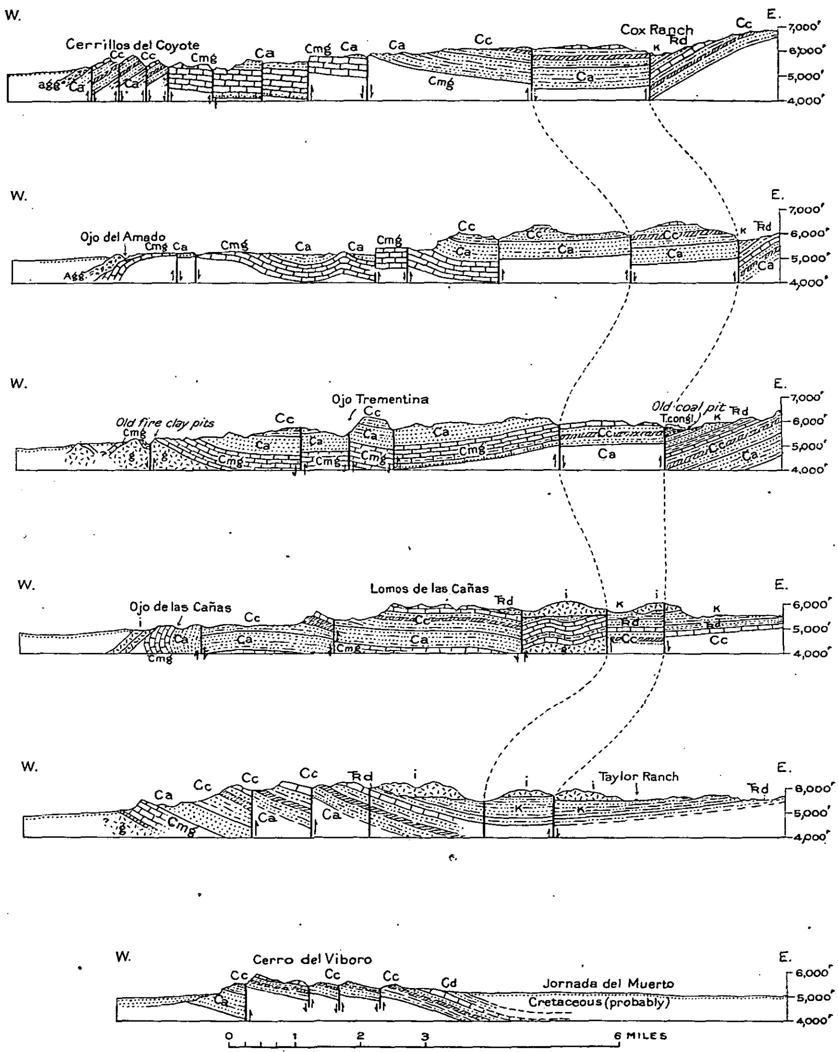


C. FAULT 6 MILES EAST OF SOCORRO

Fire-clay pit in basal Magdalena beds in middle ground. gr, Granite; f, fault. Polvadera Peak in distance to left. All strata are Magdalena group. Looking north along fault

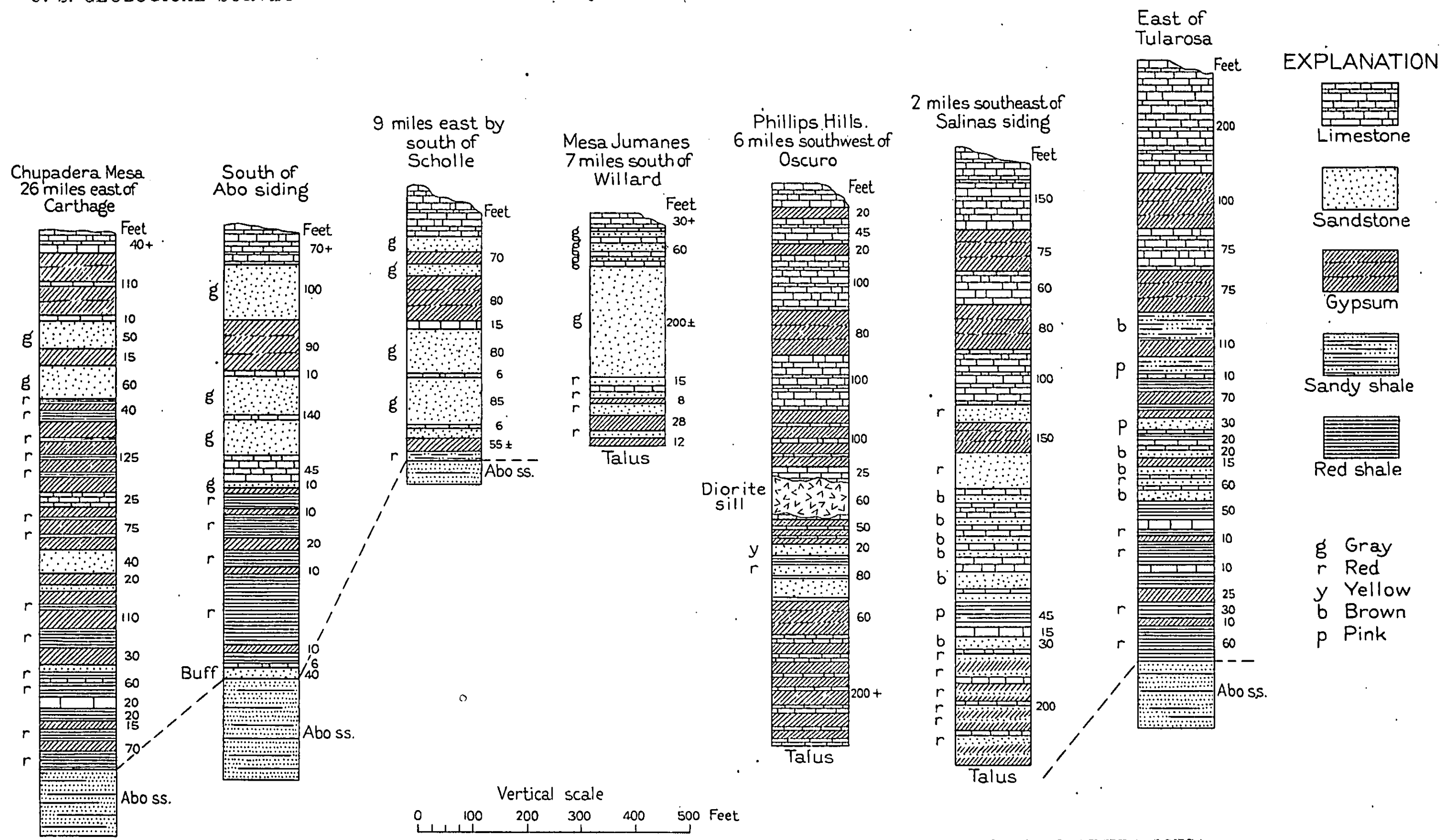


COLUMNAR SECTIONS OF CHUPADERA FORMATION IN SOCORRO COUNTY

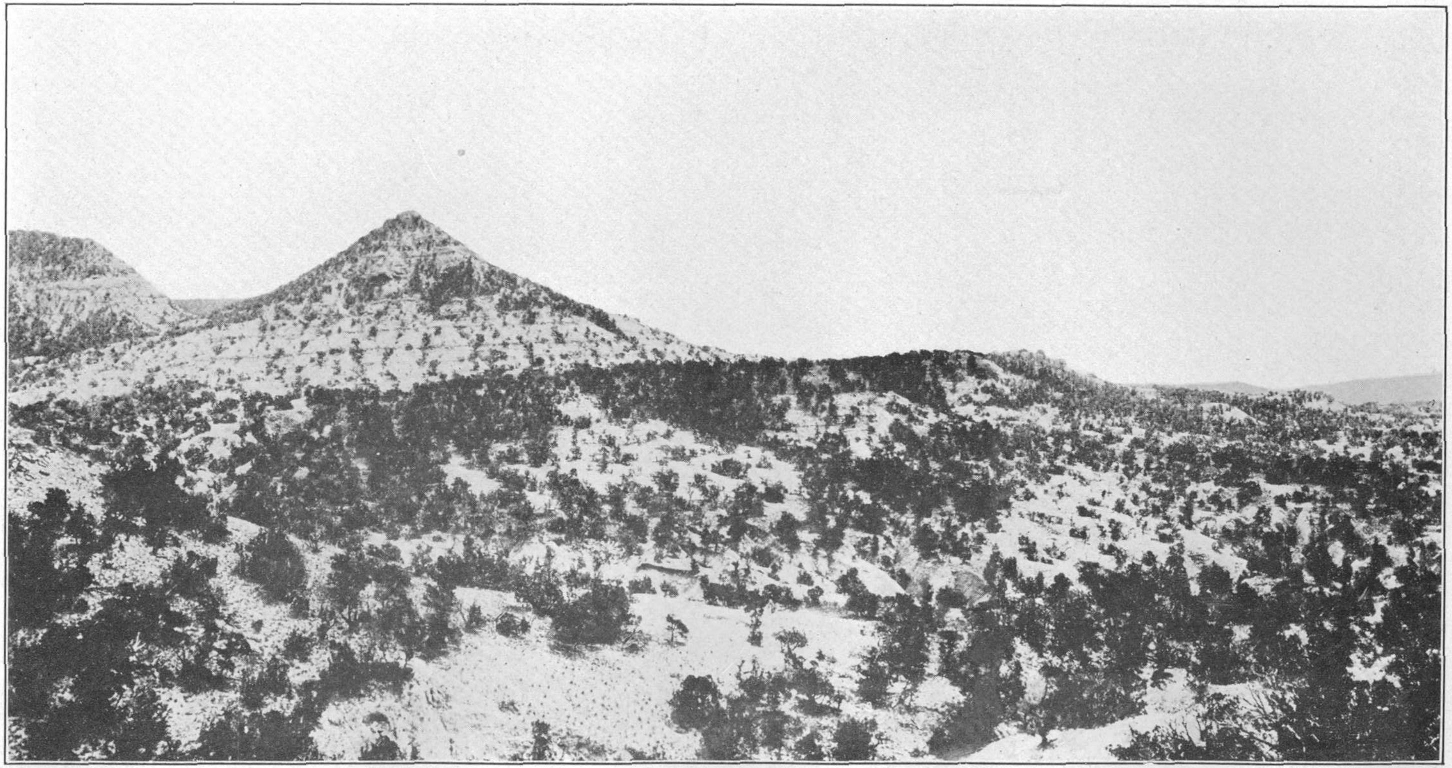


SECTIONS ACROSS RIDGES EAST OF SOCORRO

g, Granite; Cmg, Magdalena group; Ca, Abo sandstone; Cc, Chupadera formation; ₮d, "Red Beds," Triassic, Dockum (?); K, Upper Cretaceous sandstone and shale with local coal beds; T congl, Tertiary conglomerate; i, volcanic flows; agg, agglomerate (volcanic)



COLUMNAR SECTIONS OF CHUPADERA FORMATION IN AND SOUTHEAST OF CHUPADERA MESA



VIEW LOOKING SOUTH ALONG WEST FRONT OF CHUPADERA MESA FROM A POINT IN NORTHWEST CORNER OF T. 7 S., R. 6 E., NORTHWEST OF CARRIZOZO

Cliff on left and outlying cone are composed of limestone, sandstone, and gypsum. Below are alternations of soft red sandy shale and gypsum with limestone beds, the limestone making prominent bench in middle ground and distance. All Chupadera formation and there is a fault which in the vicinity of the Armijo ranch lifts the lower part of the Abo sandstone to the level of the upper limestone of the Chupadera formation. Arroyo de las Cañas cuts a canyon across the Lomos de las Cañas, exposing the structural relations particularly well. To the east are the lower beds of the Chupadera formation, including soft red sandstone, limestone, and gypsum, as shown in the columnar section on page 23. In sec. 25 these beds are upturned sharply and cut off by a fault along which the Abo formation

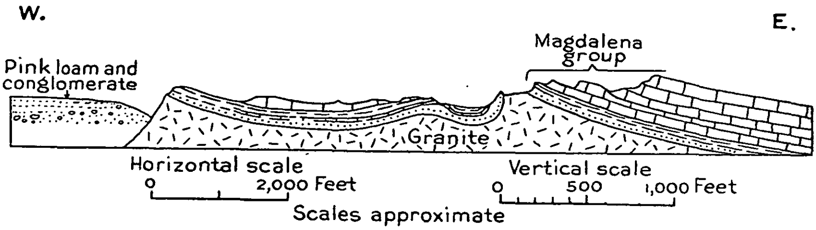


FIGURE 5.—Sketch section showing relations of granite and Magdalena group on Arroyo de Tio Bartolo, 5 miles northeast of Socorro

appears, with its beds nearly vertical, and to the west the Magdalena beds and a small amount of overlapping Tertiary agglomerate.

In secs. 31 and 32, T. 3 S., R. 3 E., two anticlines bring up the Abo sandstone in the midst of an outcrop of lower beds of the Chupadera formation, and some of the higher sandstones and limestones of the Chupadera are dropped by a fault in the western part of sec. 31. At the south end of this area there is a continuous zone of high ridges of the upper limestone and sandstone of the Chupadera formation extending nearly to Carthage and having the structure shown in

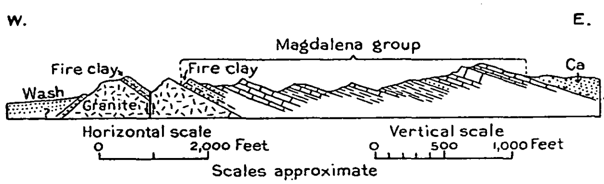


FIGURE 6.—Sketch section showing relations of granite and Magdalena group on Arroyo de la Presilla near old fire-clay pits, 6 miles east of Socorro

section 3, Figure 4. There is considerable faulting but in general a regular succession from the Magdalena on the west to Triassic red shale and the Dakota (?) sandstone on the east. A strong cross fault in the center of T. 4 S., R. 2 E., gives some complexity to the structure. South of this fault there is a general downward pitch to the south, the Triassic outcrop widens, and finally the Cretaceous rocks extend across the anticline in the coal basin of Carthage. Overlying the Cretaceous beds is a conglomerate of early Tertiary age, which also appears at intervals to the north, in Tps. 2 and 3 S., R. 3 E. On the east side of this part of the Tertiary area, in the western part of sec.

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1, T. 5 S., R. 2 E., there is a well-defined anticline or elongated dome of Cretaceous coal measures. On its west side is the main fault, which extends far north from the eastern part of Carthage.

A boring in sec. 30, T. 5 S., R. 1 E., about 5 miles south of San Antonio, was 3,237 feet deep in the later part of 1927. It was in red shale below 3,230 feet, and 8 feet of limestone was reported at 3,080 feet.

CIBOLA CONE SYNCLINE AND FAULT

The southern prolongation of the anticline of the Los Pinos Mountains, pitching downward, bears on its eastern slope in T. 1 S., R. 3 E., and farther south a thick wedge-shaped mass of the Chupadera formation. On its east side the wedge is cut off by a fault with upthrow on the east that brings into view the top limestone of the Magdalena group. The resulting topographic features are strongly marked, as the hard limestone and sandstone of the Chupadera formation give rise to a prominent ridge culminating in the very

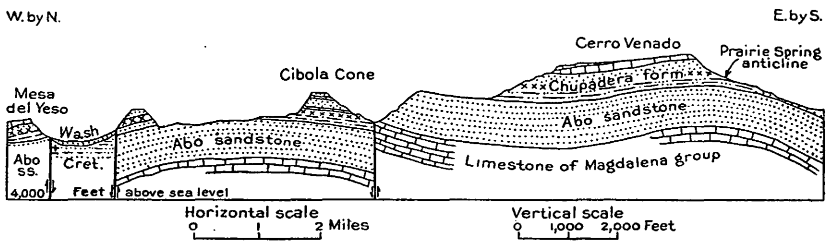

FIGURE 7.—Sketch section across Cibola Cone syncline and fault, showing relations to adjoining anticline

conspicuous butte long known as Cibola Cone (see pl. 6, *A*), and east of the fault the uplifted Abo sandstone presents to the west a high red escarpment. Some of these features are shown in section 1, Plate 21, and they are represented on a larger scale in Figure 7. The Chupadera and Abo formations in the area do not present any unusual features.

VALLE DEL OJO DE LA PARIDA

Structurally the Valle del Ojo de la Parida is a syncline with a regular succession of Cretaceous to Pennsylvanian rocks rising in its east side and an overlap of Tertiary igneous rocks on its west side. Possibly the Tertiary rocks are cut off by a fault at the Joyita Hills and southward along the prolongation of the east side of the Joyita uplift. A heavy covering by Santa Fe and later deposits in T. 1 S. and farther south hides the structural relations on the west side of the valley. Part of the valley is floored with sand and gravel, but ridges and slopes show Triassic and Cretaceous rocks along its center, and the outcrop of the Cretaceous widens greatly in the southern part of T. 1 N., R. 2 E. The principal structural features of the valley and adjoining ridges are shown in the sections in Figure 8, and some of the general relations are shown in section A, Plate 21. In the northern part of sec. 3, T. 1 S., R. 2 E., Abo and Chupadera strata are cut by several dikes, as shown in Plate 19, *A*.

TAYLOR COAL BASIN

The Cretaceous rocks occupy a trough of considerable extent along the valley of Taylor Creek and adjoining slopes. As shown in sections A to E, Plate 21, they lie in regular succession on red shale of Triassic age and dip at low angles to the west. To the south they are overlain by a thick mass of Tertiary igneous rocks, in places at least with an intervening conglomerate (Eocene?) that is well exposed northwest of the Cox ranch and west of the old coal pit 4 miles north of the Taylor ranch. This basin is cut off by a fault on its west side. In the higher beds near this fault there is a thin coal bed, which has been prospected

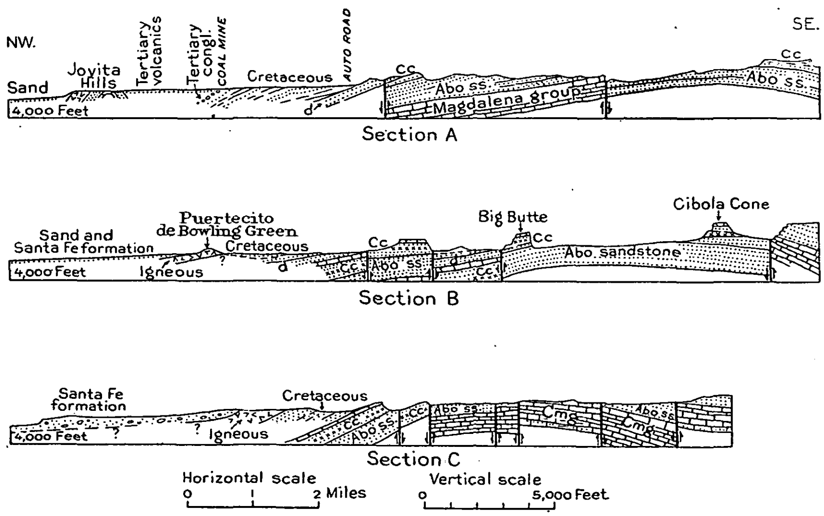

FIGURE 8.—Sections across Valle del Ojo de la Parida, northeast of Socorro. A, Near Arroyo Cibolo; B, through Mesa del Yeso; C, near Ojo de la Parida. d, Red shale (Dockum(?) group); c, Chupadera formation; Cmg, Magdalena group

at several places. Probably this basin underlies a wide area of the Jornada del Muerto south of the Taylor ranch, but owing to the cover of sand and gravel and the absence of borings nothing is known of its character or relations in that area.

BASIN OF ARROYO CHUPADERA

The valley of Arroyo Chupadera is in a broad syncline (see section *B*, fig. 4), which is a northern extension of the basin of the Jornada del Muerto. It rises to the north and is lost in the table-lands of southern Torrance County. The sides are broad outcrops of the Chupadera formation, and in the center, in Tps. 2 and 3 S., are red shales of Triassic age, largely covered by dune sand. In the center of T. 4 S., R. 4 E., the overlying Cretaceous strata appear, cut by some igneous intrusive rocks. Farther south are the wide sandy flats of the Jornada del Muerto.

OSCURA ANTICLINE

The prominent anticline which has produced the Oscura Mountains extends far north of the northern termination of the mountains, probably to the Torrance-Socorro County line. The limestones of the Magdalena group pitch down steeply in the northern part of T. 5 S., R. 6 E., and there is considerable faulting for some distance in the southwest corner of the township. Northward for 8 or 9 miles there is a broad anticline of the Abo sandstone flanked on both sides by the Chupadera formation. On the west side of the axis this formation constitutes ridges of moderate prominence, and on the east it forms the western slope of Chupadera Mesa. The dips are low, especially those on the east side. Near the center of T. 4 S., R. 6 E., the Abo sandstone pitches down to the north, and for 15 miles or more the uplift is expressed in Chupadera beds. The west limb of the anticline, where the dips are mostly from 5° to 10°, is marked by a north-south ridge of the limestones of the Chupadera formation. The dips on the east side are very low, and, as shown in section *B*, Figure 4, the limestones cap Chupadera Mesa. Although in general the anticline is fairly regular there are a few local irregularities. One of the most notable of these is a subordinate syncline and anticline with steep dips in and near the western part of T. 4 S. and the southwestern part of T. 3 S., R. 7 E.

JOYITA HILLS

The Joyita Hills, which lie mostly in T. 1 N., R. 1 E., present a prominent anticline with pre-Cambrian granite exposed for a distance of about 3 miles along the center of its north-south course. Some of the features are shown in section A, Figure 4.

At the north end of the area the limestone of the Magdalena group is exposed pitching down under the Abo sandstone, but at the south the relations are hidden by sand and gravel. On the east there is a broad belt of the Tertiary igneous rocks, which overlap on the granite unless, perhaps, there is a separating fault. The cross section in Figure 9 shows some of the local details of structure.

The central ridge of granite is the highest topographic feature, and next west of it are slopes of limestone of the Magdalena group. A fault separates this limestone from the granite. The red sandstone of the Abo formation, about 800 feet thick, forms a line of ridges or knobs, with soft beds of the lower member of the Chupadera formation just west. These lower beds comprise 400 feet of reddish shale and soft red sandstone with some included limestone beds but no gypsum. Next above is soft red sandstone grading upward into massive gray sandstone, mostly hard, with two thin beds of limestone. This sandstone is overlain by limestone, the usual top member of the Chupadera formation. These upper sandstones and limestones, about 700 feet in all, constitute a zone of ridges and knobs of considerable prominence extending all along the west side of the uplift. The Abo sandstone shown at the left end of the section in Figure 9 is an uplifted block which crops out only for a short distance and west of which are agglomerate and a bed of limestone conglomerate and Tertiary igneous rocks.

On its east side the granite ridge is flanked by limestone of the Magdalena group dipping steeply to the east. To the south these rocks show only in places, as the Tertiary igneous succession extends to the foot of the ridge, but to the north the limestone area widens and reveals the pitching anticlinal structure shown near the right-hand part of Figure 9. As the anticline pitches to the north the limestone area widens, and it passes across the end of the uplift. In this part of the area, in a deep canyon cut by a small arroyo, the limestone of the Magdalena group is exposed overthrust onto the red Abo sandstone apparently by an extension of the fault shown to the right of the center of the section. (See fig. 9.) The relations at this place are shown in Plate 19, *B*. The limestone dips to the north and northwest, and the

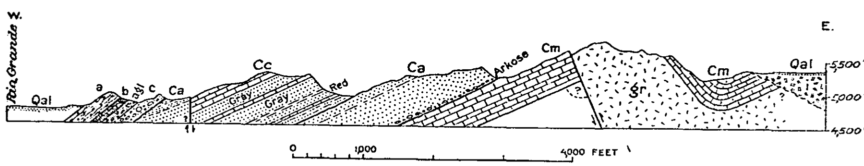

FIGURE 9.—Sketch section across Joyita Hills, in T. 1 N., R. 1 E., Socorro County. Qal, Alluvium; a, andesite; b, basalt; agl, agglomerate; c, conglomerate; Cc, Chupadera formation; Ca, Abo sandstone; Cm, Magdalena group; gr, granite; l, lava, etc.

Abo sandstone to the west. The limestone extends northward to Arroyo Cibolo, where it pitches below the Abo formation, and this in turn is covered by sand, gravel, and the Tertiary igneous succession. There is no evidence of its extension in Agua Torres, and the isolated knob of granite 6 miles east of La Joya is due to a separate uplift.

SOCORRO AND LEMITAR MOUNTAINS

The Socorro and Lemitar Mountains are parts of a westward-dipping succession of Tertiary igneous rocks on a platform of limestone of the Magdalena group underlain by pre-Cambrian rocks. Schist is exposed in a very small area low in the east slope of Socorro Peak, and granite is a prominent feature for 6 miles along the east slope of the Lemitar Mountains. The structure of these mountains is shown in the sections given in Figure 10.

To the east of these mountains are long sand and gravel covered slopes extending to the Rio Grande and in part underlain by tilted sandstone of the Santa Fe formation, which are well exposed near the north end of the Lemitar Mountains. To the west, as well as on the north and south, lies a thick body of the Tertiary igneous rocks, which extend to the wide valley separating these ranges from the

Magdalena Mountains. At the south end of Socorro Peak is a deposit of fuller's earth overlain by a sheet of basalt.

On account of the eastward-dipping limestone on the east side of the ridges as shown in sections B and C, Figure 10, it is believed that these ridges are of anticlinal structure throughout, and probably under the plain east of them there is a regular succession of Abo, Chupadera, Triassic, and Cretaceous rocks in a syncline. Ladron Peak is on a northern continuation of the axis. There is no evidence that the mountains are fault blocks, and the only fault noted is in the middle of the Lemitar Mountains, halfway between the sections A and B, shown in Figure 10, where the displacement is 500 feet or

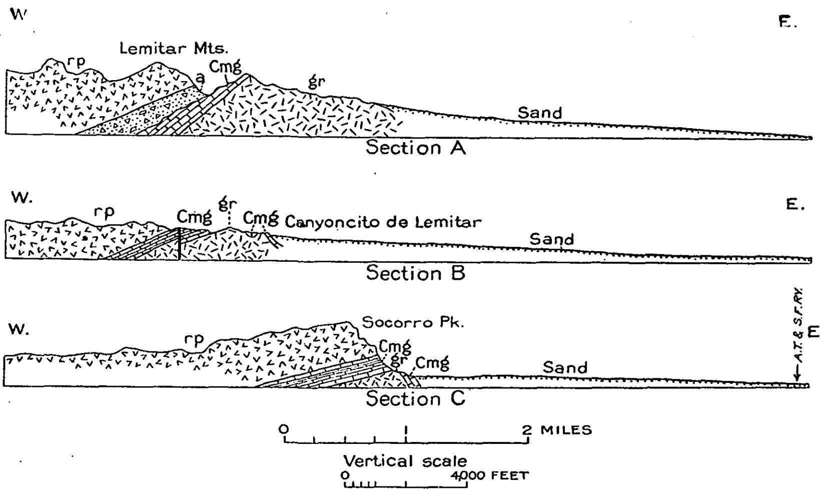

FIGURE 10.—Sections across Socorro and Lemitar Mountains, west and northwest of Socorro. A, Through Lemitar Mountains 1 mile south of Polvadera Mountain; B, along Canyoncito del Puertecito de Lemitar; C, through Socorro Peak to a point 1 mile north of Socorro. gr, Pre-Cambrian granite and schist; Cmg, Magdalena group; a, agglomerate and ash; rp, rhyolite and porphyry.

more, with the drop on the east side. The probable continuation of this fault is shown in section B.

CHUPADERA MESA TO TULAROSA

GENERAL RELATIONS

Chupadera Mesa is a high plateau of nearly horizontal beds of limestone, gypsum, and sandstone of the Chupadera formation. It extends across the east end of Socorro County and the southwestern part of Torrance County, with a length of about 65 miles, and for a long distance its width averages 15 miles. Much of it is more than 7,000 feet in altitude. In a large part of it the strata dip at very low angles to the south and east. The mesa presents escarpments 500 to 700 feet high to the north and west, and most of its surface is a smooth plain of limestone of the upper part of the Chupadera formation bearing a heavy growth of junipers. Its north end, known as Mesa Jumanes, rises steeply from the Estancia Basin south of Willard and Mountainair; its western escarpment, 1,000 to 1,500 feet high, overlooks the wide basin east of Socorro and the northeast slope of the Oscura Mountains. To the northeast the mesa broadens out into the wide plateaus about Gallinas Mountain and the Corona region, where limestone also caps several detached buttes. In general the central and northern parts of Chupadera Mesa form a broad, very shallow syncline in which the beds lie nearly horizontal. This syncline pitches under the broad valley of the Tularosa Basin. The Chupadera rocks cross this basin southwest of Carrizozo, and near Tularosa they rise again in the ridges along its east side, which finally extend into the Sacramento Mountains. The principal structural features are shown in Figure 11, and the appearance of the western face in Plates 6, *B*, and 23.

FORMATIONS

CHUPADERA FORMATION (PERMIAN)

The Chupadera formation in this its typical area presents the same general features as in the region to the west and north, above described. Some of the members, especially the lower ones, vary somewhat in character and thickness from place to place. The limestones probably thicken toward the south, there being a relatively rapid increase in their amount near Tularosa. The lower member of soft red sandstone and sandy shale with gypsum deposits and thin limestone members is not sharply separable from the Abo sandstone, which crops out all along the west side of the region. The columnar sections in Plate 22 show the principal stratigraphic features. In these sections the top of the formation is not represented because of erosion, and the section at the Phillips Hills does not indicate the basal beds because they are covered by talus. The gray sandstones are thick and conspicuous in the northern region and much less developed to the south. The alternations of gypsum and limestone in the upper half of the formation and the occurrence of gypsum-bearing red sandstone in the lower part are characteristic features throughout. An analysis of a typical sample of the limestone taken 1 mile south of Corona was made by A. A. Chambers in the laboratory of the United States Geological Survey. It was found to contain magnesium carbonate 27.4 per cent, insoluble material 5.5, and calcium carbonate (by difference) 67.1 per cent.

In the vicinity of Ancho and Oscuro the uppermost beds are exposed with overlying red beds and Cretaceous rocks. The succession is somewhat variable, but the upper Chupadera strata are alternations of limestone and gypsum. Next above is a sandstone, locally prominent east of Ancho, about Largo, and east of Coyote, which may be

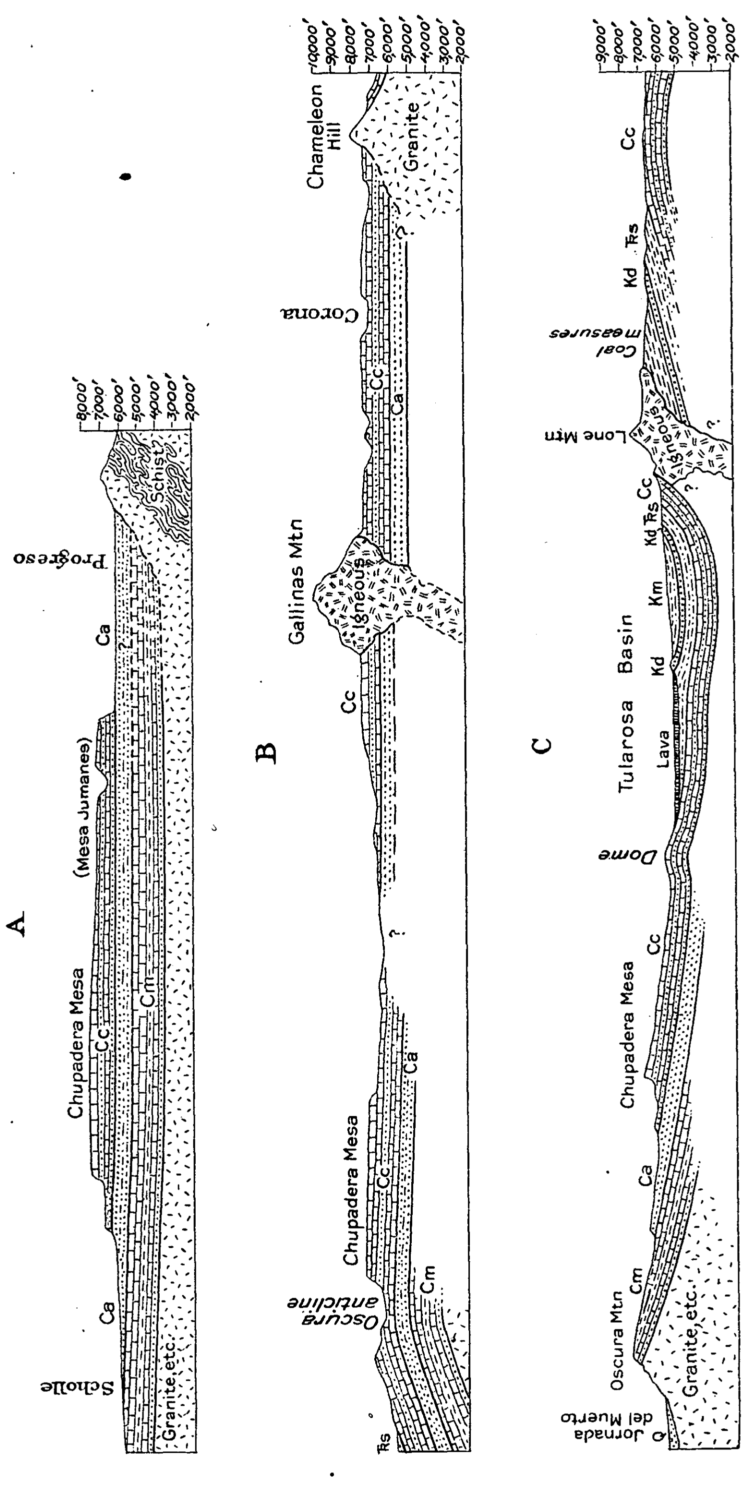

FIGURE 11.—Sections across Chupadera Mesa, in the southern part of Torrance County and the eastern part of Socorro County, showing relations to some adjoining ridges. A, From Scholle to Progreso; B, from a point north of the north end of the Oscura Mountains to Chameleon Hill, northeast of Corona; C, from the Oscura Mountains through Lone Mountain near White Oaks. Q, Quaternary; Km, Mancos (?) shale; Kd, Dakota (?) sandstone; TRs, Dockum group; Cc, Chupadera formation; a, Abo sandstone; Cm, Magdalena group

regarded as the top member of the Chupadera formation. Above it is 200 feet or more of red shale (presumably Dockum) capped by sandstone which may possibly be Dakota. The limestone and gypsum succession is well exposed at Ancho, where the gypsum is worked,

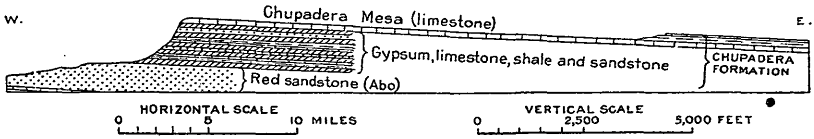

FIGURE 12.—Section showing succession of strata in Chupadera Mesa, 35 miles east of Socorro

and the outcrop zone extends north and south for some distance, finally being cut off by the igneous masses of Lone and Baxter Mountains. Some of the structural features in this zone of outcrop are

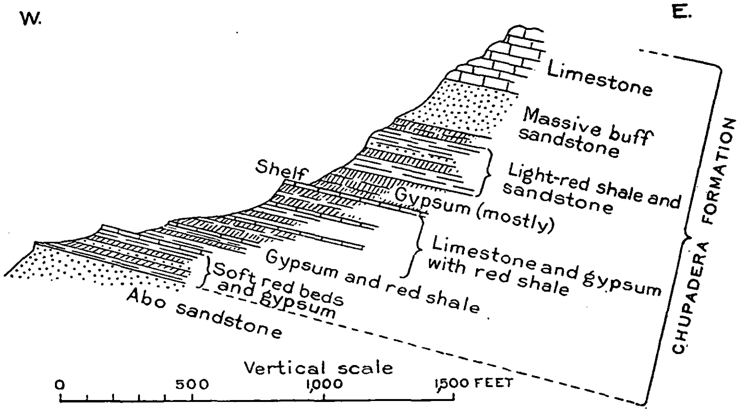

FIGURE 13.—Section of west front of Chupadera Mesa, in the southeast corner of T. 5 S., R. 6 E.

shown in Figure 20. At Ancho the main bed of gypsum is 40 feet or more thick but is cut off to the east by a porphyry dike. The succession farther east is shown in Figure 14. These beds of lime-

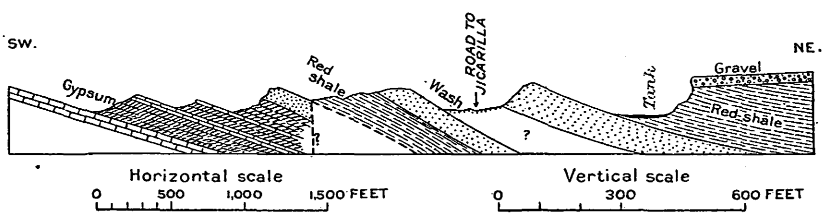

FIGURE 14.—Sketch section 4 miles southeast of Ancho, looking northwest. Length about 1 mile

stone separated by thick bodies of gypsum are traceable southward from Ancho along the west side of the Jicarilla Peak eruptive mass, passing a short distance east of Largo, where the pitch of an anticline carries them beneath the surface. They reappear east of Coyote, and their outcrop extends along the west slope of Lone Mountain to a point west of White Oaks. At a point 4 miles due east of Coyote the upper gypsum member is about 100 feet thick, including some thin beds of limestone. At the top is a 30-foot member of gray sandstone, here mostly soft but thickening and becoming harder to the north. It is conspicuous about Largo siding, especially in the ridge just to the east, and also in Ancho Valley 3 or 4 miles east of Ancho, where it has the relations shown in Figure 14 (a short distance to the left of the center of the section). The outcrop of gypsum along the west side of Lone Mountain is much obscured by talus, but the limestones are conspicuous and there is a sandstone above them. (See section F, fig. 20.) The sandstone is either the bed above referred to or the Dakota (?) sandstone dropped a few hundred feet by a fault.

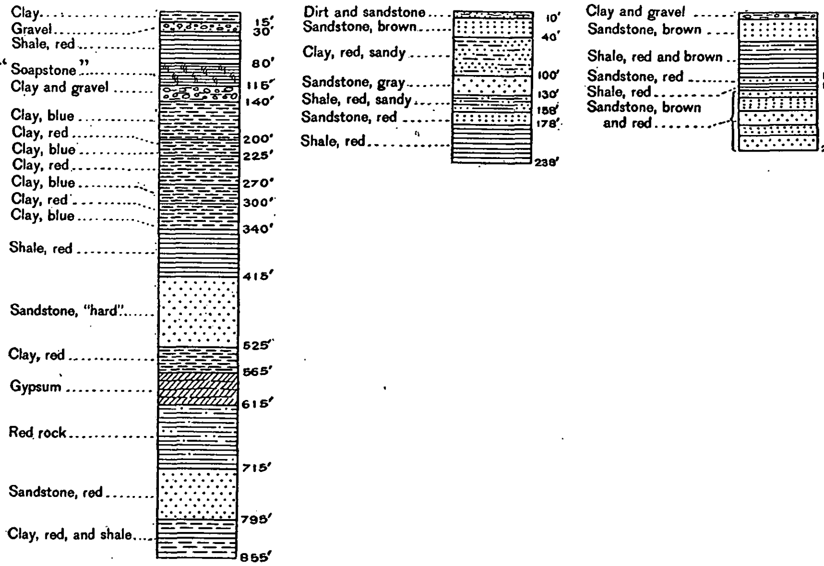

FIGURE 15.—Record of well of El Paso & Southwestern Railroad Co., 2 miles east of Ancho

The relations of the beds below the gypsum and limestone members exposed near Ancho and Largo to the rocks of Chupadera Mesa are not determined, for the connecting outcrop zone was not followed closely in the Gallinas Mountain area. The 855-foot boring near Arroyo Ancho, 2 miles east of Ancho (fig. 15), began in red beds (probably Dockum) and entered what is thought to be the upper sandstone of the Chupadera formation at 415 feet. It penetrated gypsum at 565–615 feet and other beds which match the strata exposed not far southeast, as shown in the cross section of Figure 14.

In the deeper one of the borings at Carrizozo, of which records are given in Figure 16, the Chupadera formation was probably entered at 625 feet and continued to 1,125 feet.

A hole bored by the El Paso & Southwestern Railroad Co. at Oscuro shows the succession of strata under that place as given in

Figure 17. A shallower hole, 489 feet deep, did not report limestone, and shale from 65 feet to the bottom was interrupted by many sandstone members, the principal one extending from 305 to 340 feet. Sandstone was also reported from 205 to 275 feet. All these strata appear to be Upper Cretaceous.

In the well of E. E. Phillips, west of Duck Lake, the Chupadera beds were penetrated for 732 feet. The first 300 feet was reddish sandstone, which was underlain by 190 feet of limestone and gypsum,

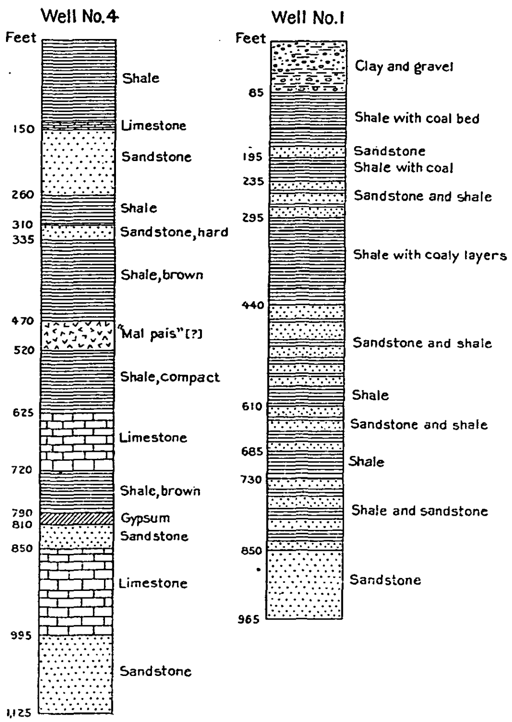

FIGURE 16.—Records of deep wells at Carrizozo

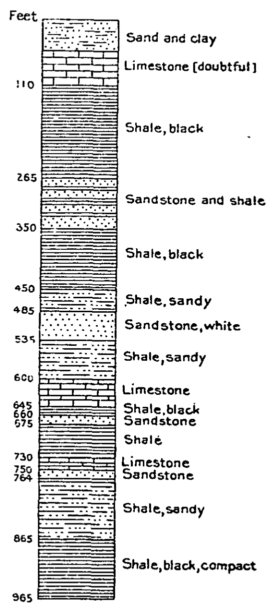

FIGURE 17.—Record of deep boring at Oscuro

170 feet of yellow limestone, 40 feet of black shale, and 32 feet of sandstone at the bottom.

TRIASSIC ROCKS (DOCKUM? GROUP)

Red shale and sandstone overlying the Chupadera formation along the east side of the north end of the Tularosa Valley are probably in large part of Triassic age and presumably represent the Dockum group, but locally they may possibly include some Permian beds at the base and Morrison beds above. They crop out extensively about Ancho and in a zone extending southward and passing under the Malpais, southwest of Coyote. They reappear again west of Oscuro, and there are outcrops at intervals to a point southeast of Three Rivers. Similar strata also appear under the Dakota(?) sandstone on the east side of the basin near Capitan and Fort Stanton. They may possibly include in their upper part a representative of the Morrison formation, for some of the material resembles the Morrison of northern New Mexico. This is well shown at the fire-clay mine 1¾ miles east of Ancho.

The rocks are red shale in larger part, with some local red or gray sandstone members. In Figure 15 are shown strata penetrated by wells in Arroyo Ancho southeast of Ancho.

CRETACEOUS ROCKS

A basin of Cretaceous rocks covering an area of about 500 square miles extends along the east side of the Tularosa Basin from the vicinity of Three Rivers to Coyote, and small outliers of the lowest sandstone occur northeast of Coyote, east of Ancho, and near Luna. This sandstone is tentatively assumed to be the Dakota, for it presents the usual characteristics and relations of that formation and is overlain by shale carrying the Colorado fauna, while higher up are representatives of the Montana group, including coal beds that have been worked near White Oaks, Capitan, and Carrizozo. These rocks have been described by Wegemann.[61] They represent the Mancos shale and possibly later Cretaceous beds.

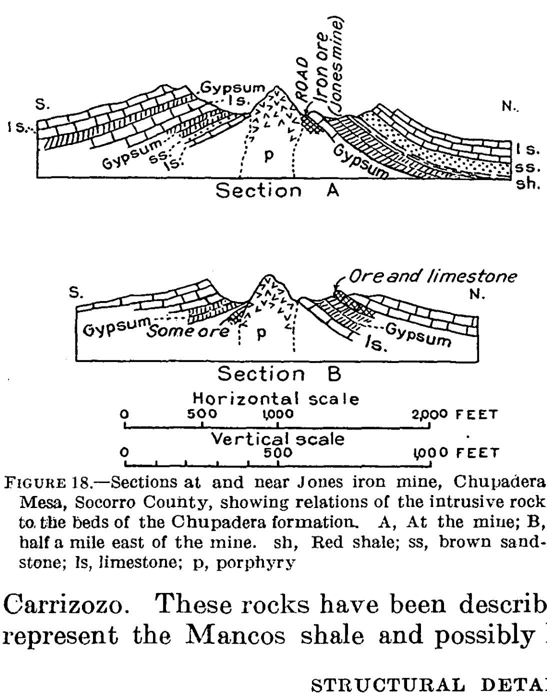

FIGURE 18.—Sections at and near Jones iron mine, Chupadera Mesa, Socorro County, showing relations of the intrusive rock to the beds of the Chupadera formation. A, At the mine; B, half a mile east of the mine. sh, Red shale; ss, brown sandstone; ls, limestone; p, porphyry

STRUCTURAL DETAILS

The structure of Chupadera Mesa is in general that of a broad, shallow syncline, which on the southeast merges into an eastward-dipping monocline, as shown in Figure 11. At the Jones iron mine, which is near the east line of T. 5 S., R. 7 E., the sedimentary beds are cut by a long, narrow dike of dark intrusive rock, which gives rise to a ridge or line of ridges about 6 miles long. The sandstone that crops out in this area is a part of the Chupadera formation and is not Cretaceous, as formerly supposed.[61a] The relations are shown in Figure 18.

[61] Wegemann, C. H., Geology and coal resources of the Sierra Blanca coal field, Lincoln and Otero Counties, N. Mex.: U. S. Geol. Survey Bull. 541, pp. 425–432, 1914.

[61a] Keyes, C. R., Iron deposits of the Chupadera Mesa: Eng. and Min. Jour., vol. 78, p. 632, 1904; Unconformity of the Cretaceous or older rocks in central New Mexico: Am. Jour. Sci., 4th ser., vol. 18, p. 362, 1904.

One of the most marked variations in the monoclinal structure of the southern part of Chupadera Mesa is an anticline of considerable

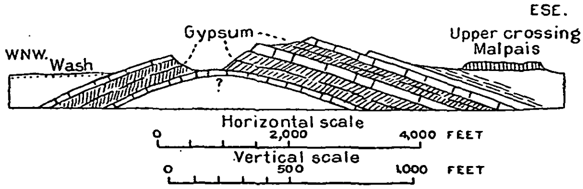

FIGURE 19.—Section of anticline in Chupadera formation west of the upper crossing of the Malpais, 15 miles southwest of Carrizozo

prominence lying just west of the Malpais, southwest of Carrizozo. The section in Figure 19 shows its relations near the main road.

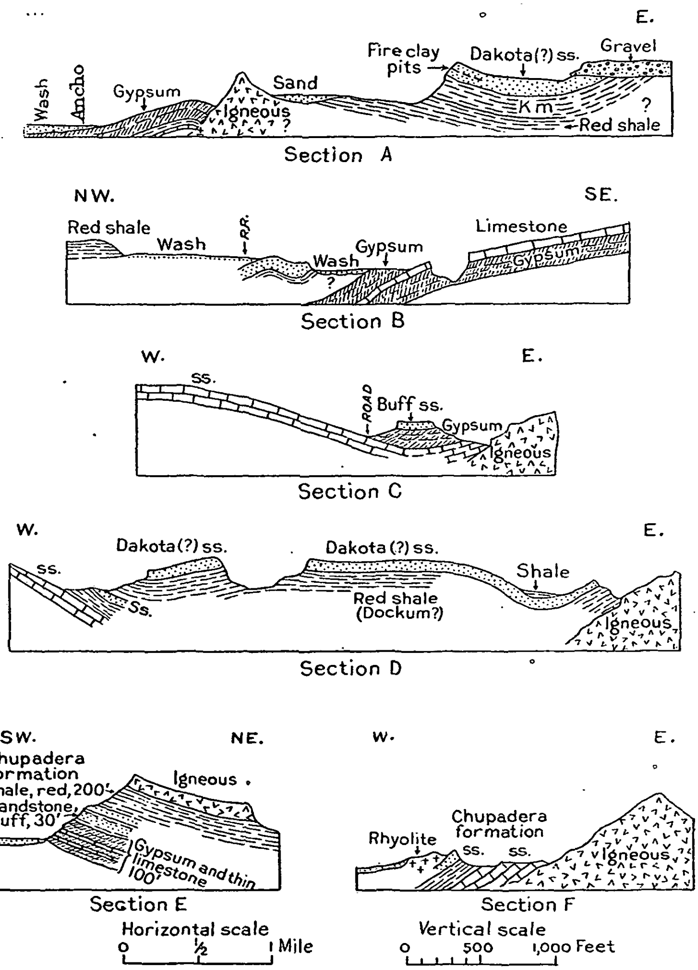

FIGURE 20.—Sketch sections near Ancho, Largo, and Coyote, Lincoln County. A, West to east through Ancho; B, 1½ miles northeast of Largo; C, on road 4 miles southeast of Largo; D, 6 miles northeast of Coyote; E, 5 miles east of Coyote; F, on west slope of Lone Mountain. ss, Sandstone

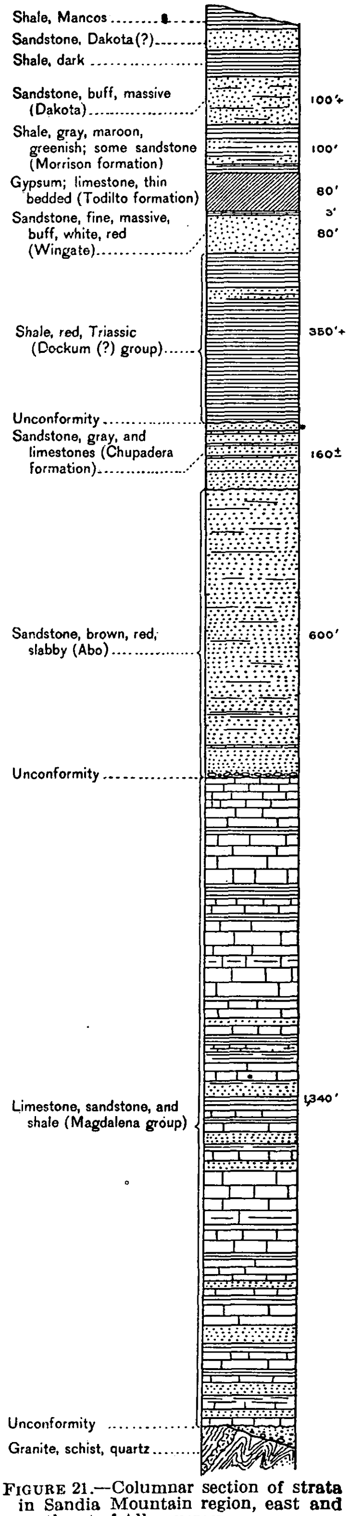

FIGURE 21.—Columnar section of strata in Sandia Mountain region, east and northeast of Albuquerque

In the vicinity of Ancho and southward along the north end and west side of the Sierra Blanca the strata are considerably deformed and penetrated by igneous rocks. The principal features near Ancho and for several miles south are shown in the sections in Figure 20.

SANDIA-MANZANO UPLIFT FROM ROSARIO TO LOS PINOS MOUNTAINS

GENERAL RELATIONS

An anticline of great prominence gives rise to the Sandia and Manzano Mountains and continues southward into Socorro County. To the north this anticline pitches not far east of Bernalillo and disappears under a cover of sand and gravel, but a probable extension appears east of Rosario in the Galisteo Valley near the Santa Fe County line. This great uplift is separated from the south end of the Rocky Mountains by the broad structural basins of the Cerrillos coal field and Estancia Valley.

The principal structural features of the uplift are shown in the cross sections of Figure 23. Detailed descriptions of local relations are given on page 98, and the structure of the southern continuation across Socorro County is set forth on page 77. The formations exposed comprise pre-Cambrian granite, schist, and other rocks, limestone and sandstone of the Magdalena and Manzano groups, red shale and sandstone that may represent the Dockum group, the Wingate sandstone, the Todilto limestone (with its gypsum member at the top), the Morrison and Purgatoire (?) formations, the Dakota sandstone, the Mancos shale, the Mesaverde formation, and overlaps of Tertiary and Quaternary gravel and sand. The columnar section in Figure 21 shows the principal features of the stratigraphic succession as exposed in the Sandia Mountains and vicinity.

FORMATIONS

PRE-CAMBRIAN ROCKS

The pre-Cambrian rocks of the Sandia, Manzano, and Los Pinos Mountains comprise granite and gneiss and a large body of white slabby quartzite similar to that which occurs in the Hills of Pedernal. Some beds are conglomeratic. These rocks dip at steep angles and apparently are cut by large bodies of coarse-grained light-colored granite of the type so common in the Rocky Mountain province and also by some darker rocks of dioritic character. Some details regarding these rocks in the Sandia Mountains have been given by Ellis.[62]

MAGDALENA GROUP (PENNSYLVANIAN)

The summit and east slope of the Sandia Mountains and of the uplift east of San Pedro consist of limestone and sandstone of the Magdalena group. The rocks include two formations, the type localities of which are in this area—the Sandia formation [63] below and the Madera limestone [64] above. The total thickness is about 1,200 feet. The Sandia formation, about 400 feet thick, consists of alternating beds of limestone, sandstone, and shale. In most places the lowest member, lying directly on granite, schist, or quartzite, is sandstone, locally conglomeratic. The limestone is nearly all massive and light blue-gray. Abundant Pennsylvanian fossils occur throughout the succession. A few species collected on the slope 1 mile northeast of Barton were identified by G. H. Girty as follows:

Stenopora sp.
Derbya sp.
Productus pertenuis.
Productus cora.
Productus semireticulatus.
Marginifera wabashensis.
Spirifer cameratus.
Composita subtilita.

Some details of the stratigraphy in the Sandia Mountains are given by Ellis.[65] South of Arroyo Tijeras the limestone of the Magdalena group presents an outcrop 15 miles wide. A boring for petroleum in 1925 in the SW. ¼ sec. 5, T. 6 N., R. 7 E., about 8 miles south of Chilili began near the top of the formation and penetrated 1,340 feet of Magdalena strata to the underlying schist.

Fossil plants of Pottsville age have been identified by David White in the lower part of the Magdalena (Sandia of Herrick). The upper beds exposed along Tonque Creek south of Alamillo consist of limestone with many fossils and alternations of reddish-gray sandstone and thick-bedded limestone, possibly with transition to the overlying Abo sandstone.

ABO SANDSTONE (PERMIAN)

The outcrop of Abo sandstone nearly encircles the Tijeras coal basin and extends prominently along the south and west sides of the Uña del Gato Basin. It also encircles South Mountain. The thickness of the formation is about 500 feet to the north and considerably

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62 Ellis, R. W., Geology of the Sandia Mountains: New Mexico Univ. Bull. 4, Geol. ser. 3, pp. 21–29, 1922.
63 Herrick, C. L., The geology of the White Sands of New Mexico: New Mexico Univ. Bull. 2, p. 4, 1900.
64 Keyes, C. R., Geology and underground water conditions of the Jornada del Muerto, N. Mex.: U. S. Geol. Survey Water-Supply Paper 123, p 22, 1905.
65 Ellis, R. W., op. cit., pp. 17–20.

more to the south. The rocks are reddish-brown sandstone, mostly slabby, with a subordinate amount of red shale. In places there are at the base some coarser beds and local deposits of conglomerate containing limestone pebbles which doubtless indicate unconformity. There is, however, no noticeable channeling and no discordance in dip, and in some localities, as near Alamillo, there appears to be a transition, as above described. The basal conglomerate is overlain by a thin bed of limestone. The upper limit of the formation is somewhat indefinite, for the red sandstone appears to grade up into red shale of the overlying Chupadera formation. Lee[65a] found Manzano fossils in the lower bed of the formation in Abo Canyon.

A 1,080-foot boring at Abo station made by the Atchison, Topeka & Santa Fe Railway Co. was entirely in red strata and yielded no satisfactory water supply. The record is shown in Figure 22. Probably this hole entered the Abo formation at about 135 feet below the surface and was discontinued at no great distance above the top of the limestone of the Magdalena group. It penetrated strata which are exposed lower down the valley, near Scholle.

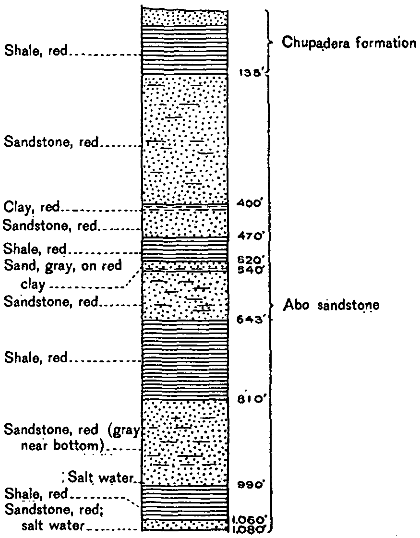

FIGURE 22.—Record of 1,080-foot boring by Atchison, Topeka & Santa Fe Railway Co. at Abo

CHUPADERA FORMATION (PERMIAN)

The red shale penetrated for the first 135 feet in the boring mentioned in the last paragraph is probably the same as that which constitutes the basal part of the Chupadera formation in the vicinity of Abo and farther south. In this area, however, it does not contain gypsum, and its thickness is not much more than 120 feet. Next above is a succession of limestone and sandstone beds that have the relations shown in Figure 21. The total thickness of these beds is only about 100 feet; the limestone occurs in three beds 10 to 15 feet thick. This succession appears to be the member which farther south and east is represented by the sandstones so prominent in Glorieta Mesa and the thick series of limestone and sandstone of Chupadera Mesa. The sandstone is hard and makes a ridge which is conspicuous near Tejon and Alamillo and east, north, west, and southwest of San Antonito. It is cut off by the fault a short distance west of Tijeras. It is conspicuous in a ridge west of San Pedro, where it forms the east side of the basin. Two miles southeast of San Antonito the formation is well exposed and dips 20° WSW.

[65a] Lee, W. T., op. cit. (Bull. 389), p. 21.

WEST FRONT OF SANDIA MOUNTAINS FROM BERNALILLO

Looking east. Granite slopes 3,300 feet high surmounted by cliff of eastward-dipping limestone and sandstone of Magdalena group (a)

At the top of the exposure is 40 feet of compact gray sandstone, and in order below a few feet of shale, a 20-foot bed of limestone, and 150 feet of shale, including two beds of limestone in which Lee [65b] found fossils belonging to the Manzano fauna. The gray sandstone is overlain by 400 feet or more of red sandy shale, not well exposed, which underlies the valley extending north and south from Tejon and about San Antonito. The lower part of this shale may possibly be an upper member of the Chupadera formation, but probably it is all Triassic, representing either the Moenkopi formation or the Chinle shale, or possibly both. The presence of the Dockum group in this part of the State has not yet been established.

Between Alamillo and San Pedro the Chupadera formation contains two beds of limestone, one of them 20 feet thick, included in gray sandstone; much of the outcrop zone is covered with talus.

WINGATE SANDSTONE (JURASSIC?)

Massive pink sandstone of typical Wingate character is well exposed between Tijeras and San Antonito, along the west side of the Uña del Gato Basin, and on Golden Creek north and northwest of Golden. It forms a bluff on the east bank of Tonque Creek about 2 miles north of Tonque, where it consists of 80 feet of soft massive sandstone, white in the upper part but buff at the top. In a bluff east of the road a mile east of Canyoncito the thickness is less and gray sandstone predominates, but the characteristic fine grain and massive structure are well exhibited.

TODILTO FORMATION (JURASSIC?)

Throughout its course in the basins east of the Sandia Mountains the Wingate sandstone is capped by characteristic Todilto limestone 3 to 5 feet thick, in very thin beds. This rock is well exposed in the bluff on the east bank of Tonque Creek below Tonque, at Tejon, and east of the plaza of Canyoncito, in the arroyo at the road crossing three-quarters of a mile north of Golden, in the slopes halfway between Uña del Gato and San Pedro, at the fault 2 miles east of Uña del Gato, and at several places not far south and southwest of Placitas. The thick gypsum bed that is so characteristic a feature of the upper part of the Todilto formation west of Cerrillos and west and northwest of Albuquerque is present in both basins east of the Sandia Mountains. The gypsum is covered by talus for intervals of considerable length, but exposures occur here and there. In the bluff below Tonque above referred to, the gypsum member is about 80 feet thick. East of Canyoncito it is about 60 feet thick and dips steeply to the east under the coal basin, as shown in section C, Figure 23. South and southwest of Placitas both limestone and gypsum members are well exposed in places, but in part of the outcrop zone the gypsum is crushed and covered by talus. The limestone is about 3 feet thick.

[65b] Lee, W. T., op. cit. (Bull. 389), p. 19.

MORRISON FORMATION (CRETACEOUS?)

Shale having all the physical features of the Morrison is exposed in both basins east of the Sandia Mountains. The thickness is about 100 feet. In excellent outcrops in the ridges north of Tonque the formation consists of pale-greenish clay with maroon and gray beds, intercalated beds of gray to brown crumbling sandstone, and near the base a thin layer of nodular limestone. These clays lie on the thick gypsum member of the Todilto formation and are overlain by thick massive hard sandstone probably representing the Purgatoire formation. Similar materials are exposed at intervals south of this p ace and in the outcrop zone extending along the north and west margins of the Tijeras coal field.

PURGATOIRE FORMATION (LOWER CRETACEOUS) AND DAKOTA SANDSTONE (UPPER CRETACEOUS)

The hard massive sandstone that marks the base of the recognized Cretaceous succession throughout northeastern New Mexico is a conspicuous feature in the basin east of the Sandia Mountains. In the ridge passing through Tonque and east of Tejon, and also in the Tijeras basin, there are at the base of the section two sandstones with an intermediate member of gray shale, in all about 200 feet thick. The lower sandstone is hard and massive; the upper one is thinner bedded and locally softer. The lower sandstone and the overlying shale are believed to represent the Purgatoire formation, and the upper sandstone corresponds to the Dakota sandstone.

MANCOS SHALE AND MESAVERDE FORMATION (UPPER CRETACEOUS)

No special study was made of the stratigraphy of the rocks above the Dakota sandstone. At the base is dark shale about 1,000 feet thick, which is well exposed in the region west of Cerrillos and includes a thin limestone member in its lower part. It apparently corresponds to the Mancos shale. Above is sandstone supposed to represent the Mesaverde formation, as in the Cerrillos Basin; it contains a coal bed which also has been mined to some extent. The reports of Lee and Campbell, already cited, give data regarding this coal. The Mancos shale is of both Colorado and early Montana age; the Mesaverde formation is of later Montana age. On the map of this are (pl. 24) for convenience an approximate boundary has been drawn between the beds of Montana age and those of Colorado age, so that the map units do n t correspond to the Mancos and Mesaverde formations.

STRUCTURAL DETAILS

SANDIA MOUNTAINS AND RIDGES TO THE EAST

The Sandia Mountains consist of a thick sheet of limestone of the Magdalena group lying on granite and schist which rise high on the west slope of the ridge. The easterly dip of the limestone carries it down the east slope of the mountains, and in the Tijeras and Uña del Gato region it passes under basins of Mesozoic rocks that include small areas of Mesaverde coal measures.[66] These features are represented on the map (pl. 24) and in the sections (figs. 23 and 24). A view of the steep western front of the Sandia Mountains is shown in Plate 25.

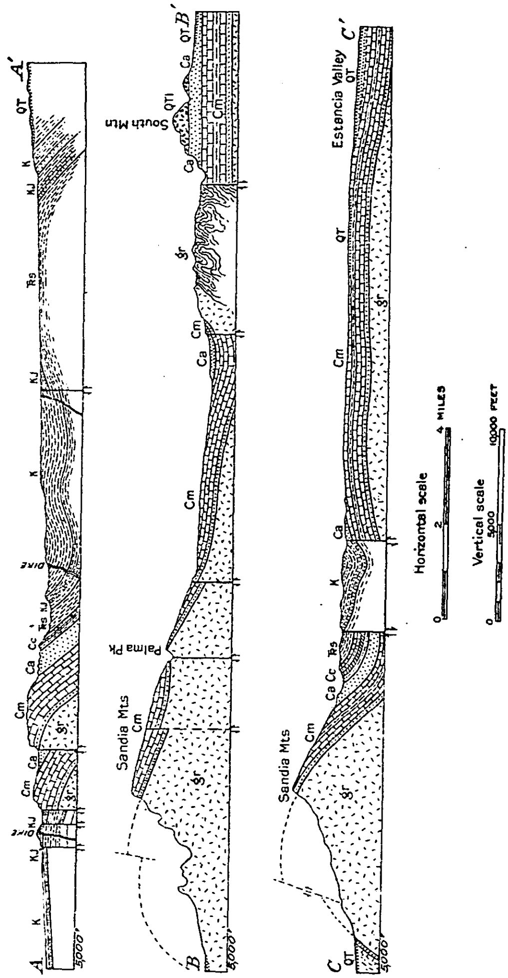

FIGURE 23.—Sections across Sandia Mountains and basins on the east. A–A′, Section passing north of Placitas and south of Tejon; B–B′, section from Sandia Peak east; C–C′, section through Canyoncito, 7 miles north of Tijeras. m, Magdalena group; a, Abo sandstone; b, Chupadera formation; c, red shale capped by Wingate sandstone, Todilto limestone, and gypsum; e, Dakota and associated sandstones; f, Mesaverde sandstones

The strata on the west side of the Sandia Mountains are crushed and faulted along the higher part of the uplift, but the general structure is that of an anticline with a steep western limb, as indicated by small outcrops of limestone which are shown at the left in section C–C′, Figure 23. Some features of the structure of this range have

[66] Lee, W. T., The Tijeras coal field, Bernalillo County, N. Mex.: U. S. Geol. Survey Bull. 471, p. 575, 1912. Campbell, M. R., The Uña del Gato coal field, Sandoval County, N. Mex.: U. S. Geol. Survey Bull. 316, p. 428, 1907.

been described by Ellis.[67] Doubtless under the bolson deposits and Santa Fe formation to the west, in the Rio Grande Valley, there is a thick succession of Carboniferous and Mesozoic rocks in regular order. The anticline pitches to the north, as shown by the relations of the beds near Placitas, east of Bernalillo. A cross anticline passing through the plazita of Madera connects the Sandia Mountain uplift with the uplift of the San Pedro region. The Uña del Gato Basin lies north of this cross anticline, and the Tijeras Basin south of it. A prominent fault with lift on the southeast side

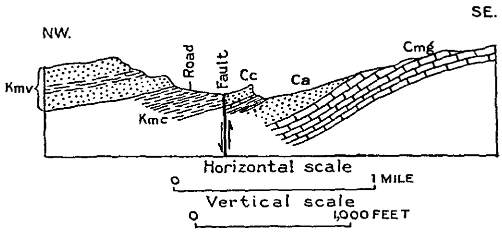

FIGURE 24.—Section across fault in Primera Agua Canyon, northeast of Tijeras, three-fourths of a mile north of the forks of the road to Sadillo. Kmv, Mesaverde formation; Kmc, Mancos shale; Cc, Chupadera formation; Ca, Abo sandstone; Cmg, Magdalena group

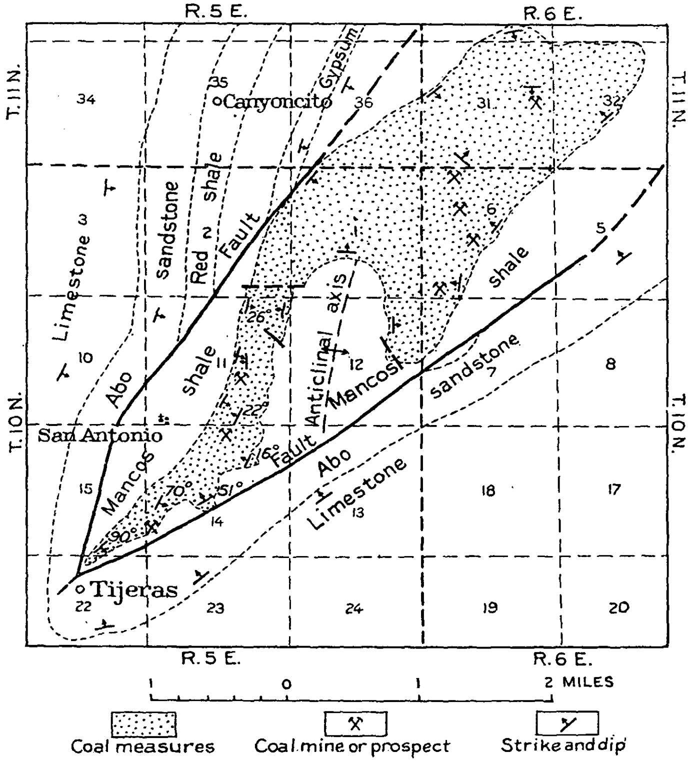

FIGURE 25.—Map showing relations of anticline in Tijeras coal field, on east slope of Sandia Mountains east of Albuquerque

cuts off the coal measures near Tijeras and northeast of that place. Some of the relations of this fault are shown in Figure 24, and the dis-

[67] Ellis, R. W., op. cit., pp. 29-33.

tribution of the formations involved is shown in Figure 25. Herrick [67a] mentions an outcrop of pre-Cambrian quartzite 2 miles north of Sedillo, but I did not find it.

PLACITAS-TEJON REGION

At the north end of the Sandia Mountains, near Placitas, the strata pitch steeply to the north and present a succession from the pre-Cambrian schist to the Mesaverde formation. The dips are mostly to the north, from 8° to 12°. This feature is shown in section A–A′, Figure 23, and in the section in Figure 26, which shows the principal structural features west and southwest of Placitas.

Limestone of the Magdalena group forms prominent cliffs on the mountain slope. The larger faults are indicated by the successive exposures of the underlying schist and granite in the canyons south of Placitas and at the base of bluffs on the east side of the valley a mile due east of Placitas. The Abo red beds are overlain by a hard light-buff sandstone of the Chupadera formation, 60 to 80 feet thick, that forms a prominent ridge 2 miles southwest of Placitas. The Wingate and Todilto formations are well exposed a quarter of a mile south of Placitas and also 1½ to 2 miles to the southwest, where

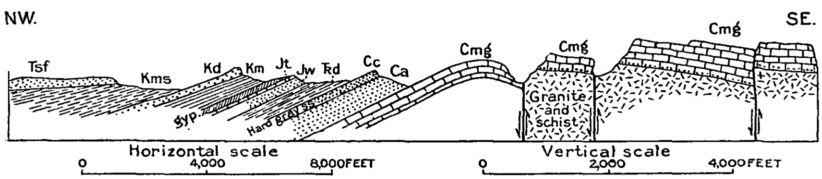

FIGURE 26.—Sketch section from northwest to southeast 1 to 2 miles southwest of Placitas. Cmg, Magdalena group; Ca, Abo sandstone; Cc, hard buff sandstone of Chupadera formation; ₸d, Dockum (?) group (red shales); Jw, Wingate sandstone; Jt, Todilto formation (with gypsum member, gyp); Km, Morrison formation; Kd, Dakota sandstone; Kms, Mancos shale; Tsf, Santa Fe formation

however, the gypsum member of the Todilto is in places crushed out or covered by talus. The Dakota sandstone ridge is conspicuous just south of Placitas and also 1½ miles to the west, where good exposures of light-colored Morrison shale appear in its south slope. The Mancos shale is exposed along the main road from Bernalillo to Placitas, and north of Placitas it is cut by a basalt dike, which causes a ridge. Farther north is a heavy cover of the Santa Fe formation, which also extends to the foot of the mountain along the road 1½ miles northeast of Placitas and thence to San Francisco Spring. This spring doubtless issues along a fault. East of it is exposed an eastward-dipping succession from the top of the Magdalena upward, which, as shown at the east end of section 1, Figure 23, finally extends to the Mesaverde coal measures east of Tejon. The Chupadera formation makes a small but prominent foothill ridge, which extends southward into the northeastern part of T. 12 N., R. 5 E., where it

[67a] Herrick, C. L., op. cit., p. 18.

swings to the east with the general change of strike around the south end of the Uña del Gato coal basin.

A boring in sec. 7, T. 13 N., R. 6 E., near Tonque, about 12 miles northeast of Bernalillo, made in 1912–1914, is reported to have the following record:

Record of boring near Tonque, 12 miles northeast of Bernalillo

	Feet
Yellow clay	0–60
Shale, gray brown, black, with 10 feet of sandstone at 521 feet	60–920
Sandstone with 5 feet of blue shale at 960 feet	920–970
Shale and "gypsum"	970–1, 000
Sandstone	1, 000–1, 030
Shale and "gypsum"	1, 030–1, 100
Shale, blue and gray	1, 100–1, 135
Sandstone	1, 135–1, 185
Shale	1, 185–1, 250
Sandstone and gypsum on 5 feet of blue shale	1, 250–1, 275
Sandstone, hard	1, 275–1, 290
Shale, blue and red; 15 feet of white sandstone at 1,305 feet	1, 290–1, 345
Shale, blue; about 10 feet of sandstone at 1,400 feet	1, 345–1, 444
Shale and sandstone, largely red	1, 444–1, 587
Shale, gray	1, 587–1, 630
Sandstone, red	1, 630–1, 675
Sandstone, gray and red	1, 675–1, 750
Shale, red; 20 feet or more of gray sandstone at 1,760 feet	1, 750–1, 840
Sandstone, gray	1, 840–1, 850

Apparently this boring began on shale of Colorado age, reached the Dakota sandstone at 920 feet, entered the Wingate sandstone at or near 1,444 feet, and penetrated deep into the Abo formation. However, I have much uncertainty as to the identity of the strata. It is hardly likely that the so-called gypsum reported between 970 and 1,100 feet is the deposit in the Todilto formation exposed near Rosario siding, 15 miles to the northeast.

GOLDEN-SAN PEDRO REGION

Golden and San Pedro are on the west side of an irregular elongated dome in which the pre-Cambrian rocks are brought up, as shown in Figure 27. The dome is separated from the Sandia uplift by a syncline that is shallow toward the south but deepens so greatly toward the north that it holds a wide basin of higher Cretaceous rocks, including the Mesaverde coal measures.

The schist area is surrounded by limestone of the Magdalena group, though with some marginal faulting, and the limestone is spread out widely and extensively invaded by porphyry in the San Pedro and South Mountains. The structure of South Mountain is shown in Figure 27; the San Pedro Mountains are of complex structure, some details of which have been presented by Yung and McCaffery.[68] These observers found that the Magdalena beds were uplifted by a large wedge of porphyry and also penetrated by several dikes and sheets of that rock. The general dip of the strata is about 13° E. Some of the rocks are greatly metamorphosed and considerably mineralized. Copper, lead, silver, and gold ores are produced by mines in this altered zone. West of San Pedro is a valley of limestone, on the west side of which rises a prominent ridge of pre-Cambrian white quartzite of the sort exposed in the Sandia Mountains and the Hills of Pedernal. The structure is anticlinal, but probably parallel faults bound the quartzite, and owing to diminished throw this rock disappears to the north, and northwest of Golden the limestones also drop below the surface. On the west side of the quartzite ridge are upper members of the Magdalena group and some of the overlying red beds of the Abo formation, standing nearly vertical or dipping steeply to the west toward a sloping plain, under-

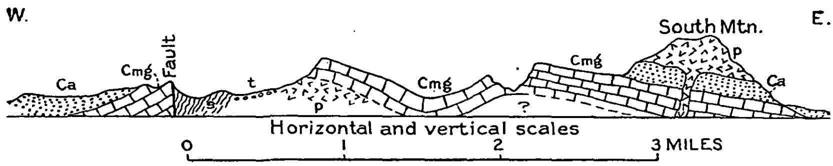

FIGURE 27.—Section through San Pedro uplift, 2 miles south of San Pedro. s, Schist and granite; p; porphyry; Cmg, limestone of Magdalena group; Ca, Abo sandstone; t, talus

lain by Abo and overlying beds. There are extensive exposures of the Todilto formation and Wingate sandstone on the road west-northwest of San Pedro, along the south rim of the Uña del Gato Basin. Just east of Golden is a small area of Abo red beds, and just north is a ridge of hard sandstone resembling the sandstone in the Chupadera formation, but the structural relations were not ascertained. At the crossing of Tuerto Creek, nearly a mile north of Golden, is exposed Todilto limestone 8 feet thick lying on Wingate sandstone. A fault cutting off Todilto, Morrison, and Wingate beds is well exposed below the old mill erected to work the placer gravel of the Santa Fe cap. W. T. Lee has called my attention to a fault that crosses the road in sec. 2, about 3½ miles southeast of Uña del Gato. It trends north-northeast and has high Mancos beds on the west side dropped against Abo red shales on the east side. A drill hole west of this fault is reported to be 1,016 feet deep, all in Mancos shale.

[68] Yung, M. B., and McCaffery, R. S., Ore deposits of the San Pedro district, New Mexico: Am. Inst. Min. Eng. Trans., vol. 33, pp. 350–362, 1903; Eng. and Min. Jour., vol. 75, pp. 297–299, 1903

MANZANO MOUNTAINS

The Manzano Mountains consist of a prominent anticline which in general is the southern continuation of the Sandia Mountains and is continued southward by the Los Pinos Mountains. Tijeras Gap is due partly to a transverse syncline and in small part to the fault which passes diagonally across the uplift. In general the Manzano Mountains are similar in structure to the Sandia Mountains in presenting to the west a high escarpment of granite or schist, capped by limestone that forms a cuesta extending down to the east. In the Manzano Mountains the cuesta is very wide, for near Yirisarri and Chilili the limestone area is 15 miles wide from west to east, extending down nearly to the middle of the Estancia Valley. Along the higher part of the range, and especially on its west slope, there are faults, most of them trending north, but there is no evidence that the steep western face is a single fault scarp. Limestone on the west slope at Coyote Springs and farther south indicates anticlinal structure broken to some extent by faults. The mountains become higher farther south, in Torrance County, reaching an altitude of 10,080 feet (Wheeler Survey) in Manzano Peak. In this region the granite and schist rise higher in the western face, and the limestone cuesta is narrower and steeper. Possibly faults extend along the range, but as no detailed study of this part of it was made details of structure are not known. The sketch section (fig. 28) illustrates the general relations and shows the presence of Abo sandstone, which rises above the Estancia Basin just east of Manzano. This formation is a prominent feature to the south, and in T. 4 N. the overlying lower beds of the Chupadera formation appear, followed

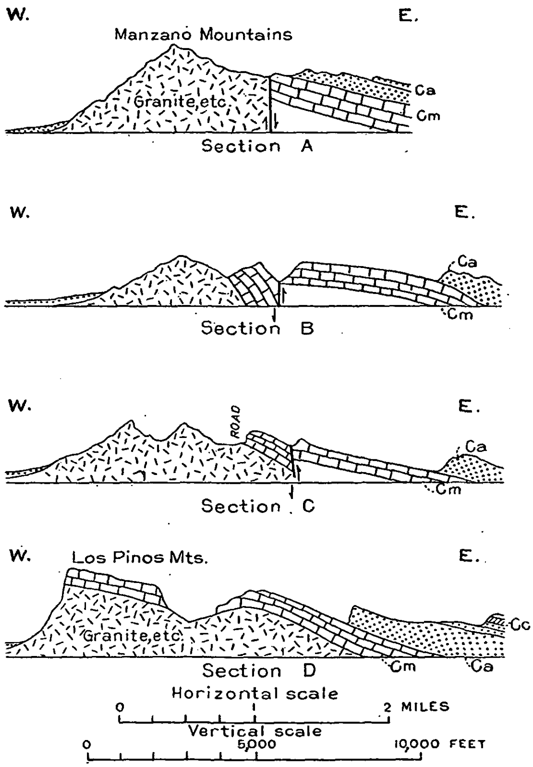

FIGURE 28.—Sketch sections across south end of Manzano Mountains and north end of Los Pinos Mountains. A, 3 miles north of Abo Gap; B, Abo Gap; C, 4 miles south of Abo Gap; D, north end of Los Pinos Mountains. Cm, Limestone of Magdalena group; Ca, Abo sandstone; Cc, Chupadera formation

east of Abo by the upper beds of that formation, constituting Chupadera Mesa. (For columnar section see pl. 20.) The southward ending of the Manzano Mountains is due partly to erosion by Abo Creek and partly to downward pitch in the anticline, together with downfaulting along its east side. The main anticline rises again in the Los Pinos Mountains in an elongated dome, which continues far to the southwest, as described on page 106. The structure of the south end of the Manzano Mountains and the north end of the Los Pinos Mountains is shown in Figure 28. The relations of the main fault to the tilted block of limestone on the west and the cuesta of limestone on the east are well exhibited at Abo Pass, east of Sais, where the Belen cut-off of the Atchison, Topeka & Santa Fe Railway crosses the range.

About Cedro ranger station and for 7 or 8 miles south the limestone dips to the west at a low angle, on the west side of a low anticline whose axis passes along the west side of R. 6 E.

South of Chilili through R. 7 E. the limestone dips at a low angle to the east and passes under the Estancia Basin. The boring in the SW. ¼ sec. 5, T. 6 N., R. 7 E., 8 miles south of Chilili, reached green schist at 1,340 feet, the basement which underlies the Magdalena group. Near Manzano plaza the Abo beds rise above the plain at first in a low knob and then in a ridge which extends west from Punta del Agua to the east wall of Priest Canyon. A high gravel plain about Eastview extends west to the foot of the mountains.

At Willard the Atchison, Topeka & Santa Fe Railway Co. has sunk a group of wells 221 to 443 feet deep, which yield a large supply of water from the base of a succession of Quaternary sand, gravel, and clay about 260 feet thick. The deepest well found this series to be underlain by 42 feet of sand and clay lying on 138 feet of red sandstone.

Two borings made for water by the Atchison, Topeka & Santa Fe Railway Co. at Mountainair penetrated the lower member of the Chupadera formation. Below thin superficial deposits, red shale was found with a 27-foot member of gray shale from 283 to 310 feet, and in one hole gray shale was reported from 180 to 200 feet.

LOS PINOS MOUNTAINS

The Los Pinos Mountains rise on a continuation of the Sandia-Manzano uplift south of Abo Canyon. As shown in the sections in Figure 28, the structure of the range is monoclinal, the limestone and sandstone dipping eastward, mostly at a low angle. The pre-Cambrian quartzite, granite, and schist are lifted high above the adjoining country and for 15 miles present to the west a high rocky escarpment. At the west foot of the range is a long bolson plain sloping continuously to the Rio Grande, 15 miles farther west. The only interruption in this plain, two small basalt buttes and a knob of granite in sec. 33, T. 2 N., R. 2 E., give no clue to the structure on the west side of the uplift. In the southern part of the range the limestone of the Magdalena group pitches down and arches over the uplift in a complete anticline, on the west side of which the valley of Agua Torres reveals a regular succession of Abo, Chupadera, Triassic, and Cretaceous beds and the Tertiary igneous series, as shown in section A, Figure 4. Possibly the same regular succession extends northward past Black Butte and Becker, and it may be cut off by a fault along the west foot of the ridge. The structural relations of the granite knob in sec. 33, T. 2 N., R. 2 E., are enigmatical, for this knob is only a short distance north of the regular succession revealed on Agua Torres.

The fault on the east side of the Los Pinos Mountains shown in Figure 28 is possibly continuous with the one shown in section A, Figure 4, which continues south along the east side of the Cibolo Cone block. (See p. 82.) The outcrop of the limestone of the Magdalena group, which narrows in the north end of the range, owing to faulting and steep upturn, widens greatly in T. 1 N., Rs. 3 and 4 E. Here also it extends to the top of the mountains. To the east is a broad belt of Abo sandstone, which with gentle easterly dip passes beneath the Chupadera formation. In the south half of T. 1 N., R. 3 E., the Magdalena beds pitch down on the axis of the anticline, and in the northern part of the next township to the south they pass beneath the Abo formation, in which the anticline continues for several miles, passing midway between Mesa del Yeso and Cibolo Cone (see map, pl. 17, and section A, fig. 4), as described on page 82.

The rocks of the Los Pinos Mountains were not studied in detail. The limestone of the Magdalena group shows a thickness of about 1,200 feet and presents its usual characteristics. The overlying Abo sandstone consists of reddish-brown slabby sandstone, as in other areas, and its thickness is probably slightly over 1,100 feet.

The conditions under the wide plain west of the range are not known. In the northwest corner of T. 2 N., R. 2 E., there is a knob of volcanic rock, but probably the adjoining region is thickly covered by Santa Fe beds more or less mantled by more recent wash. A 494-foot boring at Becker penetrated red clay and gravel to 380 feet, below which lies red clay.

CERRILLOS BASIN AND GALISTEO VALLEY

A short distance east of Rosario siding, on the Atchison, Topeka & Santa Fe Railway, 6 miles west of Cerrillos, the Wingate and overlying rocks appear in an extensive eastward-dipping succession on the west side of the Cerrillos coal basin. Doubtless this is connected with the north end of the Sandia uplift, although for 6 to 8 miles between the two there is a cover of Tertiary and later sand and gravel. There are excellent exposures of all the beds in the bank of Galisteo Creek and along the railroad, presenting the relations shown in Figure 29. An uninterrupted section was also studied along the main road in Canyon del Yeso, about 2 miles north of the railroad, where the dips are to the east at low angles. At the base is typical Wingate sandstone, red to pink in the lower part but buff near the top. About 120 feet is exposed. The base is covered by Santa Fe beds, which occupy the plain and the badlands to the west. Next above is characteristic Todilto limestone, 10 feet thick, which is impure and breaks into thin plates. The overlying gypsum member of the Todilto formation is here about 60 feet thick, mostly white and evidently nearly pure.[68a] It crops out along the railroad for some distance, as shown in Plate 9, *C*. The Morrison begins with 50 feet of massive clay, gray to chocolate-colored but in places purplish or maroon, with thin beds of sandstone. It is capped by massive buff

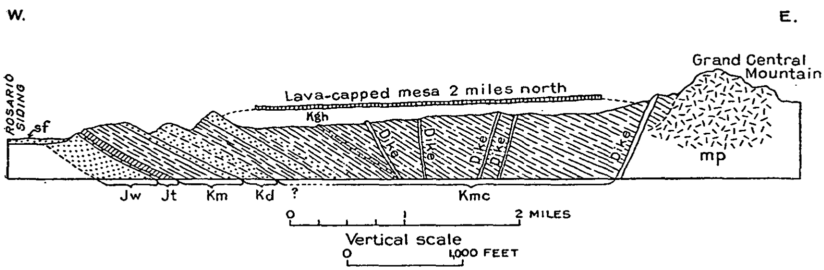

FIGURE 29.—Sketch section from a point near Rosario siding to Cerrillos along and north of Galisteo Creek. sf, Santa Fe formation; mp, monzonite porphyry; Kme, Mancos shale; Kgh, beds resembling Greenhorn limestone; Km, Morrison formation, including Purgatoire formation at the top; Kd, Dakota sandstone; Jw, Wingate sandstone; Jt, Todilto limestone overlain by thick gypsum

soft sandstone, regarded as the lower member of the Purgatoire formation, overlain by 100 feet or more of greenish-gray clay with purplish layers and impure limestone and sandstone beds (probably Purgatoire), capped by 50 feet of gray massive sandstone, undoubtedly Dakota, that gives rise to a ridge of moderate prominence. The overlying black shale, 100 feet thick, is similar to the lower member of the Graneros in most parts of the Rocky Mountain province. The 32-foot member of hard slabby sandstone next above is a feature common at this horizon in north-central New Mexico. It is followed by dark shale, including a limestone member with abundant *Inoceramus labiatus*, undoubtedly representing the Greenhorn limestone, as in the Las Vegas region and northward. A few hundred feet higher is a limy bed suggesting the Timpas limestone. This dark shale is classed as Mancos shale and with a total thickness of 2,000 feet or more extends to the base of the Mesaverde coal measures.

[68a] A sample tested by A. A. Chambers in the laboratory of the U. S. Geological Survey contained 96.22 per cent of $CaSO_4.2H_2O$.

The wide syncline or basin in the vicinity of Cerrillos east of this locality contains a thick succession of Upper Cretaceous rocks, including the well-known coal beds worked at Madrid, south of Cerrillos. In this basin there is also an early Tertiary (?) deposit known as the Galisteo sandstone and the later Tertiary Santa Fe formation with thick wash of sand and gravel on most of the slopes. Los Cerrillos (the little hills), north of Cerrillos, consist of large masses of monzonite porphyry intruded in the Cretaceous strata, and similar intrusions appear in the Ortiz Mountains, a short distance to the south. Many dikes also cut the strata. The geology of the basin has been described by Hayden,[69] Stevenson,[70] Johnson,[71] Lee,[72] Lindgren,[73] Campbell,[74] and others. Johnson's report is a detailed description of a large area including Los Cerrillos, and Lee and Campbell have described the coal fields.

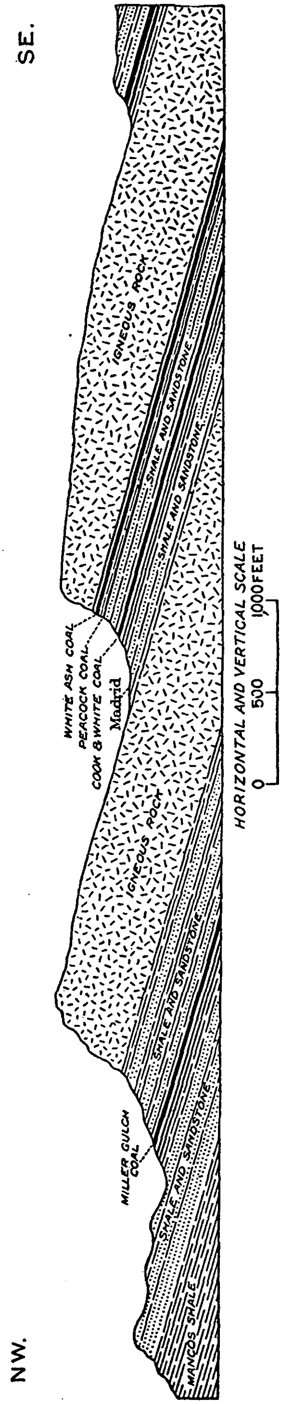

FIGURE 30.—Section through Madrid, 3 miles south of Cerrillos, showing relations of coal beds in Mesaverde formation to sills of igneous rock. (After W. T. Lee)

Along the west side of the Cerrillos Basin there is a wide zone of easterly dips, but the direction of dip changes to south in the vicinity of Cerrillos. There is a zone of similar easterly dips in the ridge 12 miles east of Bernalillo, east of which, as also in the plateau south of Cerrillos, are Mesaverde sandstones with coal beds, which are mined extensively at Madrid and were formerly worked at several places farther south. At Madrid three beds of coal are worked—the lowest bed, 3 feet thick; the middle bed, 100 feet above, about 1½ feet thick; and the top "white-ash bed," 22 feet higher, about 5½ feet thick. Near Madrid the upper coal bed has been changed to anthracite by an intruded sill of porphyry 400 to 500 feet thick, having the relations shown in Figure 30. At Madrid the beds dip about

[69] Hayden, F. V., Preliminary field report of the United States Geological Survey of Colorado and New Mexico, pp. 66–68, 1869.
[70] Stevenson, J. J., The Cerrillos coal field: New York Acad. Sci. Trans., vol. 15, pp. 105–122, 1896.
[71] Johnson, D. W., The geology of the Cerrillos Hills, N. Mex.: School of Mines Quart., vol. 24, pp. 1–204, 1903.
[72] Lee, W. T., op. cit. (Bull. 531), pp. 1–30.
[73] Lindgren, Waldemar, op. cit. (Prof. Paper 68), pp. 164–167.
[74] Campbell, M. R., op. cit. (Bull. 316), pp. 427–428.

15° E., but drill holes to the east show that the amount diminishes in that direction. Not far east of Madrid are outcrops of the Galisteo sandstone, which occupies a considerable area in the center of the basin and extends north of the railroad a short distance east of Cerrillos. The coal measures come to the surface again at the Omera mine, on the east side of the basin about 18 miles southeast of Cerrillos, but at this place the coal beds are thinner. The relations in this vicinity have been described by Gardner [75] and Lee.[76] Farther east the Mancos shale and underlying formations to the Chupadera come up on the east side of the basin. The lower strata are well exposed about 17 miles south of Lamy, where Dakota sandstone, Morrison formation, Todilto limestone, and Wingate sandstone show characteristic features. The large igneous mass of Cerro Pelon and two long dikes of diabase cut the Mancos strata in the wide outcrop area of that formation southwest of Lamy. The Greenhorn (?) limestone in the Mancos shale also is well defined on this side of the basin. The coal measures in the southern extension of the Cerrillos Basin form the Uña del Gato (Hağan) coal field, which has been briefly described by Campbell.[77] A section of the strata in this part of the basin is given below:

Section in Hagan coal field

[Modified after Lee, W. T., op. cit. (Prof. Paper 101), pp. 201–203]

		Feet
Conglomerates (Quaternary and Santa Fe formation)		Many
Shale and sandstone	Galisteo sandstone	3, 445
Sandstone, conglomeratic at base	Galisteo sandstone	345
Unconformity.		
Sandstone and shale with coal beds; 265-foot sandstone member at base (Mesaverde formation)		1, 854±
Shale with fossiliferous layers (Mancos shale)		2, 076
Sandstone, light, cross-bedded, local conglomerate (Dakota sandstone)		50
Shale, variegated, and sandstone (Morrison formation)		200

SAN JOSE RIVER TO RIO SALADO

GENERAL RELATIONS

A large exposure of "Red Beds" extends southward from the valley of San Jose River 35 miles to the valley of the Rio Salado in eastern Valencia County and the adjacent north-central part of Socorro County. Very little information is on record regarding this region, but several reconnaissances across it in 1913, 1914, and 1917 afforded many interesting data as to stratigraphy and structure. The map forming Plate 26 shows the distribution of formations, and the cross sections in Figure 31 show the general structure. Some details of the Cretaceous boundaries near the Rio Salado have been taken from a map by Winchester,[78] who made a detailed study of the coal-bearing beds in north-central Socorro County in 1912.

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[75] Gardner, J. H., Isolated coal fields in Santa Fe and San Miguel Counties, N. Mex.: U. S. Geol. Survey Bull. 381, pp. 447–449, 1910.

[76] Lee, W. T., op. cit. (Prof. Paper 101), pp. 206–217.

[77] Campbell, M. R., op. cit. (Bull. 316), pp. 431–434.

[78] Winchester, D. E., op. cit. (Bull. 716), pl. 5.

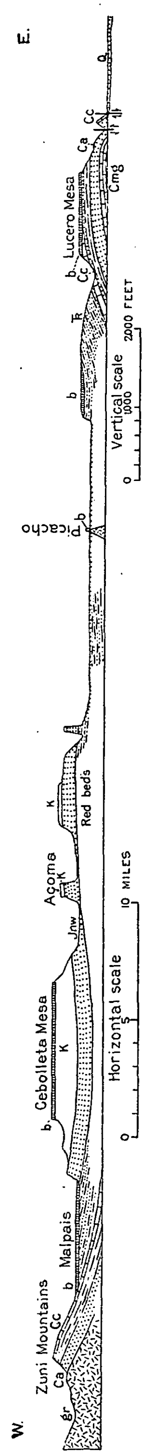

FIGURE 31.—Section across parts of Valencia and Socorro Counties. Q, Quaternary; K, Cretaceous; Jnw, Navajo sandstone underlain by Todilto limestone and Wingate sandstone; TR, Triassic; Cc, Chupadera formation; Ca, Abo sandstone; Cmg, Magdalena group; b, basalt; gr, granite

As shown in Figure 31 the predominating structural feature is a very broad monocline sloping westward into the wide basin of the Cebolleta Mesa and Mount Taylor area. To the east this monocline rises into an irregular anticline and zone of faulting—the "Lucero anticline"—that culminates in the Sierra Ladrones uplift, in which granite reaches an altitude of 9,412 feet (Wheeler Survey), or 3,500 feet above the plain to the east. In the region of the Sierra Lucero and in Mesa Gigante and westward the strata dip so gently that their inclination is perceptible at but few localities. There are, however, variations in the rate and direction of dip and a few local crenulations and faults. Owing to the low dip the Cretaceous sandstones constitute wide, high plateaus to the west, which are deeply incised by valleys. The great pile of Tertiary igneous rocks of the San Mateo Mountains surmounts this plateau, and there are similar masses in the Datil and Bear Mountains, to the south. Some of the plateaus are capped by basalt, and streams of relatively recent lava extend down several valleys, notably that of the Rio San Jose, part of which appears to have come from the large fresh crater of Cerro Verde.

The general succession of sedimentary rocks ranges from Mississippian to late Cretaceous, but the area contains still younger igneous sheets, and there is overlap by the Santa Fe formation (Miocene and Pliocene) and Quaternary sand and gravel. Permian and Triassic "Red Beds" are widely exposed, overlain to the north by Wingate sandstone and the overlying Todilto limestone with its thick bed of gypsum. These and the overlying Morrison are overlapped to the south by Dakota (?) sandstone, which there lies directly on the Triassic red shale. In the Sierra Ladrones the pre-Cambrian granite and gneiss appear.

FORMATIONS

LAKE VALLEY LIMESTONE (MISSISSIPPIAN)

From limestone on Rio Salado, just south of Ladron Peak and not far above the granite, W. T. Lee[79] obtained fossils identified by G. H. Girty as follows:

Zaphrentis, 2 sp.
Granatocrinus? sp.
Platycrinus? sp.
Rhipidomella aff. R. dubia.
Spirifer aff. S. logani.
Spirifer aff. S. tenuicostatus.
Spiriferella aff. S. neglecta.
Athyris lamellosa.
Cliothyridina aff. C. obmaxima.
Phillipsia sp.

79 Gordon, C. H., Mississippian formations in the Rio Grande Valley, N. Mex.: Am. Jour. Sci., 4th ser., vol. 24, p. 58, 1907.

Girty states that this fauna is beyond question of lower Mississippian age but that it does not agree closely with that of the typical Lake Valley limestone, having a somewhat younger aspect, though it may have been contemporaneous. This locality was mapped as Kelly limestone by Gordon.

MAGDALENA GROUP (PENNSYLVANIAN)

The anticline east of the Sierra Lucero exposes limestone of the Magdalena group from Arroyo Gallina southward to and beyond Arroyo Raton and also in a very small area on Arroyo Carrizo. Another exposure extends along the west slope of the Sierra Ladrones uplift from the valley of Arroyo Raton to the Rio Salado, on which it constitutes canyon walls. (See pl. 4, *B*.) The greatest thickness exposed is about 1,000 feet. Fossils were collected at several places and identified by G. H. Girty as follows:

Top beds of limestone of Magdalena group at salt springs on Arroyo Pato, 25 miles west of Belen:

Fenestella sp.
Polypora sp.
Batostomella sp.
Fistulipora sp.
Productus cora.
Productus semireticulatus.
Marginifera splendens.
Spirifer cameratus.
Squamularia perplexa.

Uppermost limestone northwest of Ladron Peak:

Productus cora.
Productus nebraskensis.

Limestone in 20 feet of gray basal sandstone at north end of the Sierra Ladrones, about NW. ¼ sec. 14, T. 3 N., R. 3 W., a few inches above granite:

Batostomella sp.
Polypora sp.
Chonetes sp.
Spirifer rockymontanus.
Composita subtilita.

Winchester collected molluscan fossils from upper ledges of limestone near the west end of the canyon of Rio Salado in the southeast corner of T. 2 N., R. 3 W., which are regarded as Pennsylvanian. In an unpublished report he gives the following section:

Section north of Rio Salado in T. 2 N., R. 3 W.

	Feet
Limestone, brownish gray, hard	4
Shale, dark, argillaceous, and thin-bedded sandstone, with fossil plants	20
Limestone, dark, and thin-bedded sandstone	50
Sandstone, coarse fossiliferous	4

This 4-foot sandstone member is underlain by 520 feet of limestone, which is exposed in the ridge in the Range just east. This limestone yielded two lots of fossil shells determined by G. H. Girty as follows:

Lot 1, below the plant-bearing shale:

Lophophyllum profundum.
Stenopora sp.
Rhombopora sp.
Derbya crassa.
Meekella striaticostata.
Productus semireticulatus.
Productus nebraskensis.
Marginifera splendens.
Spirifer cameratus.
Aviculipecten, 2 sp.
Euphemus nodicarinatus?
Phillipsia major.

Lot 2, above the plant-bearing shale:

Lophophyllum profundum.
Fistulipora sp.
Crinoid stems.
Fenestella sp.
Pinnatopora sp.
Polypora sp.
Stenopora carbonaria.
Derbya robusta.
Productus nebraskensis.
Productus cora.
Productus semireticulatus.
Marginifera lasallensis.
Composita subtilita.
Chonetes verneuilianus.
Pustula semipunctata?
Pustula nebraskensis.
Pugnax osagensis.
Dielasma bovidens.
Spiriferina kentuckyensis.
Spirifer cameratus.
Spirifer rockymontanus.
Squamularia perplexa.
Ambocoelia planiconvexa.
Cliothyridina orbicularis?
Platyceras parvum?
Griffithides? sp.
Fish tooth.

Girty states that both these lots of fossils consist of species which occur in the Magdalena group of central New Mexico and are essentially identical with the Pennsylvanian faunas of the Mississippi Valley and that the fauna is entirely distinct from that of the Manzano group (Chupadera formation and Abo sandstone).

In the shale between these two limestones in the NW. ¼ sec. 12, T. 1 N., R. 3 W., Winchester collected in 1913 fossil plants that were determined as follows by David White:

Callipteris? sp.
Odontopteris sp., probably O. obtusa (Brongniart).
Neuropteris? sp., probably new.
Sphenophyllum sp., small fragment of the filiculine type.
Walchia pinniformis (Schlotheim) Sternberg.
Walchia gracilis (Dawson) (probably).
Gomphostrobus bifidus (Geinitz) Potonie.
Araucarites?, part of scale.
Two seeds.

Gomphostrobus and a neuropteroid, probably *Odontopteris obtusa*, appear to be abundant. The probable *Callipteris* appears to be related to *C. scheibei*. The material, especially that of the fernlike forms of which only small fragments are present, "will not permit definite correlation, but * * * it can not be regarded as older than very late Pennsylvanian."

Additional material collected at this place by Winchester in 1914 was reported on as follows by David White:

Sphenopteris sp.
Callipteris cf. C. hyratifolia.
Neuropteris aff. N. gleichenoides.
Taeniopteris sp.
Cycad? Leaf fragment suggesting Ctenophyllum saportaea?
Gomphostrobus bifidus.
Walchia cf. W. pinniformis.
Walchia seeds.
Araucarites sp.
Voltzia?
Trigonocarpum sp.
Liverwort, new genus.
Insect wing.

Notwithstanding the insufficiency of much of the material for specific or even generic identification, the evidence points very strongly to the Permian age of the flora.

D. E. Winchester[80] also collected fossils from the lower beds of the Magdalena group in the canyon of the Rio Salado in the NW. ¼ sec. 7, T. 1 N., R. 2 W., which were determined by G. H. Girty as follows:

Campophyllum sp.	Dielasma bovidens.
Chaetetes milleporaceus.	Spirifer rockymontanus.
Productus semireticulatus.	Spirifer cameratus?
Productus punctatus.	Squamularia perplexa.
Productus cora.	Composita subtilita.
Marginifera wabashensis?	Anomphalus rotulus.
Marginifera splendens.	Griffithides sp.

These fossils were about 500 feet below the top of the Magdalena. Girty states that they show an early Pennsylvanian type of fauna about comparable to that of the lower part of the Kansas section, for example, the Fort Scott limestone.

ABO SANDSTONE (PERMIAN)

The Abo outcrop extends along the east side of the Sierra Lucero from the latitude of Rio Puerco station to sec. 25, T. 3 S., R. 4 W., where it is cut off by a fault. An area of considerable size is exposed in a syncline extending from Arroyo Pato into the southern part of T. 3 S., and probably the formation continues southward under the sand and travertine to and beyond the Rio Salado. In the area next east of the Sierra Lucero the formation is exposed in a succession of ridges in which the beds dip gently to the west and have an aggregate thickness of about 800 feet. The rocks consist of rich red-brown sandstone, mostly slabby, and sandy shale, with some layers of greenish shale and limestone in the lower part, possibly beds of passage to the limestone of the underlying Magdalena group.

A few fossils were collected by me in 1902 in the basal beds of the Abo sandstone on the axis of the Lucero anticline, in sec. 36, T. 6 S., R. 3 W. They were found in 20 feet of greenish-gray sandy shale with thin sandstone layers and an inch of coal at the top, at a warm spring. They were identified by G. H. Girty as follows:[81]

Myalina permiana.	Bakewellia? sp.
Myalina perattenuata.	Bulimorphia near B. nitidula.
Aviculipecten cf. A. whitei.	Spirorbis sp.

These fossils are regarded as Permian in the sense in which that term is used in the Mississippi Valley but are not of the same fauna as that which occurs in the Chupadera formation.

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[80] Personal communication.

[81] Darton, N. H., op. cit. (Bull. 435), p. 37.

CHUPADERA FORMATION (PERMIAN)

The Chupadera formation constitutes the wide westward-sloping monocline or cuesta of the Sierra Lucero and also the anticlinal ridge extending southward from Garcia to the southeast corner of T. 6 N., R. 3 W. The rocks are limestone, gypsum, and gray and red sandstone in a succession precisely similar to that presented in the region east of Socorro and Chupadera Mesa. The thickness is about 600 feet, and the upper and lower limits of the formation are distinct, without marked signs of unconformity in either direction. Figure

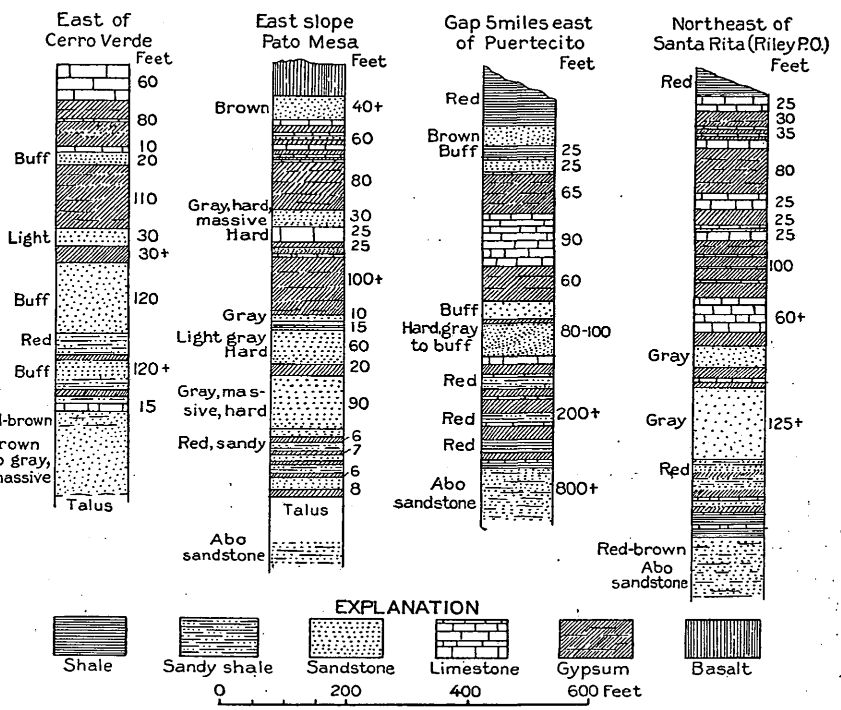


FIGURE 32.—Columnar sections of Chupadera formation in Sierra Lucero, Valencia County

32 shows the characteristic succession at several places in the east face of the Sierra Lucero.

The upper limestones constitute the summit and long western slope of the mesa, and the soft basal beds, which are mostly reddish, crop out along the lower eastern slopes and in the wide plain east of the foot of the mesa. Some of the gray sandstones are moderately hard, and these beds together with some limestone layers cause steps and buttes along the east slope.

In the ridge east of Lucero Mesa the Chupadera formation consists of the following members:

Section of Chupadera formation in ridge east of Lucero Mesa

	Feet
Limestone	30–50
Gypsum	40–50
Gray sandstone	40
Gypsum, sand, and limestone	60
Gray sandstone, hard, massive	140
Red sandy shale and soft sandstone with several thin beds of gypsum and limestone; one persistent 10-foot bed of limestone 30 feet above base	300±

The massive sandstone is conspicuous because it is hard and constitutes most of the crest of the ridge. Similar stratigraphy is presented in the southeastern extension of the formation south of Santa Rita (Riley post office), as shown by the section in Figure 32.

TRIASSIC "RED BEDS"

The thick succession of red shales overlying the limestone of the Chupadera formation is believed to be of Triassic age, but it is barely possible that at the base some Permian (Chupadera) strata may be included. To what extent the Chinle, Dockum, and Moenkopi may be represented has not been determined. The succession is 900 feet or more thick, and owing to very low dips the beds crop out in a broad area of lowlands in the valleys of Arroyo Lucero, Arroyo Colorado, Rio Salado, and San Jose River. Much of this area is covered by lava flows, alluvium, and talus. To the east the red strata extend far up the west slope of the Sierra Lucero, to the southwest they pass beneath Dakota sandstone, and to the northwest they pass beneath Wingate sandstone. Very few details of the stratigraphy were noted. Red shale predominates, but some included beds are greenish and purple, and there are also beds of red, brown, and gray sandstone. Limestone nodules occur in purplish-brown members at several horizons.

In the ridges southwest of Lucero Mesa the lower part of the Triassic is extensively exposed. The beds comprise three layers of reddish-brown cross-bedded sandstone, 20 to 30 feet thick, separated by an equal amount of red shale and overlain by red shale, including concretionary limy layers. In a wide area south of Lucero Spring and west of Cerro Verde these "Red Beds" are capped by a sheet of conglomerate with lime matrix, evidently the remains of a valley filling of an earlier stage of erosion, impregnated with deposits from springs. On the north side of the San Jose Valley the red shale comes up under Wingate sandstone a short distance east of Mesita Negra. Not far below is a 30 to 40 foot member of brown-red sandstone on 100 feet or more of red shale, all of Chinle character. These beds extend east with gradual rise to the fault north of Suwanee, where they abut against Cretaceous strata, as shown in Figure 40. On the east slope of the anticline south of South Garcia the Triassic beds are not more than 300 to 400 feet thick and dip 15° E. under Wingate sandstone. They consist of soft red shales, in part purple, with included sandstone members. Probably their lower portion is cut off by the fault.

Several deep holes bored by the Arizona & New Mexico Land Co. near the Atchison, Topeka & Santa Fe Railway threw some light on the stratigraphy. One 942 feet deep at Armijo, after passing through a thin bed of lava, penetrated red sandstone and shale and at the bottom 42 feet of gray sandstone, all in the Triassic "Red Beds" that overlie the Chupadera formation. The hole begins about 200 feet below the top of these beds as exposed in the slopes north of Armijo and therefore indicates that they have a thickness of about 1,150 feet. An 853-foot hole in sec. 17, T. 8 N., R. 5 W., 8 miles south of Laguna pueblo, penetrated red shale and sandstone (including 90 to 160 feet of gray sandstone), the same strata as in the Armijo hole. Much salty water was found. Holes 855 feet deep at North Garcia and 1,015 feet deep at Rio Puerco are in the sand plain east of the main fault and penetrate strata that can not be identified from the records furnished.

WINGATE SANDSTONE (JURASSIC?)

The Wingate sandstone in this region presents the same characteristics as in the type locality on the Zuni uplift. It is massive, fine and even grained, and cross-bedded. In large part it is of a pale pink tint, but this fades into white near the upper part, and at the top the color is buff. At the base it is strongly separated from the Triassic red shale by an abrupt change of material and possibly some slight channeling, indicating hiatus. It is overlain by the characteristic platy Todilto limestone. The thickness is 140 feet near Mesita Negra, and 270 feet east of Dripping Springs, but it decreases farther south, and the formation disappears in the southern part of Valencia County. Possibly its thin edge is present in Bluewater Canyon. A small outcrop of it appears in the Acoma Valley, it is bared by San Jose River in a small area a mile north of Suwanee, and it appears for a mile or more in the monocline south of South Garcia. The Wingate sandstone crops out extensively along the south and east fronts of the escarpments from Mesa Gigante at Suwanee past Mesita Negra, Dripping Springs, and Petoch Butte. In general it comprises two members—an upper one of gray cross-bedded sandstone weathering in rounded forms and a lower one of red massive sandstone weathering in vertical cliffs with somewhat columnar structure. Similar cliffs extend eastward from Mesita Negra along the south front of Mesa Gigante to the fault north of Suwanee, where the formation abuts against the Morrison formation and the lower part of the Dakota, as shown in Figure 40.

In the high cliffs 4 miles east of Dripping Springs it presents the features shown in Figure 33 and Plate 28, *B*.

To the southwest the formation thins somewhat, mainly by thinning out of the red shale member. Cliffs of the massive columnar red sandstone are conspicuous at the ranch 1½ miles east of Dripping Springs, overlain by the gray member. Sand and talus cover more or less of the red member farther south, but the cross-bedded gray sandstone, capped by the Todilto limestone, is conspicuous in spurs and cliffs near Dripping Springs. In the prominent butte known as Petoch there is the great exposure shown in Plate 11, *B*, and Figure 34. Here the upper softer gray cross-bedded member, 50 feet thick,

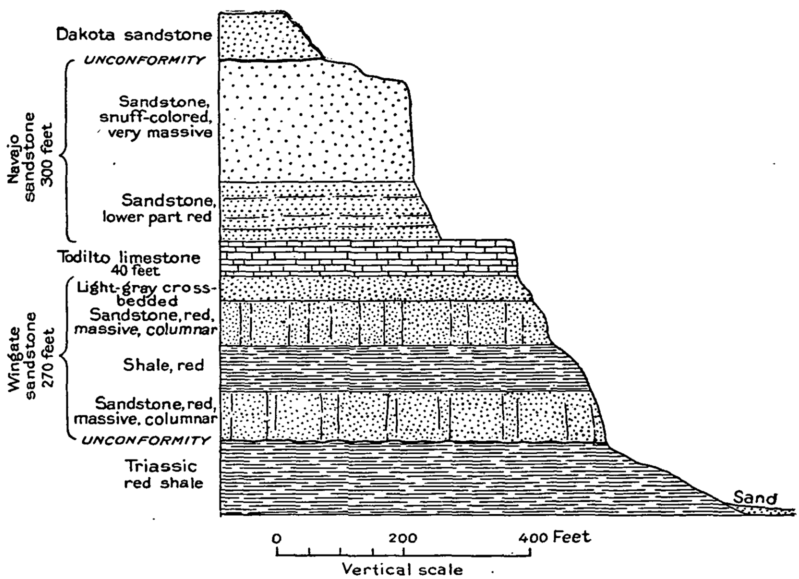


FIGURE 33.—Section of strata exposed in cliffs 4 miles northeast of Dripping Springs, Valencia County

and the lower red columnar member, 60 feet thick, are present and the basal unconformity is well marked. In the section 1 mile south of Petoch Butte (pl. 29, *A*) the thickness is about 200 feet. The upper gray sandstone member is of very light tint and the character of its cross-bedding suggests eolian origin. Here, as in the region to the north, it grades down into massive red sandstone with columnar structure in the cliffs. At the base it is sharply separated from the top of the Triassic red shale. It thins rapidly southward from this place, but its southern edge was not located.

In an arroyo 3 miles south of South Garcia the Wingate sandstone is 35 feet thick; the upper third is nearly white, and the lower part is bright red and massive and lies unconformably on purplish-red shale (doubtless Triassic). The top of the formation is exposed in the faulted block on the north bank of San Jose River a mile northeast of Suwanee.

The Wingate sandstone is well exposed in the ridge north of Grant, where it is the typical red massive fine-grained rock. The outcrop extends continuously westward from this place along the north slope of the Zuni uplift. The sandstone lies on Triassic red shale (Chinle), from which it is sharply separated, and it is capped by Todilto limestone. There is a cover of lava about Horace, but 5 miles south of that place the sandstone reappears at the foot of a high cliff of Navajo sandstone for a short distance, and it crops out also in the northern part of T. 7 N., 4 miles southwest of the Garcia ranch.

TODILTO FORMATION (JURASSIC?)

The Todilto limestone, which overlies the Wingate sandstone in and west of the Zuni uplift, also occurs throughout the extent of that sandstone in Valencia County, and in most of the area it comprises two members, a lower member of typical Todilto limestone and an upper member of massive gypsum. The limestone member is from 10 to 16 feet thick and is characterized by thin bedding. It is well exposed, underlying the thick gypsum member at Rito siding, northwest of Mesita Negra, as shown in Figure 36 and Plate 28, *B*. Here it is 10 feet thick, and its outcrop extends along the north side of the valley of San Jose River to the fault northwest of Suwanee. To the south it was traced to and beyond Petoch Butte. It appears in the Acoma Valley a mile northwest of Acoma and also a mile southeast of the pueblo and in extensive areas farther down the valley. There is a long exposure of the limestone southeast of Mesa Redonda, where a ridge of it extends as a cuesta for 1½ miles along the south side of the northwest-southeast fault west of South Garcia. It is also exposed on Wingate sandstone a mile northeast of Suwanee, where it is about 6 feet thick, and on the railroad 1½ miles east of Suwanee. It rises as a low ridge along the railroad (west-bound tracks) south of South Garcia and for a mile or more to the south. Here it is 15 feet thick and mostly in very thin layers, especially where weathered.

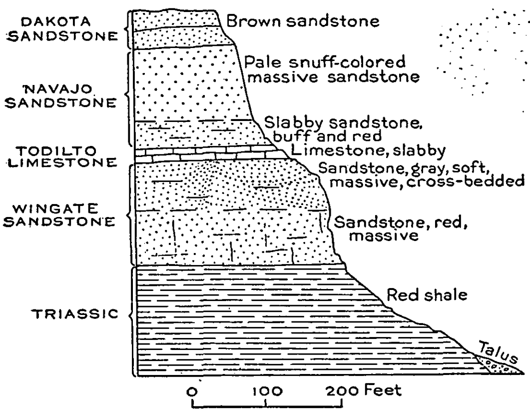


FIGURE 34.—Section at Petoch Butte, Valencia County

The limestone is a conspicuous feature south from Mesita Negra to and beyond Dripping Springs, at most places forming a wide shelf terminating in a cliff. This feature is shown in Figure 33 and Plate 28, *A*. Here the limestone is 40 feet thick and part of it is massive or slabby. It is thinner at Dripping Springs, and in Petoch Butte it appears to grade into a sandy layer. In the slopes a mile south of Petoch Butte it is represented by a few thin limestone layers interbedded in hard slabby sandstones just above the Wingate cliff, and no trace of it was noted farther south.

The limestone is well exposed in the ridge a mile northeast of Grant and also in a low ridge 3½ miles east-northeast of Grant, where it is 15 feet thick and lies on a shelf between ledges of Navajo and Wingate sandstone. It also appears in the southern part of T. 10 N., R. 9 W., 5 miles southwest of Horace, where the thickness is 15 feet. It is absent in the Wingate-Navajo exposure in the northern part of T. 7 N., R. 10 W., where its place is taken by white conglomerate.

In the San Jose Valley near Mesita Negra and for some distance to the south and east the Wingate sandstone and the limestone member of the Todilto formation are overlain by a thick bed of white massive, nearly pure gypsum. It is undoubtedly the same bed as the one of similar stratigraphic relations and character that occurs in the Chama Valley and Nacimiento uplift and extends from a point west of Cerrillos nearly to Tijeras. Its outcrop is especially conspicuous near Rito siding, where it extends along the north side of the Atchison, Topeka & Santa Fe Railway for some distance. (See pl. 28, *B*.) Here, as shown in Figure 33, its thickness is about 80 feet, and it is quarried for shipment to be made into plaster of Paris. The outcrop extends eastward along the south front of Mesa Gigante on the north side of the valley to the fault north of Suwanee, thinning gradually to 60 feet. It appears again 1 mile north of Suwanee, where it is 50 feet thick, and also on the north and east sides of Mesa Redonda, where it presents a wide outcrop. A small amount shows a short distance northwest of South Garcia, at milepost 44a on the west-bound railway track. It may be present in the ridge 2 to 3 miles south of that station, but if so it is thin and covered with talus. Its outcrop extends south from Mesita Negra for some distance but ends in or near the northern part of T. 8 N., R. 5 W. As the typical Todilto limestone appears to be conformably overlain by the Navajo sandstone, this gypsum bed, which is also overlain by the Navajo, is regarded as a local development of the upper part of the Todilto.

NAVAJO SANDSTONE (JURASSIC?)

Overlying the gypsum member of the Todilto formation and extending considerably beyond the south and west margins of that deposit is a thick body of sandstone that is doubtless equivalent to the Navajo sandstone of the Zuni uplift. The lower member is dark brown-red and not very massive; the upper member is light buff, massive, and moderately hard. The red member, of which the upper part is hard and massive and the lower part slabby to shaly, conspicuously overlies the gypsum in the bluff north of Mesita Negra (El Rito) as shown in Plate 28, *B*. Here and in Arroyo Verde, which its outcrop crosses a mile above the mouth, its thickness is 140 feet, and it is rather sharply separated from the upper or buff member, which is somewhat thinner and much harder. The upper member constitutes the high mesa on which Acoma is built, Mesa Encantada, and many bluffs along the Acoma Arroyo, the north face of Mesa Gigante, and the valley of San Jose River. The pueblos of Laguna and part of Acoma (see pl. 29, *B*) are built on it. It is conspicuous in Mesa Redonda and in the faulted blocks north of Suwanee, where it is 150 feet thick and the lower member of red sandstone is only 35 feet. It also shows at points both west and 3½ miles south of Garcia siding. In this region the top part is fine grained and the lower red member is sharply separated from it. The top of the high butte called Petoch (see pl. 11, *B*), on the east side of the mesa 8 or 10 miles east of Acoma, is Navajo sandstone except for a small cap of Dakota(?) sandstone. Here the main body of the Navajo sandstone is nearly 200 feet thick. Next below is 30 feet of red sandy shale on 10 feet of white soft sandstone, and similar basal beds appear at Dripping Springs, representing the red member so conspicuous north and west of Mesita Negra. Immediately below the sandstone is 10 feet of Todilto limestone on Wingate sandstone. Farther south this red member thins and finally disappears, but the buff sandstone member of the Navajo apparently continues along the east side of the mesa to a point 2 or 3 miles south of Bluewater Canyon. Near Dripping Springs, where the Navajo sandstone is about 200 feet thick, the upper and lower parts are hard and marked by cliffs, but the medial member weathers in more rounded forms on a long rough slope. At the base are 30 feet of soft to moderately hard gray sandstone, 30 feet of red sandy shale, and 10 feet of white soft sandstone lying on Todilto limestone. In Petoch Butte and to the southwest there are similar basal members. In the 150-foot bluff 1 mile south of Petoch Butte the Navajo massive buff sandstone of very pale greenish-gray tint lies on 60 feet of buff sandstone, partly slabby,

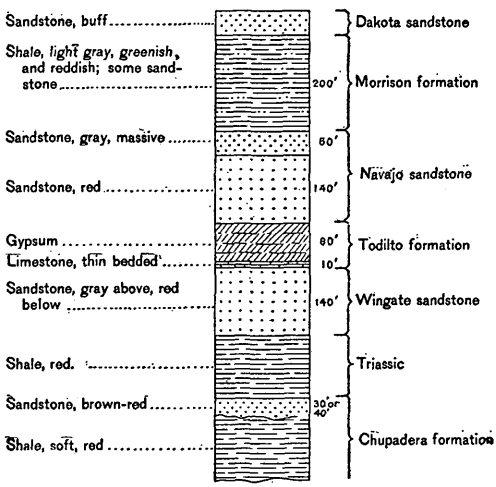
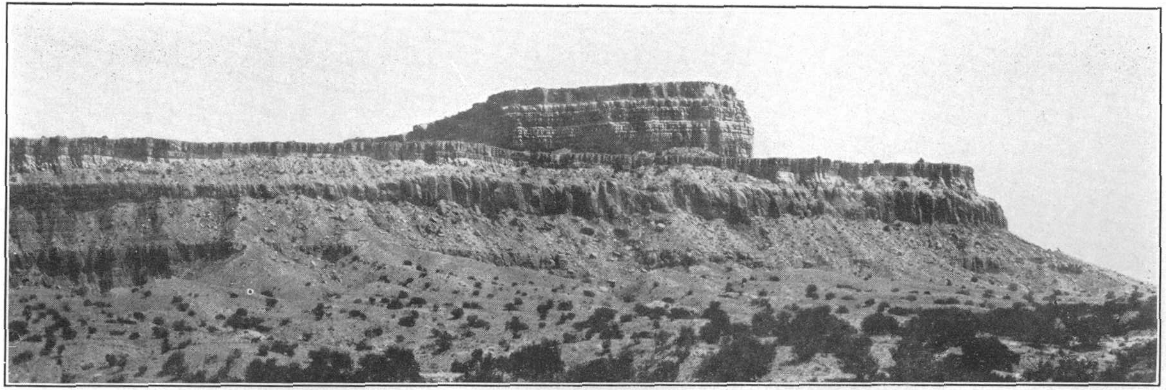


FIGURE 35.—Columnar section at Rito siding

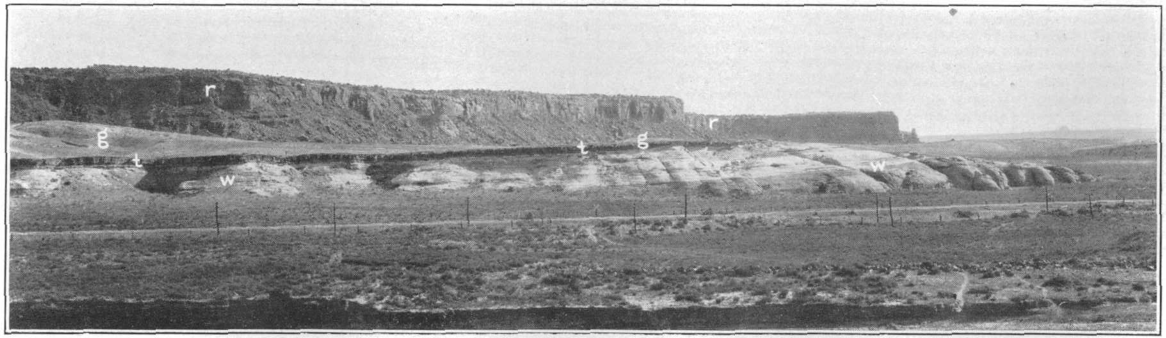
GYPSUM OVERLAIN BY RED SANDSTONE (NAVAJO) AT EL RITO

Looking northwest. Atchison, Topeka & Santa Fe Railway in middle ground. g, Gypsum member of Todilto formation; t, limestone member of Todilto formation on Wingate sandstone



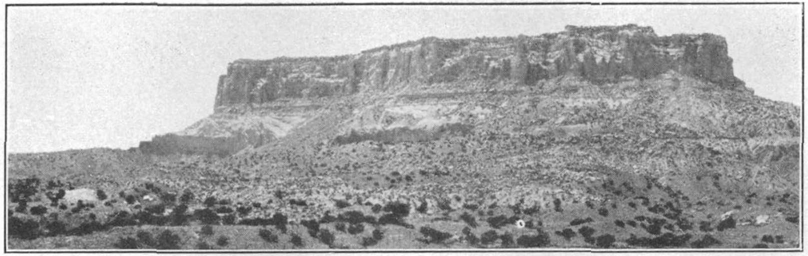
A. EAST EDGE OF HIGH MESA 8 MILES SOUTH-SOUTHWEST OF LAGUNA

Looking north. Higher cliff, Dakota sandstone on Navajo sandstone; the shelf is Todilto limestone, below which is cliff of Wingate sandstone surmounting red shale slopes



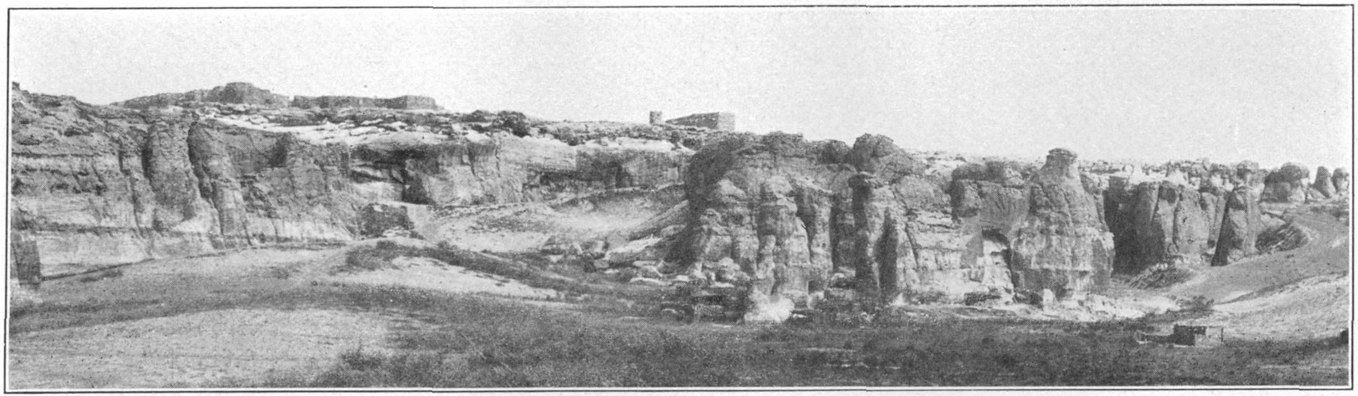
B. WINGATE SANDSTONE NORTHEAST OF EL RITO SIDING

w, Wingate sandstone, red below, white above; t, limestone member of Todilto formation; g, gypsum member of Todilto formation; r, red sandstone (lower Navajo)



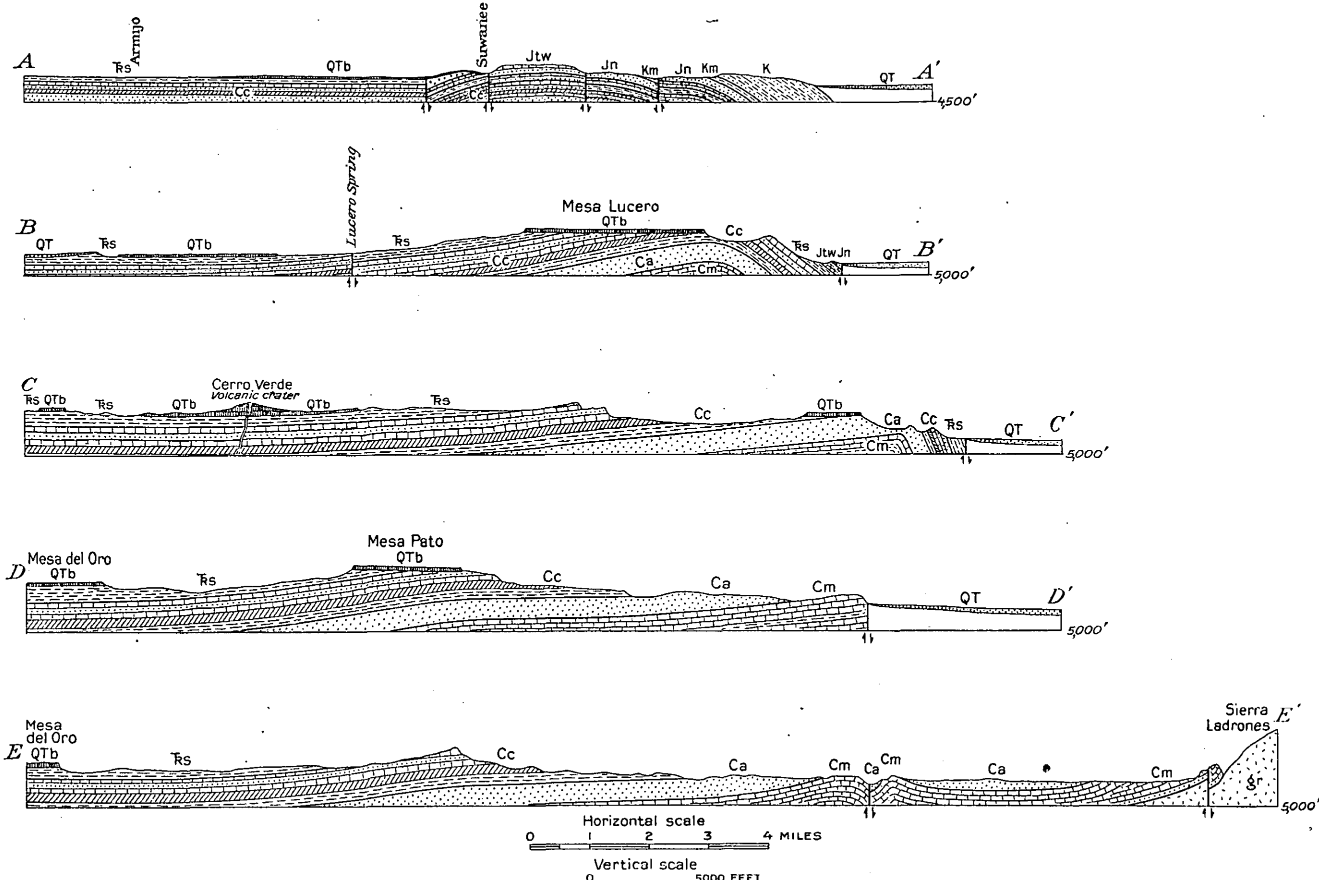
A. MESA OF DAKOTA SANDSTONE UNDERLAIN BY "RED BEDS," 1 MILE SOUTH OF PETOCH BUTTE, SEC. 6, T. 7 N., R. 6 E., VALENCIA COUNTY

Looking south. Upper high cliff, Navajo sandstone; lower steep slope and cliff, Wingate sandstone



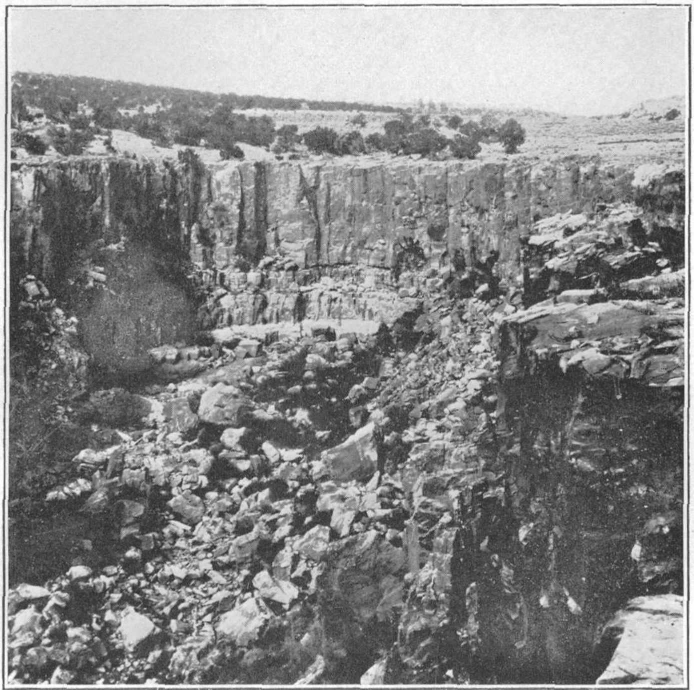
B. ACOMA, AN INDIAN PUEBLO ON A MESA OF GRAY NAVAJO SANDSTONE WITH SMALL CAP OF DAKOTA (?) SANDSTONE

View from west showing practically the entire thickness of the gray member



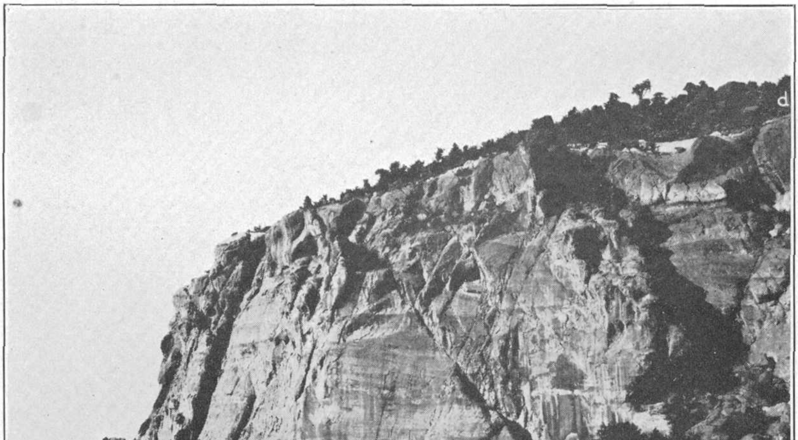
SECTIONS ACROSS THE SIERRA LUCERO

QT, Quaternary and Tertiary sand, gravel, and loam; K, sandstone and shale of Montana and Colorado ages, Dakota sandstone at base; Km, Morrison shale (Cretaceous?); Jn, Navajo sandstone; Jtw, Todilto formation on Wingate sandstone; Ꞧs, Triassic red shale; Cc, Chupadera formation; Ca, Abo sandstone; Cm, Magdalena group; QTb, Quaternary and Tertiary lava flows (basalt); gr, pre-Cambrian granite, gneiss, and other rocks



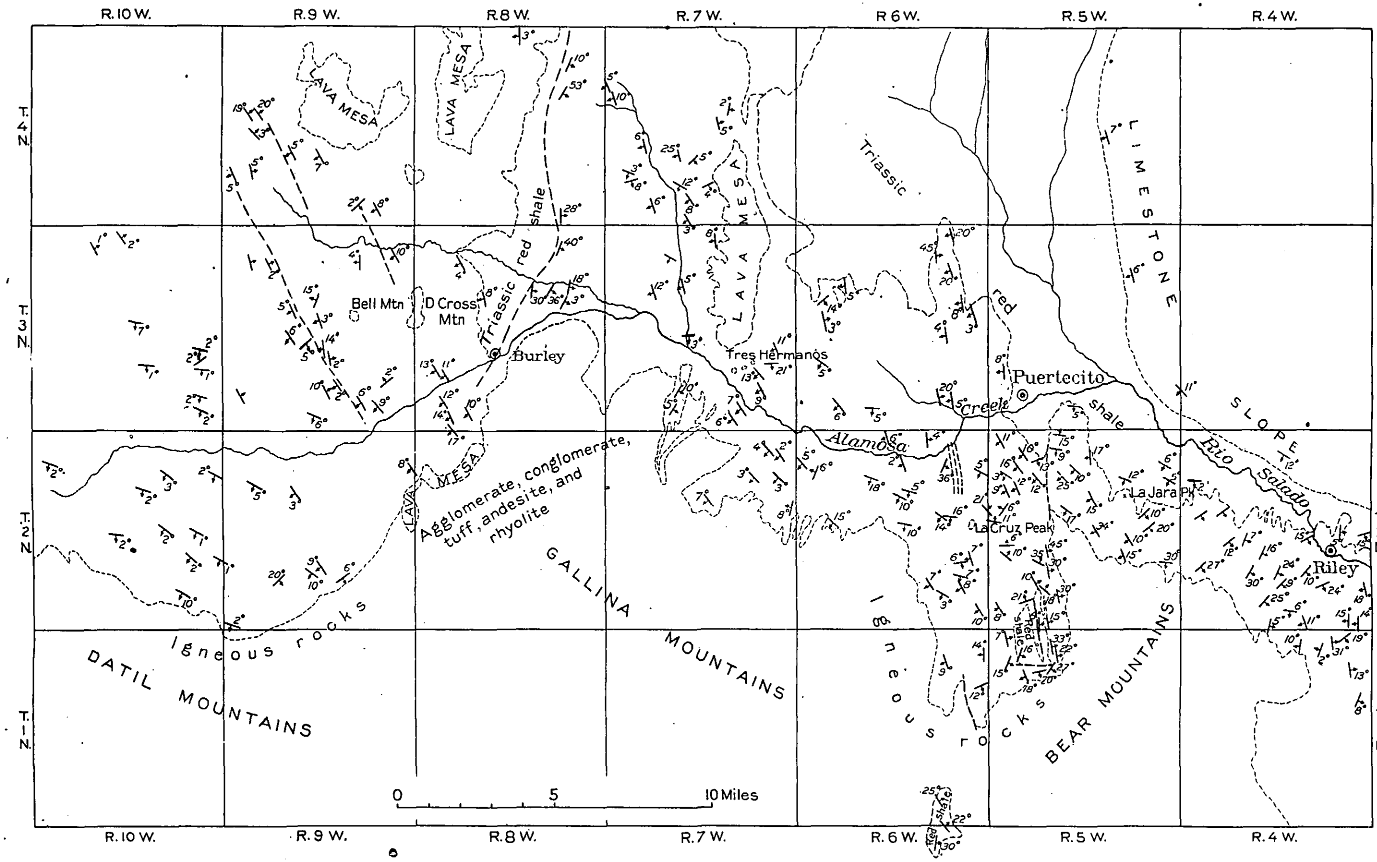
A. CANYON INTO WHICH BLUEWATER CREEK FALLS WHEN IT CONTAINS WATER

South center of T. 6 N., R. 7 E., Valencia County. Looking west. The cliff is Dakota sandstone on Navajo sandstone. Valley in distance in Cretaceous shale



B. CLIFF OF NAVAJO SANDSTONE 2 MILES NORTH OF GARCIA'S RANCH 23 MILES SOUTH OF GRANT

Looking north. Thin cap of Dakota sandstone at d. Great lava flow is at foot of cliff



MAP SHOWING STRUCTURE OF VALLEYS OF RIO SALADO AND ALAMOSA CREEK

Mainly from data by Dean E. Winchester

with a few thin reddish layers. In this bluff this slabby sandstone lies on 40 feet of thin-bedded hard sandstone with a few thin layers of limestone, doubtless Todilto. West of the Gunn ranch the thickness is not more than 60 feet, and in Bluewater Canyon it is still less. (See fig. 37 and pl. 31, *A*.)

A continuous outcrop of Navajo sandstone extends for many miles along the west side of the basin of Cebolleta Mesa to the north past Horace and Grant. This outcrop is on the east slope of the Zuni uplift, and the strata dip to the east at a low angle. The sandstone forms a cliff 200 to 250 feet high, which rises from the great plains of lava and is capped by ledges and slopes of Cretaceous sandstones. (See pl. 31, *B*, and fig. 44.)

The underlying Wingate sandstone appears at a point 6 miles east of Horace, in the northern part of T. 7 N., and the Todilto formation is present east of Grant and 6 miles south of Horace. The sandstone is massive, cross-bedded, and of light-gray tint, as at the pueblo of Acoma. In T. 7 N. it has at the base, on the Wingate sandstone, 20

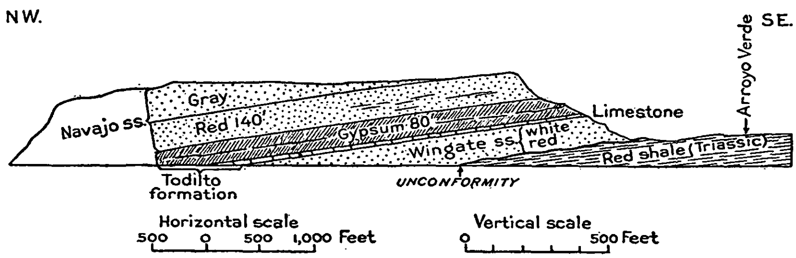


FIGURE 36.—Section at Rito siding, opposite Mesita Negra, looking north. ss, Sandstone

feet of white conglomerate. Here it is 250 feet thick, but to the north the amount is slightly greater. The overlying Dakota(?) sandstone is sharply separated from it by an erosional unconformity.

MORRISON FORMATION (CRETACEOUS?)

In the vicinity of the valley of San Jose River the Navajo and Dakota (?) sandstones are separated by 100 to 200 feet of gray massive shale which so closely resembles the Morrison of the region farther northeast that I feel certain of its identity with that formation. It is very conspicuous in the high slopes north of Laguna, Quirk, Mesita Negra, and Armijo and in the mesas between Acoma pueblo and Cubero station and appears also to be characteristic east and west of Grant. It thins out south of Horace and also at a point a short distance northeast of Acoma, probably as a result of pre-Dakota erosion, and it is absent in the southern part of T. 8 N. and farther southwest. In the slopes northeast of Laguna, at the place shown in Plate 12, *C*, the formation is about 200 feet thick. Much of it is a pale greenish-gray clay or massive shale with thin layers of sandstone and near the top a thin bed of limestone. Some of the clay is of a maroon tint. The formation apparently lies conformably on the Navajo buff sandstone, but doubtless there is a hiatus between them and also at the base of the overlying Dakota (?) sandstone. In Arroyo Verde, north of Mesita Negra, the formation is 200 feet thick and consists of pale-green to gray shale with some reddish layers and thin beds of limestone and sandstone. This outcrop extends along the south front of Mesa Gigante to a point where the formation is dropped by the fault 5 miles north of Suwanee. In the exposures near Suwanee, where the Morrison is 40 to 100 feet thick, it consists largely of a pale greenish-gray clay or massive shale, some members of which weather maroon, and includes limestone layers and concretions. In this area it varies in thickness from place to place and appears to grade down into soft white sandstone 30 to 80 feet thick. There are many good exposures on the slopes north of San Jose River northeast of Suwanee and at the north and south ends of Mesa Redonda.

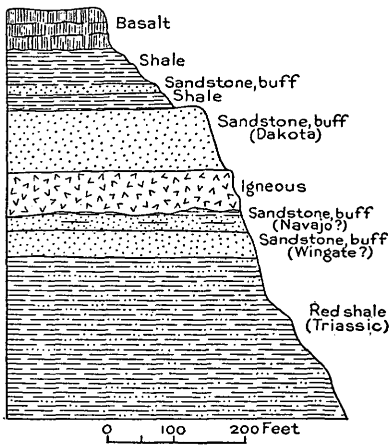


FIGURE 37.—Section of south wall of Bluewater Canyon, Valencia County

DAKOTA (?) SANDSTONE AND OVERLYING UPPER CRETACEOUS ROCKS

The name Dakota sandstone has been applied to the lower sandstone member of the Cretaceous in this region without certainty that it represents the true Dakota sandstone or the underlying Purgatoire formation (Lower Cretaceous), which have usually been combined under the name Dakota by previous writers.

The Dakota (?) sandstone, as the name is here employed, constitutes several high mesas in the area represented on Plate 26. It lies on supposed Morrison shale to the north but overlaps lower beds toward the south and finally lies directly on the Triassic red shale on Alamosa Creek and the Rio Salado. The formation was crossed at several places in this area, and the outcrop boundaries were mapped at many localities. Most of the formation is a hard massive buff to gray sandstone, locally conglomeratic at the base and from 60 to 100 feet thick at most places. It is overlain by several hundred feet of shale and alternating shale and sandstone, in the lower beds of which are abundant fossils of the Benton fauna, such as are found in the lower part of the Mancos shale. A section northeast of Laguna is as follows:

Section of part of Cretaceous rocks 2 miles northeast of Laguna

		Feet
1. Lava.		
2. Sandstone		25
3. Shale		60
4. Sandstone, buff, massive, moderately soft		40
5. Shale with sandstone layers, fossiliferous		60
6. Sandstone, massive, hard, light buff		40
7. Shale, dark gray to gray-green, sandy layers, fossiliferous		60
8. Sandstone, hard, red, irony	Dakota (?) sandstone	5
9. Sandstone, white, massive, in part coarse	Dakota (?) sandstone	80
10. Shale, greenish gray, in part maroon; some sandstone and limestone (Morrison formation)		235

From bed No. 5 of the foregoing section were obtained the following fossils:

Exogyra columbella.
Gryphaea sp., probably a variety of G. newberryi.
Avicula gastrodes Meek?
Cardium sp.
Panopea sp.
Turritella sp.
Rostellites sp.
Fusus sp.

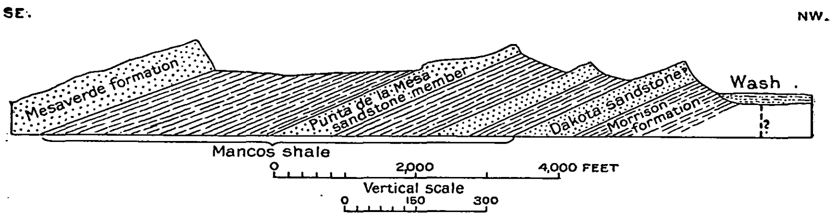


FIGURE 38.—Sketch section of Cretaceous rocks in the valley of Rio Puerco, 22 miles northwest of Albuquerque

From bed No. 7 the following were collected:

Exogyra columbella (few).
Pecten sp.
Pinna petrina sp.
Inoceramus? sp.
Leda sp.
Cardium sp.
Lucina? sp.
Isocardia sp.
Cyprimeria? sp.
Corbula sp.
Liopistha (Psilomya) concentrica.
Turritella whitei.
Tritonium kanabense.
Actaeon sp.
Cinulia sp.
Turrilites or Heteroceras sp.

These fossils were determined by T. W. Stanton, who reported that they indicate faunal facies like that developed in the lower part of the Mancos shale in southern Colorado and southern Utah.

A section of the Cretaceous succession in the valley of the Rio Puerco, 3 miles above the ruins of the old plazita of San Francisco, 22 miles northwest of Albuquerque, is shown in Figure 38. The following fossils were collected at a point about 2 miles above these ruins:

Ostrea.
Avicula gastrodes.
Inoceramus sp.
Cardium sp.
Cyprimeria?
Liopistha (Psilomya) sp.
Anchura fusiformis.

These forms were determined by T. W. Stanton, who regards them as lower Colorado.

A small outlier of Dakota (?) sandstone caps the Navajo sandstone at Acoma. (See pl. 29, *B*.)

Winchester [82] has subdivided the Upper Cretaceous rocks in the Alamosa Valley into the following formations:

Section of Cretaceous rocks in Alamosa Valley

	Feet
Chamiso formation: Soft sandstones and sandy shales, yellow, with intercalated carbonaceous beds. Fossil leaves abundant. Coal beds at three horizons, one about 75 feet above the base being the only one of importance	1, 850
Miguel formation: Sandstones, yellow, sandy shales, drab and yellow, with a few beds of clay and several beds of coal in upper half. Many fossil invertebrates and plants. Includes four persistent members of yellow sandstone; the top or the Bell Mountain sandstone member, about 80 feet, contains *Halymenites* and *Inoceramus*, and one 900 feet above the base, the Gallego sandstone (50–90 feet), contains *Halymenites*	2, 080
Dakota sandstone: Sandstone, gray to brown, in places with pebbles and fragments of underlying rocks. Few plant remains	0–40

The basal sandstone was classed as Dakota because of its analogy in character and position with the Dakota sandstone in other parts of the State. It lies unconformably on the "Red Beds," but without notable discordance in attitude. The Miguel formation carries abundant invertebrates of Colorado age and a sparse flora of supposed Montana age. It represents, in whole or in part, the Mancos shale, but the position of the upper limit of the Mancos formation is not ascertained. The Chamiso formation carries an abundant Montana flora, although wholly of nonmarine origin, and is in part equivalent to the Mesaverde formation, which consists of alternating beds of marine and nonmarine origin.

STRUCTURAL DETAILS

SIERRA LUCERO

The Sierra Lucero which is not shown on previous maps, rises about 1,000 feet above the adjacent country and extends from Mesa Lucero to the Rio Salado. Its higher summits reach an altitude of considerably more than 7,600 feet. These are plateau remnants covered by basalt. At the north end the summit is Mesa Lucero, which consists of basalt, a remnant of an old lava flow possibly from a crater on its northern part. The ridge consists of a cuesta of the Chupadera formation, the summits and long western slopes being made up largely of limestone. To the west this formation passes under the Triassic red shales; to the east is a valley of lower red beds of the Chupadera

[82] Winchester, D. E., op. cit. (Bull. 716), p. 5, 1920.

formation lying on Abo sandstone. Not far east for part of its course is an anticlinal ridge of limestone of the Magdalena group cut off by a fault along its east side. These ridges extend to the west slope of Ladron Peak. The principal structural features of the Sierra Lucero are shown in the four cross sections in Plate 30.

At the north end of the range there is a cross fault that passes west-northwest through the valley that separates it from Mesa Redonda. The Sierra Lucero side is uplifted, so that the Chupadera formation and Abo sandstone abut against Wingate sandstone. A fault on the west side probably passes south through Lucero Spring, as shown in section 1, Plate 30, but its relations were not studied in that area. The steep anticline east of the Sierra Lucero is faulted on its east side, and the drop is on the east. Along much of its course this fault is obscured by Santa Fe and later deposits, but apparently it extends southward from Bernalillo County, passing east of Suwanee and a short distance west of Garcia. (See fig. 40.) It drops sandstone of Cretaceous age against the Chupadera formation three-fourths of a mile southeast of South Garcia and again in a draw 6 miles west-northwest of Rio Puerco. It cuts off the greater part of the red beds south of South Garcia, as shown in section 2, Plate 30. Along its course rise several vigorous salt springs, some of which have built extensive mounds and terraces of travertine deposits, on the slopes northwest of Rio Puerco station. On Arroyo Carrizo the red Abo sandstone is bared in the arch, and at one point the canyon reveals the top of the underlying Magdalena group. Steeply dipping Abo and Chupadera beds make ridges on the east side of the axis, and Triassic "Red Beds" appear in small amount. These beds all pass into the fault to the south, and the relations at Arroyo Gallina and Arroyo Pato are those shown in section 3. Large salt springs rise at the place where Magdalena limestone is exposed in the arch. Near Arroyo Raton, as shown in section 4, a small anticline or faulted block of Magdalena beds occurs in the canyon near the northwest corner of T. 3 N., R. 3 W., and a wide syncline of Abo beds lies on the east and north. The fault extends south to the Rio Salado Valley, which it crosses 3 miles above Santa Rita (Riley). In this region the strike of the Chupadera outcrop from the Sierra Lucero turns south-east, and the ridge which it forms extends into T. 2 N., R. 3 W., where it passes under a high terrace deposit extending east to the foot of the Sierra Ladrones.

MESA GIGANTE TO ACOMA AND BROOM MOUNTAIN

The great plateau extending across the central part of Valencia County consists of a shallow syncline occupied by Cretaceous and volcanic rocks. (See fig. 31.) Along its east side underlying formations appear in a line of high cliffs and also in outlying mesas such as Mesa

Gigante. On the east side the beds slope generally to the west at low angles, but in a few areas there are low dips to the east. No notable faults were observed except at Pico Pintado, where owing to faults or land slips or both the structure is as shown in Figure 39. The plateau and escarpment are deeply trenched by the valley of San Jose River. The general succession of rocks begins with the Triassic red shales, above which are Wingate sandstone, Todilto formation (with its gypsum member), Navajo sandstone, Morrison shale, Dakota (?) sandstone, and overlying Upper Cretaceous shales and

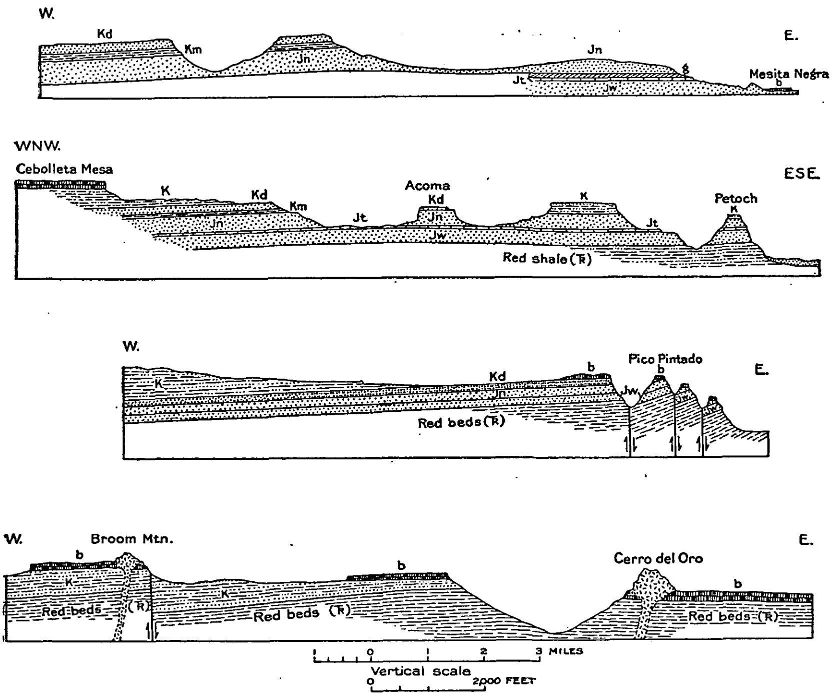


FIGURE 39.—Sections of escarpments from Mesa Gigante to beyond Acoma, central Valencia County. K, Cretaceous undifferentiated; Kd, Dakota sandstone; Km, Morrison formation; Jn, Navajo sandstone; Jt, Todilto formation (g, gypsum member); Jw, Wingate sandstone; ₮, Triassic; b, basalt.

sandstones. The gypsum member of the Todilto thins out southwest of Mesita and the limestone member thins out not far south of Petoch Butte; the Wingate sandstone thins out northwest of Mush Mountain, and the Navajo sandstone not far south of Bluewater Creek. The Morrison thins out near the north line of T. 8 N. The succession and structure of the east side of the plateau are shown in Figure 39, and the relations in Mesa Gigante in Figure 40.

MESA REDONDA AND SUWANEE AREA

Several faults complicate the relations in the San Jose Valley near Suwanee. The section in Figure 40 shows the features exposed along the north slope of the valley opposite that place. The easterly dip carries the Dakota (?) sandstone down in the slopes 4 miles northwest of Quelites, where it passes under higher shales and valley filling. Mesa Redonda is a basalt-capped butte on a block dropped along the fault that cuts off the north end of Mesa Lucero. Possibly the basalt is part of the flow capping that mesa. A section through the butte is shown in Figure 41. The Todilto gypsum and limestone outcrops extend some distance east of the butte and along the slopes north to the railroad, which they cross at a point 1½ miles east of Suwanee. The top of the Wingate is visible near the northwest-southeast fault in some of the slopes southeast of the butte. West of Garcia there are outcrops of gypsum, Navajo sandstone, and Dakota (?) sandstone in a block dropped a few hundred feet by the fault shown near the east end of Figure 40.

Owing to the general westerly dip the Wingate sandstone and Todilto formation cross the bottom of the San Jose Valley a short distance west of Mesita Negra. To the south, however, the outcrops

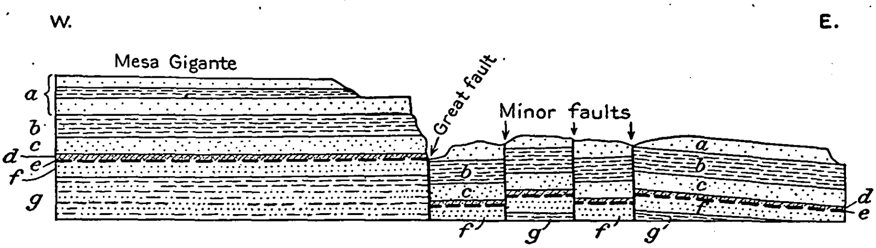


FIGURE 40.—Section north and east of Suwanee, looking north, showing relations of faults. *a*, Dakota (?) and overlying Cretaceous sandstone and shales; *b*, Morrison shale; *c*, Navajo sandstone with a lower red member; *d*, *e*, Todilto formation (gypsum on limestone); *f*, Wingate sandstone; *g*, Red shale and sandstone. The Mesa Gigante is projected south 4 miles or more

extend along the east front of the high mesa, which has Navajo sandstone at the top and red shales along the base, the shales, however, covered in places by sand of the plain on the east. The Todilto thickens to 40 feet and makes a shelf, which in places is conspicuous. The dip is low to the west. Not far south of Mesita Negra a sill of diabase is intruded in the Wingate and underlying red beds, causing some blackening of the shales, and there are several dikes in a hill west of the main road 4 miles south of Mesita Negra. Dome Mountain, not far east, is a stock of basalt. In sec. 9, T. 8 N., R. 5 W., there is a small knob exhibiting Todilto limestone and Wingate sandstone dipping 20°–60° NNW., dropped by a fault or possibly residual from an old landslide. The knob is surrounded by wash and sand, so that the relations could not be determined. On its east slope there is a deep boring from which water is flowing. In R. 6 W. and at intervals to the southwest the plateau is surmounted by several buttes consisting of outliers of Dakota (?) sandstone. The dip in this region is to the northwest at a low angle, and the face of the escarpment extends nearly due west past Dripping Springs, south of which it resumes a southerly course.

The long, narrow anticline extending southward from Garcia is cut off on the east by a fault with large downthrow on that side. Near its north end it is crossed by a fault which passes a short distance south and west of South Garcia. The general structure is shown in the four cross sections in Figure 39, but there are many minor complexities. The arch is highest in Tps. 4 and 5 N., where for 15 miles it shows several hundred feet of limestone of the Magdalena group as shown in section C. It declines south of Arroyo Raton, where along the fault the Abo sandstone finally swings into contact with the Chupadera formation, and on Rio Salado it becomes part of a general change in trend from south to southeast. Not far north of Arroyo Gallina the limestone of the Magdalena group pitches below the surface, but its top is revealed on the crest of the anticline in the deep canyon of Arroyo Carrizo. The structure in the vicinity is shown in section 2, Plate 30; the main fault or a parallel one is but

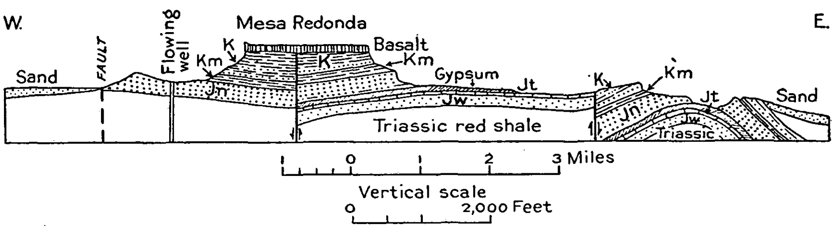


FIGURE 41.—Section through Mesa Redonda, south of Suwanee, looking north. K, Dakota (?) and overlying Cretaceous sandstones and shales; Km, Morrison formation; Jn, Navajo sandstone; Jt, Todilto formation, including gypsum member at top; Jw, Wingate sandstone

a short distance east of the axis of the anticline. The relations along the east side of the ridges from Arroyo Pato to Rio Puerco are mostly hidden by overlapping sand, in part of the Santa Fe formation.

The north-south fault may end at a point 3 miles south of South Garcia, where, as shown in section 1, Plate 30, there is an unbroken succession of eastward-dipping beds from Chupadera to Navajo, which, however, is cut off to the south by the northwest-southeast cross fault. The main fault probably extends to the south along the Chupadera ridge, as indicated by many tepid saline springs located at short intervals along the upper part of the limestone slope. These springs are conspicuous features because they are building up white travertine terraces, which are plainly visible from the railroad. The northernmost spring is a short distance west of South Garcia station. There are along the limestone slopes in this vicinity many terraces of conglomerate with matrix of travertine deposited by springs of former times. Not far south of the line of section 1 Cretaceous sandstone is exposed faulted against red shale (probably Triassic), as shown in Figure 42. A small block of Cretaceous sandstone also lies against the fault three-fourths of a mile southwest of South Garcia. The conglomerate, clay, and sandstone of the Santa Fe formation are more or less upturned all along the foot of the ridge, showing dips as high as 50° in places, notably a mile north of Arroyo Carrizo.

GRANT REGION AND WESTERN ESCARPMENT OF CEBOLLETA MESA

West of the syncline crossing Valencia County the strata rise on an easterly dip toward the high uplift of the Zuni Mountains. The Dakota (?) and associated sandstones present a steep escarp-

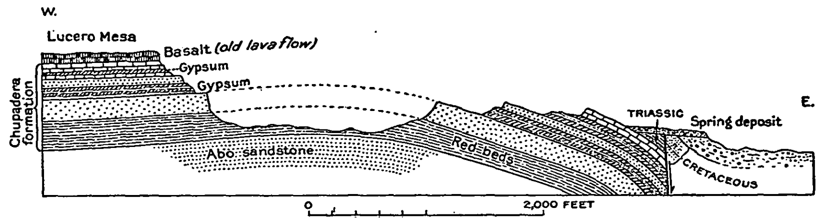


FIGURE 42.—Section of ridge on east side of Lucero Mesa 4 miles south of South Garcia station

ment to the west overlooking a wide valley of Triassic "Red Beds," mostly covered by a great basalt flow of relatively late age. These red beds appear about Grant, where, however, they are traversed by a fault trending northeast and passing into the high lava-covered plateaus of the San Mateo Mountains. A section along the high ridge north of Grant is shown in Figure 43. Just south of the center of this section the upper part of the "Red Beds" abuts against Dakota (?) sandstone dropped about 1,000 feet by the fault. A short distance west of the ridge of this sandstone the Todilto

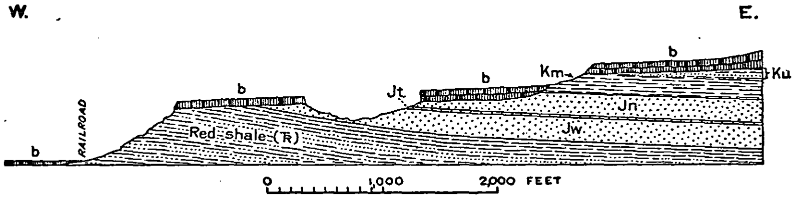


FIGURE 43.—Section through ridge north of Grant, looking north-northwest. Km, Morrison formation; Ku, Upper Cretaceous; Jn, Navajo sandstone; Jt, Todilto limestone; Jw, Wingate sandstone; b, basalt; TR, Triassic

limestone appears for a short distance as a low ridge rising out of the wash that covers most of the rocks in the valley from Grant to Horace. South of the railroad and of the tongue of very recent lava extending down the San Jose Valley are high westward-facing cliffs which extend many miles to the south. At the north end these cliffs consist of Dakota (?) and overlying Cretaceous sandstones, but in the southern part of T. 10 N. the Navajo sandstone, Todilto limestone, and Wingate sandstone come up, as shown in Plate 31, *B*. The Morrison is absent. In an exposure at the south line of T. 10 N. the cliff presents the following section:

Section of cliff in southern part of T. 10 N., 10 miles southeast of Grant

	Feet
Dakota (?) sandstone.	
Navajo sandstone, pale buff, fine grained, cross-bedded	100
Todilto limestone, thin bedded	12
Wingate sandstone, red, massive, top only exposed.	

This cliff extends southward to the middle of T. 7 N. with short interruptions where it is broken by valleys in T. 9 N. and near T. Garcia's ranch in T. 8 N. The cliff is 200 feet or more high, and at the top there is more or less of the hard brown massive Dakota (?) sandstone. A fault in Tps. 9 and 8 N., a short distance east of the escarpment, repeats the outcrop zone, as shown in Figure 44. This fault crosses Arroyo Cebolleta near T. Garcia's ranch but was not traced farther south. In this vicinity the cliff of Navajo sandstone is a prominent feature, as shown in Plate 31, *B*. At its foot is the wide plain of basalt of the recent lava flow, but at one point near its eastern edge there is an island of Navajo sandstone.

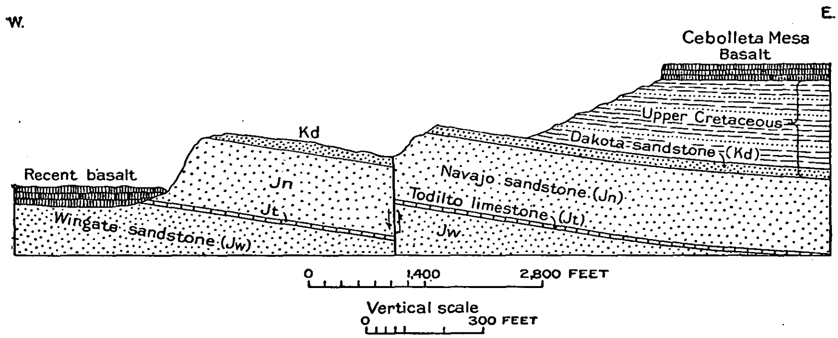


FIGURE 44.—Section of escarpment on west side of Cebolleta Mesa in southern part of T. 9 N., about 15 miles south of Grant

The cliffs are capped by Dakota (?) sandstone, sharply defined by an unconformity, although the strata have apparently the same attitude. To the east are long slopes of higher Cretaceous sandstone and shale extending to the base of the great lava flow of Cebolleta Mesa. In the high point in the northern part of T. 7 N. the beds below the Navajo sandstone appear for a short distance. The Navajo here is about 250 feet thick, and at its base is 20 feet of white conglomerate. Below this is about 40 feet of soft red Wingate sandstone, the Todilto limestone being absent.

SIERRA LADRONES

The prominent range known as the Sierra Ladrones occupies most of T. 2 N., R. 2 W., and extends north and southwest into adjoining townships. Its greatest portion consists of granite, which rises into the culminating summit of Ladron Peak at an altitude of 9,214 feet (Wheeler Survey). On its west slope is a monoclinal ridge of limestone of the Magdalena group which extends nearly to Arroyo Raton, in the northern part of T. 3 N., R. 3 W. The bed dips to the west, and there is some longitudinal faulting. On the Rio Salado the lowest limestone just above the granite has yielded the Mississippian fossils mentioned on page 110 which shows that the attenuated north end or an outlier of the Lake Valley limestone is present. Fossils of the Magdalena group were obtained not far above this limestone. The place where the Lake Valley limestone terminates to the north was not ascertained, but in 1913 at the north end of the range I found fossils of the Magdalena group a few inches above the granite surface without possibility of an intervening fault. At the south end of the range the limestone of the Magdalena group passes under red sandstone of the Abo formation, but in T. 2 N. a thick mass of sand and travertine extends across the Abo-Magdalena contact, the Abo sandstone, and the Abo-Chupadera contact.

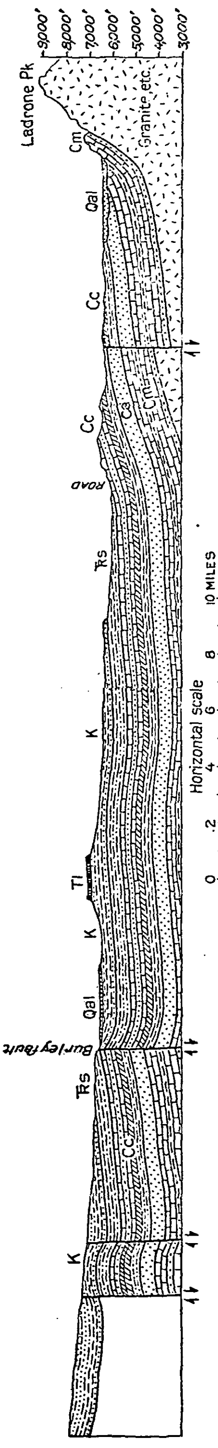


FIGURE 45.—Section across north-central Socorro County. Qal, Alluvium; Tl, basalt; K, Cretaceous sandstone and shale; Ꞧs, Triassic red shale; Cc, Chupadera formation; Ca, Abo sandstone; Cm, Magdalena group

ALAMOSA VALLEY

The geology of Alamosa Valley has been described by Winchester,[83] to whose report the reader is referred for details as to stratigraphy and structure. The salient features of this valley and of that of the Rio Salado are shown in Figure 45 and Plate 32. The greater part of the valley of the Alamosa is excavated in sandstone and shale of Upper Cretaceous age, but upper members of the "Red Beds," which pass beneath the surface a short distance above Puertecito, are not very deeply buried, and they are brought again to view by a fault near Burley, as shown in Figure 45. Southwesterly dips predominate, but the "Red Beds" uplifted by the Burley fault dip mostly west at a low angle and pass under Cretaceous strata within a short distance to the west. Other smaller faults cut the Cretaceous shale northwest of Burley and in a zone crossing the county near Puertecito.

[83] Winchester, D. E., op. cit. (Bull. 716), pp. 1-15.

Winchester refers to the "Red Beds" of the region as predominantly red and consisting of "a great thickness of red, vermilion, and lavender clay shales, coarse cross-bedded sandstones, and thin beds of conglomerate. * * * In some places there is about 600 feet below the top of the series a thin bed of conglomerate which may represent the Shinarump conglomerate." In places this conglomerate contains chert pebbles. The Dakota (?) is quartzitic in places and conglomerate here and there. It is thin and locally absent on the west side of the Red Lake fault. The Dakota (?) sandstone is overlain by 3,930 feet of shale and sandstone of Colorado and Montana age, divided into two formations—the Miguel below and the Chamiso above. The Miguel formation, of which 2,080 feet were measured, consists of yellow sandstone and drab and yellow sandy shale with a few beds of coal in its upper part. It includes four persistent beds of yellow sandstone—one at the top named the Bell Mountain sandstone member, one near the middle called the Gallego sandstone member, and two near the base which may represent the Tres Hermanos sandstône member of Lee. The formation contains a Colorado fauna throughout and therefore represents a large part of the Mancos shale of regions to the north. The Chamiso formation is composed of 1,850 feet of soft sandstone and sandy shale with Montana plant remains. It is believed to be a nonmarine representative of the Mesaverde formation and probably also to include the upper part of the Mancos shale.

Remnants of basalt lava flows lie on the mesas on both sides of the Alamosa Valley, and to the south, in the Bear and Gallina Mountains, is the Datil formation, consisting of a thick succession of compact tuff, rhyolite, cross-bedded sandstone, and conglomerate lying nearly horizontal. (For section, see p. 63.) These beds are of late Tertiary age and constitute the northern margin of the great west-central volcanic area. Many basic dikes and sills cut the Cretaceous rocks, notably in La Java and La Cruz Buttes, which are remnants of volcanic necks.

A boring in 1924 at Red Lake, in the northwest corner of sec. 2, T. 3 N., R. 8 W., was continued to a depth of 4,012 feet and ended in granite, which is supposed to have been entered at 3,952 or perhaps 3,922 feet. It is on the anticline just west of the Red Lake fault and begins some distance below the top of the Triassic "Red Beds" (Chinle?). It had the record given on page 133 below 780 feet. This boring probably indicates a thickness of 1,177 feet for the Chupadera if that formation was entered at 1,028 feet, which appears likely. The Abo strata appear to extend from 2,205 to 3,410 feet, but the limits are somewhat uncertain.

Partial record of boring at Red Lake, Socorro County

	Feet
Gray shale	781–820
Red beds with thin limestones at 845 and 910 feet	820–934
Limestones	934–957
Red shale (probably base of Triassic)	957–1, 028
"Talc" and gray shale	1, 028–1, 090
Gypsum	1, 090–1, 095
Limestone with 23 feet of sandstone at 1,167 feet and 20 feet at 1,271 feet	1, 095–1, 316
Sandstone, gray, fine above, hard below	1, 316–1, 347
Limestone	1, 347–1, 367
Sandstone, light	1, 367–1, 555
Red shale, some sandstone	1, 555–1, 747
Shale and sandstone, gray	1, 747–1, 775
Red shale and sandstone	1, 775–1, 840
Limestone on shale, gray	1, 840–1, 868
Red shale and sandstone	1, 868–1, 945
Shale on dark limestone	1, 945–1, 995
Red shale and sandstone, some gray	1, 995–2, 043
Limestone and shale, gray	2, 043–2, 060
Red shale, some sandstone	2, 060–2, 175
Limestone, gray (probably base of Chupadera formation)	2, 175–2, 205
Sandstone, brown on gray	2, 205–2, 240
Red sandstone and shale	2, 240–2, 260
Sandstone, gray	2, 260–2, 280
Red shale and sandstone with 45 feet of dark-brownish water sand at 2,545 feet, 8 feet of dark limestone at 2,626 feet, and 20 feet of gray shale at 2,823 feet (base of Abo sandstone)	2, 280–3, 410
Limestone and gray and dark shale; sandstone at 3,865 feet (Magdalena)	3, 410–3, 890
Sandstone, very soft	3, 890–3, 900
Shale on 2 feet of hard sandstone	3, 900–3, 924
Sandy limestone on sandstone (probably basal Magdalena)	3, 924–3, 952
"Very hard" rocks and "granite"	3, 952–4, 012

PUERTECITO DISTRICT

Puertecito is on Alamosa Creek 3 miles above the point at which that stream joins the Rio Salado. There are in the vicinity extensive exposures of the upper member of the "Red Beds" of supposed Triassic age, and not far to the south and west these strata pass under the Dakota (?) sandstone and overlying Upper Cretaceous strata. The dips are low and mostly to the southwest. Some of the relations are shown in Figure 45 and Plate 32, from Winchester's report.[84] A few miles to the east are slopes in which the limestone and gypsum of the Chupadera formation rise in the flanks of the general uplift culminating on the Sierra Ladrones. The total thickness of the "Red Beds" in this vicinity is about 1,100 feet, and it is not unlikely that representatives of the Moenkopi, Shinarump, and Chinle formations are present.

[84] Winchester, D. E., op. cit.

Wells[85] has made a detailed study of the structure of an area not far south of Puertecito, and part of his map is reproduced in Figure 46. Wells describes the "Red Beds" as consisting of 1,150 to 1,250 feet of strata in which shale predominates over sandstone and a few thin layers of conglomerate are interbedded. "Maroon, purplish red, and

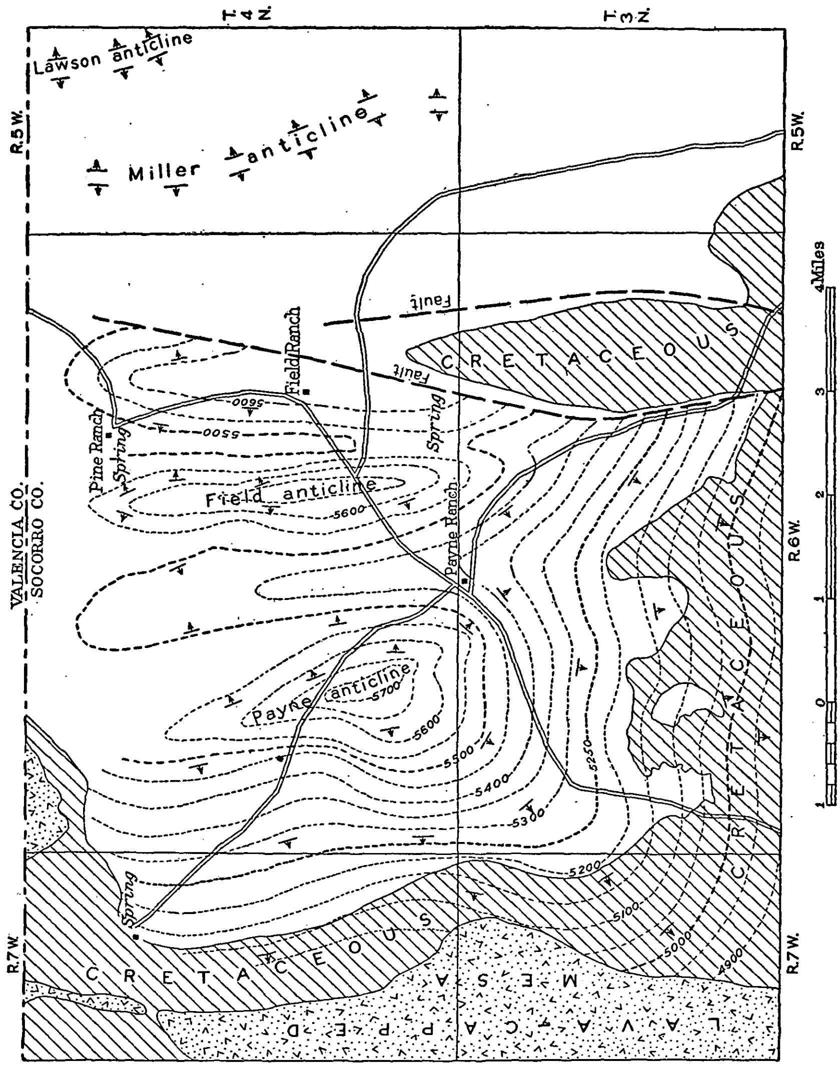


FIGURE 46.—Map showing structure north of Puertecito, Socorro County, by E. H. Wells. The contours are drawn on the base of the "Red Beds"; interval, 50 feet

purplish gray are the characteristic colors, and white, grayish drab and purplish blue are subordinate." He suggests the name Puertecito formation, but it is probable that the three formations exposed in the Zuni uplift can be recognized here by a careful comparison of the areas.

[85] Wells, E. H., Oil and gas possibilities of the Puertecito district, Socorro and Valencia Counties, N. Mex.: New Mexico School of Mines Bull. 3, Socorro, 1919

The lower three-fourths, though consisting largely of purplish-red shale, contain many purplish-red and purplish-gray sandstone layers 10 to 25 feet thick. The sandstones are relatively most abundant near the base of the formation. Members of minor importance include purplish-blue shales and light-colored sandstones. The upper one-fourth is almost entirely of maroon shales and to a minor extent of purplish-red sandstones and grayish-drab shales. Most of the conglomerate is in the middle of the formation, where it constitutes beds 6 inches to 2 feet thick consisting of rounded pebbles one-fourth to 1 inch in diameter. The shales are in small part calcareous. They are notably soft and very easily eroded. The sandstones, on the other hand, are resistant to weathering and erosion and outcrop prominently.

The only fossils found are fragments of wood.

A boring for oil 8 miles northwest of Puertecito had the following record:

Record of boring by Ohio Oil Co. in sec. 32, T. 4 N., R. 6 W., Valencia County

	Feet
Shale, red and purple, some sandstone	0–335
Sandstone, gray	335–347
Shale, red	347–355
Sandstone, gray, water	355–375
Shale, gray	375–380
Sandstone, gray	380–470
Shale, red	470–573
Limestone, white and blue, much water	573–630
Shale, blue, sandy	630–680
Sandstone and gypsum	680–700
Limestone, white	700–745
Shale, red	745–770
Limestone, black	770–875
Sandstone, white (yellow at base)	875–900
Limestone, upper half white, lower half black	900–945
Limestone "shells" and gypsum	945–975
Gypsum and sand	975–990
Sandstone, "Glorieta"	990–1, 185
Limestone, soft, white	1, 185–1, 225
Shale, sandy, red	1, 225–1, 260
Sandstone, red	1, 260–1, 280
Limestone, black	1, 280–1, 325
Limestone, black sandy, with gypsum	1, 325–1, 370
Limestone, black sandy, with water at 1,405 feet	1, 370–1, 405
Limestone and gypsum	1, 405–1, 410
Crystalline rocks (mica, etc.)	1, 410–1, 997

This boring began in the Triassic beds and apparently entered the Chupadera formation at 573 feet; Abo beds appear to be well characterized in the red materials extending to 1,280 feet. Below this is 180 feet of limestone, presumably Magdalena, lying on pre-Cambrian rocks. The mention of gypsum in the lower succession is probably a mistake. There is, however, a possibility that all the lower strata are Chupadera, here overlapping on the pre-Cambrian rocks. The identity of the pre-Cambrian rocks is not fully established, but the rocks were very hard, and some of them contained much mica.

MAGDALENA MOUNTAINS

The northern part of the Magdalena Mountains consists of an uplifted block of Carboniferous rocks lying on granite and schist. To the south, however, the range consists of a thick mass of Tertiary igneous rocks. The granite extends nearly to the summit on the very high eastern slope, where the overlying limestone, sandstone and shale form a westward-sloping cuesta. These strata are cut by dikes and stocks, especially to the west, and on the west slope there is extensive overlap of sheets of rhyolite, andesite, and tuff The cuesta is broken by numerous faults, most of them trending north and some having sufficient throw to bring granite and schist to the surface on the west slope of the range. The general features are shown in Figure 47, which is mostly compiled from sections and data given by Gordon,[86] with the addition of the Abo formation.

The sedimentary formations exposed in the Magdalena Mountains are the Lake Valley limestone (Mississippian) (see pl. 4, *A*),

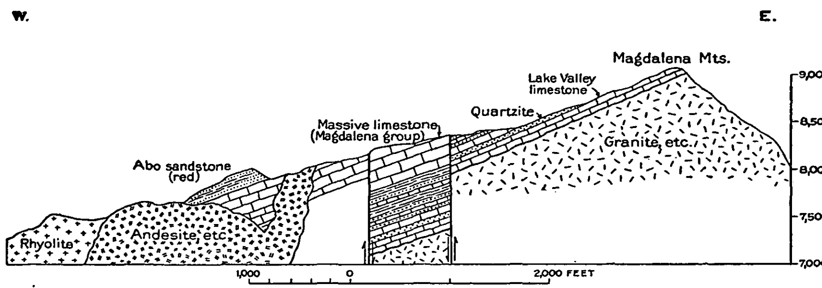


FIGURE 47.—Section across Magdalena Mountains south of Kelly

Magdalena group (Pennsylvanian), and Abo sandstone (Permian). The Lake Valley limestone (in previous reports on this region called Kelly limestone) is the principal ore-bearing formation. It is stated by Gordon to consist here of 125 feet of light-colored subcrystalline limestone, mostly heavily bedded. Keyes[87] and Herrick[88] report Mississippian crinoids in these limestones, which doubtless indicate equivalency with the typical Lake Valley limestone to the south. The limestone lies on a remarkably smooth surface of granite and schist, locally with thin deposits of conglomerate intervening. In places the limestone is considerably silicified.

According to Gordon the Magdalena group consists of a lower division of shale and hard sandstone about 125 feet thick, 40 feet of white quartzite, 75 feet of compact earthy limestone, 410 feet of shale, limestone, and sandstone, and a top division, of which 300 to 500 feet remain, of blue compact limestone, mostly thick bedded. This group contains many fossils of Pennsylvanian age.

[86] Gordon, C. H., op. cit. (Prof. Paper 68), pp. 248–249.

[87] Keyes, C. R., Northward extension of the Lake Valley limestone: Iowa Acad. Sci. Proc., vol. 12, p. 170, 1905.

[88] Herrick, C. L., Laws of formation of New Mexico mountain ranges: Am. Geologist, vol. 33, p. 310, 1904.

The red Abo sandstone overlies the upper limestone of the Magdalena group at Kelly and crops out at other places along the mountain slope to the south. Its continuity is broken and its upper beds are hidden by andesite and other Tertiary igneous rocks. The greatest amount exposed, in a ridge about half a mile from Kelly, is about 350 feet. At this place G. E. Anderson collected a slab of red sandstone that showed a fine impression of a plant, on which David White has furnished the following report:

The fossil plant on the slab of red sandstone from the Abo formation near Kelly, N. Mex., was considerably worn and slightly macerated before fossilization, and some of the criteria essential for its absolute paleontologic determination are lacking. However, it appears to be a representative of the *Callipteris* group, of distinctly Permian type, and probably belongs to the genus *Glenopteris*, which was described from the Wellington shale, which in Kansas is considerably above the base of the Permian. Though the evidence is not conclusive, because the identification is somewhat uncertain, it is probable that this is a Permian plant.

Gordon [89] has given the following facts regarding the center of the range:

In its lower portion the slopes of Hop Canyon [6 miles south of Magdalena] are occupied mostly by rhyolite and rhyolite tuffs and breccias. Andesite tuffs and breccias appear wherever the overlying rhyolite has been cut through by erosion. In its upper half on the east side along the axis of the ridge the eruptive rocks have been removed, exposing granite. * * * Dikes of basic rock cut the rhyolite. * * *

Mill Canyon [heading southwest] lies south of Hop Canyon and is separated from it by a prominent divide capped with rhyolite porphyry.

ZUNI MOUNTAINS AND ZUNI-ATARQUE UPLIFTS

GENERAL RELATIONS

The Zuni Mountains consist of an elongated dome in which the strata in its center have been uplifted vertically several thousand feet and which in its more obvious features affects an area about 65 miles long by 40 miles wide. The rocks exposed by the erosion of this dome comprise pre-Cambrian granite, Abo sandstone, Chupadera formation, Moenkopi formation, Shinarump conglomerate, Chinle formation, Wingate sandstone, Todilto limestone, Navajo sandstone, Morrison formation, and Dakota (?) sandstone. The Dakota (?) is overlain by an extensive succession of Upper Cretaceous rocks composing the Mancos shale and Mesaverde formation. The map (pl. 33) and cross sections (figs. 48–50) show the principal features of distribution and structure, but considerable of the mapping was reconnaissance and the base is somewhat imperfect.

The Magdalena and older sedimentary formations are absent, at least in the central part of the uplift, owing doubtless to the presence of a land surface in this area which continued until Permian time. The granite is not a post-Carboniferous intrusive mass, and the strata are not faulted onto it.

[89] Gordon, C. H., op. cit. (Prof. Paper 68), p. 258.

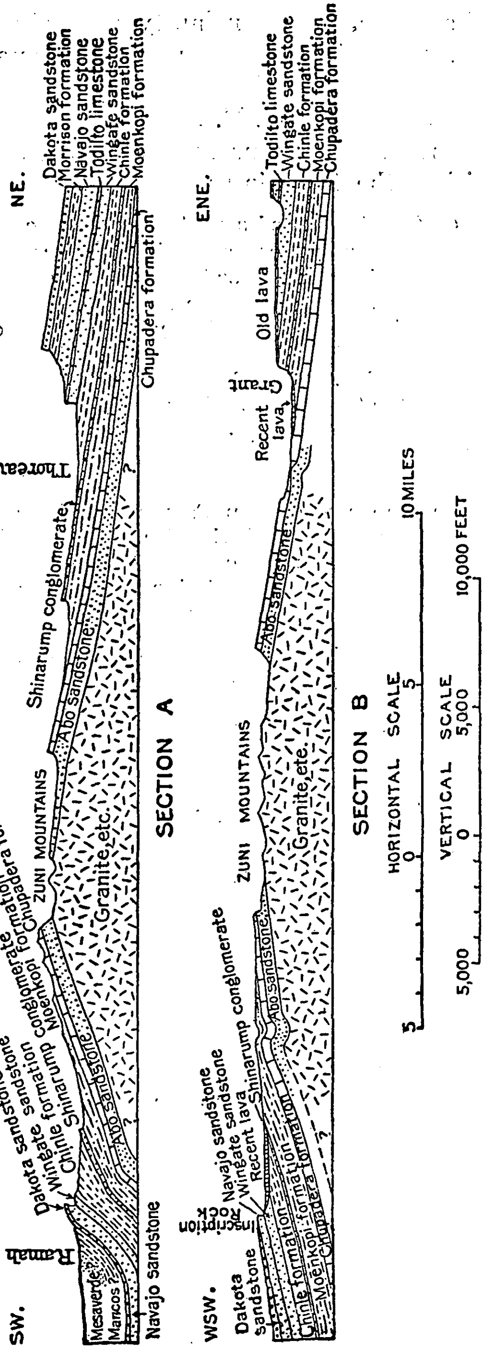


FIGURE 48.—Sections across Zuni Mountain uplift. A, west of Thoreau; B, west of Grant

The following is a list of the formations in the general region:

Formations in the Zuni Mountains and near Zuni

Age	Group and formation	Characteristics	Approximate average thickness (feet)
Upper Cretaceous.	Mesaverde formation.	Sandstone with coal beds.	1,000
	Mancos shale.	Shales and sandstones; coal in upper part.	750
	Dakota (?) sandstone.	Sandstones, massive, gray, hard.	120-250
Cretaceous (?).	Morrison formation.	Sandstone and sandy shale, gray-greenish to maroon.	150
Jurassic (?).	Navajo sandstone.	Sandstone, massive, gray to pink.	300-650
	Todilto limestone.	Limestone, mostly very thin bedded.	0-20
	Wingate sandstone.	Sandstone, fine-grained, massive, pink, hard, making high cliffs on north side, soft on south side of uplift.	300-400
Triassic.	Chinle formation.	Shale, red to gray, limestone concretions.	850
	Shinarump conglomerate.	Sandstone, gray to buff, locally conglomeratic.	20-60
	Moenkopi formation.	Shale, mostly sandy and red.	500-850
Permian.	Manzano group. Chupadera formation.	Limestone and hard gray sandstone above, soft red sandstone below.	400
	Manzano group. Abo sandstone.	Brown-red slabby sandstone and sandy shale; local thin limestone in lower part and basal massive sandstone.	600-700
Pre-Cambrian.		Granite, etc.	

A section showing the typical succession of the strata in the northeastern slope of the Zuni Mountain uplift is given in Figure 49. The larger features of this region were described delightfully by

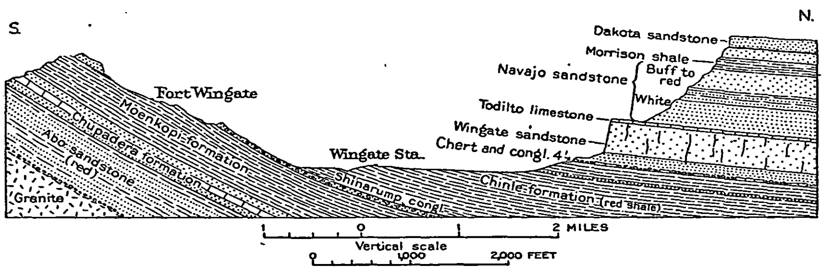


FIGURE 49.—Sketch section north from Fort Wingate. Dips exaggerated

Dutton [90] more than 40 years ago, but since that time much new light has been obtained on the classification and relations of the formations.

[90] Dutton, C. E., Mount Taylor and the Zuni Plateau: U. S. Geol. Survey Sixth Ann. Rept., pp. 105-198, 1885.

FORMATIONS

ABO SANDSTONE (PERMIAN)

The Abo sandstone is extensively exposed in the central part of the Zuni Mountain uplift. It consists of 600 to 700 feet of red sandstone and sandy shale having all the characteristics of the Abo in the central and eastern parts of the State as well as those of the Supai formation in Arizona. The color is mostly a brownish brick-red, the bedding is predominantly slabby, and the relations to the overlying Chupadera formation are the same as in the region farther east. In much of the uplift these red rocks lie directly on the granite, but in places in the vicinity of Sawyer, as shown in Figure 54, and farther east they are underlain by limestone and a basal conglomerate. A notable feature is a 40-foot member of massive pink sandstone, shown in Plate 7, *A*, about 225 feet above the base, underlain by coarse brown sandstone. A typical section of the formation in the high cliffs at the head of Bluewater Canyon, 8 miles east of Sawyer, is as follows:

Section of the Abo sandstone and lower part of the Chupadera formation 8 miles east of Sawyer

	Feet
Chupadera formation:	
Limestone, light gray	60
Sandstone, massive, hard, buff	100
Sandstone, reddish buff	50
Sandstone, reddish buff, softer	40
Limestone, slabby	6
Sandstone, soft, buff	12
Abo sandstone:	
Sandstone, brown-red, slabby; some shale	360
Sandstone, pink, massive	40
Sandstone, brown-red, slabby	150
Limestone, light bluish gray	25
Sandstone, conglomeratic, hard, brown	40
Granite and schist. Pre-Cambrian.	

At McGaffey's sawmill, where the strata are nearly vertical, the formation is 550 feet thick from granite to hard sandstone at the base of the Chupadera formation.

A limestone member near the base of the Abo formation is exposed in two areas in the Zuni Mountains. One is at the head of Zuni Canyon, and the other begins a mile west of Sawyer and extends eastward for 10 miles or more. The relations near Sawyer are shown in Figure 54. At both places there is about 40 feet of limestone underlain by 20 feet or more of conglomeratic sandstone, which lies on the granite. At many other localities the bright-red sandstone and shale of the Abo lie directly on the granite. The limestone near Sawyer yielded the following fossils, determined by G. H. Girty, which he regards as a "Manzano (Permian) fauna":

Productus, fragments.
Composita subtilita.
Myalina aff. M. permiana.
Schizodus? sp.
Pleurophorus? sp.
Bellerophon? sp.
Goniospira? sp.
Naticopsis? sp.
Bulimorphia aff. B. chrysalis.

This limestone probably represents the similar member in the lower part of the Supai extensively exposed in central-eastern Arizona and carrying the same fauna.

CHUPADERA FORMATION (PERMIAN)

The limestone and sandstone overlying the red beds of the Abo formation in the Zuni uplift unquestionably belong to the Chupadera formation and they are closely similar to beds exposed in the Sierra Lucero uplift, not far to the east. At the base is red sandy shale, mostly massive, with thin limestone members and local beds of gypsum. Above are massive gray sandstone and limestone, which constitute the broad outsloping cuesta on each side of the central mountain area. A typical exposure at the head of Zuni Canyon is as follows:

Section of Chupadera formation in Zuni Canyon west of Grant

	Feet
Limestone	80+
Sandstone, gray, massive	20
Limestone	40
Sandstone, massive, gray to pale buff	150
Sandstone, pale red, massive, soft	60±
Limestone, slabby	10
Gypsum	20
Limestone, slabby	12
Sandstone, red, soft	30
Limestone, slabby	12
Sandstone, pale red, massive, soft (may be Abo sandstone)	40

The basal member lies on characteristic Abo sandstone, and the upper limestone constitutes the long cuesta sloping northeastward nearly to the Atchison, Topeka & Santa Fe Railway, where it is overlain by the Moenkopi shale. Probably the total thickness of this top member is much greater than 80 feet, for on the cuesta its surface is considerably eroded.

The Chupadera beds west of Agua Fria consist of a similar succession, apparently without the gypsum, and with several thin beds of limestone as shown in Figure 57. The medial bed of gray sandstone is hard and with the overlying limestone constitutes a ridge of considerable prominence on the west slope and the higher ridges to the northwest. The great cinder cone of Crater de la Bandera is built on a platform of the limestone. In the ridge 8 miles northeast of Ramah the thick member of hard gray sandstone constitutes the summit, the overlying limestone occupies the higher southwest slope, and an underlying gray hard limestone, 40 to 50 feet thick, is conspicuous farther down. In an excellent exposure about 12 miles northeast of Ramah, on the road to Thoreau, the hard gray sandstone member is 100 feet or more thick and constitutes the summit of the ridge as shown in the section in Figure 58. Below is 160 feet of shale and sandstone, with several thin beds of limestone in its lower half.

The formation is deeply trenched by the canyon of Bluewater Creek where it presents features shown in Plate 6, *C*. A section at the head of the canyon is as follows:

Section of Chupadera formation at south end of Bluewater Canyon, 8 miles northeast of Sawyer

	Feet
Sandstone, brown, under red shale (Moenkopi formation).	
Limestone, hard, light gray, slabby to massive	60
Sandstone, massive, hard, buff	100
Sandstone, reddish buff	50
Sandstone, reddish buff, softer	40
Limestone, slabby	6
Sandstone, soft, buff	12
Sandstones, red, slabby, at top of Abo.	

At McGaffey's mill, where the beds are nearly vertical, the hard lower sandstone is 80 feet thick and the limestone 60 feet or more thick. The formation thins greatly to the north, near Milk ranch, as shown in Figure 53.

Limestone of the Chupadera formation is exposed in the axis of the anticline on the summit of the ridge about 2 miles southeast of Ojo Caliente. Only a few of the upper beds appear, but they are highly fossiliferous. A collection made by M. K. Shaler was determined by G. H. Girty as follows:

Domatoceras n. sp.
Stenopora sp.
Chonetes aff. C. geinitzianus.
Productus ivesi.
Productus occidentalis.
Productus mexicanus?
Pernipecten? sp.
Deltopecten coreyanus.
Pteria sp.
Pleurophorus? sp.
Plagioglypta canna.
Pleurotomaria sp.
Euphemus subpapillosus?
Murchisonia sp.
Bellerophon aff. B. crassus.
Phymatifer pernodosus.
Domatoceras sp.
Fish spines and plates.

The fauna is that of the Kaibab limestone of the Grand Canyon, which is regarded as equivalent to the upper part of the Manzano group.

Only a very few fossils were collected from the Chupadera formation in the Zuni Mountains, but a sufficient number were obtained to establish correlation. *Productus ivesi* was found to be very abundant in the upper limestone at most localities. Three miles southwest of Fort Wingate an associated *Metacoceras* sp. was collected, and in the top beds in Bluewater Canyon *Productus occidentalis* was obtained. These forms were determined by G. H. Girty.

MOENKOPI FORMATION (TRIASSIC)

The thick mass of red and purple shale overlying the Chupadera formation undoubtedly represents the Moenkopi formation of Arizona. It underlies slopes and valleys along both sides of the Zuni uplift, and north of Ramah, where the thickness is about 850 feet, it extends far up the flanks of the southern limestone ridge. Some sandstone is included, notably a basal member of considerable prominence, and also a mottled shale of very compact texture. The formation underlies Las Tusas Valley and the Bluewater Valley southwest and south of Bluewater, where, however, it is mostly covered by lava. It is also exposed in the uplift at Ojo Caliente, overlain by Shinarump conglomerate and having at its base, according to Winchester,[91] 30 feet of pink conglomerate.

In the ridges a few miles northwest of Bluewater, where the formation is about 600 feet thick, it consists of the usual succession of soft gray, buff, reddish, and purplish shale, containing beds of sandstone from a few inches to 20 feet thick. One of the sandstone beds at the base is red and conglomeratic, and other reddish sandstone layers occur in the lower beds. Higher up the sandstone members are of lighter color and more or less cross-bedded. A peculiar limestone conglomerate layer about 3 feet thick noted about 50 feet above the base of the formation in this section was found to extend westward to a point beyond Fort Wingate, and a similar stratum was noted on the south side of the uplift. An exposure south of Guam shows at the base 30 to 40 feet of gray sandstone, followed by 50 to 70 feet of red shale, 30 feet of the peculiar conglomerate with many limestone pebbles, and 120 feet of maroon to pale-green massive shale with three layers of gray sandstone in its upper half. A thick hard sandstone is also present at the base of the formation along the southwest side of the uplift. The succession and character of beds vary greatly from place to place. It seems likely that there is an unconformity at the base of this formation but without notable angular discordance.

SHINARUMP CONGLOMERATE (TRIASSIC)

The sandstone overlying the Moenkopi formation in the Zuni Mountain uplift is regarded as a representative of the Shinarump conglomerate of Arizona, as suggested by Dutton.[92] The sandstone constitutes a conspicuous front ridge along the north slope of the uplift, notably from a point west of Bluewater to Fort Wingate. It also forms a sharp foothill ridge extending east of Nutria, north of Ramah and near Tinajas, and plateaus of considerable extent near Fort Wingate and east and west of McGaffey's sawmill. There is a small outcrop a mile northwest of Grant. In the high ridge south

[91] Winchester, D. E., personal communication. [92] Dutton, C. E., op. cit. (Sixth Ann. Rept.), p. 134.

of Thoreau the sandstone is 40 feet thick, is massive and hard, and includes some conglomerate layers. The sandstone here constitutes a cuesta sloping down toward the valley followed by the Atchison, Topeka & Santa Fe Railway from Bluewater to Wingate and beyond. It is well exposed in the Zuni Valley near Ojo Caliente and southward along the uplift and fault toward Atarque.

CHINLE FORMATION (TRIASSIC)

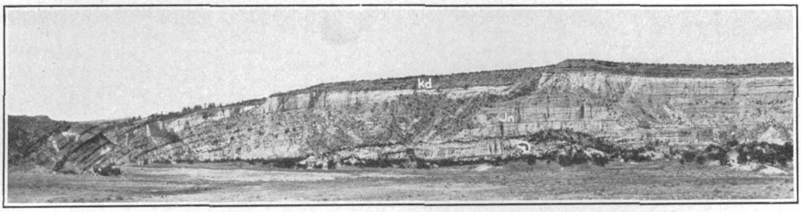
A wide valley underlain by soft shale of the Chinle formation extends along both sides of the Zuni Mountains. The valley on the north side is followed by the Atchison, Topeka & Santa Fe Railway, and that on the south side lies about 2 miles north of Ramah and passes between Inscription Rock and Tinajas where, however, part of the area is covered by lava. The strata closely resemble those of the Chinle formation in Arizona, and the thickness ranges from 850 to 950 feet as far as observed. The rocks are mostly sandy clay or massive shale, largely of reddish and maroon tints, with thin sandstone members, but the succession varies somewhat from place to place. One dark-purplish sandstone about 200 feet below the top of the formation was found to extend from a point near Guam to a point 8 miles southeast of Gallup. The Chinle formation is extensively exposed in the valley of Zuni River between the pueblos of Zuni and Ojo Caliente, where its thickness is about 900 feet. In this area Sears[93] noted an upper member about 100 feet thick of red, purple, and mottled lavender and white clay and shale, underlain by a 30-inch bed of lavender cross-bedded conglomerate which contains pebbles and clay balls as much as 1 inch in diameter.

WINGATE SANDSTONE (JURASSIC?)

The high red cliffs of the Wingate sandstone are a prominent feature along the north side of the Zuni Mountain uplift from a point north of Grant to and beyond Wingate. The greatest thickness of the formation here is about 300 feet. It thins somewhat to the south but reappears in extensive exposures in the valley of Zuni River about Zuni Pueblo. Here, however, it is less massive and darker than in the cliffs on the north side of the uplift. The thickness near Zuni is about 280 feet, and at Atarque it is not over 40 feet. Exposures north of Thoreau are shown in Plate 35, *A*, and north of Wingate in Plates 10 and 35, *C*.

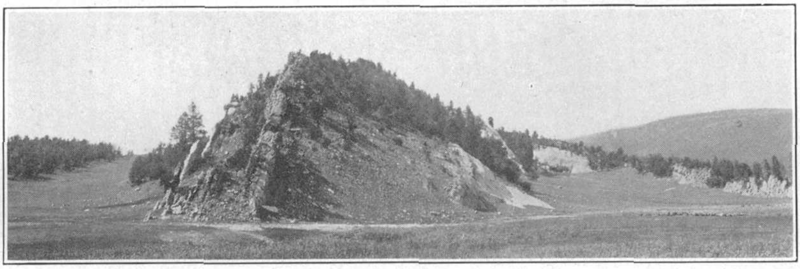
At the base of the formation there is a thin but persistent stratum of calcareous sandstone and shale of purplish tint containing bone fragments. The stratum was not followed east of Guam, but it was traced far west and south. Its thickness is 12 feet near Guam, 4 feet in the gap east of Gallup, and 2 feet in a section 8 miles southeast of Gallup. No determinable bones were obtained.

[93] Sears, J. D., op. cit. (Bull. 767), p. 11.



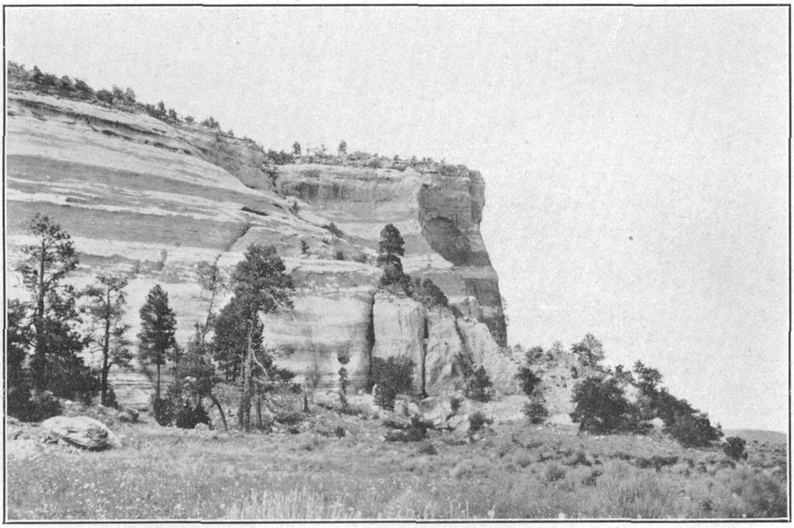
A. NORTHWEST END OF ZUNI MOUNTAIN UPLIFT, 4 MILES NORTHEAST OF GALLUP

Strata pitch to the northwest. Kd, Dakota sandstone; Jn, Navajo sandstone



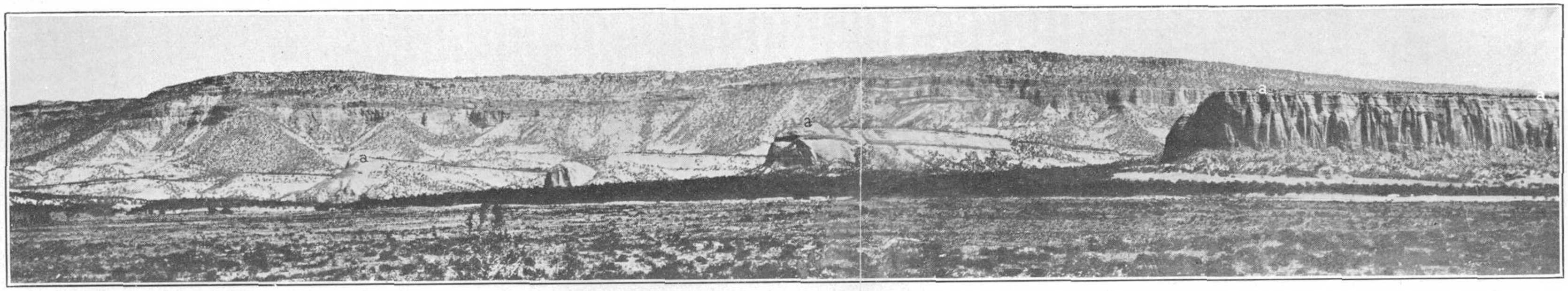
B. CRETACEOUS AND NAVAJO SANDSTONES ON SOUTHWEST SIDE OF ZUNI UPLIFT NEAR NUTRIA, NORTHEAST OF ZUNI

Looking northwest. Zuni Mountain at right



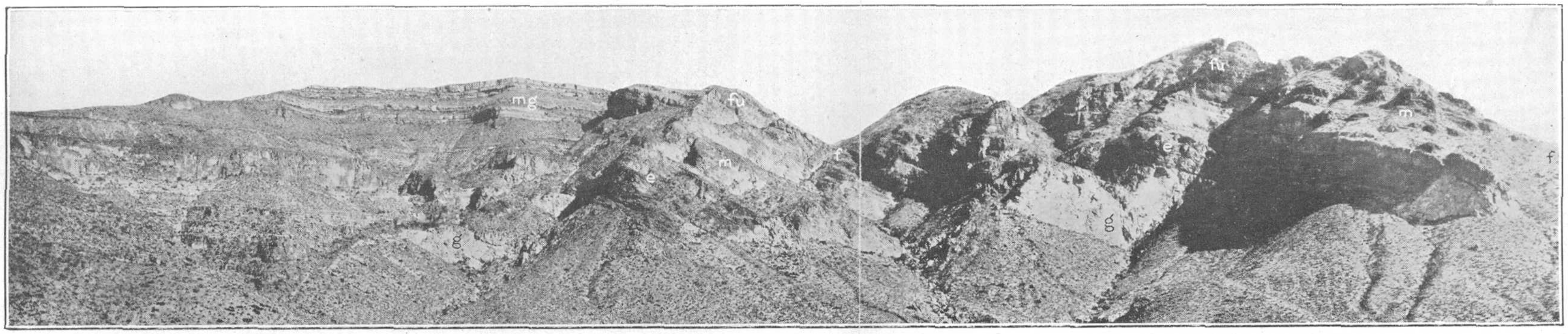
C. NAVAJO SANDSTONE IN NORTH WALL OF CANYON 1 MILE SOUTHEAST OF RAMAH

Looking northeast. Massive gray sandstone banded with pink



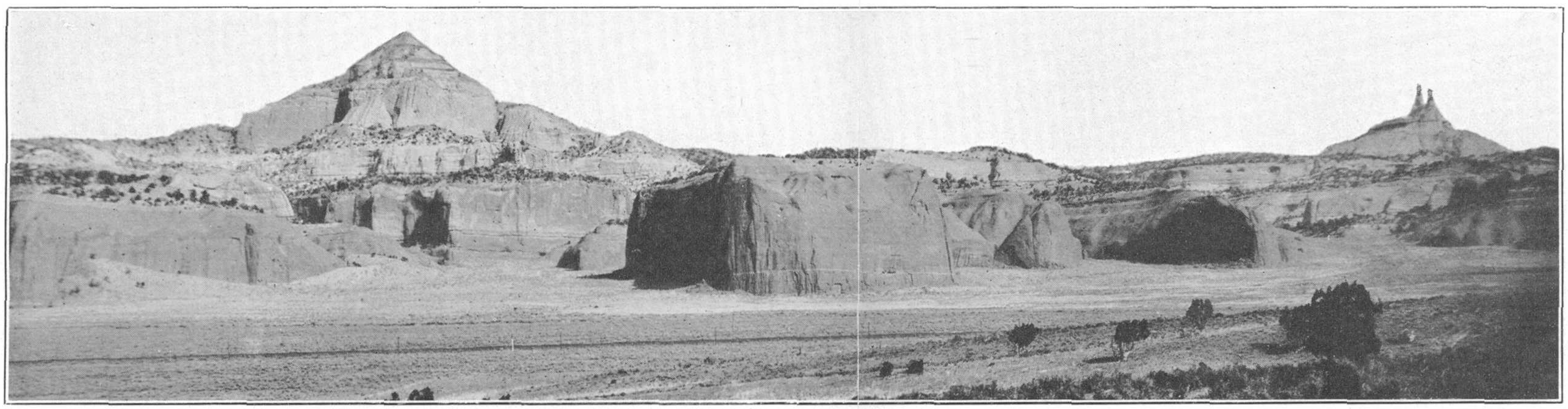
A. HIGH CLIFFS ON CONTINENTAL DIVIDE NORTH OF THOREAU

Looking north. Massive Wingate sandstone, Navajo sandstone, Morrison formation, and capping of Dakota sandstone. a, Bench of Todilto limestone on Wingate sandstone



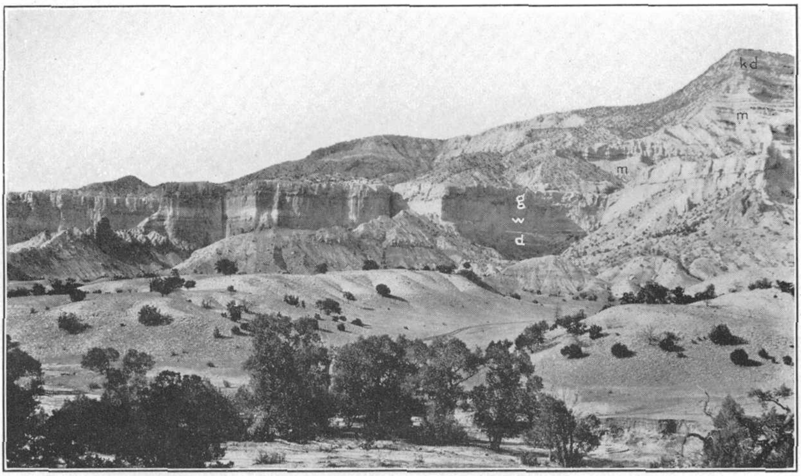
B. NORTH WALL OF BENNETT CANYON, SAN ANDRES MOUNTAINS, 25 MILES NORTHEAST OF LAS CRUCES

Looking north. f, Faults; g, granite; e El Paso limestone on Bliss sandstone; m, Montoya limestone; fu, Fusselman limestone; mg, limestones of Magdalena group



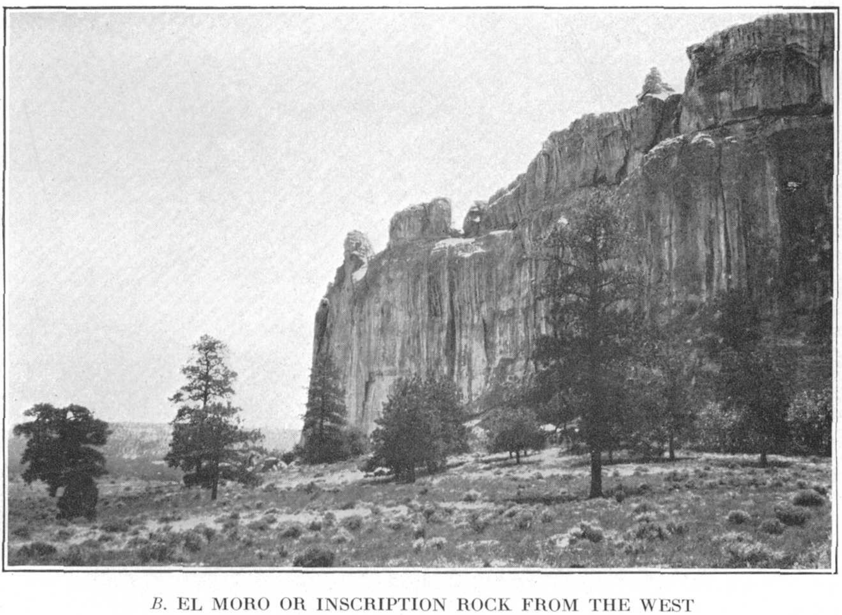
C. RED CLIFFS OF WINGATE SANDSTONE OVERLAIN BY NAVAJO AND HIGHER SANDSTONE FROM PYRAMID ROCK TO NAVAJO CHURCH, 6 MILES EAST OF GALLUP

Looking north. Atchison, Topeka & Santa Fe Railway in foreground



A. BUTTRESS AT EAST SIDE OF MOUTH OF CANYON OF CANJILON CREEK, WEST OF ABIQUIU

d, Red shale (Chinle? formation); w, Wingate sandstone; g, gypsum member of Todilto formation; m, Morrison shale; kd, Dakota sandstone



B. EL MORO OR INSCRIPTION ROCK FROM THE WEST

Massive gray Navajo sandstone lying nearly horizontal, 9 miles south of Ramah

TODILTO LIMESTONE (JURASSIC?)

The Wingate sandstone is separated from the Navajo sandstone by the Todilto limestone from a point north of Guam to Grant and beyond. As stated on page 130, this limestone also appears in T. 10 N., R. 9 W., south of Horace, but it thins out farther south. In the slopes north of Guam and Thoreau the limestone is from 10 to 12 feet thick and caps the high red cliff of Wingate sandstone, as shown in Figure 49. It consists of thin-bedded impure limestone and has yielded no fossils.

NAVAJO SANDSTONE (JURASSIC?)

The Navajo sandstone is one of the most conspicuous formations in the Zuni Mountain uplift and southward to Zuni. Its high cliffs are especially notable in the Zuni region and along the ridge that extends northwestward from Inscription Rock past Nutria, as shown in Plate 34, *C*. In this region it is from 425 to 475 feet thick, is compact and massive, and presents alternating bands of pink and gray; the pink banding is especially noticeable on the upper half. Two miles east of Ramah 12 feet of basal conglomerate is exposed, probably taking the place of the Todilto limestone. In the great ridge north of Wingate and Thoreau the formation begins on a bench above the high cliffs of Wingate sandstone, as shown in Figure 49, and forms a rugged slope with many fantastic erosion features, notably the "Navajo Church" (see pl. 10). The thickness here is 550 to 650 feet, but no detailed section was made. Some typical views of outcrops of the formation are given in Plates 34–36. Plate 36, *B*, shows Inscription Rock, which consists of Navajo sandstone, on the south slope of the Zuni Mountain uplift. In the butte at Atarque (pl. 12, *B*) the formation is not more than 120 feet thick, and the Dakota(?) sandstone lies on its eroded surface. The same relations prevail from a point east of Gallup all along the southwest side of the Zuni Mountain uplift and on the east side south of Grant.

MORRISON FORMATION (CRETACEOUS?)

In the high slopes on the northeast side of the valley followed by the Atchison, Topeka & Santa Fe Railway on the north slope of the Zuni Mountain uplift, the Navajo sandstone is overlain by gray and greenish shale and sandy shale, grading into sandstone, which have been classed as "McElmo formation" by Gregory [94] but which are now regarded as a westward extension of the Morrison formation. This formation is from 150 to 300 feet thick but thins out southeast of Gallup and is absent farther south.

DAKOTA(?) SANDSTONE AND OVERLYING CRETACEOUS ROCKS

The Zuni uplift is encircled by an outcrop of sandstone that has commonly been called Dakota sandstone, which dips under an extensive succession of Upper Cretaceous shale and sandstone represent-

[94] Gregory, H. E., op. cit. (Prof. Paper 93), p. 59.

ing the Mancos shale and Mesaverde formation of northwestern New Mexico. These rocks were not studied, although in many areas their limits were mapped. Details regarding them and their coal beds have been given by Sears.[95] (See also pp. 139 and 153.)

BORINGS

Some deep borings on the north slope of the Zuni uplift throw light on the stratigraphy. One at Bluewater had the following record:

Record of boring at Bluewater station

	Feet
Lava in two beds (?), thin tuff and red clay between	0–90
Clay, red	90–159
Clay, blue	159–260
Sandstone, gray, soft	260–263
Clay, blue	263–270
Sandstone, hard, gray above, red below	270–291
Limestone, hard, with dark sandstone at 439–447 feet	291–455
Sandstone, white; small amount of water	455–575
Sandstone, red; bad water	575–735

The hole penetrated the lower beds of the Moenkopi formation to 291 feet, where it entered the limestone and sandstone of the Chupadera formation, exposed in the canyon 1 mile to the west. (See pl. 6, *C*.) The red sandstone at 575 feet was the lower member of that formation, but possibly the bottom of the hole reached the top of the Abo sandstone.

A 707-foot hole at old Chaves station reached Shinarump sandstone, which gives an artesian flow. The record shows gray sandstone from 52 to 191 feet (under valley fill), red clay from 195 to 530 feet, blue clay from 530 to 570 feet, and then gray sandstone belonging to the Shinarump conglomerate. A 930-foot boring at North Chaves obtains an excellent water supply, apparently from sandstone high in the Chupadera formation. At Guam a 600-foot hole failed to reach this sandstone but passed through an alternation of shale and sandstone of various colors, as shown in the following section:

Record of boring in Chinle formation at Guam

	Feet
Sand, clay, and gravel	0–55
Sandy clay; petrified wood at base	55–76
Shale, blue, compact	76–92
Sandstone, soft, white	92–103
Shale, red	103–108
Sandstone, red	108–135
Shale, red	135–145
Sandstone and conglomerate	145–155
Sandstone, gray	155–210
Shale, blue, compact	210–410
Shale, soft	410–540
Sandstone, red, hard	540–560
Shale, red, hard	560–600

[95] Sears, J. D., op. cit. (Bull. 767), pp. 13–18, 1925.

The test well sunk by the Carter Oil Co. in 1919 in the SW. ¼ sec. 17, T. 11 N., R. 19 W., about 30 miles southwest of Gallup, reached a depth of 1,980 feet. The boring began not far below the top of the Chinle formation on the crest of a pronounced anticline and was discontinued in the Abo sandstone. The following strata were reported by Mr. Nesselrode, the superintendent; the identifications of the formations are my own:

Record of well in the SW. ¼ sec. 17, T. 11 N., R. 19 W.

	Feet
Chinle, Shinarump, and Moenkopi formations:	
Shale, all red	0–1, 006
Sandstone, gray to white	1, 006–1, 010
Shale, red	1, 010–1, 070
Chupadera formation:	
Limestone	1, 070–1, 100
Sandstone, gray	1, 100–1, 355
Shale, red	1, 355–1, 630
Abo sandstone (?):	
Limestone, very hard, some grit	1, 630–1, 650
Shale, red	1, 650–1, 980

Boring was discontinued mainly because it was supposed that the hole had nearly reached the base of the sedimentary succession. The report that this hole reached granite is doubtless a mistake. It is likely that the Abo formation is 800 feet thick at this place, as it thickens westward from the Zuni Mountain uplift to the outcrops of corresponding strata of the Supai formation in eastern Arizona. Possibly some of the underlying Magdalena is also present, although this limestone is absent in the Zuni Mountain uplift; its equivalent is prominent not far west in Arizona. The 20-foot limestone member at 1,630 feet in this boring may be the extension of one that occurs high in the Supai formation 60 miles farther west in Arizona. The relations of this boring are shown in Figure 60.

Record of flowing well at Wingate

	Feet
Shale, mostly brown, few thin sandstone layers	0–119
Sandstone, brown, conglomeratic	119–151
Shale, brown, with few sandstone layers	151–241
Rock, clay, and blue shale	241–245
Gypsum	245–247
Sandstone, light brown	247–283
Shale, red	283–293
Sandstone, pale red	293–335
Shale, red	335–411
Shale, part blue, part red; limestone at 425 feet	411–457
Limestone	457–475
Sandstone, mostly gray, some shale	475–511
Shale, white, red, and brown	511–530
Sandstone, white	530–535
Shale, mostly blue or brown; some limestone at 580 feet	535–625

	Feet
Shale, red	625–870
Shale, blue on white	870–882
Limestone	882–892
Shale, mostly red, some purple	892–972
Sandstone, mostly white, coarse	972–990
Shale and sandstone, red; very hard, 1,022–1,057 feet; limestone, pink, at 1,007 feet and 1,020 feet	990–1, 076
Sandstone, hard, red	1, 076–1, 082
Sandstone, yellow to white, pink	1, 082–1, 205
Sandstone, mostly red	1, 205–1, 228
Shale, yellow, with 4-foot bed of red sandstone near base	1, 228–1, 259
Sandstone, white, buff, and red on yellow shale	1, 259–1, 271
Sandstone, red to pale pink, with 60 gallons flow, 85 pounds pressure	1, 271–1, 305

This boring penetrated the Chinle shale, Shinarump sandstone, and Moenkopi formation. Apparently its flow comes from sandstone in the Chupadera formation, which may have begun with the limestone at 882 feet. The borings, which I had opportunity to examine, from the lower part of the hole, suggest to me the massive sandstone near top of the Abo, but this member was hardly to be expected at such moderate depth. The success of this well was the verification of a prediction that strata on the north slope of the Zuni uplift should yield a flow.

Borings at Gallup and farther west are described on pages 151 and 154.

STRUCTURAL DETAILS

ZUNI MOUNTAINS

The Zuni Mountain uplift is structurally a broad, flat-topped dome, the salient features of which are shown in Figures 48–58. The steep dip of the strata on the northwestern part of the uplift from the region east of Gallup to and beyond Nutria is shown in Figure 51 and Plate 34, *B*.

Local domes bring up the granite at several places in the center of the main uplift, and there is a notable fault on Bluewater Canyon. Of the many minor irregularities of structure only a few were examined.

In the vicinity of McGaffey's sawmill there is locally increased uplift in the center of the main anticline, and the granite is exposed encircled by steeply dipping Abo and overlying strata. Just south of the sawmill the dips are 70°, and a sharp ridge of hard sandstone marks the outcrop of the lower part of the Chupadera formation. West of the mill this ridge and the outcrop of Abo sandstone circle around to the southwest, where the section given in Figure 52 is presented. The relations in the center of the northern part of the Zuni uplift are shown in Figure 53, and near Sawyer there is a local basin having the features shown in Figure 54.

The long, crooked canyon of Bluewater River is excavated in a monocline of the Chupadera formation dipping gently northeastward. A fault with uplift on the east side lies a short distance east of this canyon and marks the head of the west-east canyon at the old dam site at the east end of Las Tuces Valley. To the south it was not traced beyond the outcrop zone of the lower beds of the Abo formation not far north of Diener. The red Abo sandstone rises to the surface in the walls of the southern part of the north-south canyon. (See fig. 55.) The relations on the south slope of the uplift near Diener are shown in Figure 56. In Figures 57 and 58 are shown the relations on the south end of the mountains and on the west slope north of Ramah.

GALLUP-ZUNI BASIN

The structure of the wide basin lying next west of the Zuni Mountain uplift has been described and mapped in detail by Sears.[96] The basin is somewhat complex owing to several corrugations of irregular form, some of which are shown in Figure 59. One of the subordinate flexures is the Gallup anticline, with steep westerly slope near Gallup; another is the Torrivio anticline, which crosses the railroad at Defiance switch, bringing into view the Gallup sandstone member of the Mesaverde formation; and a third is the Piñon Springs anticline, which extends from a point near Manuelito to a point near Black Rock and brings the Chinle formation to the surface

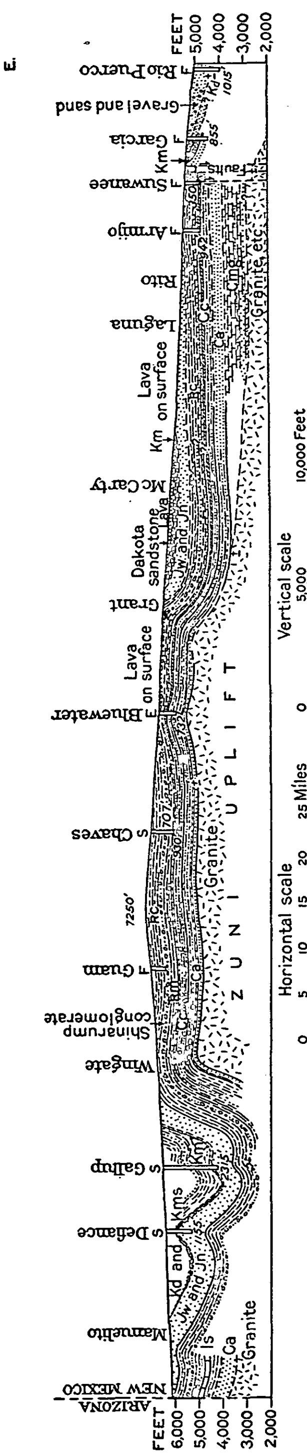


FIGURE 50.—Section across northwestern New Mexico along Atchison, Topeka & Santa Fe Railway. Exaggeration of dips is caused by great exaggeration of vertical scale. S, Successful borings for water; F, borings that failed to obtain good water; E, boring yielding a small supply of water. Cmg, Magdalena group; Ca, Abo sandstone; Cc, Chupadera formation; Ꞧm, Moenkopi formation; Ꞧc, Chinle formation; Jw, Wingate sandstone; Jn, Navajo formation; Km, Morrison formation; Kd, Dakota sandstone; Kmc, Mancos shale; Kmv, Mesaverde formation

[96] Sears, J. D., op. cit. (Bull. 767).

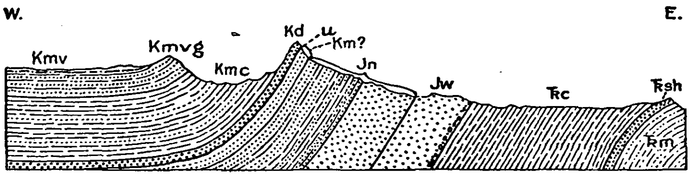


FIGURE 51.—Sketch section of northwest slope of Zuni Mountain uplift 3 miles northeast of Gallup. Kmv, Mesaverde formation; Kmvg, Gallup sandstone member of Mesaverde formation; Kmc, Mancos shale; Kd, Dakota(?) sandstone, 50 feet or more, with an unconformity (u) at its base; Km, Morrison formation, consisting of white sandstone, purple to gray sandy shale, buff sandstone 40 feet, and light-gray to maroon sandy limestone; Jn, Navajo sandstone; Jw, Wingate sandstone, red massive, with conglomerate at base; Ꞧc, Chinle formation, red shale; Ꞧsh, Shinarump sandstone; Ꞧm, Moenkopi formation

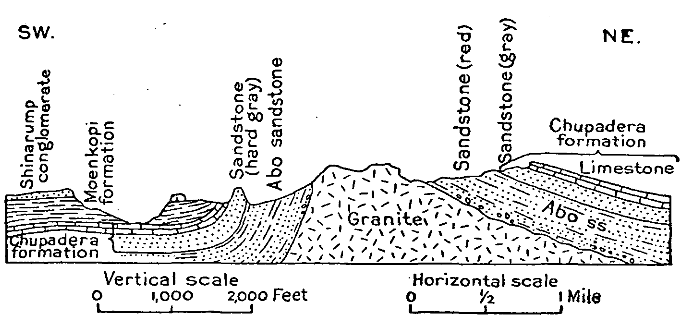


FIGURE 52.—Sketch section across upturned strata in center of Zuni Mountain uplift, southwest of McGaffey's sawmill

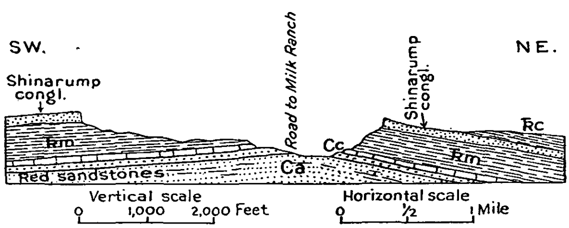


FIGURE 53.—Sketch section across part of Zuni Mountain uplift 3 miles south of Fort Wingate. Ca, Abo sandstone; Cc, Chupadera formation; Ꞧm, Moenkopi formation; Ꞧc, Chinle formation

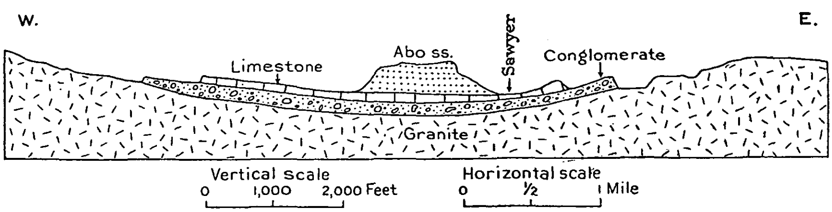


FIGURE 54.—Sketch section near Sawyer, in the Zuni Mountains, showing relation of limestone in the Abo formation

near Piñon Springs. To the west of this latter anticline the strata rise steadily on the east slope of the Defiance uplift, the crest of which is in Arizona. Some features of the arch near Piñon Springs, where a 1,980-foot hole has been drilled, are shown in Figure 60. Still farther south are an anticline and fault which extend south-

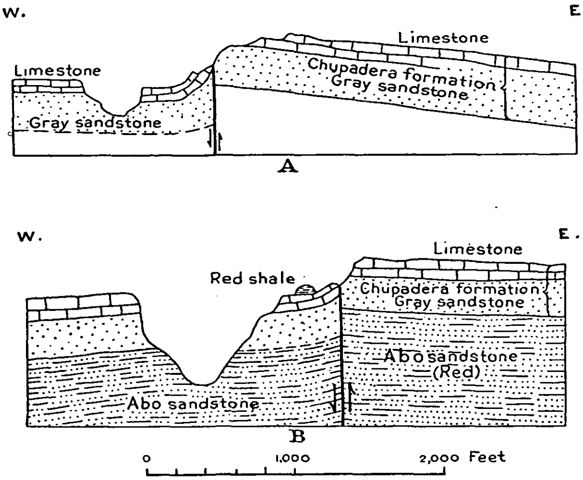


FIGURE 55.—Sketch sections across upper canyon of Bluewater River northeast of Sawyer. A, Near north end; B, near south end

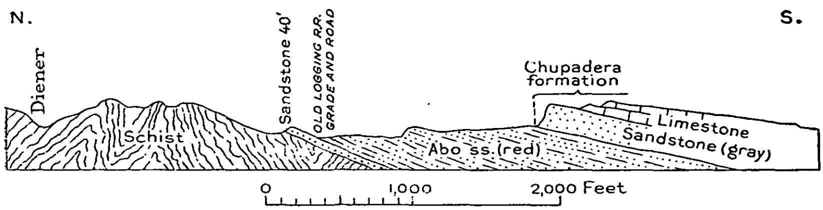


FIGURE 56.—Sketch section across Zuni Mountains south of Diener

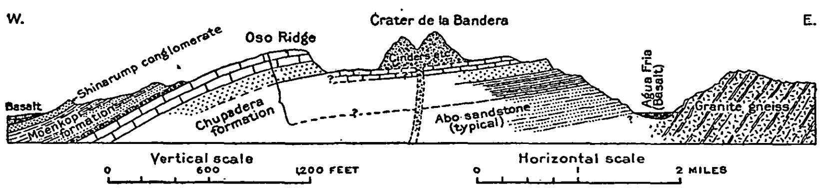


FIGURE 57.—Sketch section across southern part of Zuni Mountains near latitude 35°

ward to Atarque, where on the east side for many miles there are prominent cliffs of Navajo sandstone capped by Cretaceous sandstone.

In 1926 a boring for oil was made in the local anticline which crosses the railroad at Defiance. It was abandoned at a depth of 1,405 feet. The following strata were penetrated:

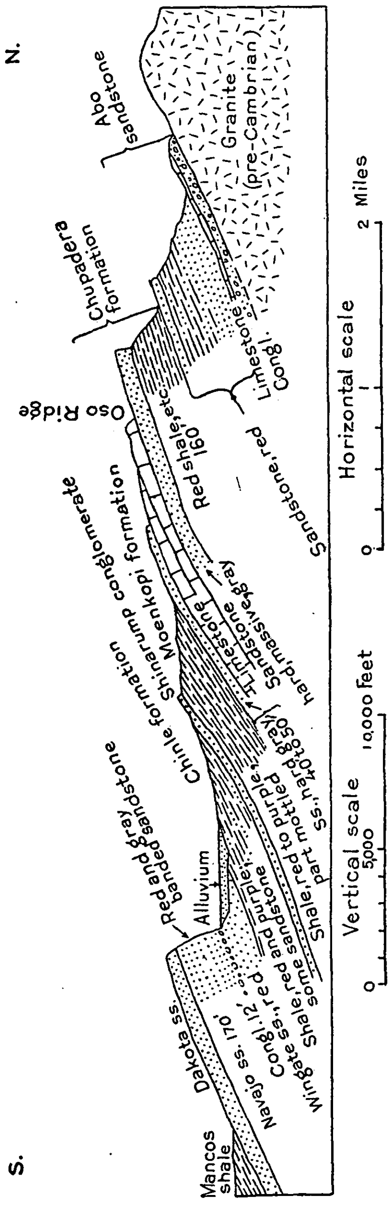


FIGURE 58.—Sketch section across southwest slope of Zuni Mountains near Savoia Wash

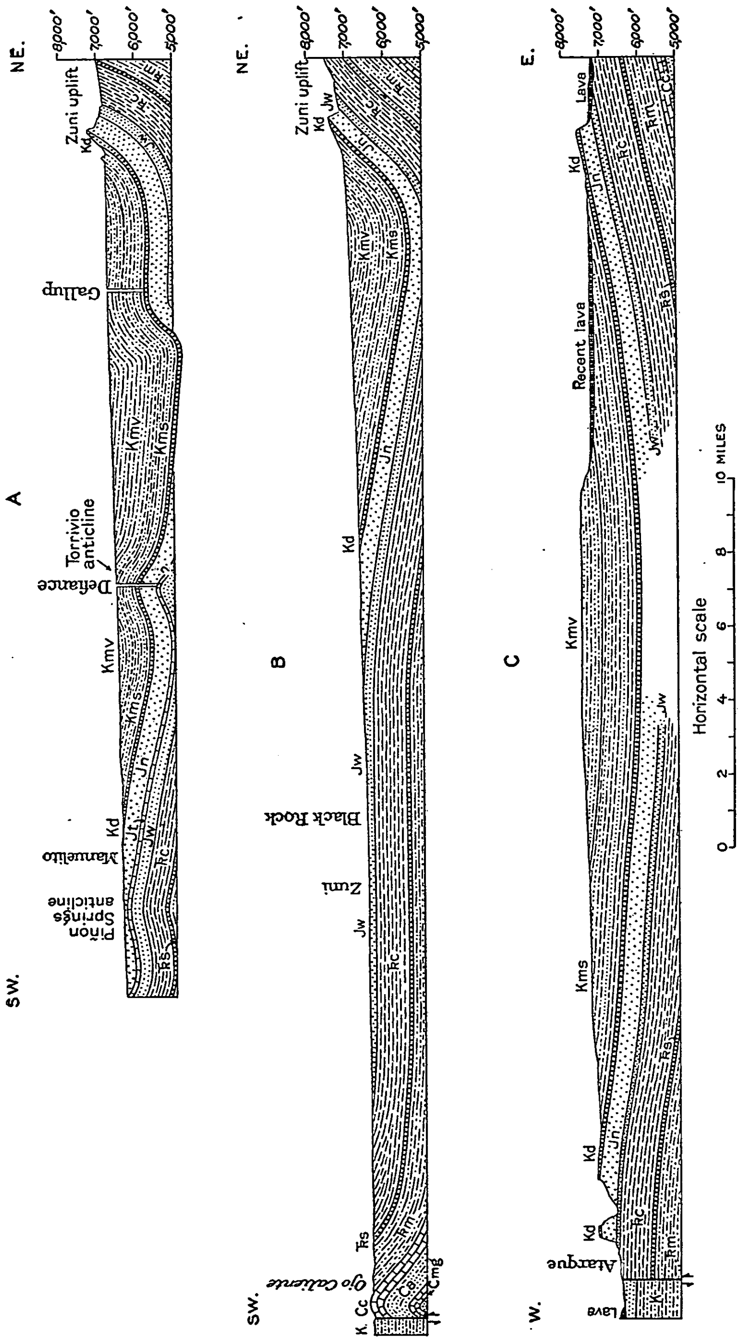


FIGURE 59.—Sections across Gallup-Zuni Basin, McKinley and Valencia Counties. A, Through Gallup; B, near Zuni; C, near Atarque. K, Cretaceous; Kmv, Mesaverde formation; Kms, Mancos shale; Kd, Dakota sandstone; Jn, Navajo sandstone; Jt, Todilto limestone; Jw, Wingate sandstone; TRc, Chinle formation; TRs, Shinarump conglomerate; TRm, Moenkopi formation; Cc, Chupadera formation; Ca, Abo sandstone; Cmg, Magdalena group

Section of boring at Defiance

	Feet
Clay and sand	0–35
Shale, blue and black	35–137
Limestone (very doubtful)	137–180
Shale with thin sandstones at 189, 240, and 751 feet	180–822
Sandstone, "broken"; water	822–860
Shale, brown on blue	860–898
Sandstone; water	898–996
Red rock	996–1, 008
Sandstone, white, brown in center	1, 008–1, 320
Sandstone, red	1, 320–1, 330
Sandstone, white	1, 330–1, 405

This hole began in the lower part of Mancos shale and penetrated the Navajo sandstone. Probably the 98 feet of sandstone at 898 feet is the Dakota (?). Doubtless the 410 feet of red and white sandstones next below are Navajo.

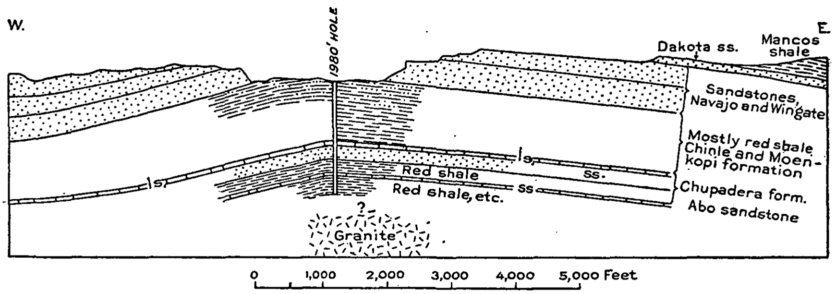


FIGURE 60.—Section of Piñon Springs anticline at Whitewater Creek

Several holes have been bored in Gallup to obtain water supplies, which come mainly from 940 to 1,356 feet. One record is given in a previous publication.[95a] Another boring, made in 1925, shows shale, with some sandstone, to 815 feet, sandstone 815–870 feet, dark shale 870–938 feet and sandstones, white and pink, which were penetrated for 462 feet. This is probably Dakota sandstone but possibly underlying sandstones were reached.

ANTICLINE AND FAULT, OJO CALIENTE TO ATARQUE

In 1903 it was noted that the strata are arched up and faulted at Ojo Caliente. Later it was found that the fault continues southward to Atarque, where it passes under the northern edge of a sheet of basalt. In the highest part of the anticline, which is about 2 miles southeast of Ojo Caliente pueblo, the top limestone of the Chupadera formation is exposed for a short distance.

The arch flattens toward the southeast and within the next few miles either dies out or becomes very low. The fault, which brings Mancos beds in contact with the Chinle formation a mile southwest

[95a] Darton, N. H., op. cit. (Bull. 435), p. 78.

of Ojo Caliente, trends south-southeast and passes a short distance west of Atarque. Along it to the south Shinarump and Moenkopi beds are in contact with Mancos shale, and to the east rises a prominent cliff of Navajo sandstone capped by Dakota (?) sandstone which extends to Atarque, as shown in Plate 12, *B*. North of Ojo Caliente the anticline pitches considerably under the east-west cliff of Shinarump sandstone. At the pueblo of Ojo Caliente the relations of the fault are concealed by alluvium of Zuni River, and sand dunes cover the region farther north to the State line and into Arizona. The anticline and fault were examined only at intervals

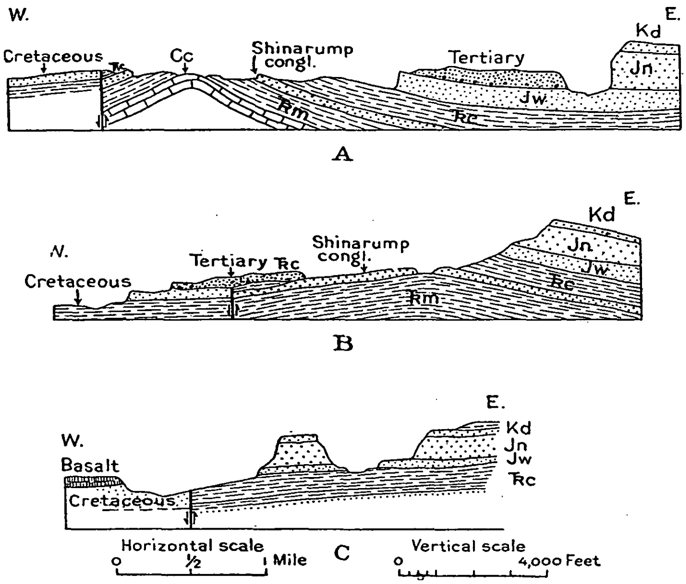


FIGURE 61.—Sketch sections across anticline and fault extending southward from Ojo Caliente. A, Near Ojo Caliente village; B, about 4 miles south of Ojo Caliente; C, a short distance north of Atarque. Kd, Dakota sandstone; Jn, Navajo sandstone; Jw, Wingate sandstone; Ŧc. Chinle formation; Ŧm, Moenkopi formation; Cc, Chupadera formation

along their course, where the features shown in the three sections in Figure 61 were observed.

NACIMIENTO UPLIFT AND ITS NORTHERN AND EASTERN EXTENSION IN CHAMA BASIN

GENERAL RELATIONS

The Nacimiento Mountains, in the north-central part of Sandoval County, are caused by an anticline which lifts granite and overlying limestone and sandstone considerably above the general country level. The flexure rises rapidly north of latitude 35° 30′ and continues northward through San Pedro Mountain and Capulin Mesa in Rio Arriba County. It pitches considerably near the Rio Chama but is continued as a notable structural feature for some distance north of Gallina Peak. In the Chama Basin the outcrops of the uplifted older rocks and overlying Jurassic and Cretaceous are spread out widely by several low corrugations, but toward the south the east side of the uplift is heavily flanked by the igneous succession that constitutes the Valle Mountains. To the west is a broad basin of Upper Cretaceous rocks. The general structural relations of the Nacimiento uplift and its northern and eastern extension in the Chama Basin are shown in the cross sections in Figure 62. The distribution of formations is shown in Plate 37. The strati-

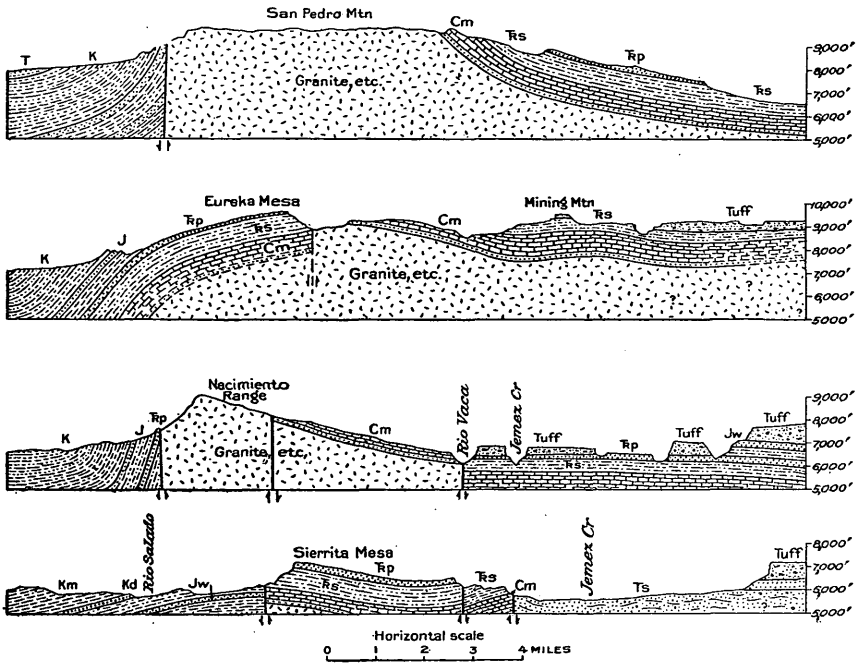


FIGURE 62.—Sections across San Pedro and Nacimiento Mountains in Sandoval and Rio Arriba Counties. T, Tertiary; Ts, Santa Fe formation; K, Cretaceous; J, Navajo sandstone and Todilto formation (limestone and gypsum); Jw, Wingate sandstone; TRp, Poleo sandstone overlain by red shale; Ca, Abo sandstone; Cm, Magdalena group

graphic succession in the Nacimiento uplift and its extension to the east and north is shown in Figure 63.

The formations are closely similar to those which appear farther east and south in New Mexico, but to the north the Chupadera formation and most if not all of the Lower Triassic appear to be absent. Lying on pre-Cambrian granite is limestone of the Magdalena group. Next above is more than a thousand feet of sandstone and shale, mostly red, of Permian and Triassic age. These beds are overlain by typical Wingate sandstone capped by the Todilto formation, consisting of limestone overlain by a great bed of gypsum. Above the Todilto are the Morrison formation, Dakota

(?) sandstone, and the Mancos, Mesaverde, Lewis, and later Cretaceous and early Tertiary deposits, which occupy the deep basin west of the main uplift. There are several irregularities of overlap.

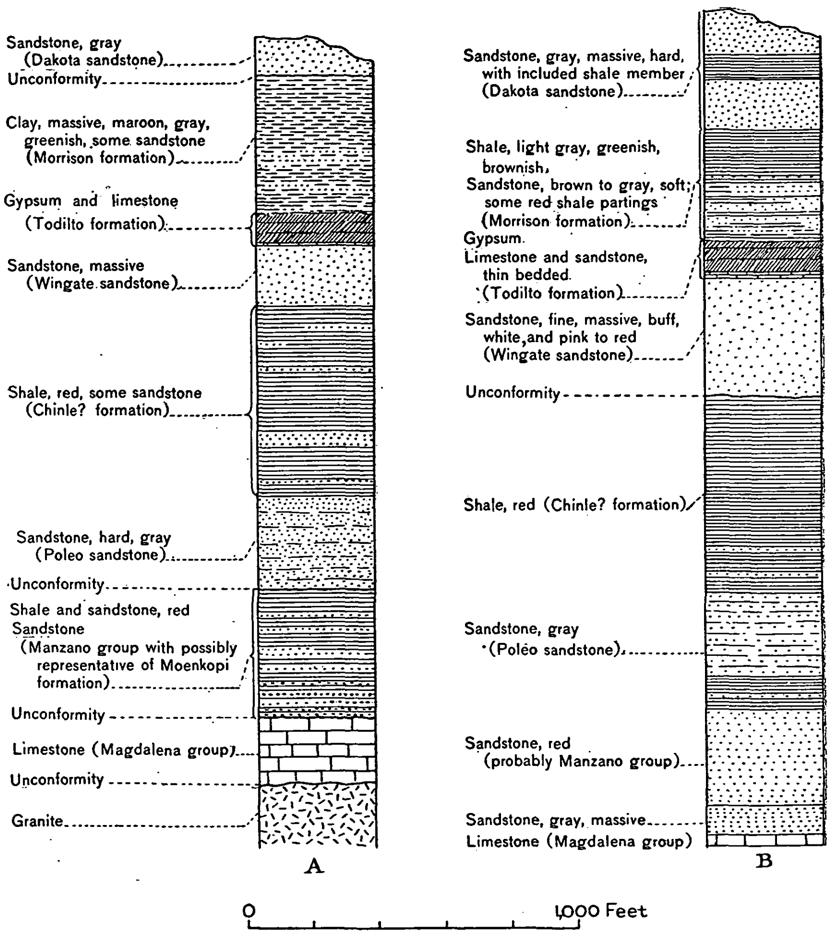


FIGURE 63.—Columnar sections of beds exposed in Nacimiento uplift. A, West of Jemez; B, Rio Chama-Gallina area

FORMATIONS

MAGDALENA GROUP (PENNSYLVANIAN)

There are extensive exposures of the Magdalena group along the sides of the Nacimiento and San Pedro Mountains, especially in the deep canyon and headwaters of the Rio de la Vaca. The rocks are faulted out or overlapped along the west side of the uplift except for a few miles north of Sierrita Mesa. They are also revealed in the deep canyon of Jemez Creek above Jemez Springs, and the underlying granite is exposed at the "soda dam" 2 miles above the springs. The outcrops also extend eastward down the valley of the Rio Puerco on the east side of San Pedro Mountain. The Magdalena in places is at least 500 feet thick, and although it consists mainly of limestone it includes also more or less shale and limy shale and local beds of sandstone, in part conglomeratic. In places it is absent.

The upper members of the Magdalena are exposed on the east slope of San Pedro Mountain, in the upper part of the Rio Puerco Valley 8 miles southwest of Coyote, with the relations shown in Figure 64. In the limestone at this place were collected *Productus*

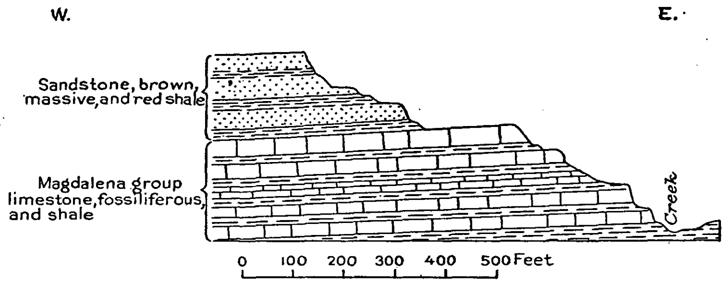


FIGURE 64.—Section of Magdalena group and overlying sandstone on Rio Puerco 8 miles southwest of Coyote, Rio Arriba County

nebrascensis, *Spirifer cameratus*, and *Composita subtilita*. In strata 110 feet above the granite 2 miles northwest of Jemez pueblo were collected *Lophophyllum profundum*, *Septopora* sp., *Spirifer cameratus* and *Composita subtilita*. A collection a mile above the soda dam at about the same horizon comprised the following:

Fenestella, several sp.
Polypora sp.
Batostomella sp.
Productus cora.
Productus punctatus?
Productus nebrascensis?
Productus semireticulatus.
Spirifer rockymontanus.
Composita subtilita.

In upper ledges of the limestone just above Jemez Springs were collected *Rhombopora* sp., *Productus cora*, *P. coloradoensis* var., *Marginifera splendens*, *Spirifer triplicatus*, *Ambocoelia planiconvexa*, and *Composita subtilita*. These were all determined by G. H. Girty, who regards them as Pennsylvanian.

PERMIAN AND TRIASSIC "RED BEDS"

The "Red Beds" succession in the Jemez-Nacimiento-Chama region comprises a basal massive sandstone, red shale, and red to brown sandstone (Abo sandstone and probable Chupadera formation, both Permian, and possibly a representative of the Triassic Moenkopi formation); a medial division of massive gray sandstone (Poleo sandstone, Triassic); and an upper division of red shale, probable Chinle.

The Abo formation is not as clearly separable in this region as in the Sandia Mountains and farther south, but it is believed to constitute the lower part of the "Red Beds." It is a conspicuous feature in the Canyon San Diego, in Canyon Guadalupe for 3 miles above the plazita of Canyon, and in the west front of Sierrita Mesa. This formation, consisting of massive brown sandstone about 100 feet thick, is exposed lying on limestone of the Magdalena group in the headwater region of Rio de la Vaca, on the slopes of San Pedro Mountain, and near Jemez Springs. To the north especially it contains several thin members of red shale. The strata next above are red to brown massive to slabby sandstones with some red shale, and the tints are mostly bright. The total thickness ranges from 600 to 1,000 feet. These rocks are extensively exposed on the west slope of the uplift and in the valleys of Poleo Creek, Rio Puerco, and Rio Chama, and in Cobre Basin on the east slope. Next above are massive gray sandstones, the Poleo sandstone in the Chama Basin, but in the region west of San Ysidro there is also a massive gray sandstone 150 feet thick, strongly resembling the sandstone of the Chupadera formation or the Coconino sandstone of Arizona. Here the top "Red Beds," 300 feet thick, consist of red shale with a few layers of red or red-brown sandstone closely resembling Chinle. There are extensive exposures of these strata in Canyon San Diego from Jemez Springs to a point below Canyon and also in the lower part of Canyon Guadalupe above Canyon.

The tuff of the adjoining plateau lies on an irregular plane on the "Red Beds" high in the canyon walls, as shown in Plate 39, *C*. The contact is well exposed just south of Jemez Springs, where irregularities in the old surface are conspicuous. The basal formation consists of alternating red and buff shale and limestone and a massive gray sandstone 30 feet or more thick, as on the south and east slopes of San Pedro Mountain. It grades up into alternating beds of hard sandstone, mostly brown but some red and gray, with reddish shale partings, in all about 200 feet thick. Next above is an 80 to 100 foot member of bright-red soft but massive sandstone, mostly in walls. In places under the tuff this sandstone is capped by the medial member of gray hard sandstone constituting the long dip slope of the ridge just north of Jemez pueblo. To the east this gray sandstone passes under about 500 feet of red shale of the Chinle (?) formation, which, as shown in Figure 62, is capped by the Wingate sandstone. The hard massive gray sandstone is a prominent feature in the west front of the Sierrita Mesa (pl. 43), where its thickness is about 250 feet, and it is underlain by bright-red sandstone. In the mountain slopes east of Senorito (see second section in fig. 62 and section A, fig. 67) the red beds have a basal member of massive brown sandstone 30 feet thick, which is also extensively exposed in the headwater region of the Rio de la Vaca. It is the same bed that is exposed at and northeast of Mining Mountain on the east slope of San Pedro Mountain. Next above are slabby brown sandstone and red shale grading up into a rather bright-red massive sandstone, 150 feet or more thick, which is a conspicuous member throughout this part of New Mexico. It is overlain by the Poleo sandstone, about 200 feet thick, which constitutes Eureka Mesa and the cuestas southeast of Senorito and is extensively exposed in the canyon just above Senorito. This sandstone is gray, hard, and mostly in massive beds and it carries copper ore in the basal part. It is overlain by 600 feet or possibly more of soft red shale (Chinle formation), as in the Chama and Jemez regions, extending to the base of the Wingate sandstone. For some distance along the west slope this shale carries a conspicuous sandstone member near its base.

South of Gallina the Poleo sandstone is about 100 feet thick, and having considerable dip it gives rise to a ridge of moderate prominence through which Gallina Creek has cut a canyon 1½ miles south of the village. Below the sandstone is 150 feet of softer sandstone of red color underlain by red shale and alternations of red shale and brown to gray sandstone which extend far up the north slope of San Pedro Mountain. The Poleo sandstone is overlain by 500 feet of red shale (Chinle formation) which contains layers of gray to brown sandstone and several thin beds of pale-greenish sandy shale. The outcrop of this shale extends through Gallina and along Capulin Mesa to the Rio Chama.

In the Chama Basin the Poleo sandstone is a hard massive sandstone of dirty buff color, which gives rise to wide plateaus and benches terminating below in cliffs and extending to slopes of the overlying red shale. This sandstone forms the west rim of the Cobre Basin, the wide plateau cut by the Rio Chama for several miles above and below the mouth of the Rio Puerco, Poleo Mesa, Capulin Mesa, and the ridges south and southeast of Gallina. Its outcrop is one of the most conspicuous topographic features in the area. In character, aspect, and relations the formation so closely resembles the sandstone of Glorieta Mesa (basal member of Chupadera formation) that it is difficult to believe that it is not the northwestern extension of that sandstone, but the evidence of fossil plants appears to indicate that it is of Triassic age. The overlying red shale, about 500 feet thick, includes some sandstone members and doubtless is Chinle. It is exposed in the slopes of Mesa Prieta, Mesa de los Viejos, and Mesa Canjilon, on the side of the Capulin Mesa anticline, and along the valleys of the Rio Chama and Gallina River in the vicinity of the junction of those streams.

The succession of these red rocks on the eastern slope of the uplift constituting San Pedro Mountain is about 1,000 feet thick. Red shale and red to brown sandstone predominate, and the Poleo sandstone, about 300 feet above the base, forms a wide bench ending in cliffs along the Rio Puerco near Coyote and El Rito and along the valley of the Rio Chama from a point above the mouth of the Rio Puerco to a point about 5 miles west of Abiquiu. The red shale and sandstone below this Poleo sandstone extending down to the limestone of the Magdalena group probably represent the Abo sandstone; and if so, the Chupadera and Moenkopi are not represented. In places it lies directly on granite. In this region the Abo has yielded many bones of Permian saurians, notably at the old Baldwin bone quarry, 3 miles west of Coyote, and Cope, Williston, and Case[97] have collected also at other places in the general vicinity. Remains of saurians of Triassic age have also been found in the over-lying red shale (Chinle).

The following section of these Triassic and Permian strata was measured by Williston and Case on Poleo Creek a mile above its mouth:

Section on Poleo Creek about 2 miles west of Coyote

	Feet
Upper Triassic: Gray sandstones, mostly even grained, with pebbly conglomerates and shales below; phytosaurs	30
Age undetermined: Softer gray sandstones, weathering into sand	30
Upper Triassic (?): Sandy clay, with beds of thin black shale; plant remains, fossil wood	40
Lower Triassic (?):	
Sandy clay, black and green	12
Purplish sandy clay	6
Coarse yellow sandstone	33
Loose gray sand	6
Green and purplish sandstones	3
Gray and purplish sandstones	12
Hard clay, variegated and jointed; cliffs	3
Purplish sandstones and red clay	30
Loose white sand with beds of red clay	40
First red nodular layer	6
Soft fine-grained light-red sandstones, cross-bedded, forming tops of pyramids and cliffs	6
Soft fine-grained light-red sandstones, cross-bedded, with lighter bands of pebbles	3
Second red nodular layer, with clay	3
Red clay	2
Coarse cross-bedded sandstones	6
Third red nodular layer	6
Red cross-bedded sandstones	12
Dark-red and green clay	3
Coarse red and green sandstones	17
Hard red sandstones, cliffs	3
Red sandstone and clay with thin band of harder sandstone	18
Hard red coarse sandstone	3
Red clay	35
Red sandstone; bluffs	23

[97] Williston, S. W., and Case, E. C., The Permo-Carboniferous of northern New Mexico: Jour. Geology, vol. 20, pp. 1-12, 1912; Carnegie Inst. Washington Pub. 181, pp. 1-6, 1913.

Permian:	Feet
Red sandstone with thin seams of clay; reptile bones	18
Red clay with thin nodular layers	55
Dark-red coarse sandstones; cliffs; fossiliferous	6
Red sandy clay	35
Dark-red coarse sandstone, jointed	18
Red clay, even texture, vertical rain erosion	50
Dark-red clay	8
Red shaly clay	17
Heavy gray sandstones on red sandstones and clays	25
	623

The position of the boundary between Triassic and Permian in this section is uncertain. The beds doubtless extend down to the creek level, but the position of the bench-making stratum of sandstone is not stated; presumably it is in the middle of this section and lies in the lower part of the "Lower Triassic." A more extended section of the same general locality given by Huene,[98] who was with the Williston-Case party, is presented in columnar form in Figure 65. In this column the bed of hard plateau-making sandstone is indicated as No. 9, 50 feet thick. It is stated that in the shale just below are phytosaur bones which are of Triassic age. The division line between Triassic and Permian is placed at the top of No. 20, as the bones of Permian animals were found not far below. The member that yielded abundant remains of Permian animals at Baldwin's quarry is near the base of the section.

Williston [99] has given a list of the bones of animals collected by David Baldwin for O. C. Marsh in 1877–1880 and now in the Yale Museum. The locality is about 2 miles west of Coyote. Williston states that the strata are in the lower part of the "Red Beds" and that the matrix was red, white, and reddish-brown sandstone and red and black clay. Bones were later collected by Baldwin for E. D. Cope, and these have been described by Case. The statement of Williston regarding these bones is as follows:

In the examination of these Permian fossils preserved in the Yale Museum I have distinguished with more or less assurance at least ten genera of amphibians and reptiles; I found no trace whatever of fish remains. These genera are *Nothodon* Marsh, indistinguishable from *Diadectes* Cope, published ten days earlier; *Sphenacodon* Marsh, the type of which is indistinguishable from *Dimetrodon* Cope, published five days later; *Ophiacodon* Marsh, closely allied to the genus which Case has called *Theropleura* Cope on somewhat questionable evidence; *Eryops* Cope, a species of which was described by Marsh as *Ophiacodon grandis; Clepsydrops* Cope, represented by very characteristic limb bones; "*Dimetrodon*" *navajoicus* Case, not a true *Dimetrodon*, but a short-spined pelycosaur, probably belonging to a new genus; *Dimetrodon* Cope, represented by

[98] Huene, Friedrich von, Kurze Mitteilung ueber Perm, Trias und Jura in New Mexico: Neues Jahrb. Beilage-Band, vol. 32, pp. 730–739, 1911.

[99] Williston, S. W., A new family of reptiles from the Permian of New Mexico: Am. Jour. Sci., 4th ser., vol. 31, pp. 379–380, 1911.

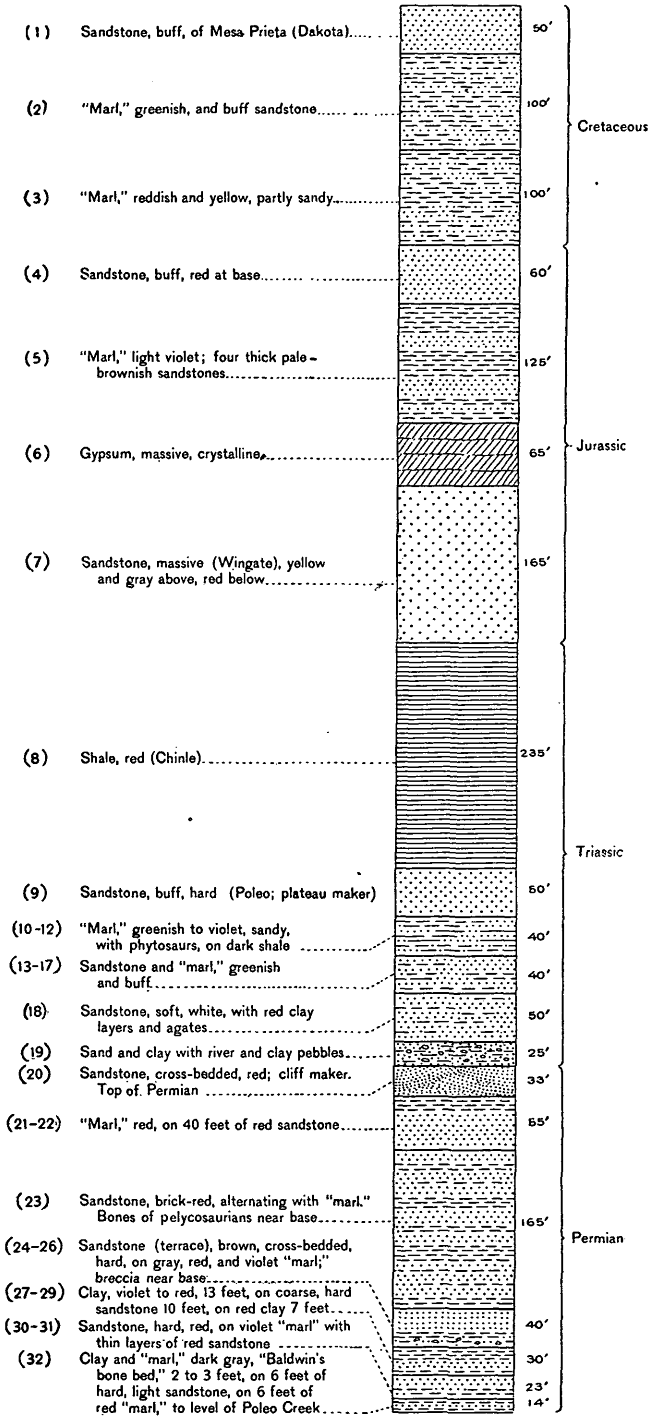


FIGURE 65.—Columnar section of strata in south face of Mesa Prieta, west and northwest of Coyote. By F. von Huene

very characteristic specimens either closely allied to or identical with species from Texas; "*Ctenosaurus*" *rugosus* Case, which is not a real *Ctenosaurus* von Huene from the Trias of Europe but a new genus which I shall describe and figure later as *Platyhistrix* gen. nov.; a pelycosaurian reptile with long, flattened spines, probably new; one or two other reptiles which I can not at present determine; *Aspidosaurus*, represented by a new species which I shall describe as *novamexicanus;* and the genus *Limnoscelis* herein described. In addition, Case has named the genera *Elcabrosaurus* (melius *Elcobrosaurus*) and *Diasparactus* from vertebrae in the Cope collection.

In this examination I was especially struck by the absence of forms characteristic of the Upper or Clear Forks division of the Texas Permian, such as the Pariotichidae, and especially *Labidosaurus*, *Diplocaulus*, etc. *Diplocaulus* may not be a characteristic guide fossil, because of its occurrence in the Illinois beds that are probably lower than the Wichita division, but the Pariotichidae are reliable. Not only is there an absence of forms characteristic of the Clear Fork division, but forms such as *Diadectes* and *Clepsydrops* have never been found in Texas in the upper beds. The evidence thus seems to indicate, almost conclusively, that the New Mexico beds are the stratigraphical equivalent of the lower or Wichita division of the Texas beds. The presence of certain forms, like those of *Dimetrodon*, either closely allied to or identical with Texas species, indicates a

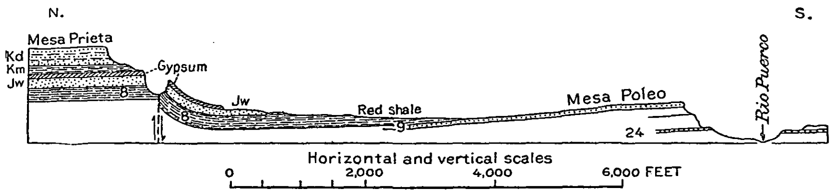


FIGURE 66.—Section from Mesa Prieta across Mesa Poleo west of Coyote. After F. von Huene. Kd, Dakota sandstone; Km, Morrison formation; Jw, Wingate sandstone; 8, 9, 24, Triassic and Permian beds shown in Figure 65.

faunistic relationship between the New Mexico and Texas faunas. On the other hand, the majority of the New Mexico genera, and perhaps all the species, will be found to be distinct from those of Texas, indicating either interrupted communication between the two not very widely separated regions during these Permian times or different environmental conditions. The latter conclusion seems the more probable one, since those forms most nearly allied are more chiefly from the red clays and red sandstones quite like those of the Texas deposits, while most of the unlike forms come from sandstones or clays unlike anything in Texas. Furthermore, the entire absence of concretionary material, pebbly sandstones, and apparently of all fish remains may also indicate different environmental conditions. Remains of sharks and dipnoans are rather abundant in Texas deposits, and while they may not be absolutely characteristic of marine or brackish waters, they probably are. Of interest is the fact that there is not a single fragment in the New Mexico collections that is even suggestive of *Naosaurus*, perhaps the most widely distributed and at the same time fragmentary and tantalizing of Texas fossils.

A full discussion of the Yale collection of New Mexico Permian fossils would be beyond the limits of a single magazine article and will be given elsewhere, with figures of some of the more characteristic specimens and of Marsh's types. I restrict myself here to a description of a remarkable new family of reptiles [Limnoscelidae], coming from the very base of the deposits in the vicinity of El Cobre.

Newberry[1] refers to a 450-foot succession of strata at the old copper mine 9 miles north of Abiquiu capped by 150 feet of heavily bedded coarse yellow sandstone which constitutes the western rim of the Cobre Basin. He climbed up over the red sandstone and marl and entered very old openings on the southwest side of the basin. The rock is coarse, in part conglomeratic, and the copper ore is distributed through a layer 4 or 5 feet thick, in part replacing trunks of trees and fragments of wood. The following plants were found in the shale roof: *Otozamites macombii*, *Zamites occidentalis*, branches of the conifers *Brachyphyllum?* and *Pachyphyllum?*, and a cone of *Pachyphyllum?*. Newberry stated that the *Otozamites macombii* also occur in Triassic strata at Los Bronces, Sonora, with *Pecopteris stutgardtensis*, *Taeniopteris magnifolia*, and other well-known plants such as occur in the Triassic of Virginia, North Carolina, and Europe. The idea of Newberry that "the Lower Cretaceous sandstones immediately overlie the plant bed of the Cobre" was an error, for, as shown in the section in Figure 69 there intervene the upper red shales (Chinle? formation), the Wingate sandstone, and the Todilto limestone with its gypsum member at the top.

In 1886 a small collection of fossils was obtained here by J. W. Powell, and in 1889 F. H. Knowlton[2] obtained additional material at the old mine openings and also at a lower horizon in the basin. The upper fossiliferous bed, the one at the mine, was found to be an 8-inch bed of fragile, highly carbonaceous shale in thin layers containing a large amount of vegetal material. It lies on the copper-bearing conglomerate, which is at the base of the heavily bedded light-yellowish coarse sandstone. Next below are 200 feet of sandstone and marl. The plants obtained by Knowlton and Powell were described by Fontaine[2] as *Zamites powelli*, *Cheirolepis munsteri*, *Zamites occidentalis?*, *Palissya braunii?*, *Palissya* cone?, *Cycadites?*, and *Ctenophyllum?*. Fontaine states: "These fossils * * * are not numerous enough or sufficiently well preserved to enable one to determine with positiveness the age of the strata which contain them. They, however, indicate that the beds are not older than Rhaetic." Remains of plants identical with the *Zamites powelli* of Abiquiu have been recently described by Berry.[3] They came from the Shinarump conglomerate of southern Utah.

Knowlton also collected fragments of silicified wood from the sandstone 10 feet above the plant-bearing shale at the old mine and identified it as *Araucarioxylon arizonicum*, a form of frequent occurrence in the Shinarump conglomerate and Chinle formation of eastern Ari-

[1] Newberry, J. S., in Macomb, J. N., Report of the exploring expedition from Santa Fe, N. Mex., * * * in 1859, p. 68, 1876.

[2] Fontaine, W. M., and Knowlton, F. H., Notes on Triassic plants from New Mexico: U. S. Nat. Mus. Proc., vol. 13, pp. 281–285, 1890.

[3] Berry, E. W., Cycads in the Shinarump conglomerate of southern Utah: Washington Acad. Sci. Jour., vol. 17, pp. 303–307, 1927.

zona. In a personal letter Knowlton made the statement that according to the best evidence the "Abiquiu plants are undoubtedly Mesozoic, or, as Fontaine has said, they are not older than Rhaetic."

Knowlton also collected plant remains at a copper prospect opened in 1889 in the floor of the northwestern part of the basin in a white, very coarse grained sandstone at a horizon several hundred feet lower than that at the old mine. The ore is mostly in stems with which occur casts of many large and small stems of *Equisetum.* These were reported on by Fontaine, who suggests that one might be called *E. knowltoni* and another probable *Equisetum E. abiquiuense* and compares them with species from the Richmond coal basin of Virginia. In a personal letter Knowlton stated that "*Equisetum* or *Equisetum*-like plants are found in both Permian and Triassic rocks, and I suppose it is possible that the specimens in question might belong with the Permian." This flora is of a totally different character from that at the old mine and not sufficiently distinct to preclude the probability that these lower beds are Permian in age and apparently Abo.

Williston and Case [4] describe the exposure in El Cobre Canyon as an eroded, more or less faulted dome with rim of hard massive sandstone "of basal Upper Triassic age." It is about 2½ miles long, with walls 800 feet high on the northwest side, where many Permian beds are exposed, mostly dipping west at low angles. The lowest beds are dark-brown sandstones, in part conglomeratic, grading up into more massive sandstones that weather more or less whitish. Bones of Permian vertebrates were found and also in a fragment of rock apparently from lower beds a cast identified by Charles Schuchert as *Spirifer rockymontanus.* The upper beds yielded bones of Upper Triassic vertebrates, and Cope also collected bones of Triassic age at this locality many years ago. The strata in El Cobre Canyon are as follows, according to Williston and Case:

Section of rocks in El Cobre Canyon, 9 miles northwest of Abiquiu

	Feet
Upper Triassic:	
Sandstone and conglomerates, yellowish; bones	75
Clays, purplish and gray; bones	40
Lower Triassic(?):	
Sandstones, purplish	20
Clays, purplish, and nodular sandstone	25
Sandstone, red	5
Clay, bright red	35
Clay, purple	12
Sandstones, bright red	22
Coarse sandstone, purplish	12
Clay, bright red, with greenish nodules and purplish bands	100

[4] Williston, S. W., and Case, E. C., The Permo-Carboniferous of northern New Mexico: Jour. Geology, vol. 20, pp. 1-6, 1912. See also Carnegie Inst. Washington Pub. 181, pp. 1-3, 1913.

	Feet
Lower Triassic(?)—Continued.	
Hard sandstone, coarse, purplish	8
Clay and sandstone, bright red	65
Hard sandstone, red and purplish	6
Sandy clay, bright red, with purplish streaks	90
Clay, purplish and dark brown	22
Hard sandstone and clay, both red	30
Hard sandstone, purplish	35
Clay, red	7
Sandstone, purplish	3
Clay, red	22
Permo-Carboniferous: Sandstone and clay, red-brown; bones.	
	634

WINGATE SANDSTONE (JURASSIC?)

The outcrop of Wingate sandstone extends along the west side and across the south end of the Nacimiento uplift to the north-south fault that cuts off all the beds a short distance southwest of the mouth of the Rio Salado. The sandstone also appears in the block 1 mile west of San Ysidro, and there is a small outcrop in the high ridge 6 miles northeast of Jemez pueblo. It is prominent in the face of Mesa Prieta, Mesa de los Viejos, and Mesa Canjilon (see pl. 36, *A*) and in the monoclinal ridge of which Cerro Blanco is a part. Smaller outcrops appear southeast of Coyote, along the north end of the Cerro Pedernal ridge, north of Canones, at the south margin of the Cobre Basin, and in the west side of El Rito Canyon southeast of Canjilon. The rock is a fine-grained massive sandstone with some cross-bedding, only moderately hard. Its color is red in greater part, but the upper portion is white, grading into buff or pale yellow at the top. The outcrop is generally marked by conspicuous cliffs, such as those on the south side of the Rio Salado Valley 5 miles southwest of Sierrita Mesa, and it is everywhere capped by the Todilto formation, with its thick gypsum member at the top. The sandstone is sharply separated at the base from the underlying red shale (Chinle?), and there is some slight channeling at the contact, which represents a hiatus of considerable length. The thickness of the Wingate is about 100 feet through Sandoval County but increases to nearly 200 feet on the Rio Chama. According to Huene it is 165 feet on the east front of Mesa Prieta ("Mesa Alta").

TODILTO FORMATION (JURASSIC?)

The thin-bedded limestone characteristic of the Todilto, which overlies the Wingate sandstone, is continuous throughout the Jemez-Nacimiento-Chama region. It is less than 10 feet thick and in places is hidden by talus from the overlying gypsum member of the Todilto. It is well exposed on slopes of the high mesas in Chama Valley, about Gallina, west of Canyon, and at the south end of the Cobre Basin. The easternmost outcrop observed was in the west slope of El Rito

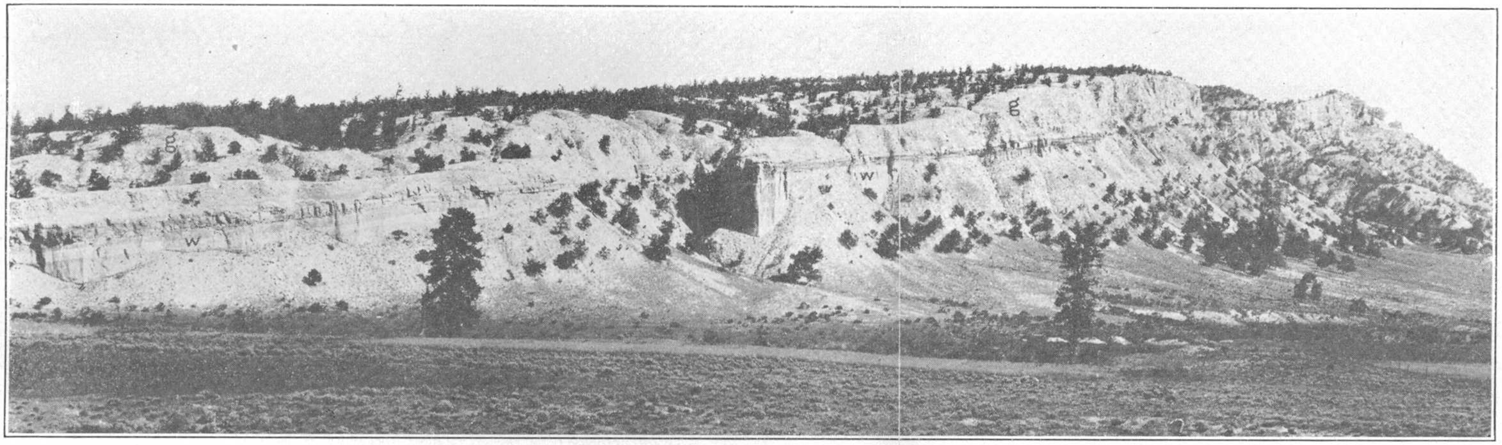
Canyon, just north of the road 10 miles southeast of Canjilon. It is only 4 feet thick on the block a mile west of San Ysidro and about the same in the vicinity of Senorito and the San Miguel mine and 4 to 12 feet on the Rio Chama, where thin sandstone layers are interbedded. No fossils were found in these beds.

The great bed of gypsum that overlies the limestone and forms the top member of the Todilto formation throughout the Nacimiento uplift and Chama Basin is the same as that exposed in San Jose Valley near Rito siding and in Galisteo Valley west of Cerrillos. The gypsum outcrop adjoins that of the Wingate sandstone, as above described, but is wider, because the gypsum caps the bluffs, making a bench, and extends down the slopes, especially in the region about the Rio Salado. The gypsum at the foot of Sierrita Mesa lies on a dropped block, as shown in Plate 39, *B*, and owing to a low arch the exposure is very wide. The gypsum member is a conspicuous feature in Cerro Blanco (pl. 38, *A*), in the Chama Valley (pls. 11, *A*, and 38, *B*), and on the south front of Mesa Canjilon, near the Rio Chama (pl. 36, *A*). The gypsum is 60 to 80 feet thick and is a continuous deposit of nearly pure white selenite, mostly massive. In places near the top there are thin partings of red shale and at the top a few thin layers of limestone. At Senorito it is about 80 feet thick. It may possibly thin out east of Canjilon. Shaler [5] noted a thickness of 100 feet at a point 3 miles southeast of Ojo del Espiritu Santo and 60 feet near the San Miguel mine. An analysis of a sample of gypsum collected by Shaler near Senorito, made by W. T. Schaller, of the United States Geological Survey, reported 97 per cent of the pure mineral with about 3 per cent of probable calcium carbonate and only 0.18 per cent of insoluble residue.

MORRISON FORMATION (CRETACEOUS?)

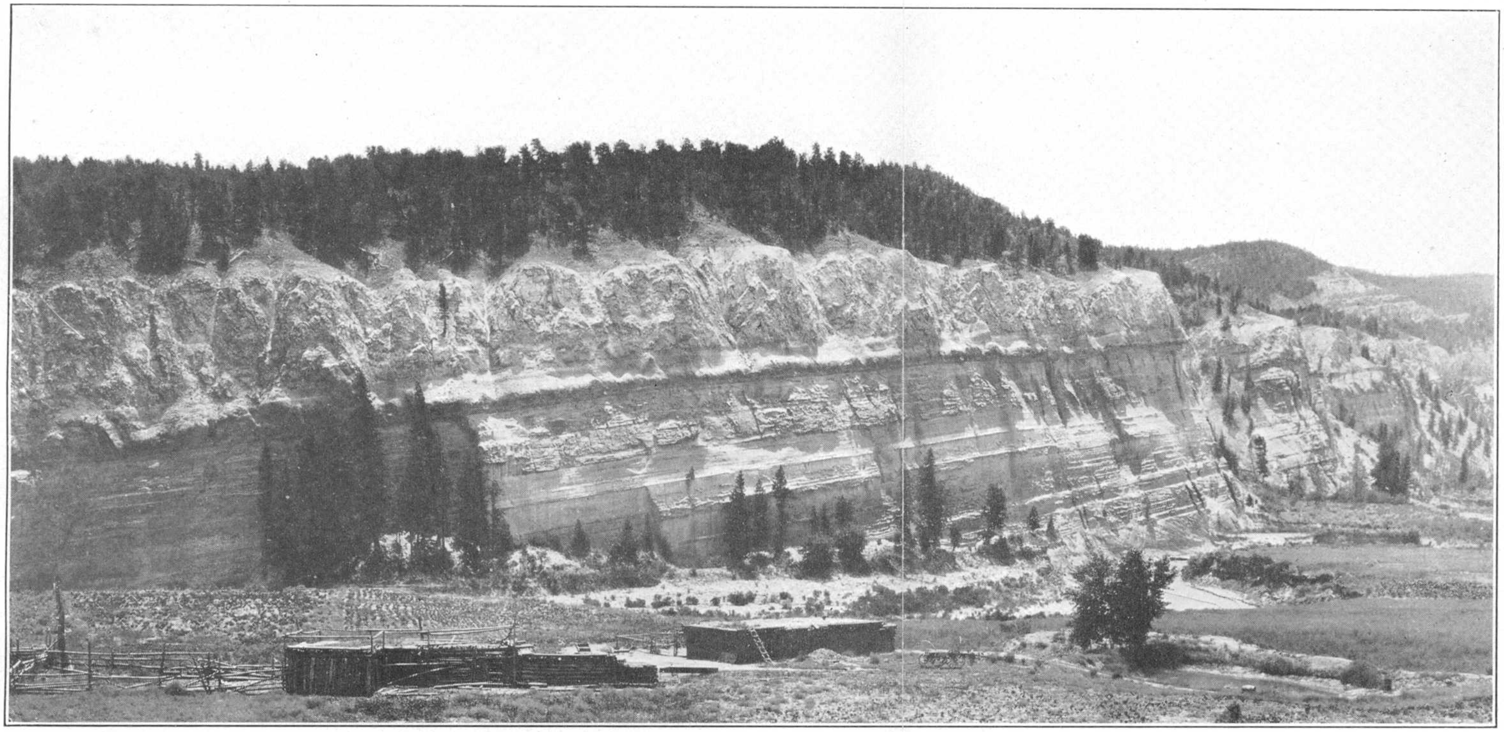
From 450 to 600 feet of beds lying between the gypsum member of the Todilto formation and the Dakota (?) sandstone undoubtedly represent the Morrison formation. In the Nacimiento region the formation presents the usual distinctive feature of light greenish-gray massive clay or shale with maroon stains and with thin buff sandstone and thin dark limy members, but in the Rio Chama region the lower half is mostly chocolate-brown soft sandstone and shale of a sort not seen elsewhere. The formation appears extensively in slopes south and west of the Rio Salado, where it has a prominent medial sandstone member, and it is well defined on the small faulted block a mile west of San Ysidro. Its outcrop extends for miles along the higher part of the mesa slopes north of the valley of the Rio Chama, in the Mesa Prieta and along the north-south monocline west of Capulin Mesa and Gallina. It is also exposed in the Cerro Pedernal ridge, southeast and east of Coyote. On the west slope of

[5] Shaler, M. K., Gypsum in northwestern New Mexico: U. S. Geol. Survey Bull. 315, p. 264, 1907.



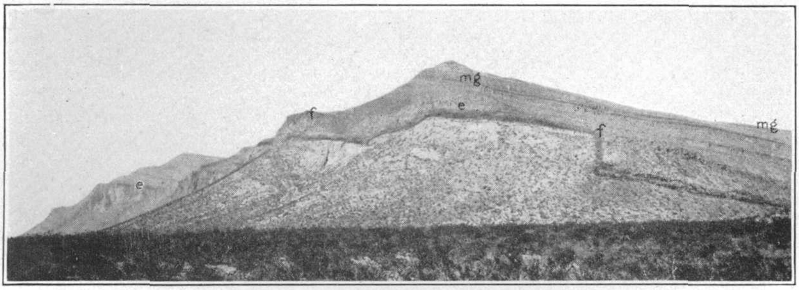
A. CERRO BLANCO, NORTH OF GALLINA

Looking north. w, Wingate sandstone; g, gypsum member of Todilto formation, forming crest



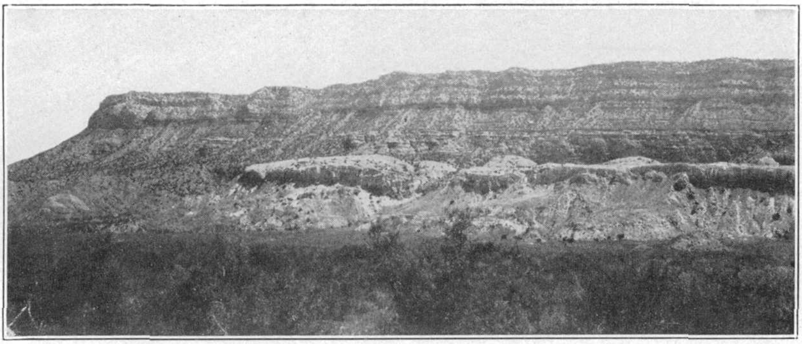
B. WINGATE SANDSTONE CAPPED BY GYPSUM MEMBER OF TODILTO FORMATION ON BANK OF GALLINA RIVER, 30 MILES NORTHWEST OF ABIQUIU

The wooded slope is Morrison shale. Dakota sandstone is at top of plateau. Looking south



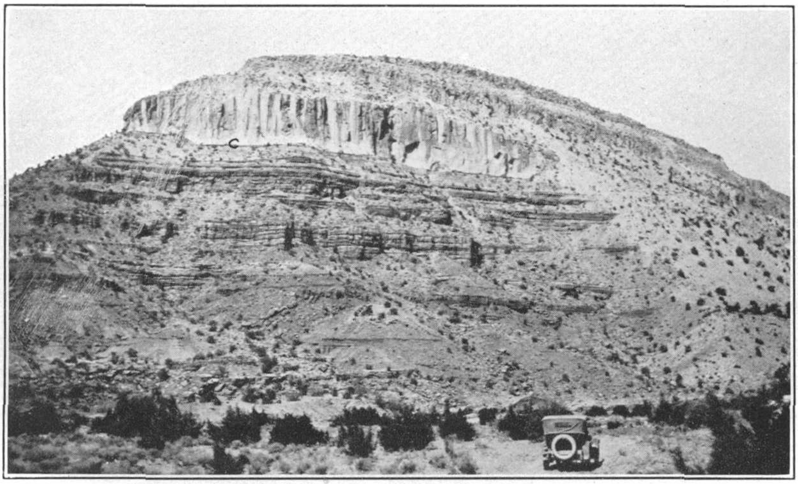
A. 3,000-FOOT ESCARPMENT ON WEST SIDE OF OSCURA MOUNTAINS, LINCOLN COUNTY

Looking north from a point in sec. 16, T. 9 S., R. 6 E. Granite capped at e by sandstone and limestone of the Magdalena group (mg); f, faults. At extreme right of view is north end of El Paso limestone and associated early Paleozoic strata



B. WEST EDGE OF SIERRITA MESA, 6 MILES WEST OF SAN YSIDRO, SANDOVAL COUNTY

Looking east. Massive gray sandstone in middle of "Red Beds." Thick bed of gypsum (Todilto) in foreground, dropped by fault



C. WEST WALL OF CANYON SAN DIEGO 5 MILES BELOW JEMEZ SPRINGS

Looking west. Red Abo sandstone overlain at c by rhyolite tuff

Cerro Blanco the formation is 300 feet thick and consists mainly of pale-greenish, brownish-gray, white, or maroon massive shale or clay with a few thin buff sandstone layers and several thin beds of dark limestone. Renick [5a] measured 710 feet near Los Bancos, comprising a lower member 180 feet thick, composed of maroon soft sandy shale with thin beds of white and gray sandstone, and an upper member composed of alternations of soft sandstone and shale of green, buff, lavender, white, tan, and maroon tints.

DAKOTA (?) SANDSTONE (UPPER CRETACEOUS)

The high mesas adjoining the Chama Valley from Mesa Canjilon westward consist of a thick body of hard buff sandstone that is believed to represent the Dakota sandstone. It lies on the Morrison shale, with abrupt change of material, for the basal beds are conglomeratic in most places, but no great channeling is apparent, and there is no noticeable discordance in attitude between the two formations. It is possible that the sandstone here called Dakota includes in its lower part a representative of the Purgatoire formation (Lower Cretaceous) of the east slope of the Rocky Mountains, but as there is no evidence of the presence of the Purgatoire the sandstone is all mapped as Dakota (?). (See pl. 37.) There is also a possibility that the sandstone may be younger than the true Dakota. A steep westward-dipping monocline of the sandstone extends from Gallina Peak southward past Gallina and along the west side of San Pedro and Nacimiento Mountains, as shown in Plate 39, *A*. In the vicinity of the Rio Salado there are extensive outcrops of a massive brown sandstone 40 to 80 feet thick. It is underlain by an alternation of light-colored massive shale or clay and sandstone, 200 feet thick in places, and 60 to 100 feet of gray to grayish-buff massive sandstone, which appears to be Morrison but may be of later age.

In the outcrop west of Gallina the formation comprises a lower member of hard massive cross-bedded sandstone about 120 feet thick, a middle member of 20 feet or more of dark shale and thin-bedded sandstone, and an upper member of 50 feet of massive hard sandstone that constitutes the outer slope of a "hogback" ridge. In Canjilon Canyon the upper sandstone of the Dakota (?) formation is 70 to 80 feet thick and is separated from the thicker basal member by about 75 feet of dark shale with scattered sandstone layers.

LATER CRETACEOUS FORMATIONS

The Dakota (?) sandstone passes under a thick body of shale to the west, and a moderately thick mass of shale caps the sandstone in the region about Canjilon and northward. The shale in the Canjilon region appears to include a representative of the Greenhorn

[5a] Renick, B. C., The geology and artesian-water prospects in the San Jose-Rio Puerco Valley in Sandoval County, N. Mex.: New Mexico State Engineer Seventh Bienn. Rept., pp. 61-75, 1926.

limestone, for abundant specimens of *Inoceramus labiatus* were found a few hundred feet above the base, and higher beds show features characteristic of the Carlile shale, but no attempt has been made to map these subdivisions.

In the Gallina Valley west and northwest of Gallina these later Cretaceous deposits include the Mancos, Mesaverde, and Lewis formations and still younger deposits of Montana age. By comparison with Cretaceous formations recognized to the east, the lower beds consist of about 100 feet of dark shale of Graneros character, overlain by 30 feet of limestone of typical Greenhorn character, consisting of thin beds of limestone interlaminated with dark shale and carrying many *Inoceramus labiatus*. Above the limestone is several hundred feet of shale of the character of the Carlile shale, with large lens-shaped concretions, and also an upper bed of thin sandstone with many fossils. Next above are shales of Niobrara and Pierre age extending to the base of the Mesaverde sandstone.

Southwest of Canjilon the limestone that appears to represent the Greenhorn limestone is 20 feet thick and lies on about 100 feet of dark shale which separates it from the Dakota (?) sandstone. Next above is shale with large concretions, fossiliferous layers, and a persistent thin bed of hard sandstone; these seem to represent the Carlile shale. Some distance above is shale which weathers to a light-buff tint strongly suggestive of the Niobrara. It contains thin beds of buff sandstone.

The lower portion of the Mancos shale south of the Rio Salado presents the subdivisions that are characteristic elsewhere. At the base is 350 feet of dark shale with some sandstone members in the middle part; next above is light-colored calcareous shale with *Inoceramus labiatus*, undoubtedly representing the Greenhorn limestone, overlain by several hundred feet of shale with large oval concretions regarded as representing the Carlile shale.

Gardner [6] has described the coal-bearing beds of the Mesaverde and associated Cretaceous formations and also the overlapping early Tertiary sediments. He makes a very brief reference to the Dakota sandstone, which is conformably overlain by Mancos shale. The Mancos consists of 500 to 1,000 feet of shale, but at a point 10 miles north of Gallina a 30-foot sandstone bed is included about 275 feet below the top, and this bed continues far to the south. In the vicinity of San Miguel the upper part of the formation for 300 feet is argillaceous sandstone and sandy shale, grading into the Mesaverde formation. The Mesaverde, 200 to 900 feet thick, consists mainly of sandstone forming a prominent hogback or series of ridges. Coal beds occur at varying intervals between a prominent basal sandstone and a capping sandstone. The most persistent coal bed lies just below the top sandstone. The Lewis shale, 1,000 to 2,000

[6] Gardner, J. H., The coal field between Gallina and Raton Spring, N. Mex.: U. S. Geol. Survey Bull. 341, pp. 338–340, 1909.

feet thick, and the "Laramie" formation, 900 feet thick, complete the succession. Detailed sections of the coal measures are given in Gardner's report. Northeast of Cuba and at points three-quarters of a mile west of Senorito and 1 mile southwest of Senorito the beds are estimated to dip 70° E.

Gardner[7] has given further details regarding the coal measures from Cuba to La Ventana and westward and has set forth the age and relations of the early Tertiary deposits that overlap the coal measures in the region north of Cuba.[8]

STRUCTURAL DETAILS

The general structure of the Nacimiento uplift is that of a long anticline, faulted and considerably overthrust along its west slope.[8a] There are many minor crenulations and faults, and in the extension of the area eastward into the Chama Basin there are several subordinate anticlines and synclines.

NACIMIENTO MOUNTAINS

Some facts regarding the relations along the west slope of the uplift have been given by Newberry, Shaler, Gardner, Renick,[8b] and Schrader. Newberry[9] skirted the range from Cuba southward and crossed to Jemez. He noted the anticlinal structure, with steep dips on the west slope, the granite core, and the general succession of strata, including the cupriferous sandstone in the "Red Beds."

Shaler[10] described some features of the gypsum member of the Todilto formation in the outcrop extending from Gallina to the Rio Salado. It is hidden by overlapping early Tertiary sediments for some distance northeast of Cuba and at several localities between Gallina and Senorito. Throughout this outcrop zone the dips are to the west, mostly at very steep angles. At Senorito the relations and succession are as shown in section A, Figure 67. The gypsum, about 80 feet thick, lies on 4 feet of platy limestone of the Todilto formation, and the Wingate sandstone, although not well exposed, is the usual soft massive rock, white above and red below. The Chinle red shale is 400 to 600 feet thick. The Poleo sandstone of Eureka Mesa is about 200 feet thick and lies on bright-red sandstone believed to be Abo, the Chupadera and Moenkopi strata being absent. The supposed Abo beds, about 300 feet thick, are moderately hard and of bright-red color in the upper part and softer and more slabby

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[7] Gardner, J. H., The coal field between San Mateo and Cuba, N. Mex.: U. S. Geol. Survey Bull. 381, pp. 169–180, 1910.

[8] Gardner, J. H., The Puerco and Torrejon formations of the Nacimiento group: Jour. Geology, vol. 18, pp. 702–741, 1910.

[8a] This overthrust was discovered by B. C. Renick (op. cit., pp. 72–73).

[8b] Renick, B. C., op. cit., pp. 69–73.

[9] Newberry, J. S., in Macomb, J. N., Report of the exploring expedition from Santa Fe, N. Mex., to the junction of Grand and Green Rivers * * * in 1859, pp. 114 et seq., 1876.

[10] Shaler, M. K., Gypsum in northwestern New Mexico: U. S. Geol. Survey Bull. 315, pp. 260–265, 1907.

below, with a basal member of hard coarse massive red-brown sandstone which is underlain by limestone to the east but appears to overlap the granite in the center of the uplift. Between San Pablo Creek and the San Miguel gap the structural relations are somewhat complex owing to offsetting by the fault. At one place in this vicinity the Todilto limestone is in contact with the granite, but not far to the south the underlying beds to the Poleo sandstone come up, as shown in section C. At the San Miguel mine this sandstone is a conspicuous feature and carries the copper deposits. Just west of the mine is about 600 feet of red shale, presumably Chinle. The Wingate sandstone, 80 feet thick, white and buff near the top and red below; the Todilto limestone, 5 feet thick; and the gypsum, 80 feet thick, are conspicuous features on the east slope of the hogback ridge. The Dakota sandstone, forming the crest and west slope of the ridge west of the mine, is 175 feet thick.

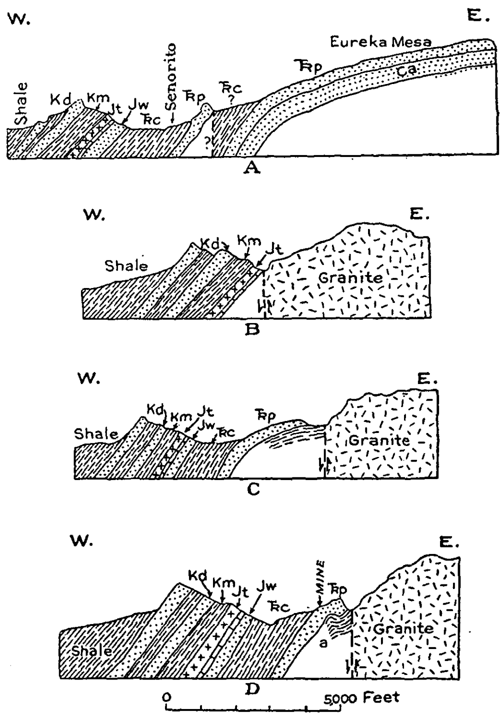


FIGURE 67.—Sketch sections on west slope of Nacimiento uplift in northern part of Sandoval County. A, Through Senorito; B, in gap of San Pablo Creek; C, in San Miguel Arroyo; D, near San Miguel mine. Kd, Dakota (?) sandstone; Km, Morrison formation; Jt, gypsum and limestone of Todilto formation; Jw, Wingate sandstone; Ꞧc, Chinle shale; Ꞧp, Poleo sandstone; Ca, red sandstone (probably Abo)

Shaler states that at the head of a tributary of the Rio Salado about 3 miles southeast of Ojo del Espiritu Santo the dip of the strata on the mountain slopes is 70°, but the steepness diminishes to the west. The gypsum bed, 100 feet thick, white and massive, is overlain by shale (Morrison) and sandstone (Dakota?). Several hundred feet of red shale and red sandstone, only partly exposed, extend to the granite. These beds appear to be the Abo formation or the lower Chupadera, but some Triassic strata may be included.

Schrader [11] has described some features of the rocks on the west slope of the Nacimiento Mountains in connection with the copper

[11] Schrader, F. C., Copper deposits of the Sierra Nacimiento: U. S. Geol. Survey Prof. Paper 68, pp. 141-150, 1910.

deposits, which have been worked at various times. He states that the pre-Cambrian rocks consist mainly of massive red granite but include gneiss, schist, and other metamorphic rocks. These are cut by a fine-grained red granitic rock which was intruded after the shearing of the other crystalline rocks. Next above are limestone

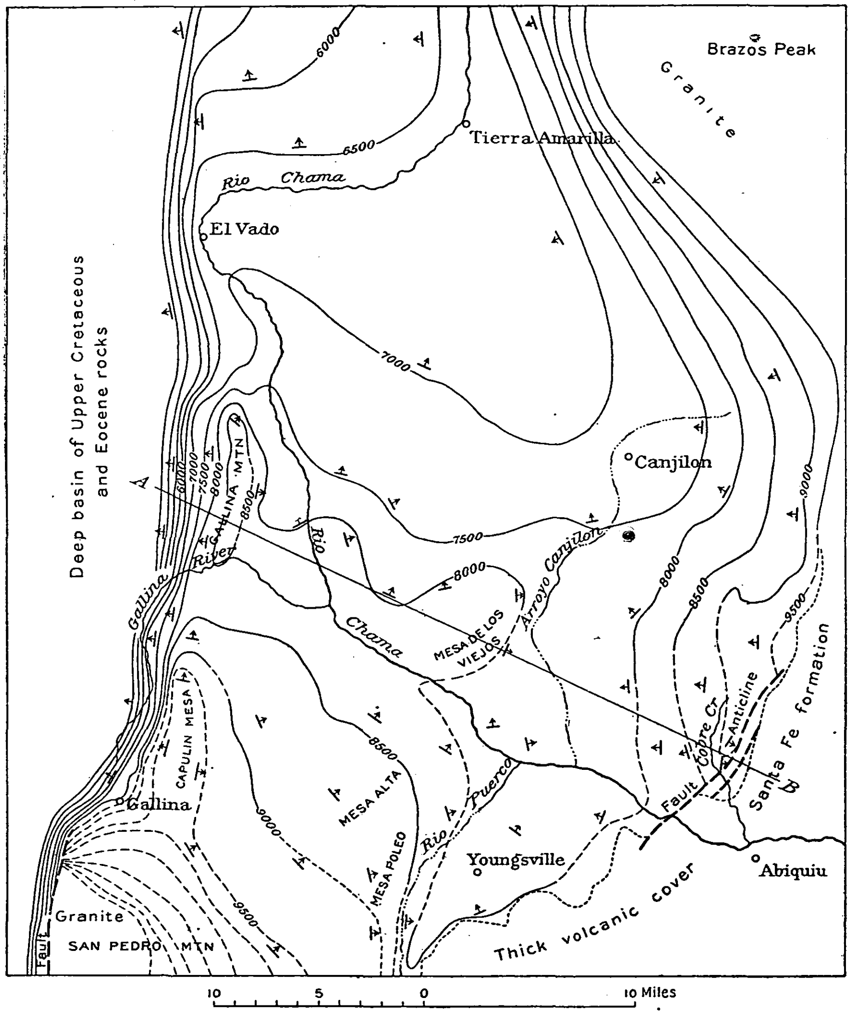


FIGURE 68.—Map showing structure of part of Rio Arriba County. Represented by contour lines at the top of the Dakota (?) sandstone. Broken lines indicate areas from which the Dakota (?) sandstone has been eroded. A–B, Line of upper cross section in Figure 69

and grit of Pennsylvanian age and several hundred feet of sandstone, mostly red. The sandstone is overlain by about 100 feet of reddish-white sandstone and conglomerate (Triassic?), which contains most of the copper ore and grades up into a thick series of red shale. Much of the copper ore has been formed by the replacement of

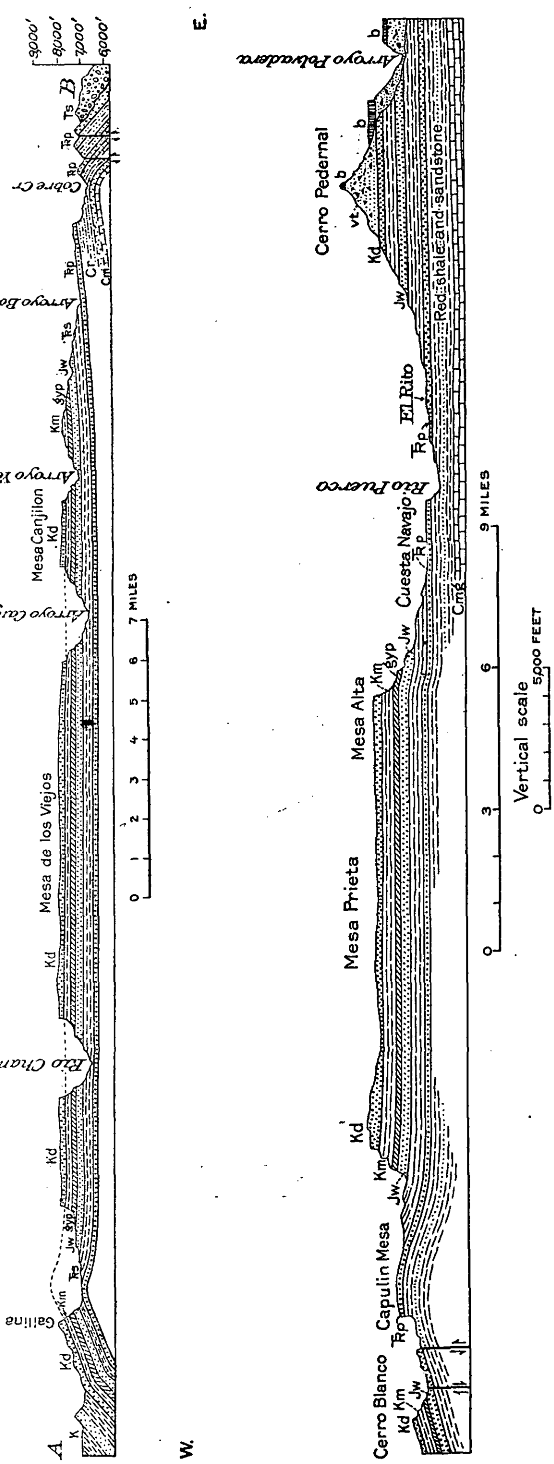


FIGURE 69.—Sections across Chama Basin. Upper section, from Gallina Mountain to Arroyo Cobre north of Abiquiu; Lower section, from Cerro Blanco, west of Gallina, through Cerro Pedernal. Kd, Dakota (?) sandstone; Km, Morrison formation; gyp, gypsum (Todilto); Jw, Wingate sandstone; Ꞧp, Poleo sandstone; Cmg, Magdalena group; vt, volcanic tuff; b, basalt

trunks, stems, and barks of trees. Some of the trees replaced by ore are 60 feet long and 2½ feet in diameter. At the Eureka mine, 3 miles northeast of Senorito, the ore is in sandstone and conglomerate not far above the granite. At the San Miguel mine several hundred feet of limestone underlies the ore-bearing sandstone. In the Jarossa district, on the east slope of San Pedro Mountain, the ore occurs in arkose, from some layers of which Schrader obtained fossil plants that were regarded by F. H. Knowlton as Triassic.

SAN PEDRO MOUNTAIN

San Pedro Mountain is a large flat-topped dome due to local widening of the northern prolongation of the Nacimiento uplift. Some of the central part of the mountain was not examined. Along the west side the strata from Upper Cretaceous to Pennsylvanian dip steeply west. Southwest of Gallina the strike changes to east, and the outcrop of the "Red Beds" curves around the north end of the dome. This feature is well exhibited in the west-east ridge south of Gallina, in which the Poleo sandstone of the "Red Beds" dips about 15° N. In the eastern part of R. 1 E. the strike changes again to south and the strata on the east slope of the uplift dip east and northeast at various low angles. The principal feature is a long dip slope of the sandstone of the lower part of the "Red Beds," onto which toward the south the tuffs of Tertiary age overlap. A section across San Pedro Mountain is shown in A, Figure 62.

CHAMA BASIN

The principal structural features of the Chama Basin are shown in Figures 68 and 69. Along the western margin of the area is the northern extension of the Nacimiento-San Pedro uplift, which is well marked in Capulin Mesa and has locally increased prominence in Gallina Peak. East of this arch is a broad, shallow basin marked by Mesa Prieta, Mesa de los Viejos, and Mesa Canjilon. In this basin the beds are horizontal or nearly so for broad areas, but they rise rapidly in the prominent anticline of Arroyo Cobre, in which the lower beds of the Abo sandstone are exposed as given on page 166. Faulting causes considerable complexity in outcrops of Abo, Poleo, Chinle, Todilto, and Wingate strata and overlapping Tertiary or later rocks in this anticline.

The northern extension of the Nacimiento uplift bears two prominent anticlines or domes in Capulin Mesa and the ridge culminating in Gallina Peak. The configuration of these features is shown in Figure 68, and details of the Capulin Mesa anticline are represented in Figure 70.

A test hole for petroleum was bored in the dome on Capulin Mesa and was abandoned at a depth of 3,355 feet early in 1926. It began in lower beds of the Chinle shale and had the following record:

Record of boring in SE. ¼ SW. ¼ sec. 25, T. 24 N., R. 1 E., 5 miles northeast of Gallina

	Feet
Shale, red	0–20
Sandstone, gray and yellow	20–170
Shale and limestone, blue [12]	170–245
Sandstone, gray	245–260
Sandstone and sandy shale, red	260–1, 320
Sandstone	1, 320–1, 390
Shale, chocolate-colored	1, 390–1, 450
Sandstone	1, 450–1, 490
Shale, limy, brown	1, 490–1, 550
Sandstone on sandy shale, brown	1, 550–1, 660
Red sandstone	1, 660–1, 700
Shale, brown, with sandstone at 1,790–1,873 feet	1, 700–1, 925
Sandstone, white above, brown in lower part	1, 925–2, 045
Sandy shale and sand	2, 045–2, 177
Shale, brown	2, 177–2, 328
Limestone; "top of Magdalena?"	2, 328–2, 332
Sandstone, white or gray; 4 feet of blue shale at 2,361 feet	2, 332–2, 375
Shale, brown, blue near bottom	2, 375–2, 417
Sandstone, red and white	2, 417–2, 425
Shale, brown	2, 425–2, 436
Sandstone on shale, gray	2, 436–2, 495
Sandstone, gray and red, with 8 feet of brown sandy shale in middle	2, 495–2, 568
Shale, brown	2, 568–2, 579
Sandstone, gray	2, 579–2, 615
Shale, gray, blue, and black, with 2 feet of limestone at 2,660 feet	2, 615–2, 665
Sandstone, gray	2, 665–2, 688
Shale, brown	2, 688–2, 752
Sandstone, white to gray, with some shale near the middle	2, 752–2, 817
Shale with some sandstone	2, 817–2, 860
Sandstone, gray	2, 860–2, 876
Shale, brown, broken, and sandstone	2, 876–2, 890
Sandstone, gray	2, 890–2, 905
Shale, sandy	2, 905–3, 025
Shale, blue on black, with limestone	3, 025–3, 055
Limestone, gray, with sand and blue shale in lower half	3, 055–3, 085
Shale, black, with sandstone layers	3, 085–3, 095
Sandstone, gray; blue shale in center	3, 095–3, 140
Shale, brown and blue, sandy, on 10 feet of black slate	3, 140–3, 255
Limestone	3, 255–3, 258
Sandstone, white	3, 258–3, 265
Shale, sandy, blue and black	3, 265–3, 307
Sandstone, gray	3, 307–3, 315
Shale, sandy, blue and brown	3, 315–3, 343
Limestone, sandy, blue	3, 343–3, 355

[12] Another report states that 4 feet of hard limestone was penetrated at 232 feet.

Logs of this character are usually so unreliable that it is difficult to classify the strata. It is possible that the Magdalena began with a 4-foot bed of limestone at a depth of 2,328 feet, but the underlying sandstone and shale for the next 700 feet are not distinctive of Magdalena strata in the outcrops. The beds above 2,328 feet probably represent Abo and overlying Triassic strata. Doubtless the sandstone at a depth of 20 feet is the Poleo.

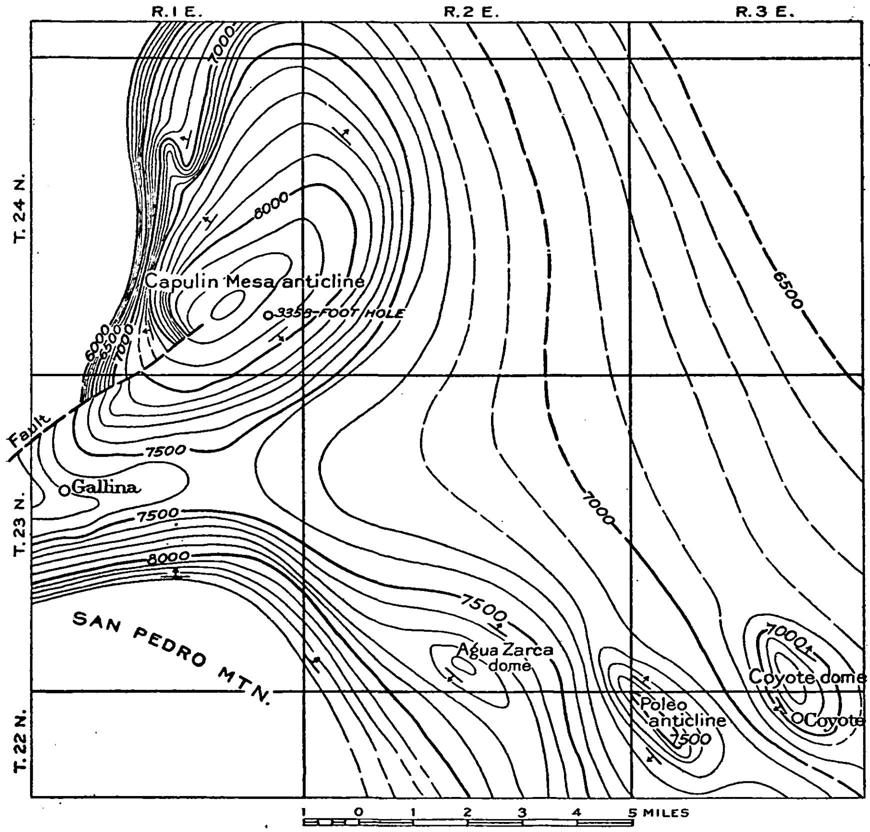


FIGURE 70.—Map showing configuration of Capulin Mesa near Gallina and small uplifts near Coyote, Rio Arriba County. The contours, with 100-foot interval, show the altitude of the top of the Poleo sandstone. From a survey by Dean Winchester in 1923

Several deep borings have been made in the wide area of Upper Cretaceous rocks in the northern part of the Chama Basin. One of these on the Martinez ranch, in T. 30 N., R. 3 E., 12 miles southwest of Chama, had the record shown in Figure 71. It is difficult to suggest any correlation of these beds unless possibly the sandstone at 225 feet is Dakota, with Morrison and Wingate below. It is reported that this hole was continued and reached granite at 2,000 feet. A hole was drilled 1,472 feet in sec. 20, T. 31 N., R. 2 E., in which the top of the

Dakota sandstone was reported at 1,393 feet, the overlying strata being Mancos. A hole in the NW. ¼ NW. ¼ sec. 13, T. 31 N., R. 1 W., is reported to have found the top of the Dakota sandstone at about 1,500 feet.

PETACA-BRAZOS REGION

The high rugged region lying between the upper valley of the Rio Chama and the western margin of the Rio Grande lava plain, in the northern part of Rio Arriba County, consists of an extensive series of ridges culminating in Brazos Peak. It is a zone of uplift in which pre-Cambrian quartzite, granite, and schist are extensively revealed, overlain by deposits of gravel and sand and sheets of volcanic rock, both of Tertiary age. The structural relations and distribution of the formations have not been determined in detail. On the west slope of the range east of Tierra Amarilla granite is faulted against Mesozoic rocks. In this vicinity the Dakota sandstone is well exposed, underlain by the Morrison formation, and these two formations are also exposed extensively in the deep valleys traversed by the railroad northeast of Chama.

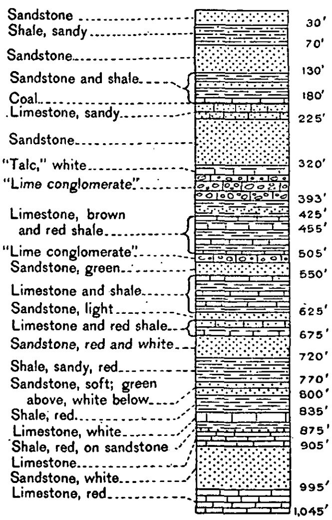


FIGURE 71.—Record of boring on ranch of J. H. Martinez, 12 miles southwest of Chama, Rio Arriba County

The pre-Cambrian rocks are revealed in the deep canyon of the Rio Brazos and in the valleys on the headwaters of Caliente River and El Rito Creek, and they also constitute knobs and ridges on the intervening divides. Graton [13] observed the rocks in the Hopewell and Bromide districts, especially at Tres Piedras and in the ridge extending past Ojo Caliente. The principal rock is gneissic granite, which in places cuts dark dioritic gneiss. There are also porphyries of various kinds. Prominent ridges north and west of Hopewell are massive gray quartzite, which also occurs in a high knob 30 miles south of Hopewell. Probably some of these older rocks underlie the gravel and lava sheet of the Rio Grande plain in the western part of Taos County, for they appear extensively in the deep canyon of the Rio Grande near Glenwoody and thence eastward, rising to the east in the high U. S. (Picuris) Mountain. It is possible, moreover, that the entire Rio Grande Valley in the western part of Taos County is excavated in these pre-Cambrian rocks.

[13] Graton, L. C., op. cit. (Prof. Paper 68), pp. 124-133.

SAN JUAN BASIN

A district of about 10,000 square miles in northwestern New Mexico is occupied by a structural basin widely rimmed by Upper Cretaceous rocks and containing in its center a large area of sand and clay of lower Eocene age up to the Wasatch formation. It is margined on the east by the Nacimiento uplift and the northern continuation of that uplift, in which the dips are mostly steep. On the southern and southwestern margins are the uplifts of the Mesa Lucero and Zuni Mountains, and on the west the strata rise on the east flank of the Defiance uplift, which reaches its culmination in Arizona. In the wide basin area the strata have very low dips, mostly 1° to 2° or even less, an inclination which is hardly perceptible to the eye. There is a gradual deepening of the basin to the north, in which the Wasatch formation probably attains a thickness somewhat in excess of 1,000 feet. The strata rise more steeply in the Great Hogback

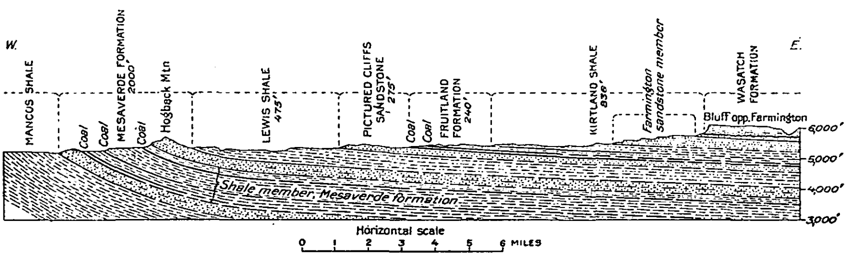


FIGURE 72.—Section along San Juan River from the Great Hogback to the bluff opposite Farmington, San Juan County. By C. M. Bauer

and its continuation, which crosses San Juan River 4 miles west of Liberty. This ridge is due to sandstone of the Mesaverde group tilted in a sharp monocline known as the San Juan fold, and to the west of it is a broad area of the outcropping zone of Mancos shale. There are in this area several arches and domes that are being explored for petroleum by borings, some of which reach the Dakota (?) sandstone. The stratigraphic succession in this general region is shown in Figure 72.

According to Bauer and Reeside [14] minor structural features superimposed on this general basin are not numerous in the San Juan County field. Several broad, low anticlines cross the rim at right angles north of San Juan River, but they are noticeable chiefly in the bulges they make in the outcrop lines of the formations. A small, sharper anticline occurs in T. 30 N., R. 15 W., and another in T. 25 N., R. 16 W. (unsurveyed). In T. 30 N., R. 15 W., there is

[14] Bauer, C. M., and Reeside, J. B., jr., Coal in the middle and eastern parts of San Juan County, N. Mex.: U. S. Geol. Survey Bull. 716, p. 161, 1921.

some evidence of a flattening of the dip to form a structural terrace parallel to the basin rim; in T. 29 N., R. 16 W., likewise an obscure structural terrace is observable in the Lewis shale. The only fault noted is a small one in T. 22 N., R. 7 W. In the shale areas on both sides of the sharp upturn causing the Great Hogback the dips flatten within a short distance. Toward the north the axis of this upturn shifts eastward, and in T. 31 N., Rs. 13 and 14 W., and T. 32 N., R. 13 W., the steepest dips are in the Fruitland formation and the Kirtland shale, while the rocks of the Mesaverde group flatten to form the prominent southern extension of the table-land known as Mesa Verde. Farther to the north the fold is not very distinct.

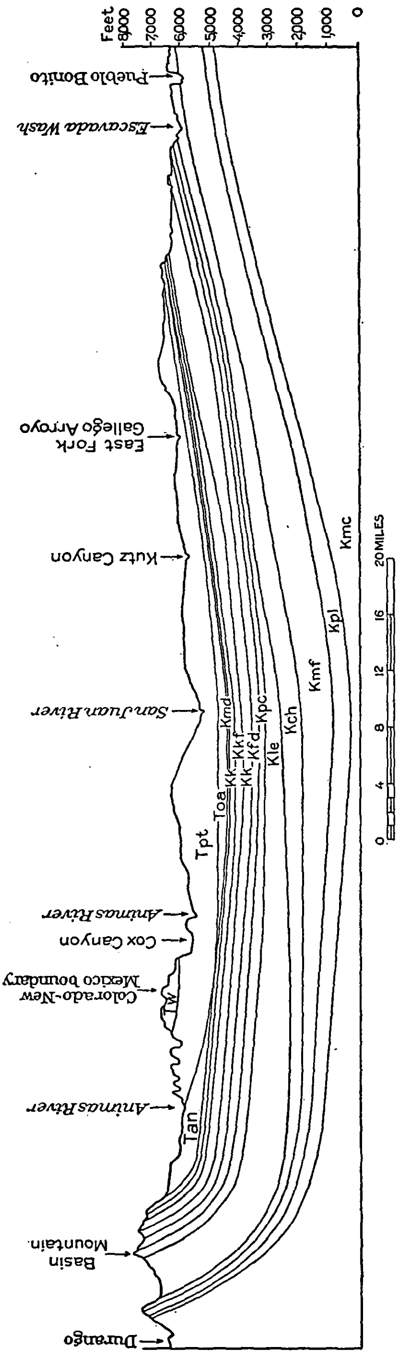


FIGURE 73.—Diagrammatic section across San Juan Basin from Durango, Colo., to Pueblo Bonito (Putnam), N. Mex. By J. B. Reeside, jr. Tw, Wasatch formation; Tpt, Torrejon and Puerco formations; Tan, Animas formation; Toa, Ojo Alamo sandstone; Kmd, McDermott formation; Kk, Kirtland shale containing Farmington sandstone member, Kkf; Kfd, Fruitland formation; Kpc, Pictured Cliffs sandstone; Kle, Lewis shale; Kch, Cliff House sandstone; Kmf, Menefee formation; Kpl, Point Lookout sandstone; Kmc, Mancos shale and older beds

A section from north to south across the greater part of the basin is reproduced in Figure 73.

The Cretaceous and overlying formations that crop out in a broad zone along the western and southern margins of the San Juan Basin have been studied in detail by Reeside.[15] A condensed statement of his descriptions of the principal features of stratigraphy and variations of thickness in this zone is given in the descriptions of formations from Mesaverde to Wasatch on page 44. In Figure 74 are shown his views as to some of the stratigraphic relations in the basin.

[15] Reeside, J. B., jr., op. cit. (Prof. Paper 134), pp. 1-70.

Coal occurs in the Menefee formation of the Mesaverde group and in the Fruitland formation, and the beds have been measured and mapped in detail by Bauer and Reeside.[16] The beds in the Menefee are near the top and bottom of the formation and except in a few places are thin and lenticular. Many coal beds occur in the Fruitland formation, but the thickest and most persistent ones are in the lower part and are found mostly in the region north of San Juan River, where one bed attains a thickness of 23 to 38 feet.

Many facts regarding the geology of the oil district have been presented in a recent paper by Nowels.[17] In the Beautiful Mountain dome the Dakota (?) sandstone is exposed in a small area in the north-

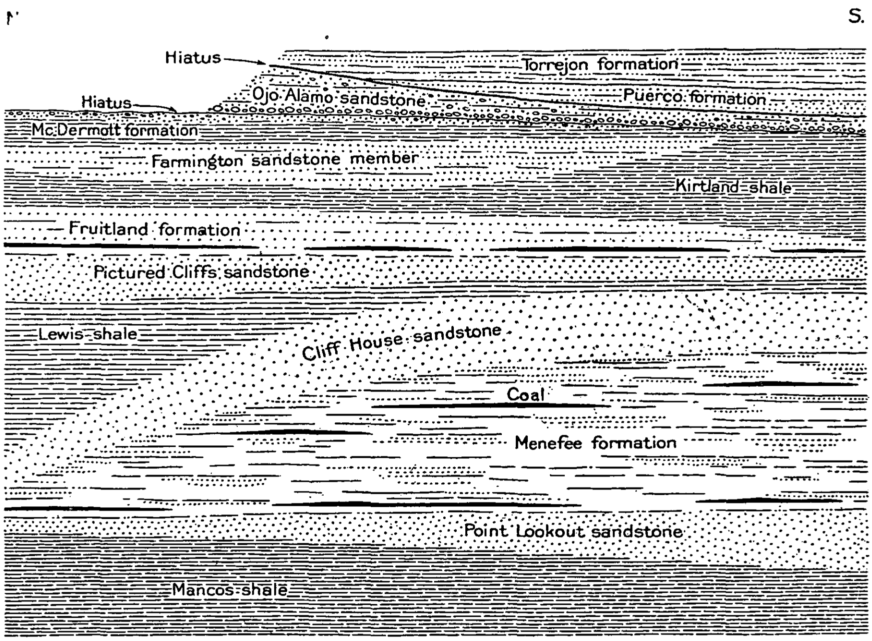


FIGURE 74.—Diagram showing probable relations of Upper Cretaceous strata in western part of San Juan Basin. After Reeside

east corner of T. 9 N., R. 4 W., and the outcrop of the Tocito sandstone member of the Mancos shale very nearly encircles the uplifted area. This bed is about 125 feet thick, and its base is 750 feet above the Dakota(?). Two thin layers of limestone 125 feet above the Dakota horizon appear to represent the Greenhorn limestone. A boring near the south end of the uplift reached Dakota(?) sandstone at 275 feet. It contained water but no oil. The upper part of the Biltabito dome exposes the Navajo sandstone, 600 feet thick, and the Wingate sandstone, 700 feet thick, separated by 80 feet of limy beds believed to represent the Todilto. Above the Navajo sand-

[16] Bauer, C. M., and Reeside, J. B., jr., op. cit. (Bull. 716), pp. 155–241.
[17] Nowels, K. B., Navajo Reservation development: Oil and Gas Jour., Oct. 1, 1925, pp. 255–264, 300.

stone is about 200 feet of light-colored shale capped by Dakota(?) sandstone and suggesting the Morrison formation.

In the Hogback dome there is an extensive outcrop of the Tocito sandstone lying about 800 feet above the Dakota(?) sandstone, which is reached by several wells that yield oil and water. The supposed Greenhorn limestone horizon is here from 50 to 80 feet above the Dakota(?). One boring that reached the Dakota(?) sandstone at 772 feet entered green shale, thought to be Morrison, at 980 feet.

In the Rattlesnake dome the relations of the strata are similar to those in the Hogback dome, but the interval from the Tocito sandstone to the Dakota(?) sandstone is about 50 feet greater. A 1,040-foot boring reached the Dakota(?) sandstone at 810 feet and green shale supposed to represent the Morrison formation at 1,035 feet. In the Table Mountain dome the Tocito sandstone is found 525 feet below the surface. The following record of a boring on the Tocito dome is given by Nowels:

Record of boring on Tocito dome

	Feet
Tocito sandstone member of Mancos shale	0–45
Shale (lower part of Mancos)	45–842
Sandstone, some shale, and coal (Dakota?)	842–1, 043
Shale, green, some sandstone, part red (Morrison?)	1, 043–1, 175
Sandstone, part red, part white (Navajo)	1, 175–2, 110
Shale and limestone, part white, part red (Todilto?)	2, 110–2, 165
Sandstone mostly (Wingate)	2, 165–2, 650
Shale, red; 15 feet of limestone at 2,750 feet (Chinle)	2, 650–3, 022

A boring in sec. 2, T. 29 N., R. 19 W., found a flow of artesian water at 1,950 feet estimated at 60 gallons a minute.

A boring made by the United States Indian Service at Shiprock revealed the following strata:

Record of boring at Shiprock

	Feet
River deposit	0–15
Shale, dark	15–275
Sandstone, light gray (Tocito)	275–340
Shale, dark	340–1, 000
Sandstone, fine; some water	1, 000–1, 025
Shale, dark	1, 025–1, 055
Sandstone, gray to brown; 6 feet of coal at base (Dakota)	1, 055–1, 140
Shale and sandstone of various colors (Morrison)	1, 140–1, 440
Sandstone, massive (Navajo)	1, 440–1, 510

Several deep borings have been made in the southeastern part of the San Juan Basin, but unfortunately very few data are available as to the strata penetrated. The following are on record:

Data on borings in San Juan Basin

Location	Depth (feet)	Remarks
Sec. 14, T. 17 N., R. 8 W	1,320	Sandstone at 1,107-1,147 feet and in bottom.
Sec. 14, T. 15 N., R. 10 W	1,084	Water, probably from Dakota sandstone.
Sec. 13, T. 15 N., R. 10 W	1,420	Sandstone at 0-150 feet containing 3-foot coal bed at 107 feet. Water at 1,268-1,286 feet (Dakota). Dry sand at 1,376 feet. Red, green, and blue shale at 1,420 feet (probably Morrison).
Sec. 4, T. 15 N., R. 6 W	2,154	Sandstone at 825 feet. Supposed Dakota at 1,725 feet.
Sec. 33, T. 19 N., R. 10 W	3,260	Shale, blue, with sandstone layers; 3,083-3,262 feet, sandstone, hard gray and fine white.

SAN ANDRES MOUNTAINS

GENERAL RELATIONS

The San Andres Mountains are one of the most prominent ranges in New Mexico. They begin at San Agustin Pass, northeast of Las Cruces, and extend nearly due north to Mockingbird Gap, a distance of 75 miles. The altitude of the adjoining plains is 4,000 feet, and most of the higher peaks of the range rise somewhat more than 7,000 feet; Salinas Peak, the highest summit, is 9,040 feet above sea level according to the Wheeler Survey. The range presents to the west a long slope of limestone and to the east a precipitous slope consisting mostly of granite and schist surmounted by cliffs of limestone. The range is structurally a westward-dipping monocline, the principal features of which are shown in Plate 41. At Salinas Peak a huge mass of quartz monzonite porphyry is intruded in the lower limestones of the Magdalena group and extends along the mountain front for some distance south as a thick sill. In Figure 75 is shown the general succession of Paleozoic rocks in the range.

FORMATIONS

PRE-CAMBRIAN ROCKS

The granite and schist that appear in the west front of the San Andres Mountains are in general similar to the pre-Cambrian rocks in many other uplifts in New Mexico. Massive coarse-grained granite is most abundant, but schist was observed in Cottonwood, Deadman, Sulphur, Membrillo, and San Andres Canyons. In Lostman Canyon the rock is diorite containing much hornblende. Granite appears in Goodfortune and Membrillo Canyons, near Rhodes Canyon, and from Lava Gap northward.

BLISS SANDSTONE (CAMBRIAN)

The Bliss sandstone crops out all along the east front of the San Andres Mountains to a point 2 miles northeast of Organ, where it is cut off by igneous rocks. In the southern part of the range it is from 80 to 110 feet thick, in the central part 30 to 50 feet, and in the northern part it thins to less than 10 feet at most localities. It lies on a remarkably smooth plain of erosion on the granite and schist, a feature well shown in Plate 3, *A*. The principal rock is hard gray sandstone, but some layers, especially the upper ones, are thin bedded and softer, and scattered grains of glauconite abound in many beds.

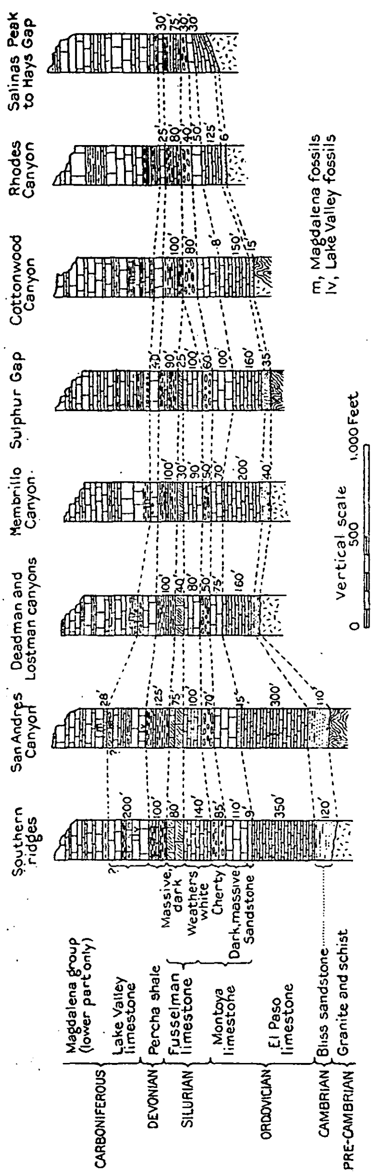


FIGURE 75.—Columnar sections of Paleozoic rocks in San Andres Mountains

In San Andres Canyon, where the formation is 110 feet thick, it consists of a lower member of gray quartzite, mostly massive; a medial member of brown sandstone, partly slabby; and an upper slabby member that apparently merges into the base of the El Paso limestone. In Sulphur Canyon there is 25 feet of brown sandstone, conglomeratic at the base, grading up into 30 feet of thin, slabby softer sandstone, in part glauconitic and fine-grained in its upper part, where it appears to grade into impure buff slabby limestone at the base of the El Paso. In Rhodes Canyon and northward to the north end of the range the Bliss sandstone is only 6 feet thick. It caps the granite cliffs, as shown in Plate 3.

EL PASO LIMESTONE (ORDOVICIAN)

The El Paso limestone overlies the Bliss sandstone all along the east front of the range. Its thickness is about 300 feet at the south but gradually diminishes northward from San Andres Canyon to 160 feet on Lostman and Sulphur Canyons, 125 feet at Rhodes Canyon, and 80 feet in Lava Gap. The limestone has all the characteristics that are exhibited in the type locality in the Franklin Mountains near El Paso, Tex. The bedding is mostly slabby, and the slabs weather to a very light bluish-gray tint with their surfaces mottled with reticulations of brownish-buff markings, probably due to a seaweed. Locally the medial beds are massive and less distinctive in appearance. Some notable outcrops are shown in Plate 3.

The formation is conspicuous in Rhodes Canyon, where it is separated from the granite by only 6 feet of Bliss sandstone, a relation that extends to the north end of the range. Northwest of Bennett Camp, 15 miles northeast of Las Cruces, there were obtained *Polygyrata rotuliformis?* and an indeterminable cystid. In Rhodes Canyon were collected *Syntrophia calcifera* and *Ophileta.* In the canyon 3 miles south of San Andres Peak and at other places in the range were found *Calathium* cf. *C. anstedi*, *Polygyrata trochiscus*, and some other forms. The El Paso fauna is regarded by Kirk as representing late Beekmantown time.

MONTOYA LIMESTONE (ORDOVICIAN)

The Montoya limestone appears in prominent cliffs along the east side of the San Andres Mountains, from the igneous contact northeast of Organ to Mockingbird Gap. It lies on the El Paso limestone and is overlain by the Fusselman limestone as far north as the southern part of T. 14 S., beyond which the Percha shale is next above it. Both upper and lower contacts show sharp separation from adjoining formations. The principal features of thickness and relations are shown in Figure 75. The formation comprises two characteristic members, as in other regions. The upper member consists of alternating thin beds of limestone and chert, averaging about 75 feet in thickness but thinning to 30 feet at Hays Gap. The lower member is a very massive, dark-colored limestone about 100 feet thick to the south but thinning gradually north of Rhodes Gap. The lower member includes locally at its base a sandstone that lies on the slightly uneven surface of the El Paso beds. This sandstone is 9 feet thick in the slopes 3 miles south of San Andres Peak and 11 feet thick in San Andres Canyon. The Montoya ledge forms a high cliff of dark color and in places makes a shelf or bench along the mountain front, as shown in Plate 3.

Fossils occur in both members of the formation. One ledge of cherty limestone in Sulphur Canyon yielded the following, determined by Edwin Kirk: *Bythopora gracilis*, *B.* cf. *B. meeki*, *B. striata*, *Monotrypella quadrata*, *Endotrypa* sp., *Dalmanella* sp., *Zygospira recurvirostris* (Richmond variety), and *Calymene*. In the canyon 3 miles south of San Andres Peak *Dinorthis subquadrata* was found, and in Cottonwood and Rhodes Canyons were collected numerous specimens of *Dalmanella testudinaria* var. These fossils are species common in the upper part of the Richmond group of the Mississippi Valley, but the formation probably comprises two or possibly three representatives of the Richmond epoch.

FUSSELMAN LIMESTONE (SILURIAN)

The Fusselman limestone is a conspicuous feature in the limestone succession along the east front of the San Andres Mountains from a point near Organ, where it is cut off by igneous rocks, to a point 2 or 3 miles north of Sulphur Gap, where it thins out. The thickness ranges from 220 feet in the southern part of the range to 120 feet in the middle part and at Sulphur Gap, and there is rapid thinning toward its northern termination. The formation has two members—an upper one of hard dark-colored massive limestone, marked by a cliff at most places, and a lower one of fine-grained limestone, most of which weathers nearly white. The upper member contains distinctive fossils, but the lower one has yielded no fossils and is arbitrarily placed in the formation because of its distinctness from the underlying cherty beds, which are everywhere characteristic of the upper part of the Montoya. The massive bed gives rise to a shelf at the base of the slope of the overlying Percha shale. Its thickness is 80 feet in the southern part of the range, but it gradually thins northward to 40 feet in Lostman Canyon, 30 feet in Membrillo Canyon, and 25 feet in Sulphur Gap. The lower limestone is 140 feet thick in the south end of the range, but it thins somewhat north of San Andres Peak. It is nearly 100 feet thick in Sulphur Gap but thins out and disappears in slopes north of the gap. In places some of its beds are soft and earthy, as in Lostman Canyon, but most of it is a fine-grained, compact, dark-gray rock that weathers to very light gray or nearly white, so that it is conspicuous in all outcrops. A sample of the upper member from ledges in San Andres Canyon was tested by Chase Palmer in the laboratory of the United States Geological Survey and found to contain 52 per cent of calcium carbonate, 38 per cent of magnesium carbonate, and 10 per cent of insoluble matter.

From the upper ledge of the limestone 1½ miles southwest of San Nicolas Spring, or about 22 miles northeast of Las Cruces, the writer collected the following forms, determined by Edwin Kirk: *Pentamerus* sp., *Cyathophyllum* sp., *Heliolites* sp., and *Hormotoma* sp.—a distinctive Fusselman fauna, which is regarded as of Niagara age. The *Pentamerus* was observed at many other localities in the San Andres Mountains as far north as Sulphur Gap.

PERCHA SHALE (DEVONIAN)

Shale with Upper Devonian fossils extends along the San Andres Mountains from a point 2 miles northeast of Organ, where igneous intrusions cut off the succession, to Mockingbird Gap. Its thickness is 75 to 125 feet, and it crops out in a slope between the prominent ledge of massive Lake Valley limestone above and a shelf or cliff of Fusselman or Montoya limestone below. The basal beds are black shale, above which are layers of slabby and nodular limestone separated by gray shale. Possibly in places in this area some beds of Carboniferous age have been included in the Percha shale.

Fossils were found in this formation, mostly in the medial beds, at several places in San Andres Mountains. The following species, collected in 1915 a mile south of Capitol Peak, in the northern part of the range, were identified by Edwin Kirk:

Tropidoleptus carinatus var.	Atrypa reticularis.
Alveolites sp.	Atrypa hystrix.
Spirifer n. sp.	Schizophoria striatula var. australis?.
Stropheodonta near S. arcuata Hall.	Diaphorostoma sp.
Productella hallana.	

On the north slope of Sheep Mountain, in Lava Gap, a mile farther south, were obtained *Zaphrentis*, *Atrypa reticularis*, *Cyrtia* n. sp., *Productella hallana*, and *Stropheodonta* near *S. arcuata*. In Sulphur Gap the following forms were collected from medial beds:

Atrypa hystrix.	Camarotoechia contracta?
Atrypa reticularis.	Chonetes sp.
Schizophoria striatula var. australis.	Stropheodonta n. sp.
Pugnax pugnus.	Spirifer whitneyi var. animasensis.

In a canyon 3 miles south of San Andres Peak were found *Rhipidomella* sp., *Spirifer* sp., and *Chonetes* sp. In Cottonwood and Ritch Canyons the shale yielded *Spirifer whitneyi*. In nodular beds in the middle of the formation in San Andres Canyon were found the following:

Zaphrentis sp.	Schizophoria striatula var. australis.
Fenestella sp.	Leiorhynchus? sp.
Productella cf. P. coloradoensis var. plicata.	Spirifer cf. S. utahensis.
Ambocoelia sp.	Reticularia undifera var.
	Phacops sp.

At the same horizon in Membrillo Canyon were obtained *Fenestella*, *Atrypa reticularis*, *Pugnax pugnus*, *Cyrtia* sp., *Stropheodonta* near *S. arcuata*, *Gypidula* sp., and *Productella* sp.

The fossils from the Percha shale are regarded by Kirk as indicating that the formation is late Devonian, equivalent to the lower part of the Ouray limestone of western Colorado, the upper part of the Martin limestone of the Bisbee region, Ariz., and the upper 2,000 feet of the Nevada limestone of the Eureka district, Nev. The beds in the San Andres Mountains appear to carry a smaller number of the typical lower Ouray forms than are present in Lake Valley, Colo., and more of the forms characteristic of the Martin limestone and Nevada limestone.

LAKE VALLEY LIMESTONE (MISSISSIPPIAN)

The Lake Valley limestone occurs throughout the San Andres Mountains, but it is not thick and locally may be discontinuous. In the central part of the range a heavy bed of limestone overlying the Percha shale yielded lower Mississippian (Lake Valley) fossils at several localities, notably in San Andres Canyon, on the slopes 3 miles south of San Andres Peak, and at a locality west of San Nicholas Spring, about 16 miles northeast of Las Cruces. The greatest thickness observed was in San Andres Canyon and northward for 10 or 12 miles, where the amount may be 100 feet or more. The principal bed that yielded Lake Valley fossils is a massive limestone, cherty in its upper part; some overlying softer beds and a higher massive bed may possibly also be included in the formation. In San Andres Canyon the higher massive bed is capped by 28 feet of hard gray sandstone, immediately above which is shaly limestone containing Magdalena fossils. In Membrillo Canyon the only member present is the one massive bed that caps the Percha shale, for the strata next above carry Magdalena fossils. This bed extends northward past Salinas Peak to and beyond Hays Gap, where, however, no fossils were found in it. In Sulphur Canyon it is 60 feet thick and is capped by 30 feet of a peculiar sandstone, including considerable conglomerate of large pebbles and fragments of white chert. This material is presumably basal Magdalena. Some of it appears also in Lostman Canyon. In Deadman Canyon the massive limestone bed above the Percha shale is 80 feet thick and grades upward into 50 feet of limestone with cherty layers. In Rhodes Canyon the ledge is only 25 feet thick, and in Lava Gap it is 30 feet thick. The outcrop at Lava Gap is shown in Plate 3, *A*.

The following lower Mississippian (Lake Valley) fossils collected in the San Andres Mountains were identified by G. H. Girty:

San Andres Canyon, in massive bed on Percha shale:

- Triplophyllum sp.
- Schizophoria aff. S. swallowi.
- Productus aff. P. arcuatus.
- Spirifer aff. S. grimesi.
- Spirifer centronatus.
- Brachythyris suborbicularis.

In cherty beds at top of this massive bed in a canyon 3 miles south of San Andres Peak:

- Triplophyllum sp.
- Spirifer aff. S. pellensis.
- Eumetria vera.

In the basal part of the first massive bed above the Percha shale on the ridge west of San Nicolas Spring:

- Cystodictya sp.
- Chonetes aff. C. logani.
- Spirifer sp.

In Sulphur Canyon, in massive bed on Percha shale.

- Spirifer centronatus.
- Cliothyridina incrassata?

MAGDALENA GROUP (PENNSYLVANIAN)

A large part of the San Andres Mountains, including most of the main divide ridge, consists of limestone, sandstone, and shale of the Magdalena group. The thickness of these beds is about 2,000 feet. No detailed sections were made, but the general features were observed at several localities. The lower members consist of hard massive limestone in bodies 50 to 80 feet thick, separated by softer beds, in part shaly, in all about 400 feet thick. The medial beds are largely sandstone, limestone, and shale, 1,000 feet or more thick, with many beds of gray sandstone 20 to 30 feet thick and of limestone 2 to 40 feet thick. The upper members are limestone and shale, with several thick beds of limestone, one near the base making the divide ridge extending from T. 20 S. north to Sulphur Canyon. The uppermost portion consists of alternations of limestone and reddish sandy shale which are overlain by Abo sandstone. Pennsylvanian fossils occur abundantly in many beds. The lower limit of the Magdalena strata was not ascertained in all places. In San Andres Canyon a 28-foot member of gray quartzite occurs under limestone with Magdalena fossils. Next below is a thick bed of massive limestone of light-gray color with scattered chert, separated from limestone carrying Mississippian fossils by 100 feet of softer limestone. These beds are cut off by a fault at the Lead mine. In Membrillo Canyon the massive limestone, apparently the same one noted in San Andres Canyon, yielded Magdalena fossils, and the same fauna occurs in underlying shaly beds. In Sulphur Canyon the hard massive bed, only 30 feet thick, is underlain by softer limestone at the base of which is a 40-foot member of a peculiar conglomerate of large cherts, the base of which probably marks an unconformity at the base of the Magdalena group. This conglomerate also appears in Lostman Canyon, where Magdalena fossils were collected just above it.

Fossils from Magdalena beds were identified as follows by G. H. Girty:

San Andres Canyon, beds just above basal quartzite of the group:
- Polypora? sp.
- Schizophoria aff. S. altirostris.
- Orthotetes sp.
- Productus semireticulatus, small var.
- Composita subtilita.

Ritch Gap, lower heavy ledge and talus below it:
- Textularia sp.
- Monilopora prosseri.
- Campophyllum sp.
- Echinocrinus sp.
- Orthotetes aff. O. robustus.
- Fistulipora sp.
- Marginifera muricata?
- Marginifera aff. M. splendens.
- Spirifer rockymontanus.
- Composita subtilita.

Membrillo Gap, lower heavy ledge and talus below it:
- Fusulina secalica.
- Monilipora aff. M. prosseri.
- Productus semireticulatus.
- Composita subtilita.
- Deltopecten aff. D. occidentalis.
- Marginifera aff. M. splendens.

Lostman Canyon, not far above lower massive ledge:
- Lingulidiscina sp.
- Marginifera muricata.
- Spirifer rockymontanus.
- Composita subtilita.
- Cliothyridinia orbicularis.
- Myalina sp.

Rhodes Canyon, bed No. 2:
- Lingulidiscina missouriensis.
- Marginifera muricata.
- Spirifer rockymontanus.
- Aviculipecten sp.

Rhodes Canyon, bed No. 3:
- Campophyllum? sp.
- Echinocrinus sp.
- Batostomella sp.
- Derbya crassa.
- Productus semireticulatus, small var.
- Spirifer rockymontanus.
- Spirifer cameratus.
- Composita subtilita.

Low in Magdalena group in Mockingbird Gap:
- Ambocoelia planiconvexa.
- Composita subtilita.
- Bellerophon sp.

ABO SANDSTONE (PERMIAN)

The Abo sandstone (the lower formation of the Manzano group) crops out along the west slope of the San Andres Mountains from Hays Gap south to the fault on Bear Creek. The dip is to the west at a moderate angle, and the thickness of the beds is 1,000 feet in greater part, apparently diminishing somewhat near the southern outcrop. The material is sandstone, mostly slabby, and sandy shale of reddish-brown color, all rather hard. At the base there appears to be a transition into Magdalena beds, at least in places, and at the top a rapid transition into the Chupadera formation. For the greater part of its course the formation gives rise to a narrow flanking ridge broken by many cross valleys. In Lava Gap the outcrop zone of the formation is offset 2 or 3 miles by a fault, and it is faulted in Sulphur and Bearden Canyons and at Hays Gap. Small masses of the formation occur on the east side of the range near Lava and Hays Gaps, and there is a wide area in Mockingbird Gap. No fossils have been found in the Abo sandstone in the San Andres Mountains.

CHUPADERA FORMATION (PERMIAN)

The Chupadera formation constitutes the western slope of the San Andres Mountains from Hays Gap to a point in the northern part of T. 18 S., appears at intervals in T. 19 S., and extends across T. 20 S. to the fault on Bear Creek. There are small outcrops in the northwestern part of T. 10 S., R. 5 E., and in Mockingbird Gap. The formation consists of limestone, red and gray sandstone, and gypsum beds. The upper member is a thick body of massive limestone, the San Andres limestone of Lee,[18] which makes a high ridge throughout Socorro County and is the main divide from Sulphur Canyon to and beyond the head of Bearden Canyon. A representative section west of the Henderson ranch in the southern part of T. 12 S. is shown in Figure 76.

The stratigraphy of the beds below the thick limestone varies considerably from place to place, and there is rapid thinning of the formation to the south in Dona Ana County. In Sulphur Gap the following beds appear, but a portion of the outcrop is obscured by talus:

Section of Chupadera formation in Sulphur Gap

	Feet
Limestone	200+
Sandstone	20+
Gypsum, etc	200
Limestone	60
Gypsum	50±
Limestone (cliff)	30
Sandstone, limestone, shale	100±
Limestone (cliff)	40
Gypsum and red sandy shale	40
Limestone, thin bedded	5
Gypsum	100+
Limestone	10
Red sandy shale and gypsum	100+
Limestone on Abo sandstone	10
	965

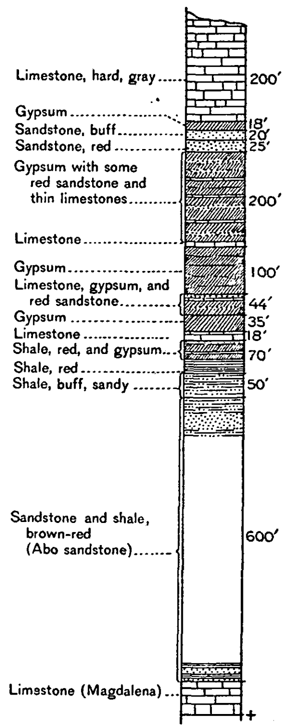


FIGURE 76.—Columnar section of Chupadera and Abo formations west of Henderson ranch, Rhodes Canyon

From the limestone near the Rhodes ranch Lee[18a] collected *Productus ivesi?*, *P. leei?*, *P. mexicanus*, *Aviculipinna nebraskensis*, *Pseudomonotis occidentalis*, *Mylaina apachesi*, *Schizodus wheeleri*, *Deltopecten manzanicus*, *Bellerophon majusculus*, *Pleurophorus* aff. *P. taffi*, *Composita mexicana*, and others.

CRETACEOUS ROCKS

Although Cretaceous rocks probably underlie parts of the basins adjoining the San Andres Mountains, exposures are very few in the vicinity of the range. Small outcrops of Dakota (?) sandstone are reported west of Mockingbird Gap in the northern part of T. 11 S., R. 3 E., and in sec. 25, T. 11 S., R. 2 E. Slightly higher strata were found overlying Chupadera limestone near the Davis ranch along the west line of T. 20 S., R. 4 E., 11 miles north of Organ, where 100 feet or more of shale and sandstone occur, including a thin bed of coal that has been worked to a small extent. The following fossils collected at this place were determined by T. W. Stanton, who states

[18] Lee, W. T., op. cit. (Bull. 389), pp. 12-13. [18a] Idem, p. 29.

that the fossils belong to the Benton fauna and indicate a horizon in the lower part of the Mancos shale:

Syncyclonema? sp.
Camptonectes? sp.
Inoceramus labiatus.
Cardium?
Legumen sp.
Corbula sp.
Baculites gracilis?
Prionocyclus wyomingensis.

TERTIARY ROCKS

Conglomerate, presumably of early Tertiary age, overlies the Cretaceous succession at the Davis ranch above referred to. Several hundred feet of strata are exposed, cut off by a fault on the west side which brings up limestone of the Magdalena group, as shown in cross section 7, Plate 41.

IGNEOUS ROCKS

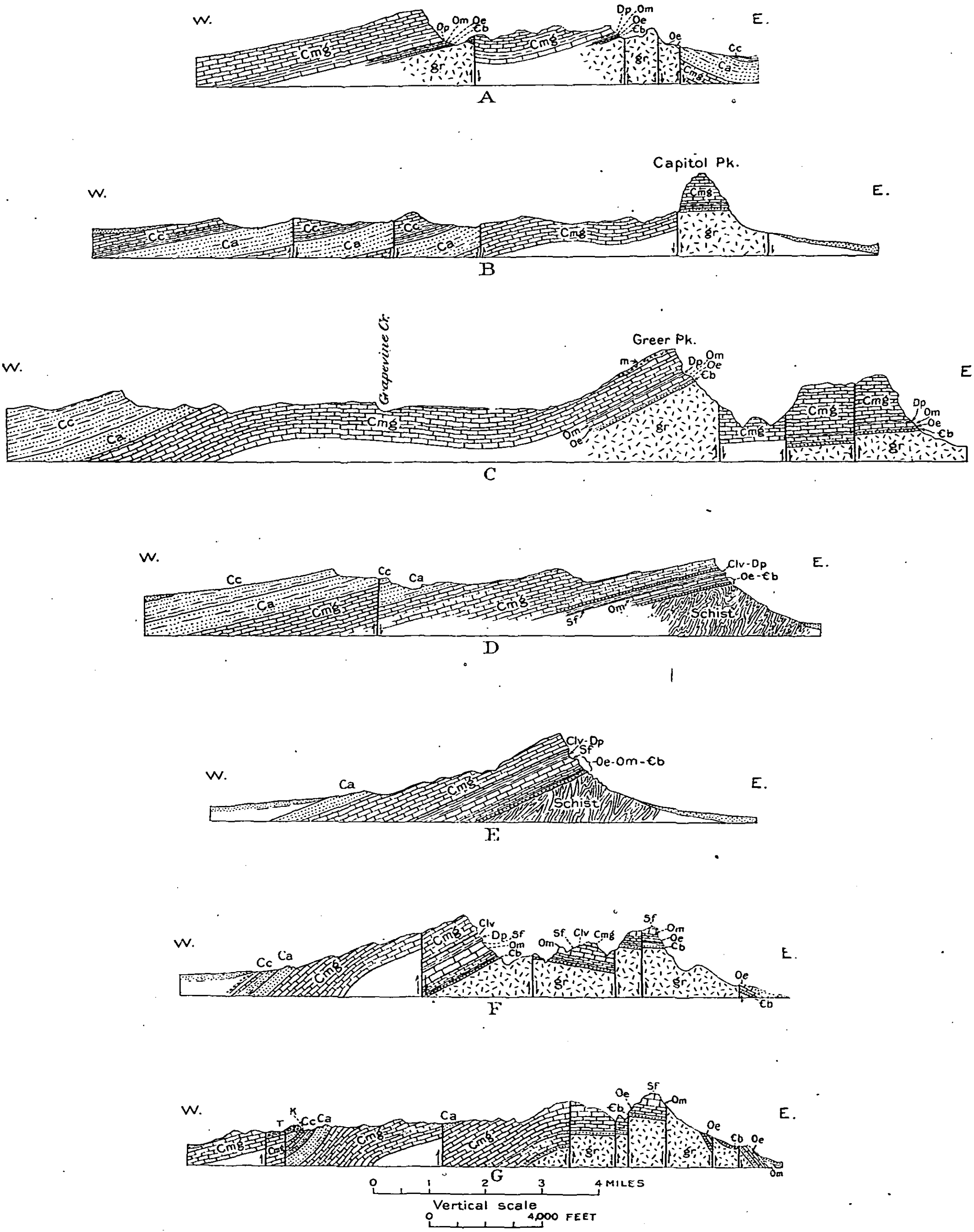
Lindgren [19] has described the igneous rock from the southern part of the San Andres Mountains, "near Merrimac mine, 3 miles north of Organ City." He states that the rock is reddish gray and appears like granite in outcrops. It is medium grained but contains some large ill-developed crystals of orthoclase as much as 15 millimeters in length. The mass of the rock has an average grain of 3 to 4 millimeters and consists of anhedrons of orthoclase, rarely with microperthite, laths of oligoclase, some andesine, and small quartz grains. There are small amounts of chestnut-brown biotite and pale-green augite, in places roughly prismatic and partly converted to a greenish hornblende. Accessory minerals are magnetite, apatite, and titanite; the titanite is visible to the naked eye. The rock is a quartz monzonite. An analysis by George Steiger, of the United States Geological Survey, is as follows:

Analysis of quartz monzonite 3 miles north of Organ

SiO_2	61. 12	TiO_2	1. 30
Al_2O_3	15. 78	ZrO_2	. 04
Fe_2O_3	2. 69	CO_2	. 22
FeO	3. 15	P_2O_5	. 45
MgO	1. 90	S	. 05
CaO	3. 95	MnO	. 09
Na_2O	4. 14	BaO	. 07
K_2O	4. 48	SrO	. 04
H_2O-	. 32		
H_2O+	. 56		100. 35

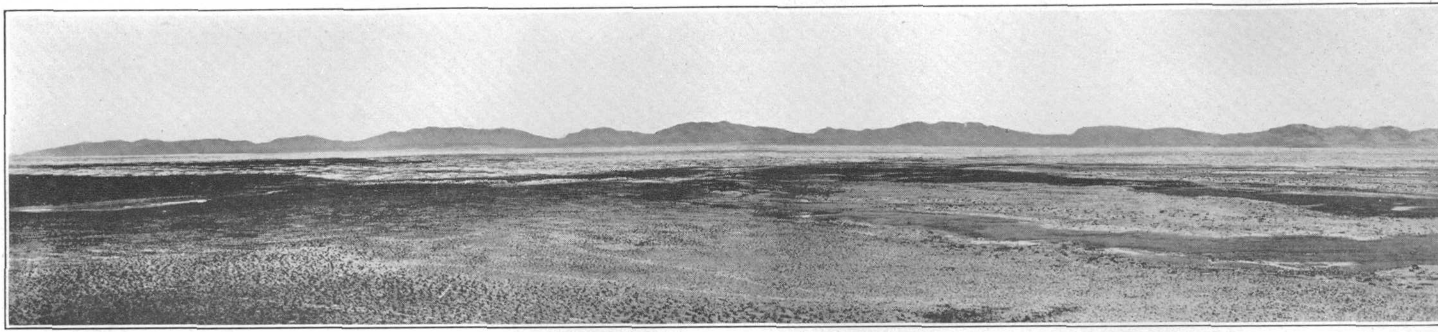
Salinas Peak consists of a large mass of microgranite intruded at a horizon low in the Magdalena group. This mass extends some distance north and south of the peak as a thick sill, which is nearly constant in horizon throughout and from 250 to 500 feet thick in greater part. According to E. S. Larsen, the rock consists of fine-textured quartz and orthoclase with sericite and probably some plagioclase.

[19] Lindgren, Waldemar, op. cit. (Prof. Paper 68), pp. 37-38, 39.



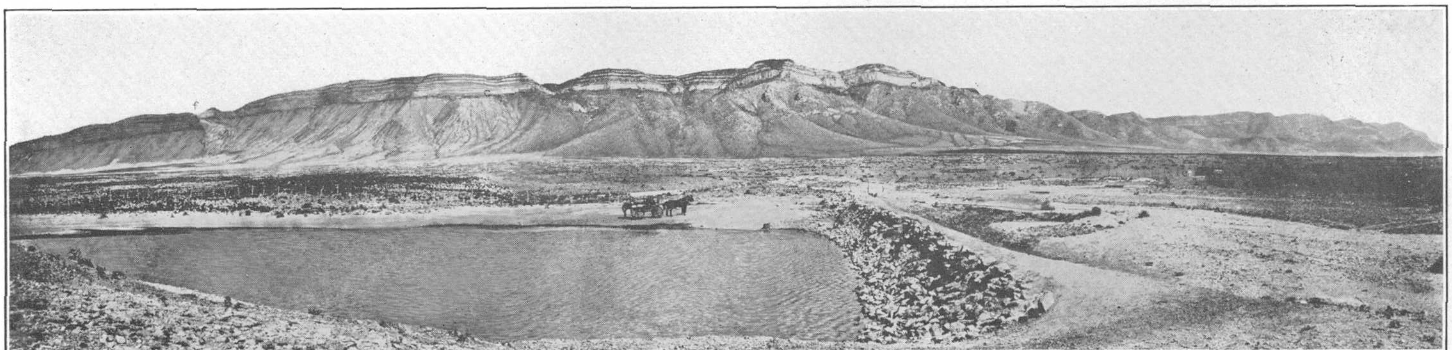
SECTIONS ACROSS SAN ANDRES MOUNTAINS

gr, Granite and other igneous rocks; Ꞓb, Bliss sandstone; Oe, El Paso limestone; Om, Montoya limestone; Sf, Fusselman limestone; Dp, Percha shale; Clv, Lake Valley limestone; Cmg, Magdalena group; Ca, Abo sandstone; Cc, Chupadera formation; K, Upper Cretaceous; T, Tertiary; m, porphyry sill. The location of the sections is shown in Plate 40



A. TULAROSA BASIN FROM THE EAST

"White Sands" (gypsum) in middle ground. San Andres Mountains in distance



B. WEST FRONT OF OSCURA MOUNTAINS FROM A POINT NEAR THE CENTER OF T. 6 S., R. 5 E.

c–c, Contact of granite and base of Magdalena group; f, fault

STRUCTURAL DETAILS

The San Andres Mountains mark an anticlinal uplift faulted extensively along its east side. The principal structural features are shown in Plate 41. For many miles the eastern face is a rugged slope of pre-Cambrian granite and other rocks, surmounted by a cliff consisting of a succession of lower Paleozoic rocks dipping to the west. Along the western slope are ridges of the overlying Abo and Chupadera formations, also dipping westward and passing beneath the surface of the Jornada del Muerto. A few small areas of overlying Cretaceous rocks appear on the west side, and in places on the east side there are small exposures of Paleozoic strata, mostly dipping eastward and indicating the presence of the eastern limb of an anticline downfaulted along the higher part of the uplift. There are also several cross faults, notably near the north and south ends of the range, and many minor slips and breaks that could not be shown on the geologic map (pl. 40). The strata are cut by large igneous masses at the south end of the range and in its southern continuation (Organ Mountains), and the laccolith in the Salinas Peak area has deformed the strata in places.

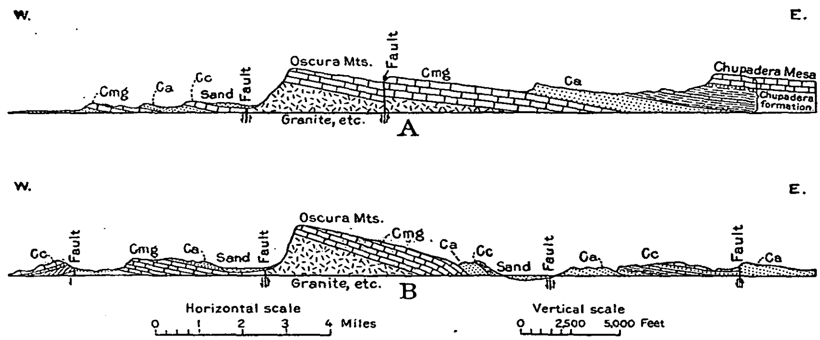


FIGURE 77.—Sketch sections across Oscura Mountains. A, Near north end of the range; B, not far north of Mockingbird Gap. Cmg, Magdalena group; Ca, Abo sandstone; Cc, Chupadera formation

OSCURA MOUNTAINS

The Oscura Mountains were found to present the features shown in Figure 77. In general structure the range is similar to the Sandia Mountains, an elongated dome faulted along part of its west side, where the granite and other pre-Cambrian rocks rise more than 3,000 feet above the Jornada del Muerto. The steep westward-facing slope of these older rocks (see pls. 39, *A*, and 43, *B*) is surmounted by an escarpment of limestone of the Magdalena group, which constitutes the summit and long eastern slope of the cuesta. To the east is a ridge of the red Abo sandstone, and farther east the outcrop zone of limestone belonging to the Chupadera formation, rising into Chupadera Mesa to the south. There are several faults along the mountains, and the higher part of the west front is undoubtedly due to a fault. Just west of the foot of the range are small ridges of Abo sandstone and Chupadera limestone rising out of the talus slopes and indicating the general anticlinal structure. A very conspicuous diagonal fault trending northwestward, with a drop of several hundred feet on the southwest side, crosses the mountains in T. 7 S., R. 6 E. It extends eastward to the northwest corner of T. 8 S., R. 8 E.

In the southern part of the Oscura Mountains the Montoya and El Paso limestones and probably the Bliss sandstone are present; to the north all these formations thin out and the Magdalena group lies directly on the pre-Cambrian rocks, with a basal sandstone member below the thick mass of limestone. Figure 78 shows the strata exposed on the southwestern slope in the south-central part of T. 9 S., R. 6 E., about 4 miles southwest of Estey.

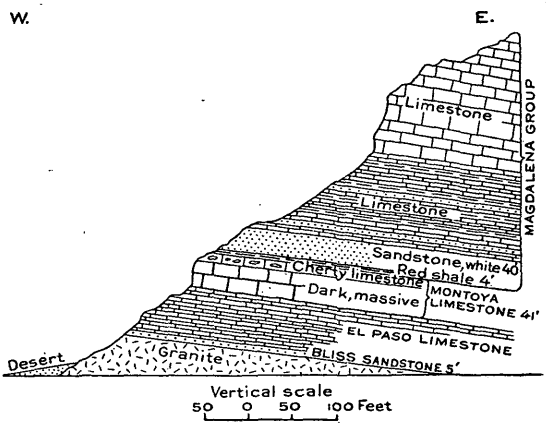


FIGURE 78.—Section of west front of Oscura Mountains, 4 miles southwest of Estey, Lincoln County

The Bliss sandstone, although thin, is characteristic and appears to grade into the El Paso limestone through a few feet of slabby rusty glauconitic limestone. The El Paso beds are highly characteristic with thin, slabby bedding and brown reticulations on the bedding planes and weathering to a dirty buff tint. They contain abundant *Ophileta*. The Montoya limestone includes the dark massive lower member, 35 feet thick, grading up into a 6-foot member with cherty layers, much thinner than the corresponding member in the San Andres Mountains, with which it was found to be continuous. The overlying red shale is of unknown age—possibly Percha—but the succeeding white sandstone is doubtless the same as the bed which is at the base of the Magdalena group to the south, as well as to the north, where it is the shore deposit separating the limestone from the granite.

The northern termination of the Cambrian and Ordovician rocks was not observed, but it is probably in T. 8 S. In cliffs just east of the Snider ranch, in the south-central part of T. 8 S., R. 5 E., the Bliss sandstone is 5 feet thick; the El Paso limestone, 23 feet; the red shale, 8 feet; and the basal sandstone of the Magdalena group, 30 feet, the Montoya being absent.

It is stated by Keyes [19a] that strata of Mississippian age are present in the limestone succession in the western face of the range.

JORNADA DEL MUERTO

The wide desert valley to which the Spaniards gave the expressive name Jornada del Muerto extends from the southeast corner of Socorro County southward along the west side of the Oscura and San Andres Mountains a distance of 125 miles. Its remarkably smooth and nearly level floor consists mostly of sand or loam, which in an area southeast of San Marcial is covered by a large sheet of recent lava that was ejected from a crater near its center. In most places the deposit of sand, loam, and gravel is moderately thick, and underlying rocks appear at only a few points. The general structure, however, is indicated by the relations of the formations in the adjoining ridges, and some additional data are afforded by a few widely scattered outcrops and records of deep borings. The chief feature is a long, moderately narrow syncline, which is not very deep, as the dips appear to be gentle at most places. The principal structural features observed or inferred are shown in Figure 79.

Local anticlines or domes may occur in this valley, but except for those on the margin no evidence can be obtained as to their existence until numerous borings are made. The anticline at Carthage and Prairie Springs and the prominent plunging anticline at the north end of the Oscura uplift, in Tps. 2, 3, 4, and 5 S., R. 6 E., are outside of the main basin. In the valley of Arroyo Chupadera the north end of the Jornada syncline holds a thin remnant of Triassic red shale, mostly hidden by loose sand. As the basin deepens toward the south, Cretaceous shales and sandstones appear in regular order, and they are exposed about Carthage, where the higher sandstones carry a coal bed that is extensively mined. The structural relations from Prairie Springs to Carthage are described on page 79. Early Tertiary conglomerate crops out south and east of Carthage, and this formation may extend widely under the basin to the south. The Cerro Colorado in this vicinity is a mass or group of masses of igneous rocks of the Tertiary volcanic series, which is not of wide extent underground. The eastward-dipping limestone of the Magdalena group in the ridge in T. 6 S., Rs. 4 and 5 E., appears to be cut by a fault on its west side, for Cretaceous sandstone crops out a short distance southwest of its foot, and wells 250 and 300 feet deep in this vicinity are in sandstone that is reported to be coal bearing and to show traces of oil. The higher part of the west face of the

[19a] Keyes, C. R., Northward extension of the Lake Valley limestone in New Mexico: Iowa Acad. Sci. Proc., vol. 12, p. 171, 1905.

Oscura Mountains, in which granite and other pre-Cambrian rocks rise high above the valley floor, is doubtless due to a fault, but it is

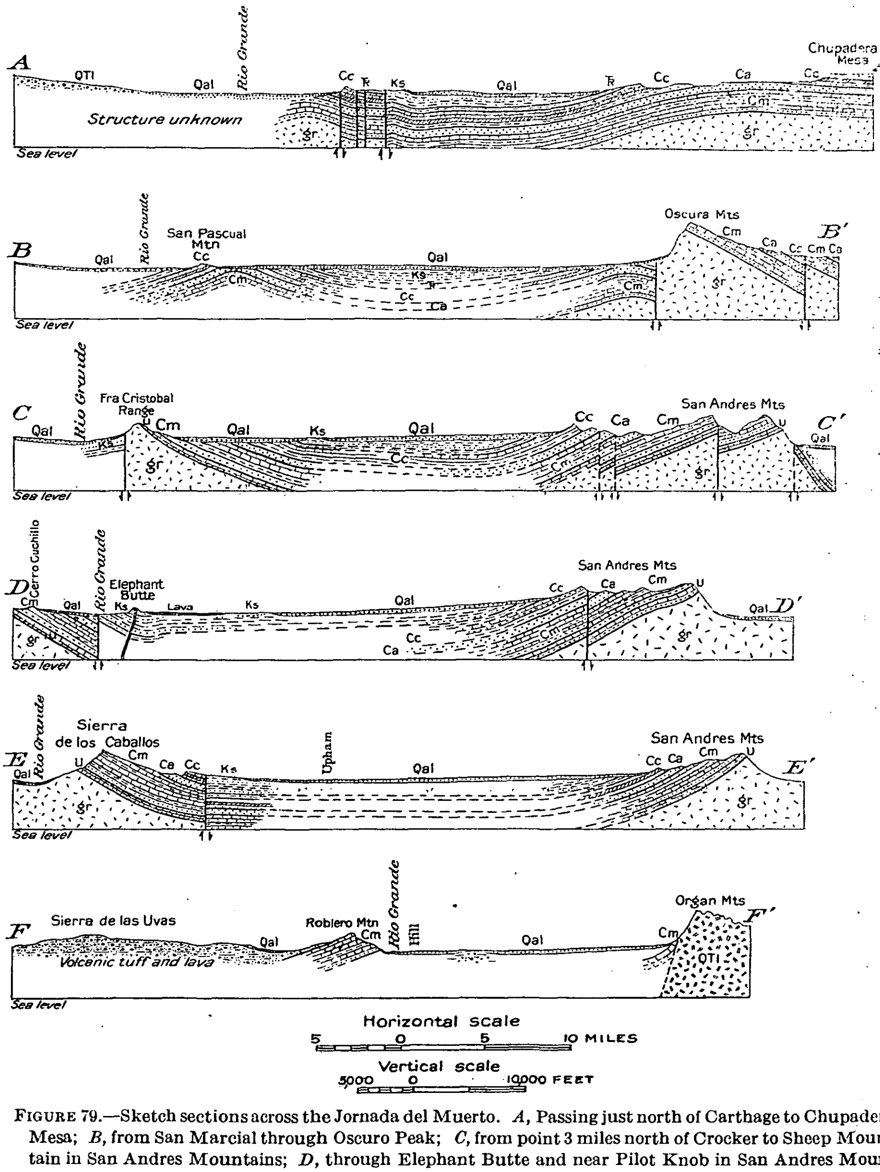


FIGURE 79.—Sketch sections across the Jornada del Muerto. *A*, Passing just north of Carthage to Chupadera Mesa; *B*, from San Marcial through Oscuro Peak; *C*, from point 3 miles north of Crocker to Sheep Mountain in San Andres Mountains; *D*, through Elephant Butte and near Pilot Knob in San Andres Mountains; *E*, through Upham; *F*, from Sierra de las Uvas through Hill to Organ Mountains. Qal, Alluvium and older sand and gravel; Ks, Cretaceous sandstone and shale; ℞, Dockum group (?); Cc, Chupadera formation; Ca, Abo sandstone; Cm, Magdalena group; u, Lake Valley limestone, Percha shale, Fusselman, Montoya, and El Paso limestones, and Bliss sandstone; gr, granite, etc.; QTl, intrusive porphyries

probable that westward-dipping rocks on the west limb of a general anticline occur not far west of the foot of these mountains. This structure is indicated by outcrops of Cretaceous sandstone of Colorado age in the southeast corner of T. 8 S., R. 4 E., and by outcrops of westward-dipping Dakota (?) sandstone in the northern part of T. 11 S., R. 3 E., and the southeastern part of T. 11 S., R. 2 E. Sandstone is also reported in the western part of Tps. 6 and 7 S., R. 5 E., 18 miles southeast of Carthage.

In a well in sec. 36, T. 10 S., R. 2 E., an 18-inch bed of coal was reported at a depth of 320 feet, indicating the presence of the higher sandstones of the Upper Cretaceous, and a similar bed is reported in wells in the center of T. 11 S., R. 2 E., where the sandstone lies under 60 to 70 feet of wash. A well in the east-central part of T. 10 S., R. 1 E., penetrated sandstone reported to carry coal streaks and "oil indications." In Tps. 9 and 10 S. limestone of the Chupadera formation dips gently to the west on the west slope of the San Andres Mountains and rises again on an east dip on the east slopes of the Fra Cristobal Range and Sierra Caballo, this forming a synclinal basin, as shown in sections *C* and *E*, Figure 79. A fault along the west side of the basin is traceable along the east side of the Sierra Caballo. The basin flattens and spreads to the west near Engle and Elephant Butte, as shown in section *D*, Figure 79. Wells in the Engle and Carthage regions penetrated sandstone, presumably in the Cretaceous coal measures (Mesaverde?), overlain by valley fill from 10 to 100 feet thick. Similar sandstone has been penetrated in several wells in the plain south of Cutter, and there is every reason to believe that Cretaceous sandstone and shale occupy the basin as far south as Las Cruces. In the Point of Rocks area, San Diego Mountain, and the Dona Ana Hills the Tertiary agglomerate and lava overlie these Cretaceous strata, which are doubtless intersected by dikes and other intrusive bodies of the igneous rocks.

ORGAN MOUNTAINS

The high rugged range of the Organ Mountains, east of Las Cruces, is in general a southern continuation of the San Andres Mountains, but it consists mainly of a huge intrusive mass of quartz monzonite with pre-Cambrian granite at its northeast end and Paleozoic limestone on its north end and northwestern slope. At its south end are some extrusive rhyolite, andesite, and tuff, and Pyramid Mountain, an outlying butte to the south, consists of limestone of the Magdalena group. The character of the rocks and the relations of the intrusive bodies in the vicinity of the mines near Organ have been described by Lindgren.[20] At this place the igneous rocks cut the Carboniferous limestone and have altered it to a considerable extent. In the north end of the range the granite is overlain by a regular succession of Bliss sandstone, El Paso limestone, Montoya limestone,

[20] Lindgren, Waldemar, op. cit. (Prof. Paper 68), pp. 205–213.

Fusselman limestone, Percha shale, and Lake Valley and Magdalena limestones, in which there are several intrusions of porphyry in the ridges about 6 miles northeast of Organ. The east side of the range has not been examined.

SACRAMENTO MOUNTAINS

GENERAL RELATIONS

The Sacramento Mountains extend for about 30 miles along the east side of the Tularosa Basin. To the north they merge into the Sierra Blanca, or White Mountains, and to the south they decline into a low ridge which extends to the Hueco Mountains near the Texas boundary. In their higher portion, which is east of Alamogordo, they attain an altitude of 9,600 feet, or about 5,000 feet above the plain to the west. The range is part of a great cuesta of limestone belonging to the Chupadera formation sloping up from the Pecos Valley and ending in a steep westward-facing escarpment or series of steps, as shown in Figure 80 and Plate 45. The

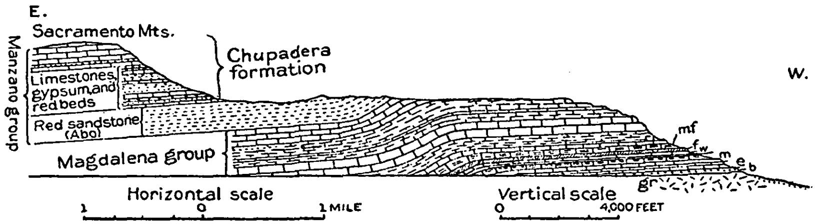


FIGURE 80.—Section of the west front of the Sacramento Mountains. gr, Granite; b, sandstone (Bliss?); e, El Paso limestone; w, limestone, white when weathered (Fusselman?); f, Fusselman limestone; mf, shaly limestone with Mississippian fossils

increased prominence of the portion constituting the Sacramento Mountains is due to a local arch or dome trending east and probably cut off on the west by a fault. The dome is so high in the central part of the range that the lower Paleozoic rocks are revealed in the steep western front, from a point near Alamogordo to a point 20 miles south of that place, and the underlying granite is exposed for a short distance at Little Agua Chiquita Canyon. (See fig. 82 and pl. 45, *B*.) The general structure of the range and the wide cuesta on its east slope are shown in Figure 81.

FORMATIONS

BLISS (?) SANDSTONE (CAMBRIAN?)

A thin sandstone at the base of the sedimentary rocks exposed near Little Agua Chiquita Canyon is probably the Bliss sandstone. Possibly, however, it is a shore deposit at the base of the El Paso limestone. It lies on a smooth surface of dark diorite or granite and is about 8 feet thick. No fossils were found in it.

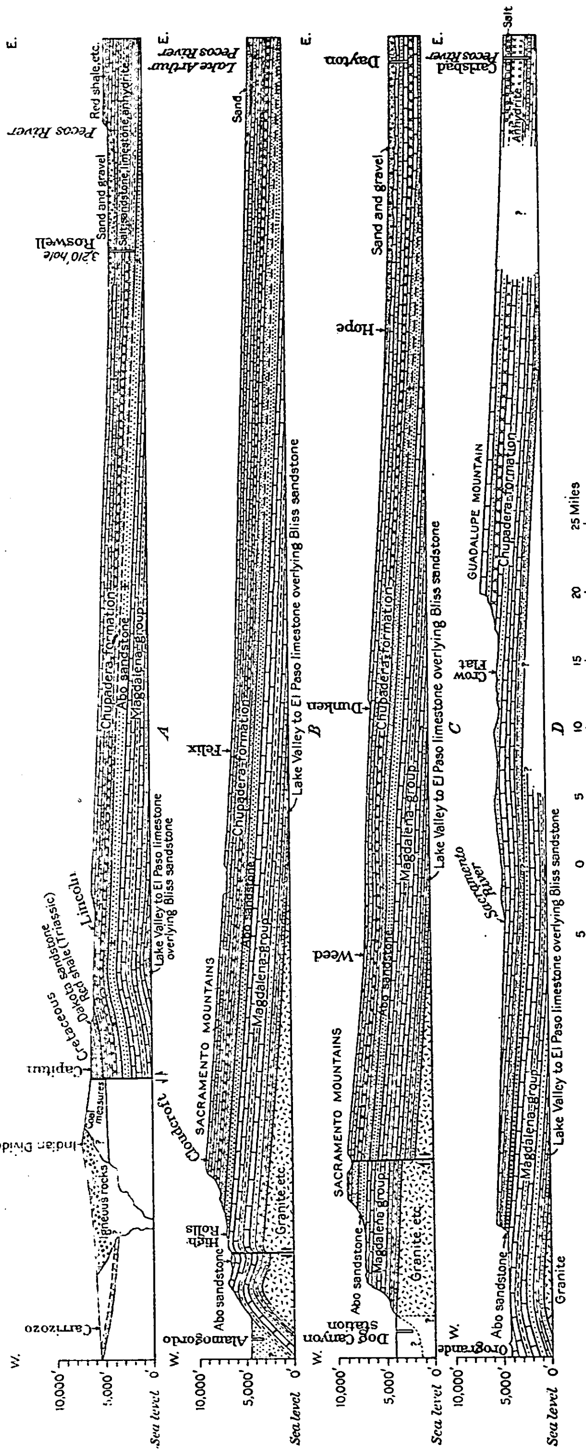


FIGURE 81.—Sections across Sacramento Cuesta and Guadalupe Mountains in Lincoln, Chaves, Otero, and Eddy Counties. *A*, From Carrizozo through Roswell; *B*, Alamogordo to Lake Arthur; *C*, Dog Canyon (Shamrock post office) to Dayton; *D*, Orogrande to Carlsbad

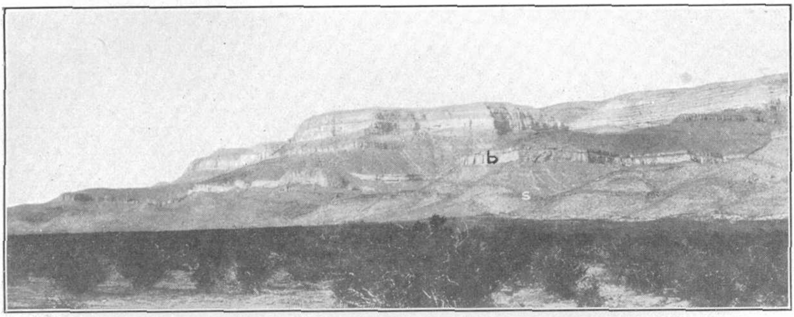
EL PASO LIMESTONE (ORDOVICIAN)

Typical El Paso limestone is exposed along the foot of the west slope of the Sacramento Mountains from the vicinity of Grapevine Canyon to a point a short distance north of Alamo Canyon, except for a short interval at San Andres Canyon, where it is covered by talus. The relations are shown in Figure 80. About 250 feet of the formation is exposed in the complete section at Little Agua Chiquita Canyon, but only a part of it appears in the slopes to the north, where there is more or less talus. At Dog Canyon 200 feet is exposed above the talus slope, and on the north side of Alamo Canyon 125 feet of beds constitute a cliff, capped by thin sandstone and dark massive limestone at the base of the Montoya, as shown in Plate 45, *C*. The El Paso rocks are slabby limestones, weathering light gray, and in part the bedding planes show brownish-buff reticulations—features that are characteristic near El Paso and in many parts of New Mexico. The medial beds, however, are more massive here than at most other places. A few fossils occur, and *Calathium* cf. *C. anstedi* and *Dalmanella pogonipensis* were collected in Alamo Canyon. The El Paso fauna is regarded by Ulrich and Kirk as Lower Ordovician, representing chiefly late Beekmantown time.

MONTOYA LIMESTONE (ORDOVICIAN)

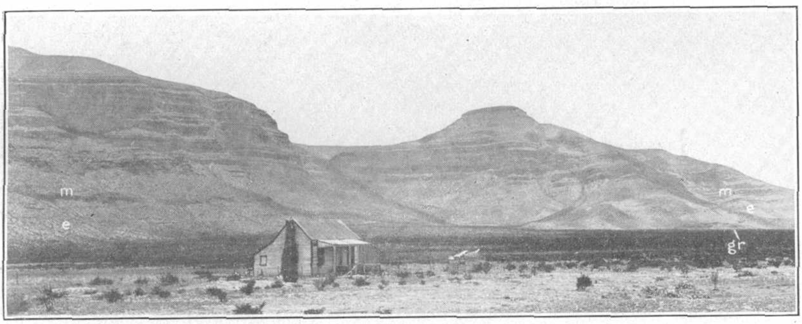
The dark ledges of Montoya limestone are a prominent feature in the limestone succession exposed along the west front of the Sacramento Mountains. They occur immediately above the El Paso slopes and are continuous except for a short distance at the mouth of San Andres Canyon, where a slight syncline depresses the beds and they are covered by talus. The relations are shown in Figure 82 and Plate 45, *C*.

Here, as in other regions, the formation comprises two distinct members, and both are highly characteristic. The lower member is dark-colored, very massive limestone which crops out as a high cliff; its thickness is 75 feet at Dog Canyon and 120 feet at Alamo Canyon. At the latter place its base is gray sandstone and it is separated from the El Paso beds by an abrupt change in character of material, possibly with slight channeling of the surface of the older formation. In the low arch that brings up El Paso limestone 2 miles up Alamo Canyon a local sandstone member about 1 foot thick marks the base of the Montoya. The upper member is 60 feet thick and consists largely of alternating thin beds of chert and limestone. Many corals are scattered through the dark massive limestone, and *Halysites gracilis*, *Streptelasma* sp., *Receptaculites* sp., and *Rhynchotrema capax* were collected from this member near Dog Canyon. Fossils occur in the cherty layers of the upper member, and abundant remains of *Dalmanella* cf. *D. corpulenta* were collected from it near Dog Canyon. These fossils are indicative of the Richmond age of the formation.



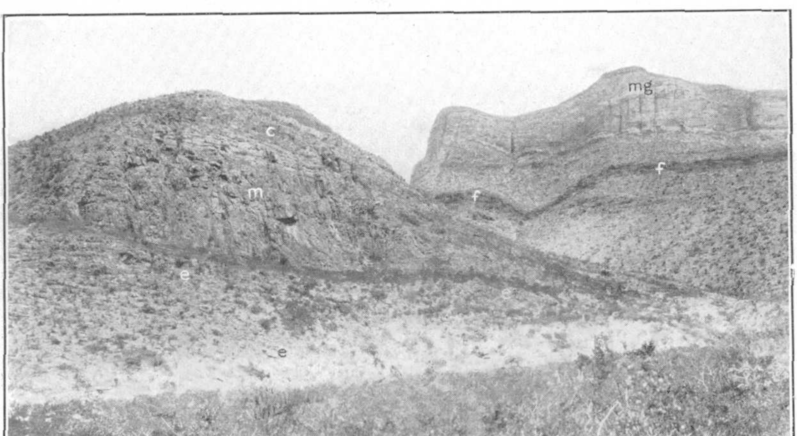
A. WEST FRONT OF SACRAMENTO MOUNTAINS 6 MILES SOUTH OF ALAMOGORDO

Looking northeast. s, Ledge of Fusselman limestone at mouth of San Andres Canyon; b, "big ledge," Mississippian limestone overlain by limestones of Magdalena group



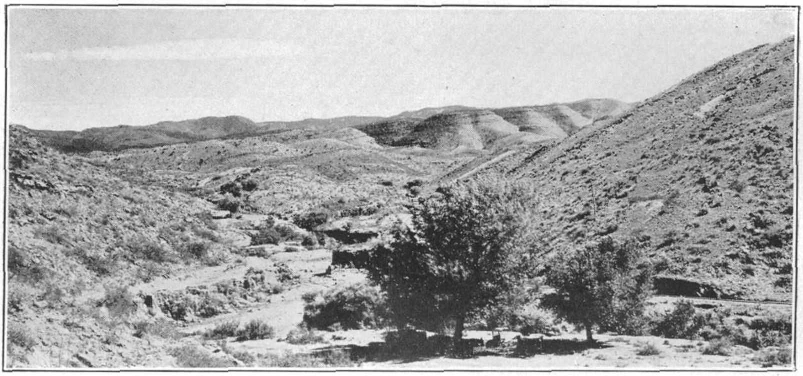
B. WEST FRONT OF SACRAMENTO MOUNTAINS AT *LITTLE AGUA CHIQUITA* CANYON, 18 MILES SOUTH OF ALAMOGORDO

Looking southeast. m, Montoya limestone; e, El Paso limestone; gr, granite



C. NORTH SIDE OF ENTRANCE TO ALAMO CANYON, 3 MILES SOUTHEAST OF ALAMOGORDO

mg, Limestone of Magdalena group; f, Fusselman limestone; c, cherty member of Montoya limestone; m, dark massive member of Montoya limestone; e, El Paso limestone

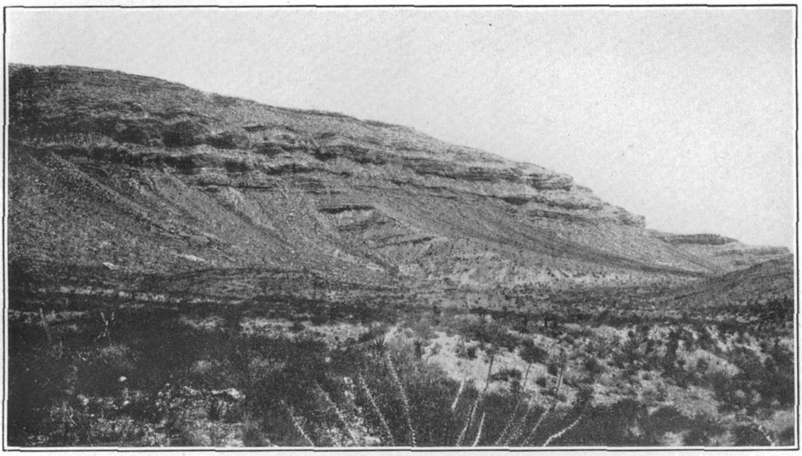


A. VIEW LOOKING NORTHWEST DOWN FRESNAL CANYON, SACRAMENTO MOUNTAINS, FROM A POINT HALFWAY BETWEEN LA LUZ AND HIGH ROLLS

Ridges of Abo sandstone in syncline with limestones of Magdalena group on each side

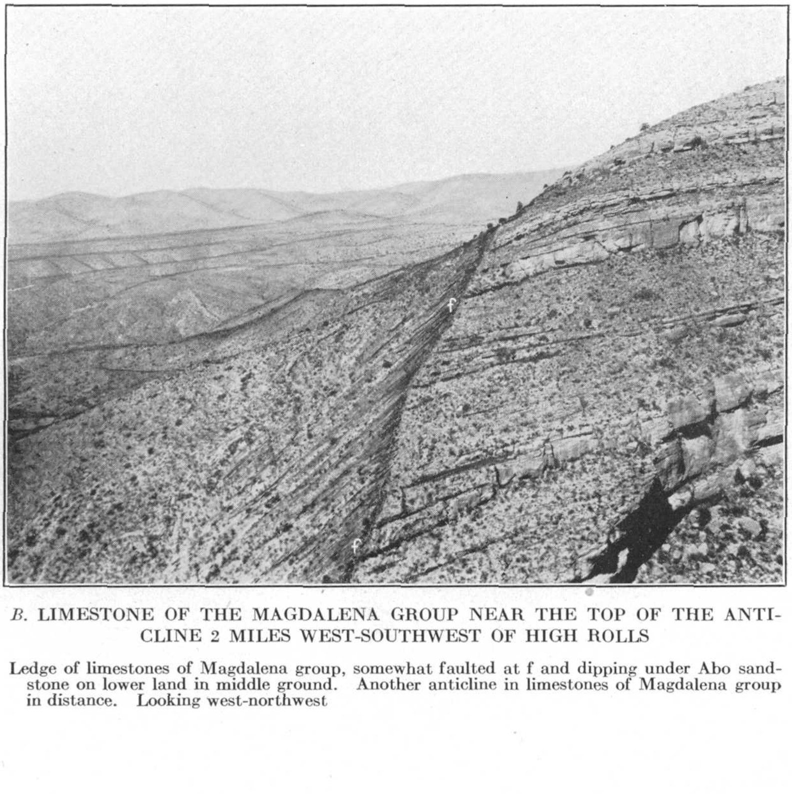
B. SURFACE OF RECENT LAVA FLOW OR "MALPAÍS" AT UPPER CROSSING, 12 MILES SOUTHWEST OF CARRIZOZO

Looking south



A. SOUTHERN EXTENSION OF WESTERN RIDGE OF SACRAMENTO MOUNTAINS, 6 MILES EAST OF ORO GRANDE

Looking southeast. Chupadera formation, massive limestone on gypsum and red shales. Abo sandstone in ridge at extreme right



B. LIMESTONE OF THE MAGDALENA GROUP NEAR THE TOP OF THE ANTICLINE 2 MILES WEST-SOUTHWEST OF HIGH ROLLS

Ledge of limestones of Magdalena group, somewhat faulted at f and dipping under Abo sandstone on lower land in middle ground. Another anticline in limestones of Magdalena group in distance. Looking west-northwest

FUSSELMAN LIMESTONE (SILURIAN)

The ledge of Fusselman limestone extends continuously along the steep slope of the mountain front from Alamo Canyon to a point near Little Agua Chiquita Canyon. (See fig. 82.) The thickness ranges from 105 to 130 feet, the maximum being in Alamo Canyon. As in other uplifts in New Mexico, the formation comprises two members—an upper one about 50 feet thick of hard dark limestone carrying distinctive fossils, and a lower one of compact, fine-grained gray limestone that weathers nearly white and is 60 feet thick in Dog Canyon and 85 feet thick in Alamo Canyon. The lower member yielded no fossils but is arbitrarily included in the formation. In Alamo Canyon it is sharply separated from the upper member. It constitutes a steep light-colored slope below the dark cliff of the upper member of the formation. This cliff is well shown in Plate 45, *C*. The fossils from the upper member indicate Niagara age.

PERCHA SHALE (DEVONIAN)

Above the Fusselman ledge there is a slope in which black shale is exposed in places, and some of it contains limestone layers all closely similar in character to the Percha rocks exposed in the San Andres Mountains and other ranges. A few fragmentary fossils obtained from these rocks are regarded by Kirk as probably Devonian.

LAKE VALLEY LIMESTONE (MISSISSIPPIAN)

Next above the dark shale supposed to represent the Percha is gray shale with layers of limestone containing abundant crinoid fragments and a large number of other fossils. The shale is about 50 feet thick and is capped by a massive bed of limestone which makes a conspicuous ledge or bench along the mountain slope as far north as the latitude of Alamogordo. This is presumably the bed in which G. H. Girty found fossils 2 miles north of Alamo Canyon. The section, which he has kindly given to me from his notes, is as follows:

Section of Mississippian limestone at a point N. 63° E. of Alamogordo

	Feet
Light-colored crinoidal limestone, some very soft and weathering to fragments; fossils	75
Dark siliceous limestone with chert in beds	30
Massive, rather soft calcareous shale; large crinoid stems and *Schizophoria*	5
Dark limestone and thin shale interbedded; limestone with "Cauda galli"	20
Dark bluish-gray calcareous shale, thin bedded and rather massive, extending to talus of desert plain; fossils	15+

Above the top is 300 feet of light sandstone, presumably at the base of the Magdalena group but without fossils. (See section, p. 203.) The fossils obtained by Girty from these beds were as follows:

Triplophyllum sp.
Leptaena analoga.
Schuchertella aff. S. chemungensis.
Rhipidomella diminutiva?
Schizophoria poststriatula?
Productus gallatinensis.
Productella n. sp. aff. P. pyxidata.
Shumardella? aff. S. missouriensis.
Brachythyris suborbicularis.
Ambocoelia levicula.
Reticularia cooperensis.
Proetus peroccidens.

In 1915 I collected from shale about 50 feet above the Fusselman ledge on the north wall of Alamo Canyon the following forms identified by Girty:

Zaphrentis sp.
Rhipidomella dalyana.
Schizophoria? sp.
Spirifer rowleyi.
Spirifer centronatus?
Delthyris novamexicana.
Composita humilis?
Cliothyridina prouti?
Cliothyridina sp.

At the same horizon in the slope near Dog Canyon were collected the following:

Schizoblastus aff. S. roemeri.
Dielasma sp.
Spirifer aff. S. grimesi.
Platyceras aff. P. fissurella.
Platyceras aff. P. paralius.
Platyceras aff. P. equilatera.

MAGDALENA GROUP (PENNSYLVANIAN)

The broad middle slopes of the west front of the Sacramento Mountains expose the limestone and shale of the Magdalena group from the middle of T. 20 S. to and beyond La Luz Canyon. East and southeast of Alamogordo these rocks constitute the high cliffs and huge steps of the front ridge and the plateau spurs extending from the higher part of the range. This feature is well shown in Plate 45, and the structural relations in Figures 80 and 82. Plate 46, *A*, shows the character of some of the higher strata. The thickness of the beds approximates 1,500 feet, but no precise measurement was made. White limestone predominates, and there are many beds of shale and some of sandstone. The following section, given to me by G. H. Girty from his notebook, shows the succession in the steeper slopes east of Alamogordo. It comprises considerably more than two-thirds of the group.

Partial section of limestones of Magdalena group in the ridge N. 63° E. of Alamogordo

	Feet
Limestone, massive	50±
Thinner beds and concealed	100±
Limestone, dark	50±
Concealed	30
Dark limestone	3
Concealed	50
Soft greenish gritty sandstone	10
Concealed, débris, limestone, and thin greenish sandstone	100
Dark massive limestone, weathering brown	25
Concealed	20
Dark limestone	5
Sandy shale, partly concealed	10
Earthy limestone; fossils	4
Dark shale above (20 feet), concealed below	50
Argillaceous and calcareous shale; fossils	10
Dark siliceous limestone	10
Greenish sandy shale	15
Greenish-brown gritty sandstone	10
Shaly material	5
Thin dark siliceous limestone	10
Concealed, probably thin impure limestone	15
Massive dark limestone	10
Concealed	15
Siliceous limestone below, concealed in middle, purer and fossiliferous limestone above	20
Greenish gritty sandstone, thin-bedded below, massive in middle, thinner above	60
Partly concealed, upper part with thin black limestone weathering bluish and yellowish	50
Lower 30 feet probably thin gritty sandstone; upper 20 feet massive; some layers calcareous, with quartz pebbles and fossils	50
Gritty sandstone, calcareous below and fossiliferous	10
Dark-brown limestone, somewhat shaly; many fossils	10
Poorly exposed; probably thin dark siliceous limestone, weathering brown; poor fossils	100±
Black limestone, siliceous, weathering brown	3
Poorly exposed; probably thin impure limestone and a few ledges of dark cherty limestone; poor fossils	50
Light-colored sandstone and fine conglomerate; poorly exposed	100±
Shale with calcareous layers; fossils	30
Dark impure limestone	15
Unexposed; probably thin sandstone and thin impure limestone; *Productus cora* and *P. semireticulatus* in débris	100
Whitish and rusty gritty sandstone, and fine conglomerate, not well exposed, lying on about 150 feet of limestone and shale with Mississippian fossils (see p. 202)	300±
	1,505

From beds relatively low in this section Girty collected the following fossils:

Sponge.	Marginifera splendens.
Stenopora sp.	Dielasma bovidens.
Fenestella sp.	Spirifer cameratus.
Rhipidomella pecosi.	Spiriferina rockymontanus.
Derbya crassa.	Spiriferina campestris?
Meekella striaticostata.	Squamularia perplexa.
Chonetes flemingi var. verneuilianus.	Composita subtilita.
Productus semireticulatus.	Platyceras sp.
Productus cora.	Paraparchites? sp.
Productus nebrascensis.	Aviculipecten n. sp.

From a horizon considerably higher, between Pinto and La Luz, Girty collected *Lingula carbonaria*, *Aviculipecten* sp., *Modiola?* sp., and *Naiadites elongatus.*

On the west side of the La Luz anticline, in 1900, R. T. Hill collected *Fusulina secalica*, and this species was also found by Girty above Pinto. In still higher beds half a mile to 1½ miles below High Rolls, along the road to Alamogordo, Girty in 1902 found the following species:

Meekella striaticostata.	Spirifer cameratus.
Productus semireticulatus.	Squamularia perplexa.
Productus pertenuis.	Composita subtilita.
Marginifera splendens?	

One mile below Pinto, in 1902, Girty found in the top beds *Fusulina secalica, Productus semireticulatus, Marginifera wabashensis*, and *Composita subtilita.*

Between High Rolls and Pinto Girty found in beds high in the group *Marginifera wabashensis* and *Squamularia perplexa.* At about the same horizon in the creek bed above Pinto I collected *Axophyllum?* sp., *Spiriferina kentuckyensis, Squamularia perplexa*, and *Composita subtilita.* In medial or upper beds 2 miles east of La Luz R. T. Hill collected the following species in 1900:

Fusulina secalica.	Composita subtilita.
Enteletes hemiplicatus.	Allerisma terminale?
Derbya sp.	Aviculipinna nebraskensis.
Meekella striaticostata.	Aviculipecten sp.
Chonetes granulifer.	Schizodus sp.
Productus cora.	Plagioglypta canna?
Productus semireticulatus.	Bellerophon crassus?
Spirifer cameratus.	Nautilus sp.
Ambocoelia planiconvexa.	

Not far below the base of the Abo formation in Caballero Canyon, east of Alamogordo, G. B. Richardson in 1909 found the following:

Fusulina secalica.	Trepospira? sp.
Rhynchopora aff. R. taylori.	Bucanopsis sp.
Dielasma bovidens.	Euomphalus catilloides.
Composita subtilita.	Meekospira sp.
Nucula sp.	Gonioloboceras goniolobus.
Pleurotomaria sp.	

I found *Fusulina cylindrica* on the west side of the ridge a few rods from La Luz siding.

ABO SANDSTONE (PERMIAN)

The outcrop of the Abo sandstone, the basal formation of the Manzano group, extends continuously along the middle part of the west slope of the Sacramento Mountains, from Fresnal Canyon to the center of T. 20 S., where the south pitch of the anticline carries it beneath the surface. In the Fresnal Canyon region the outcrop zone is greatly widened by an anticline, as shown in Plate 46, *A*. The thickness of beds is about 700 feet to the north and 400 feet in the vicinity of Grapevine Canyon. The rocks are brownish-red sandstone and sandy shale, with beds of coarse brown sandstone, which are conspicuous about Fresnal Creek and near High Rolls. At the base are alternations of shale, fine conglomerate, and limestone, lying on or part of the Magdalena group. Böse [20a] reported fossils from this horizon or its vicinity east of Tularosa. Although new species, they were thought to be Pennsylvanian, but G. H. Girty informs me that even if they were obtained from Abo beds they are not diagnostic as to precise age. J. W. Beede [20b] also states that the material is not critical.

CHUPADERA FORMATION (PERMIAN)

The Sacramento Mountains are capped by a thick sheet of the Chupadera formation, the upper formation of the Manzano group, which ends on the west in cliffs and steep slopes but extends eastward as a sloping plateau or cuesta that continues to the Pecos Valley. The thickness is about 1, 500 feet. The top half is a succession of massive limestones, and the bottom half consists of sandstone and sandy shale, in part red. Thick beds of gypsum are included at several horizons in the medial and lower members. Bright-yellow sandstone also occurs in the medial part. Owing to the large amount of talus it was not possible to make a detailed section of the rocks that underlie the thick body of limestone from La Luz Canyon to the south end of the range. The most conspicuous features on the steep west front are high cliffs of limestone extending along the mountain crest, and most of the canyons on the east slope do not cut through this limestone. Exposures of the underlying beds appear along the east side of the fault in T. 19 S., and there are fairly good exposures of them in Grapevine Canyon. In the ascent to Cloudcroft from Mountain Park there are a few small outcrops of red beds and buff sandstones, but talus and extensive land slips cover the softer beds.

On the north side of La Luz Canyon there are long bare slopes of red and buff sandstone, with interbedded gypsum, which affords a fairly good idea of the strata that underlie the slopes near Cloudcroft

[20a] Böse, Emil, On the ammonoids from the Abo sandstone of New Mexico: Am. Jour. Sci., 4th ser., vol. 49, pp. 57-60, 1920.

[20b] Am. Assoc. Petroleum Geologists Bull., vol. 5, p. 331, 1921.

and for a long distance to the south. In slopes near Grapevine Canyon a thick body of red sandstone with included thin deposits of gypsum is exposed. The limestones of the upper member appear to be 600 to 800 feet thick, chiefly in thick massive beds separated by sandstone, mostly buff or yellow but in part red. The limestones constitute high cliffs all over the mountain crest and along the valleys leading out to the east and south in an area 75 miles or more in width, or nearly to Pecos River. The gorge of Sacramento River presents many such cliffs, some of them showing 200 feet of solid limestone ledges. Successively lower beds are exposed in this gorge down to the mouth of Surveyors Canyon, where the dip changes to the south. In James Canyon, east of Cloudcroft, 500 feet of limestone is exposed within a few miles, because the descent of the valley is steeper than the low easterly slope of the beds. In places the solid ledges are separated by slopes showing red dirt or buff sandstone. Finally the grade of the canyon and the dip of the beds become the same and no lower strata are exposed. About Mayhill the canyon walls are more lofty, owing to the descent of higher beds of limestone on locally increased dip. The canyon of Rio Penasco has limestone walls due to thick members of rock, as shown in Plate 7, *C*. The dips are very low, but just below Elk there is a small roll or anticline, and just east of Dunkin there is a small dome. (See p. 214.) Fossils were collected at the falls of the Rio Penasco from beds about 200 feet below the top of the formation. Two miles below the falls is a 250-foot cliff of limestone, and this member crops out for several miles down the creek. At the YO ranch the limestone walls are 80 feet high, and a bed of bright-yellow sandstone is included. I estimate that the sum of beds exposed from the cliffs at Cloudcroft to Hope is not more than 1,000 feet, but this is only an approximation. The strata thicken considerably underground to the east, as is shown by the records of borings. Much of the limestone contains magnesium carbonate, samples from near Hope and Queen both containing 39 per cent, with about 7 per cent of insoluble matter.

In the higher western slopes of the south end of the Sacramento Mountains there are more or less continuous exposures of the lower members of the Chupadera formation, but the succession is greatly obscured by talus. Soft red sandstone prevails, with red sandy shale, a few thin layers of limestone or dolomite, and deposits of gypsum 10 to 20 feet thick. Exposures near the Oro Grande ditch in T. 19 S. show these features with 200 to 250 feet of the Abo sandstone below.

Fossils are very abundant in some of the limestone beds in the upper part of the Chupadera formation. Extensive collections were made by G. H. Girty, C. A. Fisher, G. B. Richardson, R. T. Hill, and myself at several localities. A list of the principal species as determined by Girty is given in the following table:

Fossils collected from limestone of Chupadera formation in Sacramento Mountain region

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Lophophyllum			×		×						×			
Echinocrinus sp	×		×		×		×		×		×			
Batostomella? sp	×													
Stenopora sp	×				×									
Derbya sp	×													
Chonetes aff. C. geinitzianus	×		×											
Productus ivesi	×	×	×	×	×					×	×			
Productus leei?	×	×			×								×	
Productus subhorridus?	×		×	×			×		×		×		×	×
Productus mexicanus?	×		×	×				×		×			×	
Productus occidentalis	×		×											
Pugnax osagensis var. pusilla	×		×	×					×					
Marginifera cristobalensis	×													
Marginifera manzanica	×													
Composita subtilita									×					
Composita mexicana	×	×		×	×	×	×		[illegible]		×	×		
Cardiomorpha? sp	×				×			×				×		
Solenomya sp	×													
Nucula levatiformis	×				×		×	×				×		
Euphemus subpapillosus								×						
Manzanella elliptica	×					×		×						
Aviculipecten aff. A. vanvleeti	×											×		
Acanthopecten carboniferus?	×													
Pernipecten? sp	×							×						
Modiola sp	×						×							
Myalina aff. M. meliniformis	×						×	×				×		
Myalina aff. M. perniformis	×													
Pleurophorella gilberti?	×							×						
Cleidophorus aff. C. pallasi	×											×		
Pleurophorus mexicanus?	×													
Pleurophorus aff. P. occidentalis	×													
Bakewellia? sp	×					×	×		×					
Parallelodon? sp	×							×						
Schizodus n. sp	×													×
Schizodus wheeleri?	×													
Bucanopsis modesta	×													
Astartella? sp	×													
Sedgwickia sp	×													
Plagioglypta canna	×	×							×					×
Bellerophon majusculus	×	×	×	×							×			
Pleurotomaria sp	×		×	×										
Murchisonia aff. M. terebra	×?		×											
Murchisonia sp.?	×	×												
Soleniscus sp	×													
Euomphalus n. sp	×	×	×	×		×				×	×			×
Naticopsis deformis?	×		×					×						
Orthoceras sp	×					×								
Coloceras globulare?	×													
Metacoceras aff. M. inconspicuum	×													
Domatoceras highlandense?	×													
Nautilus sp	×				×									
Anisopyge inornata	×													
Griffithides sp	×					×			×					

1. Railroad cuts on slopes west of Cloudcroft, by Girty, Fisher, Richardson, and Darton.
2. Pine Springs, Sacramento Mountain, by Fisher. Also *Schizodus* aff. *S. ulrichi*.
3. Near the falls, 2 miles above Lower Penasco, by Darton and Fisher.
4. High hill on south side of Penasco Creek near Weed, by Fisher.
5. Five miles east of Lower Penasco, by Hill.
6. Ten miles east of Lower Penasco, by Hill.
7. At Weed, by Fisher.
8. Sawmill Canyon, south of Cloudcroft, by Fisher.
9. About 5 miles below Maybill, by Richardson. Also *Productus horridus*.
10. At C A ranch, by Fisher.
11. Pretty Bird Creek, Guadalupe Mountains, by Richardson.
12. Two miles east of Pine Spring, by Hill.
13. On Lincoln-Roswell road near Picacho, by Richardson.
14. Four miles above Mescalero Indian Agency, by Fisher.

Borings.—A 4,895-foot hole in sec. 29, T. 17 S., R. 18 E., near Dunkin, penetrated strata given in the following record:

Record of boring on Dunkin Dome, SW. ¼ sec. 29, T. 17 S., R. 18 E., Chaves County

	Feet
Limestone, yellow on gray on brown	0–600
Sandstone, red, soft	600–610
Limestone, hard, gray on brown	610–705
Sandstone, yellow; conglomeratic at top	705–765
Limestone, hard, dark	765–790
Conglomerate, red, soft	790–815
Sandstone, yellow, soft	815–845
Limestone, brown, hard, on 5 feet of red gravel	845–860
Shale, red, soft	860–980
Limestone, mostly gray and hard, some shale	980–1, 170
Shale, blue on red on gray; 30 feet of limestone at 1,300 feet	1, 170–1, 350
Limestone, hard, mostly dark or gray; 20 feet gypsum at 1,600 feet	1, 350–2, 210
Sandstone, hard, mostly red, white at top and bottom	2, 210–2, 375
Limestone, hard gray on brown	2, 375–2, 420
Sandstone, hard,brown gray, on 10 feet of red shale	2, 420–2, 450
Limestone, hard, mostly gray, red in middle	2, 450–2, 510
Sandstone, soft white, salt water, on 5 feet of red shale	2, 510–2, 555
Limestone and gray sandstone on red shale	2, 555–2, 565
Limestone, hard, gray, with thin beds of blue shale, 5 feet of red sand at 2,615	2, 565–2, 685
Sandstone, black on brown to gray limestone	2, 685–2, 755
Shale, blue and green	2, 755–2, 812
Shale, red, 10 feet of hard gray shale at base	2, 812–2, 995
Limestone, gray on black, sandy in part	2, 995–3, 150
Shale, red, some sandy, few thin limestones	3, 150–4, 155
Sandstone, gray, shale, black, and hard gray lime stone	4, 155–4, 228
Shale, pink on red, on hard gray shell	4, 228–4, 255
Limestone, gray, little shale	4, 255–4, 280
Shale, red and gray	4, 280–4, 320
Limestone, gray and blue, hard, part sandy	4, 320–4, 420
No record	4, 420–4, 895

The Chupadera formation probably extends to 3,150 feet and the Abo sandstone from 3,150 to 4,155 feet. The lower strata are doubtless Magdalena beginning with 72 feet of gray sandstone, black shale and hard gray limestone at 4,155 feet. The precise location of the boring is shown in Figure 87.

A boring at Picacho had the following record:

Condensed record of boring at Picacho

	Feet
Sand, loam, and gravel	0–113
Shale, with limestone and much gypsum	113–530
Limestone, with some red sandstone	530–789
Sandstone, part red	789–882
Shale, red	882–968
Limestone	968–1, 026
Sandstone, mostly gray	1, 026–1, 109
Salt, limestone, and shale; some sandstone	1, 109–1, 250
Limestone and shale; some sandstone, part red	1, 250–1, 580
Sandstone mostly	1, 580–1, 670
"Granite"	1, 670–2, 199

This boring appears to have penetrated Chupadera beds to 1,580 feet and then Abo sandstone for 90 feet. It is possible that the material called "granite" is an intrusive mass similar to that in the Capitan Mountains, not far west.

The following record is considerably condensed from a log kindly furnished by the Arkansas Fuel Oil Co.:

Record of Manning well, in the SE. ¼ NE. ¼ sec. 14, T. 15 S., R. 17 E., near Felix, Chaves County

	Feet
Sand, caliche, and quicksand	0–60
"Gyp rock" (?)	60–68
Limestone	68–78
Sandstone, mostly fine and light	78–115
Shale, blue, sandy, with 10 feet of limestone at 125 feet	115–215
Sandstone; artesian water in large volume at 275 feet	215–290
Limestone and sandstone on sandy shale	290–315
Limestone, sandy in lower part	315–355
Sandstone, yellow, on sandy limestone	355–375
Shale, blue	375–400
Limestone	400–415
Sandstone, yellow, on blue shale	415–435
Limestone with 10 feet of blue shale at 450 feet	435–465
"Red rocks"	465–525
Sandy limestone on gray limestone	525–550
Sandy shale, blue	550–560
Red rocks with gray limestone at 565, 595, and 615–635 feet	560–650
Limestone, mostly light	650–830
Red rocks	830–850
Limestone; some gypsum at 860 feet	850–895
Gypsum	895–915
Limestone; some gypsum	915–955

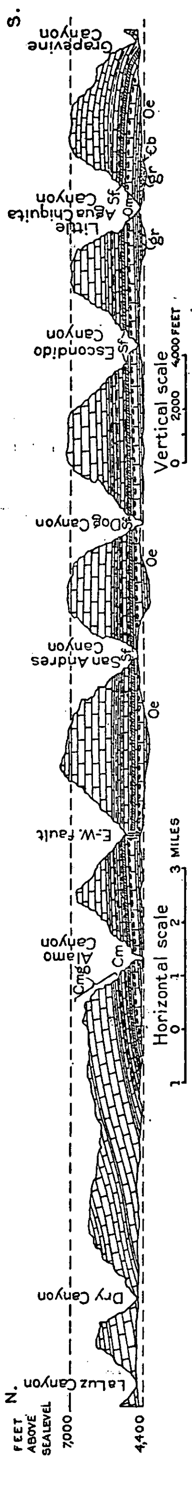


FIGURE 82.—Section along west slope of Sacramento Mountains east of Alamogordo, from La Luz Canyon to Grapevine Canyon. Base of section is upper edge of alluvial fan and valley fill. gr, Granite; Єb, sandstone (Bliss?); Oe, El Paso limestone; Om, Montoya limestone (dark massive limestone overlain by cherty limestone); Sf, Fusselman limestone; Cm, shaly limestone with Mississippian fossils; Cmg, Magdalena group

	Feet
Limestone, mostly dark	955–1, 090
Red rocks and limestone	1, 090–1, 158
Limestone	1, 158–1, 380
Red shale and limestone on sandstone	1, 380–1, 403
Sandy limestone on black sandy shale	1, 403–1, 430
Shale, red, sandy	1, 430–1, 525
Not given	1, 525–1, 535
Limestone, dark	1, 535–1, 545
Red rocks and red gypsum	1, 545–1, 566?
Limestone, mostly dark	1, 566?–1, 595
Red rocks (mostly)	1, 595–1, 695
Blue shale and limestone	1, 695–1, 732
Limestone, gray (mostly)	1, 732–1, 790
Limestone, black, and salt	1, 790–1, 795
Limestone, white	1, 795–1, 816
Limestone and salt	1, 816–1, 825
Red beds (mostly)	1, 825–2, 185
Sandstone, limestone, and shale	2, 185–2, 235
Red beds with limestone	2, 235–2, 600
Limestone and red beds	2, 600–2, 820

This boring was continued to a depth of 3,440 feet, but no record was obtained below 2,820 feet, to which depth all the beds apparently were Chupadera. Probably much more gypsum or anhydrite was penetrated than is given in the record.

STRUCTURAL DETAILS

The greater part of the Sacramento Mountains is a cuesta sloping eastward into the Pecos Valley. Its western summits exceed 9,000 feet in altitude and the slopes eastward finally decline to 3,600 feet. At first glance the great western escarpment appears to be due solely to a fault, but closer scrutiny shows that the dominant feature is an anticline, faulted somewhat in its higher portion south of Alamogordo. This anticlinal structure is well exhibited near Alamo Peak and in Alamo Canyon and for several miles near the north and south ends of the mountains. At La Luz the westerly dips are pronounced, and not far north of that place the limestone of the Magdalena group pitches to the north as well as to the east. Similar conditions exist from Grapevine Canyon south for some distance. The arch rises so high from Alamo Canyon to Little Agua Chiquita Canyon and beyond that the Ordovician limestones are exposed, and near Little Agua Chiquita Canyon the Bliss (?) sandstone and pre-Cambrian appear for a short distance. This upward pitch of the strata is shown in Figure 82.

The westerly dips are well exhibited in the long slopes due east of Alamogordo, but in Alamo Canyon, as shown in Figure 83, this anti-

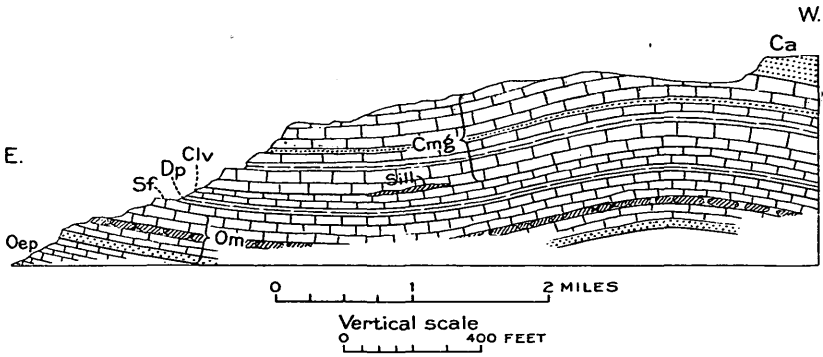


FIGURE 83.—Section in Alamo Canyon southeast of Alamogordo. Ca, Abo sandstone; Cmg, Magdalena group; Clv, Lake Valley limestone; Dp, Percha shale; Sf, Fusselman limestone; Om, Montoya limestone; Oep, El Paso limestone

clinal axis lies east of the front escarpment, and it passes under the high limestone plateau to the south. Two miles south of the north end of Alamo Canyon the escarpment is crossed diagonally by a fault which has the relations shown in Figure 84. The pronounced westerly dip in the El Paso limestone in this section is believed to

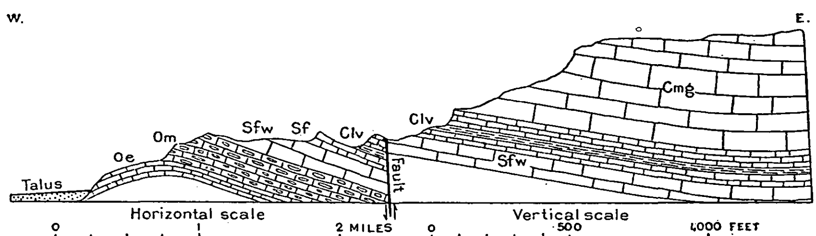


FIGURE 84.—Section of west front of the Sacramento Mountains 4 miles south-southeast of Alamogordo. Oe, El Paso limestone; Om, Montoya limestone; Sfw, limestone weathering white (probable lower Fusselman); Sf, Fusselman limestone; Clv, shaly limestone with Mississippian fossils; Cmg, Magdalena group

indicate that the axis of an anticline passes along the western front. In the mouths of San Andres, Dog, and Escondido Canyons, however, the beds are nearly horizontal. In and near Agua Chiquita Canyon there is a west-east twist in the higher beds. South of Grapevine Canyon the dips change to southwest, the Ordovician limestones pitch below the surface, and in the center of T. 20 S. the Magdalena rocks also disappear, the Chupadera formation coming to the crest of the greatly lowered front ridge that extends thence southward through R. 11 E.

For about 30 miles the canyon of Sacramento River cuts deeply into the front of the Sacramento Mountains and is approximately parallel to the face of the great escarpment and to the general strike. In the northeast corner of T. 21 S., R. 13 E., this valley opens out into a broad flat filled with wash. Above this place it presents long successions of rocky walls, locally 200 to 500 feet high, of Chupadera limestone in which minor amounts of red and gray sandstone appear. The dip is very low, in general to the east but with local variations, and finally in T. 20 S. it changes to the south, causing a great lowering of the range and eastward deflection of its front. From the head

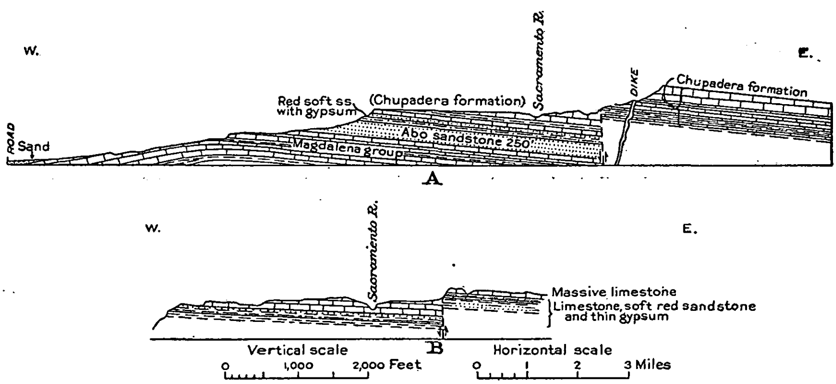


FIGURE 85.—Sections across southern part of Sacramento Mountains. A, Near Monument Creek; B, at Surveyors Canyon, in T. 20 S. (Chupadera formation)

of Sacramento River southward the higher part of the mountains lies east of the canyon of that stream, and in T. 19 S. the plateau to the west of the canyon is 1,000 feet lower than the escarpment on the east. Apparently in this vicinity, at least, this difference is due to a strike fault with considerable uplift on the eastern or higher side, a relation well shown on Monument Creek east of bench mark 7071 and also in Surveyors Canyon. The two sections in Figure 85 show the apparent relations, and the course of the fault is shown on the geologic map (pl. 44). Just west of this fault is a wide plateau capped by several hundred feet of massive limestone high in the Chupadera formation; to the east are slopes of red sandy shale and soft red sandstone with thin beds of limestone and some gypsum deposits such as are characteristic of the lower half or third of the formation and appear along the west front of the great escarpment capping the Abo sandstone. (See center of section A, fig. 85.)

In Fresnal Canyon the general uniformity of the eastward-dipping monocline of the Sacramento Mountains is interrupted by two pronounced anticlines shown by limestone of the Magdalena group, one somewhat faulted on its west side, and an intervening syncline occupied by the Abo formation. In places the dips are very steep, but the disturbance does not affect a large area. Figure 86 shows the principal relations, and some features are shown in Plate 46, *A*. The fault, which for most of its course is less than 150 feet in throw, extends north-northeastward for a mile or more, passing into a steep upturn of the upper Magdalena beds in a railroad cut a short distance west of Pinto siding. The western anticline of the two mentioned above continues southward to Alamo Canyon. (See fig. 86.)

The very wide eastward-sloping cuesta extending east from the summit of Sacramento Mountains presents a nearly general easterly

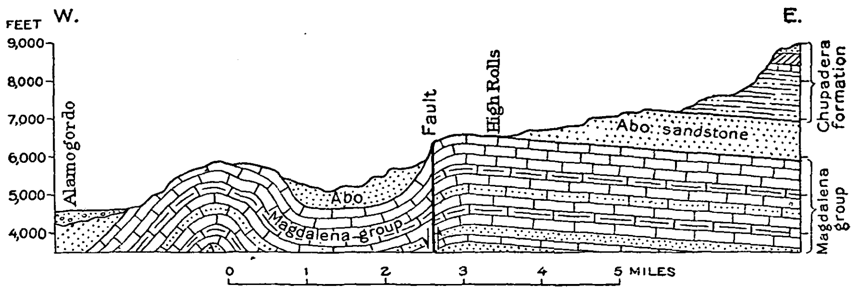


FIGURE 86.—Section from a point south of La Luz through High Rolls, Otero County

dip of the Chupadera formation. The rate of dip is so low that no great thickness of the strata is exposed on the plateau surface, which consists mainly of a great sheet of limestone. There are, however, many local undulations, the configurations of which have been worked out by geologists connected with oil companies. One dome near Dunken is shown in Figure 87 from a map kindly supplied by Mr. T. S. Hogan. Another just west of Picacho with closure of about 600 feet has its crest just west of the center of T. 11 S., R. 18 E. There is a dome with about 300-foot closure west of Rock House, in Lincoln County, with its apex in sec. 30, T. 12 S., R. 17 E. The Felix dome, with its apex in sec. 2, T. 15 S., R. 17 E., is stated to have a closure of 150 feet. It is on the long, slender but sharp Border Hill uplift and fault, which extends from the southwest corner of T. 9 S., R. 21 E., to T. 15 S., R. 17 E. According to Merritt [21] it is traceable still farther, 65 miles in all, and a parallel fold to the south extends northeastward from Felix River in T. 15 S., R. 19 E. A small anticline was noted just below Elk. The Sixmile Hills, west

[21] Merritt, J. W., Structures in western Chaves County, N Mex.: Am. Assoc. Petroleum Geologists Bull., vol. 4, pp. 53-57, 1920.

and northwest of Roswell, are due to an anticline about 9 miles long. Renick [21a] has located a number of flexures in the Penasco Valley, and Nye [21b] has traced the YO overthrust northeastward into T. 14 S., R. 22 E.

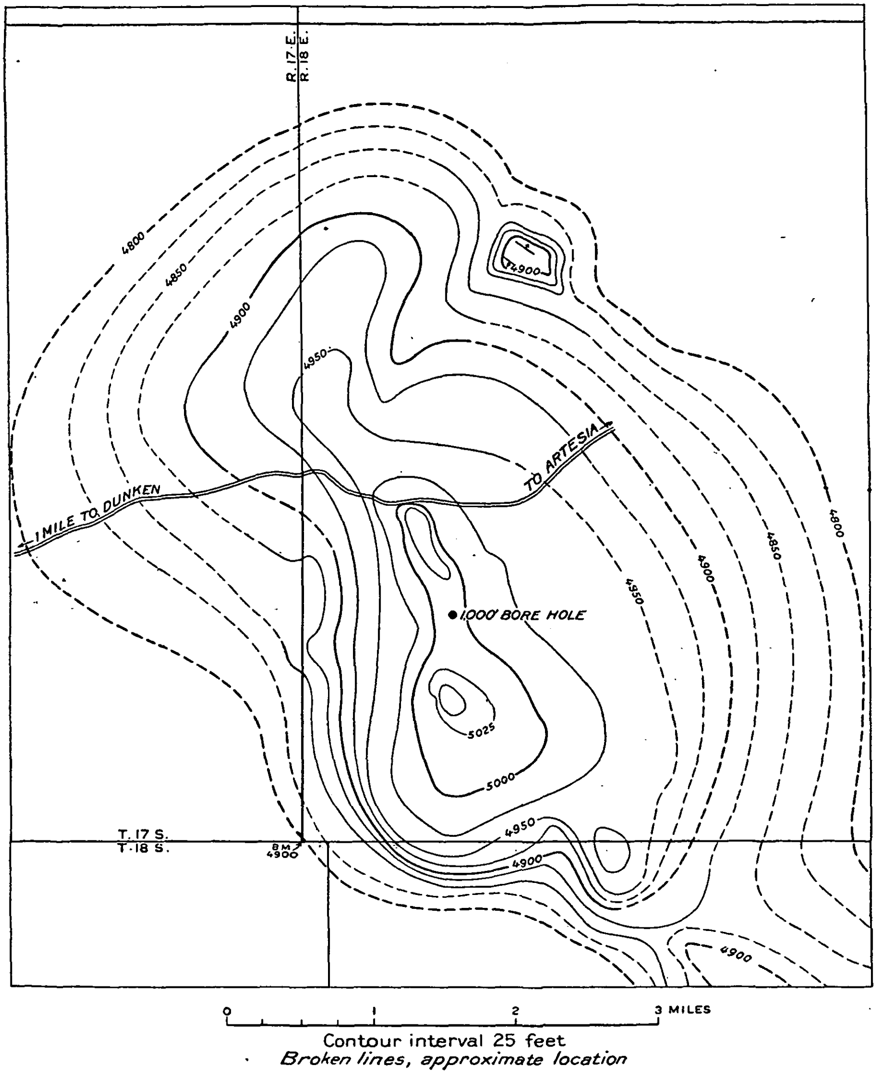


FIGURE 87.—Map showing configuration of Chupadera formation in Dunken dome. By I. E. Stewart

Some years ago an *Ostrea* or *Gryphaea* was sent to me from Pine Spring on Sacramento Mountain, which may indicate that a remnant of Lower Cretaceous rocks exists in that region.

[21a] Renick, B. C., Geology and ground-water resources of the drainage basin of the Rio Penasco above Hope, N. Mex.: New Mexico State Engineer Seventh Bienn. Rept., pp. 103–138, 1926.

[21b] Nye, S. S., personal communication.

SIERRA BLANCA BASIN

In the region south and east of Carrizozo there is an extensive structural basin in which the Chupadera formation is overlain by Triassic and Cretaceous strata cut by large intrusions of porphyry of various kinds and overlain in turn by Tertiary volcanic rocks. The high Sierra Blanca Peak, consisting of igneous rock, is near the center of the basin. These igneous rocks have not been studied in detail, and their representation on the map is only approximate in most places. The Cretaceous rocks consist of Dakota (?) sandstone and sandstone and shale of Colorado and Montana age. The Montana beds contain coal which has been mined to a small extent at several places on the sides of the basin. The relations of the coal beds have been described by Campbell[22] and Wegemann.[23] The Morrison (?) formation underlies the Dakota (?) sandstone in most of the area, resting on red beds presumably of the Dockum group. North of Ruidosa the coal measures are overlain by 600 feet of coarse sandstones probably of Tertiary age.

Many of the igneous rocks, which are mostly monzonite porphyry, are in large dikes and stocks. Their character and relations in the White Oaks, Jicarilla, Nogal, and other mining districts have been described by Graton.[24] They extend north in the Jicarilla Mountains and Jacks Peak, and a great dike of similar rock extends north from Tecolote station to Gallinas Mountain, in which it expands into a large stock or sill with an area of about 50 square miles. A notable deposit of iron ore is developed along its contact with the limestone of the Chupadera formation near Elda.

On the west side of the Sierra Blanca area are volcanic rocks comprising latite, rhyolite, agglomerate, and tuff from beneath which to the south rise Cretaceous, Triassic, and Permian rocks. East of the Sierra Blanca basin is an anticline of considerable prominence (shown in section A, fig. 88), which passes a short distance west of Lincoln and extends several miles north through the Jicarilla Mountains. It dies out in the plateaus northeast of Ancho. A minor dome on the east crest of this anticline lies near Richardson post office. There are in this region some large intrusive masses, notably that of the Capitan Mountains. In places along the slopes of this ridge north of Lincoln[24a] the lower shale and gypsiferous beds of the Chupadera formation are considerably crumpled by this intrusion, but the upper more massive beds of limestone are not much affected.

[22] Campbell, M. R., Coal in the vicinity of Fort Stanton, N. Mex.: U. S. Geol. Survey Bull. 316, pp. 431–434, 1907.

[23] Wegemann, C. H., Geology and coal resources of the Sierra Blanca coal field, N. Mex.: U. S. Geol. Survey Bull. 541, pp. 419–452, 1914.

[24] Graton, L. C., op. cit. (Prof. Paper 68), pp. 175–184.

[24a] Semmes, D. R., Notes on Tertiary intrusives of the lower Pecos Valley, N. Mex.: Am. Jour. Sci., 4th ser., vol. 50, pp. 415–430, 1920.

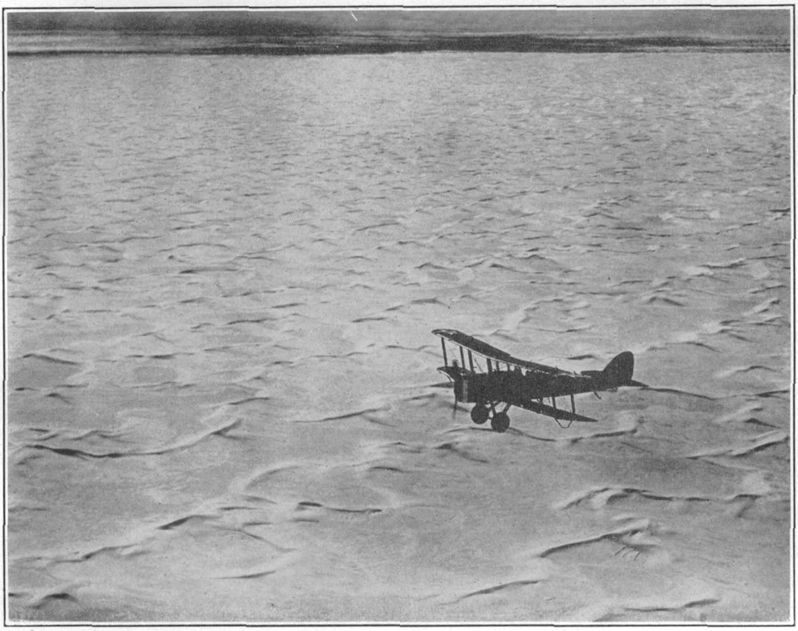
TULAROSA BASIN

The Tularosa Basin is a wide valley lying between the Sacramento and San Andres Mountains and extending from the vicinity of Carrizozo to the Texas line. Most of the surface is covered by sand, lava, and wash, but data obtained at intervals along its edges indicate that the general structure is synclinal, and probably there is considerable faulting. The four lower cross sections in Figure 88 show the principal structural features so far as they are known. On the west side of the basin are granite and schist constituting the medial and lower eastern slope of the San Andres Mountains, and on the northwest is the eastward-sloping cuesta of the Oscura Mountains and Chupadera Mesa. An anticlinal arch crosses the basin southwest of Carrizozo and, passing west of Oscuro, extends under the eastern part of Alamogordo, rises in the west face of the Sacramento Mountains, and continues southward into the Hueco Mountains. The structure west of this anticline to the foot of the San Andres Mountains is concealed by valley fill, but the small exposures of the limestone of the Chupadera formation in Cerrito Tularosa, Tres Hermanos, and the Jarilla Mountains indicate that a portion at least of this area is underlain by that formation, probably lying in a syncline.

Several unsuccessful deep borings for petroleum have been made in the Tularosa Basin, but the records are not sufficiently definite to indicate the nature of the underlying formations. Borings near Oscuro and Carrizozo penetrate deeply into sandstone and shale of the Upper Cretaceous, and it is not unlikely that these formations underlie a part of the basin toward the south. An 800-foot boring for water at Temporal records 185 feet of loam, gravel, and sand, 20 feet of pink clay, and 595 feet of alternations of pink clay and "conglomerate." Probably the "conglomerate" is not correctly designated. A detailed account of this region has been given by Meinzer and Hare.[25]

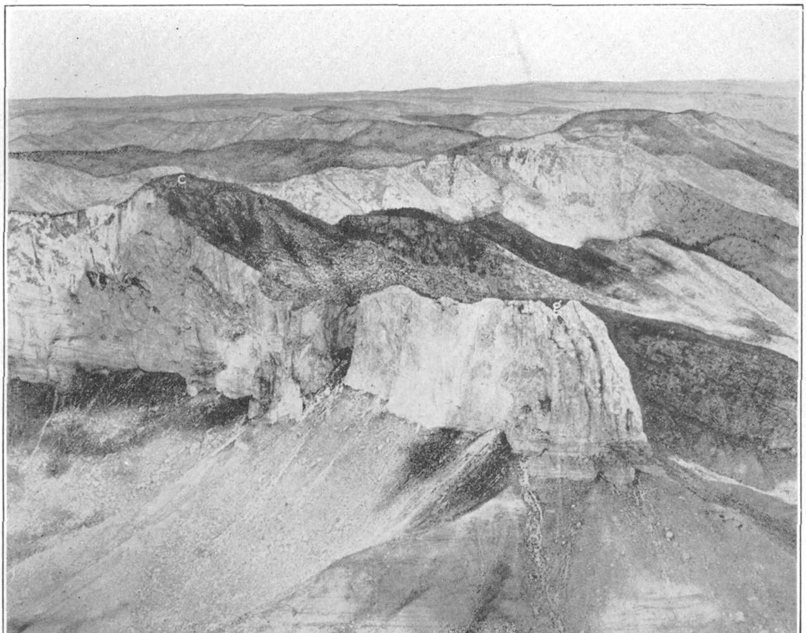
One of the most notable features in the area is the great deposit of white granular gypsum constituting the "White Sands" west of Alamogordo and Tularosa, views of which are given in Plates 43, *A*, and 48, *A*. This deposit is about 27 miles long from north to south and averages about 10 miles wide, although for some distance northwest of Alamogordo its width exceeds 13 miles. It covers fully 300 square miles in all. Its thickness possibly averages 50 feet, and much of the material contains no more than 2 or 3 per cent of impurity. The tonnage may be roughly estimated at 13 billion tons by calculating the weight of gypsum sand at 60 pounds to the cubic foot. Toward the north this deposit merges into quartz sand, also in dunes that occupy an area of about 20 square miles. Meinzer

[25] Meinzer, O. E., and Hare, R. F., Geology and water resources of Tularosa Basin, N. Mex.: U. S. Geol. Survey Water-Supply Paper 343, 1915.



A. WHITE SANDS OF TULAROSA BASIN WEST OF ALAMOGORDO

The material is gypsum. From photograph by U. S. Army Air Service, 1925



B. SOUTH END OF GUADALUPE MOUNTAINS, TEX.

Looking north far into New Mexico. c, El Capitan; g, Guadalupe Point. From photograph by U. S. Army Air Service, 1925 believes that this gypsum is largely derived from chemical deposition in lakes in the basin, which is an inclosed one, but much of it has been

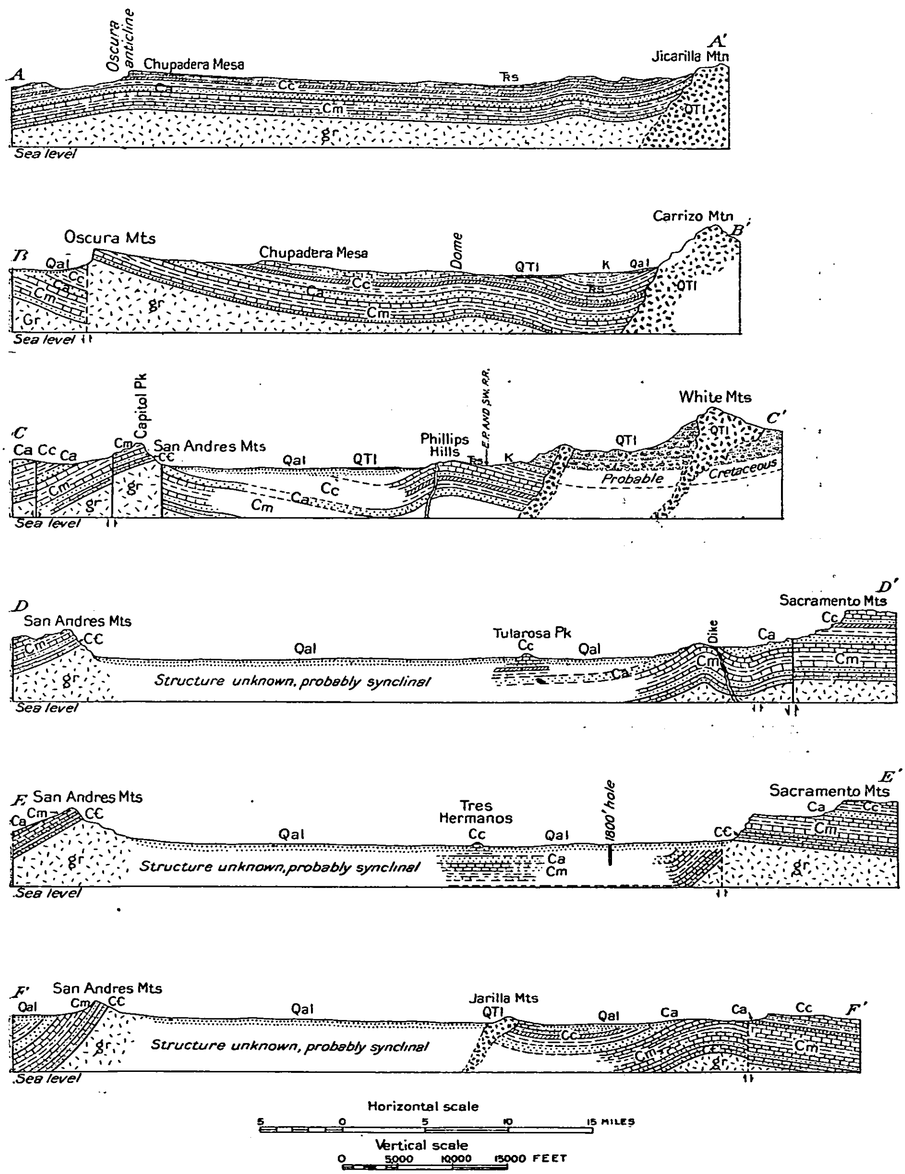


FIGURE 88.—Sections across Tularosa Basin and Chupadera Mesa. A, From southeast corner of T. 3 S., R. 6 E., to Jicarilla Mountains; B, from north end of Oscura Mountains to Carrizo Peak; C, through Capitol Peak, San Andres Mountains, to Sierra Blanca; D, from San Andres Mountains east through Tularosa Peak; E, through Lake Lucero and Tres Hermanos butte; F, east from south end of San Andres Mountains through northern part of Jarilla Mountains. QTl, Porphyries; Cc, Chupadera formation; Ca, Abo sandstone; Cm, Lake Valley and Magdalena limestones; C€, Bliss sandstone, El Paso, Montoya, and Fusselman limestones and Percha shale

brought to the surface by ground waters "through processes in some respects similar to those involved in the formation of caliche," and it has been heaped into eastward-moving dunes by wind action. Deposits of salt, sodium sulphate, and other compounds occur in the lowest part of the basin.

Another interesting feature in this region is a long, narrow flow of recent lava, "the malpaís," which occupies the center of the basin west of Carrizozo. It came from a crater in T. 6 S., R. 10 E., and flowed south for about 50 miles. Some of its features are shown in Plate 16, *A*.

Condensed record of boring in sec. 34, T. 13 S., R. 8 E., 12 miles northwest of Tularosa

	Feet
Sand, clay, and gypsum (largely valley fill)	0–370
Sandstone, gray	370–380
Red beds with gypsum (sandstone and shale), some brown, yellow, gray, and green; water sand at 1,150 feet	380–1, 302
Limestone with black shale at 1,350 and 1,375 feet	1, 302–1, 385
Shale, black, gray, and green	1, 385–1, 485
Limestone	1, 485–1, 495
Shale, black, and "soapstone"	1, 495–1, 575
Limestone, gray	1, 575–1, 614
Shale, black; lignite streaks	1, 614–1, 642
Limestone, gray on blue	1, 642–1, 694
Sandstone, "red from about 1,750 to 1,860 feet;" quicksand at bottom	1, 694–1, 870
Limestone, gray	1, 870–1, 935
Sandstone, red	1, 935–1, 980
Limestone and sandstone, gray to blue; water at 2,070 and 2,332 feet	1, 980–2, 800
Shale, gray	2, 800–2, 910
Limestone, gray and black, and sandstone, brown; 10 feet of shale at 3,000 feet, water at 3,043 feet	2, 910–3, 350
Sandstone, red	3, 350–3, 368
Limestone, gray, on shale, gray	3, 368–3, 381
Shale, red	3, 381–3, 395
Limestone, black and gray, alternating	3, 395–3, 491
Shale, black, with 27 feet of hard black limestone near base	3, 491–3, 545
Shale, gray on brown on red; water sand at 3,580–3,586 feet	3, 545–3, 596
Limestone, gray	3, 596–3, 604
Shale, red, on 5 feet of brown shale	3, 604–3, 635
Limestone, black on brown	3, 635–3, 672
Limestone, "broken," on blue sandy limestone	3, 672–3, 700
Shale, dark	3, 700–3, 708
Limestone, black on gray	3, 708–3, 745
Shale, red	3, 745–3, 770
Limestone, gray	3, 770–3, 795
Shale, sandy	3, 795–3, 800
Shale, red	3, 800–3, 865
Limestone, gray on black	3, 865–3, 885
Shale, sandy	3, 885–3, 900
Shale, red, and shale and gypsum	3, 900–3, 955
Sandstone, water	3, 955–3, 965

It is difficult to identify formations in this record, but probably the lower strata are Magdalena, notwithstanding the inclusion of considerable red material below 3,381 feet. The 110 feet of red strata from 1,750 to 1,860 feet may be part of the Abo sandstone.

A hole bored in 1917 near Twin Buttes, 16 miles southwest of Alamogordo, reached a depth of 989 feet. The first 783 feet were reported to be in valley fill with considerable clay and gypsum. Red sandstone was penetrated from 783 to 797 feet, below which were limestones parted in a few places by small deposits of green to brown shale. These strata suggest Chupadera formation.

SOUTHERN EXTENSION OF SACRAMENTO MOUNTAINS

The more elevated portion of the Sacramento Mountains trends far to the east in the southern part of T. 20 S., but in the center of R. 11 E. there is a branch range which extends southward to Texas.

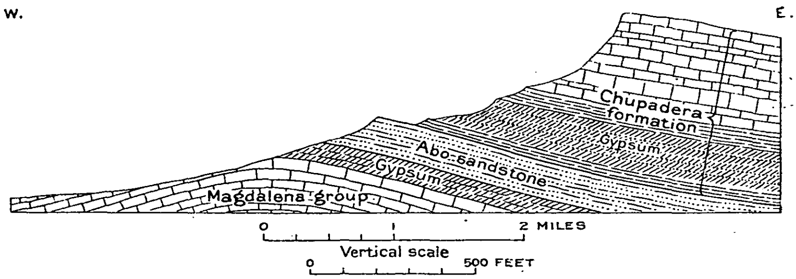


FIGURE 89.—Section of ridge about 6 miles northeast of Orogrande

It is crossed by a low pass in the northern part of T. 21 S., but farther south it rises into a ridge of considerable prominence, which near the Texas line is separated from the north end of the Hueco Mountains by a northward-trending valley of moderate width.

This range consists of limestone of the Chupadera formation, underlain by gypsum and red sandy shale belonging to the same formation, the shale lying on characteristic Abo sandstone, in turn underlain by the limestone of the Magdalena group, which becomes prominent in the Hueco Mountains. A cross section of the ridge at a point nearly due northeast of Orogrande is given in Figure 89, and the aspect of the ridge at this place is shown in Plate 47, *A*. The occurrence of gypsum below the Abo in this section is a novel feature. The overlying gypsum and massive limestone capping the ridge are characteristic of the Chupadera formation.

The long slope west of the mountain is made up of limestone of the Magdalena group, in a broad syncline that extends to the railroad but is possibly traversed by faults. The limestone farther west in the Jarilla Mountains carries a Chupadera fauna. At Orogrande station the limestone is traversed by andesite. A well bored at this place penetrated gypsum, limestone, sandstone, and clay to 80 feet, where the igneous rock was encountered. This rock continued to 580 feet, and below it limestone continued to the bottom at 960 feet.[26]

Not far south of Orogrande limestone ridges rise above the sand hills, and near the Texas line these ridges become the Hueco Mountains. A section was examined from Campbell Wells to Owl Tanks, 18 miles southeast of Orogrande, with the results shown in Figure 90. The Chupadera formation is well represented at this place by the succession of gypsum and red beds, and sandstone layers occur in the lower part of the limestone. The Abo beds are either absent or dropped by a fault. The limestone ridge was followed southward for some distance, but the west slope was found to be covered with talus and sod, so that the lower Chupadera beds were not seen. Finally, near the Texas line, the limestone ridge becomes low, and nothing could be ascertained as to its relations. The lower limestones rise into the Hueco Mountains a short distance to the east. There appears to be excellent evidence that in the extension of the range into Texas the

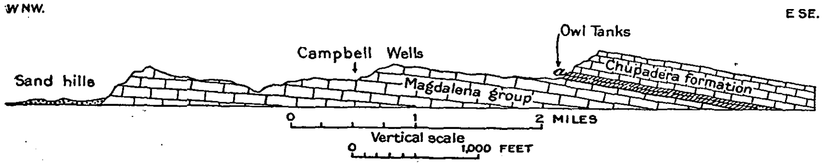


FIGURE 90.—Sketch section through Campbell Wells and Owl Tanks, 18 miles southeast of Orogrande. *a*, Thick bed of gypsum capped by 30 feet of red shale

red sandstone of the Abo and the red sediments at the base of the Chupadera formation thin out so that the limestones of the Chupadera come down onto the limestone of the Magdalena group to constitute the greater part of the Hueco limestone of Richardson,[27] which has yielded both Manzano and Magdalena faunas. In Texas later Mississippian fossils occur below it. Borings 3,146 and 4,010 feet deep east of Newman penetrated limestone and shale of the Magdalena and probably underlying formations.

GUADALUPE MOUNTAINS

The Guadalupe Mountains are a southward extension of part of the central cuesta of the Sacramento Mountains with continuous limestone outcrops. Many features of the range in Texas have been described by Tarr,[28] Girty,[29] and Richardson.[30] The stratigraphy of the Guadalupe Mountains was investigated at a number of places in New Mexico, and in 1925 I examined the extension in Texas in company with J. B. Reeside, jr.[31]

[26] Meinzer, O. E., op. cit. (Water-Supply Paper 343), p. 168.

[27] Richardson, G. B., Report of a reconnaissance in trans-Pecos Texas north of the Texas & Pacific Railway: Texas Univ. Mineral Survey Bull. 9, pp. 32-38, 1904.

[28] Tarr, R. S., Reconnaissance of the Guadalupe Mountains: Texas Geol. Survey Bull. 3, pp. 9-42, 1892.

[29] Girty, G. H., The Guadalupian fauna: U. S. Geol. Survey Prof. Paper 58, 1908; Guadalupian fauna and new stratigraphic evidence: New York Acad. Sci. Annals, vol. 19, pp. 135-147, 1909.

[30] Richardson, G. B., op. cit.; Stratigraphy of the Upper Carboniferous in west Texas and southeast New Mexico: Am. Jour. Sci., 4th ser., vol. 29, pp. 325-357, 1910.

[31] Darton, N. H., and Reeside, J. B., jr., Guadalupe group: Geol. Soc. America Bull., vol. 37, pp. 413-428, 1926.

The great cap of limestone that constitutes the crest and long eastward-sloping cuesta of the Guadalupe Mountains is at least 500 feet thick in New Mexico and more than 1,500 feet at the south end of the mountains in Texas. The underlying gypsum deposits and red beds come to the surface a short distance south of Russell Gap (latitude 32° 30′), and their outcrop continues southward in the west front of the range to a point west of Queen, where they merge laterally into limestone. A section examined a few miles northwest of Queen presents the features shown in Figure 91. The capping limestone is hard and massive and extends southward to El Capitan in Texas, where, however, it is overlain by a higher member. The appearance near the State line is shown in Plate 48, *B*. Fossils found in the lower part of the section shown in Figure 91 were identified by G. H. Girty as follows:

Batostomelloid Bryozoa.
Chonetes aff. C. hillanus.
Productus aff. P. popei.
Productus mexicanus.
Productus subhorridus var. rugatulus.
Rhynchopora aff. R. illinoisensis.
Squamularia guadalupensis?
Composita? sp.
Anisopyga perannulata?

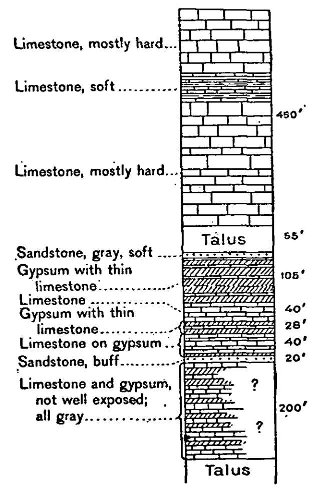


FIGURE 91.—Columnar section of west front of Guadalupe Mountains northwest of Queen

These forms are regarded as largely Guadalupian, but some of them may not be restricted to that fauna. The included gypsum series, as in the ranges farther north, consists of alternations of gypsum, or anhydrite, and light greenish-gray limestone. Some of the gypsum beds are 40 feet thick. One bed of limestone in the middle of this series is thicker and harder than the others, and a few miles north of the latitude of Queen, where it is 30 feet thick, it makes a conspicuous bench. Here it is underlain by 200 feet of alternating gypsum and limestone beds with some members of pink and red sandstone. A section of these beds on the east side of the northern part of Crow Flat is shown in Figure 92. The capping limestone pitches considerably to the north and at Russell Gap constitutes the entire western front of the mountain, here much lower than to the south. A creek cuts through the front ridge, so that the gap in the main divide, or true Russell Gap, lies a mile east of the western summit. In the limestone in the gorge were obtained *Productus ivesi*, *Productus occidentalis*, and *Composita subtilita*.

The eastern slope of the Guadalupe Mountains east of Queen is a long cuesta consisting of the thick eastward-dipping sheet of limestone that constitutes the main summit. As shown in cross sections 2 and 3, Plate 50, this cuesta descends into a valley, to the east of which is a ridge showing a succession of gypsum deposits and red beds about 500 feet thick. It is capped by an upper member of massive limestone 500 to 1,200 feet thick constituting a ridge of considerable prominence which crosses Pecos River between Carlsbad and Lakewood. Above this limestone member are the very thick gypsum deposits of the northern extension of the Castile gypsum of Texas.

The relations which these rocks present in their extension farther south in New Mexico and in Culberson County, Tex., are set forth in Plate 50 and Figure 93. In these sections it is shown that the strata of the Chupadera formation appear to merge into the Capitan limestone and Delaware Mountain formation of the Guadalupe group. These two formations were defined by Richardson,[32] who stated that the Capitan limestone consists of 1,800 feet of massive light-colored limestone, and the Delaware Mountain formation comprises 2,300 feet of beds, mostly sandstone, with a limestone

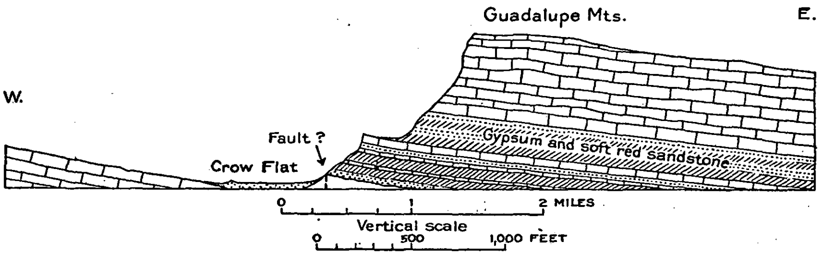


FIGURE 92.—Section of Chupadera formation in Crow Flat and west front of Guadalupe Mountains, 10 miles south of Russell Gap

member at the summit and 200 feet of dark limestone below, which extends down to the edge of the valley fill. These strata all contain the very distinctive Guadalupian fauna of more than 300 species, which has been described by Girty,[33] and only a few of which have been found in the great limestone succession of the Chupadera formation north of the latitude of Carlsbad.

It was found that the upper limestone member of the Delaware Mountain formation is a characteristic and persistent stratum recognizable for some distance northward in New Mexico, where it is revealed in the canyons of Rocky Arroyo and Last Chance Creek. It was also found, however, that to the north the Capitan limestone and lower limestone of the Delaware Mountain formation change gradually in character to the pale greenish-gray earthy-looking limestone of medial members of the Chupadera formation. This feature is well exposed in the western range of the Guadalupe Moun-

[32] Richardson, G. B., op. cit. (Bull. 9), pp. 38-43. See also Am. Jour. Sci., 4th ser., vol. 29, pp. 330, 335-336, 1910.

[33] Girty, G. H., op. cit. (Prof. Paper 58).

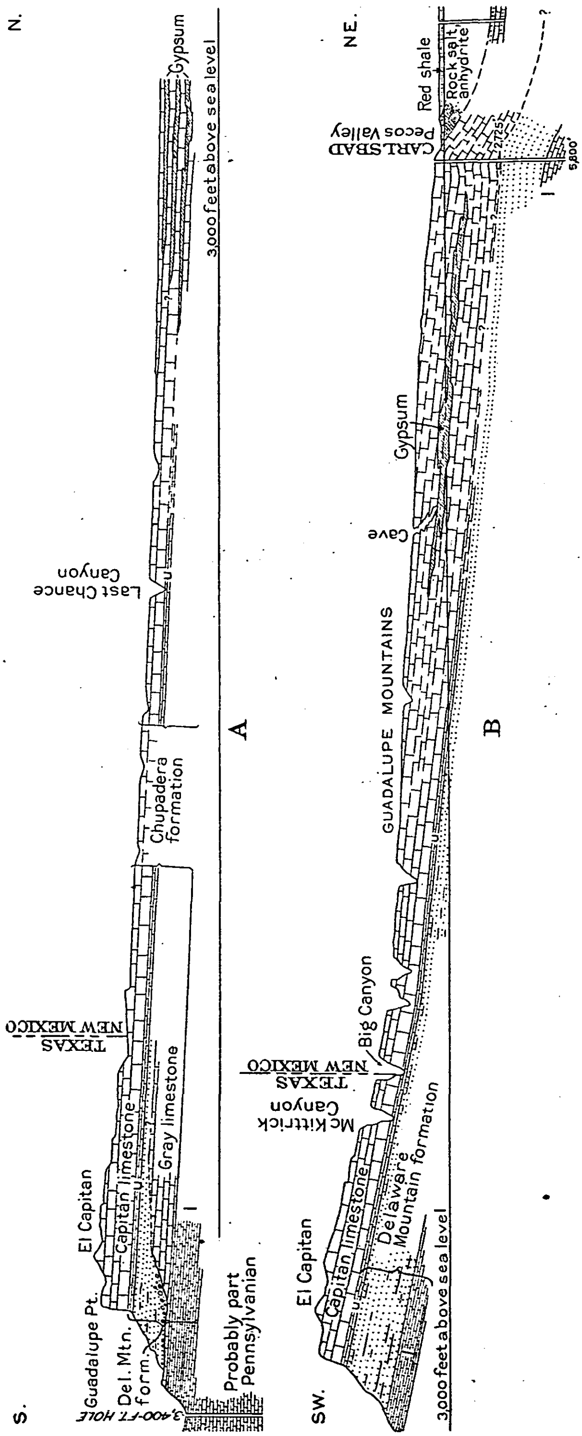
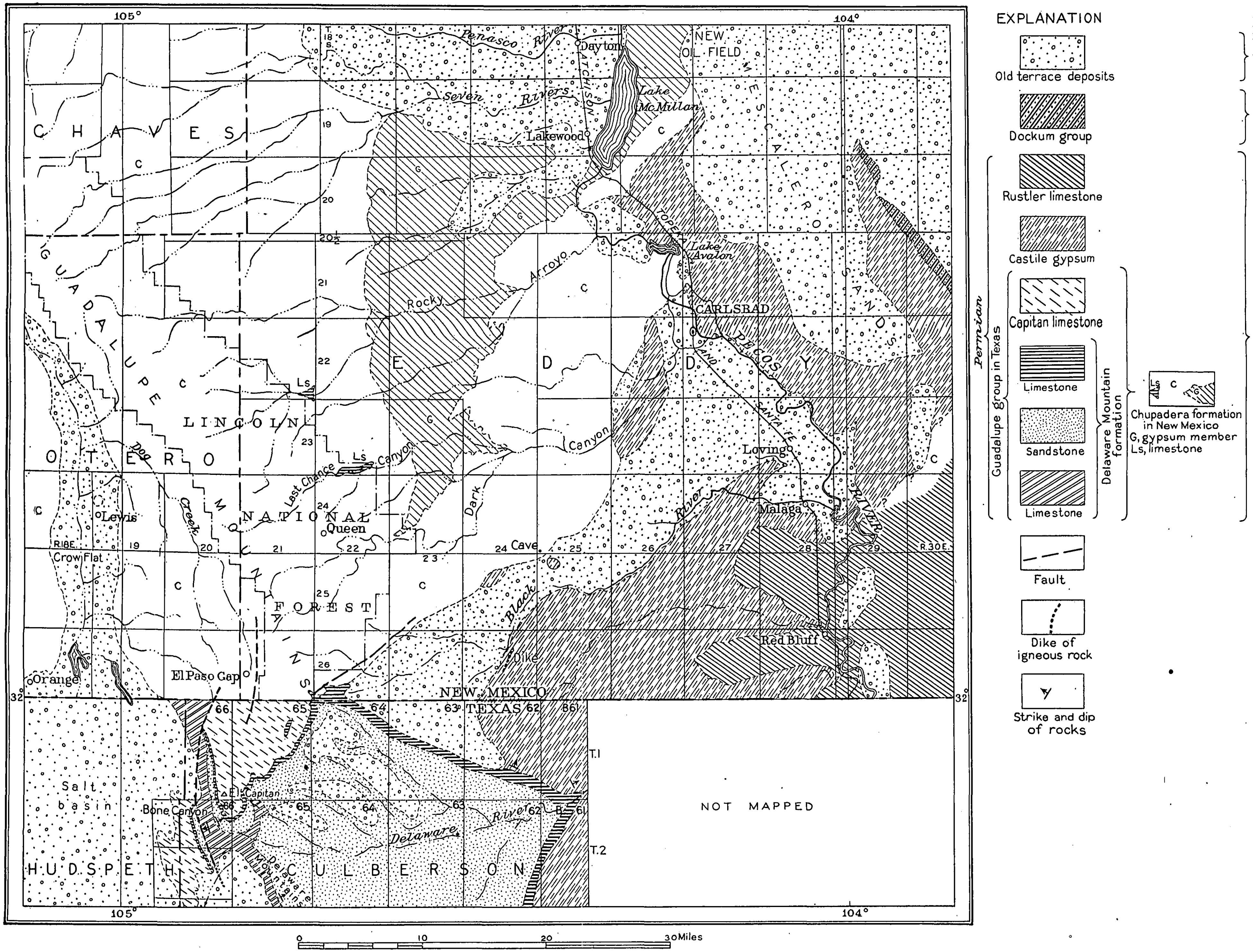


FIGURE 93.—Sections along western and eastern ridges of Guadalupe Mountains in Eddy County, N. Mex., and Culberson County, Tex. A, Along center of range; B, along east side of range

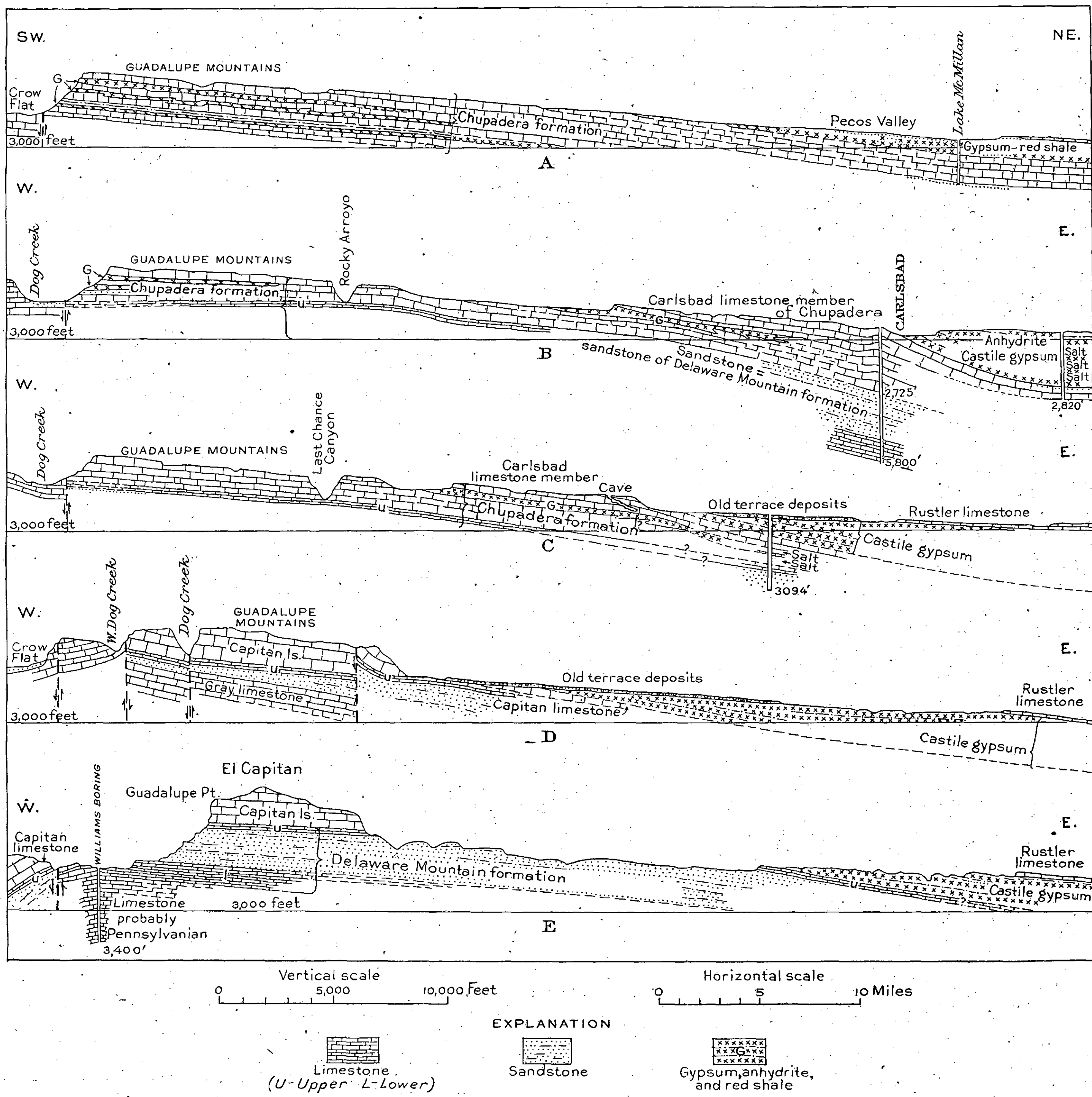
tains, in Tps. 24 and 25 S., where also appear the intercalated gypsum deposits that thicken rapidly northward and are so conspicuous in New Mexico. As shown in sections 2 and 3, Plate 50, on the east slope of the main mountain ridge these limestones dip under a thick member of gypsum and red beds which begins about 6 miles east of Queen and, thickening northward, underlies the Pecos Valley from the vicinity of Lakewood far into Chaves County. To the south this gypsum member thins rapidly and also merges laterally into the overlying limestone so that it disappears, or possibly part of it is represented from Queen southward by a bed of brownish sandstone in the midst of the Capitan limestone.

The next overlying member is the Carlsbad limestone, the top member of the Chupadera formation. It is a massive limestone, 600 to 800 feet thick, which constitutes the higher part of the mountain at El Capitan. As shown in sections 2 and 3, Plate 50, this member constitutes the prominent ridge that extends northeastward just west of Black River valley and is trenched by Pecos River just north of Carlsbad. Farther north, however, it thins or merges into red beds with limestone layers that pass under the "Mescalero Sands" in Tps. 18 and 19 S. Two deep borings near Carlsbad show that to the east the Carlsbad limestone member lies directly on lower limestones without intervening gypsum, or with the same relation that it has in the El Capitan region. (See section B, fig. 93.) One of these borings, completed in 1926, penetrated 2,925 feet of these limestones and an additional 2,005 feet of sandstone, which doubtless is the northeastern extension of the great sandstone of the Delaware Mountain formation in the El Capitan region. It is underlain by dark limestone, of which 870 feet was penetrated.

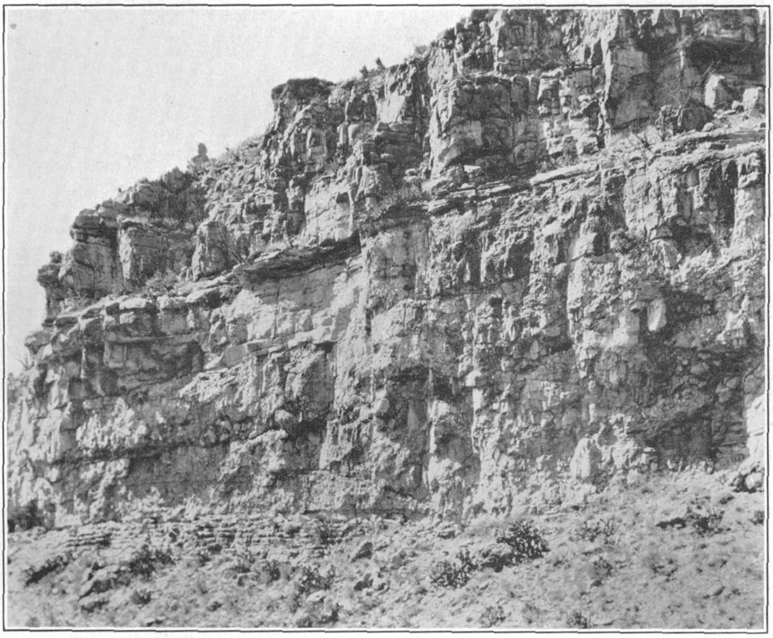
In most of southern Eddy County the upper limestone member of the Capitan (the Carlsbad limestone) dips beneath a thick body of Castile gypsum. The gypsum is largely covered by old valley deposits of sand, conglomerate, and breccia, which extend far southward along the foot of the mountains, as shown in sections 3 and 4, Plate 50, but the relations are well exposed near the center of T. 25 S., R. 24 E., and near Carlsbad, and a boring 8 miles east of Carlsbad passes through the thick deposits of salt and anhydrite listed on page 251. (See also section 2, pl. 50, and section B, fig. 93.) In the northern part of Texas, however, the Capitan limestone thins out very rapidly, so that finally, in longitude 104° 30′ and in the northern part of Culberson County, the Castile gypsum lies directly on the top dark limestone member of the Delaware Mountain formation. This thinning out of the Capitan limestone to the southeast near the Texas State line must take place within a short distance and mostly in the southeastern part of T. 26 S., R. 22 E., where, however, the relations of the limestone are hidden by the Quater-



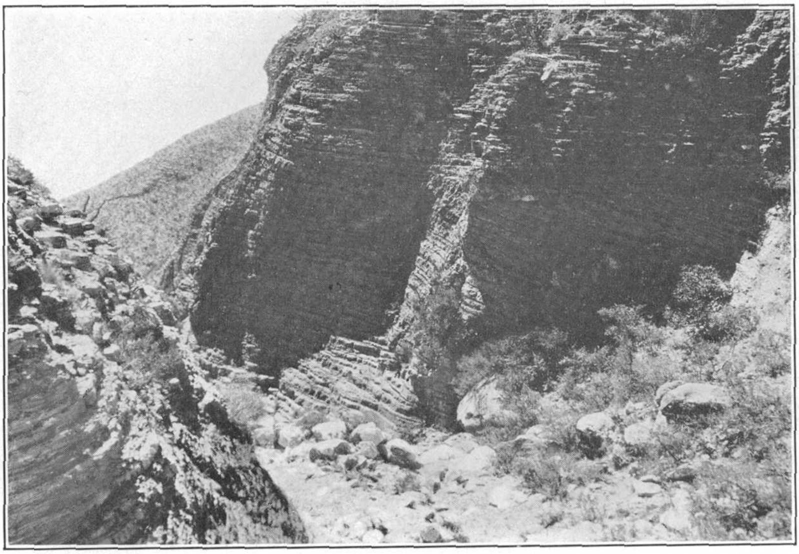
GEOLOGIC MAP OF GUADALUPE MOUNTAIN REGION



SECTIONS ACROSS GUADALUPE MOUNTAINS

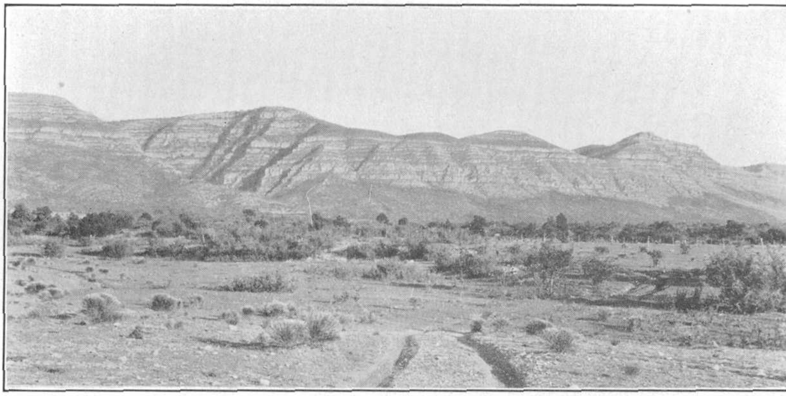


A. CONGLOMERATE AT BASE OF SANDSTONE MEMBER OF DELAWARE MOUNTAIN FORMATION, NORTH WALL OF BONE SPRINGS CANYON, TEX.



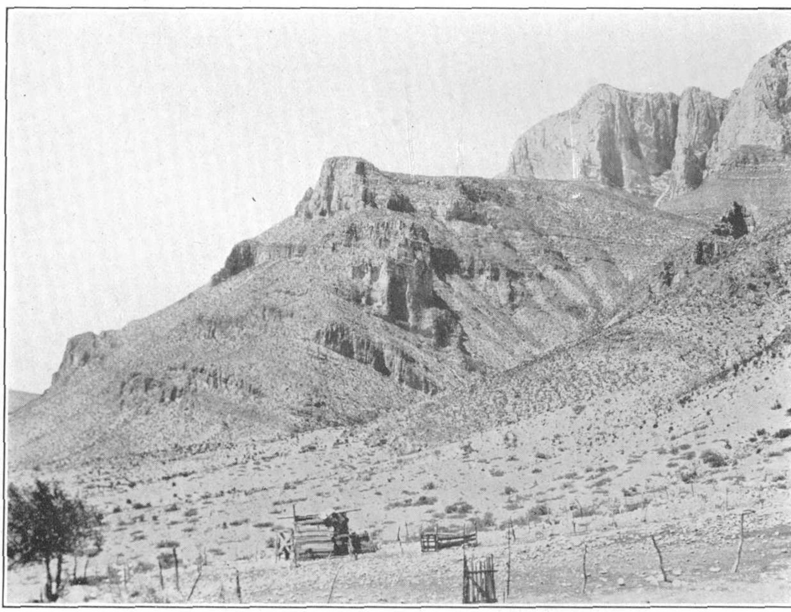
B. LOCAL UNCONFORMITY IN LOWER LIMESTONE MEMBER OF DELAWARE MOUNTAIN FORMATION, BONE SPRINGS CANYON, TEX.

Looking northwest



A. WEST FACE OF MAIN CENTRAL RIDGE OF GUADALUPE MOUNTAINS, 2 MILES NORTH OF TEXAS-NEW MEXICO LINE

Looking southeast. Part of Capitan limestone merging into part of Chupadera formation



B. LOWER LIMESTONE MEMBER OF DELAWARE MOUNTAIN FORMATION IN WEST SLOPE OF GUADALUPE MOUNTAINS JUST NORTH OF BONE SPRINGS CANYON, TEX.

Looking north. Cliffs of Capitan limestone to right surmount bench of sandstone near top of Delaware Mountain formation nary or late Tertiary deposits, which extend thence southeastward into Texas. The idea that the Capitan strata merge into the Castile gypsum is precluded, in large part at least, by the superposition of the gypsum plainly exhibited farther north in Eddy County. Faulting is out of the question.

Some of the stratigraphic relations in the Delaware Mountain formation are revealed on the west slope of the range in the northern part of Culberson County, Tex., notably in very interesting outcrops near Bone Springs Canyon.[34] At this place J. B. Reeside, jr., and I observed a local coarse conglomerate, made up largely of a light-colored limestone (see pl. 51, *A*), at the base of the sandstone of the Delaware Mountain formation, and the rapid thinning of the sandstone member to the north. In Bone Springs Canyon the conglomerate lies on the black lower limestone of the Delaware Mountain formation, of which nearly 900 feet is exposed, and in the next canyon to the north, not more than a mile distant, there appear the eroded edges of gray limestone 300 feet or more thick, which overlies the black limestone and evidently furnished the coarse material in the Bone Springs Canyon exposure. This conglomerate is local and does not represent any great time hiatus, for fossils in the underlying limestone represent the same lower Guadalupian fauna that is found in the limestone at the top of the Delaware Mountain formation. The stratigraphic relations in this region are shown in Figure 94.

Several very striking unconformities are exposed in the black limestone some distance below the conglomerate in Bone Springs Canyon above referred to, which appear to have been caused by local uplift and planation. One of these is shown in Plate 51, *B*. The thinning of the sandy shale and sandstone of the Delaware Mountain formation continues northward from this locality, owing to the rise of the surface of the underlying gray limestone in that direction, and on the New Mexico State line little more than 100 feet of the sandstone remains. Owing, however, to a fault along the west slope of the mountains in this area with a drag on its downthrown side, the relations of the beds at that horizon farther north are not revealed. In New Mexico most of the limestone, both of the greatly thickened lower part of the Delaware Mountain formation (gray and black limestones) and of the Capitan limestone, gradually becomes greenish gray and has the aspect of the Chupadera formation, a feature that is very striking in the great cliffs in the West Dog Creek region, a few miles farther north. Still farther north, near latitude 32° 15′, thick intercalations of gypsum (or anhydrite) come in, as shown in sections 1 and 2, Plate 50, and Figure 93.

[34] Baker, C. L., Contributions to the stratigraphy of eastern New Mexico: Am. Jour. Sci., 4th ser., vol. 49, pp. 112-114, 1920.

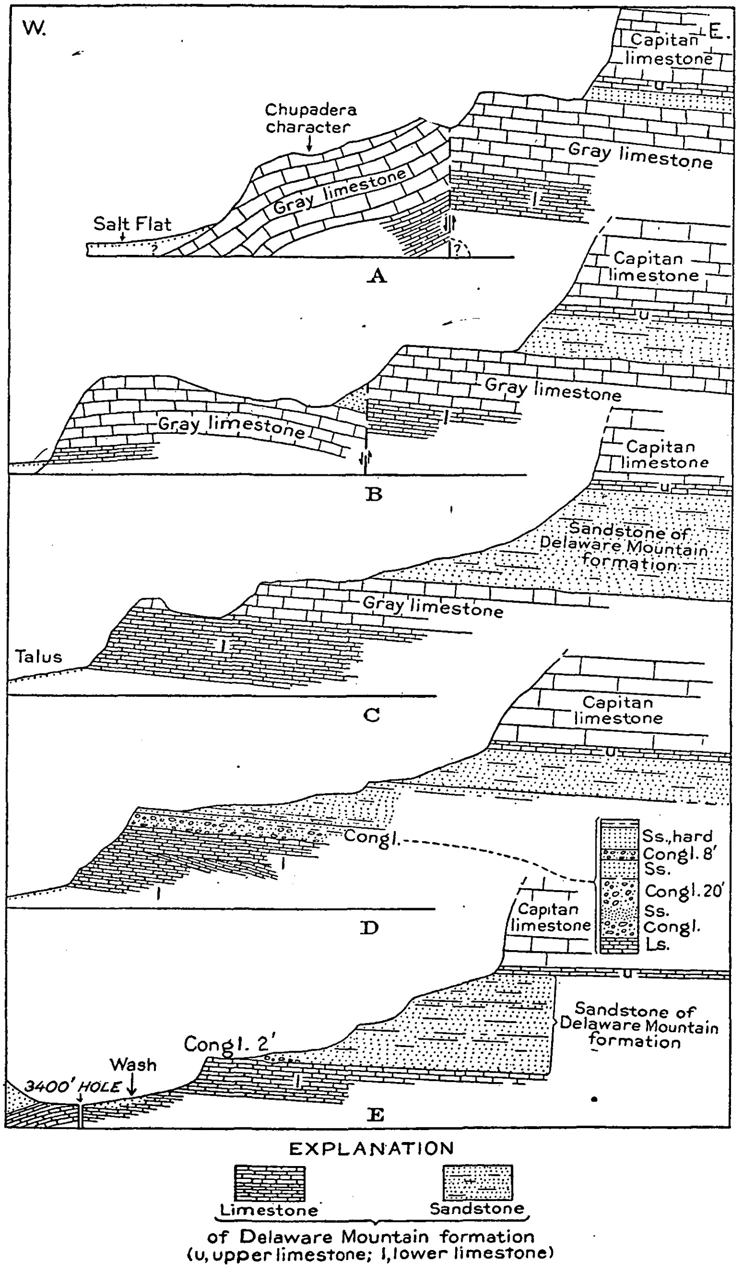


FIGURE 94.—Sketch sections along west front of Guadalupe Mountains from the vicinity of Guadalupe Point, Tex., into New Mexico. A, Near State line; B, 2 miles north of Bone Springs Canyon; C, 1 mile north of Bone Springs Canyon; D, Bone Springs Canyon; E, 3 miles south of Bone Springs Canyon

Some of the deep canyons that trench the formations of the Guadalupe Mountains in New Mexico reveal the limestone member at the top of the Delaware Mountain formation, here mostly of dark color but distinguished from the lower dark limestone member not only by its stratigraphic relations but by distinctive fossils. This upper limestone of the Delaware Mountain formation is well exposed in McKittrick Canyon and also still farther north, in Big Canyon, in the southwestern part of T. 26 S., R. 22 E., where large collections of fossils were made by Reeside. These outcrops, however, are continuous with those in the Pine Spring and Guadalupe Point area.

In the lower part of the section in Last Chance Canyon is revealed 40 feet of dark limestone believed to be a northern extension of the upper member of the Delaware Mountain formation. It includes a limestone conglomerate, indicating a local intraformational unconformity but probably no great time hiatus. The overlying limestone, 400 feet or more thick, is ordinary Chupadera but in part presents a very sandy phase, a feature exaggerated by weathering and not unusual locally in that formation. Three samples of this rock contained 57, 61, and 95 per cent of insoluble material, mostly sand, but considerable calcium carbonate had been lost by surface weathering. Farther north, in the Dark Canyon and Rocky Arroyo regions, as shown in sections 2 and 3, Plate 50, and section 1, Figure 93, these Chupadera beds dip below the thick gypsum member of the formation, which there separates them from the upper limestone member, the Carlsbad limestone.

The suggestion that the sandy formation in Last Chance Canyon is the sandstone of the Delaware Mountain formation is not valid, because the underlying limestone carries the typical fauna of the top member of that formation and not that of the basal limestone. This top member is again exposed in Rocky Arroyo, in the southeast corner of T. 22 S., R. 21 E., where it is a dark slabby limestone that yielded many fossils. Probably it is penetrated in deep borings at Carlsbad just above the great body of sandstone believed to represent the sandstone of the Delaware Mountain formation, but its identity in these records is not established.

PECOS VALLEY IN CHAVES AND EDDY COUNTIES

GENERAL RELATIONS

The broad valley of Pecos River in southeastern New Mexico is excavated in red shale and sandstone with intercalated gypsum and limestone. These beds overlie the massive limestones of the Chupadera formation, which rise to the surface to the west in the long monoclinal slope constituting the Sacramento and Guadalupe Mountains and the plateau extending north of Corona, Duran, and Vaughn.

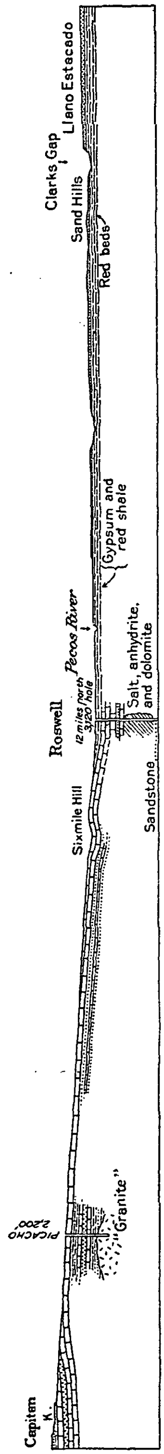


FIGURE 95.—Section of Pecos Valley and adjoining slopes passing through Roswell. K, Cretaceous

The red strata with their included limestone and gypsum members appear at intervals in bluffs and along the valley slopes, especially on the east side of Pecos River. They are of Permian age and below Carlsbad they appear to be the northern extension of the Castile and Rustler strata. It is barely possible that below Carlsbad they may also be overlain by strata of Lower Triassic age representing the Moenkopi formation of the western part of the State. A few miles east of Pecos River the "Red Beds" pass under red sandstones of the Dockum group (Upper Triassic), which overlap the older formations diagonally, lying on lower and lower strata to the north. Most of the area east of the river is covered by loose sands (the "Mescalero sands"), which extend to the base of the escarpment of the Tertiary capping of the Llano Estacado. The general structural relations of the northern part of the region are shown in Figure 95 and the relations from Dayton southward in Plate 50.

In the southern part of the area, between Lake McMillan and Carlsbad, the massive Carlsbad limestone member of the Chupadera formation crosses the valley diagonally from the southwest and thins out in a few miles, its place being taken by red beds in the new oil field southeast of Artesia. It is overlain by a thick succession of gypsum and salt-bearing red beds, extending up the valley from Texas, where they have been designated the Castile gypsum by Richardson.

The principal data as to the succession of strata in the lower part of the Pecos Valley are derived from records of the many deep borings. Some of these records are unreliable as to the identity of the beds penetrated, but they demonstrate the presence of two thick series of gypsum and salt-bearing strata separated by the massive Carlsbad limestone member of the Chupadera formation. It is clearly evident that near Carlsbad and farther south the limestone of the Guadalupe Mountain front dips beneath a thick succession of gypsum deposits (Castile), and near Malaga and to the south the gypsum is overlain by limestone, presumably the Rustler, as shown in section 3, Plate 50. A 3,705-foot drill hole (Flood No. 1) 40 miles due west of the Pecos, in Texas, penetrated 257 feet of this limestone and passed through gypsum (with certain interruptions) to 2,148 feet, indicating a thickness of nearly 1,900 feet for the Castile gypsum in that part of the Pecos Valley.

LOCAL SECTIONS

The most extensive description of the geology of Pecos Valley is one prepared by Fisher [35] in 1906. The following statements are taken from his report:

The rocks of the district comprise limestone, sandstone, clay, and gypsum, which are believed to be of Permian age. Overlying these deposits throughout the Roswell Basin are extensive sheets of sand, gravel, clay, and silt, probably of Quaternary age, which have been deposited in successive terraces between Pecos River and the high limestone slopes to the west. The so-called Permian series of this district consists of an upper red-bed member of gypsum, red sand, limestone, and clay 600 to 800 feet thick, forming the high bluffs along the east side of Pecos River and underlying the recent deposits of Pecos Valley, and a lower member of massive limestone, clay, and gypsum of undetermined thickness, which constitutes high rugged slopes to the west. Overlying the red-bed division east of Pecos River is a reddish-brown sandstone about 100 feet thick. * * *

Red-bed division.—These rocks consist of alternating beds of gypsum, red sand, and clay, with an occasional layer of dark-gray compact limestone. The gypsum predominates and usually occurs in beds about 10 feet thick. It is often found, however, in thinner layers, interbedded with clay and limestone. The red beds are provisionally placed in the Permian, although no fossils have been found in them. They are not shown separately on the geologic map but are represented with the underlying massive limestones. The upper part of the beds is well exposed in the bluffs along the east side of Pecos River, where a number of sections have been measured. These sections are as follows:

Sections of gypsum bluffs along the east side of Pecos River

	Feet
East of Roswell:	
Alternating layers of gypsum and red sand, with an occasional layer of limestone	50
White gypsum	6
Red sand	6
White thin-bedded gypsum	10
Red sandstone containing thin layers of limestone	24
White gypsum	5
Red sand	13
Gypsum	10
Red sand	3
Gypsum	8
Red sand	8
Gypsum	4
Greenish-gray sandstone	25
Gypsum	6
	178

[35] Fisher, C. A., Preliminary report on the geology and underground waters of the Roswell artesian area, N. Mex.: U. S. Geol. Survey Water-Supply Paper 158, 1906.

At Dimmit Lake:

	Feet
Gray sandy limestone	20
Alternating layers of gypsum and red and green clay, with an occasional bed of porous limestone	100
Gypsum	4
Red clay	2½
Gypsum	18
Alternating layers of gypsum and red clay	6
Gypsum	11
Alternating layers of gypsum and red sandstone	6
Gypsum	9
Red clay	1
Gypsum	10
Alternating layers of gypsum and red clay	15
Gypsum	5
Red clay	1½
Gypsum	10
Red clay	7
Alternating layers of gypsum and red clay	8
Gypsum	6
Red clay, with thin layers of gypsum	3
Gypsum	6
	249

Eight miles northeast of Artesia:

Gray compact limestone	5
Gypsum and red sandy clay in alternate succession	65
Red sandy clay	10
White massive gypsum	15
Red sandy clay	5
White gypsum	10
Gray limestone	5
Gypsum	18
Red clay	12
Gypsum	5
	150

About 2 miles southeast of the mouth of South Fork of Seven Rivers:

Massive gray limestone	35
Gypsum and red sandstone in alternate layers, with an occasional limestone ledge	50
Gypsum, thin-bedded porous limestone, and red sandstone arranged alternately, the gypsum predominating	150
Gypsum, with thin layers of gray limestone	50
	285

Limestone division.—The massive limestone beds underlying the so-called Permian red beds of this region consist mainly of gray compact limestone, with layers of soft sandstone, clay, and gypsum. In the upper part the limestone is more or less thin-bedded and porous and contains many sandy layers. From these beds some of the strongest artesian flows in the Roswell Basin are obtained. Limestone outcrops along the west side of the district and farther to the west forms high rugged plateaus, extending toward the mountains. Fossils are not abundant in the formation, but in one locality northwest of Roswell a number were collected, which consisted mainly of *Schizodus* [*ovatus*] and *Pleurophorus* [aff. *P. subcostatus*], preserved as casts. According to Doctor Girty the fauna and lithology of these specimens suggest the highest Carboniferous beds or the Permian of the Mississippi Valley in Texas.

To the east of the Roswell district the high plains are traversed by dikes of igneous rocks. One of these dikes extends into the area in the northeast corner but passes beneath the surface at a point about 5 miles east of Pecos River. Its location is shown on the geologic map. The dike is about 35 feet wide and consists of a light-colored rock, which is much decomposed on the surface.

In the wide river flat near Roswell there are no exposures of rocks. On the east bank of Pecos River, 6 miles to the east, there is 50 feet of soft red sandy shale with some gray and pale-greenish beds, and higher up are several beds of gypsum 4 to 10 feet thick succeeded by red and brown shale and sandstone and a 30-foot bed of brown to gray massive sandstone. At Acme, 12 miles north of these exposures, the gypsum is quarried for the manufacture of plaster of Paris. West of Roswell are slopes of limestone with some showings of red shale and gypsum, the latter 10 feet thick. At Sixmile Hill there is an anticline of the limestone with dips of 20° on the east side and 5° on the west side but apparently local. Near the Hondo Reservoir, 8 miles southwest of Roswell, the thin-bedded limestone dips east at a low angle, and at one place half a mile east of the east end of the reservoir an 8-foot bed of gypsum is exposed under the limestone. This limestone and gypsum succession is well exposed 13 to 15 miles west and northwest of Roswell. A mile east of the Richardson (Block) ranch a low arch brings up red beds and gypsum under limestone, but this succession all dips down again northwest of the ranch and finally passes under Cretaceous strata or is cut off by igneous masses.

In the Hondo Valley the limestones are extensively exposed, in large part rising gradually to the west but with a few very low local flexures. In one of these flexures at Picacho, in 1919, a 2,199-foot boring was made for oil which penetrated "granite" from 1,670 feet to the bottom. The identity of the rock, however, is not fully established, and it may possibly be a post-Paleozoic intrusive mass similar to the gray porphyritic rock that constitutes Capitan Mountain, 15 miles to the northwest. The relations are shown in Figure 95, and a record is given in Figure 96.

At Lincoln the beds are considerably upturned locally, and alternations of limestone and red sandy shale and sandstone are exposed. Cretaceous beds appear near Capitan.

In a trip west from Elida to a point near Olive, in the northeastern part of Chaves County, I made some observations on the upper members of red beds near the overlap of the Tertiary deposits that cap the Llano Estacado. Figure 97 shows some of the features. The red beds appear to be Dockum (Triassic). About 10 miles west of Elida a fault was noted trending west, with uplift on the south side, which lifts limestone of Tertiary age about 100 feet, causing a northward-facing step on the western margin of the Llano Estacado. Along this fault the light-colored, soft, massive sandstone is exposed, and in places the top of the underlying red shale.

In the region northeast of Roswell there are two long, narrow dikes of basic intrusive rock running nearly due east from the edge of the Pecos Valley to the sand dunes. The northern one crosses the railroad halfway between Acme and Elkins. Some details regarding these dikes are given by Fisher, as quoted above, and by Semmes.[36] Semmes has also called attention to a small sill in the Chupadera formation 10 miles southwest of Dunlap. In 1925 a narrow dike of decomposed lamprophyre was found in sec. 10, T. 26 S., R. 24 E., 30 miles south of Carlsbad.

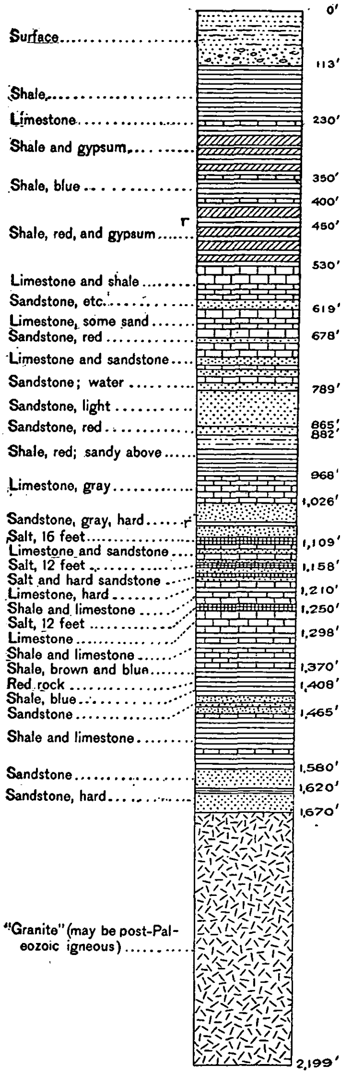


FIGURE 96.—Record of boring at Picacho, in sec. 21, T. 11 S., R. 18 E.

Some details regarding conditions near Dayton have been given by Richardson,[37] who states that

> The red beds of the Pecos Valley, which directly underlie the unconsolidated materials and outcrop on the highlands east and west, consist of a complex group of lenticular beds of red sandstone and shale, magnesian limestone, and gypsum. Satisfactory measurements of the thickness of these beds have not been made, although they are locally known to be more than 1,600 feet thick. But the thickness varies greatly because the red beds are not confined between definite horizons, the red color extending horizontally across the strike in accordance with varying conditions of deposition.
>
> The red beds of the Pecos Valley, on the evidence of fossil shells and stratigraphic position, are believed to be of Permian age and are correlated with the well-known Permian red beds of north-central Texas and Oklahoma, which outcrop east of the Llano Estacado.

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[36] Semmes, D. R., Notes on Tertiary intrusives of the lower Pecos Valley, N. Mex.: Am. Jour. Sci., 4th ser., vol. 50, pp. 415–430, 1920.

[37] Richardson, G. B., Petroleum near Dayton, N. Mex.: U. S. Geol. Survey Bull. 541 ,pp. 135–140, 1913

Some distance east of Pecos River these Red Beds are overlain by Triassic and Tertiary strata.

Rock exposures in the vicinity of Carlsbad are much more extensive than those about Roswell, but in parts of the region there are wide coverings of loose sand and it is difficult to make sections. The general dip of the strata is to the east, with a few local variations, some of which are due to caving where gypsum has been dissolved out.

West of the valley are slopes of the massive Carlsbad limestone constituting the upper member of the Chupadera formation, and 300 feet or more of this rock is extensively exposed along the river northward to the McMillan Dam, but northeast of that place it thins out and gives place in whole or in part to red beds. It passes under gypsum regarded as a northern extension of the Castile gypsum. This mineral is quarried at Oriental for making plaster of Paris; it crops out extensively in places near and south of Carlsbad, and it has been penetrated in the deep borings near Carlsbad and farther

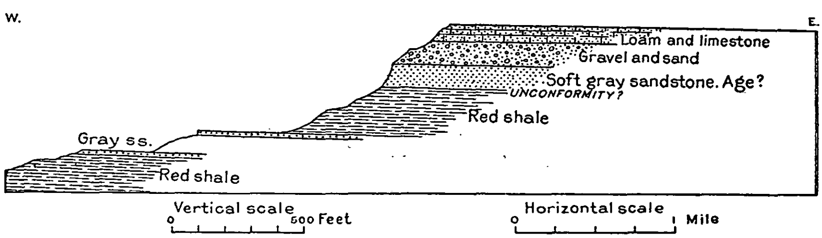


FIGURE 97.—Sketch cross section of red beds probably of the Dockum group, 5 to 6 miles east of Olive, Chaves County

east, where it alternates with thick deposits of salt. It is not likely that the Carlsbad limestone member is the bed extending from 250 to 435 feet in the boring 10 miles east of Dayton (see fig. 103), and from 420 to 533 feet in a hole in the Artesia oil field, in the NW. ¼ sec. 32, T. 18 S., R. 28 E. It thickens rapidly to the southwest in the Guadalupe Mountains, where, as shown in Figure 93 and in section 2, Plate 50, it constitutes a wide, high ridge; it is very thick in the deep borings near Carlsbad. West and northwest of Carlsbad this massive limestone is underlain by the thick body of gypsum and red beds forming a valley which joins the main Pecos Valley near Lakewood and extends thence northward to and beyond Roswell. To the south, as explained above, this member grades into limestone and also probably thins greatly, for it disappears in the valley of Dark Canyon, in the southwestern part of T. 24 S., R. 23 E. Some general relations in the valley south of Carlsbad are shown in Figure 98.

No detailed examination was made of the strata overlying the massive Carlsbad limestone member of the Chupadera formation in the lower part of the Pecos Valley. East of Carlsbad for some distance there are exposures of gypsum and red beds with thin beds of limestone, all dipping east at low angles and in large part Castile. The upper strata probably include the northern extension of the Rustler limestone, but time was not available to establish the connection. Much of the area is covered with loose sand, so that mapping in detail is difficult. In the southern part of Chaves County these upper formations of the Permian are overlapped by the Dockum beds, which extend diagonally across the outcrop zones of lower and lower beds toward the north. In the eastern part of T. 17 S., R. 29 E., and T. 20 S., R. 30 E., red-brown sandstone appears among the sand hills; it is tentatively regarded as a possible southern extension of the Santa Rosa sandstone, here the basal formation of the Dockum group.

The red beds and limestone are extensively exposed along the river banks a few miles below Carlsbad. One notable exposure occurs in a high bluff at Malaga gaging station, 1 mile southeast of Malaga, where there is 40 feet of limestone, probably the same bed as that

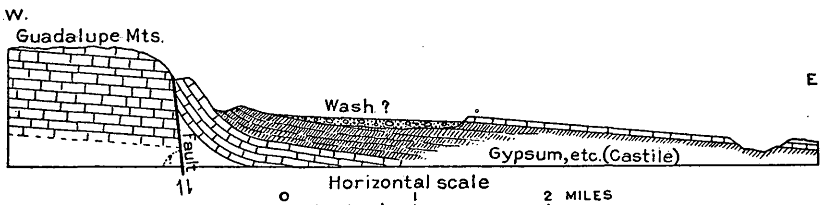


FIGURE 98.—Section across Pecos Valley 20 miles south of Carlsbad, showing slight fault in Carlsbad limestone member with abundant Capitan fossils

quarried along the railroad near Red Bluff. It is underlain by gray sandstone, and probably not far below lie gypsum and perhaps salt, indicated by extensive sink holes. Ledges of red sandstone extend across the river in sec. 32, T. 24 S., R. 28 E., about 6 miles southeast of Malaga. At this place the dips range from 5° to 15° in a narrow belt, owing to local crumpling. About half a mile west of the railroad near Red Bluff 40 feet of hard earthy limestone is underlain by 3 feet of green and red clay, 5 feet of gypsum, and 15 feet of red soft sandstone lying on an irregular surface of gray soft sandstone. Near the railroad at Red Bluff the section shows 30 feet of massive earthy limestone underlain by 15 feet of gypsum and 20 feet of red sandy limestone lying on an irregular surface of greenish-gray earthy sandstone. This locality is shown in Plate 8, *B*. The limestone appears to extend far up the slopes to the west, and the underlying gypsum is revealed in several small canyons and ridges, notably in the valley of Delaware River in T. 26 S., R. 28 E. The gypsum finally crops out in a wide zone in T. 25 S., R. 25 E., and T. 26 S., R. 24 E., near Black River, an exposure which extends southward into the well-known outcrop zone of Castile gypsum in Texas. In sec. 10, T. 26 S., R. 24 E., the gypsum is cut by an 8-foot dike of lamprophyre as mentioned above. In a wide zone along the east foot of the Guadalupe Mountains from Carlsbad southward the strata are covered by limestone conglomerates, sand, and gravel of Tertiary or later age.

Hoots[37a] has given some facts about outcrops in Eddy and Lea Counties and discussed the equivalence of the Permian and Triassic strata in that region. He describes exposures of the supposed southern extension of the Santa Rosa sandstone in sec. 17, T. 25 S., R. 36 E., 7 miles northwest of Jal, and at a point 2 miles farther northwest and another at the Red Hills in sec. 36, T. 20 S., R. 30 E., in the east-central part of Eddy County. Probably it is the same bed as the one quarried at Quito station, Ward County, Tex.

Some features of the red beds and associated limestone in the lower part of the Pecos Valley have been briefly described by Beede.[38] He collected fossils in limestone just below the mouth of Seven Rivers which suggested *Cyrtodontarca parallellidentata*, one of the species occurring in the Whitehorse and Quartermaster formations of Oklahoma and Texas. In a locality 13 miles west of Carlsbad ("5 miles west of McKitrick Spring") he reported "*Naticella transversa*, formerly known only from the Quartermaster beds, and a *Pleurophorus* common to both the Whitehorse and Quartermaster formations." These few remains seem insufficient to establish any correlation.

WELL RECORDS

As the rocks in the Pecos Valley in Chaves and Eddy Counties are largely covered by sand and gravel, it is necessary to utilize the records of borings and wells to determine the stratigraphic succession. Many borings have been made for water and petroleum, but only a few representative records can be presented here; most of these are not reliable as to the nature of rocks penetrated.

Roswell region.—The most significant record in the Roswell region is that of a deep boring for oil by the Toltec Oil Co. 13 miles north-northeast of the city. Its principal features are shown in Plate 53, and additional details are given in the following record kindly furnished by the company.

Record of boring in sec. 31, T. 8 S., R. 24 E., 13 miles north-northeast of Roswell

	Feet
Dolomite	0–90
Sandstone on dolomite	90–110
Gypsum and dolomite	110–140
Limestone	140–165
Dolomite	165–250

[37a] Hoots, H. W., Geology of a part of western Texas and southeastern New Mexico: U. S. Geol. Survey Bull. 780, pp. 73–76, 92–94, 1925.

[38] Beede, J. W., The correlation of the Guadalupian and the Kansas section: Am. Jour. Sci., 4th ser., vol. 30, pp. 131–140, 1910.

	Feet
Limestone and dolomite	250–390
Sandstone	390–396
Limestone; some sandstone at 518–600 feet	396–620
Limestone and dolomite	620–710
Sandstone	710–770
Dolomite	770–860
Shale, dark	860–864
Sandstone, red and pink	864–1, 033
Salt on dark shale	1, 033–1, 052
Gypsum	1, 052–1, 067
Dolomite	1, 067–1, 076
Anhydrite	1, 076–1, 123
Dolomite on thin gypsum	1, 123–1, 168
Salt	1, 168–1, 200
Gypsum	1, 200–1, 230
Dolomite	1, 230–1, 280
Shale, dark	1, 280–1, 295
Dolomite	1, 295–1, 318
Shale, red	1, 318–1, 349
Dolomite	1, 349–1, 366
Sandstone	1, 366–1, 380
Anhydrite	1, 380–1, 386
Salt	1, 386–1, 449
Sandstone, red with 15 feet of gypsum	1, 449–1, 504
Salt	1, 504–1, 565
Dolomite on shale	1, 565–1, 582
Sandstone, red	1, 582–1, 620
Salt	1, 620–1, 645
Dolomite, gray to brown	1, 645–1, 730
Sandstone, red	1, 730–1, 771
Salt	1, 771–1, 800
Anhydrite	1, 800–1, 858
Dolomite	1, 858–1, 906
Salt	1, 906–2, 010
Shale, gray	2, 010–2, 025
Salt	2, 025–2, 050
Dolomite, with two beds of gypsum	2, 050–2, 154
Salt	2, 154–2, 205
Dolomite on sandstone	2, 205–2, 268
Salt	2, 268–2, 310
Dolomite	2, 310–2, 317
Anhydrite	2, 317–2, 335
Dolomite	2, 335–2, 375
Gypsum	2, 375–2, 435
Salt	2, 435–2, 455
Sandstone, red, on pink shale	2, 455–2, 507
Dolomite on red sandy clay	2, 507–2, 530
Shale, dark, and dolomite	2, 530–2, 548
Sandstone, red	2, 548–2, 625
Gypsum	2, 625–2, 685
Salt	2, 685–2, 710
Anhydrite, 9 feet, on dolomite	2, 710–2, 730
Sandstone	2, 730–2, 740

	Feet
Salt	2, 740–2, 750
Anhydrite	2, 750–2, 770
Sandstone, red	2, 770–2, 800
Anhydrite	2, 800–2, 805
Dolomite	2, 805–2, 830
Salt	2, 830–2, 860
Gypsum	2, 860–2, 950
Dolomite	2, 950–2, 971
Gypsum and sandy clay	2, 971–3, 025
Sandstone, red, dolomitic below 3,063 feet	3, 025–3, 120

It will be noted that the upper 864 feet consists mainly of limestone, the succession that constitutes the great limestone cuesta extending from a point a short distance west of Roswell to the Sacramento Mountains. Next below is 170 feet of red sandstone, under which the boring penetrated nearly 2,000 feet of alternations of salt, gypsum, and dolomite, including 526 feet of salt and nearly 500 feet of gypsum. Apparently most if not all of these strata belong to the Chupadera formation, but it is not improbable that the top of the Abo sandstone is represented by the 95 feet of red sandstone at the bottom of the hole.

Another deep hole by the Toltec Oil Co. in sec. 17, T. 9 S., R. 24 E., is reported to have the record given in the next to the last section in Plate 53. It is stated that much of the material reported as white and gray lime is gypsum. There are, however, many striking differences between the records of this boring and the one in sec. 31, T. 8 S.; as the holes are only 3 miles apart and the beds are practically level, the differences probably indicate that the record of the hole in sec. 17 is not reliable.

The record of a hole 25 miles east of Roswell as given in Plate 53 and those of the recent deep borings at Orchard Park are all reasonably accordant, but the drillers appear to have overlooked the salt and most of the anhydrite. A small amount of anhydrite is mentioned in the record of the Tannehill boring, in sec. 2, T. 10 S., R. 24 E., 7 miles northeast of Roswell, also given in Plate 53.

The record of the Buffalo Roswell well, 20 miles southeast of Roswell, in progress in March, 1928, affords some interesting facts as to the stratigraphy. It is as follows:

Record of boring in southwest corner of sec. 25, T. 11 S., R. 27 E.

	Feet
Clay, mostly red, and much gypsum	0–650
Red sandstone and shales (mostly)	650–1, 460
Limestone, mostly light; some shale	1, 460–2, 683
Sandstone, white; "Glorieta"	2, 683–2, 712
Limestone and blue shale	2, 712–2, 941
Salt	2, 941–2, 954
Limestone, mostly light; some shale	2, 954–3, 277

	Feet
Sandstone and shale, red mostly; some gypsum; salt at 3,295–3,310 feet	3, 277–3, 365
Limestone, gray, on 15 feet of red sandstone, and gypsum	3, 365–3, 420
Limestone	3, 420–3, 450
Sandstone, mostly white	3, 450–3, 475
Anhydrite, 15 feet, on limestone and sandstone, gray	3, 475–3, 540
Conglomerate on white sandstone and gypsum	3, 540–3, 585
Limestone; several streaks of red sand	3, 585–3, 870
Anhydrite with thin dolomite	3, 870–4, 033
Sandstone, brown	4, 033–4, 050
Limestone, mostly sandy; some red	4, 050–4, 112
Anhydrite, some dolomite	4, 112–4, 216
Dolomite, dark gray; some anhydrite near top	4, 216–4, 260

All these strata appear to be Permian.

Records of some of the many shallow wells about Roswell throw considerable light on the stratigraphy of the beds above the thick limestone succession. In the Rasmussen well, in the SW. ¼ sec. 21, T. 11 S., R. 25 E., 6 miles southeast of Roswell, the first 65 feet is in soil, sand, and gravel; next below are 107 feet of gray sandstone and 40 feet of quicksand; red sandstone extends to 400 feet, and limestone from 400 to 570 feet. The Ogle well, in Roswell, penetrated soil, gravel, and bluish clay with gravel to a depth of 150 feet; yellowish shale, red sandstone, and red shale from 150 to 178 feet, with a thin bed of limestone near the base; and gray limestone from 178 to 242 feet, with alternating beds of sandstone in its lower portion.

Some typical deep borings in the Hagerman district are as follows:

Records of wells in Hagerman district

Hedgecoxe well, near Dexter

	Feet
Soil and gravel	0–19
Coarse sand	19–71
Quicksand	71–271
Limestone	271–273
Shale, red sandy	273–323
Shale, yellow	323–343
Limestone	343–345
Quicksand	345–545
Limestone	545–551
Clay, blue	551–601
Quicksand	601–651
"Shell rock"	651–653
Sandstone, shale, and sandy shale in alternating layers	653–800
Coarse "gravel"	800–806
Sandstone, red	806–866
Limestone, porous	866–960

Widdeman well

	Feet
Soil	0–20
Gravel	20–55
Quicksand	55–105
Shale and gypsum, alternating beds	105–360
Sandstone	360–440
Sandstone with layers of shale and one 25-foot layer of gypsum near the middle	440–800
Limestone	800–1, 000

Cummins well

	Feet
Soil and gravel	0–40
Sand	40–44
Clay	44–60
Gravel	60–65
Rock, clay, and sand in alternate layers	65–165
Sandstone, red	165–550
Sandstone and shale, all red, in alternate layers	550–820
Limestone	820–840

It is reported that the town well at Hagerman penetrated gypsum and red shale from 535 to 630 feet, red sandstone and red shale from 630 to 675 feet, and gypsum with a thin bed of sandstone and red beds in its lower part from 675 to 760 feet.

Artesia region.—Many borings have been made at Artesia and in the neighborhood, mainly for artesian wells. Some representative records are given in Figure 99. These borings show that this part of the Pecos Valley is underlain by several hundred feet of shale and sandstone, mostly red, containing local deposits of gypsum and underlain by a thick mass of the limestone that constitutes the cuesta of the Sacramento Mountains to the west. The two deepest wells penetrated the limestone from 600 to 1,378 feet and 700 to 1,350 feet, and it was reached at 500 feet or less in the Barnes well, on the slopes 12 miles southwest of Artesia. The following holes penetrated the limestone:

SW. ¼ SE. ¼ sec. 29, T. 16 S., R. 26 E., 3 miles northeast of Artesia. White limestone from 800 to 1,402 feet.

NE. ¼ NE. ¼ sec. 30, T. 17 S., R. 26 E., 3 miles south-southwest of Artesia. Limestone from 600 to 1,000 feet.

SW. ¼ SE. ¼ sec. 8, T. 16 S., R. 25 E., 8 miles northwest of Artesia. Limestone from 530 to 1,000 feet.

NW. ¼ SE. ¼ sec. 17, T. 17 S., R. 26 E., limestone from 800 to 1,172 feet, under 19 feet of red sandstone.

SW. ¼ SE. ¼ sec. 8, T. 16 S., R. 26 E. Hard rocks (with sulphur) from 620 to 1,320 feet, under 60 feet of red sandstone.

NE. ¼ sec. 14, T. 16 S., R. 26 E. Hard limestone entered at 900 feet, under 180 feet of "water rock."

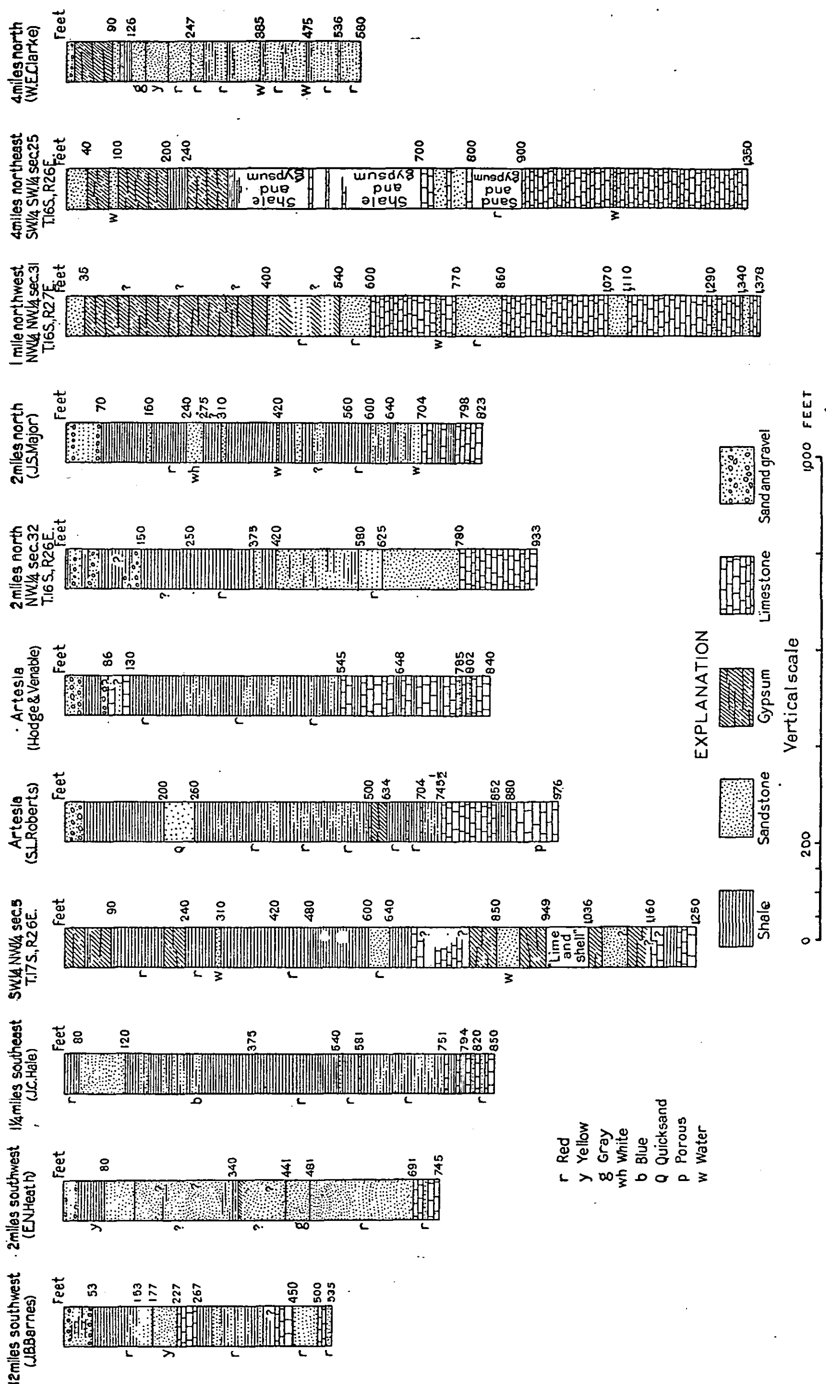
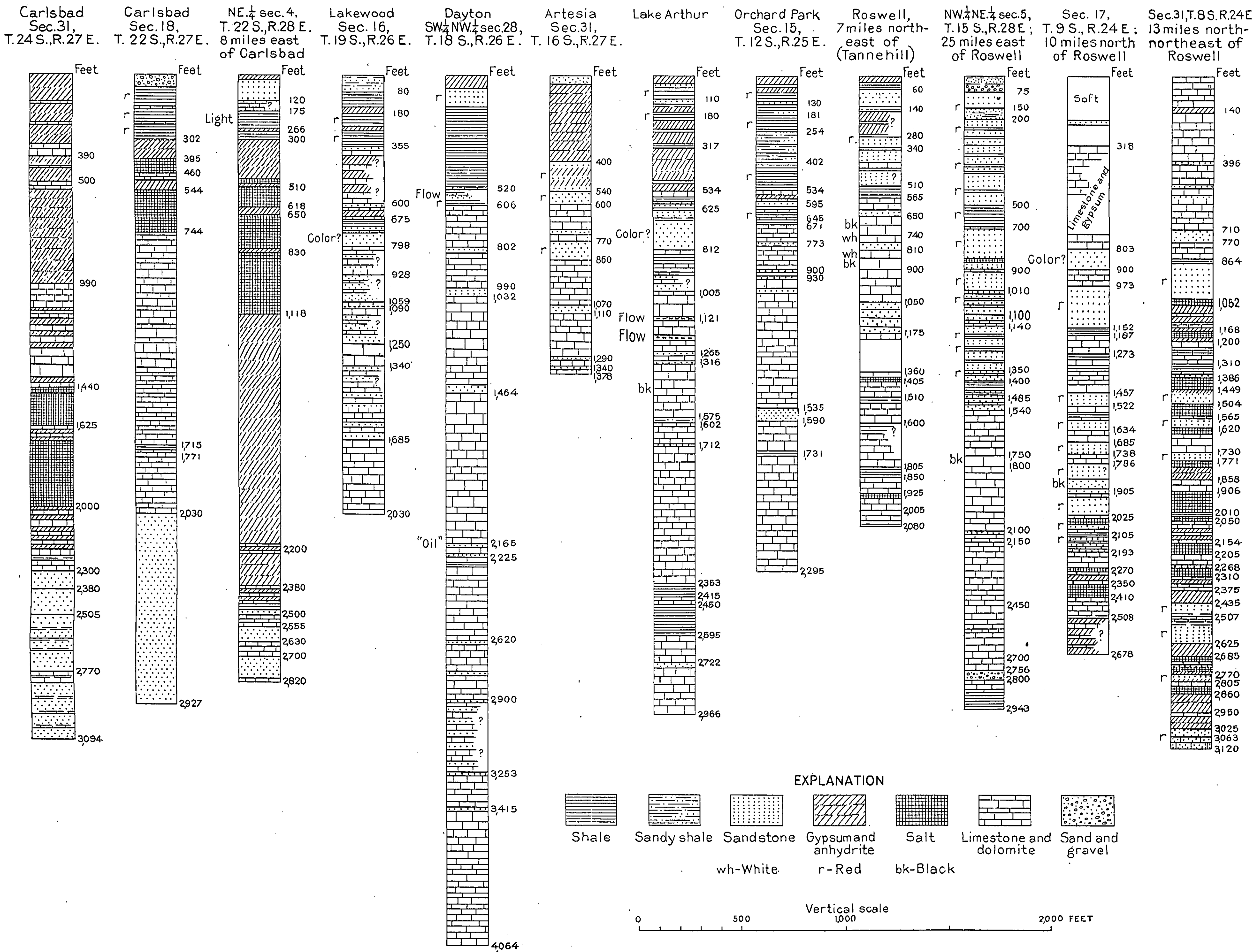


FIGURE 99.—Records of representative deep borings in the vicinity of Artesia



RECORDS OF REPRESENTATIVE DEEP BORINGS IN THE PECOS VALLEY

Much of the oil and gas in the recently developed Artesia oil field is in T. 18 S., R. 28 E., about 15 miles southeast of Artesia. The oil occurs in beds that are in the succession constituting the wide cuesta extending from the Pecos Valley to the Sacramento Mountains. No data are available as to the details of the stratigraphy in this oil field. The following is a condensed record of a representative boring:

Record of New State No. 1 boring in the SW. ¼ sec. 4, T. 18 S., R. 28 E., Artesia oil field

	Feet
Gypsum	0–15
Red beds with gypsum at 75–85 feet, 200–215 feet, 255–275 feet, and 305–375 feet and "sand and gravel" at 160–180 feet	15–400
Gypsum	400–513
Shale, brown, with gypsum at 700–720 feet	513–800
Limestone, "broken"	800–950
Limestone, with brown sandy shale at 1,150–1,165 feet	950–1, 185
Shale, brown, sandy, on red sandstone	1, 185–1, 215
Limestone, hard	1, 215–1, 230
Gypsum and limestone with 30 feet of brown sandy shale at 1,275 feet	1, 230–1, 380
Shale, brown	1, 380–1, 400
Limestone, hard, white	1, 400–1, 410
Shale, sandy, hard	1, 410–1, 445
Sandstone, red	1, 445–1, 465
Gypsum	1, 465–1, 500
Shale, brown, limestone, and gypsum	1, 500–1, 545
Limestone	1, 545–1, 640
Shale and limestone	1, 640–1, 735
Shale, brown, limestone, and shale, "broken"	1, 735–1, 825
"Conglomerate," coarse	1, 825–1, 835
Limestone; some shale, part brown	1, 835–2, 074
Sandstone with gas	2, 074–2, 077
Limestone; some dark slate	2, 077–2, 250
Sandstone, yielding oil	2, 250–2, 254

The red sandstone at 1,445–1,465 feet appears to be so widespread that it is a useful horizon marker.

The log of a 2,013-foot boring in the northwest corner of sec. 32, in the same township, reports 925 feet of red beds with considerable "limestone" from 625 to 765 feet. Limestone, with some shale, extends from 925 to 2,013 feet and carries the red sandstone member from 1,517 to 1,568 feet, and oil sand from 1,947 to 1,993 feet.

Dayton region.—The records of four representative borings near Dayton are given in Figures 100–103, and the record of a 4,064-foot boring is given in Plate 53. Another log of the Hammond boring gives gypsum at 32–42 feet, and shale, mostly blue, from 82 to 217 feet. Several thin members of red shale are included in the limestone

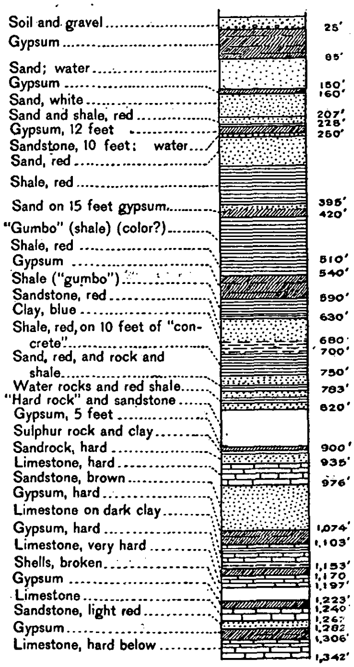


FIGURE 100.—Record of Williams or Belt well, in the N. ½ sec. 25, T. 18 S., R. 26 E., 2 miles southeast of Dayton, 1909

from 708 to 820 feet, and sandstone extends from 911 to 920 feet and from 931 to 950 feet.

A boring 10 miles east of Dayton has the record shown in Figure 103.

A 1,200-foot boring in the NW. ¼ SW. ¼ sec. 17, T. 18 S., R. 26 E., about 4 miles east of Dayton, is reported to have penetrated gypsum from 40 to 60 feet, soft limestone on shale from 352 to 394 feet, red shale from 780 to 810 feet, water-bearing sandstone from 1,050 to 1,060 feet, and limestone from 1,060 feet to the bottom.

The log of a 2,028-foot boring (No. 5) by the Illinois Producers Co. in the northwest corner of sec. 32, T. 18 S., R. 28 E., reported red beds to 1,690 feet, with 65 feet of gypsum at 330 feet, 40 feet at 675 feet, and 167 feet at 1,345 feet. Brown shale and limestone were penetrated from 1,556 to 1,635 feet and hard limestone from 1,690 to 2,028 feet, with 28 feet of sandstone at 1,740 feet and 48 feet of sandstone at 1,944 feet.

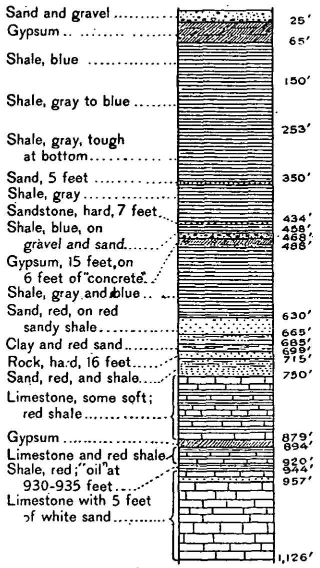


FIGURE 101.—Record of well of Dayton Petroleum Co., in the NW. ¼ NW. ¼ sec. 23, T. 18 S., R. 26 E., 2 miles east of Dayton, 1913

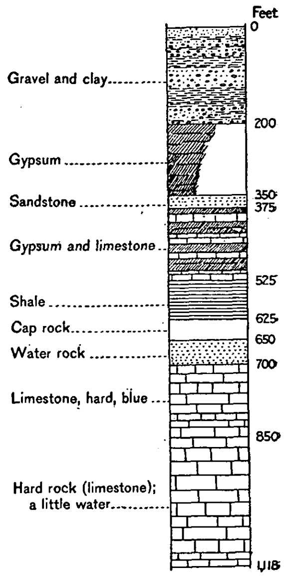


FIGURE 102.—Record of Hammond well, in the W. ½ NE. ¼ sec. 15, T. 18 S., R. 26 E., 3 miles northeast of Dayton, 1910

These records present much more diversity than probably exists in the stratigraphy of the region. They all indicate the presence of an upper series of red shales, which doubtless carries considerable gypsum, and an underlying succession of massive limestone with thin intercalations of sandstone and red shale which in the deepest well (pl. 53) extends from 606 to 4,064 feet. They are all comprised in the Chupadera formation, and probably some of the deeper borings penetrated the Abo sandstone.

A test boring for oil southeast of Dayton had a record which is given below in somewhat condensed form:

Record of boring in sec. 31, T. 18 S., R. 28 E., 10 miles east-southeast of Dayton

	Feet
Gypsum	0–20
Sandstone, red, with water at 135 and 350 feet; some limestone, especially in lower part	20–400
Limestone, shale, and red beds, with 5 feet of hard sandstone at 545 feet	400–640
Shale, red, with some limestone layers	640–870
Limestone, with some shale; 5 feet of red shale at 1,195 feet, 15 feet at 1,240 feet, and 10 feet at 1,360 feet	870–1, 380
Shale, brown	1, 380–1, 390
Limestone, gray, with 5 feet of red sandstone at 1,450 feet	1, 390–1, 460
Sandstone, red	1, 460–1, 500
Limestone, gray, some pink	1, 500–1, 635
Limestone and shale	1, 635–1, 660
Sandstone	1, 660–1, 668
Limestone, gray on brown	1, 668–1, 744
Sandstone, red	1, 744–1, 765
Limestone	1, 765–1, 780
Shale, brown on blue	1, 780–1, 789
Limestone, gray, very hard	1, 789–1, 884
Sandstone, limy near base	1, 884–1, 955
Limestone, gray	1, 955–1, 980
Sandstone, gray	1, 980–2, 005
Limestone, gray above, sandy in middle	2, 005–2, 060
Sandstone, gray	2, 060–2, 072

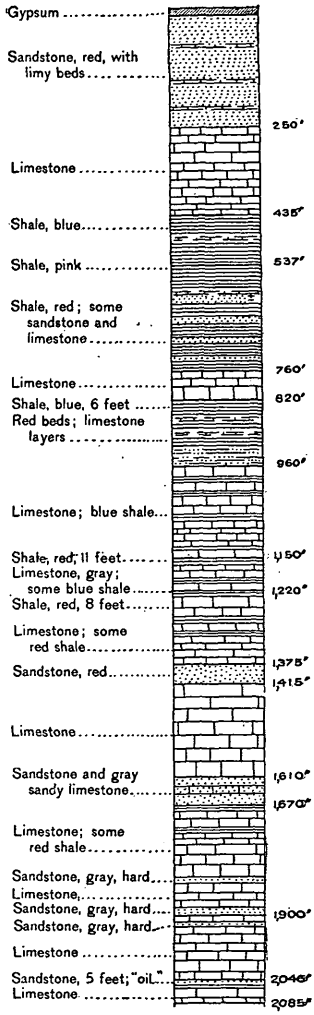


FIGURE 103.—Record of boring in the SE. ¼ sec. 25, T. 18 S., R. 27 E., 10 miles east of Dayton

Lakewood region.—A record of the boring of the Illinois Producers Co. for oil in sec. 16, T. 19 S., R. 26 E., 2 miles northwest of Lakewood, is given in Plate 53. A boring in Lakewood is reported by M. A. Fisher, driller, to have the following record:

Record of town well in Lakewood

	Feet
Not reported	0–300
Shale, soft	300–350
"Gravel," cemented	350–370
Shale, red	370–400
"Gravel," cemented	400–415
Shale, red, and gypsum	415–780
Sandstone, white	780–800
Gypsum and shale, red	800–820
Sandstone, blue	820–826
Gypsum and shale	826–834
Sandstone	834–849
Gypsum, red	849–900
Sandstone, red, hard	900–955
Sandstone	955–1, 000
Sandstone, blue, hard	1, 000–1, 017

A 617-foot hole on the Crocket farm, in sec. 10, T. 20 S., R. 25 E., about 6 miles southwest of Lakewood, passed through 240 feet of red shale with several thin gypsum and limestone members, underlain by 60 feet of gypsum parted by three thin layers of limestone and carrying near its lower part considerable sand. Below this is light-colored limestone containing a 25-foot bed of anhydrite at 375 feet, thin layers of sandstone at 455, 495, and 583 feet, and a thin bed of red shale at 604 feet.

Record of Walters & Shavers artesian well, McMillan

	Feet
Soil	0–6
Coarse gravel	6–13
White clay	13–33
Coarse sand and gravel containing water	33–43
White chalky rock	43–70
Sandstone, very hard, gray, with layers of "gravel"	70–170
Hard flinty rock	170–177
Shale, red, and coarse "gravel" in alternate succession	177–235
Shale, light-colored, sandy	235–250
Shale, red	250–254
Gypsum and red shale alternating; 23-foot bed of hard gypsum at 370 feet	254–440
Gypsum and red sandstone alternating	440–500
Sandstone, red and hard, in alternate layers 2 feet thick	500–650
Limestone, hard, white; very hard near base	650–820
Limestone, white, softer; flow of about 300 gallons a minute	820–845

Record of Lakewood Townsite Co.'s artesian well, McMillan

	Feet
Loam and gravel	0–49
Gypsum, soft, in strata 5 to 6 feet thick	49–80
White chalky rock	80–120
Sandstone and gypsum in alternating layers	120–135
Gypsum, pure white, moderately hard	135–200
Gypsum, very hard, white	200–450
Shale	450–490
White rock [limestone?], alternating layers of hard and soft; contains a few thin layers of sandstone; first flow at 770 feet; second flow at 810 feet	490–863
White rock [limestone?], very soft	863–877
Limestone, in alternating layers of soft and hard	877–880

Carlsbad region.—Many deep borings have been made in the general region about Carlsbad for water, oil, or potash. Two important records are given in Plate 53. Another record of the hole in sec. 18, T. 22 S., R. 27 E., furnished by Mr. Scott Etter, mentions white limestone from 140 to 147 feet, 156 to 173 feet, 215 to 220 feet, and 234 to 253 feet; gypsum from 325 to 348 feet and 380 to 395 feet, all in red beds; rock salt from 395 to 460 feet and 544 to 578 feet; and gypsum from 495 to 544 feet. Some salt and gypsum are included in limestone which extended very nearly in a solid body from 578 to 2,030 feet, the lower 400 feet of which is reported as dark and black. From 2,030 to 2,937 feet, where boring was discontinued in 1925, the rock is sandstone, which doubtless represents a northern extension of the Delaware Mountain formation. A third record, apparently of the same boring, reports gypsum from 300 to 480 feet, salt from 480 to 540 feet, limestone from 540 to 580 feet, anhydrite from 580 to 640 feet, salt from 640 to 670 feet, massive limestone from 670 to 2,020 feet, and sandstone from 2,020 to 2,120 feet.

The Tracy No. 1 boring, on a dome about 2 miles west of Carlsbad, was abandoned in 1926, at a depth of 5,800 feet. It is the deepest hole in the Pecos Valley region. The formations penetrated were limestone, mostly light colored and only in part dolomitic, to 2,925 feet; sandstone, presumably of the Delaware Mountain formation, to 4,930 feet; and dark limestone and shale to 5,800 feet. The relations are shown in section B, Figure 93, and section 2, Plate 50. There was little or no trace of the gypsum and red-bed succession that crops out in the broad belt about 20 miles to the west. Ten feet of gypsum was reported at 220 feet, and 5 feet at 550 feet. From 2,640 to 2,710 feet the boring penetrated "dark limestone," which may be the top member of the Delaware Mountain. It was underlain by 200 feet of dark-gray fine sandstone separated from the great lower body of sandstone by 65 feet of sandy limestone and shale. The limestone below 4,930 feet is dark gray and alternates with black shale. It is probably the lower limestone of the Delaware Mountain formation.

The following record throws considerable light on the eastward extension of the Chupadera formation under Pecos Valley with probable relations shown in section 3, Plate 50:

Condensed record of well in NE. ¼ SE. ¼ sec. 31, T. 24 S., R. 27 E., 17 miles south of Carlsbad

	Feet
Gypsum and anhydrite; some limestone	0–345
Limestone and dolomite	345–390
Anhydrite; some dolomite	390–500
Limestone and dolomite	500–530
Anhydrite; very little dolomite	530–990
Limestone, hard, gray	990–1, 030
Limestone and anhydrite	1, 030–1, 440
Salt	1, 440–1, 625
Limestone and anhydrite	1, 625–1, 705
Salt	1, 705–2, 000
Anhydrite and dolomite	2, 000–2, 180
Limestone; some sandy beds and shale	2, 180–2, 300
Sandstone, gray, with thin limestone in center, fine below	2, 300–2, 505
Sandstone, with some black shale	2, 505–2, 770
Limestone, anhydrite, and shale	2, 770–3, 000
Sandstone; some limestone and shale	3, 000–3, 094

The Castile gypsum is represented by the thick deposits of anhydrite with included dolomite members from the surface to 990 feet. The limestone from 990 to 1,440 feet is in part at least the Carlsbad limestone member. The two thick deposits of salt, 430 feet in all, separated by limestone and anhydrite, probably represent the gypsum member that crops out a few miles west and north of Carlsbad. The correlation of the strata below the salt is less certain, for the sandstone may be either the sandstone of the Delaware Mountain formation or the sandy phase of the lower Chupadera beds, such as that seen in Lost Chance Canyon. If it is Delaware Mountain the lower Chupadera beds thin rapidly toward the east.

In 1926 a core-drill hole was sunk northeast of Carlsbad to test the salt beds for potash. Its record is as follows, and the results of the potash tests are given on page 253.

Record of core-drill hole in center of sec. 4, T. 21 S., R. 30 E., 20 miles northeast of Carlsbad, Eddy County

	Feet
Surface sand, gravel, sandstone, and gypsum	0–51
Red beds, mostly sandy shale; some thin gypsum layers	51–380
Anhydrite; some fibrous gypsum at top and bottom	380–410
Red beds, mostly shale; some anhydrite	410–454
Limy shale, gypsum, and anhydrite	454–563
Shale, dark	563–586
Gypsum, gray	586–596

	Feet
Shale, red, sandy, and sandstone	596–655
Shale, dark, on red shale and thin anhydrite	655–686
Salt and red shale	686–711
Shale, red, sandy, with thin salt	711–789
Salt and polyhalite	789–802
Salt and shale	802–826
Salt and polyhalite	826–837½
Anhydrite	837½–844
Salt; some red shale and some polyhalite and anhydrite	844–1,219
Salt with some sylvite and polyhalite; very little red shale	1,219–1,416½
Anhydrite and green shale	1,416½–1,423
Salt; some sylvite; very little shale	1,423–1,468
Salt with some polyhalite, a little red shale in upper part, and small amount of anhydrite	1,468–2,021
Salt; little anhydrite	2,021–2,073½
Anhydrite	2,073½–2,093½

Bore holes put down on the east side of Pecos River at the Red Bluff dam site by the United States Bureau of Reclamation indicated 63 feet of limestone and sandstone on about 40 feet of red clay and gypsum. In the bank on the west side of the river overlying gypsum and limestone members appear.

Record of boring on west side of Pecos River at Red Bluff

	Feet
Limestone	0–31
Clay, gray above, red at base	31–32½
Gypsum	32½–72⅔
Sandy clay, red, some gypsum	72⅔–81½
Sandstone, soft, gray	81½–120

Record of boring on east side of Pecos River at Red Bluff

	Feet
Sand and gravel	0–8½
Limestone	8½–11½
Sandstone and shale, red	11½–27
Sandstone, yellow	27–29
Limestone	29–42½
Shale, limestone, and sandstone	42½–63
Clay, red, and gypsum	63–87½
Sandstone, soft, gray	87½–90
Gypsum	90–95
Clay, red, and gypsum	95–100
Sandstone, soft, gray	100–105
Gypsum	105–111
Gypsum and soft gray sandstone	111–120

Two wells in sec. 34, T. 22 S., R. 21 E., one 276 feet and the other 530 feet deep, obtain artesian flows of about 4 gallons per minute each.

Lea County.—Of the many borings recently made in Lea County the following record appears to be fairly representative:

Record of Maljamar boring No. 1, sec. 20, T. 17 S., R. 32 E., Lea County

	Feet
Gypsum, etc	0–15
Red rock with water sands at 700 and 775 feet	15–806
Limestone with 5 feet of red rock near top	806–960
Salt with 25 feet of limestone at 1,450 feet	960–1, 965
Limestone	1, 965–2, 000
Broken formation and red beds	2, 000–2, 030
Salt	2, 030–2, 060
Limestone; red sand near bottom	2, 060–2, 195
Salt and gypsum	2, 195–2, 265
Red beds and lime	2, 265–2, 328
Sandstone	2, 328–2, 333
Broken lime	2, 333–2, 420
Red bed on 3 feet of limestone	2, 420–2, 438
Sandstone	2, 438–2, 455
Limestone, white and sandy	2, 455–2, 565
Sandstone, white	2, 565–2, 570
Limestone, sandy and broken	2, 570–2, 620
Shale, brown	2, 620–2, 638
Broken formation	2, 638–2, 690
Limestone, black	2, 690–2, 705
Sandstone	2, 705–2, 717
Limestone, white on black	2, 717–2, 750
Broken formation	2, 750–3, 048
Limestone, hard	3, 048–3, 079
Broken formation	3, 079–3, 107
Limestone, sandy, on red sand; much gas	3, 107–3, 130
Shale, brown, sandy, on white sandstone; much gas	3, 130–3, 155
Broken lime and anhydrite	3, 155–3, 492
Limestone, gray on white	3, 492–3, 811
Shale, sandy, brown on white, and brown sandy limestone	3, 811–3, 835
Limestone, gray, sandy	3, 835–3, 990
Shale, green on gray, oil	3, 990–4, 025
Limestone, broken; oil	4, 025–4, 105
Limestone, brown, sandy; oil	4, 105–4, 132

The significance of the word "broken" in this record is not known. This boring doubtless penetrated the Rustler and Castile beds and the eastward extension of the Chupadera formation, but no evidence is presented to suggest the limits of these formations or to show whether the Pennsylvanian series was reached.

PENNSYLVANIAN STRATA

Several holes have been bored 3,000 feet and deeper in the Pecos Valley in Chaves and Eddy Counties, and the Tracy boring just west of Carlsbad attained a depth of 5,800 feet, reaching the lower member of the Delaware Mountain formation. The records of some representative deep holes are shown in Plate 53. The 3,120-foot hole 12 miles north of Carlsbad was mostly if not altogether in the Chupadera formation, but possibly it penetrated the Abo sandstone in its lower part. It certainly shows a great thickening of the Chupadera beds to the south and southeast. The 5,800-foot hole near Carlsbad shows that the Permian strata are at least a mile thick at that place, but the position of the top of the Magdalena group (Pennsylvanian), the thickness of that group, and the existence of the underlying Paleozoic strata so conspicuous on the west front of the Sacramento Mountains have yet to be determined.

In 1922 a hole was bored with a core drill 2 miles southwest of the Williams ranch, just west of Guadalupe Point, Culberson County, Tex. As shown in section 5, Plate 50, and in Figure 93, it began in an anticline of the lower limestone member of the Delaware Mountain formation and penetrated 3,400 feet of limestone. These strata were of various colors and texture, but no evidence was obtained as to the age of any of them. It seems very likely, however, that the Pennsylvanian series was penetrated, but the depth at which it was reached is unknown. It is reasonable to believe that this series underlies at least part of southeastern New Mexico, and it will undoubtedly be sought by drillers trying to find petroleum. Fossils, possibly minute ones, may be found in some of the deep holes, and these may throw light on such questions, but material of significant character will have to be obtained to indicate age reliably.

SALT AND GYPSUM DEPOSITS

In a special report prepared in 1920[39] an account was given of the extension of a very widespread deposit of salt under an area of about 20,000 square miles in eastern New Mexico. The principal evidence available at that time was records of borings in the Pecos and Canadian Valleys, notably the 2,820-foot hole near Carlsbad, in which 633 feet of salt and about 1,500 feet of anhydrite and gypsum were reported; a 787-foot hole for potash, of which the record is given in Figure 104; the McGee well, near Tucumcari; the boring at Lesbia; and the 3,120-foot hole bored by the Toltec Oil Co., 13 miles northeast of Roswell (see record in pl. 53), which penetrated 526 feet of salt in numerous thick beds, interstratified in anhydrite and dolomite.

Other records since received from different places in Clay County, the boring south of Buchanan, and several holes in the region east and south of Carlsbad, Lea County, east of Dayton and north of Fort Sumner, show thick salt deposits under a large part of eastern New Mexico. The maximum appears to be in the core-drill hole 20 miles east of Carlsbad, which revealed nearly 1,300 feet of salt with interbedded deposits of potash minerals. Borings in 1926 in Lea County record salt deposits 706 to 1,140 feet thick. The records of borings

[39] Darton, N. H., Permian salt deposits of the south-central United States: U. S. Geol. Survey Bull. 715, pp. 205–230, 1921.

about Lakewood, Artesia, Dayton, Lake Arthur, and Orchard Park do not indicate salt, possibly because it was not recognized by the drillers. The records of many borings in eastern New Mexico show thick and widespread deposits of gypsum and anhydrite under most of the region. The principal reported occurrences of these minerals is shown in the following list, and further details are given in the records:

Principal borings in eastern New Mexico that reported salt, gypsum, and anhydrite

Location	Depth (feet)	Salt	Gypsum and anhydrite
Roswell, 12 miles north of	3,120	At intervals, 1,052–2,880 feet; 526 feet.	At intervals, 1,060–3,025 feet (480 feet).
Roswell, 10 miles north of	2,676	At intervals, 2,025–2,410; 90 feet.	
Roswell, 25 miles east of	2,943	850–852 feet	Not reported.
Roswell, 7 miles northeast of	2,080	1,925–1,940 feet	Much to 534 feet.
Artesia	976	Not reported	500–634 feet.
Artesia, 25 miles east of; sec. 6, T. 16 N., R. 30 E.	501	231–501 feet	
Artesia, sec. 5, T. 17 S., R. 26 E.	1,250	Not reported	At intervals, 800–1,160 feet.
Artesia, 15 miles northeast of		At 281 feet	
Artesia, 4 miles northeast of	1,350	Not reported	40–900 feet (in large part with shale).
Artesia, 20 miles northeast of		At 200 feet	
Artesia, sec. 31, T. 16 S., R. 27 E.	1,378	Not reported	20–540 feet.
Lake Arthur	2,966	do	0–534 feet.
Lakewood	2,030	do	Many beds 160–670 feet.
Dayton, 2 miles east of	1,126	do	468–482 and 879–894 feet.
Dayton, 3 miles northeast of	1,118	do	Many beds 200–500 feet.
Dayton, 2 miles southeast of	1,342	do	25–85, 150, 228, 395–420, 540–590, 900, 1,074–1,103, 1,153, 1,223, and 1,282–1,306 feet (249 feet).
Dayton, 25 miles east of	3,400	535–1,177 feet	Not reported.
Dayton, 35 miles northeast of	3,465	1,005–2,040 feet	Do.
Dayton, 37 miles northeast of	3,872	752–1,710 feet	Do.
McMillan	880	Not reported	49–80, 120–450 feet.
Buchanan, 11 miles south of	3,200	2,105–2,190, 2,200–2,260, 2,415–2,460 feet (220 feet).	At intervals, 190–529 feet (285 feet).
Carlsbad, just south of	2,927	395–460, 744–1,715 feet	302–395, 470–544 feet.
Carlsbad, 17 miles south of	3,094	1,440–2,000 feet (475 feet)	0–345, 390–500, 530, 990; at intervals, 1,060–1,460. 1,630–1,700, 2,000–2,180, and 2,770–2,800 feet (1,100 feet or more).
Carlsbad, sec. 4, T. 21 S., R. 30 E.	2,093½	789–2,073 feet. (Many potash layers; 40 feet in all.)	380–563, 586–596, 837–844, 1,420, 2,073½–2,093½ feet.
Carlsbad, sec 4., T. 22 S., R. 28 E.	2,820	485–1,118 feet	300–485, 1,118–2,380, and at intervals 2,380–2,455 feet.
Carlsbad, sec. 21, T. 22 S., R. 27 E.	787	743–775 feet; some potash, 648–787 feet.	165–629 feet and at intervals below.
Carlsbad, 17 miles east of	3,260	320–1,335 feet	
Lea County, sec. 15, T. 21 S., R. 33 E.	3,000	1,960–3,000 feet	Not reported.
Lea County, sec. 11, T. 16 S., R. 32 E.	3,390	1,011–2,215 feet	Do.
Lea County, sec. 4, T. 17 S., R. 34 E.	5,339	Not reported	1,806–2,650 feet.
Lea County, sec. 21, T. 17 S., R. 32 E.	4,132	960–1,965, 2,030–2,060, and in part 2,195–2,265 feet	Much anhydrite, 3,155–3,492 feet.
Lea County, sec. 4, T. 11 S., R. 34 E.	4,859	1,806–2,506 feet	Not reported.
Picacho	2,199	Three beds, 1,109–1,250 feet (40 feet).	Several beds, 250–520 feet.
Santa Rosa, 12 miles north-northeast of.	1,003	Not reported	Several beds, 560–960 feet.
Santa Rosa, sec. 25, T. 12 N., R. 23 E.		do	985–1,006, 1,027–1,037, 1,172–1,175 feet.
Fort Sumner, 22 miles north of	3,684	865, 1,240, 1,310–1,345, 1,445, 1,620–1,710, 1,865–1,900, 1920–1,955, 2,030–2,135, 2,857 feet (380 feet).	865–1,085, thin beds at 1,205 and 1,260 feet (275 feet).
Endee, sec. 7, T. 11 N., R. 36 E.	3,503	975–1,230, 1,325–1,540; intervals 1,558–1,840, 1,910–2,120, 2,205–2,210, 2,395–2,505, 2,620–2,795, 3,300–3,315, 3,390–3,405 feet (650 feet).	760–800 feet.
McGee, sec. 14, T. 10 N., R. 31 E.	4,014	1,100–1,135, 1,430–1,455. 2,372–2,377, 3,230–3,235 feet (70 feet).	Not reported.
Dripping Spring, sec. 25, T. 13 N., R. 31 E.	2,985	1,340–1,475, 1,940–2,150, 2,300–2,310 feet (340 feet).	Thin beds 1,285 and 2,150 feet.
Lesbia	1,414	700 and 1,200–1,300 feet	Not reported.

The salt deposits in the Endee well, in the NE. ¼ sec. 7, T. 11, N., R. 36 E., 5 miles northwest of Endee, Quay County, were as follows: (see also record in pl. 59):

	Depth (feet)	Thickness (feet)		Depth (feet)	Thickness (feet)
Salt and shale	975–1, 230	150±	Salt, blue	2, 060–2, 080	210
Do	1, 325–1, 540	100±	Salt, white	2, 080–2, 100	
Salt	1, 558–1, 605	47	Salt, brown	2, 100–2, 120	
Do	1, 645–1, 665	20	Salt	2, 205–2, 210	5
Do	1, 760–1, 765	5	Do	2, 395–2, 505	10
Do	1, 770–1, 775	5	Red shale and salt	2, 620–2, 795	50±
Do	1, 815–1, 840	25	Salt and shale	3, 300–3, 315	10±
Salt, blue	1, 910–1, 925	210	Blue salt and shale	3, 390–3, 405	10±
Salt, dark	1, 925–1, 935				
Salt, brown	1, 935–1, 950				650±
Salt, red	1, 950–2, 060				

The well sunk to test for oil in the NE. ¼ sec. 4, T. 22 S., R. 28 E., 8 miles east of Carlsbad in 1913, with the record given in Plate 53, revealed the existence of a vast deposit of salt and anhydrite. Many samples were obtained which were tested by E. E. Lyder and W. A. Whitaker, chemists in the University of Kansas. The anhydrite began in the lower part of a light sandy clay extending to 300 feet. The following deposits were found next below:

	Feet
Anhydrite, part iron stained	300–485
Salt with thin bed of anhydrite near top	485–618
Anhydrite	618–650
Salt with 10 feet of anhydrite at 820 feet	650–1, 118
Anhydrite with few thin beds of limestone in lower part	1, 118–2, 455
Limestone	2, 455–2, 500

An alternation of limestone and sandstone extended for the next 320 feet to the bottom of the hole. Part of this record was verified by the strata penetrated by a 787-foot hole bored for potash salts by the E. J. Longyear Co. near Carlsbad in 1917, which had the succession shown in Figure 104. Samples were tested by R. K. Bailey in the laboratory of the United States Geological Survey.

The record of the 2,943-foot boring 25 miles east of Roswell (section I, pl. 53) reported no gypsum and only 2 feet of salt at 850 feet, but it is likely that these minerals were overlooked by the drillers, which may be the case also with several other holes to the south, such as the deep borings at Orchard Park, about Artesia, and at Lake Arthur, where no salt was reported. In the Lake Arthur hole (see section F, pl. 53) much gypsum was found down to 534 feet, and in several of the holes about Artesia (see fig. 99) thick beds of gypsum were penetrated.

The western and northern limits of the salt deposits in the eastern extension of the Chupadera formation are not very clearly indicated, especially as failure to mention them in well records is not always conclusive proof of their absence underground. They undoubtedly extend northwest some distance under the cuesta of the Sacramento Mountains, as shown by the Picacho and Buchanan borings, and northward in Guadalupe and Quay Counties and perhaps into eastern San Miguel and Union Counties.

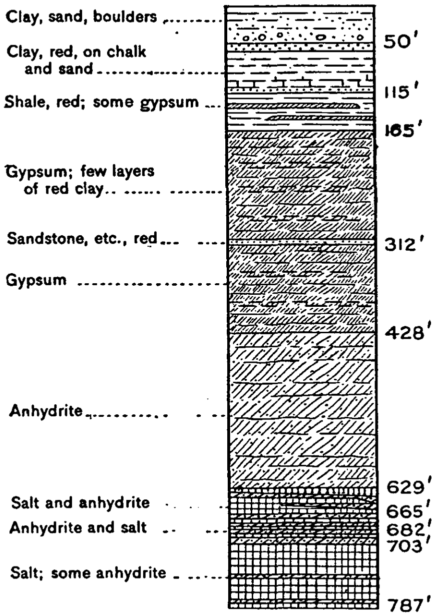


FIGURE 104.—Record of diamond-drill hole in the SW. ¼ NW. ¼ sec. 21, T. 22 S., R. 27 E., 2 miles southeast of Carlsbad

Thinning of the salt deposits to the west is indicated by the diminution to 40 feet in the boring at Picacho, and their absence in borings at Felix and Dunkin and west of Carlsbad indicates the location of their termination toward the southwest. The 475 feet of salt between 1,440 and 2,000 feet in the deep boring 17 miles south of Carlsbad shows that the basin deepens rapidly to the east in the southern part of Eddy County.

The extension of a thick deposit to the north is shown by the presence of 380 feet of salt in the boring 22 miles northeast of Fort Sumner (see fig. 135), where also a 220-foot deposit of gypsum (or anhydrite) was found from 865 to 1,085 feet.

POTASH

Potash tests of materials below 648 feet in the drillings from the hole in sec. 21, T. 22 S., R. 27 E., 2 miles southeast of Carlsbad (see fig. 104) were reported by E. M. Skeats & Sons, of San Diego, Calif., as follows:

Depth (feet)	K_2O (per cent)		Depth (feet)	K_2O (per cent)	
	Whole sample	Soluble part		Whole sample	Soluble part
648–653	0.39	0.51	687–698	0.47	0.82
653–658	.67	.77	698–720	.08	.13
658–668	.59	.83	720–746	.39	.77
668–677	.47	.64	746–775	.31	.42
677–682	Trace.	.40	775–787	.15	.28
682–687	.31	.51			

These are all considerably less than the amount in the salts of the ocean, in which the proportion of potassium averages 1.1 per cent.

In the later part of 1926 chemical tests of the cores from a boring in sec. 4, T. 21 S., R. 30 E., Eddy County, revealed the presence of layers of potash minerals in a salt deposit nearly 1,300 feet thick. The following are the principal occurrences of potash minerals, which show in all a thickness of about 40 feet:

Potash minerals found in McNutt boring in sec. 4, T. 21 S., R. 30 E.

Depth to principal beds (feet)	Thickness of deposit (inches)	Components	K_2O (per cent)
794–799	45	Polyhalite in part	9
844–845	14	do	13.3
988–996	63	Polyhalite in part, two beds separated by 28 inches of salt	14.6
1,129–1,130	14	Polyhalite	13.6
1,267–1,270	44	Sylvite in part	13.8
1,311–1,314	36	Sylvite and polyhalite in part	8.9
1,363–1,365	22	Halite	3.7
1,365–1,367	24	Sylvite	18.5
1,371–1,372±	19	do	8.8
1,395–1,399	51	Polyhalite, etc	11.9
1,429–1,433	54	Halite	4.1
		Langbeinite	17.7
		Langbeinite, kainite, and halite	6.6
		Kainite and halite	3.6
1,444–1,445	14	Sylvite and halite	14.8
1,445–1,458	18	do	17.8
1,569–1,572	11	Polyhalite	10.8
	15	do	15.3
1,762–1,765	36	do	12.1

In 1927 the Government bored three experimental holes for potash in Eddy County, with results given in the following tables: Hole No. 1, in the NW. ¼ sec. 13, T. 17 S., R. 31 E., is 1,847 feet deep and penetrated many saline deposits containing potash minerals between 838 and 1,760 feet.

Potash minerals in United States test boring No. 1, in NW. ¼ sec. 13, T. 17 S., R. 31 E.

Depth to principal beds (feet)	Thickness of deposit (inches)	Components	K_2O
873½– 876½	36	Polyhalite, kieserite, halite, etc	5.29
984 – 985	8	Carnallite, etc	13.34
1,071 –1,072	11	Polyhalite, carnallite, halite, etc	8.19
1,085 –1,087	24	Polyhalite, carnallite, kieserite, halite, etc	7.44
1,217 –1,218	12	Polyhalite and halite	9.47
1,250 –1,256	74	Halite and polyhalite, mostly	3.10
1,278 –1,281	38	Polyhalite, halite, and carnallite	4.01
1,325 –1,327	16	Halite and polyhalite	8.78
1,419½–1,421	22	Polyhalite and halite	8.10
1,478½–1,480	17	Polyhalite, anhydrite, and halite	11.39
1,647½–1,651½	58	Anhydrite and polyhalite	7.56

Minor beds occurred at or near 894, 906, 933, 940, 1,020, 1,030, 1,288, 1,293, 1,364, 1,374, 1,380, 1,496, 1,543, 1,550, 1,594, 1,690, and 1,758 feet. Some thinner beds between 890 and 990 were in part carnallite.

The second Government well, in sec. 14, T. 20 S., R. 29 E., was 1,100 feet deep. Salt deposits began at 335 feet, and many layers from 350 feet down contained more or less potash.

Potash minerals in United States test boring No. 2, sec. 14, T. 20 S., R. 29 E.

Depth to principal beds (feet)	Thickness of deposit (inches)	Components	K_2O
349 -351	26	Halite, polyhalite, and anhydrite	7.69
369 -372	35	Halite, polyhalite, anhydrite, and carnallite, etc.	8.96
476 -477	15	Polyhalite, etc	12.00
485½-488	32	Polyhalite, anhydrite, kieserite, and halite	10.05
502 -505	36	Halite, sylvite, kainite, and anhydrite	7.19
511 -515	47	Halite, sylvite, polyhalite, clay, etc	6.17
585 -587	16	Polyhalite, halite, and anhydrite	8.44
629 -636	91	Halite, polyhalite, and clay	3.76
675 -682	38	Polyhalite, halite, and anhydrite	4.97
731 -734	27	Halite, polyhalite, anhydrite, magnesite	9.40
810 -812	29	Polyhalite, halite	13.94
853 -854	18	Halite, polyhalite, anhydrite, etc	8.64
886 -887	11	Polyhalite, anhydrite, and halite	11.40

Several thinner deposits occurred at various depths.

The third Government hole is in the SW. ¼ sec. 34, T. 22 S., R. 30 E., or about 28 miles from Carlsbad. It reached a depth of about 1,500 feet, and one bed of salt nearly 9 feet thick (1,466–1,475 feet) contained 11.08 per cent of K_2O.

Potash minerals in United States test boring No. 3, in sec. 34, T. 22 S., R. 30 E.

Depth to principal beds (feet)	Thickness of deposit (inches)	Components	K_2O
868- 871	38		13.50
951- 953	27		13.13
1,012-1,016	43	Polyhalite, some halite, and anhydrite	12.86
1,200-1,203	28		12.88
1,333-1,336	39	Polyhalite and halite	12.06
1,364-1,366	28	do	8.73
1,382-1,387	28	Polyhalite, anhydrite, and halite	8.54
1,460-1,464	42		8.73
1,466-1,475	106		11.08

Potash salts found in testing samples from other borings

[In the laboratory of the U. S. Geological Survey]

County	Well and location	Depth (feet)	K_2O
Chaves	California Co., sec. 24, T. 10 S., R. 28 E	1,155-1,165	5.60
Do	Arena, sec. 18, T. 13 S., R. 31 E	1,380-1,390	10.82
De Baca	McAdoo, sec. 16, T. 1 S., R. 27 E	445- 450	7.92
Eddy	Keel No. 1, sec. 10, T. 17 S., R. 31 E	1,025-1,030	10.41
Do	do	1,030-1,035	5.45
Do	L-S Refining Co., sec. 1, T. 18 S., R. 31 E	1,650-1,665	5.93
Do	Beeson No. 1, sec. 33, T. 17 S., R. 30 E	1,125-1,130	3.24
Do	Marland Hale No. 1, sec. 11, T. 20 S., R. 30 E	520- 525	8.78
Do	Beulah-Lynch No. 1, T. 17 S., R. 31 E	1,475-1,480	8.83
Do	Ogg No. 1, sec. 30, T. 18 S., R. 30 E	485	2.71
Do	Robinson, sec. 25, T. 16 S., R. 31 E	1,150-1,160	10.93
Lea	Maljamar, sec. 5, T. 17 S., R. 32 E	985-1,015	4.48
Do	do	1,800	4.83
Do	Inglefield-Bridges, sec. 4, T. 17 S., R. 34 E	2,380-2,400	7.76
Do	do	2,585-2,595	8.73
Do	W. Mitchell No. 1, sec. 18, T. 17 S., R. 32 E	1,314-1,321	4.44
Do	Wyatt No. 1, sec. 34, T. 17 S., R. 33 E	1,580-1,590	9.40
Do	State No. 1, sec. 9, T. 19 S., R. 38 E	1,900-1,920	10.23

GLORIETA MESA AND ITS SOUTHERN EXTENSION TO NORTHERN TORRANCE COUNTY

GENERAL RELATIONS

Glorieta Mesa is a high, wide plateau on the southwestern slope of the Sangre de Cristo Mountains or south end of the Rocky Mountains. It terminates in a high escarpment on the west side of the Pecos Valley which extends across the western part of San Miguel County to Glorieta station and thence southward toward Lamy. The Atchison, Topeka & Santa Fe Railway climbs from Pecos River to the Glorieta Pass along the east slope of this escarpment, which is therefore a familiar object to travelers. The geologic relations in this vicinity are uniform for many miles—a succession of strata dipping southwest at a low angle on the southwestward-pitching slope of the Rocky Mountain axis. The top limestone of the Magdalena group crops out along the foot of the escarpment. Abo red shale and sandstone crop out along the middle slopes, and at the top is a thick cap of hard buff sandstone (basal part of Chupadera formation) that extends

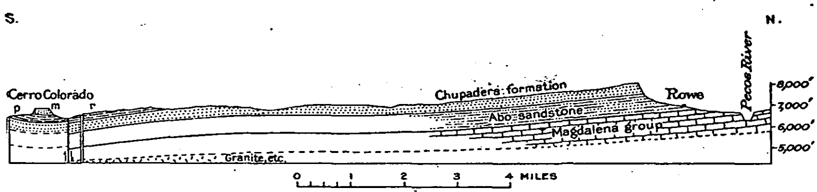


FIGURE 105.—Section across Glorieta Mesa from a point near Rowe to Lamy. r, Red shales (Dockum group, Triassic); p, shales of Colorado and Montana groups; m, sandstone of Montana group

far to the west and south under the limestone member, which in places reaches the crest. From Rowe southwestward there is general monoclinal structure, as shown in the section in Figure 105. To the north, near Glorieta, the beds are flexed in a shallow syncline, the west margin of which, however, is twisted and cut off by faulting near Canyoncito. Farther east and north the plateau extends across the south end of the Rocky Mountain axis and presents the anticlinal structure shown in Figure 105. Other features are shown in Figure 130.

FORMATIONS

MAGDALENA GROUP (PENNSYLVANIAN)

Limestone of the Magdalena group has a broad outcrop on the west slope of the southeastern ridge of the Sangre de Cristo Mountains. It is deeply trenched by Pecos River and extensively exposed in the canyon above Pecos. It lies on a remarkably smooth surface of granite and schist, the relations of which are well exposed on and near the river a few miles above Pecos. The Magdalena outcrop also extends along the east slope of the Sangre de Cristo Mountains, passing west of Glorieta and Canyoncito; but as the dips are steep and there is considerable faulting and crushing, this outcrop zone is narrow and interrupted. The greatest total thickness of the Magdalena may be 1,600 feet. Limestone predominates, with some shale and sandstone, and a thin bed of coal appears in places in the lower beds. This coal has been prospected on Pecos River 3 miles above Pecos and also, it is claimed, a short distance north of Glorieta. Some facts regarding the exposure on Pecos River were obtained by Gardner,[40] who gives the following section:

Generalized section of Magdalena group along Pecos River above Pecos

	Feet
Sandstone, shale, local conglomerate, and limestone, the whole variegated, red predominating [Abo sandstone]	(?)
Limestone with some alternating shale and sandstone	100
Limestone containing *Derbya cymbula*, *Derbya bennetti*, *Productus inflatus?*, *Productus inflatus?* var., *Spirifer rockymontanus*, *Spirifer cameratus*, and *Composita subtilita*	5
Limestone with some alternating shale and sandstone	1, 000
Limestone containing *Derbya bennetti*, *Productus inflatus?* var., *Spirifer rockymontanus*, *Composita subtilita*, and *Cliothyridina orbicularis*	5
Limestone with some alternating shale and sandstone	350
Limestone containing *Derbya bennetti*, *Productus inflatus?* var., *Spirifer rockymontanus*, and *Composita subtilita*	5
Limestone, massive	50
Limestone, shaly, containing *Zaphrentis* sp., *Productus inflatus?*, *Productus inflatus?* var., *Productus* aff. *P. wallacianus*, *Marginifera* aff. *M. muricata*, *Marginifera* aff. *M. splendens*, *Rhynchopora illinoisensis*, *Spirifer rockymontanus*, *Squamularia perplexa*, *Cliothyridina orbicularis*, *Hustedia mormoni*, and *Phillipsia* sp	1⅔
Sandstone, calcareous	3
Shale	1
Coal	Varying.
Limestone and sandstone	30
Shale containing *Derbya bennetti*, *Productus inflatus?* var., *Spirifer rockymontanus*, and *Composita subtilita*	10
Covered, about	200
Limestone, about	50
Pre-Cambrian complex.	
	1, 810½

The estimated thickness of 1,000 feet of "limestone with some alternating shale and sandstone" in this section is too great, as a later measurement by Gardner[41] gives 1,237 feet for the entire thickness of Pennsylvanian rocks in this general vicinity.

In lower beds not far above the granite on Pecos River in this region I collected the following species, determined by G. H. Girty: *Derbya crassa*, *Productus semireticulatus* var., *Pustula nebrascensis*, and *Composita subtilita*.

[40] Gardner, J. H., Carboniferous coal on Pecos River: U. S. Geol. Survey Bull. 381, pp. 449–451, 1910.
[41] Personal communication, February, 1918.

In the ridges north of Canyoncito about 500 feet of limestone of the Magdalena group is exposed, but owing to a fault the section is only a partial one, and in places the limestone is cut out entirely by the fault. However, there is probably a complete section just west of the railroad 2¼ miles north of Lamy, at the south end of the narrow granite gorge through which Apache Creek flows. The exposures extend from granite to overlying red beds. Limestone predominates, but much dark shale and some sandstone are included, also a thin bed of impure coal which has been prospected. Near the top is a 40-foot member of soft buff-gray sandstone capped by 50 feet of white limestone, probably the top of the formation. Next above is dirty-gray sugary sandstone at the base of the Abo formation. Fossils in the Magdalena beds in this region are abundant. Lee[42] found that in the vicinity of Rowe the upper part of the Magdalena comprised 100 feet of red beds containing thin layers of subcrystalline red to gray limestone with irregular "cement-like" surface containing the following species, determined by G. H. Girty:

Lophophyllum sp.
Polypora sp.
Fenestella 3 sp.
Cyclopora sp.
Fistulipora sp.
Derbya sp.
Chonetes sp.
Productus cora.
Productus nebraskensis.
Spirifier cameratus.
Spiriferina sp.
Composita subtilita.
Pugnax osagensis.
Dielasma bovidens.
Myalina subquadrata.
Myalina sp.
Modiola subelliptica.
Deltopecten occidentalis?
Acanthopecten carboniferus.
Aviculipecten sp.
Parallelodon carbonarius.
Pleurophorus? sp.
Edmondia nebraskensis?
Schizodus sp.
Pleurophorella costata.
Euconospira sp.
Bellerophon sp.
Soleniscus altonensis?
Orthonema? sp.
Naticopsis sp.
Platyceras n. sp.
Metacoceras aff. M. walcotti.
Nautilus sp.
Tainoceras aff. T. occidentale.
Orthoceras sp.
Phillipsia aff. P. scitula.

As these species are Pennsylvanian it is most likely that the containing beds belong to the Magdalena. Next below at this place is a 50-foot bed of "subcrystalline limestone in which are angular pieces of granite and yellowish-pink feldspar like that in the granite of the mountains to the north. In some places the rock consists of nearly equal parts of feldspar and limestone." It yielded *Composita subtilita*. The source of this material was near-by shores of pre-Cambrian rocks,

[42] Lee, W. T., and Girty, G. H., The Manzano group of the Rio Grande Valley, N. Mex.: U. S. Geol. Survey Bull. 389, p. 33, 1909.

against which some of the Magdalena sediments were deposited. The underlying blue massive limestone yielded the following fossils:

Productus nebraskensis.
Spiriferina kentuckyensis.
Squamularia perplexa.
Composita subtilita.
Cliothyridina missouriensis.
Hustedia mormoni.
Cardiomorphia? sp.
Astartella sp.
Aviculopinna peracuta.

From shales, limestones, and sandstones with thin beds of coal 400 feet lower down were collected:

Fistulipora sp.
Derbya? sp.
Productus semireticulatus.
Productus cora.
Spirifer cameratus.
Composita subtilita.
Myalina wyomingensis?
Metacoceras aff. M. walcotti.

The following fossils were collected by Lee in limestone of the Magdalena group near the village of Bernal:

Lophophyllum profundum.
Eupachycrinus sp.
Septopora sp.
Derbya sp.
Meekella striaticostata.
Productus punctatus,
Productus nebraskensis.
Productus nebraskensis?
Productus semireticulatus.
Dielasma bovidens.
Spirifer cameratus.
Spirifer rockymontanus.
Squamularia perplexa.
Spiriferina kentuckyensis.
Composita subtilita.
Aviculipecten sp.
Myalina sp.
Bellerophon crassus?
Platyceras nebraskense.
Dentalium? sp.
Metacoceras? aff. M. walcotti.
Orthoceras sp.
Phillipsia aff. P. major.

From upper beds of the group at a point 2 miles east of Pajarita I collecte the following species identified by G. H. Girty: *Productus semireticulatus, Pustula semipunctata, Spirifera cameratus, Composita subtilita*, and *Allerisma terminale.*

ABO SANDSTONE (PERMIAN)

The Magdalena group is overlain by about 800 feet of red beds so closely comparable in character and relations with the Abo sandstone of the Sandia and Manzano Mountains and the region to the south that there appears to be no question as to their identity. The outcrop zone extends along the slopes of Glorieta Mesa through San Jose, Fulton, Gise, Rowe, and Glorieta and spreads out rather widely in the syncline north of Glorieta. The long, deep cut for the railroad through the summit just west of Glorieta is in this formation (see pl. 5, *A*) and it extends south down the Apache Canyon to a point some distance beyond Canyoncito.

The rocks are mostly red sandstone, but red shale and white, gray, and brown sandstones are included and there appears to be much local variation in stratigraphy. I regard some underlying red shales with thin fossiliferous limestone members mentioned above as Magdalena. The following section at Rowe was described by Lee;[43] I have added an interpretation in brackets:

Section near Rowe

	Feet
Sandstone, yellow, weathering to pink and brown, coarse grained, massive [Chupadera formation]	175
Limestone, impure, cement-like [Chupadera formation]	2
Sandstone, dark red [top of Abo sandstone]	350
Sandstone, red and white beds alternating, coarse grained, locally conglomeratic	300
Conglomerate, gray, pebbles of crystalline and metamorphic rocks	10±
[Possible unconformity.]	
Shale and sandstone, red [Magdalena?]	100
Sandstone and shale, red, containing beds of subcrystalline red to gray limestone with irregular cement-like surface [Magdalena?]	100
Limestone, fragmental and subcrystalline, containing pebbles and angular fragments of quartz and feldspar [Magdalena]	50
Limestones [Magdalena]	400

Lee[44] found red conglomeratic limestone lying unconformably on limestone of the Magdalena group about 5 miles southeast of Rowe and again 15 miles farther southeast, at a point on the railroad about 6 miles east of Pecos River and 1 mile west of the old village of Bernal, where nearly horizontal beds lie on Magdalena limestone dipping 30°. The "lowest member is a coarse conglomeratic breccia containing angular and subangular fragments, some of which are several inches in diameter, composed of igneous and metamorphic rocks, red sandstone, and blue limestone," the limestone pebbles evidently derived from the underlying limestone and containing similar fossils. This member is probably represented by one of the coarse deposits mentioned in the section near Rowe given above, but the continuity was not traced.

The Abo sandstone is extensively exposed along Apache Canyon from Glorieta southward to a point within 2 miles of Lamy, where it passes under higher beds to the south, and to the west it is overlapped by the Santa Fe formation. In places the relations are obscured by faulting, and locally the formation is dropped against the granite by the main fault. It is at such a place, west of the railroad about "2 miles southwest of Canyoncito station," that the following partial section was measured by Lee.[45]

---

[43] Lee, W. T., op. cit. (Bull. 389), pp. 34–35.
[44] Idem, p. 35.
[45] Idem, p. 32.

Partial section of "Abo sandstone" exposed in Apache Canyon

	Feet
Sandstone, with partings of pink shale	150
Conglomerate, containing many subangular pebbles of blue limestone	10
Sandstone, prevailingly red, with partings of red shale	170
Sandstone, conglomeratic, locally cemented to an ironstone and containing small iron concretions and silicified trees	50
Sandstone, conglomeratic. and shale, alternating red, yellow to white; thickness estimated	1, 500
Sandstone, conglomeratic; pebbles mostly of limestone	20
Shale, red	25
Sandstone, coarse, light colored, massive	35
Sandstone, brown, calcareous, containing plant remains	8
Shale and sandstone, red	90
Conglomerate	10
Sandstone and shale, red, alternating	100
Conglomerate, red, consisting of angular and subangular pebbles of various crystalline rocks and fossiliferous limestone similar to the Magdalena beds in Pecos Valley	10
Granite.	

The plant remains above mentioned and some additional material collected by T. W. Stanton from the top of the ridge just west of Canyoncito station were reported on by F. H. Knowlton and David White as follows:

The coniferous branches and branchlets are probably to be referred to *Walchia*, of the group *W. pinniformis*, though somewhat slenderer than the usual forms of this species. We find fragments of cones which it does not seem possible with the material in hand certainly to separate generically from the cones of *Walchia*, and there are detached cone scales that apparently show the same affinity. There are also minute fragments of a fern pinnule that appear to belong to the genus *Laccopteris*. The larger cones are at least strongly suggestive of those of *Voltzia*, while the curious stem has somewhat the appearance of the pith of one of these ancient types. With these strongly suggestive facts in mind we regard the age as probably Permian or Triassic.

As shown in section A, Figure 112, this plant horizon is believed to be high in the Abo sandstone, probably only a short distance below the sandstone of Glorieta Mesa, here dropped by a fault.

Permian fossil plants, associated with insects, were later collected by David White near the south end of the great cut at Glorieta, close to the same horizon. *Walchia gracilis* is abundant in the maroon sandstone at railroad level just west of Glorieta station.

CHUPADERA FORMATION (PERMIAN)

Glorieta Mesa owes its prominence and continuity to a thick sheet of hard massive gray sandstone, which lies on the red shale at the top of the Abo sandstone. Baker [45a] correlates this sandstone with the

[45a] Baker, C. L., Contributions to the stratigraphy of eastern New Mexico: Am. Jour. Sci., 4th ser., vol. 49, pp. 99-126, 1920.

Shinarump and also with the Santa Rosa, a view criticized by Rich [45b] and by Lee.[45] In large areas of the mesa this gray sandstone is bare, but to the south it passes under limestone and a succession of limestone and gypsum beds with which it constitutes the Chupadera formation. Possibly some of the underlying red shale in the northern part of the mesa should also be included in this formation, because to the south beds apparently at the same horizon include more or less gypsum and other features characteristic of the lower member (Yeso) of the Chupadera formation in the central part of the State.

The main body of sandstone is nearly 200 feet thick in the northern part of the mesa, where it presents a high escarpment for many miles. Starvation Hill, near Bernal, a characteristic outlier of this plateau, is shown in Plate 54, *A*. An exposure in Cañada Colorado, east of Moriarty, is shown in Plate 54, *B*. The overlying limestone extends to the northern edge of the escarpment in places, but it

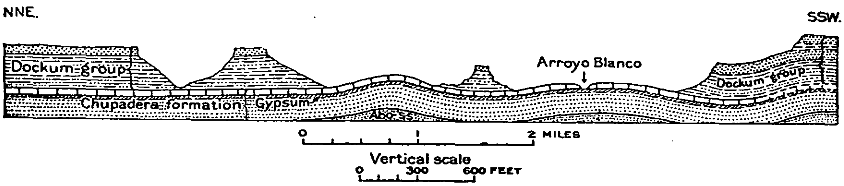


FIGURE 106.—Sketch section across Canyon Blanco near the west line of the Anton Chico grant, Guadalupe County, looking east

is thin. Its thickness increases southeast of the Pankey ranch, and it becomes a prominent feature farther east and south in the vicinity of Canyon Blanco and west of Anton Chico, about Palma and Pintada Canyon. It caps El Cuervo Butte, northeast of Moriarty. East of Lamy to and along the east side of the Eaton grant the formation dips below overlying shale and limestone, and in Canyon Blanco and southward through T. 12 N., R. 14 E., and Tps. 12, 11, 10, and 9 N., R. 13 E., the underlying red beds are revealed. The relations of the limestone, sandstone, and underlying red beds are well exposed in the sharp uplift 2 miles north of Mesa Jacinto, in T. 10 N., R. 14 E. The bed marked A–A in Figure 106 is massive gray sandstone that caps the high butte just north of Chapelle station. It is underlain by 100 feet of dark-purplish softer sandstone and shale on about 100 feet of brick-red soft sandstone which lies directly on the top limestone of the Chupadera formation. This limestone is about 30 feet thick and in part of the region is underlain by 5 feet of soft buff sandstone and a bed of gypsum. Next below is a thick body of the hard, massive sandstone which constitutes Glorieta Mesa and caps Starvation Hill. (See pl. 54, *A*.)

[45b] Rich, J. L., The stratigraphy of eastern New Mexico; a correction: Am. Jour. Sci., 5th ser., vol. 2, pp. 295–298, 1921.

[45c] Lee, W. T., Notes on the Manzano group, N. Mex.: Am. Jour. Sci., 4th ser., vol. 49, pp. 323–326, 1920.

DOCKUM GROUP (TRIASSIC)

In the region east and south of Lamy and across the Eaton grant to the cover of detrital material in the southern part of T. 12 N. the sandstone of Glorieta Mesa is overlain by a succession of red beds. The upper part is certainly Triassic (Dockum group), but the lower part may be Lower Triassic or even Permian, and if it is Permian it should be regarded as an upper member of the Chupadera formation. From the vicinity of Lamy southward for about 15 miles the upper beds are cut off by the fault (see fig. 107), but in T. 12 N., R. 10 E., where all the beds are exposed, the thickness is 800 to 900 feet. Distinctive limestone and gypsum of the Chupadera formation appear to the south and give a clue to the correlation of the lower beds in that portion of the area. The upper beds are red shale of typical Dockum aspect; they are capped by Wingate sandstone.

WINGATE SANDSTONE (JURASSIC?)

The Wingate sandstone forms conspicuous cliffs in the southern part of the Eaton grant south of Lamy. (See pl. 54, *C*.) It is in one massive ledge of pink color about 100 feet high with red shale (Dockum) at the base and a capping of Todilto limestone. Small outcrops of the formations also appear north of Lamy.

TODILTO LIMESTONE (JURASSIC?)

The cliffs of Wingate sandstone on the Eaton grant are capped by the Todilto limestone. The formation is about 10 feet thick and shows the characteristic thin platy bedding so characteristic in other areas. A small exposure of the limestone appears on the bank of Apache Creek half a mile above Lamy.

MORRISON FORMATION (CRETACEOUS?)

Light-colored massive shale of distinctive Morrison character crops out above the Todilto limestone on the Eaton grant, and a small outcrop appears in the arroyo a mile south of the Pankey ranch, just west of the fault. There are other outcrops in the slopes a short distance north of Lamy.

DAKOTA SANDSTONE AND OVERLYING CRETACEOUS STRATA

A monoclinal ridge of Dakota sandstone extends southward from the Pankey ranch to the south end of the Eaton grant, and small outcrops of the sandstone appear north and west of Lamy. In both localities are overlying shales of Colorado and Montana age, including the Greenhorn limestone. In Cerro Colorado sandstone presumably of Mesaverde age is present.

Fossils collected from the shale near Lamy were determined as follows by T. W. Stanton:

600 feet above supposed Greenhorn limestone, 1 mile southwest of Lamy; late Benton:
- Inoceramus fragilis Meek and Hayden?
- Scaphites warreni Meek and Hayden?

Sandstone 200 feet above supposed Greenhorn limestone, Lamy:
- Oculina sp.; according to T. W. Vaughan this is a coral that has not previously been recorded from the American Cretaceous.

Sandstone over lower black shale (180 feet thick) half a mile southwest of Lamy; Benton:
- Ostrea sp.
- Inoceramus sp.
- Arca? sp.
- Prionotropis sp.

Greenhorn (?) limestone just west of Lamy:
- Metoicoceras sp.

Beds of Benton age at Lamy Junction:
- Pecten sp.
- Inoceramus fragilis.
- Metoicoceras swallowi?

STRUCTURAL DETAILS

APACHE CANYON

There are extensive exposures along Apache Canyon from the granite north of Canyoncito to Lamy, where the canyon opens into a broad valley of shale of Pierre (early Montana) age. In this region the canyon follows or closely parallels a great fault along which the rocks present varied relations. To the north the upthrow of this fault is on its west side, but near Lamy and to the south the upthrow is on the east side, the change taking place about 2 miles northeast of Lamy. The principal features are shown in Figure 107.

The limestone of the Magdalena group, exposed along Apache Canyon and the slopes north of it, is so cut by branching faults near Canyoncito that some beds do not crop out. East of the fault on Apache Creek, 1½ miles north of Canyoncito (old plaza), about 500 feet of the limestone is exposed dipping about 80° SE. and overlain by red sandstone (Abo) which extends east to the railroad. On Rio de los Indios, half a mile north of Canyoncito (old plaza), the drop of the fault is so great that limestone does not appear, and the massive gray sandstone of Glorieta Mesa (Chupadera formation) abuts against the granite. These beds are, however, cut off again a short distance to the east by a narrow uplifted wedge of granite with Abo and overlying beds on its southeast side. A short distance south of the creek a wedge of the limestone is upturned along the fault, and a small outlier of limestone lies on the granite high on the hill slopes to the west, about a mile northwest of the old plaza. About 100 feet of the limestone is exposed near the railroad 2 miles southeast of Canyoncito, dipping 80° NE., under Abo red beds. Doubtless this limestone is present under the talus north from this place possibly to or nearly to the old plaza. The relations are shown in section C, Figure 107. The full

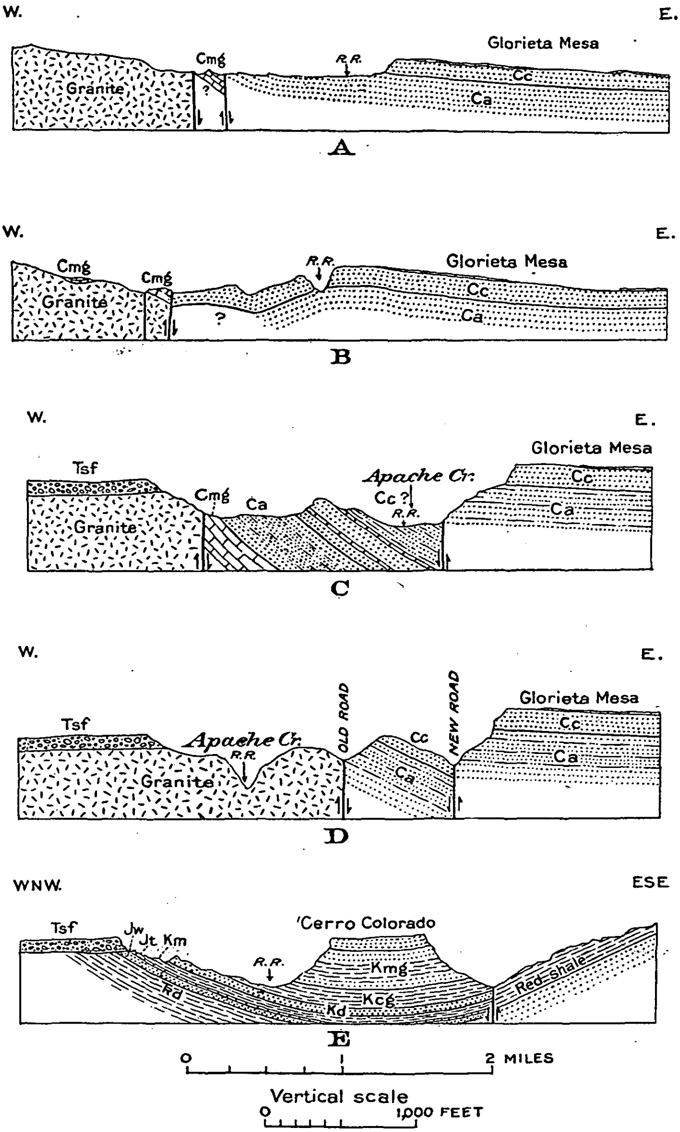


FIGURE 107.—Sketch sections across Apache Canyon, Santa Fe County. A, 3 miles northeast of Canyoncito; B, just north of Canyoncito; C, 1 mile south of Canyoncito station; D, in the narrow gorge 3 miles northeast of Lamy; E, passing west and southwest of Lamy through Cerro Colorado. Cmg, Limestone of Magdalena group; Ca, Abo sandstone; Cc, Chupadera formation; Ꞧd, red shale and sandstone of Dockum group; Jw, Wingate sandstone; Jt, Todilto limestone; Km, Morrison formation; Kd, Dakota sandstone; Kcg, Colorado group; Kmg, Montana group; Tsf, Santa Fe formation

thickness (about 500 feet) of the limestone of the Magdalena group is exposed a mile farther south, just south of the box canyon by which the railroad crosses the granite about 2¼ miles northeast of Lamy. The exposures extend up the slope just west of the railroad as far as the cover of Santa Fe beds, and the beds are cut off by the fault a short distance east of the railroad. The dip is 30° S. 15° W.

EATON GRANT

In the Eaton grant, south of Lamy, there is a westward-dipping monocline of formations from Chupadera to Montana, which constitutes the east slope of the Cerrillos coal basin. Near Lamy and for some distance to the south most of these beds are cut off by the Apache Canyon fault, but this fault diminishes in throw to the south, and strata from Colorado to Morrison rise near the Pankey ranch, and a few miles farther south the underlying Todilto, Wingate, and Dockum beds come up in succession.

BORINGS

A notable deep boring in this region is one for oil and gas sunk in 1918 near the Pankey ranch on the Eaton grant, south of Lamy. The record of the hole, given in Figure 108, was kindly supplied by the Toltec Co., which made the boring. As the record does not give the characteristics of all the beds penetrated, the position of the Chupadera formation can not be indicated, but the base of the Abo appears to have been reached at 1,720 feet, marked by conglomerate with granite fragments. Below 1,720 feet the boring was possibly in the Magdalena group, greatly attenuated as compared with its development in the outcrop region to the north, west, and south.

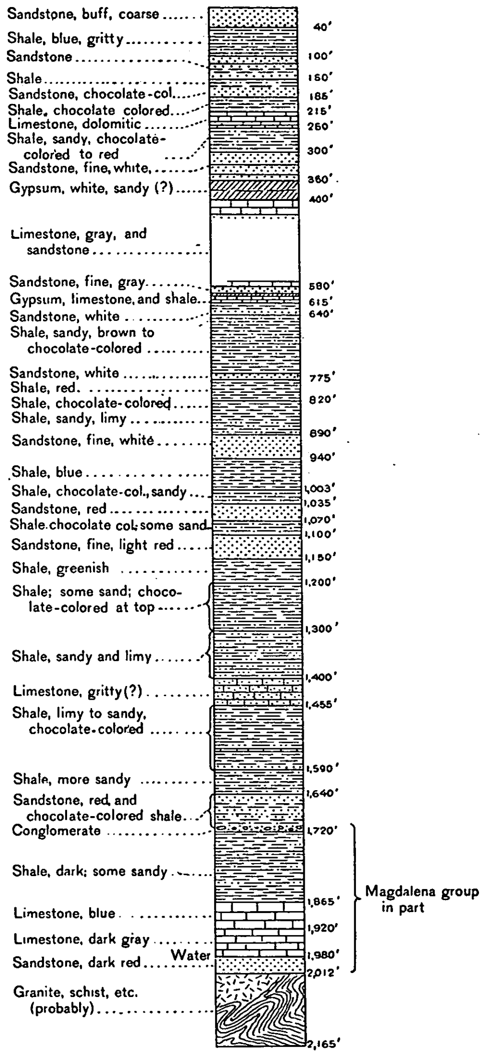


FIGURE 108.—Record of boring on Eaton grant, near Pankey ranch, approximately in sec. 2, T. 13 N., R. 10 E.

The Woods well, about 8 miles south of Kennedy station, had reached a depth of 3,380 feet in the later part of 1924. I have condensed the record somewhat and added certain correlations.

Record of Woods well, in sec. 7, T. 12 N., R. 10 E.

	Feet
Shale, mostly black; 4-foot flinty layer at 327 feet	0–411
Sandstone, brown	411–419
Shale, black, sandy	419–424
Sandstone, light; water	424–434
Shale, black, with 10 feet of sandstone near base	434–710
Sandstone, white	710–722
Shale, black above, gray or bluish below	722–755
Sandstone, brown above; inflammable gas and water	755–770
Shale, brown; black near top and bottom	770–875
Sandstone, brown, with 2 feet of "gypsum" (?) at 894 feet	875–930
Shale, black	930–935
Sandstone	935–950
Shale, black	950–990
Sandstone, dark; water	990–1, 019
Shale, hard, black	1, 019–1, 025
Limestone, blue	1, 025–1, 090
Shale, green	1, 090–1, 098
Sandstone, dark-gray (Dakota?)	1, 098–1, 250
Shale, green above, brown below	1, 250–1, 345
Sandstone, soft	1, 345–1, 405
Shale, pink	1, 405–1, 435
Limestone, green	1, 435–1, 480
Shale, pink	1, 480–1, 515
Limestone, green	1, 515–1, 525
Sandy shale, bluish	1, 525–1, 530
Sandstone, greenish above, pink shale layer below; water	1, 530–1, 765
Sand, brown with pink grains; water	1, 765–1, 795
Shale, chocolate-colored	1, 795–1, 812
Sandstone, upper half mostly brown, lower half light	1, 812–1, 985
Shale, chocolate-colored	1, 985–1, 995
Limestone, sandy, gray	1, 995–2, 005
Not reported	2, 005–2, 205
Shale, pink	2, 205–2, 220
Sandstone, red; some red shale (Abo)	2, 220–2, 965
Limestone (Magdalena)	2, 965–3, 380

The identity of some of the beds in this record is not clear, but if the 252 feet of dark sandstone from 1,098 to 1,250 feet is Dakota the underlying shale and sandstone are Morrison. The "green limestone" at 1,515 feet may be Todilto, the sandstone from 1,530 to 1,795 feet Wingate, and the shale and brown sandstone from 1,795 to 2,220 feet may comprise the Dockum group and the thin northern edge of the Chupadera formation. There appears to be no doubt as to the identity of the Abo sandstone, entered at 2,220 feet and having a thickness of 745 feet. It seems likely that granite will be found near 3,600 feet. It is stated that this boring was abandoned at 3,500 feet.

LAS VEGAS REGION, TURKEY MOUNTAIN TO BERNAL

GENERAL RELATIONS

The following paragraphs relate to the geology about Las Vegas, including the foothills of the Sangre de Cristo Mountains as far southwest as Bernal, and north to Turkey Mountain, also the mesa east of Las Vegas but not the Canadian Plateau and Escarpment. The general succession of rocks is shown in Figures 109–111, and the structure in Figure 110.

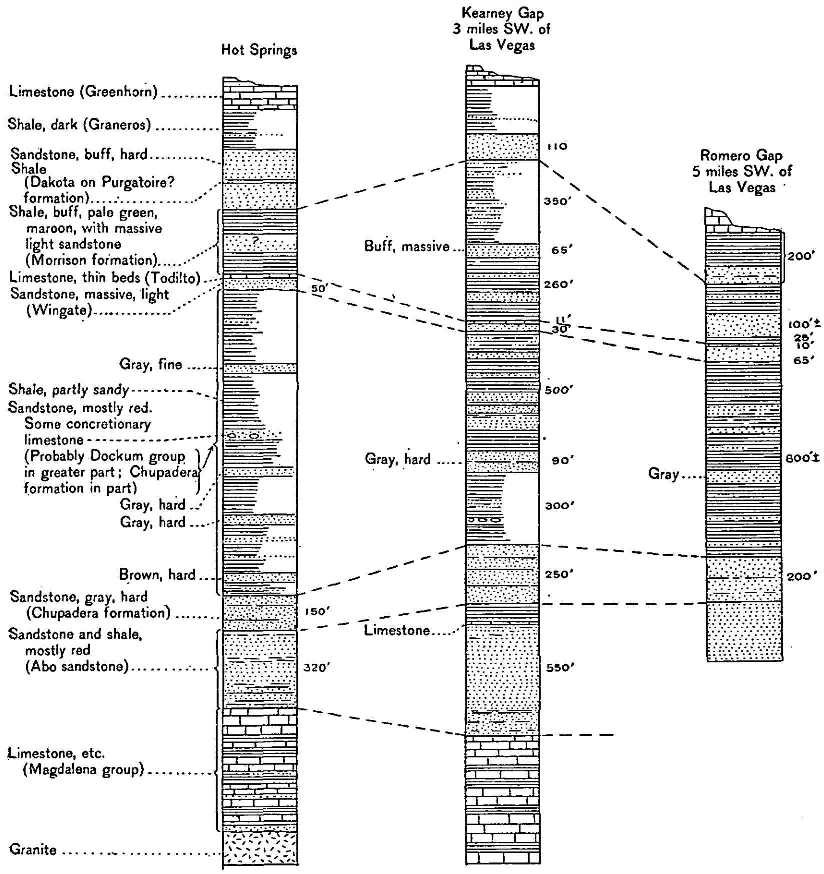


FIGURE 109.—Columnar sections in hogback ridge and slopes west of Las Vegas Gap

The beds in the hogback ridge dip steeply eastward into a shallow syncline, the north-south axis of which passes through Las Vegas. To the north the syncline holds about 2,000 feet of Cretaceous strata, including at the top a considerable thickness of the Pierre shale, as shown in Figure 110, and south of Las Vegas it holds three narrow outliers of Greenhorn limestone. Next east is a low arch or anticline flattening toward the east into an eastward-sloping monocline in which the Dakota sandstone is spread out widely in the Canadian Plateau, which terminates to the south in the Canadian Escarpment.

FORMATIONS

MAGDALENA GROUP (PENNSYLVANIAN)

The basal member of the sedimentary succession west of Las Vegas is the Magdalena group, which lies directly on pre-Cambrian granite and schist. It is between 1,000 and 2,000 feet thick and consists largely of limestone, with some beds of sandstone and shale, especially toward the top. There are good exposures at Hot Springs, where, however, the succession is apparently interrupted by considerable crushing and faulting. Pennsylvanian fossils occur abundantly in some of the limestones. The following were reported by Lee [46] as identified by G. H. Girty:

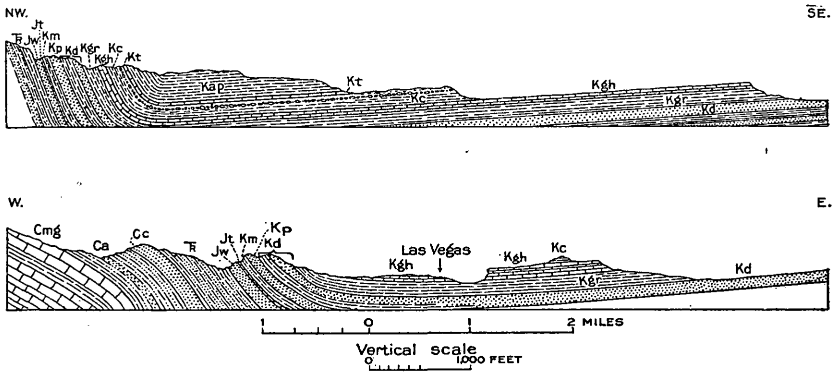


FIGURE 110.—Cross sections in Las Vegas region. Upper section, 6 miles north of Las Vegas; lower section, through Las Vegas. Kap, Apishapa shale; Kt, Timpas limestone; Kc, Carlile shale; Kgh, Greenhorn limestone; Kgr, Graneros shale; Kd, Dakota sandstone; Kp, Purgatoire (?) formation; Km, Morrison formation; Jt, Todilto limestone; Jw, Wingate sandstone; Ѣ, red beds (probably Dockum group); Cc, Chupadera formation; Ca, Abo sandstone; Cmg, Magdalena group

Lophophyllum profundum.
Rhombopora sp.
Cyclopora? sp.
Fenestella sp.
Derbya sp.
Productus cora.
Productus semireticulatus.
Pustula nebraskensis.
Pustula semipunctata.
Dielasma bovidens.
Spirifer rockymontanus.
Spirifer cameratus.
Squamularia perplexa.
Spiriferina kentuckyensis.
Composita subtilita.
Cliothyridina orbicularis.
Hustedia mormoni.
Cardiomorpha? sp.
Allerisma terminale?
Pinna peracuta.
Myalina sp.
Astartella sp.
Conularia sp.

PERMIAN AND TRIASSIC (?) ROCKS

The succession lying between the Magdalena group and Wingate sandstone west of Las Vegas has not been fully classified. The massive sandstone member of the Chupadera formation, which constitutes Glorieta Mesa, was traced northward continuously from Bernal and

[46] Lee, W. T., op. cit. (Bull. 389), p. 38.

is conspicuous near the middle of the section in the hogback ridge. Next below is red shale grading down into a thick series of sandstones, mostly brownish red, with some red shale, which undoubtedly represent the Abo sandstone. The thickness of these beds ranges from 320 feet at Hot Springs, where they are probably greatly crushed, to 550 feet in the region west of Kearney Gap.

A deep hole sunk for water by the Atchison, Topeka & Santa Fe Railway Co. at Chapelle shows the succession of these rocks. It had the following record:

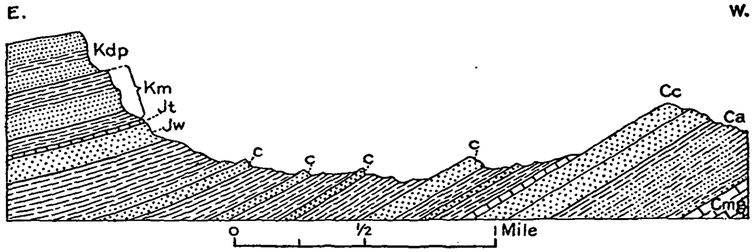


FIGURE 111.—Section near Ojita, 8 miles southwest of Las Vegas. Kdp, Dakota sandstone and Purgatoire (?) formation; Km, gray shale and sandstone of Morrison formation; Jt, Todilto limestone; Jw, Wingate sandstone; c, hard sandstone in red shale (probably Dockum group and Chupadera formation); Cc, thick hard buff sandstone of Chupadera formation; Ca, Abo sandstone; Cmg, Magdalena group

Record of well of Atchison, Topeka & Santa Fe Railway Co. at Chapelle

	Feet
Loam	0–52
Sandstone, brown	52–56
Sandstone, gray	56–72
Sandstone, white	72–82
Sandstone, yellow	82–122
Sandstone, alternating white and yellow	122–340
Limestone	340–345
Sandstone, white	345–350
Sandstone, red	350–355
Limestone	355–385
Not given	385–460
Conglomerate, sandy	460–465
Shale and sandstone, red	465–605
Sandstone, red	605–897
Sandstone, red, with some white	897–960

The sandstones of the Chupadera formation extend to a depth of 350 feet or possibly to 465 feet, where characteristic red strata of the Abo sandstone were entered. The hole was discontinued in this formation, probably about 300 feet above the top of the Magdalena beds.

Overlying the massive sandstone of the Chupadera formation in the ridge west of Las Vegas are alternations of red shale and red sandstone, 900 to 1,200 feet thick. The lower beds may be upper Chupadera or even include a representative of the Moenkopi formation, but the upper 700 feet or more represents the Dockum group. In a conglomerate in these beds Case[47] discovered a broken tooth of a phytosaur or dinosaur of Triassic age, which affords a basis for the correlation.

WINGATE SANDSTONE (JURASSIC?)

The peculiar massive fine-grained light-colored Wingate sandstone is well exposed at many places along the hogback ridge west of Las Vegas northward from the gap at Romero, and it presents a continuous and conspicuous outcrop along the Canadian Escarpment. The thickness is about 65 feet at Romero Gap, 30 feet at Kearney Gap, and 50 feet near Hot Springs. In this region it is of light-gray color and contrasts strongly with the bright-red shale of the Dockum group (or Chinle?) below and the cream-colored Todilto limestone above.

TODILTO LIMESTONE (JURASSIC?)

The characteristic and persistent Todilto limestone crops out continuously along the hogback west of Las Vegas as far north as Hot Springs, but how far it extends north of that place was not ascertained. It lies on the Wingate sandstone, as in other regions to the southwest. Except near the top it is very thinly laminated, and some of it smells of petroleum, as noted by Lee. The thickness near the west end of the gap near Romero is 10 feet, or possibly slightly less, and in the Hot Springs section it is 8 feet.

MORRISON FORMATION (CRETACEOUS?)

The Morrison formation in this region presents features which are characteristic of it in other localities in Colorado and New Mexico, and its identity can scarcely be questioned. The shale is massive and mostly of light color, with pale tints of green and buff and some stains of maroon. Thin beds of sandstone and thin layers of limestone or limy concretions are included. One bed of light-buff massive sandstone near the middle of the formation is well exposed in Kearney Gap, possibly also in Romero Gap, and apparently continues far to the north. In the Hot Springs section, however, it is not well exposed.

PURGATOIRE (?) FORMATION (LOWER CRETACEOUS) AND DAKOTA SANDSTONE (UPPER CRETACEOUS)

The hogback consists mainly of hard massive buff sandstone, which in most places, if not throughout, is in two bodies separated by more or less shale. Probably the Purgatoire formation is represented by the shale and lower sandstone, but no fossils were found.

UPPER CRETACEOUS SHALE AND LIMESTONE

The succession of the Upper Cretaceous formations in the Las Vegas region presents the features that are characteristic of them in

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[47] Case, E. C., The red beds between Wichita Falls, Tex., and Las Vegas, N. Mex., in relation to their vertebrate fauna: Jour. Geology, vol. 22, p. 258, 1914.

eastern Colorado. The lower dark shale lying on the basal sandstone is Graneros. The overlying Greenhorn limestone has a notable development. It is 100 feet thick and consists of alternating beds of limestone and shale with the representative fossil *Inoceramus labiatus*. It is well exposed in Las Vegas and on the east bank of Gallinas Creek. (See pl. 14, *B*.) The Carlile shale, next above, is extensively developed north of Las Vegas and contains the lens-shaped concretions and fossils characteristic of that formation in eastern Colorado. The two divisions of the Niobrara limestone are separable. The lower one, the Timpas limestone, carries the distinctive fossil *Inoceramus deformis;* the upper one, the Apishapa shale, appears to grade up into the fossil-bearing Pierre shale; the plane between them was not located.

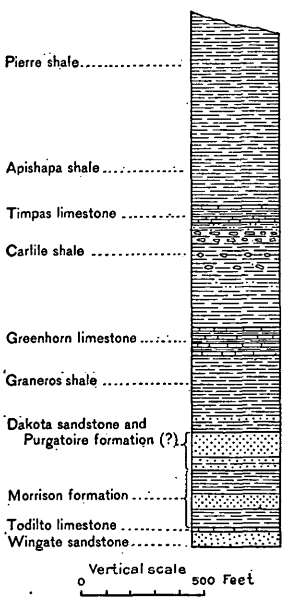


FIGURE 112.—Columnar section of Cretaceous and underlying rocks near Las Vegas

STRUCTURE OF TURKEY MOUNTAIN

Turkey Mountain is an isolated dome-shaped uplift about 10 miles west of Wagon Mound. It presents an extensive section of the upper members of the "Red Beds" succession and overlying Cretaceous rocks. The high central peak consists of hard gray sandstone, undoubtedly representing the member of the Chupadera formation that is conspicuous west of Las Vegas and in Glorieta Mesa. Apparently the underlying rocks are not revealed.

In the section given in Figure 113 the shales *a* and *c* and the included sandstone *b* appear to belong to the Dockum group. The sandstone *d* is nearly white and very conspicuous, much more resembling the sandstone member in the Morrison formation so noticeable in Union County than the Wingate sandstone. If it is Morrison, the Wingate is absent. The shale *e* is typical Morrison shale, and the sandstone *f*, although in one thick body, probably represents both Purgatoire and Dakota.

A closely similar succession is exposed along the main uplift near Sapello, La Cueva, and Don Tomas, in all of which the light-colored sandstone *d* is a notable feature.

BORINGS

Very few deep borings have been reported in the region from Turkey Mountain to Las Vegas. The log of a boring on the plateau 7 miles north of Las Vegas, somewhat condensed and with suggested correlations of beds, follows.

Record of Patterson & Stuppe well No. 1, in the SW. ¼ NW. ¼ sec. 25, T. 17 N., R. 16 E., San Miguel County

		Feet
Limestone (Greenhorn)		0–45
Shale, blue and dark, with white sandstone near bottom (Graneros)		45–290
Sandstone, white; some shale and "lime" (Dakota)		290–385
Shale, mostly greenish	Purgatoire	385–425
Sandstone, gray; some sandy shale	Purgatoire	425–521
Sandy shale, red	Purgatoire	521–549
Sandstone, fine, dark	Purgatoire	549–556
Shale, brown, green, and brown at base	Morrison	556–619
Sandy shale, gray and red, brown at base	Morrison	619–654
Sandstone, gray to brown (Wingate?)		654–808

A 450-foot boring in sec. 33, T.17 N., R. 18 E., obtained an excellent flow of artesian water, probably from the Dakota sandstone or Purgatoire formation.

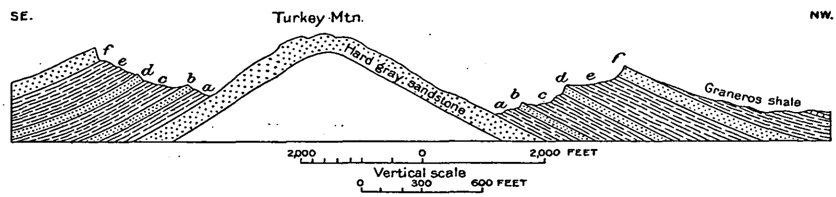
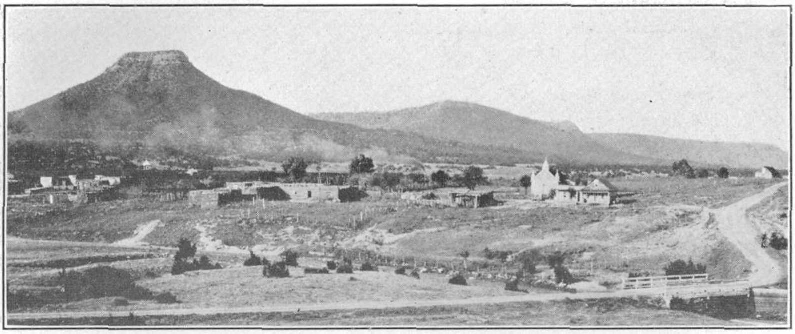


FIGURE 113.—Section through Turkey Mountain, 10 miles west of Wagon Mound, showing "Red Beds" and Cretaceous rocks. *a*, Red shales grading down into gray sandy shale; *b*, hard gray sandstone; *c*, dark-red shale and red sandstone, mostly soft; *d*, hard light-colored massive sandstone; *e*, greenish-gray shale; *f*, hard gray massive sandstone (Cretaceous)

SANGRE DE CRISTO MOUNTAINS

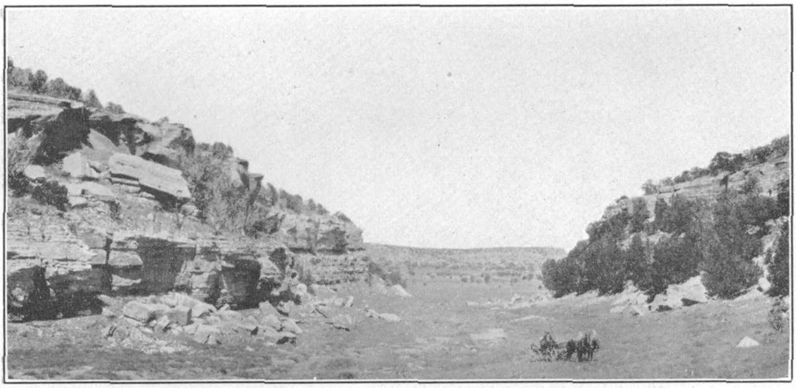
The great uplift of the Sangre de Cristo Range of the Rocky Mountains extends far southward into New Mexico as a series of high ridges consisting largely of granite, schist, and other crystalline rocks of pre-Cambrian age, overlain in places by limestone and sandstone of the Magdalena group, which arch over many of the higher ridges. There are also several local areas of igneous rocks. The range is about 25 miles wide in Taos County and 35 miles wide east of Santa Fe. Many of its relations have been described by Stevenson.[48] The structure is anticlinal, with subordinate longitudinal crenulations and many faults. Southeast of Santa Fe the uplift pitches down and the crystalline rocks and the Magdalena strata disappear under Abo sandstone and Chupadera formation near the passes through which the range is crossed by the Atchison, Topeka & Santa Fe Railway. The anticlinal structure extends for some distance southward, however, into Glorieta Mesa and other mesas, and the general zone of uplift continues to the San Andres and Franklin Mountains.

[48] Stevenson, J. J., Report upon geological examinations in southern Colorado and northern New Mexico: U. S. Geog. Surveys W. 100th Mer. Rept., vol. 3, Suppl., 1879.



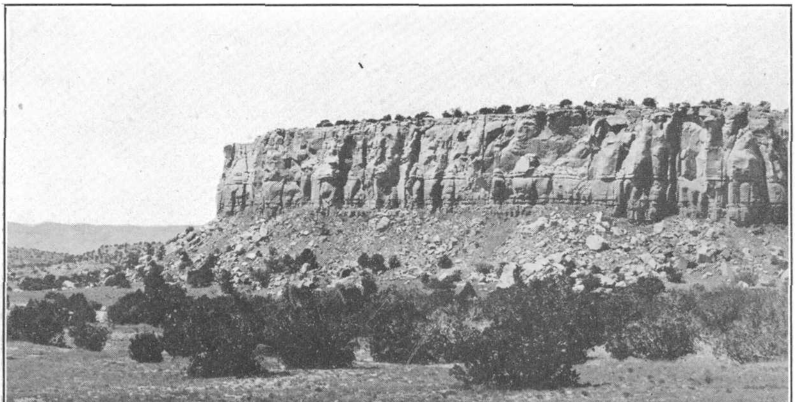
A. STARVATION HILL, AN OUTLIER OF THE GLORIETA MESA

Looking west over Bernal



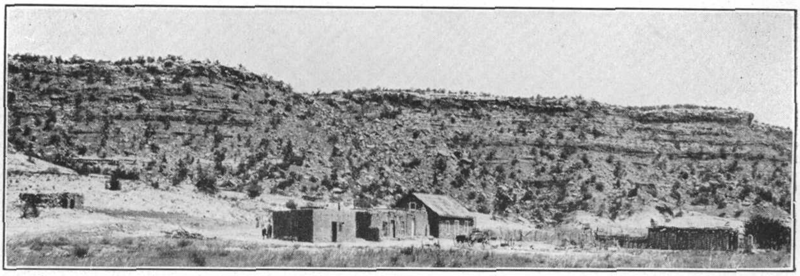
B. SANDSTONE OF CHUPADERA FORMATION IN CAÑADA COLORADA, 18 MILES SOUTHEAST OF MORIARTY

Looking northeast



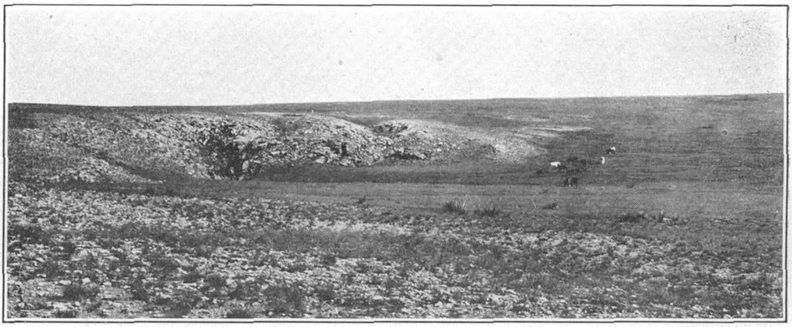
C. CLIFF OF WINGATE SANDSTONE CAPPED BY TODILTO LIMESTONE, 12 MILES SOUTH OF LAMY

Looking west. Slope of red shale of Dockum group below cliff

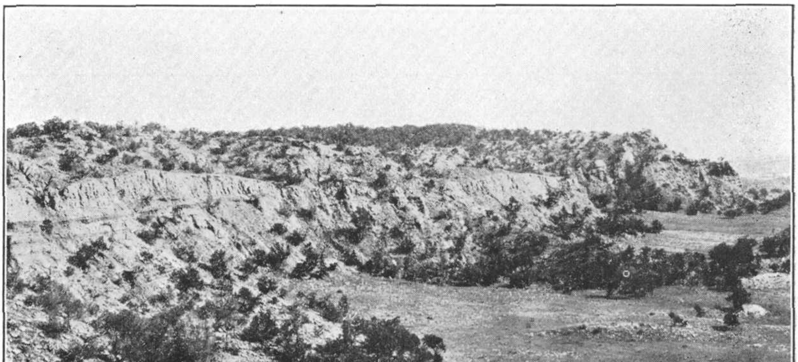


A. SANTA ROSA SANDSTONE UNDERLAIN BY GYPSIFEROUS BEDS AT TOP OF CHUPADERA FORMATION, PINTADA CANYON, 3 MILES EAST OF SAN IGNACIO

Looking north

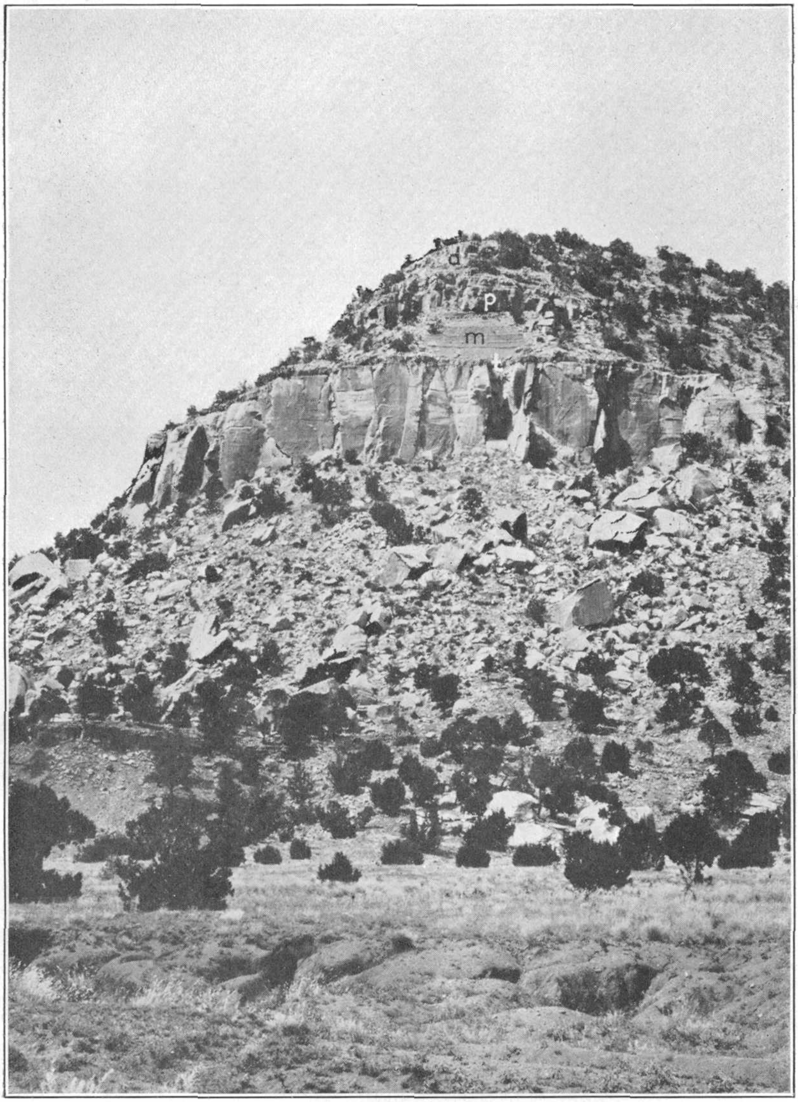


B. TYPICAL PLAINS, WITH SINKS, IN LIMESTONES OF CHUPADERA FORMATION IN NORTHEASTERN PART OF LINCOLN COUNTY



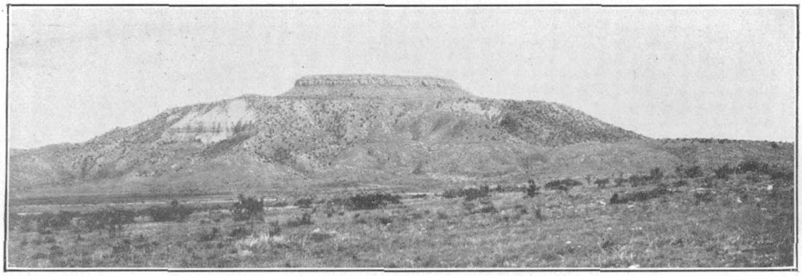
C. NORTH WALL OF RINCON COLORADO, 3 MILES SOUTHEAST OF PEDERNAL PEAK, TORRANCE COUNTY

Looking east. Gypsum and red beds capped by massive gray sandstone of Chupadera formation



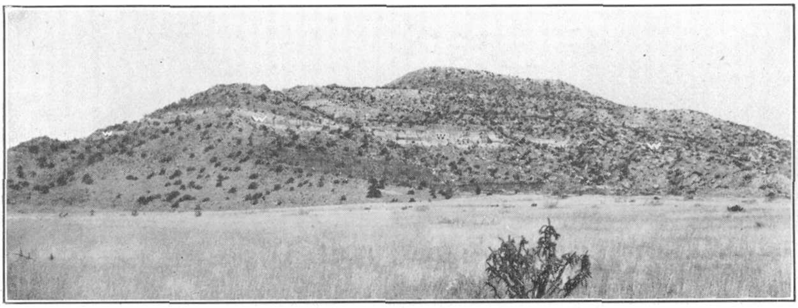
CANADIAN ESCARPMENT 18 MILES SOUTHEAST OF LAS VEGAS

d, Dakota sandstone; p, Purgatoire formation; m, Morrison shale; t, Todilto limestone on massive cliff of Wingate sandstone below which, under talus, are red shales of Dockum group



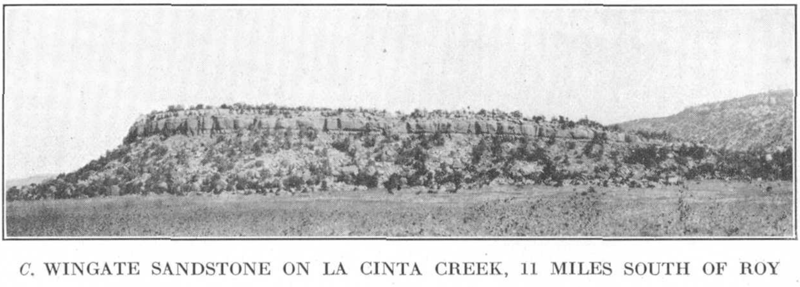
A. TUCUMCARI BUTTE, AN OUTLIER OF THE LLANO ESTACADO, SOUTH OF TUCUMCARI

Sandstones and shale of Cretaceous age, Wingate sandstone, and red shales of Dockum group



B. CUERVO HILL, AN OUTLIER OF THE CANADIAN ESCARPMENT, 20 MILES NORTHEAST OF SANTA ROSA

Looking northeast. Cap of Cretaceous sandstone. Morrison formation, Wingate sandstone (w) and Triassic "Red Beds" (Dockum group)



C. WINGATE SANDSTONE ON LA CINTA CREEK, 11 MILES SOUTH OF ROY

Looking north. Slopes of Morrison formation to right

Many data as to the character of the pre-Cambrian rocks of the Rocky Mountain ranges have been given by Lindgren and Graton.[49] In the Rociado district, 20 miles northwest of Las Vegas, the principal rocks are gneiss and schist interstratified with marble and quartzite striking N. 45° W. and dipping 60° SW. Along the upper Pecos River are fine-grained amphibolites which merge into red granite, but south of Macho Creek dioritic rocks prevail. In the ridges east of Santa Fe are schists dipping 30° W., with many dikes of granite and pegmatite, also much coarse granite, and farther east are masses of schistose amphibolite with biotite, which is possibly an altered diabase or diorite. Near the main divide still farther east are biotite schists striking N. 50° E. and standing almost vertical, associated with fine-grained granite of gneissoid structure.

Lindgren[50] states that at Picuris, southwest of Taos, the prevailing rock is granite or granitic gneiss with basic intrusives. There are

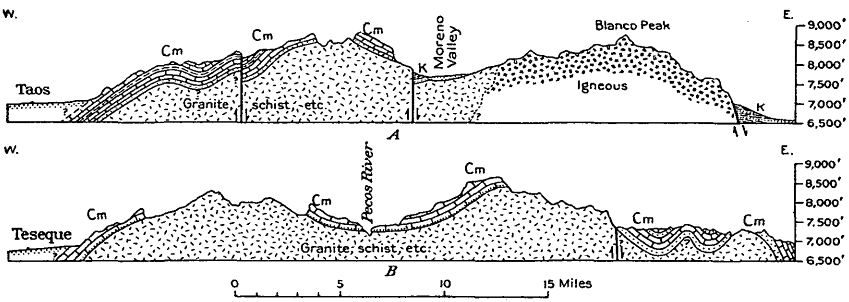


FIGURE 114.—Generalized sections across Sangre de Cristo Mountains. A, From Taos eastward; B, eastward from a point 6 miles north of Santa Fe. K, Cretaceous sandstone; Cm, Magdalena group

also metamorphosed conglomeratic quartzite, knotty schist, and slate containing garnet, andalusite, staurolite, sillimanite, and corundum, and similar rocks also appear at Glenwoody, on the Rio Grande.

The portion of the Sangre de Cristo Mountains lying between the Rio Hondo and Pueblo Creek, in Taos County, according to Gruner,[51] consists of pre-Cambrian gneiss, schist, granite, and granite gneiss penetrated by stocks and dikes of granite and rhyolite porphyry and overlain by sandstone and shale of Pennsylvanian age. The schist and gneiss are mostly of an amphibolitic or chloritic character and in places grade into greenstone. They constitute most of the northwestern part of the range and all its higher summits, except Old Mike. The plateau south of Lucero Peak is occupied by dark-green fine-grained hornblendite and greenstone in a sheet 200 to 300 feet thick lying on a granitic batholith and to some extent penetrated by

[49] Lindgren, Waldemar, and Graton, L. C., op. cit. (Prof. Paper 68), pp. 82–123.
[50] Idem, p. 90.
[51] Gruner, J. W., Geologic reconnaissance of the southern part of the Taos Range, N. Mex.: Jour. Geology, vol. 28, pp. 731–742, map, 1920.

the granite. Pre-Cambrian quartzite, quartz schist, and chlorite schist occupy a considerable area. The quartzite, for which the name "Pueblo quartzite" was proposed by Gruner, constitutes most of the very high divide at the head of Lucero and Pueblo Creeks and Red River. Figure 115 shows the relations.

The lowest material of the Magdalena group is mostly conglomerate grading into sandstone, but in places limestone occurs at the base, and there are great stratigraphic variations. Many beds of conglomeratic sandstone and shale with some red beds are included in the succession. The greatest thickness that I observed was 2,500 feet. The dips are mostly 5° to 20° SE., but in places there are flexures, and the strata are cut by several faults. As these faults appear to be due to vertical uplift of blocks and not to horizontal compression it is believed that the displacement resulted from igneous activity, probably in early Tertiary time. A rhyolite flow was noted in the Red River valley below the mouth of Sawmill Creek.

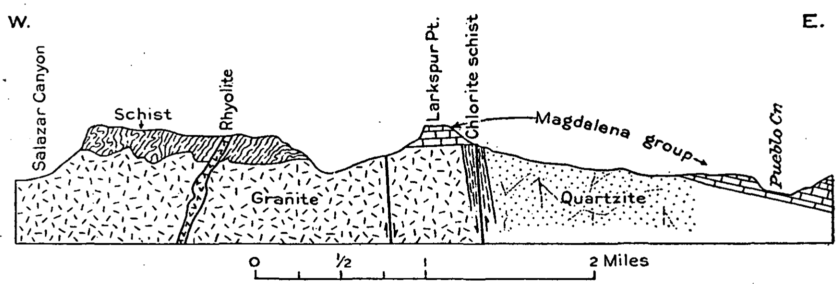


FIGURE 115.—Sketch section across crest of Sangre de Cristo Mountains northeast of Taos. After Gruner

Stevenson[52] estimated 3,276 feet as the greatest thickness of the Magdalena strata in these ranges. Gardner[53] measured 1,237 feet near Pecos.

PLATEAUS EAST OF CHUPADERA MESA FROM JACKS PEAK TO PINTADA CANYON

GENERAL RELATIONS

East of Chupadera Mesa and southeast of the Pedernal Mountain there is a broad, high plateau extending eastward to the Pecos Valley. It continues far north of Pintada Canyon, which has been cut across it. To the south it is cut off by the head of the long valley of Tularosa Basin north of Ancho, but it extends far southward on the east side of Jacks Peak and the Capitan Mountains—in fact, it is in that direction continuous with the plateau that merges into the Sacramento Mountains. The wide plateau is a region of limestone, gypsum, and gray sandstone of the Chupadera formation extending

[52] Stevenson, J. J., op. cit., pp. 77–78. [53] Gardner, J. H., personal communication.

eastward from Chupadera Mesa. Limestone greatly predominates on the surface in wide areas, and the strata slope mostly to the east at a very low angle. Some features of this plateau are shown in Plate 55, *C*. North of Ancho the Chupadera beds pitch to the south under red shale of the Dockum group in a region of much lower land. To the northwest they abut against the pre-Cambrian crystalline rocks of the Pedernal and Pinos Wells ridge. To the northeast they pass under red shale of the Dockum group. Most of the surface of the plateau is a smooth or gently rolling plain with higher buttes in places, notably to the southwest, where Gallinas Mountain, Jacks Peak, and the Capitan Mountains, masses of intrusive rock, are

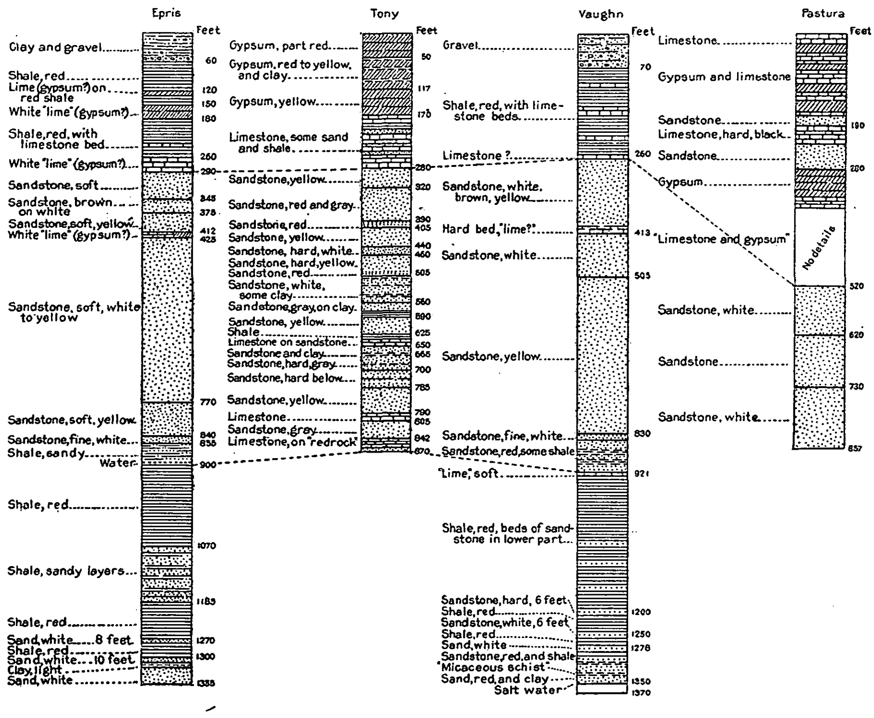


FIGURE 116.—Records of borings in the vicinity of Vaughn and at Pastura

prominent features. Many scattered observations were made in this region, especially along the two railroads that cross it and about Vaughn, Corona, Cedarvale, and Gran Quivira, but details of stratigraphy and structure were not studied. The larger relations are shown in Figure 121. Records of several deep borings which aid greatly in showing the underground stratigraphy of the Chupadera and associated formations are given in Figure 116.

The borings near Vaughn show 200 to 290 feet of limestone and gypsum with some red shale, underlain by 600 feet or more of light-colored sandstone, with a red shale succession below it. This corresponds rather closely with the section in Chupadera Mesa. The sandstone penetrated from 520 to 857 feet in the Pastura hole is doubtless part of the same formation but lying deeper on account of the dip to the east, with additional members of upper Chupadera rocks in the top part of the section. This sandstone may be the bed exposed in the deep cut just east of Encino. As shown in Figure 117 the 853-foot boring at the old Varney siding, 1 mile southwest of Torrance, was in sandstone from 535 to 853 feet, presumably this same bed; in the 1,139-foot hole at Duran (fig. 118) the body of sandstone is broken by shale, if the drill record is accurate, which is doubtful. A 414-foot hole at Gallinas entered the sandstone at 40 feet, under "dolomite," and continued in it for 365 feet to red clay at 405 feet. According to another report the lowest strata penetrated were 29 feet of red sand and red clay.

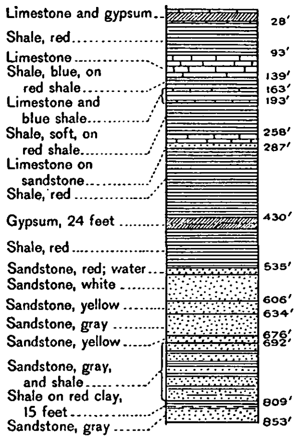


FIGURE 117.—Record of well at Varney siding, 1 mile southwest of Torrance

Along the railroad south of Corona there are many deep cuts in limestone in the divide, and this rock is extensively exposed about Gallinas. A valley leading to the southeast from that place shows the underlying gypsum, and this mineral is also exposed in a railroad cut between Gallinas and Elda. The beds all lie nearly horizontal. To the west are the large masses of igneous rock of Gallinas Mountain, and dikes and sills intersect the limestone near Elda and Tecolote. Near one of these dikes 2 miles southwest of Elda deposits of iron ore occur in the limestone along the igneous contact, and considerable mining is in progress. Half a mile south of Tecolote is an old quarry in limestone. Here and farther south the limestone dips to the south into a structural basin in the lower lands of the Ancho region.

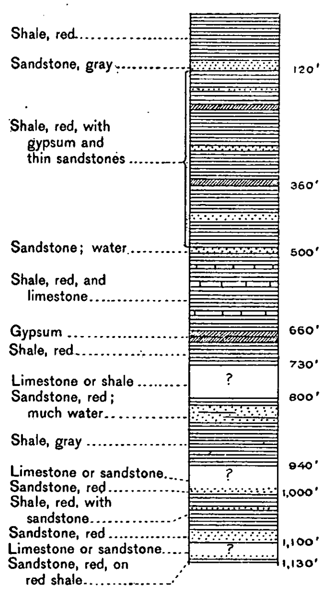


FIGURE 118.—Record of boring at Duran

The State well about 6 miles north of Pedernal Mountain had the following record:

Record of well in sec. 8, T. 8 N., R. 13 E., Torrance County

	Feet
Clay, yellow	0–14
Limestone	14–29
Sandstone, yellow	29–90
Sandstone, red, with shale beds	90–160
Limestone and gypsum	160–170
Sandstone, yellow	170–180
Sandstone, red, with thin beds of shale	180–590
Shale, hard, blue	590–598
Limestone	598–608
Shale, hard, blue	608–645
Sandstone, hard white	645–655
Limestone, blue	655–670

Apparently this well was all in the Chupadera formation.

A 528-foot boring about 2 miles southwest of Palma post office, in Torrance County, had the following record:

Record of State well No. 2, in sec. 8, T. 8 N., R. 14 E., Torrance County

	Feet
Limestone (?) and yellow clay	0–30
Limestone and gypsum (?)	30–90
Sandstone, yellow	90–470
Sandstone, red	470–480
Sandstone, cream-colored	480–524
Shale, yellow to reddish	524–528

This well evidently was in the Chupadera formation throughout.

A 615-foot boring for water in sec. 2, T. 2 N., R. 16 E., had the following record:

Record of boring in sec. 2, T. 2 N., R. 16 E.

	Feet
Soil and clay	0–60
Limestone	60–140
Limestone and gypsum	140–210
Sandstone	210–290
Limestone	290–300
Sandstone	300–360
Gypsum	360–380
Sandstone, soft from 410 to 420 feet; some water at 575 feet, 20 gallons at 612 feet; hard water	380–615

At Pastura, 20 miles northeast of Vaughn, an 857-foot boring beginning in the limestone passed through alternations of limestone and gypsum to 180 feet, then 10 feet of sandstone, 30 feet of hard black sandstone, 60 feet of gypsum, 220 feet of limestone and gypsum, and 337 feet of white sandstone, all Chupadera beds. The lower part is in the thick sandstone member of that formation.

At Ricardo, about 50 miles east of Vaughn, the body of sandstone that is nearly continuous from 450 to 850 feet doubtless represents the eastward extension of this thick bed carried deeper by the dip. (See fig. 119.) The structural and stratigraphic relations indicated by the borings and other features along the Atchison, Topeka & Santa Fe Railway from the Hills of Pedernal eastward to Pecos River and along the El Paso & Southwestern Railroad diagonally across the plateau from Ancho to Santa Rosa are shown in Figure 121. These sections show the great extent of the thick gray sandstone member and the general dip to the east in all the region east of Pedernal Mountain. The thick gray sandstone is undoubtedly the same sandstone member of the Chupadera formation that constitutes Glorieta Mesa. It is exposed extensively in the deep cut just east of Encino, and it comes to the surface in the Corona-Duran region. The overlying limestone and gypsum beds crop out in the broad plateaus to the east, cap the mesas in the Corona-Duran-Gallinas region, and extend continuously northward from the ridge northeast of Encino past Palma. In the northern part of Vaughn there is a road-ballast quarry in limestone which exposes a succession of limestone and gypsum beds. This succession constitutes the surface of the plateau over which the two railroads pass to the east. It finally goes below the surface at Pecos River. The northern part of the plateau shows many sink holes in gypsum, and there are exposures of gypsum in railroad cuts at several places. Not far northeast of the railroad at Vaughn is a higher mesa remnant capped by Santa Rosa sandstone, as shown in Figure 122.

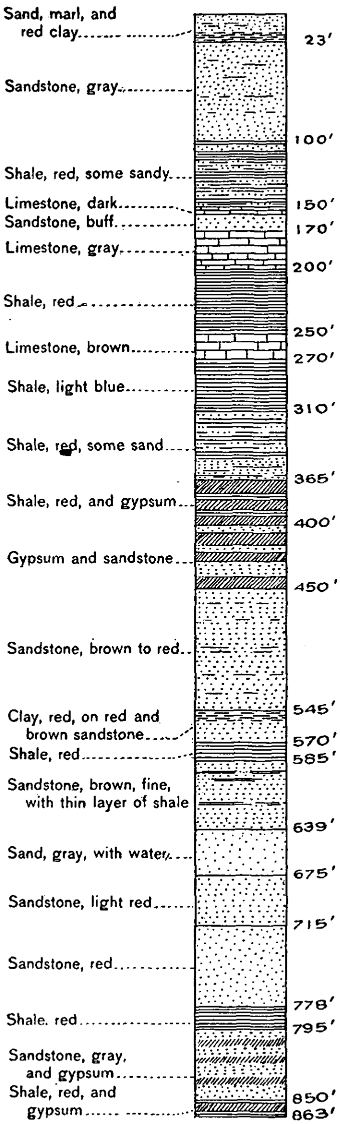


FIGURE 119.—Record of boring at Ricardo, Guadalupe County, in Chupadera formation

An unsuccessful boring for water by the Atchison, Topeka & Santa Fe Railway Co. at Buchanan, in 1908, began in gypsum and penetrated alternations of sandstone and "soapstone." The color and nature of the "soapstone" are not stated, but presumably it was gray shale.

The same company bored unsuccessfully for water at Encino to a depth of 387 feet. White sandstone with a small amount of water was found under blue clay from 25 to 43 feet and from 379 to 387 feet. Red shale, in part sandy, extended from 43 to 371 feet, including an 8-foot bed of white limestone at 357 feet, and it was underlain by 8 feet of blue limestone.

Another unsuccessful boring for water by the same company at Agudo was 208 feet deep. Below 16 feet it passed through red shale with intercalated beds of sandstone and "soapstone."

PINTADA CANYON SECTION

Pintada Canyon from its beginning on the east slope of Pedernal Mountain to its mouth near Santa Rosa affords an instructive section of the beds in the wide plateau of eastern Torrance County and west-central Guadalupe County. The principal features are shown in cross section B, Figure 120, and on Plate 24. In general the structure is monoclinal, with the dip at a very low angle to the east. On the west are outcrops of the Chupadera formation abutting against the pre-Cambrian rocks of the Pedernal region. On the east through Guadalupe County the canyon walls and adjoining plateaus present a few hundred feet of red shale and red and gray sandstones of the Dockum group overlying the Chupadera formation.

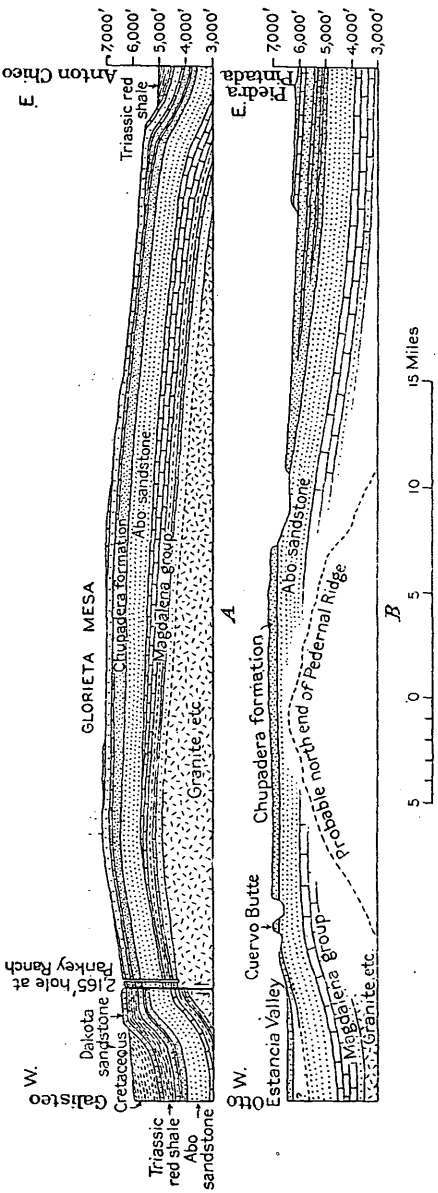


FIGURE 120.—Sections across the plateaus of southeastern Santa Fe County, southwestern San Miguel County, and eastern Torrance County. *A*, From Galisteo to Anton Chico; *B*, through Cuervo Butte. In section *A* about 250 feet of the Morrison, Todilto, and Wingate lies between the Triassic red shale and the Dakota sandstone west of the fault

In Rincon Colorado (see pl. 55, *C*) there are extensive outcrops of red sandy shale and red soft sandstone with gypsum beds, capped by gray sandstone and limestone. The gray rocks constitute the adjoining plateaus and are distinctive middle and upper members of the Chupadera formation

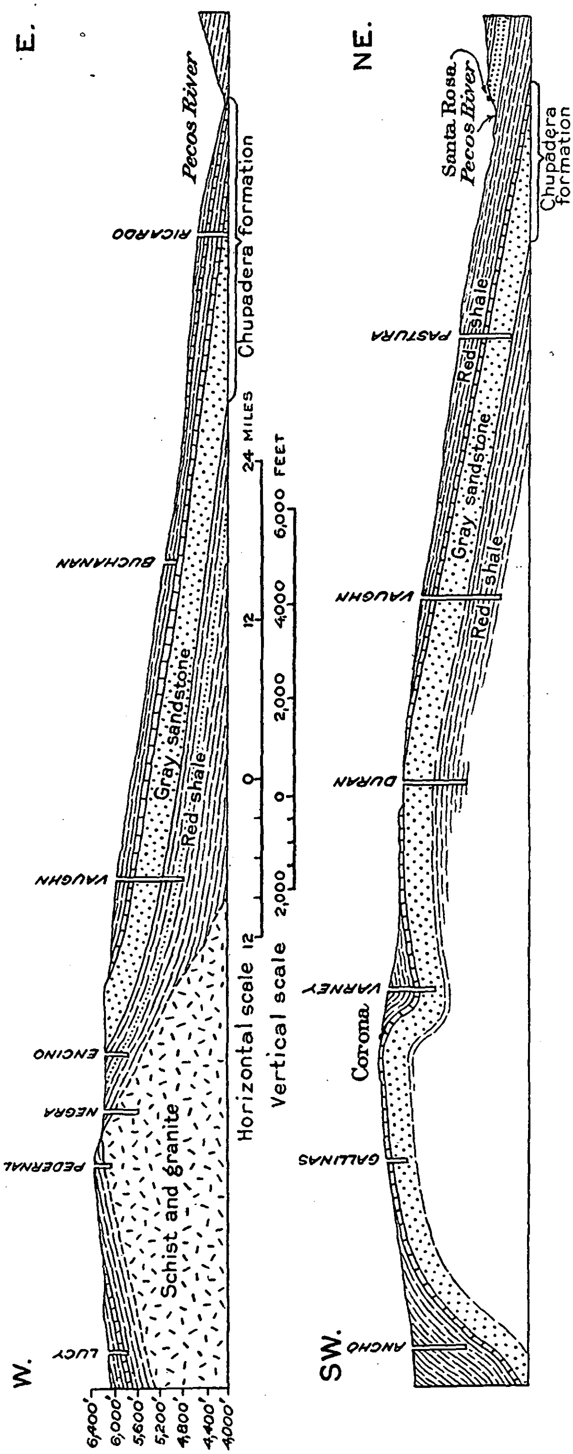


FIGURE 121.—Cross sections along Atchison, Topeka & Santa Fe Railway (Belen cut-off) and El Paso & Southwestern Railroad in Torrance and Guadalupe Counties

That these shales abut against quartzite in the Hills of Pedernal on the west is plainly exhibited in canyons on the west side of Rincon Colorado. In the eastern part of R. 14 E. the gray sandstone and limestone descend with slightly increased dip, and Pintada Arroyo has cut a steep-sided winding canyon through them as far as the plazita of Rita Madera, where the hard rocks pass below red shale and the canyon widens considerably. A conspicuous exposure of the gray sandstone appears in a butte north of the canyon in or close to sec. 23, T. 7 N., R. 14 E. Here the thickness is 160 feet, but some of the top of the member has been removed by erosion. The following section is exposed:

Section of north wall of Pintada Canyon in eastern part of T. 7 N., R. 14 E., Torrance County

	Feet
Sandstone, gray, massive to heavy bedded, mostly hard	160
Red shale and soft red sandstone, mostly concealed in slopes, with two 10 to 12 foot beds of limestone in upper half	130
Limestone	14
Red sandy shale with gypsum bed	40
	344

A short distance east of this place the easterly dip, locally increased slightly in amount, brings the sandstone down to the valley level, the canyon narrows, and roads on both sides leave it. In the next 3 miles there are high walls of hard gray sandstone which in the adjoining plateaus is capped by limestone. The limestone finally descends to the valley and presents walls 30 to 40 feet high in the east end of the steep-sided part of the canyon just west of Rita Madera, which is near the center of T. 7 N., R. 15 E. This limestone is much brecciated but is otherwise typical Chupadera. At Rita Madera it passes under red shale, which with overlying brown and gray sandstones constitutes the canyon walls for many miles to the east. A section near Rita Madera is shown in Figure 123. The red shales shown in the lower part of this section are not well exposed at Rita Madera, and there is some uncertainty as to their thickness and components. Their outcrop continues down the canyon to the east line of R. 19 E. They are everywhere overlain by red and brown sandstones and the hard dirty-gray massive sandstone that caps the walls of the canyon at most places to its mouth, southeast of Santa Rosa. The strata rise in a low dome whose summit is

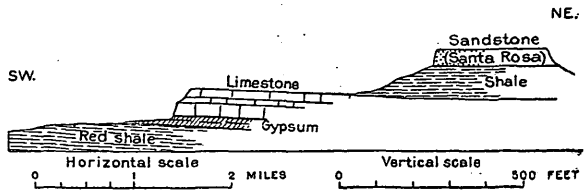


FIGURE 122.—Sketch section from Vaughn northward showing relations of strata above limestone of the Chupadera formation

near the east line of R. 16 E., or about 3 miles west of the plazita of Sombra, and although the limestone of the Chupadera formation is not exposed, it is not far below the valley bottom. In this vicinity 80 feet of the overlying red shale is exposed containing several thin beds of gypsum. The overlying red and brown sandstones about 100 feet thick are harder below and softer above and are capped by the 60-foot member of hard massive brownish sandstone. From Sombra to Pintada the beds dip at low angles to the east. East of Pintada there is a basin in which the dirty buff sandstone descends

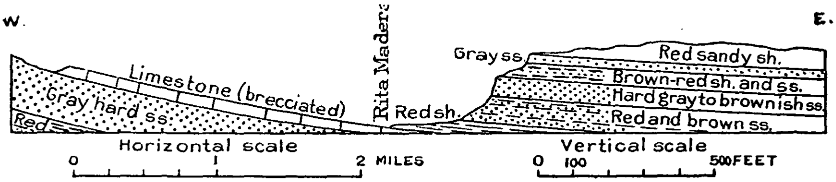


FIGURE 123.—Section showing succession of beds at Rita Madera, T. 7 N., R. 15 E., near east line of Torrance County. Chupadera formation west of Rita Madera; Dockum group to the east. sh., Shale; ss., sandstone

low into the valley, especially along its north side, but the beds rise again to the south, and there are also low dips to the west in the southeastern part of T. 8 N., R. 18 E., on the west side of a dome that reaches its apex a mile east of San Ignacio. Here limestone and gypsum are exposed in the bank of Pintada Arroyo. A section across the canyon at this place is shown in Figure 124. The lower limestone exposed is probably not the main limestone of the Chupadera formation, which comes to the surface west of Rita Madera,

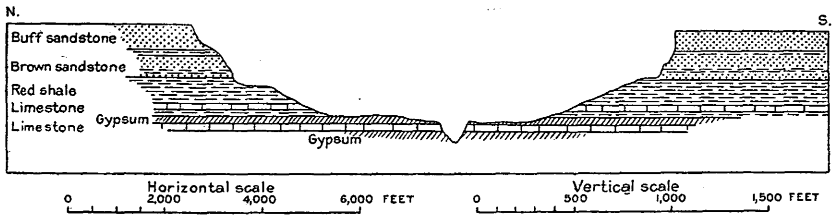


FIGURE 124.—Section across Pintada Canyon 1 mile east of San Ignacio, Guadalupe County. Limestone and gypsum at base, part of Chupadera formation; upper beds, Dockum group

but lies a short distance higher. Together with the underlying gypsum it soon sinks beneath the bed of the arroyo, but the outcrop of overlying gypsum and thin limestone continues east to a point 6 miles east of San Ignacio, where they are carried down by the eastward dip. This dip continues through R. 20 E., and the upper buff sandstone coming down to a lower level greatly narrows the canyon as the railroad is approached. East of the railroad the upper beds pitch steeply into a basin that extends part way across R. 21 E.

PEDERNAL MOUNTAIN TO CHAMELEON HILL

On the east side of Estancia Valley there is a ridge of pre-Cambrian white quartzite which culminates in Pedernal Mountain. This conspicuous peak (altitude 7,580 feet according to the Wheeler Survey), rises several hundred feet above the general level of the plateau at the southern extension of the Glorieta Mesa. A short distance to the west are the Hills of Pedernal, and 15 miles to the northwest is the Cerrito del Lobo, all consisting of the same kind of white quartzite. Johnson [54] and Meinzer [55] have given some facts regarding these features. Cerrito del Lobo, the northernmost outcrop, is an isolated butte rising out of the Estancia Valley 8 miles southeast of Moriarty. The Pedernal Mountain ridge extends only a short distance south of the peak, but outcrops of pre-Cambrian crystalline rocks appear at intervals to the south, notably in the ridges extending from Rattlesnake Hill to Cerro del Pino and also at Chameleon Hill and west of Pinos Wells, 4 miles southeast of Torrance. They are also found underground in wells at Lucia, Negra, and other places. To the north the prevailing rock is white quartzite, in part schistose; to the south are granite, gneiss, diorite, and other crystalline rocks. Rattlesnake Hill, 12 miles southeast of Willard, consists of black amphibolite, which on microscopic examination by E. S. Larsen proved to be a fine-grained aggregation of feldspar and amphibolite. The feldspar, which makes up about half the rock, is a sodic labradorite; the remainder consists of green and brown hornblende, some epidote, and a little biotite, apatite, and iron oxide. Cerro del Pino and Chameleon Hill are made up of coarse massive granite. A black schist found in a valley 4 or 5 miles north of Negra consists chiefly of quartz, feldspar, sericite, and tourmaline, with a few crushed fragments of plagioclase.

It is probable that this long area of older rock is bounded on the west by a fault passing about 15 miles east of Estancia and along the west side of Cerrito del Lobo, and that this fault may be continuous with the zone of faults in the Eaton grant and Apache Canyon. On the east side, however, the Chupadera formation, including the sandstone member that caps Glorieta Mesa, overlaps on a slope of the quartzite, a relation which is well exposed in arroyos east and northeast of Pedernal Mountain and is proved by wells at Pedernal, Negra, and other places. Therefore it is evident that the ridge existed in late Carboniferous time, and it had more prominence then than now. Doubtless it was eventually buried. The exposures on the east side of Pedernal Mountain show the sandstone lying on

[54] Johnson, D. W., Geological reconnaissance of eastern Valencia County, N. Mex.: Am. Geologist, vol. 29, pp. 80–87, 1902.

[55] Meinzer, O. E., Geology and water resources of Estancia Valley, N. Mex., with notes on ground-water conditions in adjacent parts of central New Mexico: U. S. Geol. Survey Water-Supply Paper 275, 1911.

the ledges of quartzite, with considerable coarse material at the contact in places. The relations preclude the possibility of a separating fault. A boring 1,100 feet deep a few miles northeast of Pedernal Mountain is reported not to have reached the pre-Cambrian rocks, which indicates that the slope is steep.

Records of borings made by the Atchison, Topeka & Santa Fe Railway Co. at Negra, Pedernal, and Lucy stations, on or near this ridge, are given in Figure 125. These holes were in the Chupadera formation, and the boring at Lucy did not reach the underlying granite or schist.

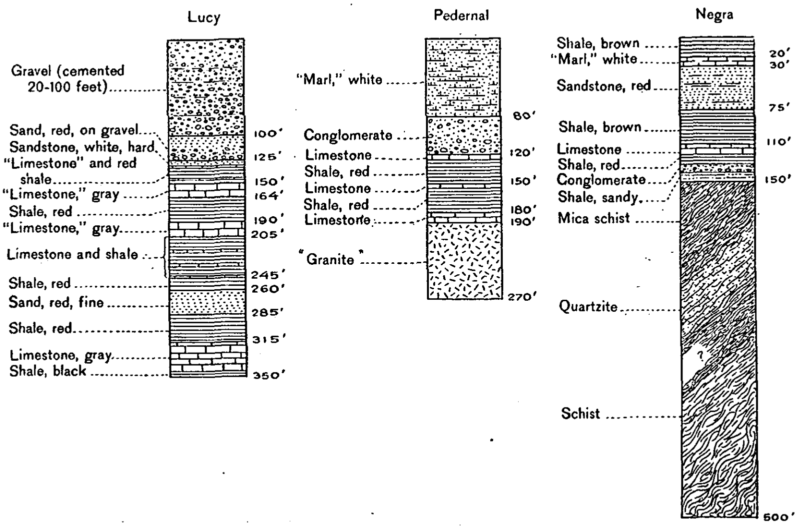


FIGURE 125.—Records of three borings on the Atchison, Topeka & Santa Fe Railway in the eastern part of Torrance County

A 655-foot hole bored by the State in sec. 8, T. 8 N., R. 13 E., 6 miles north of Pedernal Mountain, may possibly have reached the quartzite. The record is given in Figure 126.

The plateau adjoining the Pedernal Mountain ridge consists of a broad outcrop of the Chupadera formation that extends from Glorieta Mesa southward through the eastern part of Torrance County into Lincoln County and the western part of Chaves County, where it merges into the cuesta of the Sacramento Mountains. Throughout this area the predominant dip is east or southeast at a low angle. The principal surface formation in these plateaus is massive limestone of the Chupadera formation. It is cut through extensively by Arroyo Blanco and in the region north of Anton Chico by Pecos River, revealing the underlying Abo sandstone. Farther east the limestone passes under the red shale which to the north separates the Chupadera formation from the Santa Rosa sandstone.

ESTANCIA VALLEY

The Estancia Valley is a wide flat-bottomed basin without outlet, occupying the central part of Torrance County and most of the southern part of Santa Fe County. Its altitude ranges from about 6,100 to about 6,400 feet. Many data regarding the geology and water resources have been given by Meinzer.[56] The greater part of the surface is covered by sand and gravel several hundred feet thick, in part of lacustrine origin, which hide the structural relations. Probably the underlying strata dip gently to the east, and the central part of the area is underlain by the Abo sandstone, which comes to the surface near Manzano and Punta and passes under the Chupadera formation to the east. These strata abut against the old ridge of pre-Cambrian quartzite in the Hills of Pedernal and the Cerrito del Lobo and against schist in the vicinity of Lucia and Rattlesnake Hill. To the south is a high wall of the Mesa Jumanes, at the north end of Chupadera Mesa, consisting of red beds and overlying limestone of the Chupadera formation. In the northern rim of the valley are exposed Upper Cretaceous shales, which doubtless extend some distance southward under the valley deposits, possibly as far as Stanley or Otto.

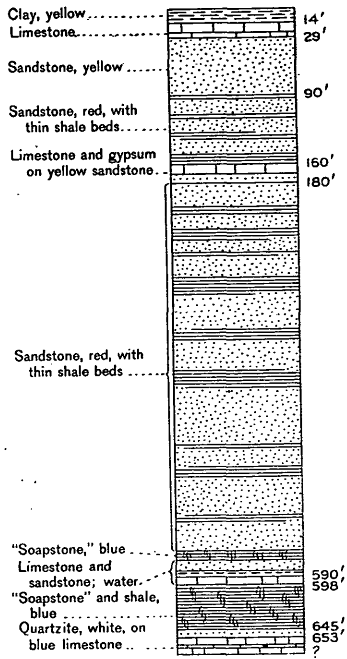


FIGURE 126.—Record of State well 6 miles north of Pedernal Mountain in sec. 8, T. 8 N., R. 13 E., Torrance County

Record of boring in NE. ¼ SW. ¼ sec. 20, T. 6 N., R. 10 E., Torrance County, 10 miles east of Estancia

	Feet
Salt, marl, gypsum, and sand on 15-foot coarse gravel	0–95
Sandstone, pink, on brown	95–102
Shale, sandy, on thin "lime shell"	102–120
Shale, sandy, and sandstone, mostly red or brown; few thin "lime shells"	120–325
Limestone, mostly light, some "flint," hard	325–353
Shale, sandy, red	353–377
Limestone, gray	377–380
Shale, sandy, red	380–405
Limestone and much sandy shale	405–485
Shale, red, sandy; some thin "lime shells" and gypsum	485–655
Sandstone, red, hard, and red sandy shale	655–710
Shale, blue at top, red below, limy at base	710–774
Sandstone, red, on red shale, some blue shale	774–965
Shale, mostly red, sandy, blue near base	965–1, 040
Limestone, black to gray, some red shale near base	1, 040–1, 072
Sandstone on sandy limestone	1, 072–1, 175

[56] Meinzer, O. E., op. cit. (Water-Supply Paper 275).

	Feet
Shale, red	1, 175–1, 202
Limestone, gray, on gray shale	1, 202–1, 218
Shale, mostly red	1, 218–1, 625
Shale, dark, sandy, on red shale	1, 625–1, 711
Limestone, gray, with 10 feet of brown sandy shale in middle	1, 711–1, 785
Shale, red, on gray	1, 785–1, 848
Limestone, some shale, and part sandy	1, 848–1, 910
Shale, red	1, 910–2, 010
Limestone, sandy; some shale	2, 010–2, 300
Shale, sandy; some limestone, red below	2, 300–2, 452
Limestone, sandy; some shale	2, 452–2, 725
Shale, gray	2, 725–2, 770
Arkose	2, 770–2, 798
Limestone, mostly dark	2, 798–2, 985
Shale, gray and "broken"	2, 985–3, 185
Shale, brown, sandy	3, 185–3, 264
Limestone, gray, sandy, on blue shale and limestone	3, 264–3, 287
Sandstone, gray; "petroleum in lower part"	3, 287–3, 310
Limestone, mostly dark red, sandy near base	3, 310–3, 415
Sandstone, blue, salty, on blue sandy shale	3, 415–3, 460
Limestone, brown, sandy	3, 460–3, 485
Sandstone, "petroleum"	3, 485–3, 500
Shale, carbonaceous, on brown sandy limestone	3, 500–3, 530
Sandstone, dark; full of "paraffin"	3, 530–3, 550
Limestone, hard, black	3, 550–3, 570
Shale, sandy	3, 570–3, 600
Limestone, brown, sandy, on dark shale	3, 600–3, 650
Sandstone, gray, with "paraffin"	3, 650–3, 660
Arkose, white and red, coarse, on fine sandstone	3, 660–3, 675
Limestone, brown, sandy	3, 675–3, 750
Sandstone, brown, like sugar	3, 750–3, 815
Limestone, dark	3, 815–3, 850
Sandstone, pink on black	3, 850–3, 865
Marble, white, on black shale	3, 865–3, 875
Sandstone, gray, coarse; salt water	3, 875–3, 905
Shale, red	3, 905–3, 925
Sandstone, pink on brown, fine	3, 925–3, 940
Shale, brown, with brown sandstone in middle	3, 940–4, 005
Sandstone, reddish, on coarse red	4, 005–4, 050
Limestone, brown, on brown shale	4, 050–4, 130
Sandstone, brown; some shale	4, 130–4, 210
Shale, brown	4, 210–4, 225
Limestone, brown, sandy	4, 225–4, 250
Sandstone, brown on gray	4, 250–4, 280
Limestone, sandy, brown and gray	4, 280–4, 462
Sandstone, gray	4, 462–4, 492
Limestone, gray	4, 492–4, 568
Shale, blue, with some black limestone	4, 568–4, 615
Limestone, gray, sandy	4, 615–4, 683
Sandstone, dark-gray; "oil"; some dark shale	4, 683–4, 703
Sandstone, brown, streaks of shale	4, 703–4, 800
Shale, brown, hard, fine sandstone, 4,850–4,855; limestone and sandy limestone layers in lower part	4, 800–4, 936

This boring appears to have reached the base of the Abo sandstone at 2,010 feet, for just below that depth are thick limestones (800 feet or more) presumably the upper member of the Magdalena group. In May, 1928, this boring had reached a depth of 5,323 feet. The great thickness of underlying strata here indicates that this formation thickens to the east from its outcrop area on the east slope of the Manzano Mountains. It is not unlikely that all the strata are cut off to the east of this boring by a fault with great uplift on its east side.

SANTA ROSA TO FORT SUMNER

GENERAL RELATIONS

In the area north, northwest, and northeast of Santa Rosa from the country beyond Anton Chico on the west to Cuervo Hill on the east the rocks dip gently eastward, but there are local variations in direction and amount, with doming in places. The principal formations exposed are the upper beds of the Chupadera formation and all of the overlying Dockum group, which extends to the foot of the Canadian Escarpment. Cuervo Hill is an outlier of the Canadian plateau and consists of Triassic "Red Beds" (Dockum

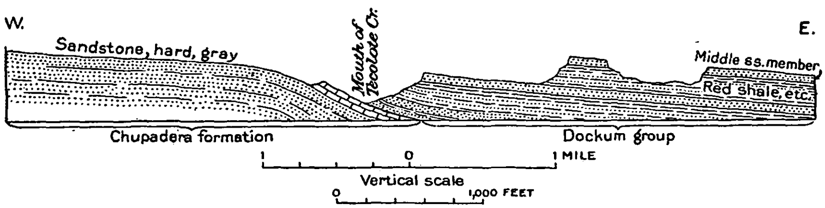


FIGURE 127.—Section along Pecos Valley above Anton Chico

group) overlain by Wingate, Morrison, and Purgatoire rocks. The broader relations are shown in Figures 130 and 131.

The sandstone member of the Chupadera formation which constitutes Glorieta Mesa passes beneath Pecos River 4 miles northwest of Anton Chico. Above this point it forms the high canyon walls, but to the east it lies at a gradually increasing depth beneath the surface except in an area east of Esterito Butte, where it appears again in a local dome. The relations are shown in Figure 127. The sandstone is immediately overlain by 20 to 30 feet of limestone which is conspicuous in the mouth of the canyon northwest of Anton Chico and in the dome above referred to. Much of the surface of the dome consists of the limestone, but several draws reveal the underlying massive light-buff sandstone. The rocks above this sandstone and limestone are red shales with two or three thick beds of gray to brown sandstone. The sandstones are conspicuous near Pecos River, Anton Chico, Dilia, and Las Colonias, in the big bend of the river 11 miles north of Santa Rosa, in the railroad cut east of Santa Rosa, and in the river banks below Santa Rosa. They also constitute the walls of the lower part of Pintada Canyon for about 15 miles. Some limestones and gypsum deposits occur in the lower and medial portions of this formation in its southern extension, notably on slopes west and southwest of Santa Rosa and in the mesa extending from Arabella to Vaughn,

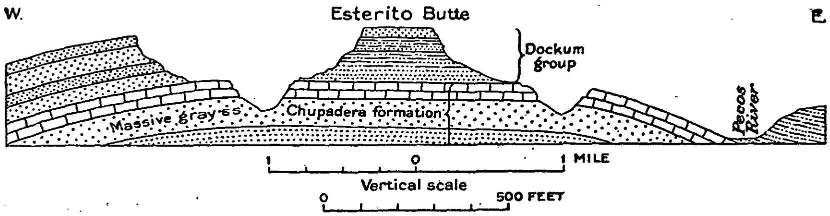


FIGURE 128.—Section through Esterito dome, northwest of Santa Rosa, Guadalupe County

as described on page 274. Rich[56a] has given an excellent brief summary of the relations in this region in criticism of a paper by Baker.[56b]

The upper sandstone of this succession, which here lies considerably above the base of the Dockum group, is well exhibited in

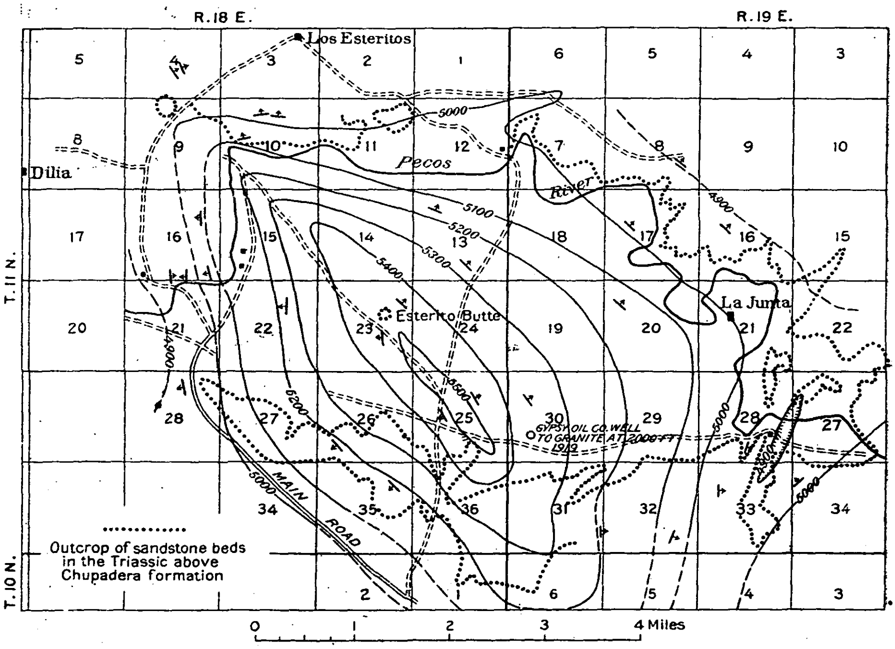


FIGURE 129.—Map of Esterito dome. By Messrs. Newby, Garrett, Crabtree & Wright for the Gypsy Oil Co.

the railroad cuts beginning at Santa Rosa and extending for 2 miles east, and for that reason it has been named Santa Rosa sandstone.[57]

56a Rich, J. L., The stratigraphy of eastern New Mexico; a correction: Am. Jour. Sci., 5th ser., vol. 2, pp. 295–298, 1921.

56b Baker, C. L., Contributions to the stratigraphy of eastern New Mexico: Am. Jour. Sci., 4th ser., vol. 49, pp. 99–126, 1920.

57 Darton, N. H., Geologic structure of parts of New Mexico: U. S. Geol. Survey Bull. 726, p. 183, 1920.

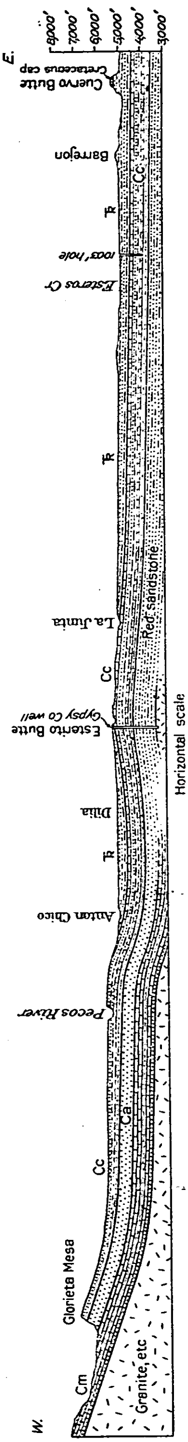


FIGURE 130.—Section from south end of Sangre de Cristo Mountains northwest of Bernal to Cuervo Hill, in San Miguel and Guadalupe Counties. Cm, Magdalena group; Ca, Abo sandstone; Cc, Chupadera formation; ℞, Triassic red sandstone and shale

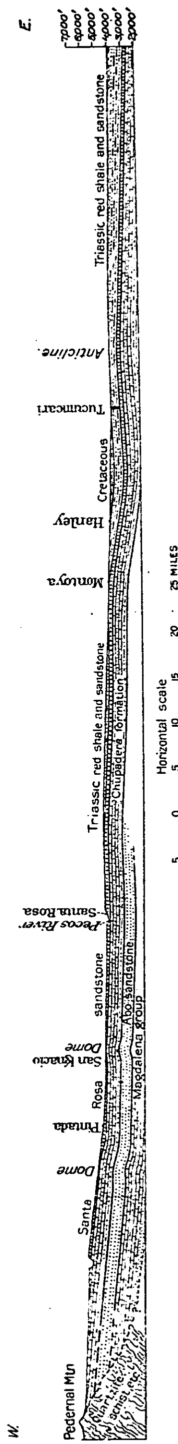


FIGURE 131.—Section from west to east across parts of Torrance, Guadalupe, and Quay Counties through Pintada Canyon, Santa Rosa, and Tucumcari

Its top bed is made up of 80 feet or more of gray massive sandstone, in part of pale-greenish tint, rather soft to the west but hard to the east. A low arch brings into view an underlying member of purplish-brown massive sandstone separated from the gray sandstone by local bodies of conglomerate. This arch also reveals some underlying red shale. The gray sandstone finally passes under red shale which extends eastward past Los Tanos and Cuervo. This upper gray sandstone is exposed west of Santa Rosa and in the canyon walls and side slopes to the south, where it is underlain by gypsum, to the presence of which are due some large sink holes in the region, notably some deep steep-sided ones a few miles northwest of Santa Rosa.

The general structural relations are shown in Figure 131.

The sandstones in the Santa Rosa region were traced over most parts of the area. The hard bed capping Esterito Butte extends eastward along the walls of the canyon of Pecos River past Las Colonias and apparently passes underground in the big bend of the river in the northern part of the Perea grant. It dips northeast at a low angle and in the 1,003-foot well 12 miles north-northeast of Santa Rosa was 253 feet below the surface. The higher bed, which is conspicuous a few miles north of Las Colonias, appears to be the stratum at the surface near the Bar Y ranch, is 140 feet thick in the 1,003-foot hole, and is exposed extensively in long cuts of the railroad beginning just east of Santa Rosa. Unio fragments found in this stratum near the Bar Y ranch suggest Triassic species described by Meek as *Unio cristonensis*, *U. gallinensis*, and *U. terrae-rubrae*. They were determined by T. W. Stanton. Gypsum, probably Chupadera, is exposed on Pecos River, 11 miles northwest of Fort Sumner.

The highest rocks appearing in the Santa Rosa region cap Cuervo Hill, a very prominent steep-sided butte in the rolling country 20 miles northeast of Santa Rosa. It is a remnant of the plateau connection that formerly existed between the Canadian Escarpment and the Llano Estacado. It presents an extended section of rocks from a cap of Purgatoire formation to Triassic "Red Beds" (Dockum group) at its base, as shown in Figure 132. A view of the butte is given in Plate 57, *B*. The few feet of soft slabby sandstone at the top of the butte contains fossils that were determined by T. W. Stanton as *Ostrea quadriplicata* Shumard, *Trigonia emoryi* Conrad, *Protocardia texana* Conrad, *Turritella* sp., and *Schloenbachia vespertina* Morton?, which belong to the fauna of the Washita group, represented in this region by the Purgatoire formation. Underlying this sandstone is 10 feet of hard gray to buff sandstone that weathers into large blocks. Below is 250 feet or more of shale, mostly light gray or greenish gray, with considerable maroon, and in the lower part red, so closely similar to the Morrison formation that it is provisionally assigned to that formation. The included 50-foot member of fine-grained soft sandstone is a notable feature. The 10 feet of limestone is thinly laminated and has the character and relations of the Todilto limestone in the Canadian Escarpment. Above it is a 5-foot breccia of limestone fragments, and below is a massive ledge of sandstone presenting the characteristic features of the Wingate. The upper part of this sandstone is buff or yellow, and its base is abruptly separated from the red shale of the Dockum group, as in the Canadian Escarpment and other places farther west. This red shale grades down into alternations of red sandstone and red shale, of which about 200 feet is exposed in the lower slope of the butte and adjoining plains. Two prominent members of harder red sandstone are included, as shown in the section.

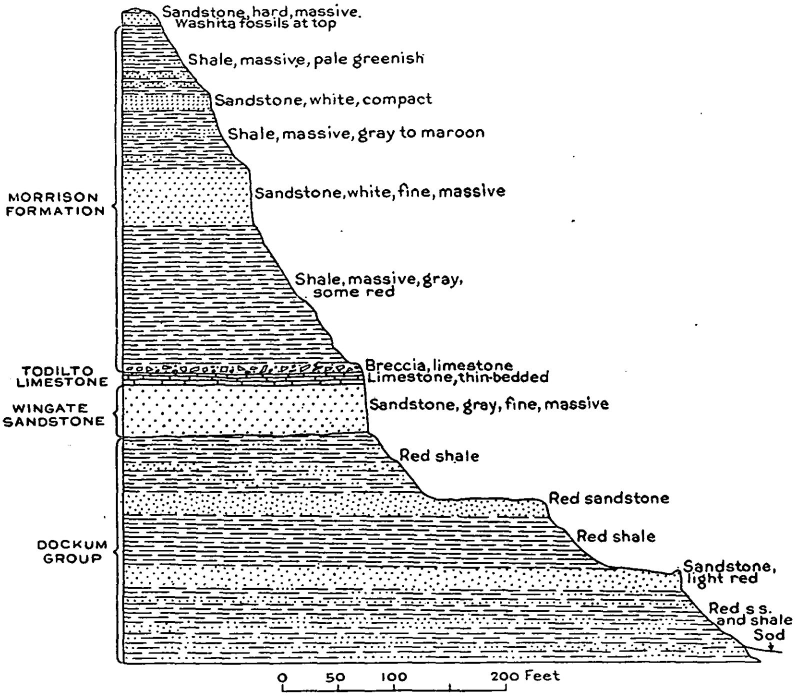


FIGURE 132.—Section of Cuervo Hill, 20 miles northeast of Santa Rosa. Thickness approximate

BORINGS

The hole bored in 1918–19 by the Gypsy Oil Co. in the Esterito dome, in the Anton Chico grant, northwest of Santa Rosa, had the following record, supplied by Mr. G. C. Matson:

Record of hole bored by Gypsy Oil Co. in the SW. ¼ sec. 30, T. 11 N., R. 19 E., Guadalupe County

	Feet
No record	0–187
Sandstone	187–380
Sandstone, dark	380–425
Sandstone, gray	425–500
Sandstone, black	500–520
Shale and sandstone, red	520–1, 026

	Feet
Limestone	1, 026–1, 045
Red rock	1, 045–1, 065
Sandstone; lower part white	1, 065–1, 108
Red rock	1, 108–1, 155
Sandstone	1, 155–1, 175
Shale, red	1, 175–1, 195
Shale, blue	1, 195–1, 200
Red rock	1, 200–1, 265
Sandstone; water	1, 265–1, 287
Limestone, red	1, 287–1, 299
Sandstone, red and gray, alternating	1, 299–1, 575
Sandstone; water	1, 575–1, 588
Limestone	1, 588–1, 600
Shale, red	1, 600–1, 660
Limestone	1, 660–1, 675
Red shale and sandstone	1, 675–1, 800
Red rock	1, 800–1, 870
Sandstone	1, 870–1, 990
No record	1, 990–2, 000
Granite	2, 000–2, 013

The heavy sandstone of the Chupadera formation extends to a depth of 520 feet, and doubtless most of the underlying red beds are also Chupadera. Some Abo sandstone may lie on the granite, or possibly some of the lower beds from 1,588 to 2,000 feet may represent the Magdalena group, but they include only 27 feet of limestone.

Early in 1916 a 1,003-foot boring was made in the Beck grant, 12 miles north-northeast of Santa Rosa, at a point 1,885 feet east and 200 feet north from the southwest corner of sec. 6, T. 10 S., R. 22 E., where there is a low dome on the general eastward-dipping monocline. The record, given in Figure 133, is compiled from the driller's log checked by the samples, part of which I tested chemically. It was found that some of the blue shale and black shale recorded in the log is limestone. The log gives the following details:

Record of strata from 575 to 780 feet in boring in Beck grant, 12 miles north-northeast of Santa Rosa

	Feet
Gypsum	575–580
Blue shale	580–590
Red, white, and blue shale	590–640
Black shale	640–670
Black shale and gypsum	670–685
Gypsum	685–695
Blue shale with some gypsum	695–700
Gypsum	700–710
Blue shale and some gypsum	710–720
Brown shale and some gypsum	720–730
Black shale	730–740
Gypsum and some black shale	740–750
White sand and gypsum	750–765
Gypsum and blue shale	765–780
Black shale and some gypsum	780–800

On examining the samples obtained from these depths it was found that the material from 575 feet was gypsum; from 580, 590, 595, 600, 605, 612, and 618 feet, limestone and gypsum; 628 and 650 feet, limestone; from 635 and 655 feet, limestone with some gypsum; from 660, 668, and 678 feet, limestone; from 673 feet, limestone and gypsum; from 695 and 710 feet, gypsum; from 700, 720, and 730 feet, gypsum and limestone; from 740 feet, gypsum with some limestone; from 750 and 765 feet, gypsum; from 770 feet, limestone with some gypsum; and from 780, 785, and 800 feet, gypsum and anhydrite.

The boring began in the sandstone which is prominent along the river banks to the north and in railroad cuts just east of Santa Rosa, and the sandstone at 255 to 345 feet probably is the bed constituting the bluffs along Pecos River near Las Colonias and passing below the river in the big bend 4 miles south of the boring.

The record of a recent boring by the Midwest Refining Co., about 25 miles northeast of Santa Rosa, is given in Figure 134. It began high in the Dockum group and apparently penetrated the Santa Rosa sandstone from 455 to 623 feet, with the underlying red shale extending to 826 feet. Next below is the Chupadera formation, predominantly light-colored sandstone but with intercalated beds of limestone and anhydrite. How near the bottom of this formation the boring reached is not known; doubtless at this place the thickness is much more than 526 feet.

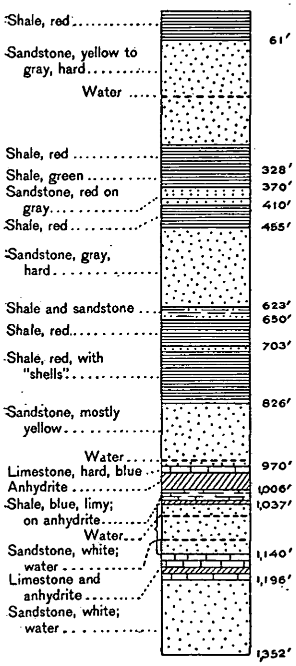


FIGURE 134.—Record of Jones well, in the SW. ¼ sec. 25, T. 12 N., R. 25 E., 25 miles northeast of Santa Rosa

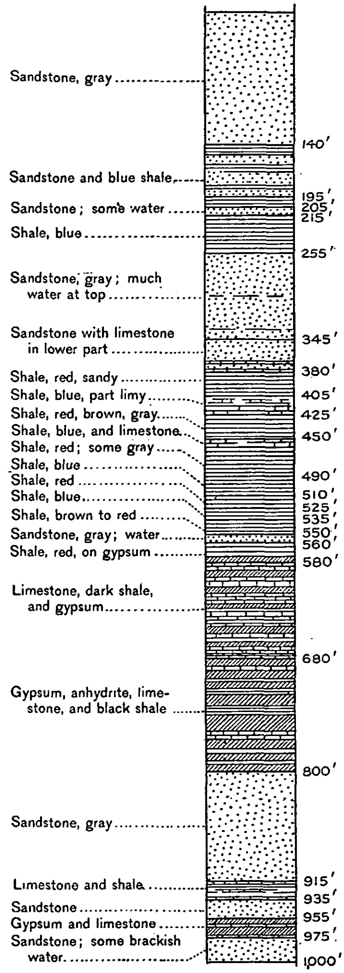


FIGURE 133.—Record of boring in Beck grant, 12 miles north-northeast of Santa Rosa

A 1,717-foot hole made by the Peerless Oil Co. 9 miles east of Santa Rosa is reported[58] to have penetrated schist from 1,585 feet. It started in Dockum beds about 200 feet above the Santa Rosa sandstone, found limestone (probably Chupadera) from 1,105 to 1,175 feet and sandstone and red beds from 1,175 to 1,585 feet. Probably these lower strata represent the Abo sandstone lying on a ridge of pre-Cambrian schist, Pennsylvanian rocks being absent.

A boring for oil in progress in 1924 and 1925 about 22 miles north of Fort Sumner afforded very important data as to the stratigraphy under the eastern part of Guadalupe County and adjoining regions. The record, which was kindly furnished by Dr. H. E. Elliott, in charge of the work, is given in Figure 135. Salt-bearing strata were entered at 860 feet lying on a 220-foot deposit of gypsum, and thick bodies of salt were penetrated at 1,620, 1,805, and 1,920 feet, with thinner beds at 1,240, 1,433, 2,030, and 2,857 feet—nearly 300 feet in all. This hole had reached a depth of 3,800 feet when abandoned in 1927. It penetrated about 460 feet of Dockum beds and apparently entered the Chupadera formation at 590 feet, where 76 feet of limestone was reported. Doubtless this formation includes the gypsum, salt, and limestone alternation to at least 2,135 feet, below which an eastern extension of the Abo sandstone is suggested. Doctor Elliott believes that at 3,417 feet the top of the Magdalena group was entered.

A boring in sec. 16, T. 1 S., R. 27 E., about 23 miles southeast of Fort Sumner, had reached a depth of 2,710 feet in the later part of 1927. Sandstone from 2,035 to 2,135 feet and salt at 2,235 feet were reported from it.

A boring for oil about 11 miles south of Buchanan affords a very interesting section of the strata. The record given in Figure 136 appears to be fairly reliable. The strata to a depth of at least 2,650 feet belong to the Chupadera formation, with limestone and gypsum in the upper part and thick deposits of salt in the lower part. Probably that formation continues to the bottom of the boring, although it is possible that the Abo sandstone and even older strata are represented.

A 1,200-foot boring for water at St. Vrain penetrated sand with some gravel near its lower part to a depth of 218 feet, probably all Tertiary capping of the Llano Estacado. From 218 to 1,200 feet the strata were red and gray shale of the Dockum group, including gray sandstone from 300 to 330 feet and 452 to 465 feet. Whether or not the top of the Chupadera formation was reached is not known.

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[58] Prout, F. S., Schist east of Santa Rosa, N. Mex.: Am. Assoc. Petroleum Geologists Bull., vol. 11, p. 88, 1927.

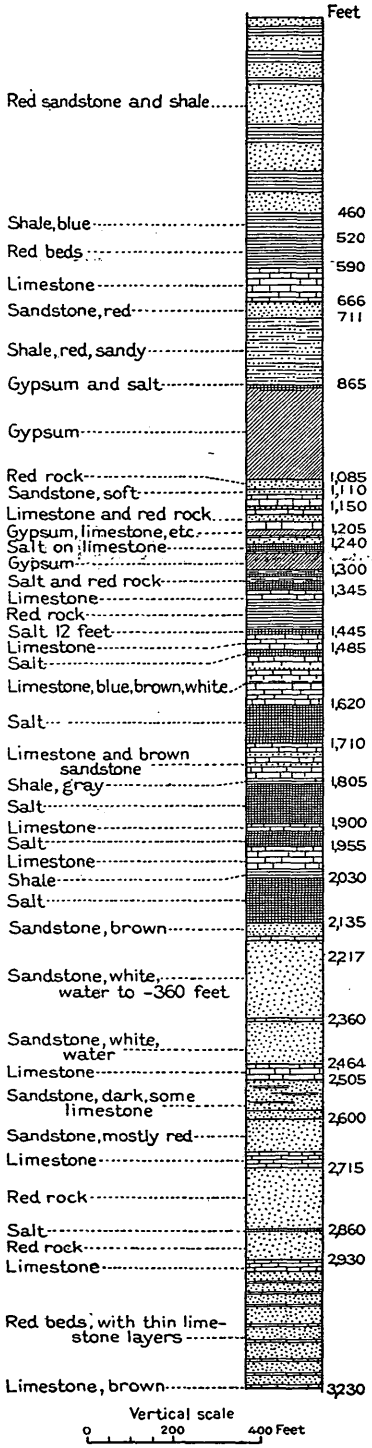

FIGURE 135.—Record of boring in the SW. ¼ NW. ¼ sec. 2, T. 6 N., R. 25 E., 22 miles north of Fort Sumner

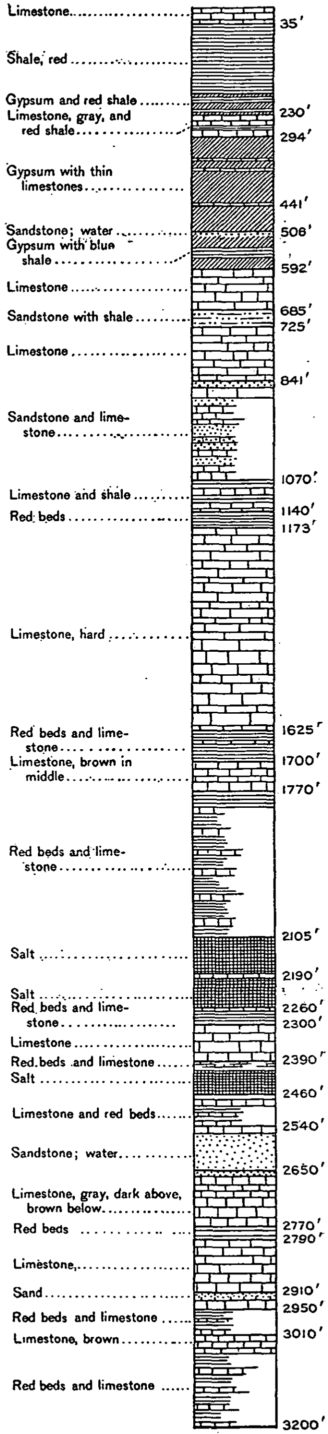

FIGURE 136.—Record of boring in sec. 36, T. N., R. 20 E., 11 miles south of Buchanan

CANADIAN VALLEY AND CANADIAN PLATEAU

GENERAL RELATIONS

In Union and Quay Counties and the eastern part of San Miguel County the principal physiographic feature is the broad eastward-sloping plateau of nearly horizontal strata known as the Canadian Plateau, which terminates to the south in the long line of cliffs known as the Canadian Escarpment. This plateau is a northern extension of the Llano Estacado, from which, however, it is separated by the wide valley of Canadian River. Cimarron River cuts a notable canyon across this plateau in the northeast corner of the State. On the south side of the Canadian Valley are the high bluffs of the Llano Estacado, and on its north side is the line of still higher cliffs of the Canadian Escarpment. The escarpment extends westward from the valley of Ute Creek and across the Canadian-Pecos divide to a point south of Las Vegas; the principal break in it is the deep canyon of Canadian River. Mesa Rica and Cuervo Hill are outlying remnants of the plateau, and there are other similar outliers south and west of Tucumcari.

A reconnaissance was made of this district along lines believed to be sufficiently close to determine the stratigraphy and larger structural features. Very few facts have been published relating to the region, for it lies east of the area covered by Stevenson's reconnaissance.[59] Lee[60] has described certain features in the canyon of Cimarron River.

The Canadian Plateau consists of Dakota sandstone with local thin cappings of sand and grit of Tertiary age and of basalt to the east and Cretaceous shale to the west. The larger valleys are excavated in red shale and sandstone of the Dockum group, and in the slopes are outcrops of the Purgatoire and Morrison formations and Wingate sandstone. The Wingate is overlain by the Todilto limestone to the west. Except in a few small areas the beds all appear to be nearly horizontal, but there is in general a broad monocline to the east, with several low anticlines and synclines. The most notable anticline is a broad, high dome whose axis passes near Des Moines, as shown in Figure 145, and the deepest syncline is in the basin west of Tucumcari, but there are many local flexures. A fault with downthrow of about 350 feet on the east side trends southward across the plateau 18 miles southeast of Las Vegas and passes out of the plateau at the east end of Carro Mesa.

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[59] Stevenson, J. J., Report upon geological examinations in southern Colorado and northern New Mexico, 1878–79; U. S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3, Suppl., 1881.

[60] Lee, W. T., Morrison shales of southern Colorado and northern New Mexico: Jour. Geology, vol. 10, pp. 36–58, 1902.

FORMATIONS

DOCKUM GROUP (TRIASSIC)

Red sandstone and shale of Triassic age, belonging to the Dockum group, underlie all of northeastern New Mexico and are extensively bared in the wider, deeper valleys and canyons. Canadian River cuts a canyon in these beds in eastern Mora County and northeastern San Miguel County, and this exposure widens greatly in the broad river valley extending across Quay County. The Dockum rocks are also exposed by Ute Creek and Cimarron River.

The Dockum group was not studied in detail, but it appears to be about 700 feet thick and to consist of alternations of red sandy shale and red sandstone. Its base is not exposed in this region, but at the top it gives place abruptly to either Wingate sandstone or Morrison formation without evidence of structural unconformity except in the canyon of Cimarron River, where the strata are considerably flexed and irregularly eroded.

Case [61] examined the Canadian Valley from the Texas State line westward to Conchas Canyon, which he ascended on the way to Las Vegas. He found Triassic bones at several localities. He refers to the lower division of the Dockum as sandstone with shaly layers. The next division is 250 feet, more or less, of red clay of varying shades, mostly very homogeneous. It is capped by conglomerate. The upper Dockum beds are exposed in slopes of the high mesas south of Tucumcari and Montoya, where they are capped by sandstone of Washita age (Purgatoire formation). Just west of Montoya a low anticline brings up the top of the lower sandstone of the Dockum group, which yields phytosaur bones. This is the Santa Rosa sandstone, which is prominent in cuts just east of Santa Rosa. Case found this sandstone exposed west of Cobra Spring, in Conchas Canyon, a deep gorge cut through heavy sandstone and conglomerate into a 40 to 50 foot bed of white sandstone, probably local. In the lower part of this sandstone is a lens of dark-red and mottled clay and shale, much distorted and streaked with greenish clay, and a greenish conglomerate of small pebbles containing Unios, the lowest Triassic stratum observed. Case gives views showing the upper red clays in Bull Canyon, south of Montoya, which he believes are the beds above the conglomerate layer traced into the eastern part of the State from Texas.

WINGATE SANDSTONE (JURASSIC?)

The Wingate sandstone crops out conspicuously all along the Canadian Escarpment in the northeast corner of San Miguel County and eastward up La Cinta Creek, as well as south-southeastward past

[61] Case, E. C., The Red Beds between Wichita Falls, Tex., and Las Vegas, N. Mex., in relation to their vertebrate fauna: Jour. Geology, vol. 22, pp. 243–259, 1914.

the Bell ranch. It is present in Cuervo Hill (pl. 57, *B*), Tucumcari Butte (pl. 57, *A*), Mesa Rica, and other outliers of the plateau. As shown in Figure 135, near the mouth of the canyon of Canadian River it consists of about 80 feet of massive pink sandstone overlain by 20 feet of slabby softer pale-brown sandstone. The cliff of massive sandstone is almost continuous. As far east as about longitude 104° 20′ the Wingate is overlain by the eastern extension of the Todilto limestone. In the walls of La Cinta Canyon the massive Wingate sandstone member is 80 feet thick and the overlying softer beds about 30 feet. Here, as in other regions, it lies on red shale of the Dockum group, from which it is separated by an abrupt change of material. The Wingate sandstone crops out extensively north and southeast of the Bell ranch and is low in the slopes near old Johnson post office. It was also found in Tequesquite Canyon about Albert, where it consists of 60 feet of massive brick-red sandstone overlain by 20 feet of more slabby beds. At the base is a sharp contact with bright-red shale. This is about 50 feet above the level of Albert. The outcrop is continuous to Bueyeros, where there are many exposures of this sandstone with the underlying Dockum red shale and overlying Morrison beds.

TODILTO LIMESTONE (JURASSIC?)

As stated above, the Todilto limestone caps the Wingate sandstone in the Canadian Escarpment through a large part of San Miguel County, but it finally thins out and disappears at a point northwest of the Bell ranch. In this region it is only a few feet thick and consists of characteristically thin layers. It is 5 feet thick in Carro Mesa, as shown in Figure 141.

MORRISON FORMATION (CRETACEOUS?)

The entire Canadian Plateau is underlain by about 200 feet of gray shale with sandstone members believed to be the southern extension of the Morrison formation. Locally it is much thinner. It crops out under the Dakota and Purgatoire sandstone ledges along the Canadian Valley, the Canadian Escarpment, Ute Valley, and the Cimarron Valley [62] and in the slopes of the outlying mesa remnants, including Cuervo Hill. It also appears with similar relations in the northern margin of the Llano Estacado south and west of Tucumcari and south of Montoya. Generally it appears in a slope above a cliff of Wingate sandstone, as shown in Figures 135–137.

Most of the shale is massive and of pale-greenish tint, with minor portions colored maroon. It includes two well-defined members of light gray-buff massive sandstone, which crop out along the Canadian Escarpment and eastward to La Cinta Creek, and along Ute

[62] Lee, W. T., The Morrison shales of southern Colorado and northern New Mexico: Jour. Geology, vol. 10, pp. 40–52, 1902. Stanton, T. W., The Morrison formation and its relations with the Comanche series and the Dakota formation: Jour. Geology, vol. 13, pp. 664–665, 1905.

Valley as shown in Figure 142, to and beyond Bueyeros; they are extensively exposed about Miera. Apparently the thicker bed (Exeter sandstone, p. 306) is prominent in Cimarron Valley east of Valley post office, where it lies in part on Dockum red beds and in part on pale greenish-gray and maroon massive shale similar to the overlying shale and typical Morrison. As this lower shale member lies on an eroded surface of the Dockum red beds it is surely post-Triassic.

PURGATOIRE FORMATION (CRETACEOUS)

The gray sandstone and shale of the Purgatoire formation underlie most of the Canadian Plateau, but their identity and limits are not fully ascertained in all parts of the area. The formation consists of a lower member of hard massive gray sandstone from 5 to 50 feet or more thick and an upper member of sandy gray shale from 50 to 70 feet thick extending to the base of the Dakota sandstone. The sandstone ledges are prominent in the Cimarron Valley and along the slopes of the Canadian Escarpment and its outliers. It is a northern extension of a portion of the Comanche series, as determined by Stanton,[63] who found that its shale member carries a Washita fauna, which is varied and abundant in Cimarron Valley near the Oklahoma State line but very scanty to the west near Folsom. The sandstone and shale in the mesas about Tucumcari and south and west of that place and about Montoya as far west as Cuervo Hill carry Washita fossils. The southernmost occurrence of this formation noted was on the west slope of the plateau about a mile west of Ima post office.

DAKOTA SANDSTONE (CRETACEOUS)

The greater part of the Canadian Plateau is floored by the Dakota sandstone, but in places this formation is covered by lava or by gravel and sand of the Ogallala formation. The rock is a gray sandstone, mostly hard and massive, and presents broad tabular areas on the plateau and cliffs along nearly all the valleys and canyons of the region. The thickness ranges from 100 to 200 feet in greater part. In sec. 13, T. 27 N., R. 35 E., the formation contains a bed of semibituminous coal which attains a thickness of 1½ feet and has been mined in small amount for local use.

The Dakota sandstone caps the outlying remnants of the Canadian Plateau in the mesas south and west of Tucumcari and appears for a few miles high in the bluffs on the northern edge of the Llano Estacado.

COLORADO AND MONTANA GROUPS

In the northern and western parts of the plateau area the Dakota sandstone is overlain by strata of the Colorado and Montana groups,

[63] Stanton, T. W., op. cit., pp. 664-665.

which have a thickness of 2,000 feet or more near the margin of the Raton coal field. They comprise the following formations:

Pierre shale, 1,000 feet or more.
Apishapa shale, 600 feet or more.
Timpas limestone, 50 feet.
Carlile shale, 200 feet.
Greenhorn limestone, 50 to 80 feet.
Graneros shale, 150 feet.

VOLCANIC ROCKS

The volcanic rocks that cover a large part of the Canadian Plateau are mostly basalts of recent flows which have come from several craters, one of the most notable of which is Capulin Mountain, southwest of Folsom, a gigantic cinder cone with a deep central crater in an excellent state of preservation. There have been several stages of eruption, as shown by the occurrence of lava at different levels of the topographic development of the country, notably in the Raton region, where these features have been mapped and described in detail by Mertie.[64] Lava extends eastward to Clayton and southward to the Sierra Negra, southeast of Roy. Another remarkable flow extends from Maxson Crater, northeast of Watrous, down the narrow canyon of Mora River, as shown in Figure 137, then down the valley of Canadian River to a point near latitude 35° 30′.

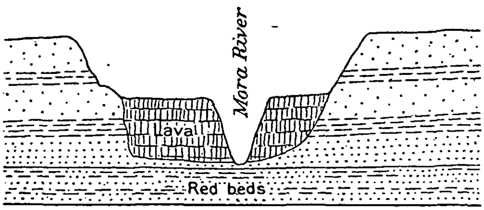


FIGURE 137.—Sketch section across canyon of Mora River southeast of Optimo, showing relations of lava flow, looking east. The canyon is 700 feet deep and is cut in the Dakota sandstone and underlying beds

OGALLALA FORMATION (TERTIARY)

A widely extended deposit of sand of the High Plains of late Tertiary age occupies much of the plateau area in the eastern part of Union County, and some outliers of it extend into Mora and Colfax Counties. These outliers are probably remnants of a mantle which originally covered the greater part of the plateau area and over which in places the recent lavas have flowed.

LOCAL SECTIONS

In the cliff about 3 miles south of Montoya is an outcrop of the strata shown in Figure 138. The top sandstone has the general appearance of the Dakota sandstone, which caps the higher mesas in this vicinity and extends southward to the Llano Estacado. In a softer sandstone next below (Purgatoire) occur shells of *Ostrea quadriplicata*, a Washita fossil. The underlying shale is so strikingly

[64] Mertie, J. B., in Lee, W. T., op. cit. (Folio 214), pp. 9–11.

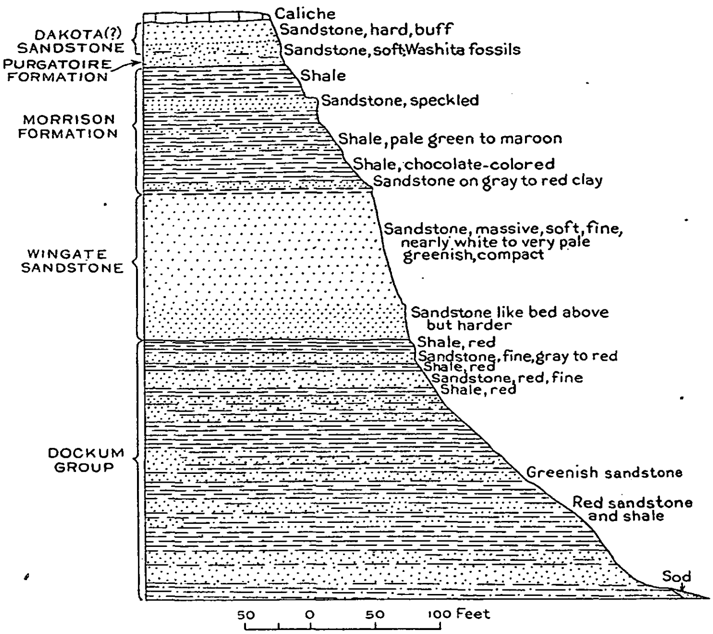


FIGURE 138.—Section of mesa 3 miles south of Montoya

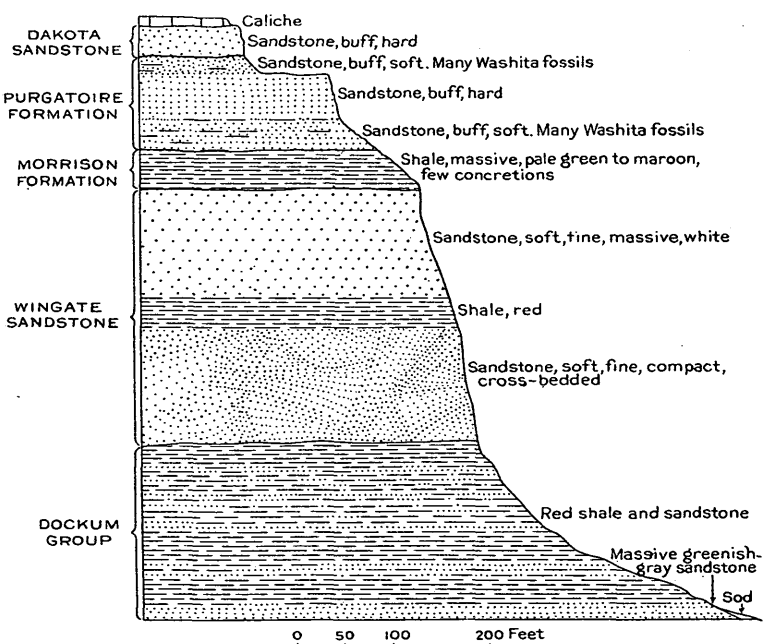


FIGURE 139.—Section of west slope of Mesa Rica 10 miles east of Isidore post office

like the Morrison in appearance and relations that I believe it represents that formation. The underlying massive sandstone, about 100 feet thick, is doubtless the Wingate. It lies on red shale at the top of the Dockum group, which constitutes the lower slopes and wide plains in the Montoya region. The underlying sandstone (also belonging to the Dockum group) is conspicuous in the area west of Montoya and in the plains to the north, about Isidore post office.

A section of the west face of Mesa Rica, 10 miles east of Isidore post office, is given in Figure 139, and the relations between this section and the mesa south of Montoya are shown in Figure 140. In the Mesa Rica section there is under the top sandstone, and also under the next sandstone ledge below, a highly fossiliferous sandy shale, containing abundant *Gryphaea corrugata*, a Washita form. Next below is pale-green and maroon massive shale or clay, with a few white calcareous concretions, which is typical Morrison. The 225 feet of soft fine-grained light-colored massive sandstone in the

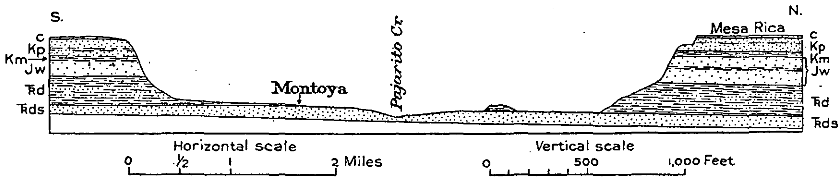


FIGURE 140.—Section from Mesa Rica to mesa south of Montoya, looking west. c, Caliche of possible Tertiary age; Kp, sandstone with Washita fossils (Purgatoire formation); Km, Morrison formation Jw, Wingate sandstone; ₸d, upper red beds of Dockum group; ₸ds, greenish-gray sandstone of Dockum group

middle slope is undoubtedly the Wingate. Here, as in the section south of Montoya and in exposures along the foot of the Canadian Escarpment, this sandstone lies on red shale with a strong suggestion of unconformity. The massive greenish-gray sandstone of the lower part of the Dockum group makes a long dip slope at the foot of Mesa Rica and in the country to the west. In the valleys cut through this slope west of Isidore post office this sandstone member, 50 to 60 feet thick, is seen to be underlain by 60 feet of purplish-gray massive sandstone, 30 feet of red shale, 60 feet of brown massive sandstone, and 100 feet of red shale, on brown sandstone and shale, all Dockum group.

Tucumcari Butte, a famous locality of Washita fossils, is a small plateau remnant about 4 miles south of Tucumcari.[64a] A view of this feature is shown in Plate 13, *B*. The top is a ledge of hard buff sandstone, probably Dakota, capped by sand and calcite such as covers the Llano Estacado. Below the sandstone are sandy shales

[64a] Hill, R. T., Outlying areas of the Comanche series in Kansas, Oklahoma, and New Mexico: Am. Jour. Sci., 3d ser., vol. 50, pp. 229–234, 1895; Science, vol. 22, pp. 23–25, 1895. Cummins, W. F., Notes on country west of the Plains, Tucumcari, N. Mex.: Texas Geol. Survey Third Rept., pp. 201–210, 1892; Tucumcari Mountain, Am. Geologist, vol. 11, pp. 375–383, 1893. The butte to which the Indians applied the name Tucumcari is a nipple-shaped eminence a short distance farther south.

and soft buff sandstone containing many fossils of the Washita fauna. (See p. 39.) A bed of white sandstone and greenish-buff sandy shale and soft sandstones, much obscured by talus, are believed to be Morrison. They lie on a cliff-making massive dirty pale-buff sandstone grading up into softer darker sandstone, in all nearly 100 feet thick, strongly suggesting the Wingate, which occurs in other buttes to the west. This sandstone lies with sharp break on soft red shale regarded as the upper part of the Dockum group, of which about 100 feet is exposed in the lower slope of the butte.

The Canadian Escarpment and the outlying mesas are capped by Dakota sandstone, and in the slopes below are sandstone of Lower Cretaceous age (Purgatoire formation), Morrison formation, Wingate sandstone, and red beds of the Dockum group. South and southeast of Las Vegas and extending nearly to La Cinta Canyon the Wingate sandstone is overlain by the Todilto limestone, as in Santa Fe, Bernalillo, Sandoval, Valencia, and McKinley Counties. A repre-

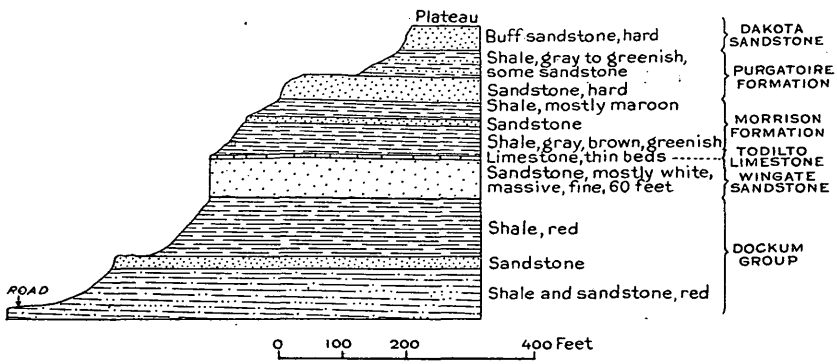


FIGURE 141.—Section of Canadian Escarpment at southwest corner of Carro Mesa

sentative succession, well exposed near the main road 18 miles southeast of Las Vegas, is shown in Figure 141. A view of this locality is given in Plate 56. The Dockum beds in the lower part of the slope represent the upper portion of the group. The Wingate sandstone, with its light color and massive structure, is a very striking feature here as well as all along the east margin of the Tecolote grant. Its outcrop was found to be continuous to the canyon of Canadian River and for some distance farther east. The Todilto limestone exhibits the same features observed farther west in the State, but it is thinner and its upper part lacks the massive character presented in exposures 5 miles southwest of Las Vegas. The Morrison formation is typical also and includes sandstone members, but there is some uncertainty as to its upper limits. The Purgatoire formation and Dakota sandstone show the same features as in regions north and west. The strata lie nearly horizontal.

The succession of rocks in the upper part of the Dockum group and overlying beds was examined on the west side of Ute Creek a short distance southwest of Gallegos, in the southern part of Union County. The principal features are shown in Figure 142. The top of the mesa, which constitutes the divide between Cañada de Atarque and Ute Creek, consists of hard buff sandstone of the formation (Dakota) capping the Canadian Escarpment, of which this mesa is a continuation. Doubtless the lower part is Purgatoire, as in Mesa Rica and south of Tucumcari, but no fossils were found near Gallegos. The underlying shale, of pale-greenish color with maroon tints in places, appears to be characteristic Morrison. The underlying sandstone and shale are less distinctive, but some of their features suggest Morrison. The 30 feet of soft pinkish-gray sandstone in a single massive cliff is undoubtedly Wingate. It is sharply separated

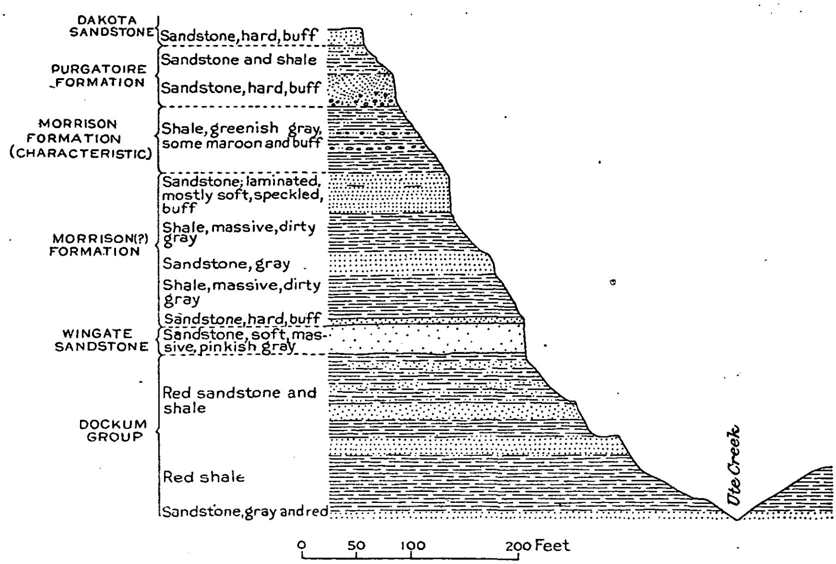
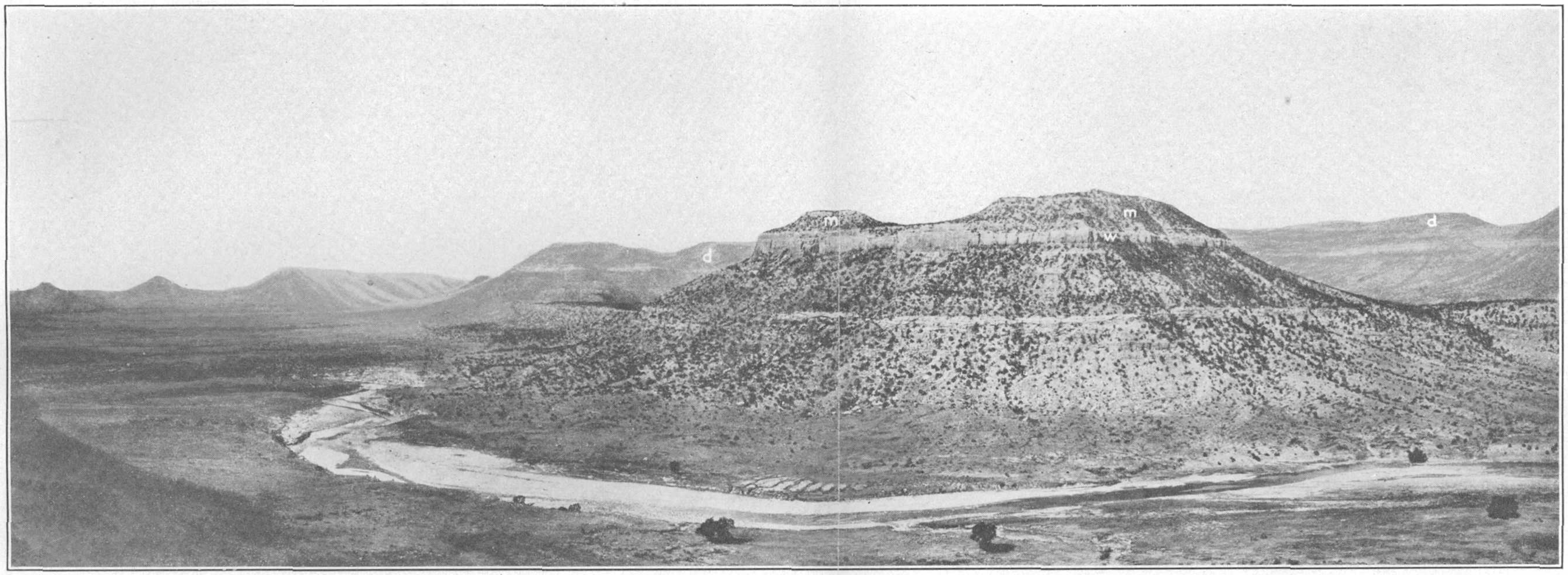


FIGURE 142.—Section of west side of Ute Valley below Gallegos, Union County

from underlying red shale and sandstone of the Dockum group, 200 feet of which is exposed down to the level of the creek. These lower beds extend far up the valleys of this creek and its branches.

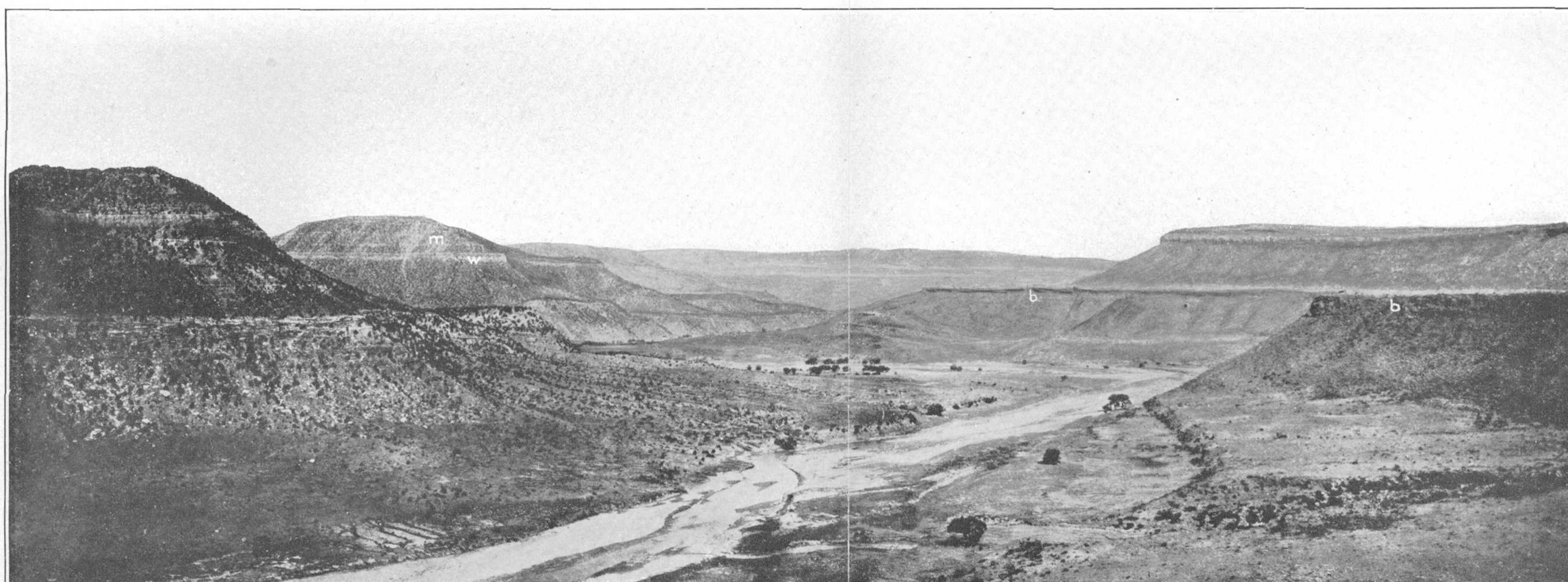
The strata in the eastern part of the Canadian Escarpment were observed in the vicinity of Canadian River and La Cinta Creek on and near the Pablo Montoya grant (Bell ranch). (See pl. 58.) The strata lie nearly horizontal, and no details of structure were determined. A section at the mouth of the Canadian Canyon, a short distance below the mouth of Canyon Largo, is given in Figure 143. The butte shown in the middle of this figure is an outlier of the main plateau as shown in Plate 58, *B*. The basalt on the shelf is a remnant of a flow that came down Mora Canyon from the Maxson crater.[65] (See fig. 137.)

[65] Keyes, C. R., Maxwell coulee and the diversion of the Rio Mora: Iowa Acad. Sci. Proc., vol. 17, pp. 165–166, 1910.



A. CANADIAN ESCARPMENT AT MOUTH OF CANADIAN CANYON, BELOW MOUTH OF CANYON LARGO

Looking west. w, Wingate sandstone capped by Todilto limestone; m. Morrison formation; d, Dakota sandstone on Purgatoire formation. The slopes below w are red shale of Dockum group



B. CANADIAN CANYON NEAR SABINOSO

Looking north. w, Wingate sandstone; m, Morrison formation. The high plateau is capped by Dakota sandstone. The terrace b–b is capped by basalt flow from Maxon Crater

In the vicinity of Roy the plateau is capped by white grit, presumably Tertiary, a northern representative of the capping of the Llano Estacado. It is well exposed in railroad cuts near Mills and beyond and appears to be about 100 feet thick. The railroad passes off of this formation to the north, the last exposure in the cuts being a mile north of Mills, where 15 feet is exposed. Under the cap is dark shale, and Greenhorn limestone is well exposed on the railroad 1½ miles north of Mills; its outcrop extends south along the western foot of the Tertiary escarpment. Near Abbott underlying black shales (Graneros) are exposed. They are about 80 feet thick and lie on Dakota sandstone, which is bare at Abbott. Not far east of the railroad is a slope of Graneros shale and buttes of Greenhorn limestone, and the Greenhorn comes down to the railroad again just north of Taylor. It extends far southwest as well as east of Taylor, which is on Graneros shale. The strata undulate to the north, but

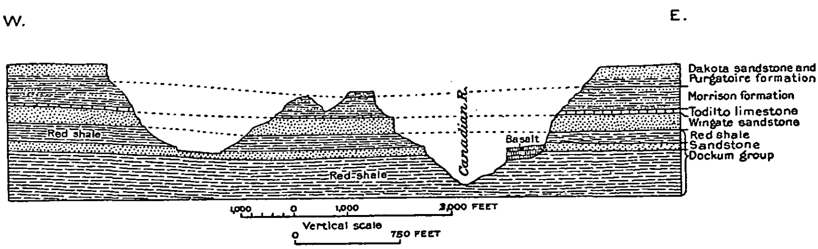


FIGURE 143.—Sketch section of Canadian Escarpment at mouth of canyon of Canadian River, near Sabinoso

Carlile shale and Niobrara strata finally cross the valley, and the overlying Pierre shale appears near French.

In the east wall of La Cinta Canyon on the road that ascends the mesa to Roy is the following section in which most of the beds are well exposed:

Section of supposed Morrison formation on east wall of La Cinta Canyon about 12 miles south of Roy

	Feet
Sandstone (Purgatoire?).	
Shale, gray, some limy beds, few thin maroon layers	170
Sandstone, light gray, moderately hard	20
Shale, mostly gray, partly greenish, brown, and maroon	90
Sandstone, light gray, moderately hard	30
Shale, mostly pale greenish gray	65
Sandstone, pale red, very massive (Wingate).	
	375

Similar beds but with more red shale and of less total thickness appear along buttes south of the Bell ranch, in the southern part of the Pablo Montoya grant.

Along the road descending into Tequesquite Canyon west of Albert there are excellent exposures of the Morrison and associated formations. The Morrison is overlain by white conglomeratic sandstone of the Purgatoire formation and lies on slabby red sandstone at the top of the Wingate. The following section was roughly measured.

Section of Morrison formation in Tequesquite Canyon, 4 miles west of Albert, Union County

	Feet
Clay or massive shale, pale greenish gray and maroon, with calcareous concretions	125
Sandstone, light-colored, massive, moderately hard	25
Clay, pale greenish and maroon	80
Sandstone, light-colored, massive	12
Clay, pale greenish and maroon; some thin sandstone layers	120

Although only about 25 feet thick the upper bed of sandstone is conspicuous here and in other canyons and slopes to the east, and it appears again also north and east of Bueyeros and in Tramperos Creek about Reyes, where the Morrison formation crops out in an area of considerable width.

In the canyon of Cimarron River in the northeastern part of Union County the Dakota sandstone, Purgatoire formation, and Morrison formation are extensively exhibited.[66] The Morrison formation constitutes the bottom of the canyon at the Oklahoma line, but the strata rise to the west, and underlying "Red Beds" appear in a short distance. From this point to the east line of R. 29 E. the outcrop extends along the lower middle slopes of the canyon, from "Red Beds" below to the heavy cap of Purgatoire formation and Dakota sandstone at the top, the altitude of the contact of Morrison and Purgatoire formations varying somewhat with changes of dip. The Morrison here consists mostly of typical light-colored clay or massive shale, in general pale greenish gray with some maroon and brown portions, and thin sandstone. One sandstone, which lies considerably below the middle of the formation, has been called the Exeter sandstone by Lee.[66] I am confident that it is the same bed that appears continuously in the southwestern part of Union County and the eastern part of San Miguel County in the middle of the Morrison formation but here increased somewhat in thickness. In places the underlying shale or clay is absent, and the sandstone lies unconformably on Triassic "Red Beds" (Dockum group) with some local discordances of dip as described by Lee.[67] This relation is well shown on the south side of the canyon on the west line of R. 35 E., where a low arch of the "Red Beds" is truncated. Near the center of R. 34 E. the surface of the "Red Beds" slopes down to the west, and 80 feet of what seems to be typical Morrison massive clay lies between the white sandstone (Exeter) and the eroded surface of the "Red Beds." Near Valley post office the lower shale is absent again, at least in

[66] Stanton, T. W., Jour. Geology, vol. 13, pp. 664–665, 1905.
[67] Lee, W. T., Jour. Geology, vol. 10, p. 45, 1902.

greater part, and the sandstone lies on or not far above the "Red Beds." As the lower shale is separated from the red strata of the supposed Dockum group by an unconformity it is believed to be post-Triassic or part of the basal beds of the Morrison formation. The Wingate sandstone appears to be absent in this valley. The general relations are shown in Figure 144.

DRILL RECORDS

A boring in 1919 by the United Oil Co., near Cimarron Canyon throws much light on the character of the strata of the "Red Beds" and underlying rocks of northeastern New Mexico. It reached a depth of 2,725 feet. The following record was supplied by R. S. Shannon, who also supplied samples of drillings that were examined chemically by O. C. Wheeler, of the United States Geological Survey.

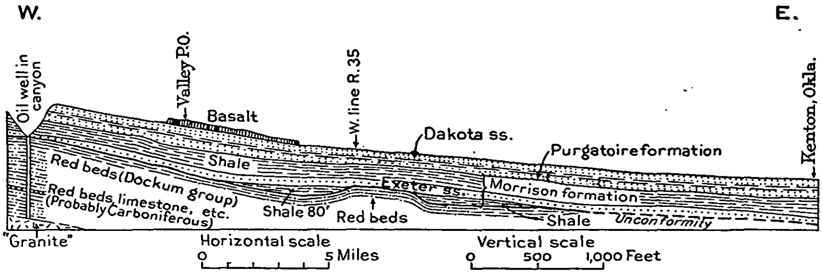


FIGURE 144.—Section on south side of canyon of Cimarron River in Union County, showing the writer's interpretation of the inclusion of the Exeter sandstone in the Morrison formation. ss, Sandstone

Record of boring of United Oil Co. in NW. ¼ sec. 6, T. 31 N., R. 33 E., Union County

	Feet
Sand and sandy shale, blue	0–68
Sandstone	68–108
Shale, blue or brown	108–159
Shale, sandy, red	159–179
Sandstone, coarse	179–193
Sandstone, red	193–227
Shale, red; some limestone	227–259
Limestone and sandstone, red	259–271
Shale, red, sandy	271–293
Limestone, red, and blue shaly sandstone	293–319
Shale, red, and limestone	319–363
Limestone	363–383
Limestone and red shale	383–400
Shale, red, sandy; some limestone near 470 feet	400–574
Limestone, sandy, hard	574–595
Shale, red, and limestone (dolomite)	595–615
Shale, blue; some gray dolomite and sandstone	615–652
Sandstone, shale, and limestone	652–680
Sandstone	680–700

	Feet
Sandstone and blue shale; some dolomite	700–720
Sandstone, mostly gray	720–760
Shale, blue, sandy	760–778
Limestone and sandstone alternating	778–847
Sandstone; some red sandy shale	847–880
Sandstone, mostly red; some limestone	880–945
Sandy shale, red	945–960
Sandstone, red	960–970
Sandy shale, red	970–990
Sandstone, red; some dolomite near 995 feet	990–1, 015
Sandy shale, red	1, 015–1, 053
Limestone, red, hard	1, 053–1, 121
Sandstone, soft	1, 121–1, 161
Sandstone, red, and sandy clay, red	1, 161–1, 205
Limestone, hard, and sandstone	1, 205–1, 211
Limestone, red	1, 211–1, 240
Sandstone, limestone, and shale, red	1, 240–1, 260
Sandy shale, mostly red	1, 260–1, 312
Sandstone, red, and limestone	1, 312–1, 342
Sandstone, red, hard	1, 342–1, 357
Sandy shale, red, and limestone	1, 357–1, 372
Limestone, hard	1, 372–1, 398
Limestone, hard, and sandstone	1, 398–1, 430
Sandy shale, red	1, 430–1, 513
Red rock, hard	1, 513–1, 700
Sandstone, red, coarse	1, 700–1, 760
Red rocks	1, 760–1, 960
Limestone, hard, sandy, red	1, 960–2, 040
Limestone, hard, sandy, white	2, 040–2, 080
Limestone, hard, sandy, red	2, 080–2, 104
Sandstone, red, soft; water	2, 104–2, 146
Granite	2, 146–2, 725

The beds penetrated comprise the Dockum group (Triassic), Permian, possible Pennsylvanian, and perhaps older strata, but the limits of each can not be indicated because the limits of possible Chupadera and Abo strata are not recognizable in the record. It is not known that the Chupadera formation extends north of latitude 36°. The identity of the granite reported in the bottom of the hole was established by abundant samples from 2,146 to 2,722 feet which consisted of quartz grains with about 20 per cent orthoclase, much black mica, and many fragments of "gneiss."

It is interesting to compare this record with the log of a boring 15 miles to the northwest in Colorado, in T. 34 S., R. 56 E. It was 3,830 feet deep in the early part of 1928 and was still in dark limestones and shales of supposed Pennsylvanian age that were entered below "red beds" at 3,150 feet.

Condensed record of Heringa well, sec. 14, T. 24 N., R. 30 E., 2 miles northeast of Pasamonte, Union County

	Feet
Shale, yellow on blue, with thin sandstone at 45 feet	0–90
Sandstone, hard, white	90–122
Shale, blue, with 3 feet of sandstone at 135 feet	122–150
Sandstone with shale, hard below	150–185
Shale, blue	185–198
Sandstone, gray to white, mostly hard; some shale at 229 feet	198–326
Limestone [?], brown from 333 to 352 feet	326–510
Red rocks; some limestone near top and water sand at 758–765 feet	510–1, 394
Shale, light brown to dark brown; sandy in lower half	1, 394–1, 520
Sandstone, brown	1, 520–1, 815
Sandstone, gray; some limestone below	1, 815–1, 840
Limestone, mostly gray	1, 840–1, 938
Sandstone, gray	1, 938–2, 031
Shale	2, 031–2, 041
Limestone and shale, bluish	2, 041–2, 066
Sandstone	2, 066–2, 095
Limestone with "shells"	2, 095–2, 120
Sandstone, white, and "shells"	2, 120–2, 142
Sandstone, gray and red, on quicksand	2, 142–2, 183
Sandstone, red, and limestone, gray, on gray sandy limestone	2, 183–2, 290
Sandstone, white; water	2, 290–2, 304
Limestone, pink, on sandstone, white	2, 304–2, 319
Limestone, red and white, sandy	2, 319–2, 378
Sandstone, white	2, 378–2, 390

This boring began not far above the Dakota sandstone and for the first 300 feet or more was in Dakota and Purgatoire strata. The identity of the limestone reported from 326 to 510 feet is doubtful. The red and brown strata from 510 to 1,520 feet are in large part Dockum group; the identification of the lower strata is not practicable, but doubtless Abo and possibly Chupadera sediments are represented. It is reported that this hole reached "gabbro" at a depth of 2,960 feet, either an intruded mass or more probably the pre-Cambrian "bedrock."

Record of boring of Arkansas Fuel Oil Co., in the SE. ¼ NE. ¼ sec. 11, T. 19 N., R. 21 E., 6 miles east of Optimo, Colfax County

	Feet
Limestone, sandy, hard	0–51
Shale (soapstone), white on pink	51–170
Limestone, mostly pink and sandy	170–325
Limestone, pink, with "red rock" at top and in center	325–385
Sandstone, pink	385–410
Limestone, pink, and red rock alternating	410–750
Red rock	750–950
Shale, blue, with limestone layers in middle	950–975
Red rock	975–1, 040

	Feet
Limestone, pink, gritty; gray shale at 1,105–1,120 feet	1, 040–1, 160
Sandstone (mostly), much gas	1, 160–1, 210
Limestone, sandy, on gray	1, 210–1, 230
Red rock	1, 230–1, 275
Limestone, brown, red, part sandy	1, 275–1, 310
Shale	1, 310–1, 370
"Limestone" and shale	1, 370–1, 412
Sandstone; much gas	1, 412–1, 425
"Limestone"; sand at 1,440–1,460 feet	1, 425–1, 475
Sandstone, hard, mostly yellow	1, 475–1, 607
"Limestone" (mostly), yellow and red	1, 607–2, 220
"Limestone"; thin sandstone at 1,800 and 2,190 feet, very hard and sandy; part gray, some pinkish; sand at 2,358–2,370 feet	2, 220–2, 613

This record is so unreliable that correlation of beds is impossible. It is claimed that from 2,220 feet the rock was granite, and the designation "limestone" is probably an error. Undoubtedly the boring penetrated Dakota, Purgatoire, and Morrison beds in the first 500 feet, below which are red strata probably of Jurassic, Triassic, and Permian age. A good record of this boring would have afforded much light on the stratigraphy.

The record of a boring in the southwest corner of sec. 15, T. 23 N., R. 24 E., about 3 miles northwest of Abbott, completed in January, 1925, supplies some very interesting facts. It began on the Dakota sandstone, penetrated the underlying Purgatoire and Morrison beds, and the soft white and pink sandstone from 600 to 705 feet is believed to be the Wingate sandstone. Red shales and sandstone, probably of the Dockum group, extend from 705 to 1,394 feet, interrupted by hard gray sandstone at 840 to 890 feet, hard blue sandstone at 1,078 to 1,118 feet, and a few thin beds of brown and blue shale and some hard "shells." The rock from 1,394 to 1,779 feet is sandstone, alternating hard and soft and all white or gray, probably of Permian age, in which the only interruption recorded is sandy limestone from 1,718 to 1,755 feet, and similar limestone occurs from 1,779 to 1,800 feet, a succession which suggests Chupadera. Next below is 179 feet of hard sandstone, red above and brown and pink below, interrupted by 5 feet of gray limestone at 1,915 to 1,920 feet. The strata from 1,800 to 1,979 feet strongly suggest the Abo sandstone. From 1,979 to 2,556 feet (bottom) pink sands were found derived from a hard rock believed to be granite.

A 2,938-foot boring for oil on the plateau 10 miles southeast of Raton affords valuable data as to the stratigraphy of the general region, but unfortunately it is not possible to identify the limits of all the formations with certainty. Its record is as follows:

Record of well, in the NW. ¼ SW. ¼ sec. 10, T. 29 N., R. 24 E., 10 miles southeast of Raton

	Feet
Surface and gravel	0–40
Shale, dark, with 10 feet of sandstone at 180 feet and 20 feet at 270 feet	40–415
Limestone, gray	415–425
Shale	425–790
Limestone [probably largely shale]	790–1, 000
Shale, brown and gray, with 10 feet of sandstone at 1,225 feet	1, 000–1, 345
Limestone	1, 345–1, 350
Shale, black	1, 350–1, 365
Sandstone, with 4 feet of shale at 1,380 feet; some "lime sand"	1, 365–1, 545
Limestone, red and green, with 7 feet of sandstone at 1,555 feet	1, 545–1, 598
Sandstone, pink from 1,625 to 1,632 feet	1, 598–1, 742
Limestone	1, 742–1, 745
Sandstone	1, 745–1, 955
Limestone, gray, hard	1, 955–1, 983
Shale, pink	1, 983–2, 017
Sandstone, dark	2, 017–2, 109
Shale, brown	2, 109–2, 143
Sandstone, hard	2, 143–2, 271
Shale	2, 271–2, 300
Sandstone	2, 300–2, 938

The boring began in either the Pierre or the Apishapa shale. Possibly the limestone at 415 feet is Timpas and the limestone between 790 and 1,000 feet is Greenhorn, with the base of the Benton (Graneros) at 1,365 feet. The sandstone from 1,365 to 1,545 feet doubtless is Dakota and Purgatoire, with more or less Morrison below. The sandstone from 1,598 to 1,742 feet may be Wingate, in which case the shales and sandstones from 1,742 to 2,300 feet are Dockum. It is not unlikely that the sandstone from 2,300 to 2,938 feet may be Chupadera and part of the Abo. This boring finally reached a depth of 4,082 feet, and some reports state that it found granite at that depth, at an altitude of 2,470 feet.

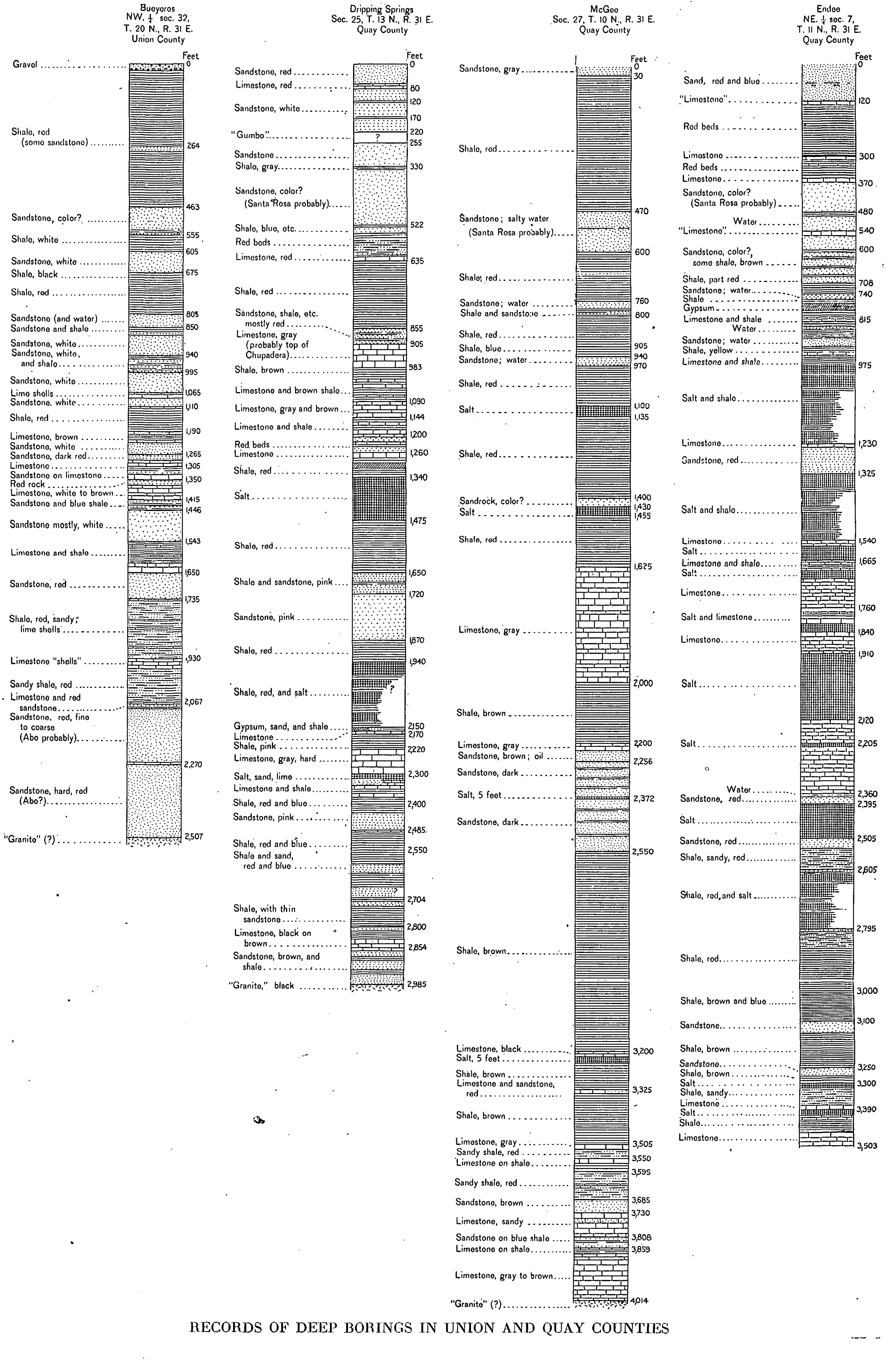
A 926-foot boring made by the railroad company at Solano station is reported to have passed through brown sandstone from 40 to 108 feet; sand, lime, and blue shale from 108 to 221 feet; very hard rock from 221 to 276 feet; white sandstone from 276 to 307 feet; and "blue shale, hard rock, and shale" from 307 to 926 feet. This record is too indefinite to throw any light on the stratigraphy.

The 4,990-foot boring on the Bell ranch, about 15 miles northwest of Tucumcari, in sec. 3, T. 10 N., R. 29 E., was supposed to have entered granite at about 3,700 feet, although "brown shale" was reported at 4,200 feet.

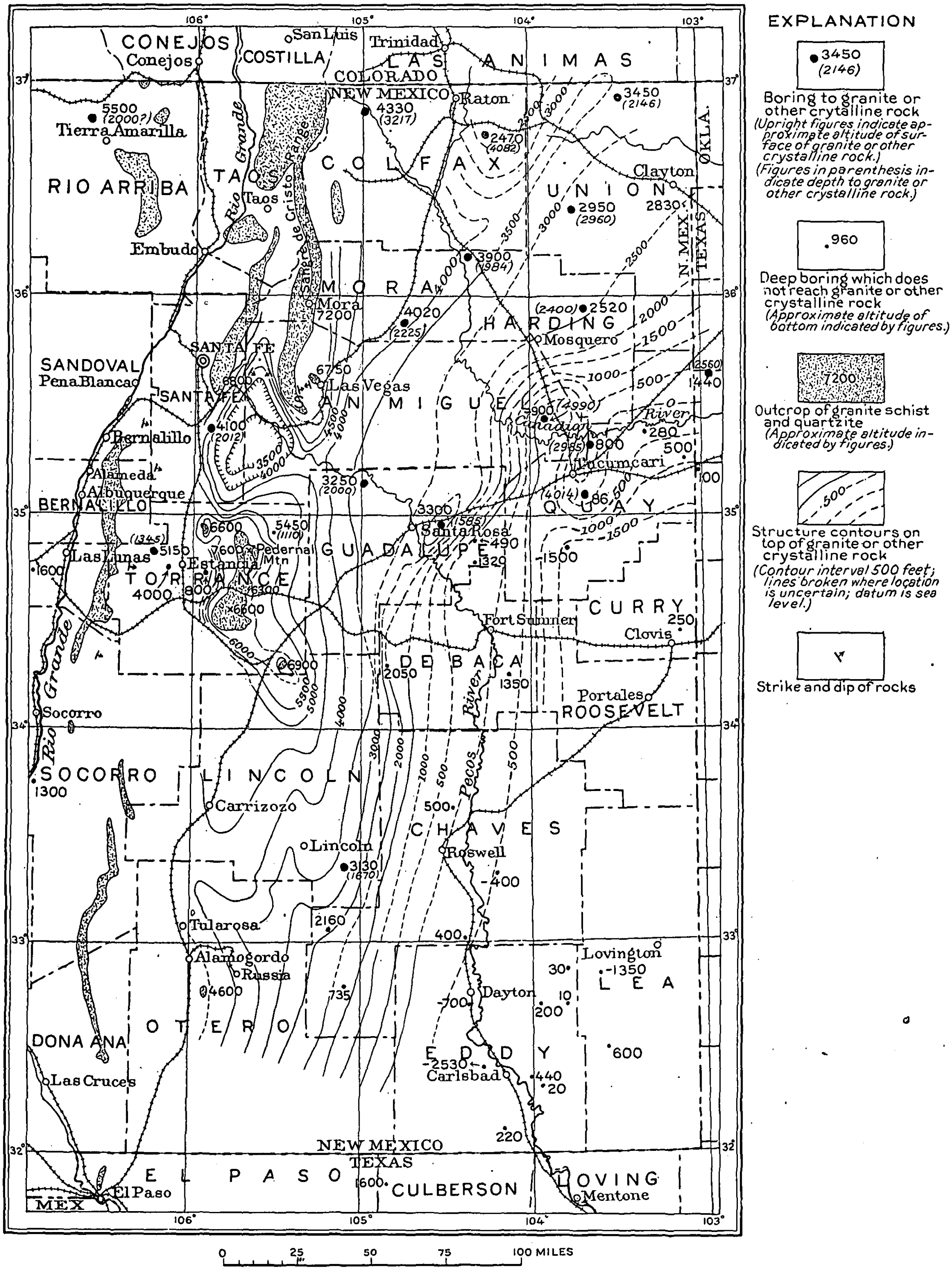
In 1919–20 several deep borings were made in the Canadian Valley in Quay County to test the strata for petroleum. The first was the McGee boring, a short distance southeast of Tucumcari, which penetrated Triassic and Carboniferous red beds and underlying strata and, it is reported, was discontinued in granite. A record furnished by H. T. McGee is given in Plate 59. This boring began in the red beds of the Dockum group, which doubtless continued to the sandstone extending from 470 to 600 feet, which is believed to represent the Santa Rosa sandstone member. Borings in Tucumcari, 578 to 703 feet deep, obtain water probably from this sandstone and also from "gravel" at 115 to 120 feet. The top of the Permian (Chupadera formation) is not clearly recognized, but it was probably reached near 900 feet. The thickness of Permian strata is not known, but the salt deposits extending from 1,100 to 1,135, 1,430 to 1,455, 2,372 to 2,377, and 3,220 to 3,225 feet—70 feet in all—are doubtless of that age. The lower limestones and shales are probably Pennsylvanian, and it is possible that the lowest strata comprise representatives of Mississippian and even older limestone. The identity of the granite reported at the bottom of the boring is not established, but the existence of granite at the depth stated seems not unlikely. The boring on the Bell ranch, 15 miles northwest of Tucumcari, is 4,990 feet deep to "granite."

The records of two other notably deep holes in the Canadian Valley, in Quay County, are given in Plate 59. One is in sec. 25, T. 13 N., R. 31 E., 12 miles northeast of Tucumcari, where a depth of 2,985 feet was attained, and the other is in the NE. ¼ sec. 7, T. 11 N., R. 36 E., a few miles northwest of Endee, where the depth is 3,503 feet. Both holes began in the Dockum group and penetrated deeply into the Chupadera formation, revealing large deposits of salt, as in other wells farther south in the State. It is barely possible that the Abo sandstone was entered in the bottom of these holes. The Santa Rosa sandstone seems to show its characteristic features in both at depths near 500 feet. The hole northeast of Tucumcari appears to have entered the Chupadera formation at a depth of about 905 feet, beginning with a limestone member 78 feet thick. The hole northwest of Endee probably entered the Chupadera formation between 750 and 800 feet, and the limestone member at 800 feet is the same as was found in the other boring. This limestone appears not to have been noted in the record of the McGee well, which is evidently greatly generalized.

A boring 5 miles southeast of Bueyeros is reported to have been abandoned in granite at 2,507 feet. It began in Dockum beds and



RECORDS OF DEEP BORINGS IN UNION AND QUAY COUNTIES



MAP SHOWING CONFIGURATION OF "BEDROCK" IN EASTERN NEW MEXICO penetrated the Chupadera formation, but the limits of these formations are not indicated in the following record:

Record of boring in SW. ¼ NW. ¼ sec. 32, T. 20 N., R. 31 E., southeast of Bueyeros, Union County

	Feet
Gravel	0–21
Shale, red; sandstone at 264–288 and 463–543 feet	21–555
Shale, white	555–605
Sandstone, white	605–675
Shale, black	675–680
Shale, red	680–805
Sandstone; water at top, 5 feet of shale at 850 feet and at 940 feet	805–950
Shale, blue, and sandstone, white, alternating	950–995
Sandstone, white, with "lime shells" in lower part	995–1, 110
Shale, red	1, 110–1, 190
Limestone, brown, with red shale in middle	1, 190–1, 225
Sandstone, white, dark at base	1, 225–1, 275
Sandstone, red	1, 275–1, 280
Limestone, white above, dark and sandy below	1, 280–1, 305
Shale, red	1, 305–1, 315
Sandstone, hard, white at top, dark below	1, 315–1, 349
Red rocks	1, 349–1, 365
Limestone, part sandy	1, 365–1, 398
Shale and limestone, brown and white; sandstone	1, 398–1, 455
Sandstone, mostly white; water at 1,460 feet	1, 455–1, 543
Shale, blue, on gray sandy limestone	1, 543–1, 650
Sandy shale, red, with "lime shells" at 1,820 and 1,880 feet	1, 650–1, 930
Limestone, gray	1, 930–1, 965
Sandstone, red, mostly hard; "lime shells" at 2,060 and 2,270 feet and black limestone at 2,265–2,270 feet lying on "granite"	1, 965–2, 507

Possibly the sandstone from 680 to 1,110 feet is Santa Rosa.

An 800-foot hole at Glen Rio, Tex., on the Chicago, Rock Island & Pacific Railroad near the New Mexico State line, about 40 miles due east of Tucumcari, was bored largely in red beds including a thick body of gray sandstone from 230 to 334 feet. It was principally, if not wholly, in strata of the Dockum group.

A 2,171-foot boring made by the Buffalo Oil Co. about 10 miles southeast of Clayton penetrated red beds with included gray and brown sandstones, limestone, and gypsum, but the record is too indefinite to throw much useful light on the stratigraphy. Gypsum is mentioned in the record at 1,696 and 1,740 feet, presumably in the eastern extension of the Chupadera formation.

GENERAL STRUCTURE IN NORTHEASTERN NEW MEXICO

In a large part of northeastern New Mexico the rocks appear to be nearly level or present a low general dip to the southeast. There are, however, several low flexures, and near the Sangre de Cristo Mountains there are many strong folds and probably faults. In Figures 145 and 146 are shown the broader structural relations, but many

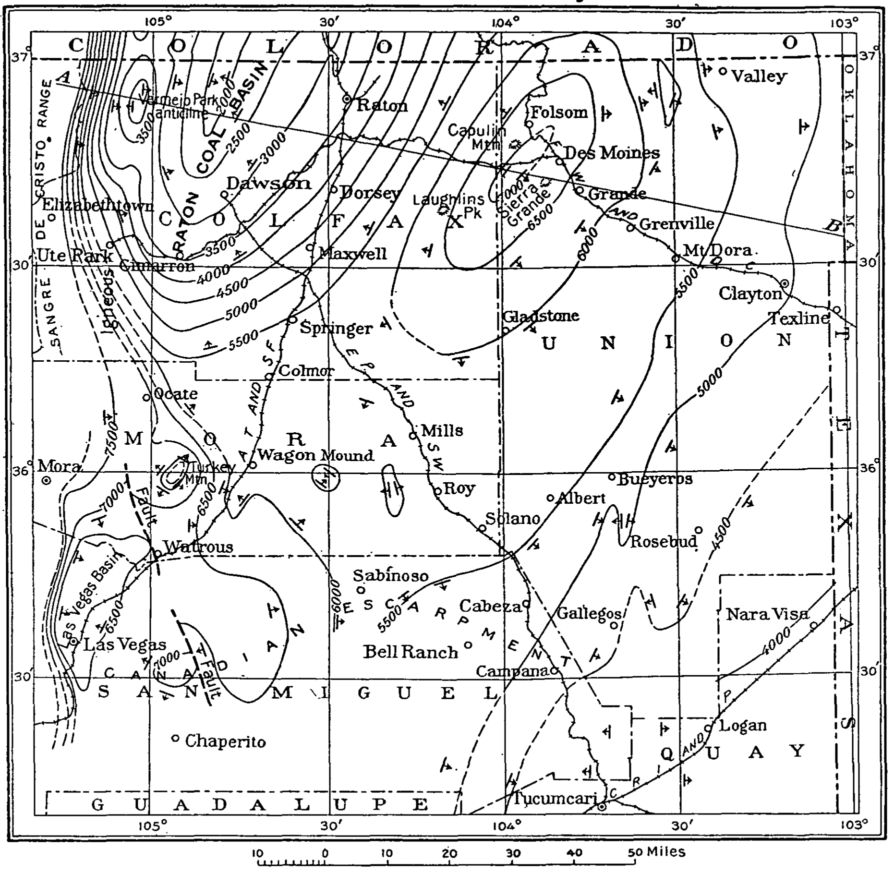


FIGURE 145.—Map showing the larger structural features of northeastern New Mexico, in Colfax, Union, Mora, and San Miguel Counties, by contours at the surface of the Dakota sandstone. Contour interval, 500 feet. Altitudes approximate. A–B, Line of section in Figure 146

minor undulations have not been studied. The largest features in the northern part of the area are the deep syncline of the Raton coal basin and the anticline which passes from Mesa de Maya, in Colorado, past Capulin Mountain. The anticline flattens out in the eastern part of Mora County, where it bears several low domes in the region north of Abbott. To the north it extends some distance into Colorado with relations that have been shown in a previous report.[68] West of Des Moines, in the highest part of this flexure, the surface of the Dakota sandstone reaches an altitude of about 6,850 feet (about 6,820 feet at Capulin station). From this place westward the dips are to the west at a very low angle, as shown in Figure 146. The Dakota sandstone passes under shale, which at Raton is more than 3,000 feet thick.

To the southwest the shale covering decreases in thickness, owing to erosion, and the Dakota sandstone is exposed in the Canadian Valley as far north as Taylor. Near Springer it is only a few hundred feet below the surface. The sandstone comes up again in Ocate Park, apparently in a low, flat anticline, and it is sharply upturned in the Turkey Mountain dome, which reveals the "Red Beds."

The Vermejo Park anticline or dome, as shown in Figures 145 and 146, rises on the west slope of the Raton coal basin. At Vermejo Park, which is on its eroded crest, the Pierre shale is exposed, and the cliffs encircling the park consist of Trinidad sandstone and overlying strata. The uplift amounts to several hundred feet.

A small uplift in the "Red Beds" under the Exeter sandstone is revealed in the canyon of Cimarron River 6 miles east of Valley. An anticline of considerable prominence extends northward across the valleys of the Cimarron and Travesser Creek, in R. 32 E. It is reported that the top of the Dakota sandstone was found in a 970-foot boring in the SW. ¼ sec. 10, T. 28 N., R. 26 E., a short distance north of Laughlin Peak, in the east-central part of Colfax County, at an altitude of 6,475 feet, which indicates the presence of a local dome of considerable prominence. A boring in the NE. ¼ sec. 16, T. 27 N., R. 22 E., a few miles west of Maxwell, reported the top of the Dakota sandstone at an altitude of 4,165 feet.

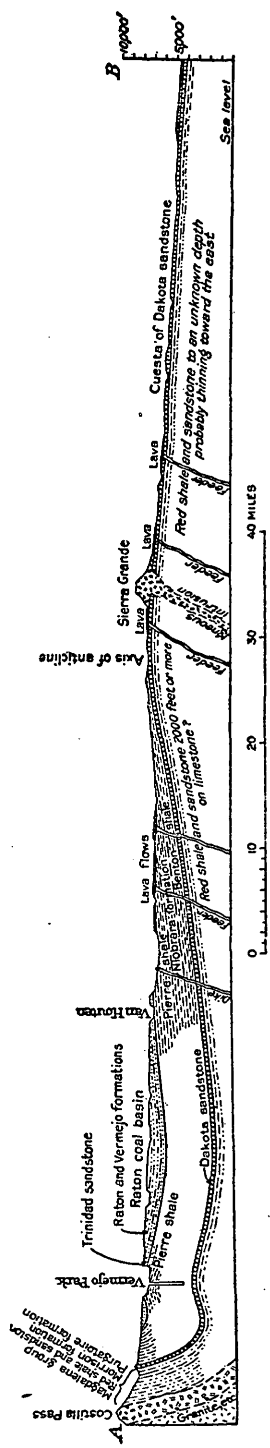


FIGURE 146.—Section across Colfax and Union Counties along line A-B, Figure 145

[68] Darton, N. H., The structure of parts of the Great Plains: U. S. Geol. Survey Bull. 691, pp. 19–21, pl. 1, 1918.

A large part of the surface of Union County consists of Dakota sandstone sloping eastward, covered to the east by Tertiary sand and gravel and to the north and west by sheets of lava which have flowed from numerous cones. The deeper canyons cut through to the underlying Purgatoire and Morrison formations and the Dockum group. In Colfax and Mora Counties the Dakota sandstone passes beneath the Benton and overlying shales, and in the Raton coal basin it is covered by several thousand feet of Cretaceous and early Tertiary beds. To the south, however, the strata rise somewhat, and the deep canyons of Canadian and Mora Rivers reveal red shale of the Dockum group.

In the central part of Quay County there is a prominent arch in which the strata are lifted about 200 feet. It is largely in T. 13 S., R. 34 E., where sandstone supposed to be Santa Rosa is exposed in an area of considerable extent. The axis of this uplift is crossed by Canadian River about 2 miles east of Logan.

"BEDROCK" IN EASTERN NEW MEXICO

Several deep borings for oil in northeastern New Mexico have reached granite or schist and throw considerable light on the configuration of the "bedrock" under the Permian and possibly older strata. The Pedernal Mountain ridge and some other outcrops of old crystalline rocks are parts of the floor which rise above the surface. Plate 60 shows the facts now available, a few of them from a paper by Gould.[69] The following data are available, but they are by no means all reliable as to the identity of the pre-Cambrian rocks.

Depth and altitude of "granite" and schist in borings in or near northeastern New Mexico

	Depth (feet)	Approximate altitude (feet)
Tucumcari, 5 miles southeast of (McGee boring)	4,014	86
Tucumcari, 12 miles northeast of (Dripping Springs)	2,985	770
Tucumcari, 15 miles northwest of	4,990	[a] −910
Esterito dome, northwest of Santa Rosa	2,000	3,250
Santa Rosa, 9 miles east of[b]	1,585	3,300
Abbott, 3 miles northwest of	1,984	3,900
Abbott, 12 miles north of	1,326	4,300
Bueyeros	2,400	2,520
Pasamonte, 2 miles northeast of	2,960	2,940
Cimarron Canyon (sec. 6, T. 31 N., R. 33 E.)	2,146	3,450
Raton, 15 miles southeast of	4,082	2,470
Optimo, 6 miles east of	2,225	4,020
Picacho	1,670	3,130
Estancia, 11 miles west of	1,345	5,150
Estancia, 32 miles northeast of	1,110	5,450
Lamy, south of (Pankey ranch)	2,012	4,100
Bravo, Tex	2,560	1,440
Vermejo Park	3,217	4,330

[a] Probably bored some distance into "granite" "bedrock."
[b] Prout, F. S., Schist east of Santa Rosa: Am. Assoc. Petroleum Geologists Bull., vol. 11, p. 88, 1927.

[69] Gould, C. N., Crystalline rocks of the plains: Geol. Soc. America Bull., vol. 34, p. 558, 1923.

It was reported that the hole 11 miles south of Buchanan found granite at 2,560 feet, but the material proved to be arkose, below which were limestone and other strata to 3,210 feet. (See record, pl. 59.) It is claimed that some of the other borings stopped in sedimentary material, but in most of them the evidence of the pre-Cambrian floor appears to be satisfactory. The boring at Picacho may have found an intrusive body similar to that in Capitan Mountain, not far away. The "gabbro" reported in the well near Pasamonte also may be intrusive. The top of "bedrock" in the 4,990-foot hole on the Bell ranch, 15 miles northwest of Tucumcari, is very uncertain, but it is far below sea level, indicating a deep valley.

The many deep borings in New Mexico that have not reached the pre-Cambrian "bedrock," indicating that this floor is at a lower altitude than the bottom of the holes, delimit the "bedrock" configuration in some measure. Data on most of these borings are given in the following table and in Plate 60.

Depth of some deep borings in eastern New Mexico

	Depth (feet)	Approximate altitude of bottom (feet)
Roswell, 12 miles north of	3,120	500 above sea level.
Roswell, 25 miles east of	2,943	960 above sea level.
Roswell, 20 miles east by south of	4,270	360 below sea level.
Lake Arthur	2,966	400 above sea level.
Felix (Manning dome)	3,440	2,160 above sea level.
Dunkin, 4 miles east of	4,895	700 above sea level.
Dayton	4,064	700 below sea level.
Dayton, 25 miles east of	3,400	200 above sea level.
Carlsbad, 8 miles east of	2,820	440 above sea level.
Carlsbad, 2 miles west of	5,800	2,530 below sea level.
Artesia, 35 miles east of	4,269	400 below sea level.
Artesia, 34 miles east of	3,872	20 above sea level.
Carlsbad, 17 miles south of	3,094	200 above sea level.
Carlsbad, 16 miles east of	3,260	20 above sea level.
Dayton, 30 miles east of	3,694	10 above sea level.
Dayton, 33 miles northeast of	3,465	300 above sea level.
Fort Sumner, 20 miles southeast of	2,650	1,350 above sea level.
Fort Sumner, 15 miles north of	3,684	1,320 above sea level.
Pasamonte, Union County	2,957	2,650 above sea level.
Buchanan, 11 miles south of	3,200	2,500 above sea level.
Glen Rio, Tex., near	3,870	100 above sea level.
Pearl, 15 miles northwest of	5,373	1,450 below sea level.
Pearl, 17 miles west-northwest of	5,339	1,400 below sea level.
Pearl, 15 miles south-southwest of	3,000	600 above sea level.
Tucumcari, 26 miles south of	5,204	1,600 below sea level.
Tucumcari, 25 miles northeast of	3,620	280 above sea level.
Clovis, 5 miles northeast of	4,022	250 above sea level.
Raton, 15 miles southeast of	[a] 4,082	2,470 above sea level.
Wagon Mound, southeast of	2,213	4,020 above sea level.
Estancia, 10 miles east of	5,323	820 above sea level.
Estancia, 6 miles west of	2,764	3,600 above sea level.
Santa Rosa, 20 miles east of	4,265	550 above sea level.
Lamy, 15 miles south of	3,380	2,850 above sea level.

[a] Reported to have reached granite.

RATON COAL BASIN

In the northwestern part of Colfax County there is a deep structural basin extending south from Colorado, which contains the Raton coal field. It has been studied and mapped in detail by Lee.[70] Figure 146 shows some of the features of the basin and the relations

[70] Lee, W. T., op. cit. (Prof. Paper 101 and Folio 214).

of a local anticline that rises in its western portion and exhibits underlying Pierre shale in Vermejo Park. The eastern margin of the coal-bearing rocks of the basin is marked by a line of high cliffs which are conspicuous just west of Raton and pass near Colfax and Cimarron. These cliffs exhibit the Trinidad sandstone, capping the Pierre shale and overlain by the Vermejo formation, which contains several beds of high-grade bituminous coal that are extensively mined at Dawson, Van Houten, Yankee, and other places. Next above the Vermejo is a thick succession of shale and sandstone of the Raton formation, which is believed to be of early Eocene age. At the base of this formation at most points there is a conglomerate or conglomeratic sandstone, which is not conspicuous near Raton but which farther southwest, near Van Houten and Koehler, forms cliffs 15 to 20 feet high. Along the western margin of the basin this conglomerate is much thicker than in the eastern part, and it extends high on the east slope of the Sangre de Cristo Mountains, notably on Baldy Peak, east of Elizabethtown, where it has the relations described by Lee[71] in connection with the gold deposits of the Aztec mine.

Along the eastern margin of the Raton basin the strata dip at low angles to the west, but along the western margin, especially to the north, the strata rise on steep dips and the underlying limestone and sandstone of the Magdalena group appear on the head of Vermejo Creek. There are coal beds in the Raton formation, but they have been developed on a commercial scale in only a few places. The principal one, which is near the base, has been worked at the Sugarite mine, east of Raton. Coal beds from 400 to 600 feet above the base of the formation are mined in Colorado and at Yankee and Brilliant, but the production is small compared to that of the more valuable coals of the Vermejo formation. The unconformity between the Vermejo and Raton formations is of great economic importance, because it cuts out some valuable beds of coal over considerable areas, and at some places all the coal of the Vermejo formation was removed by erosion before the deposition of the Raton beds. This is the case in the vicinity of Red River Peak and farther south, between Van Houten and Koehler, where the Vermejo formation is entirely removed and the Raton formation rests unconformably on the Trinidad sandstone.

The coal measures in the Raton basin are invaded by many dikes and sills of diabase, and some of these have altered the coal considerably, at one place converting it into graphite.

It is reported that two borings in the anticline at Vermejo Park reached "granite." One of them was in granite from 3,217 to 4,441 feet.

[71] Lee, W. T., The Aztec gold mine, Baldy, N. Mex.: U. S. Geol. Survey Bull. 620, pp. 327-330, 1916.

SIERRA CABALLO

GENERAL RELATIONS

The Sierra Caballo is a very prominent ridge on the east side of the Rio Grande valley in the eastern part of Sierra County. It consists of a thick succession of limestone from the El Paso to the Magdalena lying on the Bliss sandstone and granite and overlain by the Abo sandstone and Chupadera formation. The beds dip east in greater part, or toward the Jornada del Muerto, and the granite rises high on the steep western face, which slopes down to the Rio Grande. The general structure is shown in Figure 147.

Lee [72] has given many facts relating to the older strata in the central and southern parts of the range and observed the Abo sandstone overlain by limestone southwest of Engle.[73]

In 1912 and 1915 I crossed the north end of the mountain at Palomas Gap, where the Abo red beds and overlying Chupadera formation are especially well exposed, and in 1917 I examined the west face northwest of Upham.

The succession found in the western face not far east of the old mining camp of Shandon is shown in Figure 148.

The small ridge known as Cerro Cuchillo rises a few hundred feet above the terraces northwest of Palomas Hot Springs. Some of its features are shown in Plate 62. Granite is exposed at the base overlain by 900 feet or more of eastward-dipping strata. At the base of these is sandstone in which Lee [74] found trilobites and brachiopods of Cambrian age. Next above is 600 feet or more of limestone in which El Paso, Montoya, and Magdalena limestones are identified and probably Lake Valley, Fusselman, and Percha strata are also present.

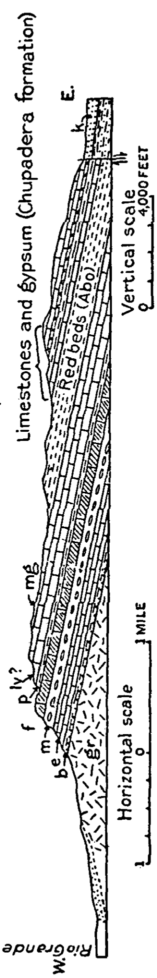


FIGURE 147.—Section across Sierra Caballo 15 miles northwest of Upham. gr, Granite; b, Bliss sandstone; e, El Paso limestone; m, Montoya limestone; f, Fusselman limestone; p, Percha shale; lv, Lake Valley limestone, probably; mg, limestones of Magdalena group; k, Cretaceous

[72] Lee, W. T., Notes on the lower Paleozoic rocks of central New Mexico: Am. Jour. Sci., 4th ser., vol. 26, pp. 180-186, 1908.

[73] Lee, W. T., U. S. Geol. Survey Bull. 389, p. 28, 1909.

[74] Lee, W. T., Am. Jour. Sci., 4th ser., vol. 26, p. 181, 1908.

FORMATIONS

PRE-CAMBRIAN ROCKS

Pre-Cambrian rocks crop out for 10 or 12 miles along the western front of the Sierra Caballo, in places, as shown in Plate 61, *A*, rising in slopes nearly 1,000 feet above the valley to the west. No data are available as to their character except that massive granite predominates with some gneiss or schist, cut locally by darker rocks that appear to be diorites.

BLISS SANDSTONE (CAMBRIAN)

The sandstone at the base of the sedimentary succession was described by Gordon and Graton [75] as the "Shandon quartzite," named from a transient mining settlement on the Rio Grande. These

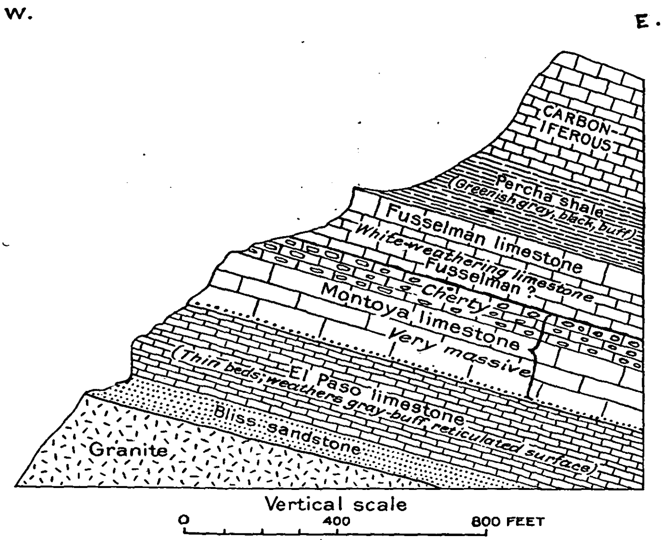
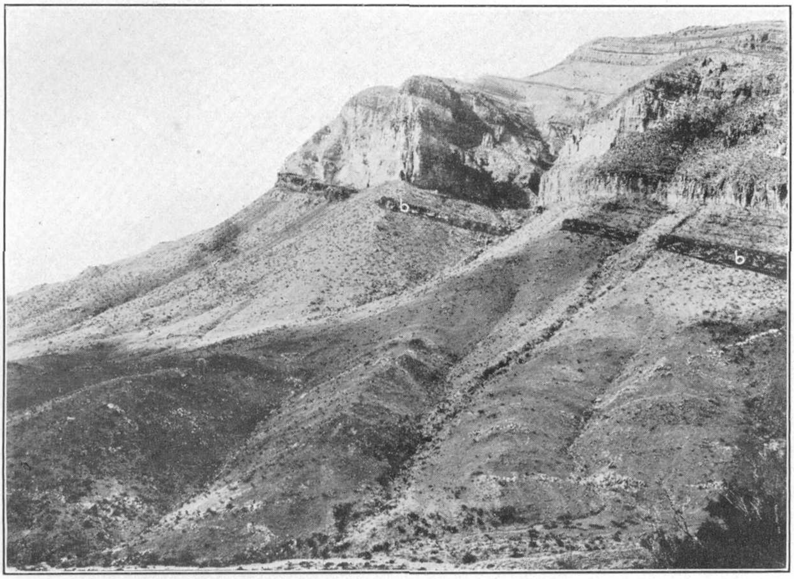


FIGURE 148.—Section of west front of Sierra Caballo 15 miles northwest of Upham

observers state that at most places there is a basal member of dark quartzite overlain by white quartzite 4 to 5 feet thick and an upper member 40 feet thick of dark-brown and green sandy shale and thin-bedded quartzite carrying *Obolus.* Lee [76] described a section 3 miles north of Shandon in which the basal quartzite, 10 feet thick and locally conglomeratic, grades up into 90 feet of dark-green shale. The shale yielded *Obolus* (*Westonia*) *stoneatus*, *Obolus sinoe?*, *Plectorthis desmopleura*, and *Lingulella acutangulata*, determined by C. D. Walcott and regarded as Upper Cambrian. Lee reports a similar section in Cerro Cuchillo, near Palomas Springs. He states that the basal quartzite is 300 feet thick 8 miles south of Shandon, but I observed only about 100 feet. The rock is mostly dark and thin

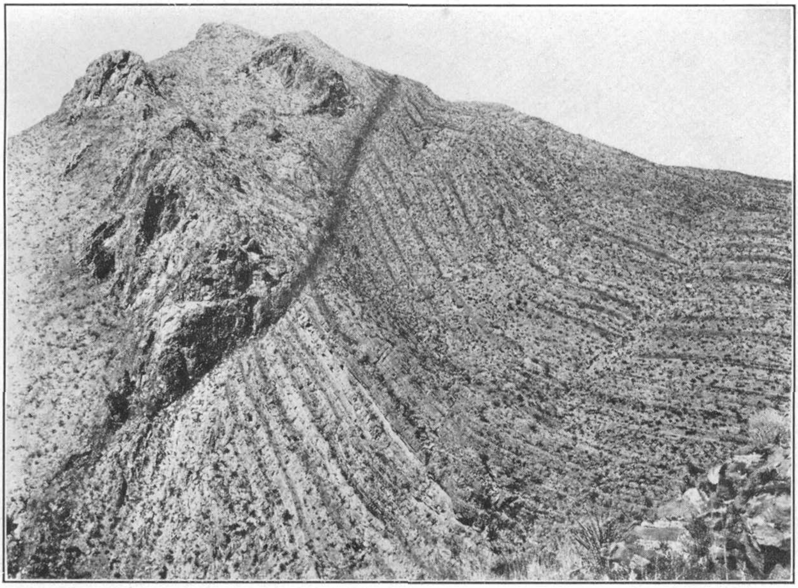
[75] Gordon, C. H., and Graton, L. C., Lower Paleozoic formations in New Mexico: Am. Jour. Sci., 4th ser., vol. 21, pp. 391–392, 1906. See also Gordon, C. H., U. S. Geol. Survey Prof. Paper 68, pp. 225–226, 1910.

[76] Lee, W. T., Am. Jour. Sci., 4th ser., vol. 26, pp. 180–181, 1908.



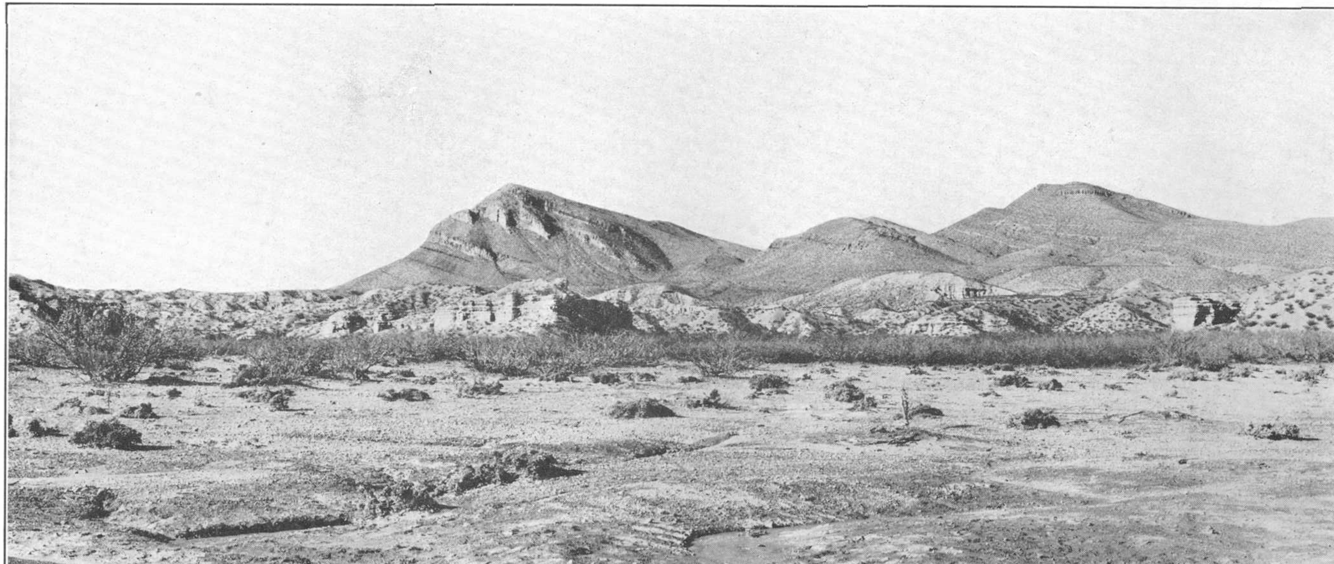
A. WEST FRONT OF SIERRA CABALLO NEAR APACHE CANYON

Looking northeast. b, Bliss sandstone overlain by El Paso, Montoya, and Fusselman limestones, Percha shale, and limestones of Carboniferous age



B. FAULT IN LIMESTONE AT PALOMAS GAP, SIERRA CABALLO

Looking north



SIERRA CUCHILLO NORTHWEST OF PALOMAS SPRINGS

Granite overlain by Bliss sandstone and El Paso, Montoya, and Magdalena limestones bedded, and many layers contain glauconite. The rocks undoubtedly represent the Bliss sandstone, and the older name is here applied to them.

EL PASO LIMESTONE (ORDOVICIAN)

The basal portion of the thick limestone succession in the western face of the Sierra Caballo is the El Paso limestone, presenting the features that are so characteristic in other areas. The lower member is massive and crops out in a high cliff, but on weathering the rock breaks into slabby layers of light-gray tint with surfaces showing reticulations of brown color. The thickness is 300 to 400 feet. At Palomas Gap there is a thick upper member of more massive character. Lee collected *Ophileta* cf. *O. complanata* and *Hormotoma* cf. *H. artemesia* from this limestone.

MONTOYA LIMESTONE (ORDOVICIAN)

Overlying the El Paso limestone is the Montoya limestone, with its characteristic upper member of cherty beds carrying distinctive fossils. Of these Lee [77] collected *Rafinesquina* cf. *R. kingi, Plectambonites saxea, Plectambonites* n. sp., *Favosites asper, Zygospira recurvirostris, Rhynchotrema capax, Calopoecia canadense,* and *Platystrophia dentata* var. I found similar rocks and fauna in Palomas Gap, where the formation is about 200 feet thick. The limestone of the Magdalena group is thrust onto it by a fault, as shown in Plate 61, *B*. Lee reported this limestone also in the south end of the mountains 8 miles south of Shandon, and 300 feet of cherty beds 6 miles west of Rincon yielded Montoya fossils. The lower member, 200 feet thick, consists of dark massive limestone with a thin sandy or sandstone member at base.

FUSSELMAN LIMESTONE (SILURIAN)

Faulting cuts out the Fusselman limestone at Palomas Gap, but it appears in the section farther south, as shown in Figure 148. It makes a prominent cliff of characteristic dark-colored massive limestone 50 feet thick.

PERCHA SHALE (DEVONIAN)

Above the Fusselman cliff in the central and southern parts of the range is a slope exposing black to gray and greenish-buff shale or thin-bedded sandstone 200 feet or more thick. No fossils were collected here, but the rocks and relations are so closely similar to those in other ranges farther south and in type localities near Hillsboro, a few miles to the west, that there appears to be no question as to identity with the Percha shale.

LAKE VALLEY (?) LIMESTONE (MISSISSIPPIAN)

No Mississippian fossils were found in the limestone next above the Percha shale, but probably it is the Lake Valley limestone, as in the Percha Creek section, 16 miles to the west, and it is so designated in this report.

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[77] Idem, p. 181.

MAGDALENA GROUP (PENNSYLVANIAN)

The light-colored limestone with a few interbedded members of shale, constituting the summit of the Sierra Caballo represents the Magdalena group. The thickness is about 600 feet.

Fossils were collected at several horizons in this succession in Palomas Gap. They were determined by G. H. Girty. The beds about 600 feet below the top yielded *Rhombopora lepidodendroides*, *Derbya* sp., *Dielasma* n. sp., *Spirifer cameratus*, *S. boonensis?*, and *Composita subtilita*. About 100 feet higher were found *Fenestella* several sp., *Polypora* sp., *Pinnatopora* sp., and *Squamularia perplexa*. Near the middle of the succession were found *Batostomella* sp., *Stenopora* sp., *Productus cora*, *P. semireticulatus*, *P. nebraskensis?*, *Spirifer cameratus*, and *Composita subtilita*, and near the top a bed was noted containing abundant *Productus nebraskensis*, *Fusulina secalica*, and *Composita subtilita*. Just below black shale high in the formation were collected *Derbya crassa*, *Productus nebraskensis*, *P. cora*, *Spirifer rockymontanus*, *Composita subtilita*, and *Deltopecten occidentalis;* and 100 feet below the black shale, *Productus nebraskensis*, *P. semireticulatus* (small var. *P. gallatinensis*), and *Spirifer rockymontanus*.

ABO SANDSTONE (PERMIAN)

The Magdalena strata are overlain by the Abo sandstone, possibly with an unconformity between. At the Vanadium mine, west of Cutter, and for some distance north of it the two formations are separated by a fault, which finally develops into a sharp upturn. The Abo formation is about 800 feet thick and the rocks are red sandstone or red sandy shale with a few hard layers. Near the middle is a thin bed of limestone. The Abo outcrop extends south to a point not far northwest of Rincon.

CHUPADERA FORMATION (PERMIAN)

The Abo beds give place abruptly to limestone and gypsum of the Chupadera formation. The Chupadera in this region lacks the basal member (Yeso) of red sandy shale with gypsum which is generally present in regions east and north, but there is no evidence of unconformity. The limestone is overlain by a thick succession of alternating gypsum and limestone beds. The thickness is 400 feet or more, and at Palomas Gap this formation constitutes the divide between water flowing east to the Jornada del Muerto and that flowing west to the Rio Grande. The succession of beds is given in Figure 149, but portions of the section are only approximated because of imperfect exposures. At the top is 100 feet or more of massive limestone sloping down the east side of the ridge in heavy ledges. The uppermost beds are cut off by a fault, shown in Figure 147, which brings up sandstone and shale carrying Benton (Upper Cretaceous) fossils. The limestone yields fossils of the Manzano fauna. Lee[78] collected the following species from the top member, which consists of 25 feet of blue limestone: *Productus leei, Aviculipinna nebraskensis, Phanerotrema* aff. *P. brazoense, Murchisonia? terebra?, Euomphalus* aff. *E. pernodosus, Euomphalus* sp., and *Orthonema* sp. Next below is 50 feet of sandy shale, succeeded by 200 feet of limestone, from which Lee collected *Echinacrinus cratis, Aviculipinna nebraskensis, Schizodus wheeleri?, Dentalium mexicanum, Megulia?* sp., *Bellerophon majusculus, Bucanopsis modesta, Sphaerodoma* aff. *S. medialis,* and *S.* aff. *S. texana,* and I collected *Nucula levatiformis, Euomphalus subpapillosus, Cytherella benniei,* and *Primitia* sp. In limestone about 200 feet below the top of the formation in Palomas Canyon Lee[79] collected *Meekella mexicana, Productus leei, Pseudomonotis hawni?, P. occidentalis?, Schizodus wheeleri?, Deltopecten manzanicus, Pleurophorus mexicanus, Plagioglypta canna, Euphemus inspeciosus?, Bellerophon majusculus, Euomphalus deformis,* and *Sphaerodoma* aff. *S. medialis.*

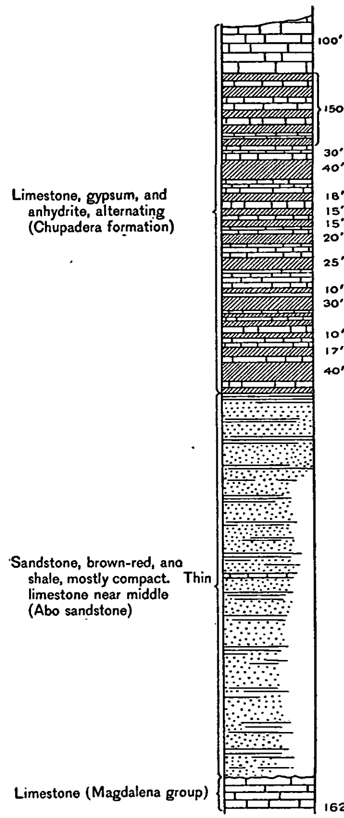

FIGURE 149.—Columnar section of Chupadera and Abo formations in Sierra Caballo at the head of Palomas Gap, southwest of Engle

Ten miles farther north, at the north end of the mountains, not far from Elephant Butte, Lee collected from steeply dipping beds near the top of the formation *Meekella mexicana, Schizodus wheeleri?, Composita mexicana, Aviculipinna nebraskensis?, Myalina apachesi, Deltopecten manzanicus, Bellerophon majusculus, Euomphalus* sp., and *E.* sp.? These were all determined by G. H. Girty.

A boring in sec. 32, T. 14 S., R. 2 W., about 4 miles west of Cutter, which had reached a depth of 3,130 feet in May, 1928, is likely to throw much light on the stratigraphy.

STRUCTURAL DETAILS

The south end of the Sierra Caballo was not examined in detail. In Palomas Gap there is an overthrust fault, as shown in Plate 61, *B*, and on the east side of the range is a fault that brings Chupadera formation and Cretaceous rocks into contact, as shown in Figure 148. The northern extension of this fault passes a few miles west of

[78] Lee, W. T., op. cit. (Bull. 389), p. 28.　　[79] Idem, p. 27.

the Elephant Butte dam and probably skirts the east side of the Cerro Cuchillo, a small group of limestone peaks north of Palomas Springs, shown in Plate 62. The northwestern ridge of the Sierra Caballo presents a syncline of limestone. Next east is an anticline which forms the principal axis of the range and is faulted in Palomas Gap. This anticline pitches down rapidly at the north end of the range, and the Carboniferous and Cretaceous strata pass under-

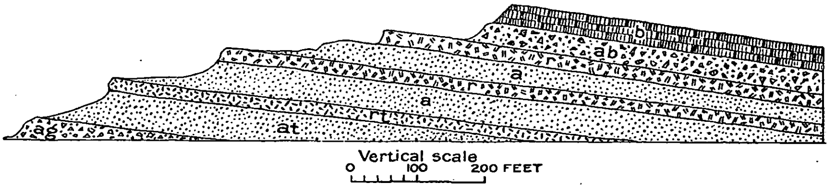

FIGURE 150.—Section across the Sierra de las Uvas. ag, Agglomerate; at, ash and tuff; rt, hard tuff; a, volcanic ash; r, rhyolite; ab, basalt agglomerate; b, basalt

ground in regular order but are cut off to the west by the fault which extends along the west side of the mountain. Mescal Canyon exposes an excellent section of beds up to the sandstones of Upper Cretaceous age which carry coal.[79a] Near Elephant Butte are still higher beds of white, brown, and reddish sandstone grading up into chocolate shale and sandy shale and sandstone carrying *Triceratops*.[79b]

SIERRA DE LAS UVAS

The Sierra de las Uvas is a feature of considerable prominence south of Rincon. Cerro Magdalena is its highest peak. It appears to consist entirely of igneous rocks, comprising a succession of flows

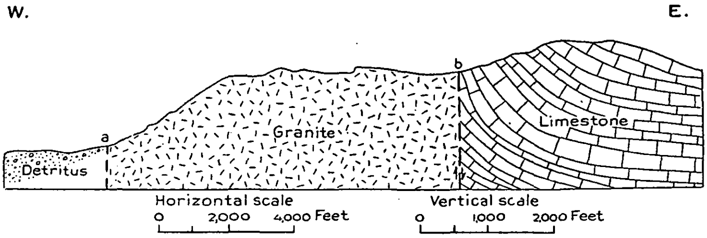

FIGURE 151.—Section of west side of Fra Cristobal Range. After W. T. Lee. a, b, Faults

of rhyolite and latite, and deposits of agglomerate, ash, and tuff, capped to the northwest and west by a sheet of basalt which dips under the plains west and north of the mountains and apparently rises again in Goodsight Mountain. On the east side the dips are to the southeast at low angles. A cross section in the center of the range is given in Figure 150. The eruptive rocks of this area extend to the Rio Grande and are conspicuously exposed in cliffs along that stream in the vicinity of Tonuco and below, nearly to Fort Selden.

[79a] Lee, W. T., The Engle coal field: U. S. Geol. Survey Bull. 285, p. 240, 1906.
[79b] Lee, W. T., Notes on the Red beds of the Rio Grande region in central New Mexico: Jour. Geology, vol. 15, pp. 52-58, 1907.

FRA CRISTOBAL RANGE

The Fra Cristobal Range is a detached northerly continuation of the Sierra Caballo uplift and consists mostly of the same rocks. A cursory inspection was made of the Magdalena and overlying formations in the south end and east slope of the range. Lee [80] gives a cross section of the west-central part of the uplift and a columnar section of the Manzano group near the south end. These sections are shown in Figures 151 and 152.

The Abo sandstone, the lower formation of the Manzano group, is well exposed lying on the limestone at top of the Magdalena group with apparent unconformity but no appreciable discordance of dip. Lee gives the thickness as 400 feet. The overlying lower member of the Chupadera formation, consisting mostly of soft sandstone and sandy shale, in part red, contains thick beds of gypsum. Next above is 75 feet of limestone from which Lee collected *Nucula levatiformis* var. *obliqua*, *Schizodus wheeleri?*, *Astartella subquadrata*, and *Euphemus subpapillosus?*. The overlying 200-foot sandstone member is regarded as the top of the Chupadera formation in this region.

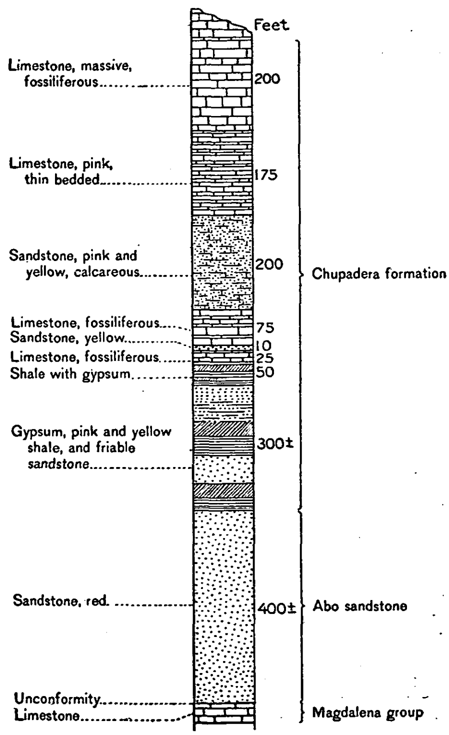

FIGURE 152.—Section of Manzano group at Saddle Peak, near south end of Fra Cristobal Range. By W. T. Lee

The limestone that constitutes the summit of the prominent buttes at the south end of the range yielded to Lee the fossils *Marginifera? manzanica*, *M.?* sp., *Composita subtilita?*, *Solenomya? naenia*, *Clinopistha* sp., *Nucula levatiformis*, *Dentalium mexicanum*, *Murchisonia* aff. *M. terebra*, and *Bellerophon majusculus*. Lee reports a small outcrop of Chupadera formation on Nogal Creek, west of the Rio Grande, opposite the north end of the Fra Cristobal Range, where several hundred feet of red and yellow sandstone and shale is overlain by 300 feet of limestone. Near the middle of this limestone Lee collected *Schizodus wheeleri?*, *Deltopecten coreyanus*, *Plagioglypta canna?*, *Murchisonia?* aff. *M. terebra*, *Bellerophon majusculus*, *Orthonema* sp.?,

[80] Lee, W. T., op. cit. (Bull. 389), pp. 25–26, pl. 5, *A*.

Temnocheilus aff. *T. conchiferum*. Fifty feet higher in the limestone were collected *Productus ivesi*, *P. leei*, *P. mexicanus*, *Euphemus inspeciosus?*, *Murchisonia?* aff. *M. terebra*, *Euomphalus* sp.?, and *Orthonema* sp.

ROBLERO MOUNTAIN

The prominent ridge of limestone rising abruptly above the Rio Grande 10 miles northwest of Las Cruces is known as Roblero Mountain. It is mostly flanked by Tertiary volcanic rocks. The limestones are mainly of the Magdalena group, but the presence of Fusselman limestone is indicated by Silurian fossils obtained by Lee,[81] and the limestones on the north side suggest El Paso beds uplifted on a block separated by an east-west fault.

MIMBRES MOUNTAINS AND RANGES ON THE EAST

The high range of the Mimbres Mountains, between the valley of Mimbres River and the Rio Grande, extends for many miles along

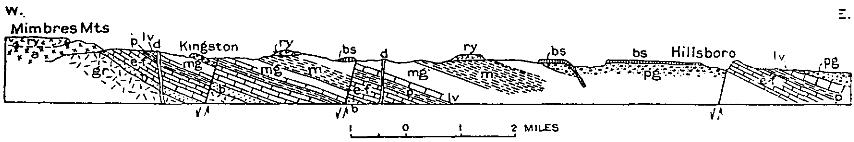

FIGURE 153.—Section from Mimbres Mountains eastward through Kingston and Hillsboro. After Gordon. d, Dike; ry, rhyolite; a, andesite; bs, basalt sheet; pg, Palomas gravel; m, Manzano group; mg, Magdalena group; lv, Lake Valley limestone; p, Percha shale; e-f, El Paso, Montoya, and Fusselman limestones; b, Bliss sandstone; gr, granite

the western part of Sierra County, its crest for most of the distance constituting the boundary between Sierra and Grant Counties. The rocks are mostly eruptive flows and fragmental volcanic deposits of Tertiary age, but in places along the east side and at the south end pre-Cambrian granite and Paleozoic rocks are exposed, indicating that the range is partly due to deformation of older strata. Apparently there is a long anticlinal axis under the range, and besides being flexed the strata are cut by various faults. A much lower parallel ridge some distance farther east shows Paleozoic rocks at Lake Valley, Hillsboro, and east of Fairview. There is also a small exposure of Abo sandstone in the midst of the igneous rocks on Salt Creek, 10 miles southwest of Cuchillo. The district was not studied in detail, but observations were made about Lake Valley, Hillsboro, Kingston, Hermosa, Chloride, and Fairview, and the range was crossed west of Lake Valley and at the head of Poverty Creek. The general structure near Kingston and Hillsboro is shown in Figure 153, after Gordon,[82] who has described many features of the region.

In the Quartzite Ridge, at Lake Valley, the El Paso, Montoya, and Fusselman limestones are exposed, overlain by Percha shale and Lake Valley limestone, with the relations shown in Figure 154, based

[81] Lee, W. T., Am. Jour. Sci., 4th ser., vol. 26, p. 184, 1908.
[82] Gordon, C. H., op. cit. (Prof. Paper 68), pp. 213 et seq.

partly on descriptions by Clark.[83] These rocks also appear west of the Sierra Blanca, about Kingston, on Sawpit, Mineral, Carbonate, and North Percha Creeks, and in the gorge of Rio Percha east of Hillsboro. The Carboniferous limestones crop out along the east foot of the range at intervals north from Kingston and Hillsboro to the site of the old mining camp at Fluorite, 15 miles northwest of Fairview.

The Abo sandstone, about 1,000 feet thick, consists mostly of red sandstone and red shale. It dips east under the Chupadera formation, of which 600 feet is exposed to a fault or an overlap, on the east of which are igneous rocks. It consists of six or seven members of hard reddish to buff limestone, 15 to 30 feet thick, and reddish shale. No gypsum was observed. The red Abo sandstone and the limestone of the Magdalena group exposed in the canyon walls just west of Chloride and on the south side of Rio Cuchillo, 2 miles south of Chloride, are extensively faulted and overlapped by Tertiary vol-

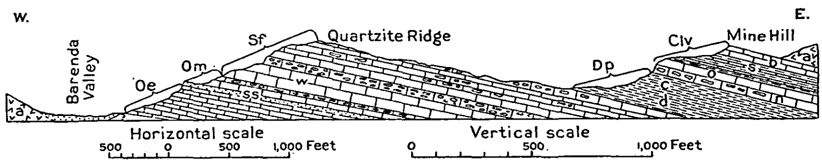

FIGURE 154.—Section across Lake Valley mining district. a, Andesite and rhyolite; Clv, Lake Valley limestone, including ore horizon or "footwall lime" (o), shale and thin limestone (s), limestone, upper beds cherty (b), and nodular limestone member (n); Dp, Percha shale (lower member d, upper member c); Sf, Fusselman limestone with white limestone (w) at base; Om, Montoya limestone with sandstone (ss) at base; Oe, El Paso limestone

canic flows and tuffs, which constitute the higher parts of the high ridge to the west. In the exposure 2 miles south of Chloride the Abo beds are cut by dikes and stocks and faulted against Gila conglomerate. A strongly marked fault appears to separate the Gila from the igneous rocks 10 miles northeast of Fairview, in the southeastern part of T. 9 S., R. 9 W., and the eastern part of T. 10 S., R. 9 W. Small outcrops of limestone of the Magdalena group occur on Wildhorse and Poverty Creeks in Tps. 9 and 10 S., R. 9 W., and on Turkey Creek near the old mines at Grafton.

A trip along the slope and across one of the passes of the Mimbres Mountains west of Lake Valley afforded a basis for the section given in Figure 155. Some of the limestone yielded Richmond and Pennsylvanian fossils, but the structural relations were not fully determined. It is stated that in Hillsboro Peak the pre-Cambrian granite appears, and I am informed by A. C. Spencer that on the east slope near Percha Pass this rock is overlain by a westward-dipping succession of Cambrian sandstone and Ordovician and later limestones and the Percha shale.

[83] Clark, Ellis, jr., The silver mines of Lake Valley, N. Mex.: Am. Inst. Min. Eng. Trans., vol. 24, pp. 138-167, 1895.

The deep canyon of Palomas Creek, a short distance east of Hermosa, exposes about 500 feet of limestone of the Magdalena group underlain by Lake Valley limestone, and at the east end of the gorge black shale, doubtless Percha, is exposed at the base of the section. The relations in this vicinity are shown in Figure 156.

Near the big bend of Palomas Creek, about 7 miles southwest of Cuchillo, there is exposed among the igneous rocks a small area of about 250 feet of Abo sandstone of the typical bright red-brown color, dipping east at a moderate angle.

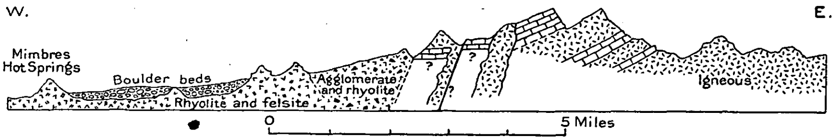

FIGURE 155.—Sketch section across Mimbres Mountains at head of Hot Springs Creek, in T. 18 S., R. 9 W., Grant County

The ridge east of Fairview consists of limestone of the Magdalena group overlain by Abo sandstone and Chupadera formation, all presenting the same characteristics as in the region east of the Rio Grande. These strata are cut off to the south by a fault, and to the north they pass under igneous rocks constituting the high ridge west of Monticello. East of Fairview there is a thick dike of porphyry intruded in the Abo and Magdalena beds. The relations are shown in Figure 157.

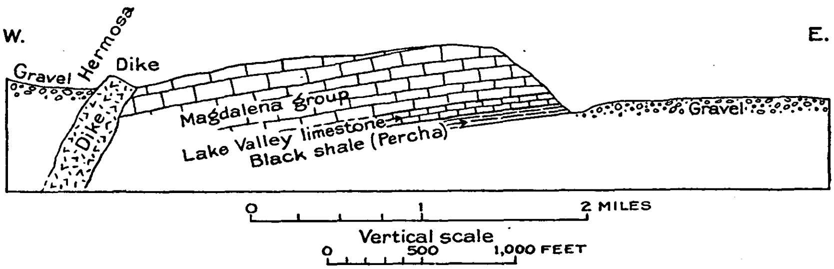

FIGURE 156.—Sketch section from Hermosa eastward

COOKS RANGE

The Cooks Range is a southern continuation of the Black and Mimbres Mountains into Luna County. It is named from Cooks Peak, a high mass of intruded porphyry rising near its center. The general structural features are shown in Figure 158.

One of the most marked structural features of the Cooks Range is a north-south fault passing along the east slope. The rocks to the east of this fault are mostly igneous, including a thick accumulation of volcanic agglomerate of Tertiary or late Cretaceous age. In the ridges south of Fort Cummings there is a succession of agglomerate, tuff, and ash deposits and igneous flows in sheets dipping in general to the east and northeast at a moderate angle. Several faults break this succession locally, and it is cut off on the west by the great fault above mentioned. About Fort Cummings some later basalts occur. The lower member of the agglomerate is cut by a few small dikes of various rocks. Interbedded brown quartzites constituting two prominent knobs 3 miles west of Mirage are an exceptional feature. The principal igneous flow is latite, which is succeeded by a widespread sheet of quartz basalt apparently merging into olivine andesite, and there is an extensive sheet of light-colored rhyolite some distance above. The igneous flows are separated by deposits of agglomerate, tuff, and ash, all dipping at low angles to the northeast.

The Cooks Peak intrusive is a large laccolithic mass of granodiorite porphyry intruded mainly in the Lake Valley limestone but locally rising across strata up to the Sarten sandstone and Colorado shale. The sedimentary rocks have in general a steep dip away from the central igneous mass, and there is some faulting along the flanks of the uplift. Several separate intrusions of large masses of porphyry

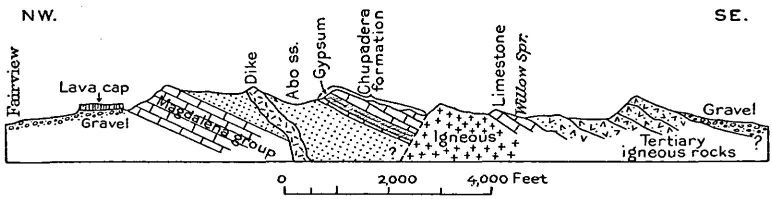

FIGURE 157.—Sketch section from Fairview toward Cuchillo. ss, Sandstone

rise in ridges to the southwest and south of the central area. North of the Cooks Peak igneous mass there is a shallow syncline which crosses the range near Cooks post office. The strata on the north side of this flexure dip to the south at a low angle and the Lake Valley limestone, Percha shale, Fusselman limestone, Montoya limestone, El Paso limestone, Bliss sandstone, and granite rise in succession to the north in a long ridge. East of this ridge there is a profound fault which extends far south along the east side of the Cooks Peak mass and Sarten Ridge. Between this fault and Cooks Peak, however, there is a shallow syncline which holds beds up to the Sarten sandstone. This sandstone also appears at intervals on the lower part of the west slope northwest of Cooks Peak, and to the west it is overlain by a small area of Colorado shale. Farther south the Lobo formation, Gym limestone, and Lake Valley limestone rise to the surface, and these formations, together with the Sarten sandstone, make up the high ridge extending south from Cooks Peak. The Sarten sandstone is a conspicuous feature in this area, constituting the very prominent dip slope 2 miles south of the peak, which on the east swings around to the south and becomes Sarten Ridge.

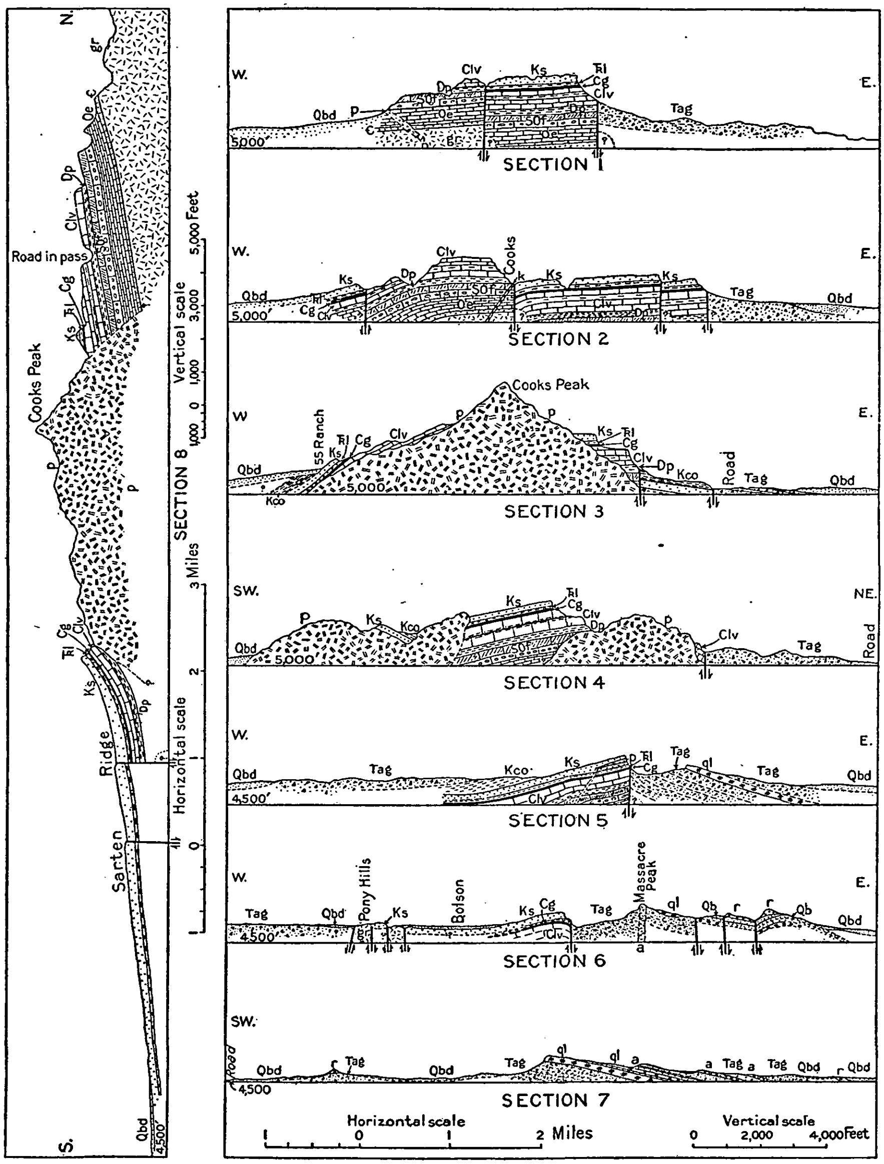

FIGURE 158.—Sections across Cooks Range. 1, 1½ miles north of Cooks post office; 2, through Cooks post office; 3, through Cooks Peak; 4, 2 to 3 miles south of Cooks Peak; 5, 1½ miles north of Fort Cummings; 6, 1½ miles south of Fort Cummings, passing just south of sandstone quarry; 7, from point 1½ miles southeast of Fluorite Camp to point 1½ miles northwest of Florida station; 8, through Cooks Range from southeast end of Sarten Ridge to the Luna-Sierra County line. Base of sections 1–4, 5,000 feet above sea level; 6–8, 4,500 feet. p, Porphyry; Tag, agglomerate; r, rhyolite, andesite, and latite; Qbd, bolson deposits; Kco, Colorado shale; Ks, Sarten sandstone; TRl, Lobo formation; Cg, Gym limestone and Magdalena formation; Clv, Lake Valley limestone; Dp, Percha shale; SOf, Fusselman and Montoya limestones; Oe, El Paso limestone; €, Bliss sandstone; gr, granite; a, andesite; Qb, quartz basalt; ql, quartz latite; k, keratophyre.

The Sarten sandstone in this ridge is underlain by the Lobo formation, the Gym and Lake Valley limestones, and a small amount of Percha shale. To the south the Sarten sandstone is overlain by Colorado shale.

The principal representative of the Carboniferous in the Cooks Range is the Lake Valley limestone (early Mississippian). On the northwestern slope of Cooks Peak this limestone is overlain by about 40 feet of dark-gray shale with limy layers containing a Magdalena fauna. Possibly this formation occurs at other places, but it was not recognized. The Gym limestone, which is believed to be a representative of part of the Chupadera formation, occurs in parts of the Cooks Range, but it is only from 20 to 30 feet thick. It is cut out by porphyry on the southwest slope of Cooks Peak but appears again on the west slope and in the cuesta east and north of Cooks post office. A few distinctive fossils were found at these places.

In the Cooks Range region the Lobo formation attains a thickness of about 100 feet, and it appears to be continuous except where cut out by igneous intrusions or faults. The principal material is reddish or brown sandstone and shale. The formation lies on Gym limestone apparently unconformably. It crops out again in the northeast face of the high ridge of Sarten sandstone in the Cooks Range and there are small outcrops on Goat Ridge and in the deep hollow near the south end of Sarten Ridge just north of the sandstone quarry. A section measured at the north end of Sarten Ridge, northwest of Fort Cummings, is given below. It begins at the first bed below an apparent marked unconformity at the base of the Sarten sandstone.

Section of Lobo formation and underlying strata at north end of Sarten Ridge

	Feet
Lobo formation:	
Sandstone, snuff-colored	20
Conglomerate, with limy matrix	25
Shale, red	40
Conglomerate	10
Gym limestone:	
Limestone, nodular, in red shale	5
Limestone, blue	20
Conglomerate, with some red jasper	5

The three beds at the base of this section must represent the Gym limestone, because the nodular bed contains Permian fossils on the west slope of the range.

A section in a canyon about 2 miles south of Cooks Peak is as follows:

Section of upper part of canyon wall and slopes in Cooks Range just north of latitude 32° 30′ N.

	Feet
Lobo formation:	
Conglomerate, with limestone matrix	30
Shale, red	50
Conglomerate	10
Gym limestone:	
Limestone, nodular	5
Limestone, blue	20
Conglomerate; some red jasper	5
Lake Valley limestone:	
Limestone, cherty	3
Limestone, gray (Mississippian fossils)	3
Conglomerate or breccia of white chert	10
White chert, with crinoid stems	20

Below is massive limestone (also Lake Valley) about 400 feet thick, on Percha shale. In this range the Lobo beds are overlain unconformably by the Sarten sandstone, of Lower Cretaceous (Comanche) age. There is no noticeable discordance in dip, but locally there is considerable channeling.

FLUORITE RIDGE

Fluorite Ridge, at the south end of the Cooks Range, consists of a thick central mass of porphyry so intruded as to cause an irregular dome-shaped uplift, elongated to the northwest and southeast. The strata on the south and east sides of the dome stand nearly vertical, but those on the north and west sides have more moderate dips. The plane of intrusion is low in the Paleozoic strata at the southeast end of the uplift, but it rises rapidly toward the north and west to the base of the Sarten sandstone. Faults at the south end of the ridge cause considerable complexity in the structure. The salient features are shown in Figure 159. Pre-Cambrian red granite and diorite are exposed in the lower slopes southwest of Fluorite Camp and also a breccia of mica schist fragments. The Bliss sandstone is overlain by a regular succession of strata of beds as high as the lower portion of the Lake Valley limestone. Some of the beds are greatly squeezed, notably the El Paso limestone, which presents a thickness of only 400 feet. Some huge masses of white silica rock at the east end of the range have undoubtedly replaced limestone, probably of both Lake Valley age and Montoya age. A profound fault that extends along the east side of the ridge appears to lift porphyry, although it is possible that the porphyry was intruded after the faulting and there is some suggestion that it is younger than the agglomerate which is exposed in the slopes on the east side of the ridge. The west end of Fluorite Ridge consists largely of Sarten sandstone penetrated by porphyry and overlain by Tertiary agglomerate. A small exposure of granite in the locality indicates either faulting or overlap, for the Sarten sandstone lies in places directly on granite. Goat Ridge, a short distance to the west, is an elongated dome with axis trending northwest that brings up the Sarten sandstone. Erosion exposes the underlying Lobo formation in part of the area, and granite appears on the northwestern slope of the ridge. The Pony Hills, a small group of knobs just north of Florida Ridge, consist of irregular outcrops of granite and Sarten sandstone in juxtaposition, owing either to overlap or to faulting.

FLORIDA PLAINS

Most of the wide desert about Deming, known as the Florida Plains, is a part of the valley of Mimbres River, past and present. It is heavily covered by valley fill, the bottom of which appears not to have been reached by borings 710, 980, and 1,665 feet deep in Deming and vicinity.[83a] Out of the level surface rise several high

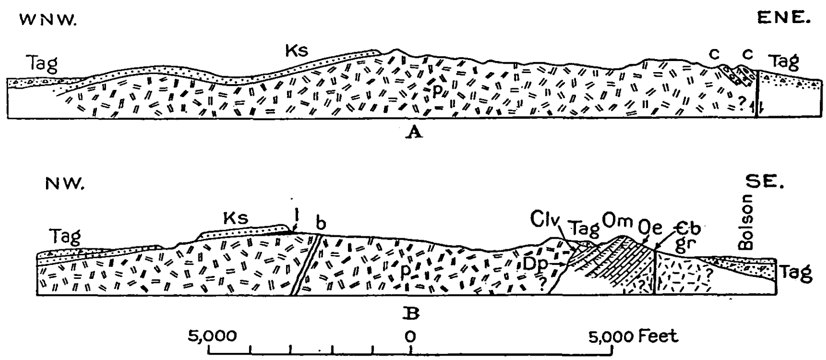

FIGURE 159.—Sections across Fluorite Ridge. A, Section from west-northwest to east-northeast; B, section across east half of ridge. c, Chert; b, basalt dike; Tag, agglomerate; Ks, Sarten sandstone; Ꞧl, Lobo formation; Clv, Lake Valley limestone; Dp, Percha shale; Om, Montoya limestone overlain in part by limestone of undetermined age; Oe, El Paso limestone; €b, Bliss sandstone; gr, granite and diorite; p, porphyry

ridges, such as the Florida Mountains, Tres Hermanas, Victorio Mountains, Goodsight Mountains, and Cooks Range, and many buttes of greater or less prominence. One of the buttes is Black Mountain, 10 miles northwest of Deming, which consists mainly of an eastward-dipping sheet of basalt 250 feet thick capping a mass of volcanic ash and sand, of which 500 feet is exposed, cut by rhyolite at one point. Red Mountain, 10 miles southwest of Deming, consists of a large mass of white felsitic rhyolite probably extruded in a viscous condition. Another mass of felsite constitutes Gray Butte, 20 miles northwest of Deming, and the same rock appears in several small buttes south and west of Midway, where in places the

83a For records, see Darton, N. H., op. cit. (Bull. 618 and Folio 207).

associated latite and agglomerate are exposed. There are also extensive exposures of felsite in the Grandmother Mountains and Cow Spring Hills and in detached areas farther north and west. The White Hills, 12 miles southeast of Deming, consist of felsite.

The Goodsight Mountains, which extend southward from Sunday Cone, in Sierra County, to the east side of the Florida Plains, consist of a thick cap of basalt dipping east and lying on agglomerate, which is well exposed in the deep railroad cut at Nutt.

In 1923 a test hole for oil in the NE. ¼ SE. ¼ sec. 8, T. 26 S., R. 8 W., had reached a depth of 3,150 feet. It was in sand, clay, and gravel to 1,560 feet, below which the material is reported as "mostly red clay" (shale). A well in sec. 8, T. 25 S., R. 6 W., found water-bearing strata at about 600 feet, from which artesian water flowed from a 12-inch pipe. Deep borings have also been made at Lanark, Kenzin, and Noria.[83b]

FLORIDA MOUNTAINS

The very high and exceedingly rugged ridge of the Florida Mountains is a conspicuous feature a few miles southeast of Deming. The northern half of the ridge, like the outlying Little Florida Mountains, consists of agglomerate and other igneous rocks, and the southern half is pre-Cambrian granite overlain in the central area by Bliss sandstone and El Paso, Montoya, and Gym limestones. The rocks are tilted in various directions and traversed by great faults. The principal structural features are shown in Figure 160.

In general the range is a tilted block of granite capped by sedimentary strata in an eastward-dipping monocline that is possibly the eastern limb of an anticline whose axis lies under the bolson on the west; or the uplift may be bounded on that side by a fault. At Capitol Dome, at the north end of the mountains, the Paleozoic rocks and agglomerate deposits all dip to the east-northeast, and the underlying granite is exposed at the foot of the western slope. This easterly dip, with repetition of the limestones by faulting, is exhibited again farther south in the center of the range, where there is a profound fault that trends northeast with an upthrow that lifts the granite 2,000 feet or more in the south end of the range. At Gym Peak the strata are arched and dip down the east side of the mountain at a moderate rate. The peak consists of Gym limestone (Permian), which on the west side of the peak is exposed extending westward over the uneven edges of the underlying Fusselman, Montoya, and El Paso limestones for some distance. There may be an overthrust at this place. Possibly Percha beds are buried under this overlap, for black shale appears along a cross fault in that vicinity.

[83b] For records, see Darton, N. H., Geologic structure of parts of New Mexico: U. S. Geol. Survey Bull. 726, pp. 232–234, 1922.

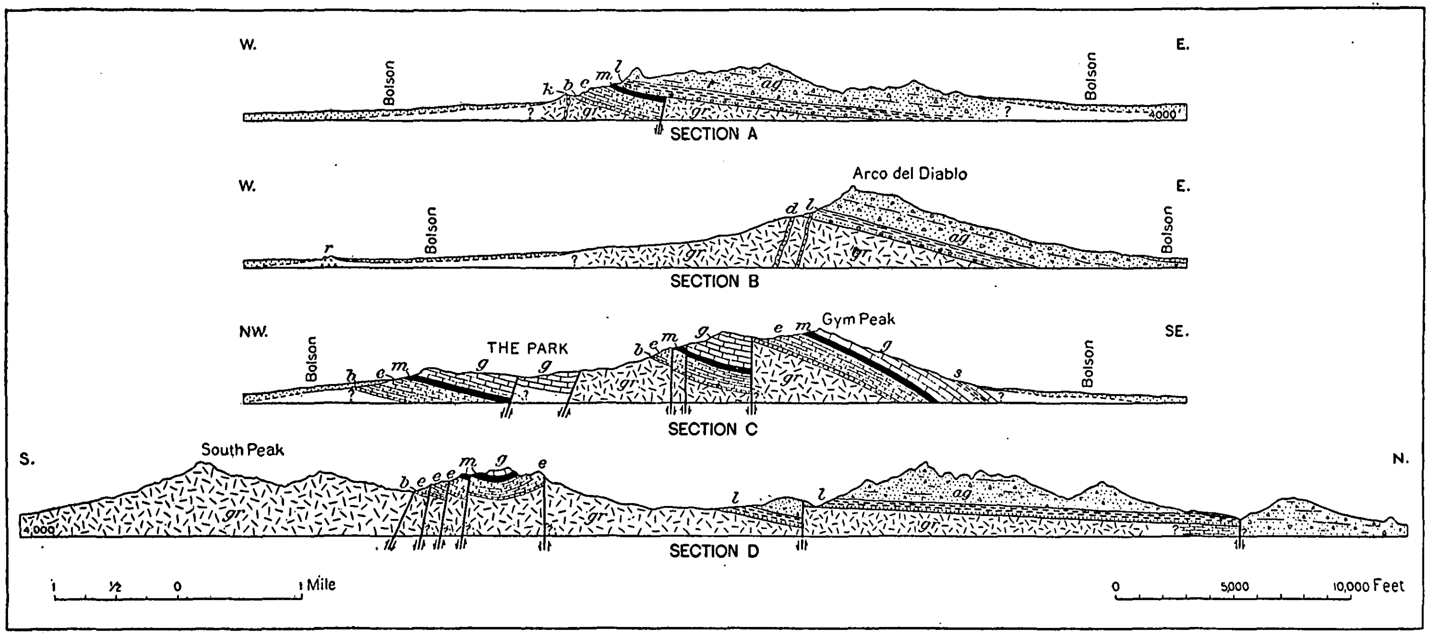

FIGURE 160.—Sections across Florida Mountains, Luna County. A, Through Capitol Dome; B, through Arco del Diablo; C, through The Park and Gym Peak; D, along the higher part of the range. *b*, Bliss sandstone; *e*, El Paso limestone; *m*, Montoya and Fusselman limestones; *r*, felsitic rhyolite in White Hills; *d*, rhyolite porphyry dikes; *l*, Lobo formation; *g*, Gym limestone; *s*, black shale member; *k*, keratophyre; *gr*, granite; *ag*, agglomerate

Near the south end of the range there is a complex fault in which granite and limestone are overthrust as shown in Figure 161. The Gym limestone caps the high ridge northwest of Gym Peak and the two ridges west of The Park, and it also extends down and along the east slope of the mountains east of Gym Peak with a thickness of nearly 1,000 feet in all. No overlying strata remain, and its upper surface is eroded. In this vicinity the strata are in several large fault blocks, and all are cut off to the southeast by a great fault that uplifts the granite so high that it constitutes the southern part of the mountains. The fossils obtained from the Gym limestone as

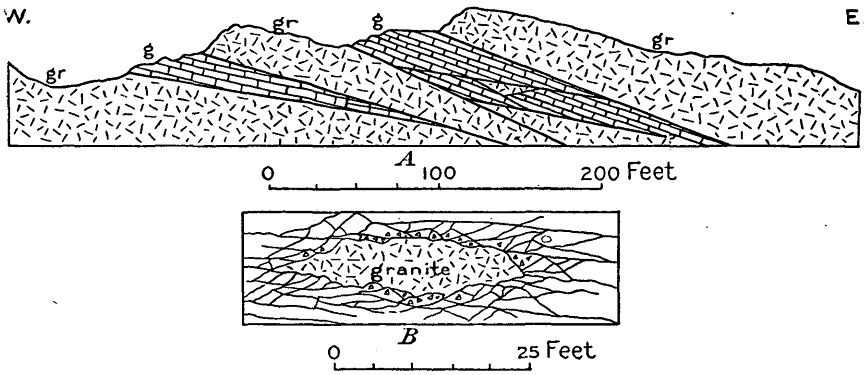

FIGURE 161.—Granite and Gym limestone interthrust by faulting at southeast end of Florida Mountains. g, Gym limestone; gr, granite. *B* shows relations of small mass of granite in center of *A*

listed below were determined by G. H. Girty. They are believed to indicate Manzano (Permian) age.

Fusulinella sp.
Echinocrinus ornatus.
Productus semireticulatus.
Pugnax uta.
Composita subtilita.
Parallelodon politus?
Plagioglypta canna.
Bellerophon crassus.
Bucanopsis modesta.
Pleurotomaria texana.
Orthonema socorroense?
Bulimorphia inornata.
Euomphalus aff. E. pernodosus.

The Lobo formation extends for about 5 miles along the higher slopes of the northern third of the Florida Mountains, which it crosses on a general northwesterly course. It consists largely of reddish and gray shale and gray to pinkish impure limestone, but it includes much conglomerate at its base. In its overlap on the granite southeast of Capitol Dome there is some basal arkosic sandstone. A section on the west slope of Capitol Dome, beginning at the unconformity at the base of the agglomerate, is as follows:

Section of Lobo formation at Capitol Dome

	Feet
Sandstone, soft, reddish, with a few thin conglomerate layers and some limy beds	50
Conglomerate, light colored, with limestone pebbles	8
Sandstone, pink, soft, with conglomerate streaks	30
Limestone, slabby, in bodies 3 to 10 feet thick, separated by buff and reddish shale with thin limestone layers; limestones weather buff	180
Shale, dark reddish	20
Limestone, massive, impure, with scattered pebbly streaks	10
Limestone, conglomerate, coarse, with chert and quartzite pebbles, red sand matrix	20
	318

The conglomerate lies on an irregularly eroded surface of the Montoya and El Paso limestones, but the dips of the three formations, as well as that of the overlying agglomerate, are all to the east at angles of 18° to 20°. A few rods southeast of the base of Capitol Dome the formation extends across the fault shown in section A, Figure 160, which lifts the granite to the level of the top of the El Paso limestone, a displacement of 1,000 feet or more. This feature indicates that the block uplifted by this fault was eroded to a plane before the deposition of the Lobo beds. Some of the limestone beds in the Lobo formation closely resemble lithographic stone but are harder and contain only 27 per cent of calcium carbonate, the remainder consisting of about 10 per cent of magnesium carbonate and of matter insoluble in acid. At the type locality in Lobo Draw the formation consists largely of buff and red shale and massive, very fine grained sandstone and limestone.

LITTLE FLORIDA MOUNTAINS

The ridge known as the Little Florida Mountains consists of a thick sheet of felsitic or vitreous rhyolite included in the great agglomerate series. Apparently the horizon is somewhat above that of the agglomerate members exposed in the Florida Mountains, as that range lies slightly west of the line of strike of the rocks in the Little Florida Mountains; however, there may be a fault between the two ranges. The felsitic rhyolite appears to be mainly the product of one outflow, or a succession of outflows without intervening deposits, and probably it ends by thinning out not far beyond the termination of the ridge. Some other igneous masses are exposed in places on the west slope. The structure is shown in Figure 162, in which section A shows the relations that prevail along the greater part of the ridge and section B shows certain local features of the faulted portion farther south. The rocks dip to the east at angles mostly less than 10°, so that the main sheet of felsitic rhyolite passes under the agglomerate to the east. There are several dikes on the west side of the range, mostly of keratophyre and rhyolite, and west of the foot of the range there are several small outcrops of rhyolite and andesite, the relations of which are not exposed. Manganese ore is mined in this range.

TRES HERMANAS MOUNTAINS

The Tres Hermanas Mountains comprise a small group of peaks and ridges about 30 miles south of Deming. They consist largely of granitic intrusive rocks with small flanking masses of Gym limestone and later volcanic flows. The principal structural features are shown in the sections in Figure 163.

The porphyry is a coarse-grained rock which weathers brown-red. The range is flanked on the west by an extensive body of felsitic rhyolite in sheets separated in places by deposits of fragmental materials. This rhyolite is overlain here and there by basalt and lies in part on andesite and in part on agglomerate, which extends along the southeastern slopes of the range. It is also cut by dikes of andesite.

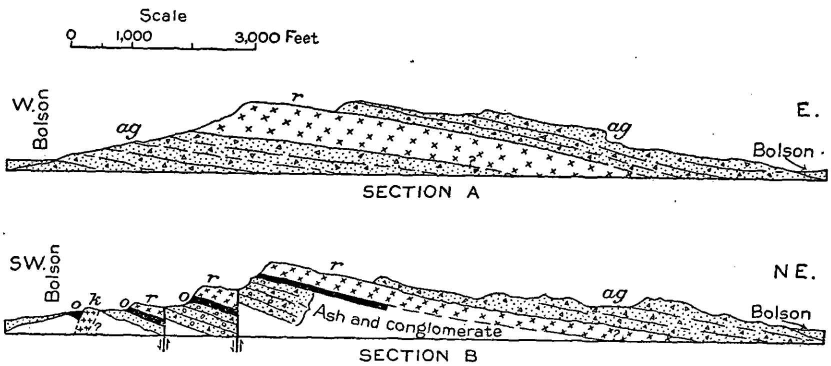

FIGURE 162.—Sections across Little Florida Mountains. A, Across center of range; B, 1½ miles farther south. *ag*, Agglomerate; *r*, felsitic rhyolite; *o*, obsidian; *k*, keratophyre

Much of the limestone is metamorphosed to marble, with development of zinc and other minerals, but in places fossils are abundant even in the altered rock. The following were determined by G. H. Girty:

Meekella mexicana?	Composita mexicana?
Productus cora.	Pinna peracuta.
Productus occidentalis.	Bellerophon majusculus?
Squamularia perplexa.	Euomphalus sp.

The species *Productus occidentalis* is a form characteristic of the beds of Chupadera limestone capping the Sacramento Mountains at Cloudcroft. The stratigraphic relations of the Gym limestone in the Tres Hermanas region are not exposed. Two small knobs of the limestone occur in the desert 3 miles northwest of the foot of the mountains.

POTRILLO MOUNTAINS

An extensive group of high hills and ridges in the southwest corner of Dona Ana County west of Lanark consists largely of cinder cones and basalt flows similar to those on the plain near Aden and Acton. Mount Riley appears to consist of older Tertiary eruptives, and a prominent ridge known as East Potrillo Mountain is made up of limestones of Comanche age mentioned on page 39.

GRANDMOTHER MOUNTAINS AND COW SPRING HILLS

Most of the peaks in the group of hills and ridges 6 to 12 miles north of Gage consist of felsitic rhyolite, uniform in character and including but little fragmental material. The structure of the masses,

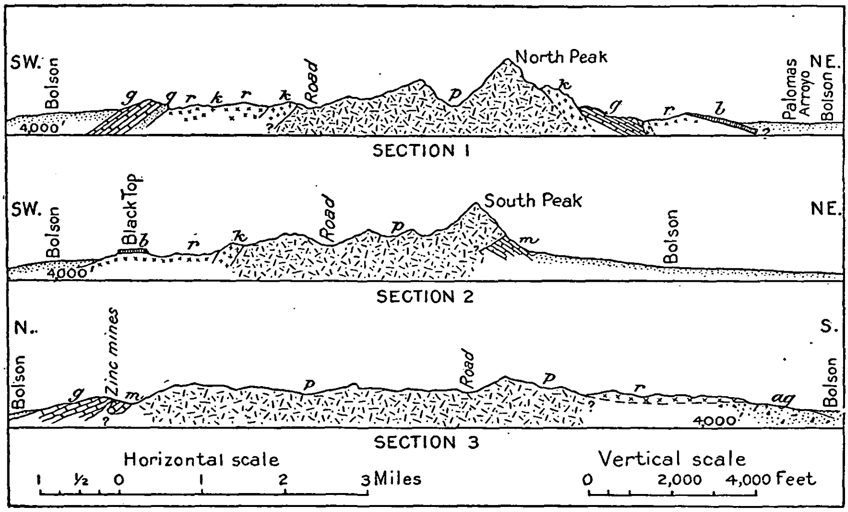

FIGURE 163.—Sketch section across Tres Hermanas Mountains. 1, From point southwest of Hancock mine through North Peak; 2, from Black Top through South Peak; 3, through center of the range east of the zinc mine. *p*. Porphyry; *r*, rhyolite; *b*, basalt; *ag*, agglomerate; *g*, Gym limestone, changed to marble at *m*; *q*, quartzite; *k*, keratophyre

their source, and their relations to sedimentary rocks are not exposed, but some of the felsite is in extended sheets, the remains of lava flows of Tertiary age. A large mass of hornblende-biotite rhyolite lying on agglomerate and other volcanic fragmental deposits constitutes the eastern portion of the Cow Spring Hills, and scattered outcrops of felsite, rhyolite, basalt, and agglomerate appear in a ridge a few miles northeast of Cow Spring. The basalt lies on agglomerate and is associated with a volcanic mud flow which may be of Quaternary age.

SNAKE HILLS

The Snake Hills are a group of low mounds of limestone trending west, about 10 miles southwest of Deming. The strata dip to the west at low angles. In the east end is about 700 feet of El Paso limestone, which passes under Montoya limestone to the west with the relations and character indicated in Figure 164.

KLONDIKE HILLS

Two narrow ridges, known as the Klondike Hills, in the western part of Luna County about 18 miles south of Gage, consist mainly of El Paso and Montoya limestones, with relations shown in Figure 165. Red to gray granite or granite gneiss is exposed in the center of the area, overlain by Bliss sandstone. The Montoya limestone is 150 feet thick and has a basal member of sandstone 8 feet thick lying unconformably on El Paso limestone. This member grades up into

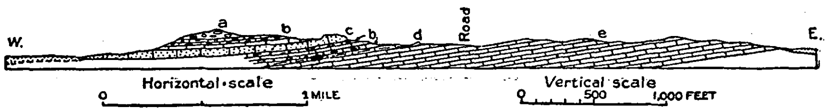

FIGURE 164.—Section through Snake Hills, 10 miles southwest of Deming. *a* to *m*, Montoya limestone with members as follows: *a*, limestone with large bodies of chert; *b*, limestone with thin chert layers; *c*, massive dark sandy limestone; *m*, dark massive limestone overlain by cherty beds; *e*, El Paso limestone

30 or 40 feet of sandy limestone, above which are alternations of pure limestone and chert, with many fossils.

VICTORIO MOUNTAINS

The isolated group of hills known as the Victorio Mountains lie just south of Gage, 20 miles west of Deming. The main ridge consists of a sheet of hornblende andesite dipping 20°–25° NNE. In the hills just south of this ridge are a succession of El Paso, Montoya, Fusselman, and Gym limestones; Devonian, Mississippian, and

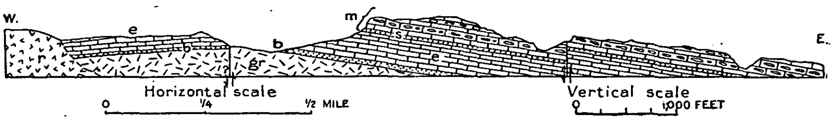

FIGURE 165.—Section through Klondike Hills. r, Felsitic rhyolite; m, Montoya limestone with sandstone (s) at base; e, El Paso limestone; b, Bliss sandstone; gr, granite and gneiss

Pennsylvanian time apparently are not represented. Figure 166 shows the principal features.

The Gym limestone crops out in a zone about 2,000 feet wide, constituting three round knobs on the southern ridge of the range. The thickness of beds is about 300 feet. The relations at the base are not clearly exposed, and there is either overlap onto Montoya limestone or a fault. The following fossils were identified by G. H. Girty, who regards them as Manzano (Chupadera), of Permian age:

Solenomya? sp.
Nucula levatiformis var. obliqua.
Manzanella elliptica.
Edmondia sp.
Monopteria marian?
Myalina sp.
Schizodus sp.
Pleurophorus sp.
Astartella n. sp.
Plagioglypta canna?
Murchisonia n. sp.
Euomphalus? sp.
Cyclonema? sp.
Sphaerodoma? aff. S. fusiformis.

The Gym limestone is overlain unconformably by about 700 feet of shale and sandstone, largely reddish, which suggests the Lobo formation (Triassic?) but may be Cretaceous or Tertiary. Dark purplish-brown fine-grained massive shale or sandstone predominate, but the beds include several members of coarse conglomerate con-

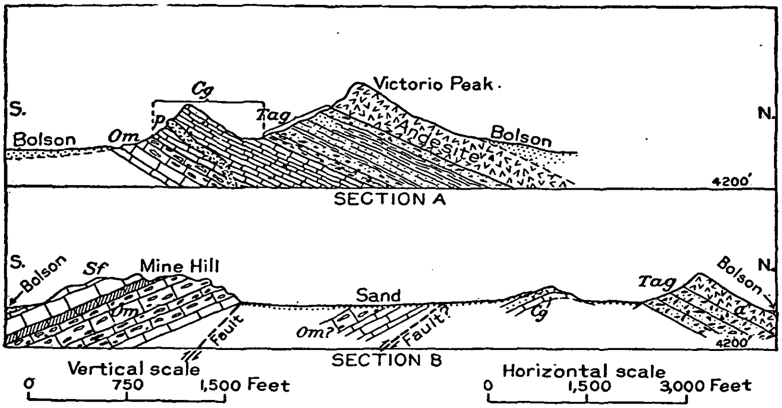

FIGURE 166.—Sections across Victorio Mountains, south of Gage, Luna County. *a*, Andesite; *Tag*, agglomerate, shale, and sandstone; *Cg*, Gym limestone; *Sf*, Fusselman limestone; *Om*, Montoya limestone; *Oe*, El Paso limestone; *p*, Porphyry

taining boulders of andesite and near the top some greenish sandstone containing conglomerate carrying pebbles of fossiliferous Paleozoic limestone. The basal contact, on the Gym limestone, shows little if any channeling and no marked discordance of dip, although for that matter the dip of the overlying thick sheet of andesite is in general accordant with the dip of all the sedimentary rocks below.

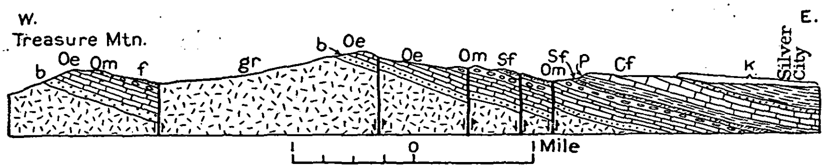

FIGURE 167.—Generalized cross section showing relations of Paleozoic rocks in Silver City region. After Paige. K, Sandstone and shale of Cretaceous age; Cf, Fierro limestone; p, Percha shale; Sf, Fusselman limestone; Om, Montoya limestone; Oe, El Paso limestone; b, Bliss sandstone; gr, granite, etc.

SILVER CITY REGION

Relations in the Silver City region have been described in detail by Paige.[84] The salient features of structure and succession are shown in Figure 167.

The formations in the Silver City region present the same succession as in the Cooks Range, Fluorite Ridge, and Florida Mountains, described above. The El Paso limestone, about 900 feet thick, is slabby and to some degree sandy in the lower part and finer and more

[84] Paige, Sidney, U. S. Geol. Survey Geol. Atlas, Silver City folio (No. 199), 1916.

massive in the upper part, where some beds are cherty. The Montoya limestone, about 300 feet thick, contains the usual alternations of chert in its upper part. The Fusselman limestone, 30 to 40 feet thick, contains abundant casts of the characteristic *Pentamerus*. The Percha shale varies greatly in thickness but reaches a maximum of 500 feet. The Fierro limestone includes strata of Lake Valley and Magdalena age, in all about 800 feet thick where most complete, but throughout this area its top is somewhat eroded. It is overlain by the "Beartooth quartzite" (Sarten sandstone, Comanche), 90 to 125 feet thick, which overlaps older rocks to pre-Cambrian. The overlying Colorado shale, which attains a thickness of 2,000 feet, consists of shale of various colors with thin sandstone layers at several horizons and many round concretions near the base.

HANOVER-SANTA RITA REGION

The important mining region around Hanover and Santa Rita has been described by Paige,[85] and a detailed survey has been made by

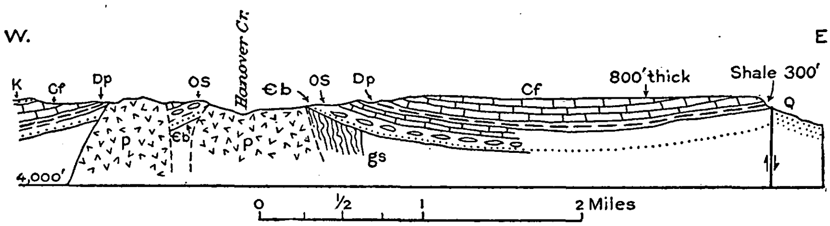

FIGURE 168.—Section across Hanover uplift three-fourths of a mile south of Fierro. By A. C. Spencer. Q, Quaternary; K, Cretaceous sandstone and shale; Cf, Fierro limestone; Dp, Percha shale; €b, Bliss sandstone; OS, El Paso, Montoya, and Fusselman limestones; gs, pre-Cambrian schist; p, porphyry

A. C. Spencer, the results of which are not yet published. The principal structural feature is an uplift with nucleus of porphyry, which is exposed from a point near Hanover to and beyond Fierro. The general relations are shown in Figure 168. Spencer found that the Bliss sandstone is about 150 feet thick on the east side of the uplift, where it lies on schist, of which about 60 feet is exposed. The El Paso limestone is 400 feet thick, the Montoya and Fusselman limestones 220 feet, the Percha shale 90 feet, and the Fierro limestone 800 feet. The Fierro is divisible into three formations—the lowest one, of early Mississippian age, 245 feet thick, and two formations of Pennsylvanian age, aggregating 555 feet thick. In places they are overlain by 200 feet of Abo red sandstone and by sandstone and shale of Cretaceous age. The strata are flexed and faulted and are intersected by large igneous masses which at Santa Rita are associated with rocks extensively impregnated with copper minerals. In the highlands to the south and north are heavy cappings of Tertiary volcanic flows interbedded with sand, gravel, and tuff.

[85] Idem, pp. 15, 16–17.

LONE MOUNTAIN

Lone Mountain, a ridge which rises out of the plain 3 miles west of Hurley, has been mapped in detail by Paige.[86] It consists of an uplifted block traversed by several faults trending north and northeast. In general the strata dip to the northeast, as shown in Figure 169. On the northeast slope of the range the strata are cut by an intruded mass of porphyry, and in places on the slopes are small exposures of sandstone and shale of Cretaceous age.

BIG BURRO MOUNTAINS

The Big Burro Mountains are in the north-central part of Grant County, south and west of Tyrone. They consist mostly of pre-Cambrian granite, which in the vicinity of Tyrone and Leopold is penetrated by a large mass of quartz monzonite porphyry. The character and relations of these rocks have been described by Paige.[87] Other porphyry dikes and masses occur in various portions of the range. At Gold Hill, an outlying ridge 15 miles northeast of Lordsburg, the pre-Cambrian rocks are mostly garnetiferous schist and amphibolite schist cut by fine-grained granite and dikes of pegmatite and diabase.

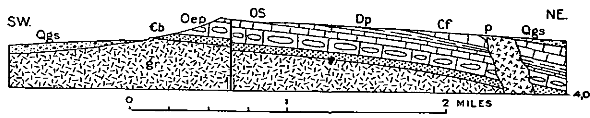

FIGURE 169.—Section across Lone Mountain, 3 miles west of Hurley. Qgs, Gravel and sand; p, porphyry; Cf, Fierro limestone; Dp, Percha shale; OS, Montoya and Fusselman limestones; Oep, El Paso limestone; -Cb, Bliss sandstone; gr, granite

LITTLE BURRO MOUNTAINS

The structure of the Little Burro Mountains, a narrow, irregular range north of Tyrone, has been determined by Paige.[88] The central and western portions of the range consist of granite of pre-Cambrian age, overlain in part by the basal sandstone of the Cretaceous and several irregular masses of Tertiary lavas. There are also some intrusive rocks. The west front is defined by a fault trending northwest, and there are numerous transverse dislocations.

CENTRAL-WESTERN VOLCANIC AREA

A large part of central New Mexico west of the Rio Grande is occupied by a vast accumulation of igneous rocks, mostly of volcanic origin and of Tertiary age, although there may also be present some late Cretaceous eruptive products. These rocks constitute the San Mateo Mountains, the southern part of the Magdalena Mountains, the Datil, Bear, Gallina, Gallo, Tularosa, San Francisco, Saliz, and Mogollon Mountains, the greater part of the Mimbres Mountains, and other detached ridges and mountains. The region is traversed

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86 Idem, p. 15. 87 Idem, pp. 3, 8. 88 Idem, pp. 10–12.

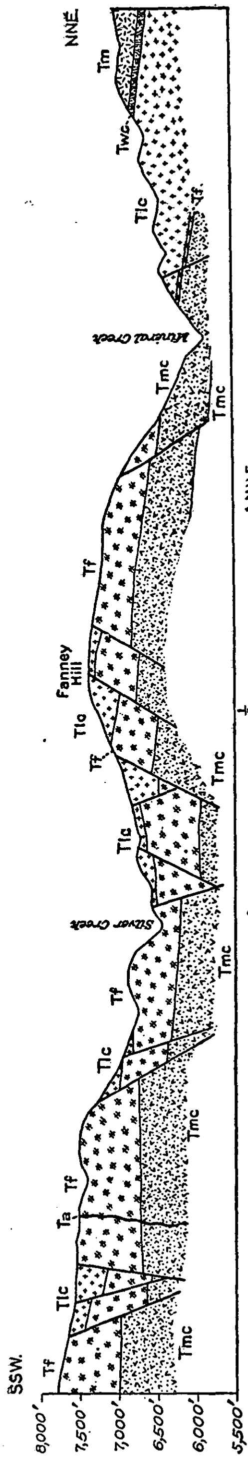

FIGURE 170.—Section across Mogollon district along a north-northeast line passing a short distance west of Mogollon, by H. G. Ferguson. Tm, Mogollon andesite; Twc, Whitewater Creek rhyolite; Ta, andesite dike; Tlc, Last Chance andesite; Tf, Fanney rhyolite; Tmc, Mineral Creek andesite

by Gila and San Francisco Rivers and some of the western branches of the Rio Grande. Except in the Mogollon Mountains and the region north of Silver City, no detailed studies have been made of the rocks of this large area, nor have their limits been accurately mapped in all places. The Plains of San Agustin, which are deeply filled with valley deposits, interrupt the continuity of the exposures of igneous rocks, and there are other smaller areas of sand and gravel in several valleys in the area. The volcanic rocks in this area consist of widespread sheets of agglomerate and tuff interbedded with extensive flows of latite, andesite, and rhyolite, and these are flexed and faulted to a greater or less extent. In most of the localities there is no suggestion as to the nature of the underlying sedimentary rocks, but to judge from the complex faulting and flexing of the strata in the Silver City–Hanover region it appears likely that the sedimentary rocks which underlie the area may present many complexities of structure, especially to the south. At the north end of the area, particularly in the vicinity of Salt Lake and in the valley of Alamosa Creek, in the northern part of Socorro County, as described by Winchester [89] the Cretaceous rocks pass under the northern edge of the volcanic series in a widely extended, gently southward-dipping monocline. How far south this structure or these relations extend has not been ascertained.

In the Mogollon mining district Ferguson [90] found a thick series of Tertiary rhyolite in many successive flows separated by deposits of tuff and sandstone and flows of dacite, andesite, and basalt.

[89] Winchester, D. E., op. cit. (Bull. 716), pl. 5.

[90] Ferguson, H. G., The Mogollon district, N. Mex.: U. S. Geol. Survey Bull. 715, pp. 174–188, 1921.

The relations of some of these deposits are shown in figure 170. In the Steeple Rock district, in the western part of Grant County, Graton[91] found effusive rocks, of which the most abundant is a rhyolite or dacite, and a diorite porphyry was noted in the dump at the Carlile mine. Graton[92] also examined parts of the Mogollon district.

PLAINS OF SAN AGUSTIN

The Plains of San Agustin occupy an area of about 300 square miles in the central part of Socorro County. Their average width is about 12 miles. On nearly all sides are ridges and mountains of igneous rocks. The general altitude of the remarkably level valley floor is about 6,850 feet.

Very little has been ascertained as to the structural relations in this area, but the rocks of the adjoining ridges lie nearly horizontal, and although there are many faults, the depression appears not to be bounded by them; probably it is an old stream valley. Now it is partly filled by loam, sand, and gravel derived from the adjoining mountains and according to Kirk Bryan[93] by deposits of an ancient

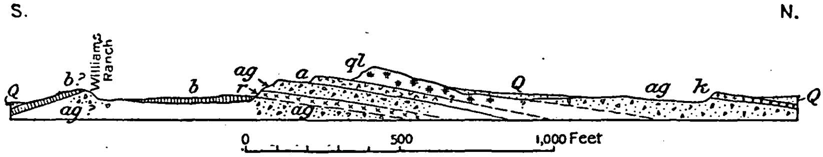

FIGURE 171.—Sketch section across Cedar Grove Mountains north of Victorio station. Thicknesses approximate; vertical scale exaggerated. *ag*, Agglomerate; *ql*, quartz latite; *a*, hornblende-augite andesite; *k*, keratophyre; *b*, basalt; *r*, hornblende-biotite rhyolite; *Q*, bolson deposits

lake which had a depth of 120 feet and was 25 miles long by 7 miles wide. Shore features are well displayed south of Horse Springs, in T. 5 S., Rs. 13 and 14 W., and a well-defined gravel beach was observed by him near the Gutiérrez ranch, on which stands bench mark 6903. Several wells ranging in depth from 125 to 335 feet have been sunk in this filling, apparently without reaching bedrock.

CEDAR GROVE MOUNTAINS AND CARRIZALILLO HILLS

The Cedar Grove Mountains, a long, narrow range of ridges and hills extending from northwest to southeast across the southwestern part of Luna County, consist of a succession of thin sheets of Tertiary igneous rocks dipping to the northeast at low angles. The cross section in Figure 171 shows the principal features of structure and succession. The basal agglomerate crops out along the southern foot of the entire range and is overlain by a thick sheet of quartz latite, which constitutes the summit. This latite continues past

[91] Graton, L. C., op. cit. (Prof. Paper 68), pp. 327–328.
[92] Idem, pp. 191–192.
[93] Bryan, Kirk, Groundwater reconnaissance in Socorro County: State Engineer of New Mexico. Seventh Bien. Rept., pp. 82–83, 1926.

Carrizalillo Spring and probably forms the barrier that brings the underflow to the surface at the spring. Locally this sheet is underlain by andesite, and it also constitutes the front ridge south of Hermanas station. Next above the latite is 600 feet or more of agglomerate with included sheets of coarse pink rhyolite and minor flows of andesite, trachyte, and latite. This agglomerate is locally overlain by a thin sheet of keratophyre. A ridge parallel to the main Cedar Grove Mountains extends northwest from Hermanas for about 16 miles and consists of a thick sheet of basalt dipping northeast and lying on fragmental volcanic deposits. Diabase also occurs in small areas at a number of other places in the vicinity of the mountains. The southeastern part of the Carrizalillo Hills consists of sheets of hornblende-biotite rhyolite and rhyolite tuff dipping east and somewhat faulted. They lie on tuff and agglomerate.

HATCHET MOUNTAINS

The Hatchet Mountains, south of Hachita, in the southeastern part of Hidalgo County, consist largely of Carboniferous limestone.

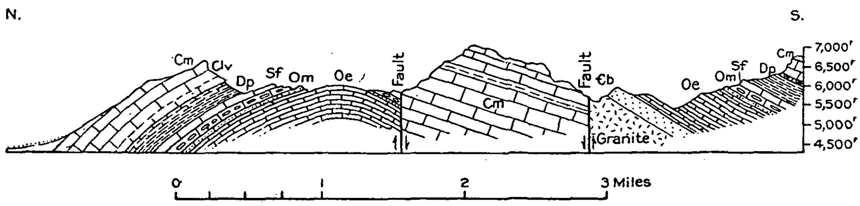

FIGURE 172.—Sketch section across north end of Hatchet Mountains, Hidalgo County. Cm, Magdalena group; Clv, probably Lake Valley limestone; Dp, Percha shale; Sf, Fusselman limestone; Om, Montoya limestone; Oe, El Paso limestone; €b, Bliss sandstone

They are flanked on the southwest by low ridges of limestone of Comanche age. In the northern part of the mountain an extensive succession of Paleozoic rocks is exposed lying on pre-Cambrian granite. The relations in this area are shown in Figure 172. Characteristic fossils were found in all the limestones, but the classification of the Percha shale is based on its character and position. The only fossils obtained in the supposed Lake Valley limestone are crinoid stems.

LITTLE HATCHET MOUNTAINS

The prominent group of ridges known as the Little Hatchet Mountains forms a northern prolongation of the Hatchet Mountains, from which they are separated by a deep gap. The north end is crossed by the El Paso & Southwestern Railroad in the low pass 10 miles west of Hachita. The Sylvanite mining district lies in this area about 10 miles southwest of Hachita. A considerable variety of rocks is exposed in this range, but they have not been differentiated at all places. At the south end is granite, which, however, may be of post-Carboniferous age, and this rock is a prominent feature in Granite Pass, 15 miles southwest of Hachita. Next north of that gap is sandy shale of Comanche age, cut by a large granite dike. The higher central part of the range consists of limestones of the Magdalena group, in a thick succession with strata dipping southwestward and cut off on the north by a large mass of quartz monzonite porphyry. In the northern ridges of the Little Hatchet Mountains are many prominent buttes, consisting of sandstone, shale, and limestone of Comanche age and several large masses of intrusive rock; in the vicinity of old Hachita limestones of the Magdalena group are exposed. On the northern slope near the railroad there are scattered exposures of dark shale of Comanche age. The ridge north of the railroad, of which Coyote Peak is the culminating summit, appears to consist mainly of eruptive rocks of Tertiary age. At its north end is a westward-trending ridge known as Quartzite Mountain, which consists of quartzite of Comanche age. A small but prominent butte a short distance north of this ridge is made up of limestone of the Magdalena group.

ALAMO HUECO AND DOG MOUNTAINS

The many ridges constituting and flanking the Alamo Hueco and Dog Mountains, in the southeast corner of Hidalgo County, consist of Tertiary volcanic rocks except the outlying ridges to the west and northwest of the Alamo Hueco ranch, which are of limestone of Comanche age. A small area of limestone, apparently of the Magdalena group, is exposed near the road 2 miles east of the Dog Spring ranch. Lord[93] has briefly described rhyolite from the Dog Mountains as containing an abundance of andesine so that the rock is near to dacite; and also a fine-grained porphyritic hornblende-mica andesite.

PYRAMID MOUNTAINS

The Pyramid Mountains, which extend southward from Lordsburg about 20 miles, consist entirely of igneous rocks, apparently eruptive and of Tertiary age. According to Graton[94] the main part of the range is chiefly andesite of porphyritic texture, but there are masses of diorite porphyry in the western part of the mining district near Lordsburg. There is considerable brecciation in parts of the area and much mineralization, with the development of several veins, some of which have yielded ore containing silver, lead, copper, and gold.

ANIMAS MOUNTAINS AND ASSOCIATED RIDGES

The name Animas Mountains is applied somewhat indefinitely to an extensive series of ridges extending southward through the central part of the southern half of Hidalgo County. A reconnaissance of this area has shown that most of the features consist of Tertiary volcanic

[93] Lord, E. C. E., Petrographic report on rocks from the United States-Mexico boundary: U. S. Nat. Mus. Proc., vol. 21, pp. 777, 779, 1899.

[94] Graton, L. C., op. cit. (Prof. Paper 68), p. 332.

rocks erupted in widespread sheets which are more or less flexed and considerably faulted. On the central eastern slope of the range, southeast of a peak called Gillespie Mountain, limestones with Comanche fossils are extensively exposed. Much if not all of the material, however, is a conglomerate, and its deposition in this form may be considerably later than Comanche. The ridges constituting the north end of the range 10 miles southwest of Playas consist largely of limestone of the Magdalena group and quartzite and shale of Comanche age. These strata are cut by some large masses of quartz monzonite porphyry. In no part of these mountains have the details of structure been determined.

SIERRA RICA AND APACHE HILLS

The group of high conical hills in the extreme southwest corner of Luna County and along the east margin of Hidalgo County consist of Paleozoic and Lower Cretaceous strata and igneous rocks. The greater part of the Sierra Rica in Luna County consists of limestone of Comanche age, containing abundant Trinity fossils. In the eastern foothills is a sandy limestone carrying large Exogyras, believed to be of Washita age, probably separated from the older limestone of the higher ridges on the west by a fault. In much of the area the strata dip to the north at low angles, but an anticline extends along the south slope of the hills, in which a gray quartzite appears a short distance north of boundary stone 38. A few small felsite dikes occur in this vicinity and also a mineral vein, which has been worked to a small extent at the International mine.

The western part of the Sierra Rica consists of limestone of the Magdalena group, but in outlying buttes at the west end of the range both this limestone and strata of Comanche age appear, the latter mostly a massive gray quartzite, which is conspicuous in a small ridge 10 miles due south of Hachita.

The Apache Hills consist mainly of intrusive quartz porphyry overlain by Tertiary volcanic rocks to the north and in contact with Comanche and probably Magdalena limestones to the south. The relations at the Apache mine have been described by Lindgren.[95]

PELONCILLO MOUNTAINS

The name Peloncillo Mountains is applied to a long, narrow ridge that extends along or near the western margin of Hidalgo County. It is crossed by the El Paso & Southwestern Railroad just west of Pratt and by the Southern Pacific Railroad at Steins Pass. Most of the range consists of thick masses of rhyolite and other eruptive rocks of Tertiary age, some features of which have been noted by Lindgren.[96] There appear to have been several centers of eruption,

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[95] Lindgren, Waldemar op. cit., (Prof. Paper 68), pp. 343–344.
[96] Idem, pp. 329–332.

and the sheets of igneous rock have been flexed and faulted. No detailed examination has been made of most parts of this range. West of Pratt sandstone of Comanche age, in part quartzitic, appears on the east slope, and a short distance farther east is a conical butte of limestone of the Magdalena group. At Granite Gap and extending northward nearly to Steins Gap there are extensive exposures of this limestone, together with underlying strata, which are cut in places by porphyries. A section about a mile north of Granite Gap has features shown in Figure 173. Many of the relations at this locality were not determined, and the identification of some of the formations

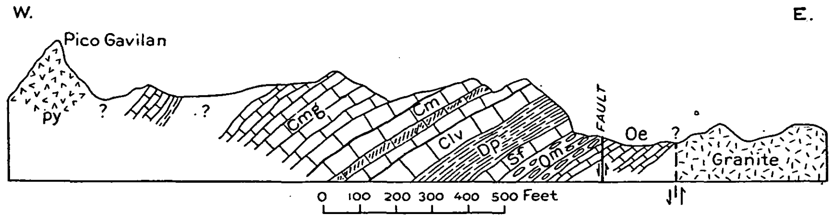

FIGURE 173.—Sketch section across Peloncillo Mountains north of Granite Gap, 25 miles southwest of Lordsburg. py, Porphyry; Cmg, limestone of Magdalena group; Cm, limestone with Mississippian fossils and interbedded chert; Cl, coarse crinoidal limestone, Lake Valley; Dp, Percha shale; Sf, Fusselman limestone (?); Om, Montoya limestone (?); Oe, El Paso limestone

is not certain. The El Paso limestone appears to be well represented, overlain by cherty strata of Montoya aspect, and a massive dark limestone about 30 feet thick strongly suggests the Fusselman limestone This is overlain by 100 feet of dark shale, probably Percha, and the limestone next above has many of the features of the Lake Valley limestone or of the Escabrosa limestone, which appear not very far west in Arizona. It contains many crinoids and a few indistinct molluscan remains, which according to G. H. Girty resemble Mississippian forms. Higher beds of limestone belong to the Magdalena group.

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