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Geology and Mineral Resources of Mesa del Oro Quadrangle, Socorro and Valencia Counties, New Mexico

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Abstract

Mesa del Oro quadrangle is located about 40 miles southwest of Albuquerque and 26 miles west of Belen, in central New Mexico. The topography of the area is varied, and elevations range from about 6,000 to 7,500 feet.

The quadrangle is on the west flank of the Lucero uplift, a westward dipping monoclinal structure that forms the east boundary of the Acoma embayment of the San Juan Basin. The quadrangle is obliquely transected by Sierra Lucero, a northeastward trending, northwest-dipping expression of the structural high formed by the Lucero uplift. The east margin of Sierra Lucero is a steep cliff, in which the upper part of the Lower Permian sequence (Glorieta and San Andres formations) forms a broad valley (Los Vallos) east of the escarpment. The dip slope is composed of resistant Permian limestones (San Andres formation), capped at places by Triassic red beds (Chinle formation) and Tertiary lava flows. Locally northwest-striking, high-angle normal faults cut the western margin of the Sierra Lucero. Sodaclase-diorite dikes parallel the strike of the faults, and sills of similar composition intrude the Permian and Triassic rocks in the eastern half of the quadrangle. In the southwestern part of the area, a series of small anticlinal folds occurs. The northwestern part of the quadrangle is typical of the Acoma embayment of the San Juan Basin. The dips are low and typically to the west and north. The region is dotted by scattered basaltic lava flows and plugs. Many of the flows cap remnants of Cenozoic erosion surfaces cut on Triassic rocks, forming broad mesas, some of which cover areas of considerable size. At a few places in the southern and northwestern parts of the quadrangle, Upper Cretaceous rocks (Dakota?, Mancos, and Mesaverde) are exposed. Jurassic rocks (Entrada, Summerville?, and Morrison formations) occur only in the northwestern corner of the area.

Water resources of the area are meager, and the water is generally of poor quality. The oil and gas possibilities have never been tested fully. The most important mineral resource is high-calcium lime rock (travertine), a large deposit of which occurs on the north end of Mesa del Oro. Other potential resources are gypsum, flagstone, and basalt blocks. No metallic deposits are known to occur in the area.

Introduction

Mesa del Oro quadrangle was mapped in 1953 and 1954 as part of the regional mapping program of the New Mexico Bureau of Mines and Mineral Resources. As the quadrangle is only 20 miles south of the large uranium mines of the Laguna Reservation and is north of the uranium prospects in the adjoining Puertecito quadrangle, it was thought that mapping of this area might be helpful in uranium exploration. The results of the study of the complex relations of the volcanic and intrusive igneous rocks should be of value in considering adjoining areas.

The 15-minute Mesa del Oro quadrangle, which has an area of approximately 245 square miles, is in central New Mexico, and includes parts of Socorro and Valencia Counties. It is about 40 miles southwest of Albuquerque and 26 miles west of Belen. Access to the western part is by a dirt road which leaves U. S. Highway 66 about 1 mile west of Correo. Several unimproved dirt roads enter the eastern part of the quadrangle, and a network of truck trails provides access to all parts of the area.

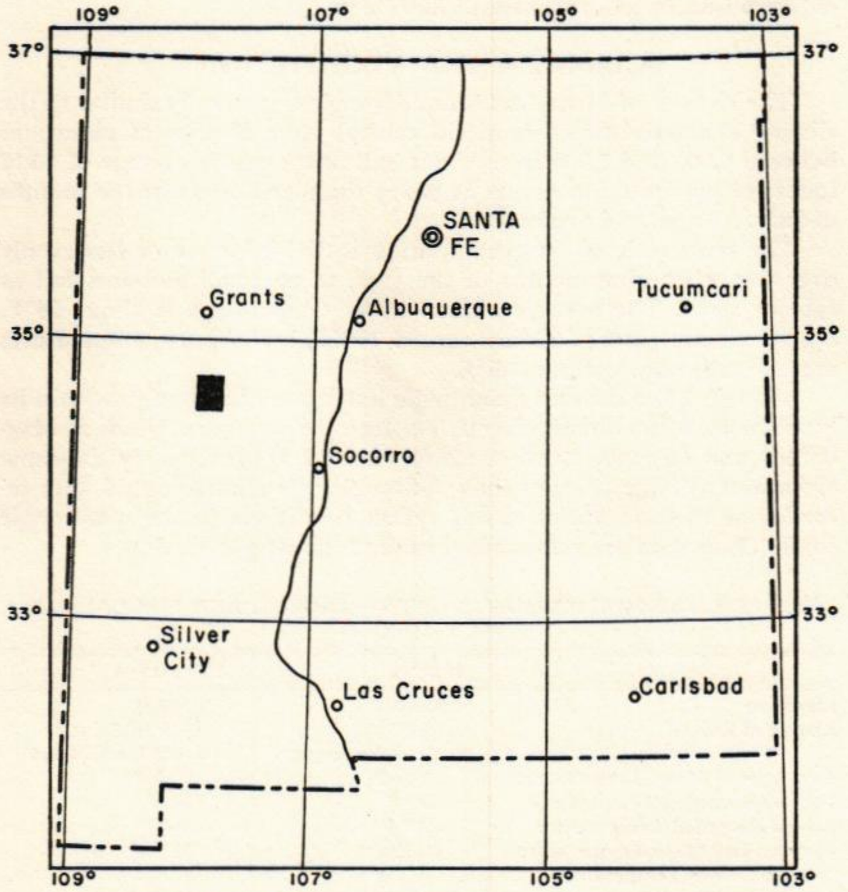
Field data were plotted on aerial photographs on a scale of 2 inches to the mile and transferred to a Soil Conservation Service planimetric quadrangle sheet of the same scale. Sedimentary sections were measured by leveling or with the aid of a plane table. Profiles for the geologic sections were made by using altimeters, according to the single-base method.

The mapping was done on an outcrop basis; that is, only actual outcrops of the formation were mapped. Where cover is very thin, areas are designated as covered formation. Where soil or alluvium completely covers the formation to a depth of a foot or more, only the covering soil or alluvium has been mapped, even though the formation is almost certainly immediately beneath the cover.

SURFACE FEATURES

The area covered by the Mesa del Oro quadrangle is within the Datil section of the Colorado Plateau (Hunt, 1956, fig. 1). Its surface features, produced by the differential etching by erosion of gently dipping soft and hard beds, are characteristic of this great region. Some areas of soft beds have been protected from erosion by late-Cenozoic hard caps of basaltic lava which form tablelands or mesas 200 to 300 feet above the surrounding areas. Of these, Mesa del Oro, which occupies much of the west-central part of the area, is the largest. All the mesas are surrounded by landslide debris.

The most prominent feature is the Sierra Lucero, a long ridge or cuesta which follows a northward course through the eastern part of the quadrangle. It rises steeply to the east, with many cliffs as much as 1,500 feet above the plains of Los Vallos, and slopes gently to the plains of the central and southwestern parts of the quadrangle. The plains,



INDEX MAP OF NEW MEXICO SHOWING AREA INCLUDED IN THIS REPORT.

Figure 1

which are underlain by weakly resistant Triassic rocks, are broken here and there by low ridges of more resistant sandstone beds or by sills of igneous rocks. The low areas are mainly at a general altitude of 6,000 feet; the high areas, near 7,000 feet, culminate in Pato Mesa, on the top of Sierra Lucero, at an altitude of 7,500 feet.

CLIMATE AND VEGETATION

The climate of Mesa del Oro quadrangle is generally similar to the climate characteristic of semiarid central New Mexico at elevations between 6,000 and 7,000 feet. About half of the yearly average of 10-12 inches of precipitation occurs as heavy thundershowers in the months of July, August, and September.

The remainder of the precipitation is divided more or less evenly over the other nine months of the year, when small amounts fall as rain or snow. The average annual mean temperature is about 53°F. Summer temperatures seldom exceed 100°F, and winter temperatures are generally not lower than -5°F.

Though Mesa del Oro quadrangle has no weather station within its boundaries, it lies almost directly between the weather stations at Magdalena and Laguna. As these stations are at approximately the same elevations as large parts of the quadrangle, the climatological data recorded at these localities closely reflect conditions in the quadrangle itself. These data are summarized in the following tables.[1]

TABLE 1. GENERAL CLIMATIC DATA — LAGUNA AND MAGDALENA, NEW MEXICO

	Laguna	Magdalena
Elevation	5,840 ft	6,556 ft
Length of Record	1905-1953, intermittent for 38 years	1905-1953, intermittent for 46 years
Ave. Annual Mean Temperature	53.2°F	52.7°F
Highest Recorded Temperature	103°F	108°F
Lowest Recorded Temperature	–20° F	–16° F
Ave. January Mean Temperature	32.4°F	33.5°F
Ave. July Mean Temperature	72.1°F	72.9°F
Ave. Annual Precipitation	10.11 in.	12.05 in.
Highest Recorded Precipitation	21.27 in. (1905)	23.84 in. (1914)
Lowest Recorded Precipitation	3.73 in. (1953)	5.76 in. (1945)

TABLE 2. AVERAGE ANNUAL RAINFALL BY MONTHS — LAGUNA AND MAGDALENA, NEW MEXICO
(In inches)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Laguna	0.37	0.46	0.48	0.70	0.61	0.80	2.11	1.66	1.29	0.56	0.40	0.56	10.11
Magdalena	0.57	0.46	0.59	0.84	0.59	0.70	1.70	2.62	1.50	0.77	0.45	0.58	12.05

1. Data for Tables 1 and 2 were derived from "Climate and Man," the 1941 Yearbook of Agriculture, U. S. Govt. Printing Office, Washington, D. C., and from the records of the U. S. Weather Bureau at Albuquerque, New Mexico.

Vegetation in Mesa del Oro quadrangle varies according to elevation and topography. The low mesas and plains are covered mainly by grass, flowering plants, and various species of cacti. Many of the sandstone and limestone cuestas in all parts of the area support a sparse growth of trees, mostly piñon and juniper. At higher elevations the cover is mainly piñon and juniper, with sparse grass, flowering plants, bushes, cacti, and yucca.

The main industry in the area is cattle raising. Part or all of eight different ranches in the area (pl. 4).

PREVIOUS GEOLOGIC WORK

Parts of Mesa del Oro quadrangle were mapped in some detail by Wells (1919) and Winchester (1920). Darton (1928-a, b) made a reconnaissance of the area and has discussed a few parts of it. Wright (1946) mapped the physiography and discussed the correlation of the erosion surfaces. Kelley and Wood's reconnaissance map of the Lucero uplift area immediately to the east appeared in 1946, and the author has used their divisions of the Permian. Silver (1948) traced the Jurassic overlap and correlated the Jurassic sediments in the northwestern corner of the quadrangle. Tonking's (1957) map of Puertecito quadrangle, immediately south of Mesa del Oro quadrangle, was of material assistance.

ACKNOWLEDGMENTS

The author wishes to acknowledge the aid of John Schilling in measuring the stratigraphic sections. The staff of the New Mexico Bureau of Mines and Mineral Resources has given many valuable suggestions and criticisms. Thanks are due to the ranchers in the area, who, out of their store of intimate knowledge of the country, provided much information about road conditions and locations of many obscure roads and trails. Mr. Carl Wilson kindly allowed the use of one of his ranch buildings as headquarters for much of the work.

Geology

Exclusive of late-Cenozoic lava flows and spring deposits and Quaternary alluvial cover and landslides, the outcropping rocks in Mesa del Oro quadrangle are almost wholly of Permian and Triassic age (pl. 1). Permian rocks occupy the eastern third of the area. Outcrops of Cretaceous rocks are limited to the southwestern corner and to the Pico Pintado, a narrow butte in the northwestern corner and the sole outcrop area of the Jurassic rocks. Intrusive igneous rocks, chiefly in the form of sills, occur mainly in the dominantly shaly Yeso formation in Los Vallos east of Sierra Lucero and in the equally shaly Chinle formation of Triassic age.

In keeping with the structural characteristics of the Colorado Plateau, the rocks dip gently, mainly to the west. The dominant feature is the Lucero uplift (Kelley and Wood, 1946), a structural high which occurs along the boundary between the Colorado Plateau and the Rio Grande depression on the east. Only the westward dipping limb of this uplift, underlain by Permian rocks, occurs in Mesa del Oro quadrangle. Gentle folds occur in the Triassic rocks in the southwestern part of the area, and a belt of normal faults follows a northward trend along the west side of the Sierra Lucero in the south half of the quadrangle. The Cenozoic rocks cap erosion surfaces on the pre-Tertiary rocks.

Stratigraphic Sequence

The oldest formation exposed within the quadrangle is the clastic, nonmarine, Lower Permian Abo formation (table 3 and p1. 1) which is incompletely exposed in the southeast corner. The Abo formation is overlain, in order, by the marginal marine Yeso formation and by the marine Glorieta and San Andres formations, all of Permian age. The nonmarine Upper Triassic Chinle formation lies unconformably on the San Andres formation. To the south the Chinle is overlain unconformably by Upper Cretaceous rocks, which include the Dakota(?) sandstone, the Mancos shale, and the Mesaverde formation. In the northwestern part of the quadrangle about 150 feet of nonmarine Jurassic sandstone and shale overlies the Chinle and is in turn overlain by the Dakota(?) formation. Not far southwest of the northwest corner of the quadrangle the Jurassic beds pinch out entirely, and the Dakota(?) sandstone lies directly on the Chinle formation.

Cenozoic deposits exposed within the quadrangle include spring deposits (travertine), pediment and terrace veneers, talus, landslide debris, soil, and alluvium. Cenozoic eruptive rocks also form part of the stratigraphic sequence in Mesa del Oro quadrangle.

PERMIAN ROCKS

ABO FORMATION

The Lower Permian (Wolfcampian) Abo formation, named by Lee (1909) from exposures in Abo Canyon at the southern end of the Manzano Range, is exposed only in 10-12 square miles in the southeastern part of Mesa del Oro quadrangle. The Abo lies apparently conformably on the Red Tanks member of the Pennsylvanian Madera limestone (Kelley and Wood, 1946), with which it is said to intertongue at places. Bates et al. (1947) indicate that the Red Tanks member is approximately correlative with the Permian Bursum formation. The basal contact of the Abo is not exposed in the area mapped, but Kelley and Wood have placed it at the top of the uppermost marine limestone in their Red Tanks member. The Abo crops out as a northeastward trending belt of sandstone cuestas in a flat, shale-floored valley on the east (east Los Vallos).

The Abo formation consists of red-brown shales, siltstones, and sandstones with a few thin fresh-water limestones. It has been divided into two units by Tonking (1957) on the basis of lithology. The lower unit is about 600-650 feet thick. The lowermost 300-400 feet is made up almost entirely of dark-red to red-brown silty shales, overlain by an alternation of fine-grained, silica-cemented, silty, thin-bedded, red-brown, platy sandstone beds and silty to sandy red-brown shale with a few thin lenses of limestone. The upper contact of the lower unit is marked by a low cuesta where the sandstone becomes predominantly

TABLE 3. GENERALIZED STRATIGRAPHIC COLUMN OF MESA DEL ORO QUADRANGLE

SYSTEM	SERIES	FORMATION	THICKNESS (feet)	DESCRIPTION
Quaternary and Tertiary				Alluvium, terrace veneers, basaltic flows, spring deposits, landslides
		Major unconformity — uplift, folding, and faulting		
Cretaceous	Upper Cretaceous	Mesaverde formation		
		La Jara Peak member	500±	Pale yellow-buff massive sandstones and gray shales
		Mancos shale	200±	Dark-gray marine shale; 10-15 ft sandstone at 60 ft (Tres Hermanos? member)
		Dakota(?) sandstone	15-30	Buff fine-grained sandstone, blocky; weathers massive
		Major unconformity		
Jurassic	Upper Jurassic	Morrison formation	60±	White to pale-buff medium-grained quartz sandstone, crossbedded
		Disconformity		
	Middle Jurassic	Summerville formation	30±	Green-gray silty shales with thin greenish sandstones
		Disconformity		
		Entrada formation	60±	White massive friable crossbedded sandstone

TABLE 3. GENERALIZED STRATIGRAPHIC COLUMN OF MESA DEL ORO QUADRANGLE (continued)

SYSTEM	SERIES	FORMATION	THICKNESS (feet)	DESCRIPTION
		Major disconformity		
Triassic	Upper Triassic	Chinle formation	1,500-2,000	Red and purple silty clay shales and mudstones with layers of lensatic red-brown and buff sandstones and limestone-pebble conglomerate
		Major unconformity		
Permian	Leonardian and/or Guadalupian	San Andres formation		
		Upper limestone member	100-125	Gray thin- to thick-bedded limestones, with some gypsum, gray-buff shale, and sandstone
		Lower evaporite member	300-325	Buff and gray silty shales and gypsum, with a few thin sandstones and thick-bedded gray limestones
	Leonardian	Glorieta sandstone	140-200	Massive crossbedded pale-yellow sandstone, with a few layers of gypsum or gypsiferous shale near middle
		Yeso formation		
		Los Vallos member	1,300-1,600	Gray, buff, and pink gypsiferous shales, gypsum, and a few persistent dark limestone beds; much gypsum in upper half
		Meseta Blanca sandstone member	0-100	White to pale-pink and pale red-brown friable sandstones with a few thin layers of red-brown shale
Permian	Wolfcampian	Abo formation		
		Upper member	200+	Fine-grained light-red to reddish-buff silty thin-bedded sandstones interlayered with red-brown silty shales
		Lower member	600-800	Red-brown silty shales, siltstones, and thin platy red-brown silty sandstones, mostly in upper part (incompletely exposed in Mesa del Oro quadrangle)

lighter in color and less siliceous. The upper unit, about 300 feet thick, consists of lighter colored sandstones with predominantly calcareous cement and thin, dark red-brown clay shales, in contrast with the darker, finer grained, arkosic, silica-cemented sandstones and silty shales lower in the section. This upper unit may possibly represent an interfingering facies change of the Meseta Blanca sandstone member of the overlying Yeso formation. It appears to be a zone of transition from the nonmarine Abo formation into the marine Yeso formation.

YESO FORMATION

The Yeso formation of Lower Permian (Lower Leonard) age which lies conformably on the Abo formation was named by Lee (1909, p. 12), from Mesa del Yeso, 12 miles northeast of Socorro. Kelley and Wood (1946) have divided it into two members in the Lucero uplift area, the Meseta Blanca sandstone member, 0-100 feet thick in the quadrangle, and the Los Vallos member, 1,200-1,600 feet thick.

The Meseta Blanca sandstone member is a series of thin-bedded to massive, massive-weathering, creamy-white to pale-buff and pinkish, fine-to medium-grained sandstone beds which are friable in the upper part. Sandstone is interbedded with thin beds of red-brown shale, similar to that in the upper part of the Abo. The cement is calcareous. The sandstone weathers into rounded forms in contrast to the more angular outcrops of Abo sandstone. The base of this member is taken at the top of the last fairly thick (10- to 20-foot) bed of red-brown shale in the Abo formation or at the top of the last thick red-brown sandstone, whichever happens to underlie the light-colored sandstone. The Meseta Blanca sandstone is thickest at the northernmost point of its exposure in the quadrangle and gradually thins southward until it pinches out in sec. 28, T. 4 N., R. 4 W. Sandstone of the upper part of the Abo resembles the Meseta Blanca sandstone locally.

The Los Vallos member is 1,200-1,600 feet thick in Mesa del Oro quadrangle. It underlies west Los Vallos and, at places, forms the lower slopes of the Sierra Lucero escarpment. The base of the Los Vallos member is taken at the base of a persistent thin, fine-grained, gray limestone which rests on either the light-colored Meseta Blanca sandstone or the slightly darker sandstone and red-brown shale of the upper member of the Abo. The lower part of the member is dominantly gray, pale-red, yellow, and buff gypsiferous shale, with a few thin, persistent limestone layers. The upper part consists of alternating beds of pale-pink and tan gypsiferous shale, and grayish-white and pink sandstone. The entire upper part of the section is highly gypsiferous. In the south, the uppermost 20 feet of the Yeso formation consists of fine-grained, thin-bedded, reddish- to pinkish-brown sandstone interbedded with thin layers of yellow and pale-gray shale. These beds are not persistent over any large area.

The Los Vallos member is poorly exposed over much of its outcrop width. The basal limestone forms a cuesta, but the overlying silty shales underlie a wide covered plain parallel to the trend of the Sierra Lucero. The upper part forms a series of cuestas held up by more resistant limestone.

In the southern part of the quadrangle the Yeso formation has been intruded by a series of thick dioritic sills at not fewer than eight horizons and also by a few northwestward striking dikes. The sills are roughly parallel to the bedding and appear to have caused some inflation of the section. At places in the southern part of the area the sills aggregate over 300 feet in thickness. The sills thin to the north, but persist almost to the northern limit of the Yeso outcrop in the quadrangle. The intrusives have caused almost no metamorphism in adjoining sediments; indeed, baking took place through a space of only a few feet at most.

The formation thickens gradually from 1,000 feet northeast of the quadrangle (Kelley and Wood, 1946) to 1,600 feet about 1½ miles north of the southern boundary of the quadrangle.

SECTION OF YESO FORMATION
(Secs. 4, 5, and 6, T. 4 N., R. 4 W.)

UNIT NO.	DESCRIPTION	THICKNESS (feet) OF UNIT	FROM BASE
	Glorieta sandstone; pale yellow-buff to pale-yellow fine- and medium-grained thick-bedded sandstone *Yeso formation, Los Vallos member*	50+	(incomplete)
43	*Covered*, presumably clay shale, buff, gypsiferous	15.0	1211.5
42	Limestone and anhydrite, dark-gray, fine-grained, silty; weathers dark gray, ledgy	5.0	11965
41	Gypsum, white, massive; weathers light gray in nodules as much as 1 cm in diameter	3.0	1191.5
40	Clay shale, light red-brown, gypsiferous; interbedded with layers of white gypsum as much as 2 inches thick	17.5	1188.5
39	Gypsum, white, massive; weathers light gray	1.5	1171.0
38	Clay shale, pale red-brown, and gypsum, white, extremely silty; weathers pale red-brown	6.0	1169.5
37	Clay shale, gypsiferous, pale red-brown	7.0	11635
36	Gypsum, white, massive; weathers light gray	4.0	11565
35	Clay shale, gypsiferous, pale red-brown	5.0	11525
34	Gypsum, white, silty, massive; weathers light gray	3.0	1147.5
33	Clay shale, gypsiferous, pale red-brown	4.0	1144.5
32	Gypsum, white, massive; weathers light gray	7.0	11405
31	Clay shale, pale red-brown and buff, silty, gypsiferous	6.0	11335
30	Gypsum, white, massive; weathers light gray	5.0	11273
29	Limestone, silty, medium-gray to yellowish-gray, fine-grained, granular, slightly gypsiferous, thin-bedded; weathers light gray	1.0	1122.5
28	Clay shale, pale red-brown and light-buff, silty, gypsiferous	11.0	11215
27	Gypsum, white, massive; weathers light gray	5.5	1110.5
26	Clay shale, pale red-brown, silty, gypsiferous	3.0	1105.0
25	Gypsum, white, massive; weathers light gray	5.0	1102.0
24	Clay shale, silty, gypsiferous, yellow-buff at base to pale red-brown at top	14.0	1097.0

UNIT NO.	DESCRIPTION	THICKNESS (feet) OF UNIT	FROM BASE
23	Limestone, dark-gray, fine-grained, granular, slightly silty; very hard, compact; bedding obscure, probably 6 inches to 1 foot thick; appears to be a local lens; weathers mottled dark gray and yellowish gray	11.0	1083.0
22	Limestone, medium- to light-gray, medium-grained, granular, sandy; bedding 3 to 6 inches thick; weathers medium to light gray	16.5	1072.0
21	Sandstone, white, medium-grained, limy matrix; grains subangular; weathers pale buff	3.0	1055.5
20	Limestone, medium- to light-gray, thin-bedded, fine-grained, granular; weathers light gray	11.0	1052.5
19	Gypsum, white, massive, friable; weathers light gray	5.5	1041.5
18	Clay shale, pale red-brown to pink, gypsiferous	22.0	1036.0
17	Limestone, medium-gray, sandy, fine-grained, granular, thin-bedded; weathers medium gray	3.0	1014.0
16	Sandstone, white, fine-grained, limy matrix; grains subangular	1.0	1011.0
15	Clay shale, buff, slightly silty, gypsiferous	15.0	1010.0
14	Gypsum, white, massive; weathers light gray	3.0	995.0
13	Limestone, medium-gray, silty, fine-grained, granular, thin-bedded; weathers medium gray	2.0	992.0
12	Covered, presumably buff gypsiferous clay shale (soil evidence)	17.0	990.0
11	Covered, presumably limestone, as in unit 10 (limestone float abundant)	10.0	973.0
10	Limestone, medium- to dark-gray, slightly silty, fine-grained, granular, thin-bedded; contains numerous ostracods which are easily discernible on broken surfaces; weathers light gray	7.0	963.0
9	Clay shale, mottled pink to buff, slightly silty, gypsiferous; forms poorly exposed gullied slope	18.5	956.0
8	Covered, presumably silty gypsiferous clay shale	27.5	937.5
7	Limestone, dark-gray to dark brownish-gray, fine-grained, granular, slightly silty, thin-bedded; contains scattered small vesicles as much as 3 mm in diameter, which are lined with crystals of yellow translucent calcite; forms ledgy slope; weathers grayish brown	11.0	910.0
6	Limestone, dark-gray to black, fine-grained, granular, slightly silty; contains poorly preserved fragments of gastropods; weathers medium gray to thin plates and chips; forms rubbly slope	5.0	899.0
5	Covered, probably gypsiferous clay shale	15.0	894.0
4	Gypsum, white, massive, friable; weathers mottled light and dark gray	12.0	879.0
3	Clay shale, pale-buff at base grading upward to pale reddish-brown at top, silty, gypsiferous, slightly limy; forms gullied slope	33.0	867.0
2	Gypsum, white, massive, slightly silty; weathers light gray	2.0	834.0
lc	Limestone, dark-gray, silty, fine-grained, granular, thin-bedded; contains numerous vesicles as much as 2 mm in diameter lined with yellow translucent calcite crystals; weathers medium gray	12.0	832.0

UNIT NO.	DESCRIPTION	THICKNESS (feet) OF UNIT	FROM BASE
lb	Covered, probably silty gypsiferous shales and some gypsum; forms broad alluvial valley	810.0	820.0
la	Limestone, medium-gray, fine-grained, granular; weathers medium gray, hackly; forms cuesta	10.0	10.0
	Total Los Vallos member	1,211.5	
	Meseta Blanca sandstone member		
1	Sandstone, pale creamy-buff to pale-brown and red-brown, fine-grained, thin-bedded, massive; and interbedded red, sandy shale in layers as much as 1½ feet thick; weathers pale brown. Shales become thinner and less frequent toward the top	93.5	93.5
	Total Yeso formation	1,305.0	
	Abo formation; red-brown shale and interbedded red-brown and buff sandstones	50+	(incomplete)

GLORIETA SANDSTONE

The Glorieta sandstone was named by Keyes (1915, p. 257, 262) from exposures on Glorieta Mesa in Santa Fe County, New Mexico. The unit was raised to formational rank by Needham and Bates (1943, p. 1662-1664). Though it is a distinct mappable unit in this area and thus may be termed a formation, it interfingers with the lower part of the San Andres formation and appears to be a basal sand of the San Andres. The Glorieta sandstone of some areas may not be strictly equivalent in time to that of other areas. It is Lower Permian (middle or upper Leonard?) in age.

The Glorieta sandstone lies conformably on the Los Vallos member of the Yeso formation. It is a massive pale-yellow to buff fine-grained well-sorted crossbedded quartzose sandstone which commonly contains some gypsum or gypsiferous shale near the middle of the section. The contact with the Yeso is drawn on top of the last bed of silty gypsiferous shale, though as much as 20 feet of pale-yellow, white, and pale-red sandstone may lie below the contact. The grains are subangular to sub-round. Small specks of limonite, each of which encloses a quartz grain, occur in many beds. The cement is largely calcareous, but locally some silica is present. Though the Glorieta forms massive cliffs in the northern and southern parts of its outcrop, which parallels the Sierra Lucero front, a part of its outcrop in secs. 18, 30, and 31, T. 4 N., R. 4 W., where it appears to be more friable than to the north and south, is a ledgy slope with exposures almost entirely confined to stream channels. Thin beds of gypsum and gypsiferous shale near the middle of the section cause the double cliffs which characterize the outcrop in the northern part of the area. In the southernmost part of the quadrangle thin dioritic sills have invaded the sandstone along bedding planes.

The contact with the overlying San Andres formation is gradational in that thin beds of sandstone similar in character to those in the Glorieta occur in the basal 100 feet of the evaporite member of the San

Andres. However, the base of the San Andres is placed at the base of the first shaly or gypsiferous horizon above the upper massive sandstone bed.

The thickness of the Glorieta sandstone in Mesa del Oro quadrangle is 135-200 feet. The Glorieta thins from north to south and then thickens again. Kelley and Wood (1946) report thicknesses of over 200 feet northeast of the quadrangle, and Tonking (1957) reports a similar thickness south of the quadrangle. From the center of its outcrop in Mesa del Oro quadrangle, the Glorieta thickens perceptibly northward over a distance of several miles. To the south the thickening is not so readily observed, as the formation makes up the basal part of the Sierra Lucero escarpment.

SECTION OF GLORIETA SANDSTONE
(Sec. 6, T. 4 N., R. 4 W.)

UNIT NO.	DESCRIPTION	THICKNESS (feet) OF UNIT	FROM BASE
	San Andres formation, lower evaporite member; gypsum, white, massive, silty; weathers variegated light and dark gray	20.0	(base only)
	Glorieta sandstone		
5	Sandstone, yellow-buff and gray interlayered; fairly hard when light gray; bedding 6 inches to 1 foot; grains subangular to subround; weathers pale yellow and pale grayish brown; forms ledgy slope	33.0	134.5
4	Sandstone, pale yellow-brown, medium-grained, with numerous limonite specks; beds 6 inches to 1 foot thick; massive; grains subangular to subround; weathers light brown; forms ledge	7.0	101.5
3	Sandstone, pale yellow-buff to pale-yellow, fine- and medium-grained, massive; beds 3 inches to 1 foot thick; grains subangular; some thin crosslaminated *beds,* with laminae 1/2-1 inch thick, planar type; cement calcareous; contains small blebs of limonite; weathers pale yellow buff; forms ledgy slope	44.0	94.5
2	Sandstone, as in unit 1; partly covered	38.5	50.5
I	Sandstone, pale yellow-buff, fine-grained; thin-bedded, with a few thin buff layers; grains subangular to sub-round; cement calcareous; forms ledgy slope; weathers massive, yellow buff	12.0	12.0
	Total Glorieta sandstone	134.5	
	Yeso formation, Los Vallos member; buff gypsiferous clay shale, mostly covered	15.0 (top only)	

SECTION OF GLORIETA SANDSTONE
(Sec. 36, T. 3 N., R. 4 W.)

UNIT NO.	DESCRIPTION	THICKNESS (feet) OF UNIT	FROM BASE
	San Andres formation, lower evaporite member; clay shale, light-gray, silty, gypsiferous	35.0	(base only)

UNIT	DESCRIPTION	THICKNESS (feet) OF UNIT	FROM BASE
	Glorieta sandstone		
4	Sandstone, fine- and medium-grained, pale yellow-brown and pale-gray, crosslaminated; bedding 2 inches to 2 feet; mostly thin; forms massive cliff; contains numerous tiny limonite specks in some beds, in others only sparse specks of limonite; grains subangular to subround; cement mostly calcareous; weathers light gray, pale yellow buff, and yellow buff in layers	50.0	143.5
3	Clay shale, pale-gray to yellowish-gray, silty, gypsiferous, and interlayered white fine-grained calcareous sandstone	11.0	93.5
2	Sandstone, like unit 4	58.5	82.5
1	Sandstone, white, fine-grained, friable, crosslaminated; bedding obscure; silty with calcareous cement; grains subangular; weathers light gray to white to a rounded, partly covered slope	24.0	24.0
	Total Glorieta sandstone	143.5	
	Yeso formation, Los Vallos member; sandstone, red-brown and yellow-brown, fine-grained, limonitic, thin-bedded, and pale-gray to white sandy gypsiferous clay shale	18.0 (top only)	

SAN ANDRES FORMATION

The Permian (upper Leonard and/or Guadalupian) San Andres formation, which was named by Lee (1909, p. 23) from the San Andres Mountains, lies conformably on the Glorieta sandstone with gradational contact. Kelley and Wood (1946) have divided the San Andres formation in this area into two members (exclusive of their Glorieta sandstone member), a lower evaporite member, 300-325 feet thick, and an upper limestone member, 100-125 feet thick.

The lower evaporite member consists of thick beds of gypsum, interspersed with silty gypsiferous tan and gray shale, medium-gray limestone, and thin fine-grained white and buff sandstone. The limestone is mostly silty and may contain scattered sand grains. In the northern part of the quadrangle a prominent 50-foot layer of massive black fine-grained silty limestone occurs about 30 feet below the top. One-third or more of the evaporite member consists of beds of white to pale-gray gypsum as much as 40 feet thick. Many of the beds are massive; in others the gypsum has thin dark-gray silty layers. The evaporite member, in which few fossils have been found, is more gypsiferous and shaly to the south.

The upper limestone member consists of a series of medium-gray fine- and medium-grained limestone beds which are variously thin bedded and thick bedded to massive. The basal contact of this member is drawn where fairly thick, persistent limestone beds begin to dominate the section to the exclusion of thick beds of gypsum and silty gypsiferous shale. The time significance of the contact is uncertain, as its exact placement- may vary slightly at different localities because of facies changes. The upper part of the member consists largely of massive and thick-bedded limestone, with a few thin beds of clay shale. Though the unconformable contact of the upper member with the overlying Chinle shale is one of low relief, Tonking (1957, p. 12) reports prominent sinkholes and solution breccia at places in Puertecito quadrangle. A few patches of tan and gray and thin-bedded fine-grained brown sandstone occur where erosion along the unconformity was not marked. These beds differ sufficiently from the overlying Chinle red beds to be classed as uppermost San Andres (Tonking, 1957, p. 12). Exposures of these beds are confined to the western part of the dip slope of the Sierra Lucero, and may be seen to best advantage in sec. 23, T. 4 N., R. 5 W. Their total thickness is not more than 20 feet. The upper and lower members of the San Andres form the upper parts of the cliff that marks the east margin of the Sierra Lucero, and they are exposed to varying degrees on the dip slope of the Sierra, depending upon the depth of erosion.

SECTION OF SAN ANDRES FORMATION

(Sec. 6, T. 4 N., R. 4 W.)

UNIT NO.	DESCRIPTION	THICKNESS (feet) OF UNIT	FROM BASE
	Top of exposed section — not top of San Andres		
	San *Andres formation, upper limestone member*		
36	Limestone, pale-gray, fine-grained, crystalline; beds 1 foot thick; weathers medium gray with rough surfaces; numerous crystals of white calcite; forms ledgy slope	10.0	44.5
35	Clay shale, light-gray, gypsiferous	7.0	34.5
34	Limestone, like unit 36	14.0	27.5
33	Limestone, light-gray, fine-grained, granular; in beds 1 foot thick; forms ledgy slope; weathers light gray with smooth surfaces	7.0	13.5
32	Limestone, pale-gray, very fine-grained to sublithographic, thin-bedded, silty; forms steep slope; weathers yellowish gray	6.5	6.5
	Total upper limestone member exposed	— 44.5	
	Lower evaporate member		
31	Clay shale, yellowish-gray, silty; forms steep slope	28.0	340.0
30	Limestone, dark-gray to black, very fine-grained, granular, massive, very silty; forms steep cliff; bedding, if any, obscure; weathers medium gray	51.0	312.0
29	Sandstone, pale yellow-buff, fine-grained, massive; with scattered limonite concretions as much as 2 mm in diameter, and limonite specks; grains subangular to subround	8.0	261.0
28	Limestone, light-gray, very fine-grained, granular; numerous vugs to 1 mm in diameter, filled with tiny crystals of yellow translucent calcite; weathers light gray, with pock-marked surface	8.0	253.0
27	Clay shale, light-gray, gypsiferous	4.0	245.0
26	Limestone, like unit 28	2.0	241.0

UNIT NO.	DESCRIPTION	THICKNESS (feet) OF UNIT	FROM BASE
25	Gypsum, white, massive, slightly silty; weathers light gray and brown	37.0	239.0
24	Gypsum, white, massive; weathers light gray	10.0	202.0
23	Clay shale, pale-gray to white, highly gypsiferous; weathers light gray	6.0	192.0
22	Gypsum, white, massive; weathers light gray	3.0	186.0
21	Limestone, dark-gray, fine-grained, granular massive, silty, slightly gypsiferous; weathers dark gray with rough surface	5.5	183.0
20	Gypsum, white, massive, friable; weathers light gray	6.0	1775
19	Gypsum, white, and clay shale, yellow-buff, silty, gypsiferous; slightly sandy at base	12.0	171.5
18	Sandstone, like unit 29	2.0	159.5
17	Gypsum, white, massive; weathers light gray	10.0	157.5
16	Limestone, light-gray, fine-grained, granular thin-bedded; weathers light gray and buff	15	147.5
15	Diorite sill	275	146.0
14	Limestone, dark-gray, medium-grained, granular, massive; beds 1-2 ***feet*** thick; contains fossil fragments on weathered surfaces; weathers medium gray, blocky	4.0	118.5
13	Clay shale, pale yellow-buff, gypsiferous, slightly silty	11.0	1145
12	Sandstone, like unit 29	1.0	103.5
11	Gypsum, white, massive; gypsiferous shale, pale-buff; occasional lenses of white fine-grained gypsiferous sandstone; all interbedded irregularly in layers as much as 2 feet thick	285	1025
10	Sandstone, white; otherwise similar to unit 29	5.0	74.0
9	Sandstone, like unit 29	5.0	69.0
8	Clay shale, pale-gray to buff, silty, gypsiferous; forms steep slope	15.5	64.0
7	Sandstone, pale yellow-brown, fine-grained, with numerous limonite specks; medium-bedded; massive; grains subangular; forms ledge; weathers buff to yellow buff	9.0	485
6	Clay shale, pale-buff, silty, gypsiferous; forms steep slope	55	395
5	Sandstone, like unit 7 but thin-bedded	1.5	34.0
4	Sandstone, white, fine-grained, gypsiferous, soft, friable; grains subangular; weathers pale gray to white	05	325
3	Gypsum, white, massive, friable, silty; weathers light gray	5.0	32.0
2	Sandstone, like unit 7 but thin-bedded	7.0	27.0
1	Gypsum, white, massive, silty; weathers variegated light and dark gray	20.0	20.0
	Total lower evaporite member (less sill)	312.5	
	Total San Andres formation exposed (less sill)	357.0	
	Glorieta sandstone; sandstone, yellow-buff and gray interlayered, fine- and medium-grained; fairly hard when light gray; bedding 6 inches to 1 foot; grains subangular to subround; forms ledgy slope; weathers pale yellow and pale grayish brown	33.0 (top only)	

TRIASSIC ROCKS

Red beds of Upper Triassic age lie unconformably on the San Andres formation in the Sierra Lucero. Kelley and Wood (1946) called the lower parts of this red bed sequence "Shinarump conglomerate," but the lack of any diagnostic Shinarump lithology makes the use of this term questionable. The lowest 50-100 feet of red beds in this area consists predominantly of mudstone and claystone, with a few thin beds of chert conglomerate and sandstone. McKee (1951, p. 89) states:

> The "D" member of the Chinle into which it [the Shinarump] grades is composed of alternating beds of sandstone, mudstone and claystone. Like the Shinarump, it is characterized by much channel-fill cross-stratification and it contains lenses of conglomerate[;] so it is sometimes confused with the Shinarump.

The features mentioned are prominent in the red beds for about 100 feet above the basal contact.

Kelley and Wood (1946) have not drawn a contact between their "Shinarump" and the overlying Chinle, because only the lowermost or uppermost parts of the red bed sequence, the former being called "Shinarump" and the latter "Chinle," are exposed in the area they mapped. The author was unable to find any continuous lithologic break in the section, or any distinctive Shinarump lithology in the basal part of the section. However, as the Shinarump, where it can be recognized, is considered by many geologists (Camp et al., 1947) to be a basal coarse facies of the Chinle formation, it seems wise to assign the entire Upper Triassic red bed section in Mesa del Oro quadrangle to the Chinle formation, of which the Shinarump conglomerate, if it is indeed present, would be a member.

CHINLE FORMATION

The Upper Triassic Chinle formation was named by Gregory (1916, p. 79) from Chinle Valley in northeastern Arizona. It consists of a monotonous series of red, red-brown, and purple clay shale, siltstones, and mudstones, and red to red-brown and buff lenticular sandstone with lenses of dark-brown limestone-pebble conglomerate. The conglomerate lenses may mark the filled stream channels. At places in the lower part of the section the clay shale is slightly gypsiferous and may even contain thin gypsum beds. In the area north of Pato Mesa a 5- to 10-foot bed of chert conglomerate is near the base of the formation. The chert pebbles are red, gray, and black, and well rounded, though sporadically distributed fractured pebbles have sharp edges remaining. This conglomerate bed could not be traced continuously south of Pato Mesa, and is probably a series of lenses. Tonking (1957, p. 15) reports lenses of similar conglomerate near the base of the formation in Puertocito quadrangle.

The sandstone is thin to medium bedded, commonly crossbedded, generally fine to medium grained, and feldspathic to arkosic. The grains are subangular and poorly sorted. The crossbedded sandstones are better sorted and less arkosic than those which are not crossbedded. The sandstones have calcareous cement, and all the strata are at least slightly calcareous.

With the exception of petrified wood, which is abundant in small areas in the mudstones and shales, no fossils were found. The degree of petrifaction is variable. At some localities the wood fragments have been almost completely converted to varicolored silica, and much of the woody structure has been destroyed. At other places considerable carbon remains, though the woody structure is not well preserved.

Tonking (1957, p. 15) has divided the formation into four units, which are generally recognizable in Mesa del Oro quadrangle, but are not mappable because of the gradational nature of the contacts. The lenticular nature of the sandstones in the Chinle would make the location of meaningful contacts extremely difficult.

The units which Tonking proposed are:

1. Lower sandstone unit: Kelley and Wood (1946) have correlated this unit with the Shinarump conglomerate. It does not consist entirely of sandstone, but rather contains many fairly persistent lenticular beds of sandstone and a few lenses of chert conglomerate and limestone-pebble conglomerate intercalated with 10- to 30-foot layers of red silty mudstone and shale. The basal 50-100 feet is largely claystone and mudstone, with scattered sandstone layers. The lower sandstone unit comprises the lower 150-200 feet of the Chinle formation.

2. Lower siltstone-shale unit: This unit, about 300 feet thick, is made up mostly of red, purple, and brown silty mudstone and clay shale, with sparse, very thin sandstone and lenses of limestone-pebble conglomerate.

3. Upper sandstone unit: The upper sandstone unit is largely made up of fairly clean crossbedded buff to brown-buff feldspathic sandstone in layers as much as 20 feet thick. Though sandstone persists at this general level in the formation throughout the length of the quadrangle, the individual sandstone layers are lenticular and vary considerably in thickness within the space of a mile or two. Red and purple silty clay shale and silty mudstone are interlayered with sandstone. The unit, averaging 200 feet thick, ranges in thickness from 150 to 250 feet.

4. Upper siltstone-shale unit: This unit (red shale member of Kelley and Wood, 1946) consists almost entirely of bright-red silty mudstone and clay shale with a few thin sandstone lenses. It ranges in thickness from about 800 feet near the southern border of the quadrangle to over 1,000 feet in the northern part of the quadrangle. A large part of this variation may be attributed to post-Triassic erosion, which in the southern part of the quadrangle caused the Upper Cretaceous Dakota(?) formation to be deposited on the Chinle formation with a considerable

degree of unconformity. To the north erosion was not so deep, and Jurassic beds begin to make their appearance atop the Chinle in the northwest corner of the quadrangle.

No evidence was found of the Correo sandstone member of the Chinle (Kelley and Wood, 1946).

The two lower units described above are probably roughly equivalent to Gregory's (1917) Chinle "D." The upper two units are probably equivalents of his Chinle "C" and possibly his "B." McKee (1951, p. 89) states that the limestones that characterize the "B" unit largely pinch out to the south.

The Chinle formation is, with minor exceptions, the only sedimentary formation that crops out in the quadrangle west of the Sierra Lucero. A large part of the outcrop is covered by basalts, and a broad belt just west of the Sierra is intruded by dioritic dikes and sills of Tertiary age. 'Where the sills are thick, some metamorphism of the enclosing sediments has occurred. The claystone and mudstone tend to become very hard (hornfels), and where the iron content is large, hollow, concretionlike geodes with specularite crystals inside have formed. These effects are best shown on the margins of the two large intrusives in the northern part of the quadrangle.

Except for areas near cuestas rimmed by the sandstone beds of the formation, the Chinle is poorly exposed, being covered by landslide debris, residual soil, and alluvium. The soil and alluvium have much the same color as the formation, but are generally lighter hued and tend to be brown buff to reddish buff, rather than the bright red and purple which characterize the formation in place.

JURASSIC ROCKS

The Jurassic system is represented in Mesa del Oro quadrangle by 150 feet of beds, which include three formations: Entrada sandstone, Summerville(?) formation, and Morrison formation. These beds crop out only in Pico Pintado Mesa, an outlier of a 400-foot basalt-capped cliff which extends in a north-south direction just west of the quadrangle boundary. The formations decrease in thickness to the south and pinch out at approximately sec. 25, T. 5 N., R. 7 W. They thicken perceptibly toward the north and increase in complexity of sediment type. Silver (1948) traced the progressive thinning in the Jurassic beds from El Rito southward to the final pinchout and has described the facies changes which accompanied this phenomenon. He indicates that this is an area of overlap on older sediments which must have formed a positive area during Jurassic time. The thinning of the formations southward also may be due in small part to progressively deeper erosion of the Jurassic formations before the deposition of the overlying Upper Cretaceous Dakota(?) formation. Correlations of the Jurassic strata in this area are based partly upon Silver's (1948) work.

ENTRADA SANDSTONE

The Entrada sandstone, a part of the San Rafael group, was named by Gilluly and Reeside (1928) from exposures at Entrada Point in the northern part of the San Rafael Swell in Utah. It is represented in Mesa del Oro quadrangle by 57 feet of white to pale-buff, fine-grained, thick-bedded, friable, crossbedded sandstone, locally stained pale orange buff by limonite. It consists of well-sorted, poorly rounded, frosted quartz grains, with a small proportion (10 percent or less) of red, black, and yellow chert. The crossbedding is of the planar type (McKee and Weir, 1953), with foresets as much as 20 feet long and 8 feet deep. The sorting is particularly well demonstrated in the coarser beds, where the coarse grains occur at the bottom of the foresets and the slightly granular and conglomeratic sandstone grades upward into fine-grained sand at the top of the bed. The beds crop out as a massive cliff.

The Entrada sandstone pinches out in sec. 19, T. 6 N., R. 6 W., but gradually increases in thickness to the north.

SUMMERVILLE(?) FORMATION

The "buff shale member of the Morrison" of Silver (1948) is probably equivalent, at least in part, to the lower Thoreau formation described by Smith (1954) in Thoreau quadrangle. The lower Thoreau formation is in turn referred by many to the Summerville formation (Red Mesa formation of Hoover [1950] in this area), the uppermost member of the San Rafael group. It is represented in the quadrangle by 30 feet of light green-gray, silty shale or siltstone interbedded with layers of poorly sorted white to greenish-gray sandstone as much as 1 foot thick. It forms a prominent break in the cliff formed by the white sandstone of the Entrada formation and the white to pale-buff sandstone above, which is part of the Morrison formation.

MORRISON FORMATION

The Morrison formation, named by Cross (1894) from prominent exposures near the town of Morrison in east-central Colorado, subsequently has been divided into numerous members, each of which is mappable over considerable parts of the outcrop area. One, or possibly two, of these members may be represented in Mesa del Oro quadrangle.

White Sandstone Member (includes variegated shale member?)

The white sandstone member of the Morrison of Silver (1948) is probably in part correlative with the Chavez member of Smith (1954) in the Thoreau area. Members of the U. S. Geol. Survey (Craig et al., (1951) consider the white sandstone member to be a part of the Recapture shale (Gregory, 1938) sequence in the Morrison. Both it and the variegated shale member of Silver (1948) are represented in the area by a white to pale-buff sandstone. The variegated shale member is probably equivalent to the Brushy Basin shale member of the Morrison formation, as named by Gregory (1938, p. 59). The variegated shale member thins and changes to a white sandstone from north to south, and it and the white sandstone member merge into one virtually indivisible sandstone unit 13 miles north of Mesa del Oro quadrangle (Silver, 1948). The unit is truncated progressively southward by the Dakota(?) sandstone, and thus the sandstone in Mesa del Oro quadrangle may represent only the lower of the two units (i.e., the white sandstone member).

The white sandstone member of the Morrison formation in Mesa del Oro quadrangle consists of about 60 feet of fine- to medium-grained, poorly sorted, pale-buff, crossbedded sandstone with calcite cement. A thin layer of green-gray shale occurs 22 feet from the base of the sandstone. The quartz grains are subangular and frosted. The uppermost 10 feet contains small lenses of chert conglomerate, with subangular pebbles of white, red, green, and black chert as much as 1 inch in diameter. Some of the sandstone layers contain considerable limonite as specks and small concretions as much as 5 mm in diameter. Each limonite speck or concretion has a sand grain at its center. The unit weathers to a pale orange-buff cliff with irregular orange streaks caused by limonite staining. The base of the overlying Dakota(?) sandstone is marked by shallow channeling and a change from white, friable sandstone with frosted grains to buff, hard, blocky sandstone in which the grains are not frosted.

CRETACEOUS ROCKS

Upper Cretaceous beds are exposed at only a few places in the southwestern and northwestern parts of Mesa del Oro quadrangle. In the southwest a small graben has dropped them to the erosion level of the upper Chinle beds exposed there. Only a few hundred feet of the Cretaceous sequence is exposed within the quadrangle, but farther south and west, over 2,000 feet of Upper Cretaceous (Dakota?, Mancos, Mesaverde) sediments is exposed. The formations represented in Mesa del Oro quadrangle are the Dakota(?) sandstone, the Mancos shale, and the lower 25-50 feet of the Mesaverde formation.

DAKOTA(?) SANDSTONE

The oldest Cretaceous unit in the mapped area is the Upper Cretaceous Dakota(?) sandstone, which rests unconformably on the Chinle formation in the southern part of the area and on Upper Jurassic (Morrison) beds in the northwestern part of the area. The unconformity is one of low angularity. The term "Dakota(?)," as it is used here, is one of convention. W. T. Lee (1915, p. 36-37) explains its use as follows:

> ... There are few places in the Rocky Mountain region where recognizable fossils have been found in it [the Dakota], and there is no certainty that the Dakota of one locality is the exact time equivalent of the Dakota of another locality. It seems to be the custom to assign a sandstone to the

> Dakota if it occurs immediately below shale known from fossil evidence to be of Benton age. In other words, the Dakota . . . seems to be the basal sandstone of the Upper Cretaceous series — that is, the sandstone formed near shore in the advancing Upper Cretaceous sea.

For this reason the term "Dakota(?)" has been adopted by the U. S. Geological Survey for this formation west of the Colorado Front Range.

The Dakota(?) is a light-gray to yellowish-gray and buff, medium-grained, well-cemented sandstone, commonly finely crosslaminated. The cement may be silica or calcite or both. The grains are well rounded and the sorting is good. Abundant red and black heavy minerals occupy positions along the lower margins of the cross laminae. Tonking (1957, p. 17) described variable amounts of iron staining and conglomeratic lenses in the sandstone, none of which were noted in the small area of outcrop within the quadrangle. However, in some places limonite specks as much as 1 mm in diameter are abundant. The Dakota(?) is 15-30 feet thick in the mapped area. The contact with the overlying Mancos shale is gradational. The Mancos shale is commonly very sandy at the base, and thin sandstone layers occur in the first few feet of the shales.

The resistance of this massive-weathering sandstone unit to erosion makes it an excellent marker horizon despite its small thickness. Lying as it does between two relatively nonresistant formations, this property is accentuated. In many areas to the south the Dakota(?) caps high ridges of Triassic shales and forms large landslide blocks where the underlying nonresistant strata have been removed.

MANCOS SHALE

The Mancos shale was named by Cross (1899, p. 4), "from its characteristic occurrence in the Mancos Valley and about the town of the same name, between the La Plata Mountains and the Mesa Verde." It consists of about 200 feet of black to gray and blue-gray calcareous and noncalcareous marine shale, with a 10- to 15-foot sandstone layer about 60 feet above the base. Tonking (1957, p. 19) reports septarian concretions. Thin limestone lenses are commonly present. The sandstone was referred tentatively by Winchester (1920) to the Tres Hermanos sandstone of Herrick and Johnson (1900), a procedure which has been followed by later workers in the area. It is here regarded as a member of the Mancos sequence, though Tonking (1957) has used the top of this horizon to mark the base of his La Cruz Peak member of the Mesaverde. The first thick sandstone unit overlying the Mancos is generally presumed to be the base of the Mesaverde formation, and the writer has so placed the contact. Inasmuch as such correlation up to the present has been based largely on the lithology rather than strict time equivalence, because of the complex intertonguing relationships of the two formations, it appears justifiable to adopt such a course.

The Tres Hermanos(?) sandstone consists of 10-15 feet of massive, pale-yellow to grayish-white, medium-grained, soft, friable, feldspathic sandstone that weathers with rounded surfaces. The cement is calcareous. The upper and lower contacts are gradational. A few thin layers of similar sandstone occur in the shales above and below the thick, massive layer designated as the Tres Hermanos(?).

The Mancos is poorly exposed, forming a gentle slope or valley on the Dakota(?) sandstone. The valley floor in shale is broken by the low cuestas of the Tres Hermanos(?) sandstone and the shale also forms a steep, largely covered slope under the sandstone cuesta which marks the base of the Mesaverde group. The author was able to collect only a few poorly preserved marine molluscs from the Mancos in the southern part of Mesa del Oro quadrangle.

At Pico Pintado, in the northwestern part of the quadrangle, the Mancos section is about 70 feet thick, the upper part having undoubtedly been removed before the cap of basalt was deposited. The formation is poorly exposed because extensive talus covers the slopes. It is made up of buff to gray, sandy and silty marine shales with intercalated, thin beds of friable, calcareous sandstone. One of these sandstone beds has yielded poorly preserved marine fauna, including representatives of the genus *Turritella* and some pelecypods and brachiopods which were not identifiable.

MESAVERDE FORMATION

Only the lowest 25-50 feet of the La Cruz Peak member of the Mesaverde group occurs within the quadrangle. The exposure consists of a thick, massively bedded, medium-grained, yellow-buff, crossbedded sandstone with numerous small iron concretions.

Tonking (1957, p. 19) describes the member as consisting of over 600 feet of olive-gray to bluish-gray marine shales, sandy shales, and gray to yellow crossbedded quartzose sandstones and subgraywackes. The member was named from Las Cruz Peak, secs. 13 and 24, T. 2 N., R. 6 W. The author has included the basal 100-120 feet of shales of Tonking's La Cruz Peak member in the Mancos formation, as described above.

CENOZOIC SEDIMENTS

TRAVERTINE

The north end of lava-capped Mesa del Oro is underlain by thick travertine deposits, doubtless formed by springs which have long since ceased to flow. The travertine mass is an irregular lens, which is thickest to the northeast but thins rapidly to the north and west and more slowly to the south. It is overlain at some places by the oldest of the Mesa del Oro flows, and lies on an erosion surface that bevels pre-Tertiary rocks. It is believed to be of late Tertiary or early Pleistocene age.

TABLE 4. CENOZOIC ROCKS OF MESA DEL ORO QUADRANGLE

AGE	NAME	THICKNESS (feet)	DESCRIPTION
Recent	Alluvium	0-50	Residual soil, sand, gravel, valley fill, and alluvial fan deposits
	Talus	0-20	Accumulations of blocks of loose material
	Spring deposits	0-100	Unconsolidated calcareous and gypsiferous deposits from modern springs
	Terrace veneers	0-20	Sand, soil, and gravel deposited on stream terraces in the Cañada Bonita
	Unconformity		
Recent and Pleistocene	Pediment gravels	0-20	Gravels on the surface of the pediment on the dip slope of Sierra Lucero
	Unconformity		
	Landslide debris	0-300+	Blocks of basalt and other rocks which slipped down from mesa tops
	Unconformity		
	Cerro Verde basalt	0-50	Basalt from Cerro Verde volcano
	Unconformity		
Pleistocene	Gunn Mesa basalts	20-50	Basalt flow on Gunn Mesa, as well as on mesas that are remnants of Mush Mesa surface
	Unconformity		
	Laguna del Oro basalt	20-100	Basalt from center west of Laguna del Oro
	Mesa del Oro basalt	200-300	A series of three basalt flows that cap Mesa del Oro; accompanying loose ejectamenta
	Disconformity		
	Travertine	0-150	Banded travertine deposited on north end of Mesa del Oro and on Pato Mesa
	Unconformity		
Pliocene(?)	Sierra Lucero basalts	150±	Basalt flows, which form mesas on Sierra Lucero, and associated plugs and necks
Middle(?) or Late(?) Tertiary	Intrusives		Sills, dikes, and small plugs of dioritic composition
	Major unconformity — uplift, folding, and faulting		
Mesozoic rocks			

The travertine, which has a maximum thickness of over 150 feet, is a yellow-buff to white, banded, porous rock that weathers in massive cliffs having a crackled surface and an orange-buff color. The bands, commonly one-fourth of an inch to one-half inch thick, vary slightly in color. In places the travertine is massive.

A small, thin (0-25 feet) deposit of similar travertine, occurring on top of the basalt on Pato Mesa, was probably formed at or about the same time as the travertine on Mesa del Oro. The travertine has been described in detail by the writer elsewhere (Jicha, 1956).

LANDSLIDE DEBRIS

Landslides of great extent constitute possibly the most striking geomorphic feature in Mesa del Oro quadrangle (pl. 2). Over 25 square miles in the quadrangle is covered by landslide debris. The northern flank of Mesa del Oro for a distance of 10 miles is an apron of slide blocks more than a mile wide. The southern flank is covered by slide blocks for a similar distance, though the apron is considerably narrower at most places. Pato Mesa is similarly surrounded by landslide debris, and even Gunn Mesa, at a level of only 200 feet above the surrounding plain, has a narrow apron of slide blocks on its margins. In the northwestern corner of the quadrangle, Pico Pintado, an outlier of Jurassic and Cretaceous rocks, has on its east side two immense landslide blocks, more than one-half mile long and several hundred yards wide. In the south, where the Dakota(?) sandstone lies on the Chinle, the slide blocks are smaller, owing to the closely spaced jointing of the sandstone.

The mechanism of sliding on the basalt mesas is described by Wright (1946, p. 451) as follows:

> ... on the western edge of Mesa del Oro, .. . the blocks start as strips of the basalt cap 150 feet thick, and as much as 3 miles long, and only a few hundred feet broad. . . . The strips are separated originally from the unbroken basalt capping by crevices only a few feet wide but more than 75 feet deep. As they slide down the slope of the mesa, the spaces between the blocks become filled with talus and alluvium. The blocks finally break up into great heaps of angular boulders, and streams coming off the mesa have adjusted their courses to the irregular masses of old landslide debris.

Landslides of the type so well illustrated in Mesa del Oro quadrangle are common in northern New Mexico and in other Southwestern States. They appear to be a feature of the late Pleistocene, when unusual precipitation permitted the soaking of bedding surfaces on weak rocks beneath massive rocks such as sandstone and basalt. E. Callaghan (personal communication) informed the writer of a similar landslide which flowed over moraines of probable Wisconsin age in central Utah. Probably all the landslides of similar type in Mesa del Oro quadrangle and adjoining areas belong to the same epoch. Some boulder trains of basalt

VERTICAL AERIAL PHOTOGRAPH SHOWING LANDSLIDING ON NORTH FLANK OF MESA DEL ORO.

PLATE 2

may possibly represent earlier slides, and prominent open crevices at the head of some slides suggest that some movement may still be in progress locally.

PEDIMENT GRAVELS

Gravels as much as 20 feet thick, made up mainly of San Andres limestone fragments, occur on dissected remnants of a once widespread pediment which slopes southwestward from the summit area of Sierra Lucero. Though the pediment was cut mainly on the weakly resistant rocks of the Chinle formation, some areas of the San Andres formation were involved also. Possibly the pediment was warped by subsequent uplift, for it has a steeper slope than the present erosion surface.

TERRACE VENEERS

Thin veneers of soil, sand, and some gravel that were deposited by the downcutting stream cover the terraces of Cañada Bonita. These veneers have been designated Qtg1, Qtg2, and Qtg8, from oldest to youngest (or highest to lowest), as determined by the relative altitudes of the terraces they cover.

SPRING DEPOSITS

At one place in the northwestern part of the area, springs that are currently active have deposited considerable amounts of poorly consolidated gypsiferous and calcareous material labeled Qs2 around their outlets (pl. 1). The outlets are surrounded by low mounds of this material, some of them as much as a quarter mile in diameter. Water samples indicate that the spring water has a high gypsum and calcium carbonate content and similar material probably is still being deposited. The deposits do not appear to be related to the earlier travertine deposits in any way beyond their mode of formation.

TALUS

At various places in the area, accumulations of loose blocks of the more resistant rocks, especially basalt, occur. These are termed talus (Qt), though it is probable that some of the accumulations are residual and have remained in the same horizontal position over considerable periods of time, a condition which is especially true of the accumulations of basaltic blocks on the isolated hills in the northeastern part of the quadrangle. At other places the blocks are true talus, having dropped down from more resistant beds during Recent time.

ALLUVIUM

Under the designation alluvium (Qal) are placed several classes of material. These include residual soil, stream sand and gravel, valley fill, and alluvial fan deposits.

CENOZOIC ERUPTIVE ROCKS

The eruptive rocks of Mesa del Oro quadrangle include a series of sodaclase-diorite intrusives of probably mid-Tertiary age and a number of basaltic flows, plugs, and cones of various ages, ranging from late Tertiary (probably Pliocene) through Pleistocene and, possibly, early Recent. The relative age of these eruptive rocks is based upon their position with regard to erosional or depositional surfaces in the area. Detailed petrography is discussed in a later section.

SODACLASE-DIORITE INTRUSIVES

On the west side of Sierra Lucero the dioritic dikes have a general N. 5°-10° W. strike and appear to be intruded into steeply dipping fractures or zones of weakness that have an en echelon pattern. No evidence of faulting was noted along the courses of the dikes. Most of the dikes are less than 5 feet thick. Locally a dike may change to a sill by turning parallel to the bedding. The dike rocks, which are black and very fine grained, closely resemble the dense margins of the thick sills and appear to be their fine-grained equivalents. Thin sills associated with thick sills resemble the dikes and are very similar mineralogically.

The thick sills west of the Sierra Lucero escarpment are made up of greenish-gray, medium-grained, melanocratic crystalline rocks with pink and white feldspars, flakes of dark biotite, and elongate crystals of pyroxene or amphibole. The least weathered rocks are dark brown to reddish brown; more deeply weathered rocks become soft and change to olive green or olive gray. The medium-grained crystalline rocks grade into a dark-gray to black, more finely crystalline to aphanitic rock on the margins of the sill. Thick sills are usually accompanied by one or more thin sills above and below and may splay out laterally into many thin, black, aphanitic sills. The sediments surrounding thick sills are altered for a distance of 25-30 feet above and below the contacts. The adjacent clay shales and mudstones of the Chinle formation are locally metamorphosed into hornfels, with some spotty bleaching of their color. Where the sediments contain much iron, geodes filled with hematite crystals were formed. The sandstones are silicified and bleached, and their iron content is concentrated in red hematite streaks running irregularly through the layers. Thin sills and dikes have caused very little alteration in the sediments which surround them. The only noticeable effect is slight hardening of the clay shales and mudstones for a few inches from their margins.

The intrusives east of the Sierra Lucero escarpment differ slightly from those to the west. Many of the intrusives on the east give the appearance of being mixtures of hornblende-biotite syenite and augite diorite, even megascopically. The essentially homogeneous intrusive rocks to the west apparently are more thorough mixtures of the two rock types represented.

In contrast to the marked metamorphism associated with the intrusives west of Sierra Lucero, the sills on the east have metamorphosed the surrounding sediments only slightly. Even the sediments on the margins of thick sills show only slight hardening and a little bleaching. This lack of alteration of the intruded sediments may reflect the lesser degree of deuteric alteration undergone by the more easterly intrusives.

The form of the sills on the east, as suggested by their outcrop pattern (pl. 1), is apparently similar to that of some sills near Pando, Colorado, described by Tweto (1951). They are generally concordant, but thicken and thin irregularly in section and terminate in several ways, including the "driblet," the "branching terminations," and the "blunt wedge type" (ibid., fig. 7-A, 7-B). All of these types were observed in the sills west of the Sierra Lucero, where exposures are better than those to the east. In plan the sills appear to be lobate; that is, they have a fairly regularly shaped main body from which project tongues, arms, or lobes of various shapes and sizes. Only this type of description reconciles the irregularity of the intrusive outcrops in plan and their considerable stratigraphic range, although exposures east of the Sierra Lucero are too poor to permit clear definition of such features. The dioritic intrusives follow post-Cretaceous structures or trends (Kelley and Wood, 1946) in rocks as young as mid-Tertiary in Puertecito quadrangle (Tonking, 1957), where they have been disturbed by later movements of Tertiary(?) age. This evidence indicates that the intrusives are probably of mid-Tertiary or late Tertiary age.

All the dioritic intrusives in Mesa del Oro quadrangle are grouped under the designation Ti.

SIERRA LUCERO BASALTS

The oldest basaltic rocks exposed in Mesa del Oro quadrangle cap Pato Mesa, a remnant of the Miocene-Pliocene(?) (Wright, 1946) erosion surface on Sierra Lucero. This erosion surface lies about 1,500 feet above the present level of erosion. For convenience in reference, the rocks are termed Sierra Lucero basalts, from their occurrence on the Sierra. They were probably extruded during late Santa Fe (Pliocene?) time (Wright, 1946; Kelley and Wood, 1946). Two plugs that may have served as feeders for these flows are in sec. 32 and sec. 20, T. 6 N., R. 4 W.

The Sierra Lucero basalts are dark gray to black, with minute phenocrysts of olivine in a very fine-grained groundmass. They exhibit prominent columnar jointing. The tops of the flows are scoriaceous and some amygdules contain zeolites. The Sierra Lucero basalts attain a maximum thickness of about 150 feet.

MESA DEL ORO BASALTS

The Mesa del Oro basalts are named from their occurrence on Mesa del Oro. They flowed out onto a surface that has been correlated by Wright (1946) with the Pleistocene Ortiz surface of the Rio Grande Valley (Bryan and McCann, 1937). This surface, which lies from 400 to 800 feet above the present erosion level, is thought to be the same as that covered and preserved by the Lucero Mesa basalts outside of the quadrangle to the northeast.

The three flows of the Mesa del Oro proper were extruded from a single center, Cerros del Oro, in sec. 21, T. 5 N., R. 6 W. The Cerros del Oro is a large, partly dissected cinder cone which appears to have been a vent only for gases, bombs, and scoria, though it undoubtedly was the center of the volcanic activity. The flows probably made their way out through fissures at or near the base of the cone. Indeed, to judge from the large number of bombs and the amount of scoria scattered about on the surface of the youngest flow, the cone appears to be a rather late feature of the volcanic activity on the mesa. Some of the bombs contain fragments of igneous rocks, including pyroxenite and granite, which are thought to have been derived from the Precambrian basement. The scoria and bombs of the cone structure were mapped separately (Qmc), as was the consolidated breccia which forms "dikes" in the area (Qmt).

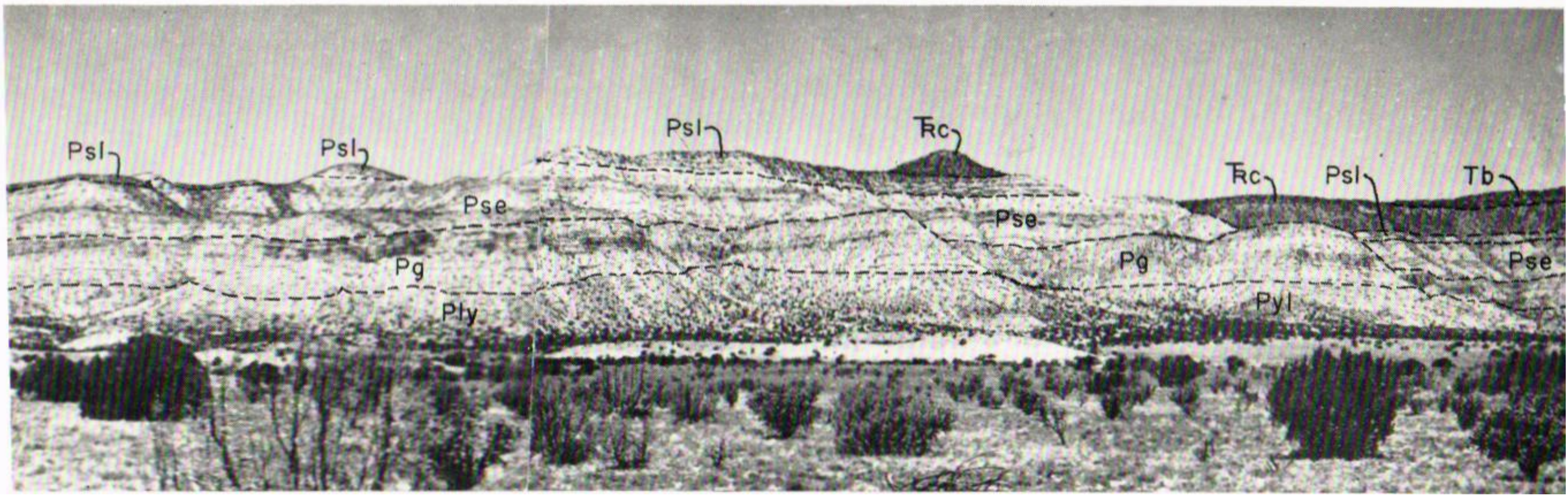
The Mesa del Oro flows are not coextensive. Each younger flow covers less area than the preceding one. The outcrop areas of the flows, from oldest to youngest, occupy 30, 15, and 31/2 square miles, respectively. It is probable that the oldest flow covered considerably more area before erosion, for a remnant (Wild Horse Mesa) lies some distance away from the present major outcrop. It is also evident that landslides have trimmed much material from the edges of the older flows.

The basalts of the three flows vary only slightly in their characteristics, so that at any given place it may be difficult to differentiate individual flows without reference to topographic features. In general, however, the oldest flow is characterized by fairly numerous phenocrysts of olivine in a fine-grained groundmass. The second flow contains fewer olivine phenocrysts. The third flow is set apart by its content of large crystals of plagioclase and its tendency to weather dark bluish gray in some outcrops. Much of the scoria of the cone also contains large feldspar crystals. All of the flows have scoriaceous tops. The margins of the flows are blocky, indicating an Aa-type of flowage. Maximum flow thickness is about 100 feet.

The age of the Mesa del Oro flows is assumed to be Pleistocene, based on the probable early Pleistocene age of the Ortiz surface. The flows have been designated Qmb1 (oldest), Qmb_2, and Qmb_3 (youngest). They are probably approximate correlatives of Kelley and Wood's (1946) Qb1 and Qb_2, the basalts of Lucero Mesa.

LAGUNA DEL ORO BASALT

On the west side of Mesa del Oro, the flow labelled Qmb_2 is partly covered by a flow from another center farther west. This flow is designated Laguna del Oro basalt (Qlb) from its occurrence near Laguna del



VIEW OF SIERRA LUCERO ESCARPMENT FROM LOS VALLOS.

PLATE 3

Oro. It is similar to the Mesa del Oro flows. Its exact age relation to the flows from Cerros del Oro is uncertain, though certainly it must be younger than Qmb2 and is probably very nearly the same age as Qmb3.

GUNN MESA BASALTS

The Gunn Mesa basalts were named from their occurrence on Gunn Mesa, in secs. 32 and 33, T. 6 N., R. 6 W., where they lie on the Mush Mesa surface of Wright (1946). These basalts appear to have been small flows, each covering from 2 to 4 square miles and each associated with its own eruptive center. Basaltic caps have protected the few surviving remnants of the Mush Mesa surface, which lies about 200 feet above the present erosion level. The Gunn Mesa flow is no more than 50 feet thick and resembles the youngest flow of Mesa del Oro (Qmb_3), even to the large feldspar phenocrysts. These rocks are late Pleistocene, slightly younger than the age of the Mush Mesa surface (Wright, 1946).

The Gunn Mesa basalt is designated Qgb. Also mapped were the scoria and bombs of the cone (Qgc) and the consolidated tuff-breccia in and around the cone (Qgt).

CERRO VERDE BASALT

The northeastern part of the quadrangle contains a few square miles of basaltic rock which flowed out from Cerro Verde, a large well-preserved, stratovolcano a few miles north of the quadrangle boundary. The cone was built up on a remnant of the Mush Mesa surface, but flows that ran northward descended to a younger surface (Suwanee surface of Wright, 1946), indicating that this volcanic activity must be somewhat younger than the Gunn Mesa activity. It is thought to have occurred in very late Pleistocene or early Recent time.

The Cerro Verde basalts (Qcb) are about 50 feet thick in the quadrangle.

CENOZOIC EROSION SURFACES

The late Tertiary and Quaternary history of Mesa del Oro quadrangle is characterized by long periods of erosion interrupted sporadically by the deposition of materials, largely basaltic flows and travertine. The erosion surfaces thus formed are largely rock-cut surfaces, even though the rocks may be extremely soft and nonresistant, and may therefore be referred to as pediments. These surfaces have been correlated by Wright (1946) with those of the Rio Grande Valley. Surfaces other than those described by Wright occur locally. These surfaces are generally erosional-depositional surfaces, such as stream terraces, characterized by gravels or other less coarse materials on their surfaces. Table 5 gives a résumé of the surfaces found in Mesa del Oro quadrangle.

TABLE 5. EROSIONAL-DEPOSITIONAL SURFACES OF MESA DEL ORO QUADRANGLE*

AGE	DESIGNATION	LEVEL ABOVE PRESENT EROSION LEVEL IN QUADRANGLE	COVER
Recent	Canada Bonita terraces		
	T_3	10-20 feet	soil, sand
	1^1	50+ feet	soil, gravel
	T_2	75-100 feet	soil, gravel
Recent and/or	Sierra Lucero pediment	10-300 feet	gravel
Pleistocene	Suwanee surface	150+ feet	basalt
Pleistocene	Mush Mesa surface	200+ feet	basalt
	Ortiz surface	400-800 feet	basalt
Miocene-Pliocene(?)	Sierra Lucero surface	1,500+ feet	basalt

* Modified after Wright (1946).

Structure

Mesa del Oro quadrangle lies on the west margin of the Lucero uplift, a large, northeast-trending, faulted monocline which forms part of the western margin of the Rio Grande trough and the southeast margin of the Acoma embayment of the San Juan Basin (Kelley, 1951). The regional dip in the area is to the west and northwest, into the San Juan Basin. The trend of the Lucero uplift is N. 30° E. Faults and folds in the quadrangle have a northward trend. Only in the southern part of the area is much structural disturbance in evidence. A large part of the northern half is covered by basalts, which obscure the attitudes of the beds. The folding and faulting appear to die out in that area, however, and give way to the north to northwestward regional dip, with only minor structural complications. Farther to the northeast, normal faults again cut the west margin of the Sierra Lucero (Kelley and Wood, 1946), but folding is absent north of the quadrangle boundary.

FAULTS

The fracture pattern in Mesa del Oro quadrangle follows a N. 10° W. trend. Exceptions to this rule are the bordering faults of the graben which brings Cretaceous rocks down several hundred feet to the level of the surrounding Triassic beds. These faults trend roughly north-south. Dikes, which must have followed lines of weakness, also trend N. 10° W.

The west flank of the Lucero uplift is characterized, in the southern part of the quadrangle, by a number of en echelon, high-angle normal faults. The faults are one-half mile to 5 miles long and have throws of from 50 to several hundred feet; the throw may decrease to zero at the ends of some of the faults. Slickensides inclined at 60 degrees to the horizontal show that some lateral displacement has taken place. The downthrown, or west, sides of these faults have been displaced toward the north. Subsidiary faults with eastward dips have produced one horst and one graben. The faults have dips of 65°-85° and trend N. 10° W.

The small graben of Cretaceous rocks in the southwestern part of the quadrangle is bounded by nearly vertical faults that have a small north-south component of movement. The exact nature of the faulting is in doubt, as it appears to end abruptly not far beyond the northern tip of the Cretaceous outcrop and dies out within 2 miles south of the border of the quadrangle. This fits into the regional fault pattern (Kelley, 1955). Inasmuch as some of the underlying formations are highly gypsiferous, removal of gypsum by solution could have caused slumping which may have produced the observed faults. Such large-scale slumping, a result of the removal of soluble materials from underlying formations, is far from unusual (Stokes, 1948). The throws of the faults probably do not exceed 300-500 feet. The synclinal structure of the

DRILLER'S LOG OF FIELD (MACDONALD STATE) WILDCAT OF THE OHIO OIL CO. AT NW¼NE¼ SEC. 32, T. 4 N., R. 6 W., SOCORRO COUNTY, NEW MEXICO*

CHARACTER OF ROCK PENETRATED	BOTTOM (feet)	FORMATION†	THICKNESS (feet)
Red and purple shale	335		
Gray sand	347		
Red shale	355		
Gray sand; water	375		
Gray shale	380		
White and gray sand; 4,000 bbl artesian water	470		
Red shale	573	Chinle formation	573
White and blue lime; 6,000 bbl artesian water; total 10,000 bbl	630	San Andres formation	
Sandy blue shale	680	Upper limestone member	107
Sand and gypsum	700		
White lime	745		
Red shale	770		
Black lime	875		
White sand	895		
Yellow sand	900		
White lime	920		
Black lime	945		
Hard shells and gypsum	975	San Andres formation	
Gypsum and sand	990	Lower evaporite member	310
White and brown sand (Glorieta sand); 20 bbl artesian water	1,185	Glorieta sandstone	195
White soft lime or shale	1,225		
Red sandy shale	1,260		
Red sand	1,280		
Black lime	1,325		
Black sandy lime and gypsum	1,370		
Sandy lime with some water	1,405		
Lime*	1,415		
Hard sand and lime	1,450		
Broken lime and hard sand	1,480		
Hard sand with streaks of shale	1,515	Yeso formation	
Broken sand, shale, and lime	1,588	Los Valles member (inc.)	403
Igneous rock, mostly quartz and mica	1,695	Precambrian? May be Tertiary	
Lava	1,830	intrusive	
Broken lime, lava, and sand	1,845		
Broken lava and sand	1,870		
Lava	1,997 T. D.		

* This log is modified from the original published by Darton (1928-a, p. 135). In the original, the igneous rock is said to have been reached at 1,410 feet. However, the driller's log, obtained through the courtesy of the Ohio Oil Company, indicates that sediments were found below that depth. It may be that the material encountered was caved and that the published log was a corrected one.

† The tops of the formations were picked by the author.

downfaulted block probably results from drag along the marginal faults (section C-C, pl. 1).

No faults are known in the northern part of the quadrangle. Darton (1928, p. 126) has reported "faults or landslips" at Pico Pintado, in the northwest corner of the area. There landslide blocks occur on the east flank of an outlier of Jurassic and Cretaceous beds capped by basalt. Blocks as much as a mile long and several hundred yards broad have slipped down from the cliffs over the soft and yielding Chinle shales which underlie the more resistant beds. Similar large-scale landslips occur along the margins of the basalt-topped mesas in the area.

FOLDS

Long, gentle, sinuous folds are exposed in the southern half of Mesa del Oro quadrangle just west of the belt of en echlon faults that cut the west margin of the Sierra Lucero. The folds trend roughly north-south. In the western part of the area, dips are from 5 to 15 degrees; toward the east, dips as great as 25 degrees occur. The more southern of the eastern folds (e. g., Miller anticline, Well anticline) are intruded by monzonitic sills. The Payne anticline, near the western border of the area, was drilled in 1926 by the Ohio Oil Company. No oil was discovered, and the well was abandoned, uncapped, to serve as a source of artesian water. No sediments older than the upper part of the Yeso formation were found in the subsurface at that locality. Drilling stopped after 409 feet of "igneous rock, mostly quartz and mica" had been penetrated. It is uncertain whether the rock described is a part of the Precambrian basement or a large intrusive similar to the dikes and sills which penetrate the strata to the east. The driller's report of "lava" in the bottom of the hole tends to confirm the latter idea. In addition, some "broken lime" is reported in the hole about 230 feet below the top of the igneous rock. Whether this was material that caved into the hole from above or actually was in place is a subject for speculation. If it could be shown that the "broken lime" was in place, the hypothesis that the igneous rock is intrusive would be much strengthened. On the other hand, the reported presence of quartz, if it was indeed that mineral, suggests that the rocks might be Precambrian. Darton (1928-a, p. 135) reported that some of the rocks were very hard and contained much mica. He expressed the opinion that the rocks are Precambrian and that the sediments are overlapping a Precambrian high. His opinion is probably based on the misconception that the well penetrated the Magdalena formation (ibid.), whereas it actually penetrated only through the upper 303 feet of the Yeso formation. Nor does it seem likely that more than 3,000 feet of beds should have pinched out over a distance of less than 15 miles. The possibility that a post-Triassic (mid-Tertiary?) intrusive of unknown shape, but considerable size, may occur in the subsurface in that area cannot be overlooked.

The folds are believed to be parallel, dying out with depth. This hypothesis is partly substantiated by the gentle nature of the folding and the decrease in sharpness away from the Sierra Lucero escarpment.

Very minor east-west folding is in evidence west of the Juan de Dios fault. Somewhat larger folds of similar nature occurring in the San Andres limestone north of Pato Mesa, are probably minor crossfolds, formed as a consequence of the Lucero uplift.

Geologic History of the Region

The geological history of the region in pre-Mesozoic time is obscure. However, lack of any pre-Pennsylvanian sedimentary record suggests that the area was a rather stable early Paleozoic highland, and may have provided detritus for the accumulation of Paleozoic sediments elsewhere. Toward the end of the Paleozoic era shallow marine conditions (Pennsylvanian), followed by subaerial flood plain conditions (lowest Permian) and restricted marine environment (upper Lower Permian and Middle Permian), prevailed. It is uncertain whether Precambrian outliers were present during this time. In the last part of the Permian period the area was a lowland subject to erosion.

The Mesozoic era was one of alternating erosion and deposition. After a long period of erosion, the Upper Triassic Chinle formation was deposited on a flood plain. As the quadrangle is just on the edge of a Jurassic-Lower Cretaceous highland, which extended over a wide area to the south, only a small thickness of Upper Jurassic sediments was deposited near its northern boundary. Over the remaining part of the quadrangle the Chinle formation was eroded to varying degrees. This erosion was deepest at the south. The regional unconformity, between Triassic and Cretaceous strata, appears to have been marked by only moderate erosion. Encroachment of the Upper Cretaceous seas from the north led to the development of the typical transgressive-regressive sequence of the Dakota, Mancos, and Mesaverde formations. Until that time, toward the close of the Upper Cretaceous, orogenic activity was rather limited, and broad epeirogenic warping was the main type of movement to which the area was subjected. The present structural pattern is a result of Cenozoic deformation.

It is evident that sometime during the close of the Cretaceous and near the beginning of Tertiary time the entire region was subjected to orogenic and epeirogenic movements of major proportions; so great were they, in fact, that the area was never again to have marine incursions. Rather, it has been, from time to time, subject to renewed uplift and rapid erosion. During this major epoch of orogeny (Laramide Revolution), the Lucero uplift was formed as a result of compressive forces which probably acted in a general east-west direction. It is probable that the anticlinal structures in the southwestern part of the quadrangle were also formed at that time. To the south extensive conglomerates (Baca formation) testify to the formation of structural features of considerable relief and to their rapid denudation. Relaxation of the compressional forces that formed the Lucero uplift may have resulted in normal faults, especially those on its west margin, which lie at an oblique angle to the strike of the uplift. However, some of the faults may have had their inception during the period of compression, when small tensional areas undoubtedly developed. A period of intrusion followed, during which the sodaclase-diorite dikes and sills, so common in the area, were emplaced.

Orogenic movements did not entirely cease after the intrusive period. Continually renewed movement occurred along faults on the margins of the Rio Grande depression, especially during Miocene time. Broad erosion surfaces were formed in the western marginal areas during periods of relative quiescence. One of these surfaces is thought to be as early as late Miocene or early Pliocene. Remnants of these surfaces have been preserved as broad mesas, largely because of volcanic activity which capped parts of the surfaces with resistant basaltic lavas. Each renewal of uplift and erosion appears to have been followed by additional volcanic eruptions. During Miocene, Pliocene, and early Pleistocene time the material derived from planation of these wide marginal areas was redeposited in the Rio Grande depression as sediments (Santa Fe group). The sediments were tilted and faulted in late Tertiary time, and later beveled with additional deposition in low areas, until the entire surface thus formed (Ortiz surface of early Pleistocene age) became a widespread peneplane. Later renewals of uplift caused dissection of the Santa Fe beds. Late erosion surfaces have not been so widespread as the Ortiz surface. The large number of low terraces arranged in a steplike manner along the margins of many of the present streams suggest recurrent erosion cycles. They may also indicate continued periodic uplift and erosion into Recent times.

Petrology and Petrography of the Eruptive Rocks

Both the intrusive and extrusive igneous rocks of the Mesa del Oro quadrangle were studied in greater detail than is normally called for in a quadrangle description, to determine (1) if progressive geochemical and petrographic changes occurred in a succession of essentially basaltic rocks whose relative age could be determined in the field, and (2) if each flow or group of flows had characteristics that would permit correlation of isolated remnants separated by erosion subsequent to extrusion. Also, it was a point of interest to determine if these rocks, both intrusive and extrusive, occurring in comparatively small volume, had characteristics different from those of similar rocks in the Datil region to the south, where volcanic rocks occur in enormous volume. E. Callaghan (personal communication) has held that rocks having unusual or aberrant characteristics are more likely to occur in areas where the volume of igneous material is comparatively small than in areas of great accumulations.

Chemical analyses of five samples from this area, both intrusive and extrusive, show that these rocks are uniformly high in soda and low in potash. All the flow rocks contain less than 50 percent silica, and the intrusive rock shows only slightly higher amounts. All these rocks are undersaturated with respect to silica, and all show nepheline and olivine in the norm.

SODACLASE-DIORITE INTRUSIVES

The thick sills west of the Sierra Lucero are composed of greenish-gray, medium- to fine-grained, holocrystalline rock with pink and white feldspars, flakes of dark biotite, and elongate crystals of pyroxene. The rock on the margins of the sills is black and aphanitic, apparently chilled.

The medium- to fine-grained rock is hypautomorphic granular with intersertal structure. The original minerals are plagioclase, orthoclase, augite, and brown biotite, with apatite and ores for accessories. The plagioclase is albite, which forms poorly terminated laths 0.5-1.5 mm long with albite and carlsbad twinning. Complex twinning is the rule and albite twinning alone is not common. The maximum extinction angle on albite twinning is 12 degrees. Orthoclase occurs very sparingly as irregular interstitial masses and as laths 0.4-1.0 mm long. It has a large 2V, is optically (—), and has a poorly defined but small (0°-5°) extinction angle. The presence of potassium-rich feldspar has been verified by staining with sodium cobaltinitrite, after the manner of Chayes (1952). The pyroxene is pale-brownish to greenish augite with a large 2V and is commonly twinned on (100). It occurs as subhedral, slightly corroded crystals 0.2-0.7 mm long and is probably an iron-poor variety.

Biotite, occurring as flakes and fragments 0.2-1.3 mm long, is optically (—) with a 2V of about 6 degrees, and pleochroic from light yellow to pale red brown and pale brown. It is apparently a magnesian variety. Apatite is found as needles as much as 1.5 mm long and with cross-sections 0.1-0.2 mm in diameter. Magnetite is common. Pyrite is rare, as cubes up to 0.7 mm on a side, surrounded by rims of hematite. Hematite also forms rims on subhedral masses of magnetite, .05-0.1 mm in diameter.

The rocks have been somewhat albitized. Albite forms rims around earlier albite crystals and also occurs as laths 0.4-1.5 mm long, which commonly exhibit carlsbad twinning. The rim albite is almost completely unaltered in contrast to the highly sericitized nature of the earlier albite and orthoclase. The late or rim albite was apparently introduced by the deuteric solutions, which must have been rich in soda. It is possible that the early "albite" may have been more calcic and was changed to albite by the introduction of soda, or by removal of calcium from the plagioclase to form clinozoisite. Other mineralogical changes include the transformation of augite and biotite to chlorite and the alteration of feldspar to sericite or to clinozoisite, zeolites (mainly chabazite), calcite, and quartz.

The chlorite may be pale-green to colorless penninite or small fan-shaped aggregates of prochlorite. It is found pseudomorphous after biotite, which is only partly replaced at many places, or, more rarely, as small isolated patches. Clinozoisite occurs as small isolated masses of radiating crystals, usually closely associated with feldspar. Calcite occurs interstitially as small irregular masses. Chabazite is found as small patches of pseudoisometric crystals. Quartz is fairly rare as interstitial masses and is not present in some specimens. Sericite occurs ubiquitously in all feldspar, except albite, as small and large (but still minute) flakes.

The mode of a thinsection of the rock from one of the thick sills in the northern part of the quadrangle, in volume percent, is as follows:

feldspar	61.3 percent
chlorite	13.7
augite	9.5
ores	6.7
biotite	5.8
clinozoisite	1.4
apatite	1.2
calcite	0.4
Total	100.0 percent

The chemical analysis and norm of this rock are given in Tables 8 and 9.

The thin sills are aphanitic and black, resembling basalt megascopically. Microscopic examination of a specimen of a thin sill showed it to be so altered as to prevent adequate determination of the original mineral content. The original texture is hypautomorphic granular with intersertal structure. Early plagioclase (oligoclase?) occurs as small, poorly terminated laths 0.1-0.3 mm long. Twinning after both albite and carlsbad laws is present, but is poorly defined because of alteration. Of the few measurable extinction angles on albite twins the maximums were about 10 degrees. Orthoclase is present interstitially and as stubby laths 0.2 mm long. The extinction angle is poorly defined but small. Albite occurs as essentially unaltered and partly altered laths 0.3 mm long, many of which exhibit carlsbad twinning, and as rims around embayed and partly replaced earlier plagioclase crystals. Outlines of relict crystals as much as 1.2 mm long, now composed completely of chlorite and calcite, suggest original augite. Outlines suggesting altered amphibole crystals have been similarly preserved. Accessory minerals are apatite and ores, largely magnetite, although one large crystal of pyrite and some hematite were noted. Apatite occurs as thin needles as much as 1.5 mm long. Hexagonal cross-sections are generally less than 0.1 mm in diameter. The ores are small anhedral masses .05 mm in diameter, with the exception of the pyrite crystal, which is 0.5 mm on a face. The feldspars, with the exception of late albite, are partly altered to calcite, quartz, and clinozoisite, and are highly sericitized. It is evident that the rock is similar in composition to the rock in the thick sills and is similarly altered.

The intrusives east of the Sierra Lucero escarpment appear to be "mixed rocks," composed of two rock types. They may show small masses of pinkish-red rock interspersed with green-gray rock in a gray matrix. The entire rock is fine grained, with flakes of biotite and dark elongate crystals of amphibole and pyroxene. Microscopically it is seen that the pink parts of the mass contain brown hornblende, brown biotite, orthoclase, oligoclase, and some albite, whereas the green-gray parts contain augite, oligoclase, and some albite. The accessories — apatite, magnetite, hematite, and minor pyrite — are the same in both parts. The gray parts of the rock appear to be a fairly homogeneous mixture of the two types of material; one is a hornblende-biotite syenite; the other, an augite diorite. Others of the rocks are more nearly homogeneous, containing all three ferromagnesian minerals scattered through them. At some places the intrusives contain exclusively brown biotite as the ferromagnesian mineral accompanying augite; hornblende is completely absent. However, in the hornblende-bearing rocks there is some evidence that hornblende has been converted to biotite by the alteration which affected all the rocks to a greater or lesser extent. With the exception that some of the rocks appear to be mixed, these intrusives resemble those west of the Sierra Lucero. The accessories are the same, and alteration has yielded the same mineral suite previously described, with the addition of some acicular tremolite in one rock. The tremolite is presumed to have resulted from the alteration of augite. Within Mesa del Oro quadrangle the rocks east of Sierra Lucero are generally less altered than those farther west. With the exception of one thick dike, all of the intrusives east of Sierra Lucero in Mesa del Oro quadrangle were emplaced as sills.

Small xenoliths of a rock which petrographically resembles the intrusives just described, except that it is much coarser grained, occur in the basalt of the plug at NE¼ sec. 32, T. 6 N., R. 4 W. Megascopically the rock is coarse grained and pale gray, with black crystals of augite as much as 2 cm long, some of which form radiating aggregates.

In thinsection the rock is seen to contain andesine, oligoclase, orthoclase, augite, apatite, magnetite, hematite, and a little iddingsite, which may have been introduced. Andesine and oligoclase occur as poorly terminated laths 0.2-4.0 mm long, averaging 1-2 mm long, with carlsbad and albite twinning. Orthoclase, interstitial, and as small, stubby, poorly terminated laths is untwinned, optically (—) with a large 2V, and has a very small extinction angle. Albite forms outer zones on plagioclase crystals at many places. It also occurs as small, untwinned crystals interstitially. Augite is found as pale purplish-brown, subhedral to euhedral, slightly corroded crystals 0.5-5 mm long. Twinning on (100) is common. The extinction angle is 30°-45° and wavy extinction is common. The mineral is optically (+) with a large 2V. Some sections are slightly pleochroic from pale purplish brown to greenish yellow brown. The purple color of this augite suggests that it may be somewhat titaniferous. The ores occur as large subhedral to euhedral crystals of magnetite rimmed with hematite. The size range is 0.2-1.6 mm in the longest dimension, intermediate to large sizes predominating. Apatite needles are as much as 1.5 mm long; cross-sections are about 0.1 mm in diameter. Alteration in these rocks is similar to the alteration in the sills and dikes in the quadrangle. It is evident that the rock has been albitized as shown by the change in soda content of the plagioclases. Original andesine has been partly transformed to oligoclase and much of the more calcic feldspar was probably completely altered to, or replaced by, albite. Augite was converted to chlorite at a few places. Some of the feldspars are slightly sericitized and locally they may be replaced by clinozoisite accompanied by very minor calcite. Though amphibole and biotite are absent, these rocks are essentially similar to those which form the intrusive sills and dikes in the area. Indeed, though exposures are poor, three small areas of rock similar to that in the xenoliths were found in sec. 21, T. 6 N., R. 4 W. They may be the outcrop of a fairly extensive intrusive body, though no conclusion as to its size could be drawn because of the paucity of outcrops.

The mode of one of these rocks, in volume percent, is as follows:

feldspar	61.5 percent
augite	17.6
ores	10.8
chlorite	8.3
apatite	1.8
Total	100.0

This mode shows some striking similarities to that of the thick sill given on a previous page.

All the rocks discussed above have the same general mineral composition and are similarly altered, suggesting that they are genetically related. The "mixed rocks" and more homogeneous rocks east of Sierra Lucero and the homogeneous rocks west of Sierra Lucero apparently had a common origin. The consistent homogeneity of the most westerly rocks may possibly result from the fact that they were intruded at a level several hundred feet higher stratigraphically than those on the east. The additional travel through the sediments could have allowed more complete mixing of rocks. It is probable that some of the rocks east of Sierra Lucero cooled before they could be completely homogenized.

The "mixing" may have resulted from the mingling of two magmas, the addition of basement rock xenoliths to one magma, or may be an alteration effect. Undoubtedly other possibilities might be suggested.

The alteration of the intrusives may have been caused by the introduction of soda-rich deuteric solutions. Alteration effects in a similar intrusion in secs. 29 and 32, T. 3 N., R. 3 W., about 5 miles southeast of the southeast corner of Mesa del Oro quadrangle, where alteration appears to have been consistently more pronounced, are described in detail by Duschatko and Poldervaart (1955). They also indicate that soda-rich deuteric solutions have altered the rocks.

Many of the thicker intrusives in Mesa del Oro quadrangle have metamorphosed the sediments around them over distances ranging from a few feet to several tens of feet from the contacts. Conversion of shales to hornfels and silicification and bleaching of sandstones are the most common metamorphic effects. The thick intrusives west of Sierra Lucero have affected the sediments for a greater distance from their contacts than those to the east. The thinner sills and dikes have only minor effects on the enclosing sediments.

The metamorphism of the sediments surrounding the intrusives is believed to have been caused by two factors: (1) the heat of the intrusives, and (2) the deuteric solutions which altered the intrusives. The heat factor is worthy of consideration in that the "mixed" and "prematurely cooled" rocks east of Sierra Lucero and the thin, completely chilled dikes and sills in both areas have affected the sediments only very slightly. The deuteric solutions must also be a large factor, as the most altered intrusives also have the most extensive and profound related metamorphic effects. The intrusive described by Duschatko and Poldervaart (1955), which is outside the quadrangle, is more altered than any described here, and the country rock around it has been albitized. The silicification of the country rock associated with the thick intrusives west of Sierra Lucero appears to be at least partly the result of movement from the intrusives of silica liberated by the deuteric alteration of feldspar to calcite and quartz.

Because detailed study of the intrusives has necessarily been restricted by the broader considerations involved in mapping an area of quadrangle size in a short period of time, only a few conclusions can be reached concerning the petrogenesis of the rocks. The intrusives appear to be genetically related and to have formed from a magma (or magmas) which was normally syenodioritic. The rocks were permeated by sufficient water and hyperfusibles after crystallization to cause their albitization. The solutions are presumed to have been deuteric and from the same underlying source as the magma, though some of the water may have been resurgent. The rocks were intruded under a cover of less than 3,000 feet and probably less than 2,000 feet at many places, as can be seen by consideration of the structure, stratigraphy, and geologic history of the area. Duschatko and Poldervaart (1955) state that the intrusive they studied was probably spilitic at the time of its emplacement; that is, it was crystallized as a soda-rich rock, though they admit that much albite was also introduced. However, Gilluly (1935) has shown that originally spilitic magmas are extremely improbable and indicates that spilitic rocks probably are formed as the result of albitization of more normal rocks by deuteric or other solutions. In the intrusives within Mesa del Oro quadrangle the albite present in the rock is divided between that which is altered and that which is usually completely unaltered, suggesting that it is at least partly deuteric and that the enrichment in soda resulted from the action of the same solutions that caused the other alteration in the rocks. It is the author's opinion that the rocks may have contained some albite, and probably more orthoclase. If so, they were normal and syenodioritic before the alteration took place. Relict embayed masses of oligoclase enclosed by broad rims of albite tend to substantiate the contention that originally more calcic plagioclase was either enriched in soda or selectively replaced by albite after its crystallization. The presence of potash feldspar is also at variance with its apparent absence in the highly altered intrusive rocks examined by Duschatko and Poldervaart (1955), but the potash-rich feldspar may have been transformed to albite by deuteric action. The lime, soda, and potash in the rocks analyzed for this report were plotted on a triangular diagram and it is evident that these rocks are not as rich in soda as the rocks discussed by Duschatko and Poldervaart. The differences in character and degree of alteration of the rocks may account for some of the divergence in viewpoints concerning the exact nature of the intrusives.

BASALTIC ROCKS

The basalt rocks of Mesa del Oro quadrangle occur as plugs, remnant cinder cones, and flows which cover a large part of the area. Though the rocks are of several ages and come from several different eruptive centers (table 4), they resemble each other physically, petrographically, and chemically. These resemblances make it probable that the rocks were developed under very similar physical and chemical conditions.

Megascopically the basalts are uniformly black or dark gray. Most of the flows have scoriaceous or amygdaloidal tops. Though predominantly fine-grained, the rocks vary considerably in grain size. Most are at least slightly porphyritic, with small phenocrysts of olivine and, more rarely, augite. Larger phenocrysts of feldspar, generally andesine, characterize a few of the late flows.

In thinsection these rocks are characterized by diktytaxitic to slightly amygdaloidal structure. The texture is intergranular to ophitic. The rocks are generally porphyritic, with phenocrysts of olivine or augite as much as 5 mm long. The groundmass feldspars range in average size from less than 0.1 mm long to 0.5 mm long. The rocks are made up almost entirely of four minerals: labradorite, augite, olivine, and magnetite. Nepheline was not recognized though the high soda content of the rocks makes it probable that some is present. Some sections contain as much as 15 percent glass, and a few contain zeolites and calcite. In spite of the presence of P_20_5 in all the analyzed specimens, no apatite was found in any of the basalts in Mesa del Oro quadrangle.

Labradorite occurs as laths in the groundmass of all the basaltic rocks. It appears to have crystallized before augite in most of the samples examined. It ranges in size from .05 mm long in very fine-grained samples to 1-2 mm long in those of the coarsest grain. Commonly it is profusely twinned; carlsbad, albite, and combined twinning are almost characteristic. Pericline twinning occurs only rarely. Zoning is not common; neither is it rare. With a few exceptions the plagioclase becomes less calcic in the younger flows (table 6). The optical sign and 2V of the mineral are not easily determinable because of the usual small size of the individual twins. Labradorite makes up 40-60 percent of the volume of the rocks.

Augite occurs in intergranular or ophitic textures and, more rarely, as phenocrysts. It is pale gray brown to pale greenish brown in thin-section. Only rarely is it euhedral. It is occasionally slightly pleochroic

TABLE 6. VARIATION IN COMPOSITION OF GROUNDMASS PLAGIOCLASE IN BASALTS OF MESA DEL ORO QUADRANGLE

Basalt	Age	Feldspar (groundmass only)	Number of Samples
Sierra Lucero (Tb)	Pliocene(?)	$Ab_{37}An_{63}$	5
First Oro (QMb_1)	Early Pleistocene(?)	$Ab_{41}An_{59}$	5
Second Oro (Qmb_2)	do.	$Ab_{42.5}An_{57.5}$	5
Third Oro (Qmb_3)	do.	$Ab_{46}An_{54}$	3
Laguna del Oro (Q1b)	do.	$Ab_{43}An_{57}$	3
Gunn Mesa (Qgb)	Middle(?) Pleistocene	$Ab_{46}An_{54}$	1
Cerro Verde (Qcb)	Late(?) Pleistocene(?) or Recent(?)	$Ab_{38}An_{62}$	1

from pale yellowish green to pale grayish brown, but pleochroism is seen only in sections that are slightly thicker than the usual .03 mm. Cleavage is generally well marked. Grain size ranges from less than .05 mm in the very fine-grained basalts to 2 mm where it occurs as phenocrysts. The average size is 0.2-0.4 mm. When phenocrysts occur, it can be seen that the mineral has crystallized in two generations, the phenocrysts being earlier. The augite is optically (+) with a 2V of about 60°. The extinction angle ranges from 35° to 45°; in most crystals it is 40°-45°. Twins and twin seams on (100) occur in the coarser rocks but are by no means common. Wavy extinction is more common than twinning, but still fairly rare. Augite makes up 20-30 percent of the volume of the rocks.

Olivine occurs in many of the basalts only as large, rounded or corroded, partly altered euhedral to subhedral phenocrysts. In some rocks it is found both as phenocrysts and in the groundmass, where it occurs as small euhedral crystals. In many sections it has been partly altered to dark red-brown iddingsite. More generally, it exhibits only slight brownish iron staining on the crystal margins. The mineral is usually colorless but may have a pale greenish tint, especially in thick sections. It is optically positive, with a large 2V, although a few crystals with negative signs occur. Commonly only optic axis figures are obtainable. The crystals are usually highly fractured and many include small euhedra of magnetite. Grain size may be as small as 0.1 mm when the grains form part of the groundmass, but phenocrysts 3 mm long are not uncommon. The average phenocryst size is 0.4-1.0 mm. Olivine makes up 5-15 percent of the volume of the rocks.

Magnetite occurs in the basalts as small euhedral crystals, cubic or octahedral in habit, as small rounded, subhedral blebs, and as thin laths. This last peculiarity of habit suggests that it may be somewhat titaniferous. The titania content of the analyzed basalts suggests that there can be no great amount of ilmenite present. Magnetite is apparently an essential constituent of all the basalts, making up 4-10 percent of the volume of the rocks.

Andesine occurs as scattered large poikilitic phenocrysts in the uppermost flow of Mesa del Oro (Qmb_3) and in the Gunn Mesa basalt (Qgb). It is twinned according to the albite and carlsbad laws. Composition is generally calcic, close to the labradorite range. Crystals as large as 2 inches long have been found weathered out of scoria on Cerros del Oro, but the more common size is 5 mm. The composition of these plagioclase phenocrysts indicates a puzzling reversal of the generally accepted crystallization sequence, as the groundmass feldspar, which apparently crystallized later, is labradorite. Such a feature may possibly be explained by slow late cooling, but in many cases it seems evident that the large andesine phenocrysts were early formed. The presence of these phenocrysts in large numbers and their poikilitic texture militates against the possibility that they may be xenocrysts. Andesine does not generally make up more than 5 percent of the volume of the rocks in which it is present in this quadrangle.

Iddingsite, an alteration product of olivine, completely replaces some olivine crystals and, more commonly, forms rims around olivine and replacement bands along cleavages in the olivine crystals. It is brownish red to blood red, shows lamellar structure, and has high relief. The 2V is large and the single optic sign determined was (+). Though no iddingsite is present in many of the basalts, it has replaced as much as 50 percent of the olivine in a few.

Zeolites of at least two kinds are commonly present as amygdule fillings. Small amounts of chabazite occur in association with minor calcite in some of the amygdaloidal rocks. The chabazite is found as small rounded fibrous masses and as small pseudoisometric crystals in the amygdules. Birefringence is very weak. Thomsonite occurs as sheaf-like fibrous aggregates associated with small amounts of calcite. Its wavy extinction, fibrous habit, and weak birefringence serve to identify it.

Calcite sometimes forms amygdule fillings. It is always anhedral, but easily identified by its cleavage and birefringence.

In addition to the well-defined minerals mentioned above, many of the basalts contain small amounts of brown, translucent, isotropic glass which commonly contains many minute particles of magnetite. The refractive index of the glass is less than that of balsam. One thin-section contains over 15 percent of this glass, though many of the rocks contain no glass at all. The presence or absence of glass in the rocks is apparently dependent on the cooling rate.

The high soda content of these rocks indicates that they probably contain some nepheline, though none has been identified in them.

EJECTA

The breached cone, Cerros del Oro, is a large asymmetrical pile of volcanic ejecta composed largely of scoria with scattered dikes of consolidated breccia. The dikes appear to have formed in areas where some lava made its way into the scoria and cemented it. The scoria itself varies considerably in vesicle size and color. Vesicles range from less than 1 mm to several centimeters in diameter. The color may be black, mottled black and red, or entirely red to red brown, depending upon the degree of oxidation. Large crystals of plagioclase feldspar (andesine) are scattered in the scoria fragments. Volcanic bombs form a small but conspicuous part of the ejecta near the crater opening.

The breached cone on Gunn Mesa appears to have been built up largely of basaltic tuff, which has been consolidated into porous red-brown tuff-breccia containing many fragments of aphanitic basalt. Small amounts of scoria and a few bombs are scattered around the cone and partly cover the tuff-breccia at many places.

The volcanic bombs of Cerros del Oro range in size from less than 2 inches to over 2 feet in diameter. Those less than 6 inches in diameter

TABLE 7. MODES OF SOME BASALTS OF MESA DEL ORO QUADRANGLE
(In volume percent)

Sierra Lucero basalts (Tb)	1*	2
labradorite (An_{63}) and feldspathoids(?)	44.4	43.2
augite	28.0	31.4
olivine	20.4	18.6
magnetite	7.2	6.8
Total	100.0	100.0

* Plug.

Mesa del Oro basalts: first flow (Qmb_1)	1	2	3
labradorite (An_{60}) and feldspathoids(?)	50.3	40.1	43.7
augite	24.5	23.1	21.1
olivine	14.1	16.2	17.8
magnetite	3.9	4.4	4.7
glass	7.2	16.2	12.7
Total	100.0	100.0	100.0

Mesa del Oro basalts: second flow (Qmb_2)	1	2
labradorite ($An_{57.5}$) and feldspathoids(?)	48.9	47.2
augite	29.8	24.1
olivine	15.8	13.3
magnetite	5.5	4.3
glass	—	11.1
Total	100.0	100.0

Mesa del Oro basalts: third flow (Qmb_3)	1	2
labradorite (An_{54}) and feldspathoids(?)	51.1	50.8
augite	36.8	34.6
olivine	7.1	7.0
magnetite	5.0	7.6
Total	100.0	100.0

Laguna del Oro basalt (Qlb)	1	2
labradorite (An_{67}) and feldspathoids(?)	61.5	59.4
augite	19.5	19.7
olivine	13.7	15.8
magnetite	5.3	5.1
Total	100.0	100.0

No modes were obtained for the Gunn Mesa and Cerro Verde basalts because of their exceedingly fine grain.

are commonly subround and slightly elongate. Larger bombs have teardrop shapes. The great majority of them are simple cooled masses of lava, but one proved to be only a shell of aphanitic lava with a geodelike center in which stalactitic coatings of calcite or aragonite had formed on pinnacles of lava. This bomb was probably gas filled at the time of its eruption. Others were found to contain xenoliths.

Two types of xenoliths were found in the lava bombs. One type is a coarse-grained, hypidiomorphic granular granite made up of micro-dine, quartz, albite, and minor muscovite, with accessory magnetite and hematite. Microcline occurs as large subhedral crystals with poorly developed twinning in two directions. It is optically (—), with a large 2V. At places it is perthitic. Some crystals are slightly sericitized. Quartz is anhedral, uniaxial, optically (+). Albite occurs as untwinned subhedral masses and as small laths with albite twinning. The extinction angle on albite twins is about 15°. It is optically (±), with a large 2V. Muscovite is sparsely scattered through the rock as small twisted colorless flakes with high birefringence. Small scattered anhedral magnetite blebs are rimmed with hematite. Xenoliths of this type of rock were found in two different bombs.

The second rock type that occurs as xenoliths is a medium-grained hypidiomorphic granular pyroxenite (websterite) which contains diallage, hypersthene, minor biotite, and magnetite. Diallage is pale bottle green and slightly pleochroic from pale yellow green to pale bottle green. The habit is stubby prismatic, with excellent parting parallel to (100). It is optically (±), with a large 2V, and has a large extinction angle. Hypersthene is found as colorless to pale-green subhedral prisms and cross-sections. It is strongly pleochroic from pale green to pale reddish brown. Birefringence is moderate and extinction is parallel. Cleavage is not always well defined. The mineral is optically (—), with a 2V of 60°-70°. Small flakes of dark-brown pleochroic biotite are scattered sparsely through the rock. The mineral is optically (—), with a 2V of about 8°. At some places where it appears to have replaced pyroxene it has a border of small cubes of magnetite. Accessory magnetite is very sparse as small anhedral masses.

The xenoliths have not been greatly altered by the basaltic lava. Most of them show only the effects of the separation of grains on their surfaces by the intrusion of small veinlets of lava.

The xenoliths are probably representative of the rock types present in the Precambrian basement of the quadrangle.

CHEMICAL DATA

The chemical analyses (table 8) show the basalts to be alkaline undersaturated types (basanites), though they are quite high in alumina. The normative plagioclase (table 9) is at variance with the actual composition of the plagioclase in the rocks, but this is a common difficulty that is apparently inherent in the normative system, as was brought out

TABLE 8. CHEMICAL ANALYSES OF SOME ERUPTIVE ROCKS OF MESA DEL ORO QUADRANGLE

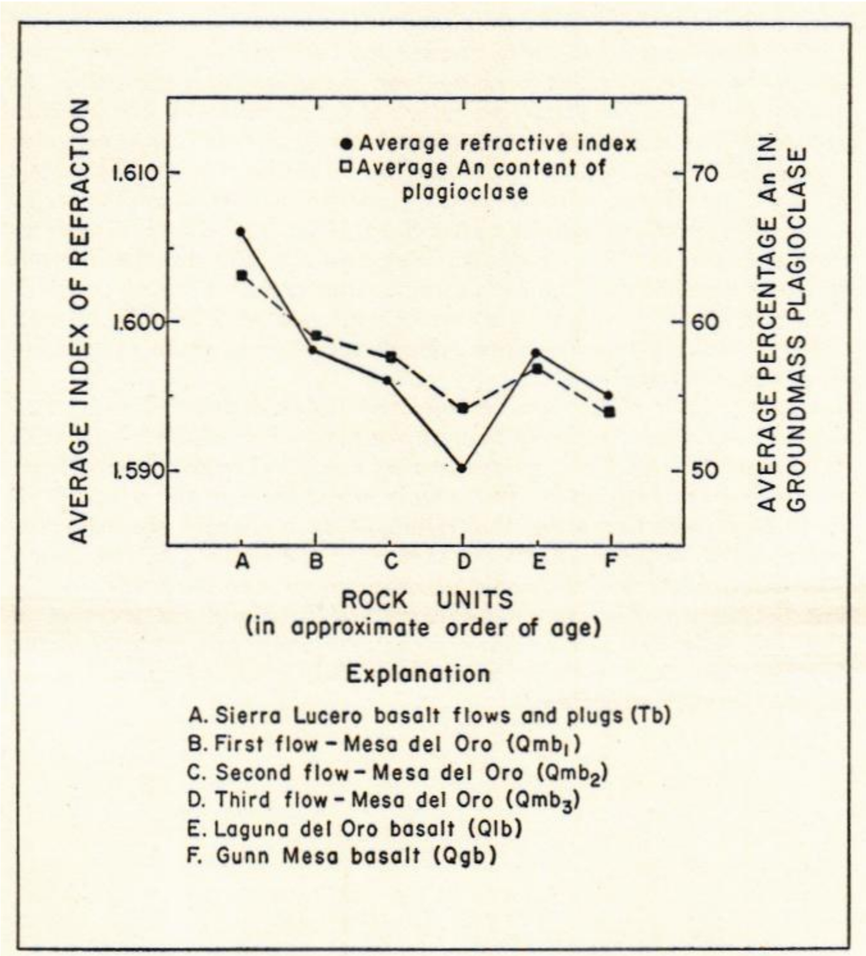
	A-53	A-2a	A-54	B-16	B-60
SiO_2	51.46	45.55	47.44	50.79	49.39
TiO_2	1.00	0.61	0.26	0.45	0.70
Al_2O_3	17.27	19.22	17.80	17.58	18.95
Fe_2O_3	5.06	6.16	3.70	1.32	2.64
FeO	4.55	4.38	5.78	9.46	7.47
MnO	0.13	0.21	0.29	0.22	0.24
MgO	5.55	7.48	8.83	6.72	4.29
CaO	4.69	9.31	7.39	7.45	6.74
Na_2O	6.70	5.08	5.58	5.43	6.50
K_2O	2.37	1.05	1.52	0.59	2.79
P_2O_5	0.50	0.44	0.45	0.14	0.54
H_2O+	0.68	0.55	1.11	0.24	0.09
H_2O-	0.44	0.42	0.33	0.10	0.11
S	tr.	tr.	tr.	tr.	tr.
Cr_2O_3	—	tr.	tr.	—	—
Total	100.40	100.46	100.48	100.49	100.45
alkali/lime	1.58	0.57	0.80	0.71	1.13
K_2O/Na_2O	0.23	0.15	0.18	0.07	0.29

Analyst: V. C. Juan.
A-53. Sodaclase-diorite sill (Ti) (SW¼SW¼ sec. 31, T. 6 N., R. 4 W.)
A-2a. Sierra Lucero basalt plug (Tb) (SW¼NE¼ sec. 21, T. 6 N., R. 4 W.)
A-54. Sierra Lucero basalt flow (Tb) (NW¼ sec. 17, T. 5 N., R. 4 W.)
B-16. First flow from Cerros del Oro (Qmb_1) (SE¼ sec. 9, T. 5 N., R. 5 W.)
B-60. Third flow from Cerros del Oro (Qmb_3) (NW¼SE¼ sec. 23, T. 5 N., R. 6 W.)

TABLE 9. NORMS OF SOME ERUPTIVE ROCKS OF MESA DEL ORO QUADRANGLE*

	A-53	A-2a	A-54	B-16	B-60
quartz	—	—	—	—	—
orthoclase	13.90	6.67	8.90	3.34	16.68
albite	37.20	17.82	20.96	33.01	19.91
anorthite	12.79	26.13	19.18	21.96	14.18
nepheline	10.51	13.63	14.20	7.10	19.03
wollastonite	3.02	7.19	6.15	6.26	6.61
enstatite	2.30	5.20	4.20	3.20	3.30
ferrosilite	0.40	1.32	1.45	2.90	3.17
forsterite	7.77	9.52	12.46	9.52	5.18
fayalite	1.73	2.45	4.69	10.00	5.92
magnetite	7.19	6.96	5.34	1.86	3.71
ilmenite	1.98	1.22	0.61	0.91	1.37
apatite	1.34	1.08	1.01	—	1.34
Total	100.13	99.19	99.15	100.06	100.40
normative plagioclase	$Ab_{74}An_{26}$ oligoclase	$Ab_{41}An_{59}$ labradorite	$Ab_{51}An_{49}$ andesine	$Ab_{58}An_{42}$ andesine	$Ab_{60}An_{40}$ andesine
CIPW class	II624	II624	II634	II635	II624

* See table 8 for identification of rocks.



PLOTS OF AVERAGE REFRACTIVE INDEX OF GLASSES PREPARED FROM BASALT AND AVERAGE ANORTHITE CONTENT OF GROUNDMASS PLAGIOCLASE IN THE BASALTS VERSUS RELATIVE AGES OF THE ROCKS.

Note the close correlation between decrease in refractive index and increase in soda in the plagioclase. Heavy lines show decrease in lime content of feldspar and decrease in refractive index in the Meso del Oro flow sequence.

Figure 2

by Johannsen (1931, p. 94-97). In addition, it is probable that the rocks contain some nepheline, as indicated by the high soda content and the occurrence of 10%-20% of nepheline in the norms.

Powdered samples of the analyzed specimens and also of many other specimens were fused in a carbon arc according to the method of Matthews (1951). The refractive indices of the glasses so formed fell into groupings that suggested real differences among the rock units and also certain relationships. It was also possible to set up a system by means of which the refractive indices of the glasses of various rock units might be used for correlation of the units (Jicha, 1954). The chemical analyses were obtained in the hope of providing substantiation for the inferred relationships, but unfortunately there are not enough analyses to give a clear picture. It is probable that the rocks are related chemically, though the few available analyses show enough variation to make correlation somewhat uncertain.

On the basis of decrease in refractive index of fused samples and decrease in the amount of calcium in the plagioclase of the basalts with decreasing age (fig. 2), it is thought that a small change occurred from relatively more basic to relatively more acidic rocks in the sequence of three flows from Cerros del Oro (Qmb1-3). Such changes are known to occur in flow sequences from the same eruptive center (Wilcox, 1954). The silica contents of the analyzed basalts do not confirm this change, but the distinct decrease in magnesia and lime and the increase in alumina, soda, and potash between the analyzed representatives of the first and third flows in the series (B-16 and B-60 in table 8) provide some support for this contention.

Mineral Resources

Apart from some deposits of low-unit-value nonmetallic minerals, Mesa del Oro quadrangle has little mineral wealth. No areas of metallic mineralization are known in the quadrangle. At present the most important resource of the area is ground water, the supply of which, though small, has been significant in the development of the area. Without the meager amounts of relatively poor-quality ground water that have been developed, cattle raising, the main industry in the area, would be impossible.

TRAVERTINE

A deposit of high-calcium limestone of possible interest to persons concerned with the establishment of a cement plant or a chemical industry requiring a high-calcium limestone as raw material, occurs in T. 6 N., R. 5 W., on the north end of Mesa del Oro, partly within Mesa del Oro quadrangle. The locality can be reached by an unimproved road about 20 miles from U. S. Highway 66 and the Atchison, Topeka, and Santa Fe Railway at Correo, 32 miles by highway from Albuquerque. See Plate 5 (in pocket).

A single analysis representing a composite of two samples shows 97.5 percent calcium carbonate, or 95.9 percent lime (CaO) on a calcined or CO_2-free basis, as calculated from the analysis. The deposit is 5½ miles long and averages over 1 mile in width. The thickness is variable, with a maximum of 150 feet. Although no drilling or other exploration has been done, it is estimated that the amount of material is in excess of 100 million tons. The size, grade, and proximity of this resource to the principal population center of New Mexico should make it attractive for industrial consideration.

The high-lime material is a travertine deposited by springs, which long since have ceased to be active, on a floor of red shale and silt-stone belonging to the Chinle formation of Triassic age. The travertine lies as a great blanket of varying thickness covering any irregularities that may have existed in the underlying surface. The travertine body is thick to the north and east, but thins sharply to the west, and less sharply to the south. The massive, heavy travertine accumulated on the relatively weak and yielding shale. Subsequent erosion removed the shale from around the travertine, so that blocks of heavy travertine slipped down over the soft shale. Thus, the travertine body is almost entirely surrounded by landslides covered by blocks of travertine. Cliff slopes behind the landslides line the north and east slides. The travertine is a yellow-buff to white porous rock with a crackled surface that weathers to orange buff or yellow buff. The rock layers, which are commonly one-fourth to one-half inch thick, vary only slightly in color. In places the travertine is not banded. Layers of sand and shale or other insoluble materials were absent in the outcrops examined. In the southern part of the area, the travertine is covered by shallow alluvium.

TABLE 10. CHEMICAL ANALYSIS OF TRAVERTINE FROM T. 6 N., R. 5 W., VALENCIA COUNTY, NEW MEXICO*

	I†	2‡
SiO,	tr.	tr.
A1$_2$0,	0.23	0.41
Fe0 and Fe.,0, as Fe$_2$0,	0.31	0.55
Mg0	0.14	0.25
Ca0	54.61	95.91
Na,O	1.30	2.29
K$_2$0	0.33	039
H$_2$O	0.66	-
CO,	42.68	-
	100.26	100.00

* Analysis by V. C. Juan.

† Composite sample representing equal portions of samples I and 2 (pl. 5) obtained from landslide blocks near where the travertine is 150 feet thick.

‡ Analysis of the same composite sample as recalculated on the basis of complete elimination of CO_2 and Hp.

Although a deposit of this size should not be judged solely on the basis of a single chemical analysis, the analysis given here may be taken to indicate that the lime content, on the fully burned basis, is in excess of 95 percent. Magnesia is less than 0.5 percent, and combined iron oxide is only slightly more than 0.5 percent. These quantities are well within the limits allowed for most uses of chemical lime or limestone for Portland cement. The unusual content of soda is unexplained.

GYPSUM

Large amounts of gypsum occur in the Yeso and San Andres formations east of Sierra Lucero. Much of the gypsum is of good quality and could be used for plaster manufacture. All of it would be usable as agricultural gypsum. However, the fairly thin outcrops and relative inaccessibility of the area make its future commercial development improbable except for limited local use.

FLAGSTONE

Platy, thin-bedded sandstones that break into slabs 2 to 5 inches thick occur at scattered localities in the Chinle and Abo formations. Many of the old dwellings in the area are constructed of such sandstone slabs, with adobe cement. Some of the sandstone at these localities may prove suitable for use as flagstone.

BASALT ROCK

Large amounts of easily available basalt rocks occur in the area. They would be suitable for use in making crushed stone, riprap, or road metal. In addition, small amounts of rather poor scoria are present in several areas. However, there is no demand for such products in the immediate area at present, and these resources will probably remain undeveloped until local demand brings them into use.

PETROLEUM

The petroleum possibilities of the southern part of Mesa del Oro quadrangle have never been fully tested. The one well drilled in the area was the Field (MacDonald State) wildcat of the Ohio Oil Co., drilled in 1926 on the crest of the Payne anticline. (See section on Structure.) It was believed at the time that the well had penetrated to the Precambrian basement (Darton, 1928-a, p. 135), and further testing was abandoned. However, the author believes that drilling was stopped in a thick sill or series of sills in the Yeso formation (see section B-B' pl. 1), and that at least 5,000 feet of drilling would be necessary to reach the base of the Pennsylvanian. The Pennsylvanian is the most likely oil-bearing part of the section.

Though the large number of intrusives in the area make it one in which petroleum possibilities may be expected to be rather poor, thorough testing of the Pennsylvanian rocks expected below the sills might yield favorable results.

GROUND WATER

With the exception of one flowing artesian well in the southwestern part of the quadrangle, the ground-water resources of the area are restricted to production from fairly shallow wells and a few springs which yield from one to several gallons per minute. Most of the water is of poor quality and serves only the needs of cattle and other animals, although a few wells and springs produce water of satisfactory quality for domestic use. The streams of the quadrangle are of no great significance in the overall picture, as they flow only intermittently, at times when there is considerable precipitation from local storms; they may, however, provide recharge for small alluvial reservoirs. The streams also serve as a small supplement to the underground water resources. Ranchers have built many earth tanks, which collect water from the runoff of the torrential summer rainstorms and store it for the use of stock. In dry years, many of these tanks collect only small amounts of water, which is used up quickly, or the tanks may even remain dry. In addition, one large perennial lake occupies a low spot at the north end of Mesa del Oro.

TABLE I I. RECORDS OF WELLS AND SPRINGS IN MESA DEL ORO QUADRANGLE. SOCORRO AND VALENCIA COUNTIES. NEW MEXICO

Well number	Owner	Year completed	Topographic situation	Altitude of land surface (feet)	Type of well	Depth of well (feet)	Diameter of well (inches)	Water level		Type of lift*	Pumping rate† (gpm)	Use†	Remarks
								Below land surface (feet)	Date of measurement				
						Socorro County							
3N.4.4.440	F. D. Huning Co.	-	Flat	-	Drilled	-	2-1/2	-	4/20/55	W	1-2	D, S	
3N.4.9.220	F. D. Huning Co.	-	Flat	-	Drilled	-	4	-	4/20/55	W	1-2	S	
3N.6.4.214	Field ranch	-	Low hill	-	Drilled	-	4	-	8/4/53	W	1-2	S	
4N.4.30.210	Ward and Dysart	-	Small flat	-	Drilled	-	4	-	12/8/54	W	1-2	S	
4N.5.17.331	Payne ranch (Andres G. Armijo)	Before 1920	Flat near stream	-	Drilled	125?	4	50?	3/25/54	W	1-2	D, S	
4N.5.33.211	Payne ranch (Andres G. Armijo)	-	Flat	-	Drilled	-	4	-	4/21/55	W	1-2	S	
4N.6.14.211	Pino ranch	-	Flat	-	Spring	-	-	0	3/26/54	F	1-2	S	Spring.
4N.6.15.422	Pino ranch	-	Edge of low hill	-	Spring	-	-	0	8/4/53	F	1-2	D, S	Spring.
4N.6.26.130	Field ranch	-	Flat	-	Dug	-	?	3	4/21/55	W	1-2	S	
4N.6.32.422	Field ranch	1926	Low hill	-	Drilled	750	18	0	8/4/53	F	50	I, S	Flowing artesian well drilled as oil test.
						Valencia County							
4N.5.6.322	Payne ranch (Andres G. Armijo)	-	Stream bank	-	Drilled	-	4	-	4/7/54	W	1/2-1	S	
4N.6.12.340	Pino ranch	-	Flat	-	Dug	-	?	-	4/21/55	F	1/2-1	S	Dug well, with small artesian flow.

TABLE 11. RECORDS OF WELLS AND SPRINGS IN MESA DEL ORO QUADRANGLE, SOCORRO AND VALENCIA COUNTIES, NEW MEXICO (continued)

Well number	Owner	Year completed	Topographic situation	Altitude of land surface (feet)	Type of well	Depth of well (feet)	Diameter of well (inches)	Water level: Below land surface (feet)	Water level: Date of measurement	Type of lift*	Pumping rate† (gpm)	Use‡	Remarks
5N.5.5.314	Seis-Wilson ranch	-	Flat	-	Spring	-	-	0	7/22/54	F	1-2	S	Spring.
5N.5.10.333	Seis-Wilson ranch	1940	Stream bank	6,355	Drilled	200§	2-1/2	150-160	10/7/53	W	2-5	S	
5N.5.16.430	Seis-Wilson ranch	-	Alluvial terrace	-	Drilled	300§	2-1/2	150-160§	-	W	2-3	S	
5N.6.3.420	Seis-Wilson ranch	-	Small rise	-	Dug(?)	-	?	-	4/22/55	W	1/2-1	S	
5N.6.25.120	Seis-Wilson ranch	-	Lava flat	-	Drilled	600§	4	600§	4/5/54	W	1-2	S	
6N.5.26.130	Seis-Wilson ranch	After 1940	Flat	6,374	Drilled	623§	2-1/2	620§	10/12/53	W	2-3	S	
6N.6.28.330	Seis-Wilson ranch	-	Stream bank	-	Drilled	-	4	-	7/22/54	W	1-2	D, S	

* W, windmill; F, flow.

† Estimated; same date as for measurement of water level.

‡ D, domestic; I, irrigation; S, stock.

§ Reported.

TABLE 12. CHEMICAL ANALYSES OF WATER FROM WELLS AND SPRINGS IN MESA DEL ORO QUADRANGLE. SOCORRO AND VALENCIA COUNTIES. NEW MEXICO* (In parts *per* million, except as noted)

Well number	Analysis number	Date of collection	Specific conductance (micromhos at 25°C)	Silica (SiO_2)	Sodium and potassium (Na+K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$ Total	Hardness as $CaCO_3$ Non-carbonate	Percent sodium
Socorro County														
3N.4.4.440	30260	4/20/55	2,680	27	66	0	143	1,660	16	0.6	30	1,750	1,630	8
3N.4.9.220	30261	4/20/55	2,500	25	88	0	68	1,490	19	0.7	45	1,480	1,420	11
3N.6.4.214	23842	8/4/53	3,430	12	788	-	268	1,260	175	0.7	7.4	72	-	96
4N.4.30.210	29084	12/8/54	2,740	10	19	-	68	1,780	35	1.0	0.2	1,920	1,860	2
4N.5.17.331	25578	3/25/54	1,130	13	231	-	388	227	14	1.4	11.0	84	0	†
4N.5.33.211	30263	4/21/55	3,580	12	473	0	98	1,940	88	1.8	0.9	1,200	1,120	46
4N.6.14.211	25579	3/26/54	1,700	13	420	24	743	213	43	2.2	0.1	24	0	†
4N.6.15.422	23843	8/4/53	781	30	147	-	322	82	41	1.0	1.3	92	0	78
4N.6.26.130	30262	4/22/55	1,520	17	358	41	395	252	93	1.0	26	30	0	96
4N.6.32.422	23844	8/4/53	3,640	15	223	-	450	1,914†	130	2.4	0.3	2,020	1,650	19
Valencia County														
4N.5.6.322	25580	4/7/54	3,560	17	726	-	277	1,600	69	0.3	1.0	414	187	†
4N.6.12.340	30264	4/21/55	909	5.2	183	84	125	117	68	1.2	0.2	66	0	86
5N.5.5.314	29085	7/22/54	3,600	21	282	-	455	1,810	335	1.2	0.1	2,120	1,750	22
5N.5.10.333	23839	10/7/53	2,200	15	210	-	1,080	470	19	0.5	0.0	945	60	33
5N.5.16.430	23840	-	2,370	11	235	-	880	775	15	0.9	0.1	1,040	319	33
5N.6.3.420	30265	4/22/55	3,480	22	299	0	65	1,950	149	2.2	0.9	1,650	1,600	28
5N.6.25.120	25581	4/15/54	2,480	15	651	43	1,320	240	27	1.4	0.0	30	0	†

TABLE 12.CHEMICAL ANALYSES OF WATER FROM WELLS AND SPRINGS IN MESA DEL ORO QUADRANGLE. SOCORRO AND VALENCIA COUNTIES. NEW MEXICO(cont.) (In parts per million, except as noted)

Well number	Analysis number	Date of collection	Specific conductance (micromhos at 25°C)	Silica (SiO_2)	Sodium and potassium (Na+K)	Car-bonate (CO_3)	Bicar-bonate (HCO_3)	Sulfate (SO_4)	Chlo-ride (Cl)	Fluo-ride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$		Percent sodium
												Total	Non-carbonate	
6N.5.26.130	23841	10/12/53	4,680	11	476	-	432	2,670	140	1.7	0.0	2,300	1,950	31
6N.6.28.330	29086	7/22/54	1,600	21	365	43	487	275	46	1.4	4.0	35	0	96

* Analyses by United States Geological Survey, Quality of Water Laboratory, Albuquerque, N. Mex.
† Not reported.
‡ Estimated.

The poor quality of the ground water in Mesa del Oro quadrangle results from the highly gypsiferous nature of the water-bearing formations. Those wells that produce water not highly charged with salts are generally located in areas of alluvial fill.

ABO FORMATION

Three wells have been drilled in the Abo formation within Mesa del Oro quadrangle. Water from these wells apparently has been used for domestic purposes from time to time. It is of poor quality, however, being highly charged with calcium sulfate. In view of the preponderance of fine-grained sediments in this formation, prospects for the development of much water from the Abo formation in this area appear to be poor.

YESO FORMATION

One shallow well has been drilled into the Yeso formation in the southeastern part of the quadrangle. The water contains much calcium sulfate, as might be expected from the fact that the Yeso sediments include large amounts of gypsum. Sandstones in this formation might yield larger quantities of water, but the quality probably would be poor.

GLORIETA SANDSTONE

The Glorieta sandstone has not been penetrated by shallow wells, and the quality of any water it may contain remains untested. The sandstone varies considerably in porosity and permeability. It is mostly well cemented; thus it would probably not be an exceptionally good aquifer. The formation is thin and generally crops out as cliffs or a steep slope; hence the recharge area within the quadrangle is very small. The log of the Field artesian well (table 11) reports 20 barrels per day of artesian water from the Glorieta sandstone.

SAN ANDRES FORMATION

No shallow wells have been drilled in the San Andres formation. It is unlikely that much water could be obtained from the San Andres formation by this means, because shallow wells would be drilled necessarily within or near the relatively small recharge area. The highly gypsiferous nature of the beds militates, moreover, against finding water of good quality, even if it were easily available. The highly charged nature of the water flowing from the Field artesian well (over 3,000 ppm dissolved solids), about 60 percent of which comes from jointed limestone strata believed to be upper San Andres, bears out this contention. No water was reported from the silty lower evaporite member of the San Andres formation.

CHINLE FORMATION

All wells in the western two-thirds of the quadrangle produce water from the Chinle formation or from alluvium. Water from an unsampled well in the Chinle is used for domestic purposes at the Field ranch, although water derived from this formation is generally of poor quality. About 40 percent of the high-sulfate water from the Field artesian well is derived from a sandstone near the base of the Chinle formation. Two shallow dug wells in the eastern part of T. 4 N., R. 6 W., produce water of fairly good quality from the same formation. Throughout the area, prospects for obtaining some water from the Chinle are good, although few wells are capable of producing more than 1-2 gallons per minute.

Small springs, flowing 1-2 gallons per minute, are fairly common in the Chinle formation. The quality of the spring waters is variable, but water of reasonably good quality (less than 1,000 ppm dissolved solids) is produced by some of the springs emerging from the Chinle sandstones. The variable quality of the water makes it evident that some fairly complex stratigraphic or structural controls are responsible for the occurrence and quality of the water.

ALLUVIUM

A few of the shallow wells in the area have tapped small alluvial reservoirs. One (4N.5.17.331) is reported to be capable of producing 25 gallons per minute. The quality of the water is fairly good (less than 1,000 ppm dissolved solids), but the size of the reservoirs appears limited, and it is doubtful that they could be expected to produce great amounts of water for an extended period.

SUMMARY

Water derived from shallow wells in Mesa del Oro quadrangle is generally of poor quality except where wells have tapped alluvial reservoirs. Spring waters from the Chinle formation vary in quality, and none of the springs produce any large quantity of water. None of the formations in Mesa del Oro quadrangle can be depended upon to produce large amounts of reasonably good-quality water, although in some areas conditions similar to those at the Field artesian well might be found, and a good flow of poor-quality water be obtained from a deep well. The location of such wells on a geologic basis would be difficult, however, because the situation is complicated by the numerous igneous intrusives in the area. The probability of drilling a successful well east of Sierra Lucero is much less than in the western part of the area.

NUMBERING OF WELLS AND SPRINGS

All wells and springs for which records are included are located on the geologic map (pl. 1). The numbering system for wells is that used by the U. S. Geological Survey Ground Water Branch in New Mexico and is based on the units of the township-range system. The well number serves to identify and locate the well in the nearest 10-acre plot. The number is divided by periods into four segments. The first segment indicates the township, the second indicates the range, the third indicates the section, and the fourth locates the well within the section. In counties where there are townships located both north and south of the New Mexico principal meridian, an N or an S is added to the first segment, to indicate whether the township lies north or south of the principal meridian.

Each section is divided into quarters numbered as follows: the NW quarter, 1; the NE quarter, 2; the SW quarter, 3; and the SE quarter, 4. The quarter section, in turn, is divided into quarters (40-acre plots) and numbered in the same order. The 40-acre plots are subdivided and numbered similarly. This procedure locates a well to the nearest 10-acre tract. In the well number, the first digit of the fourth segment locates the quarter section, the second digit the quarter quarter (40-acre plot), and the last digit the 10-acre tract. Where more than one well is located in any 10-acre tract, the well number is followed by a, b, c, etc. If a location cannot be established to a 10-acre plot, the indefinite subdivisions are replaced with zeros in the well number; for example, where a well is known to be in the NW quarter section but cannot be located with reference to the smaller subdivisions, the number ends in .100. As an illustration, well 3N.4.6.214 is located in SE¼NW¼NE¼ sec. 6, T. 3 N., R.4 W.

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