Geology of the Mockingbird Gap Quadrangle, Lincoln and Socorro Counties New Mexico

GEOLOGICAL SURVEY PROFESSIONAL PAPER 594-J

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By GEORGE O. BACHMAN

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

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A summary of the stratigraphy, geologic structure, and regional geologic setting of the southern part of the Oscura Mountains and the northern part of the San Andres Mountains

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GEOLOGY OF THE MOCKINGBIRD GAP QUADRANGLE, LINCOLN AND SOCORRO COUNTIES NEW MEXICO

By George O. Bachman

ABSTRACT

The Mockingbird Gap 15-minute quadrangle comprises about 250 square miles in eastern Socorro and western Lincoln Counties, N. Mex. The quadrangle is about 50 miles southeast of the town of Socorro.

The southern Oscura Mountains and the northern extremity of the San Andres Mountains are within the report area. The Mockingbird Gap Hills are located in the quadrangle northeast of the San Andres Mountains, about midway between the northern termination of that range and the Oscura Mountains. Mockingbird Gap, from which the quadrangle derives its name, is the divide between the San Andres Mountains and the Mockingbird Gap Hills.

The geology described in this report is primarily that of the bedrock of the uplands. The intervening areas are covered to a large extent by alluvial fans. The rock formations exposed in the quadrangle range in age from Precambrian to Quaternary. The oldest rock exposed is granite of Precambrian age. The Bliss Sandstone, assigned to Late Cambrian and Early Ordovician ages, rests on the granite in the northern San Andres and the southern Oscura Mountains; it wedges out northward in the Oscura Mountains. The El Paso Dolomite of Early Ordovician age rests with apparent conformity on the Bliss Sandstone, has a distribution similar to that of the Bliss in the quadrangle, and wedges out to the north in the Oscura Mountains. The Upham Dolomite Member of the Montoya Dolomite of Middle Ordovician age disconformably overlies the El Paso. The Montoya wedges out northward in the southern part of the Oscura Mountains. Rocks of Silurian, Devonian, and Mississippian ages are not represented in the report area, but rocks of Devonian and Mississippian ages are present and wedge out in the San Andres Mountains about 1 mile south of the quadrangle. Rocks of Pennsylvanian age lap across the Montoya, El Paso, and Bliss Formations and rest on Precambrian granite in the Oscura Mountains in the northeastern part of the report area.

Pennsylvanian strata contain the fusulinid zones of *Fusulinella*, *Fusulina*, and *Triticites*. The rocks are divided into a lower clastic formation, the Sandia, and an upper formation, the Madera. The Madera Formation consists of two informal members: A lower, dominantly calcareous sequence of rocks and an upper, clastic sequence.

Permian rocks include, in ascending order, the Bursum, Abo, and Yeso Formations. The Bursum Formation, consisting of interbedded marine limestone and red beds, interfingers with the Abo Formation. The Yeso Formation includes a persistent sandstone member, the Meseta Blanca, at the base.

Northward wedging out of pre-Pennsylvanian Paleozoic strata is attributed to repeated epeirogenic movement along a generally east-west hinge line in the approximate latitude of the present-day Oscura Mountains. The hinge line was a broad zone of crustal weakness along which the crust of the earth was tilted down to the south or was slightly uplifted to the north.

Tertiary tectonic activity occurred in at least two stages. The earlier stage was probably characterized by north-south elongate doming of orogenic proportions accompanied by both high- and low-angle normal faulting. The second stage was characterized by generally northwesterly trending normal faulting which caused the present-day block-faulted mountains.

INTRODUCTION

LOCATION AND ACCESSIBILITY

The Mockingbird Gap 15-minute quadrangle comprises about 250 square miles in eastern Socorro and western Lincoln Counties, N. Mex. (fig. 1); it is bounded by lat 33°30′ and 33°45′ N. and long 106°15′ and 106° 30′ W. The quadrangle is at the north end of Tularosa Valley, an alluvium-filled basin that has interior drainage and is about 100 miles long and as much as 40 miles wide. The valley is bounded on the east, from north to south, by Sierra Blanca, the Sacramento Mountains, and Otero Mesa, and on the west by the San Andres, Organ, and San Augustin Mountains. The valley's north boundary is less definite, but it includes the Mockingbird Gap Hills, Oscura Mountains, and the Phillips Hills. Its south boundary is also indefinite but is regarded as a low generally east trending drainage divide near the New Mexico–Texas boundary.

PHYSICAL FEATURES

The Mockingbird Gap quadrangle is within the confines of White Sands Missile Range. There are no inhabitants in the quadrangle, and access is prohibited to the general public. One main road traverses the southwestern part of the quadrangle through Mockingbird Gap, and another passes along the east margin of the quadrangle. Other access roads are maintained only

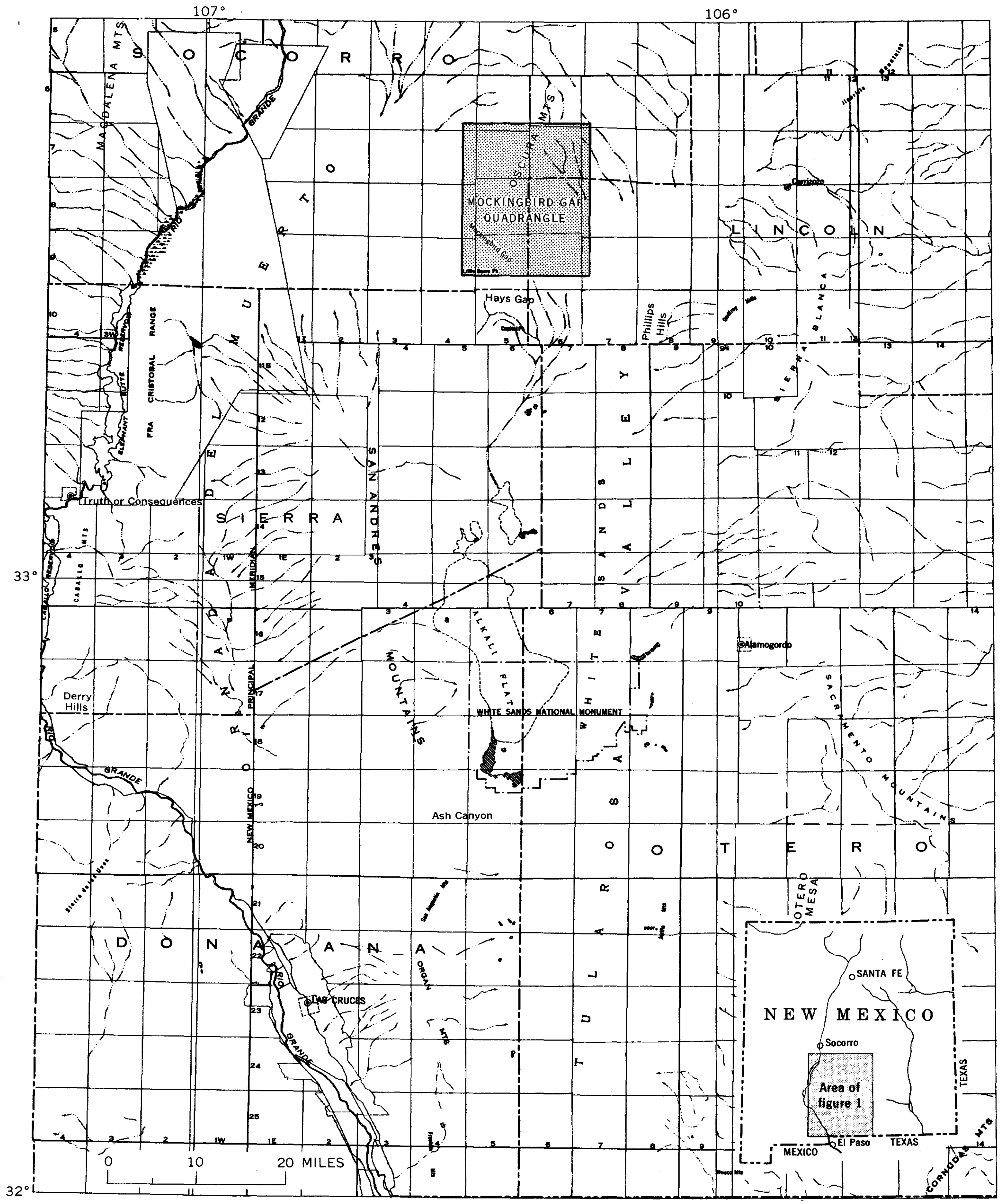

FIGURE 1.—Index map of south-central New Mexico showing location of Mockingbird Gap quadrangle.

intermittently, and their condition is generally unpredictable. A spur railway of the Southern Pacific Lines passes about 12 miles east of the quadrangle. The nearest town is Carrizozo, N. Mex., about 20 miles east of the quadrangle.

The southern Oscura Mountains are in the eastern part of the Mockingbird Gap quadrangle, and Little Burro Peak, a northern extension of the San Andres Mountains, is in the southwestern part. The Mockingbird Gap Hills (the Little Burro Hills of Meinzer and Hare, 1915) comprise an area of comparatively low relief in the south-central part of the quadrangle between the Oscura and San Andres Mountains. Mockingbird Gap is a drainage divide between Little Burro Peak and the Mockingbird Gap Hills. Oscura Gap is between the southern Oscura Mountains and the Mockingbird Gap Hills. A southern extension of the Hansonburg Hills is in the northwestern part of the quadrangle.

The southern Oscura Mountains are a series of east-dipping fault blocks that rise gradually from altitudes of about 5,000 feet on the east side to more than 8,000 feet at the summit. The west face of the mountains is more abrupt; it forms a precipitous scarp in places and has a total relief of about 3,000 feet. The lowest altitude in the Mockingbird Gap quadrangle, about 4,650 feet, is in the southeast corner, adjacent to the south end of the Oscura Mountains. The highest point is South Oscura Peak, which rises to 8,640 feet.

The Mockingbird Gap Hills reach a maximum altitude of 6,506 feet, and Little Burro Peak is 7,373 feet in altitude. Alluvial plains slope gently away from the hills and mountains. The gradient of these slopes decreases from about 500 feet per mile near the mountains to 100 feet per mile within 3 or 4 miles from the mountains.

There are no permanent streams in the quadrangle, and drainage features consist entirely of arroyos. The arroyos carry vigorous torrents for a few hours after infrequent torrential rains, but the rest of the time they are dry. Vegetation is sparse and consists of grasses, creosote bush, ocotillo, cacti, and other succulents at the lower altitudes, and of juniper and pinyon pine at the higher altitudes in the Oscura Mountains. The summits of Little Burro Peak and Mockingbird Gap Hills support only the sparse vegetation of surrounding lower altitudes.

PREVIOUS INVESTIGATIONS

As the area of the Mockingbird Gap quadrangle was apart from the main routes of early exploration in New Mexico, it apparently received no visits from trained observers until the latter part of the 19th century. Even in the present century it has received little attention from geologists, and the only previously published map of the entire quadrangle is a reconnaissance map by Darton (1928, pl. 42).

The earliest documented geologic work in the quadrangle resulted from an examination of copper deposits by Peters (1882). Turner (1903), and Graton (Lindgren and others, 1910, p. 201–203) later made reconnaissance observations of the copper deposits in the Estey district in the southeastern part of the quadrangle. Meinzer and Hare (1915) visited the southern part of the quadrangle briefly during a water-resources study of the Tularosa Valley. Darton (1928) examined stratigraphic sections in the southern part of the Oscura Mountains and prepared a reconnaissance geologic map of the San Andres and Oscura Mountains. Lasky (1932) examined the Mockingbird Gap district as part of an investigation of the ore deposits of Socorro County. Thompson (1942) studied stratigraphic sections of the Pennsylvanian System in the Oscura Mountains. Wilpolt and Wanek (1951) studied the northern Oscura Mountains, and the area of their geologic map adjoins the Mockingbird Gap quadrangle on the north.

METHODS OF WORK

Fieldwork was begun in the Mockingbird Gap quadrangle and adjacent areas in the fall of 1955 as part of a reconnaissance study of southern New Mexico in conjunction with the preparation of a geologic map of New Mexico (Dane and Bachman, 1961). The fieldwork was continued in the spring of 1957 and in the spring of 1960. Final field checking of maps was completed in the fall of 1960.

Some of the mapping was done in the field on controlled aerial mosaics at a scale of 1:25,000 (prepared by the Army Map Service in 1946). Geologic data were adjusted to the topographic base by projection and were checked in the field by triangulation and resection. Most of the south half of the quadrangle was mapped directly on the topographic base at scales of 1:25,000 and 1:31,680; in this work, aerial mosaics and stereoscopic pairs of aerial photographs were used as visual aids and to plot detailed data.

Most of the stratigraphic sections were measured with a tape and Abney hand level. The Abney level was attached to a 5-foot Jacobs staff for measurement of detailed sections. All major rock types were sampled, but the sampling of carbonate rocks was emphasized. Thin sections of all major rock types were examined, and carbonate rocks were studied by means of acetate peels and stains. A systematic study of insoluble residues was not undertaken, but residues of representative carbonates were examined to augment the study of thin sections and peels. The dolomite-limestone classification used in this report follows that of Guerrero and Kenner

(1955, p. 45–48). About 75 analyses of carbonate rocks by versenate titration methods were made during the present study.

ACKNOWLEDGMENTS

The writer appreciates the courtesies extended to him by the Commanding General, White Sands Missile Range, and his coordinating staff, without whose cooperation this investigation could not have been made. Col. Byron King was cooperative in coordinating field schedules. D. F. Merriam, of the Kansas Geological Survey, and Curt Teichert, then of the U.S. Geological Survey, contributed valuable suggestions on the development of a routine study of carbonate rocks in the laboratory. Other U.S. Geological Survey personnel who made special contributions are J. A. Weir and E. H. Herrick, who contributed ideas in the field; R. A. Gantnier and J. A. Thomas, who determined many of the insoluble residues and all the calcium-magnesium ratios of carbonate rocks; D. A. Myers, who prepared most of the fusulinids studied and identified or verified all of them; and I. J. Mittin, who translated the paper by Makhlaev (1961) for reference by the writer. The late J. E. Doty assisted in the field in 1957.

PRECAMBRIAN ROCKS

Rocks of Precambrian age are well exposed along the west face of the Oscura Mountains, in the Mockingbird Gap Hills, and at Little Burro Peak. The principal rock type is light-gray to pink coarsely crystalline granite, whose exposures range from rounded slopes to precipitous cliffs. Small pegmatitic stringers and veinlets, as much as 1 foot wide and consisting of very coarsely crystalline feldspars, are commonly associated with the granite. Diorite caps the southeastern ridge of Little Burro Peak and is locally present at many other Precambrian exposures. In the Oscura Mountains, fragments of mica schist were observed in a talus slope (sec. 19, T. 8 S., R. 6 E.), but exposures of schist in place were not observed. Silicified fault gouge occurs at a few places in association with the granite, but it is of later origin.

The granite is composed chiefly of feldspar and quartz. The feldspar crystals, which compose about 50–70 percent of the rock, are subhedral to anhedral and consist of variable proportions of microcline and orthoclase. In some specimens the microcline and orthoclase are in nearly equal proportion, and in others microcline may occur only in trace amounts. Plagioclase is in some thin sections but does not exceed 2 percent in any sample examined. Microperthite is present in trace amounts in some thin sections. Anhedral quartz composes an estimated 30–40 percent of the granite. Some grains of quartz have undulatory extinction, and nearly all the quartz grains contain distinctive "clouds" of inclusions alined across the grains. The nature of these inclusions was not determined, but some of the larger ones appear to be gas bubbles. Accessory minerals include biotite, magnetite, and sericite. The sericite is an alteration product of feldspar.

The diorite cap on the ridge southeast of Little Burro Peak (NW¼ sec. 29, T. 9 S., R. 5 E.) rests with a sharp contact on granite. It is dark greenish gray and coarsely crystalline. It consists of 58 percent plagioclase (andesine), 30 percent enstatite, about 6 percent magnetite, and about 2 percent biotite. Accessory minerals include hornblende, chlorite, sericite (altered from plagioclase), and hematite (altered from magnetite).

Several other bodies of diorite, all too small to show on the geologic map (pl. 1), were observed. Diorite occurs locally at the north end of Little Burro Peak, where it is intimately associated with granite in a zone of brecciation, and at a few localities along the east side of Little Burro Peak and in the Mockingbird Gap Hills. The diorite apparently intruded the granite and is assumed to be of Precambrian age, for nowhere was it observed to intrude younger formations. In adjacent areas to the south, similar diorite intrudes shear zones as dikes in the Precambrian granite.

STRATIGRAPHY

Stratified rocks exposed in the Mockingbird Gap quadrangle range in age from Late Cambrian to Quaternary (table 1). Paleozoic rocks are represented by the Bliss Sandstone of Late Cambrian and Early Ordovician age, which ranges in thickness from 0 to 19 feet. The El Paso Dolomite of Early Ordovician age and the Upham Dolomite Member of the Montoya Dolomite of Middle Ordovician age have an aggregate thickness ranging from 0 to about 170 feet. The wedge edges of the Bliss, El Paso, and Montoya are within the quadrangle. Rocks of Silurian, Devonian, and Mississippian age are not present in the quadrangle, but all three systems are represented in the San Andres Mountains to the south. Silurian strata wedge out about 25 miles south of the quadrangle, and strata of Devonian and Mississippian age are exposed and wedge out within 1 mile south of the quadrangle. Rocks of Pennsylvanian age rest on a major unconformity and are well represented by carbonate and clastic sedimentary rock types that range from about 1,100 to 2,000 feet in thickness. Rocks of Early Permian age rest with apparent conformity on the Pennsylvanian strata and are about 2,000 feet thick. The Mesozoic Era is not represented in the quadrangle, and rocks of assumed Tertiary age include only dikes and sills. Quaternary deposits are generally poorly consolidated and consist of alluvium.

TABLE 1.—*Summary of rock formations exposed in the Mockingbird Gap quadrangle*

Age	Formation	Thickness (feet)	Lithology
Quaternary			Alluvium, alluvial-fan deposits, and pediment deposits composed of siltstone, sandstone, and conglomerate. Mostly unconsolidated.
Permian	Yeso Formation: Upper part		Gypsum, thin beds of gray dolomitic limestone, shale, siltstone, and fine- to medium-grained sandstone. Clastic rocks are mostly light red, light brownish gray, and light gray.
	Yeso Formation: Meseta Blanca Sandstone Member	170– 260	Light-red cross-laminated medium-grained sandstone containing some interbeds of light-red siltstone and fine-grained sandstone.
	Abo Formation	525 (avg)	Dark-red arkosic sandstone, arkose, and lenticular beds of conglomerate at base; grades upward to light-red siltstone and arkosic sandstone with lenticular beds of dark-red conglomerate.
	Bursum Formation	65– 450+	Interbedded gray marine limestone and dark-red arkosic sandstone, arkose, and lenticular beds of conglomerate. Marine limestone and associated gray shale more abundant southward. Interfingers with overlying Abo Formation.
Pennsylvanian	Madera Formation: Upper member	+500–1, 575	Interbedded gray limestone, marly shale, sandstone, arkosic sandstone, arkose, and lenticular beds of conglomerate. Colors chiefly shades of gray, brown, green, and yellow. Individual beds nonpersistent.
	Madera Formation: Lower member	268– 407	Gray marine limestone, cryptocrystalline to coarsely crystalline. Commonly very cherty. Weathers to prominent ledges and cliffs. May contain scattered interbeds of marly limestone.
	Sandia Formation	16– 252	Gray to brownish- or greenish-gray siltstone, sandstone, and graywacke and lenticular beds of congolmerate. Contains a few thin beds of gray limestone.
Middle Ordovician	Upham Dolomite Member of Montoya Dolomite	0– 43	Medium- to dark-gray thick beds of fine-to medium-crystalline dolomite. Weathers to thick rounded ledges that are deeply pitted.
Early Ordovician	El Paso Dolomite	0– 128	Medium-gray to yellowish-gray thin beds of sandy dolomite and calcareous dolomite.
Late Cambrian and Early Ordovician	Bliss Sandstone	0– 19	Light-gray to dark-brown sandstone; contains greenish-gray shaly interbeds and some calcareous beds. Very glauconitic in places.
Precambrian			Pink to light-gray granite and some associated diorite.

UPPER CAMBRIAN AND LOWER ORDOVICIAN ROCKS—BLISS SANDSTONE

Definition

The Bliss Sandstone was named for exposures along the eastern base of the Franklin Mountains near Fort Bliss, El Paso County, Tex., by Richardson (1904, p. 27; 1909, p. 3). At the type locality it consists of "massive, fine-textured, brownish indurated sandstone that varies from a few feet to slightly over 300 feet in thickness" (Richardson, 1909, p. 3). Gordon (Lindgren and others, 1910, p. 225) used the term "Shandon quartzite" for beds in the Caballo Mountains that were correlated tentatively with the Bliss. On the basis of priority, Darton (1917, p. 32–33) extended the name Bliss into southern New Mexico, including both the Caballo and San Andres Mountains. Later he extended the name to the southern Oscura Mountains (Darton, 1928, p. 194). Some geologists prefer "Bliss Formation" for this unit "because the lithology is diverse over the region" (Kelley and Silver, 1952, p. 33). Some of this diversity is apparent in the Mockingbird Gap quadrangle, but Bliss Sandstone is retained in this report on the basis of priority and because sandstone and sand-sized grains are a major constituent of the formation.

Distribution

In the Mockingbird Gap quadrangle the Bliss Sandstone is exposed along the west-facing scarp of the southern Oscura Mountains as far north as sec. 12, T. 8 S., R. 5 E. It is present in the Mockingbird Gap Hills and in the northern San Andres Mountains south of Little Burro Peak (pl. 1).

Lithology

The Bliss Sandstone is divided informally into two parts in the Mockingbird Gap quadrangle. The basal part is commonly exposed as a single rounded ledge which averages about 3 feet thick. It is medium gray and consists dominantly of medium-grained subangular to subround quartz, scattered grains of glauconite, and scattered grains of hematite. Locally, a quartz-granule conglomerate is at the base. Cement consists of clay, calcareous clay, and silica. At places where relief on the pre-Bliss Precambrian surface is prominent, the basal bed is absent.

The upper part of the Bliss Sandstone, which averages no more than 10 feet thick, is a distinctive reddish brown to bluish black and is often visible at great distances (fig. 2). Although sandstone is the dominant rock type, the upper part of the Bliss locally includes granule conglomerate and varying amounts of shale and limestone. In general the sandstone and conglomerate beds are dark brown to dark reddish brown, the shaly beds are dark greenish gray to dark brown, and the limy beds are yellowish to reddish brown or dark gray. Locally some of these beds are nearly black on weathered surfaces. Bedding is thin (1–6 inches). The

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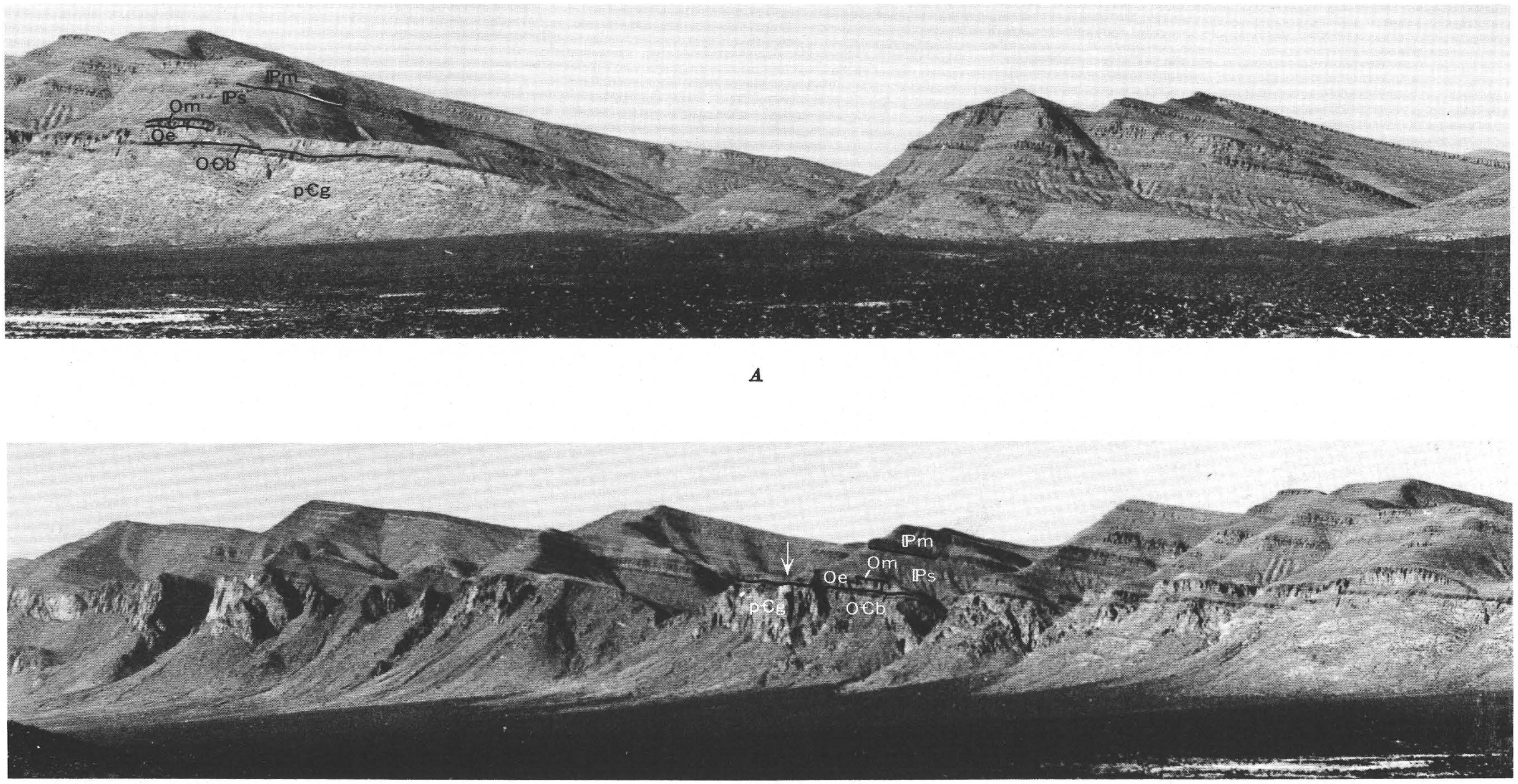


B

FIGURE 2.—Southern part of Oscura Mountains, as viewed northeastward from NW¼ sec. 29, T. 9 S., R. 6 E. *A*, Secs. 16 and 9, T. 9 S., R. 6 E. The Bliss Sandstone (OꞒb) rests on Precambrian granite (pꞒg) and is overlain successively by the El Paso Dolomite (Oe), Montoya Dolomite (Om), Sandia Formation (ℙs) and Madera Formation (ℙm). *B*, Sec. 32, T. 8 S., R. 6 E., and secs. 5 and 9, T. 9 S., R. 6 E. Formations visible include Precambrian granite (pꞒg), Bliss Sandstone (OꞒb), El Paso Dolomite (Oe), Montoya Dolomite (Om), Sandia Formation (ℙs),, and Madera Formation (ℙm). The approximate position of the wedge edge of the Montoya Dolomite is indicated by the arrow.

sandstone beds are commonly cross-laminated (fig. 3). Glauconite is abundant in the upper part of the Bliss and imparts the light-green appearance to some beds. Hematite grains are common, but the oolitic hematite beds that were observed to the south in the San Andres Mountains by Kelley (1951) are not present in the Mockingbird Gap quadrangle.

The following stratigraphic section was measured in the southern Oscura Mountains (NW¼ sec. 16, T. 9 S., R. 6 E.) and shows the general lithologic characteristics of the formation in that area.

	Thickness (Feet)
El Paso Dolomite.	
Bliss Sandstone:	
3. Sandstone, dark-reddish to greenish-brown, thinly laminated, fine- to medium-grained; some layers glauconitic; upper 6 in. hematitic	7.0
2. Sandstone, medium-gray to greenish-gray; medium grained; weathers yellowish brown to mottled dark brown. Very calcareous at base; glauconite at top	4.0
1. Quartzite and sandstone. Forms single ledge but bedding thinly laminated in places; some cross lamination. Medium- to light-gray, medium- to coarse-grained chiefly subangular quartz	4.5
Total Bliss Sandstone	15.5
Precambrian, pink biotite granite.	

The basal sandstone of the Bliss consists dominantly of quartz and, in order of decreasing abundance, minor amounts of glauconite, limonite, calcite, chlorite, and hematite. Only quartz is present in quantities greater than 10 percent of the total constituents. The quartz grains are generally well sorted, average about 0.5 mm in diameter, and are subangular to subround. Secondary accretion is common on the quartz grains, and some grains have microscopic healed fractures. Unidentified "clouds" of inclusions are alined across some grains. Some quartz grains have a ragged contact with glauconite with which they presumably have been etched or partially replaced. The chlorite occurs as fibrous interstitial fillings.

In the upper part of the Bliss Sandstone, quartz is the dominant mineral, but in some places it does not exceed 50 percent of the rock. In some samples, carbonate minerals approach 50 percent of the constituents.

Next, in decreasing order of abundance, are glauconite, limonite, hematite, and leucoxene. Although granule conglomerate was noted in the field in the upper part of the Bliss Sandstone, its grains are generally smaller (0.1–0.5 mm) than average grains in the basal bed. Sorting is fair to poor in the upper part of the Bliss.

The quartz occurs both as subangular to subround grains and as fillings in interstices and fractures. The fillings appear as a crystalline mosaic in thin sections and as drusy crystals in insoluble residues. Carbonate minerals also occur as rounded grains, or pellets, and as fracture and interstitial fillings. Individual rounded grains have single extinction in polarized light, and Curt Teichert (oral commun., 1960) suggested that they may be detrital fragments of echinoderms. Glauconite occurs both as rounded pellets and as fibrous interstitial fillings, and some alteration of glauconite to limonite is apparent. More commonly, glauconite has altered to hematite. Both glauconite and calcite have etched and partially replaced quartz grains.

As carbonates are present both as pellets and as cement in the upper part of the Bliss, four selected samples were analyzed by J. A. Thomas, of the U.S. Geological Survey, to determine the CaO/MgO molal ratio of the carbonate constituents. These ratios range from 2.91 (dolomitic calcite) to 100 (calcite). The relatively high ratios of calcite to dolomite indicated by these analyses are of interest because of the reverse relationship that exists in the overlying sandy dolomite of the El Paso Dolomite.

Contacts

The Bliss Sandstone rests unconformably on rocks of Precambrian age in the Mockingbird Gap quadrangle. The basal contact is sharp and undulatory, and local relief of 5 feet is not uncommon.

The contact of the Bliss with the overlying El Paso Dolomite in the quadrangle is gradational and difficult to define. In the San Andres Mountains to the south this contact is also problematical (Kottlowski and others, 1956, p. 15). In the present work the Bliss–El Paso contact was selected arbitrarily on the basis of four general features given below:

Color.—The Bliss Sandstone is dominantly dark reddish brown in contrast to the yellowish hues of the basal part of the El Paso Dolomite.

Lithology.—The Bliss is dominantly sandstone with various admixtures of shale or limestone, whereas the El Paso is dominantly dolomite or sandy dolomite. Glauconite is abundant in the Bliss and less common in the El Paso.

Bedding.—In both the Bliss and basal part of the El Paso, bedding is 6–12 inches thick, but the basal beds of the El Paso are generally thinly laminated.

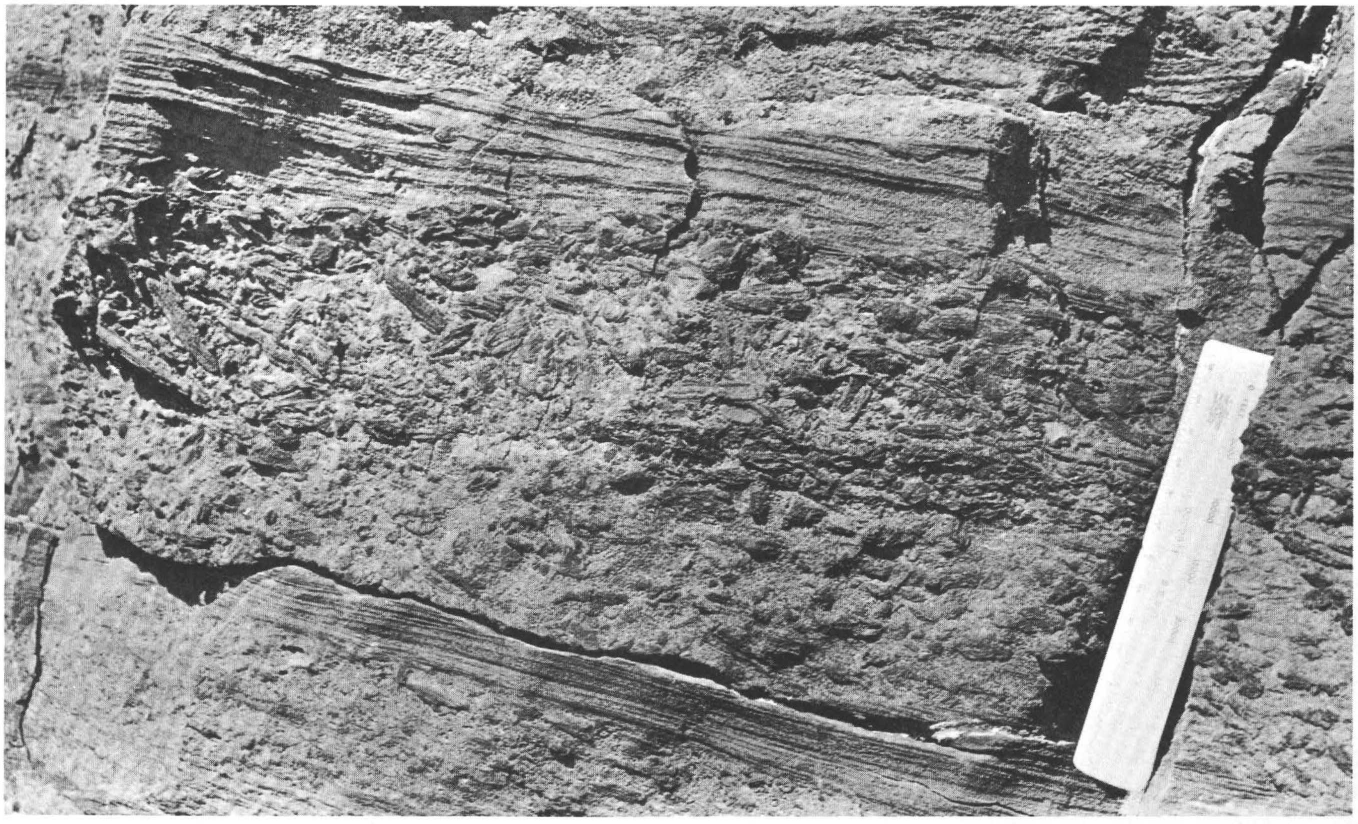
Topographic expression.—The Bliss generally forms a more prominent ledge than does the basal part of the El Paso.

Where overlain by the Sandia Formation of Pennsylvanian age, the Bliss is distinguished from the Sandia by it darker color, abundant glauconite, and more persistent ledge.

Thickness

In the Mockingbird Gap quadrangle the Bliss Sandstone ranges from 0 to 19 feet in thickness. In general,

A



B

the Bliss thins toward the north and northwest with minor local anomalies. At the southernmost measured stratigraphic section of the Bliss in the Oscura Mountains (fig. 4, col. ***P***) it is 14½ feet thick, and about 2 miles north of that point (fig. 4, col. ***L***) it is 19 feet thick. The Bliss gradually thins northward in the Oscura Mountains, and north of sec. 12, T. 8 S., R. 5 E., it is absent. At the northernmost stratigraphic section measured (fig. 4, col. ***F***) the Bliss is 7 feet thick. In the Mockingbird Gap Hills its average thickness is about 9 feet at the southern exposures and about 4 feet at the northern exposures (fig. 4, cols. ***A, E***).

In the San Andres Mountains the Bliss progressively thickens southward to a maximum of about 105 feet in the southern part of the range about 60 miles from Mockingbird Gap (Kottlowski and others, 1956, p. 16). Kelley and Silver (1952, p. 38) concluded that the Bliss thins regionally northwestward. Comparison of thicknesses of the Bliss in the Oscura Mountains with those in Mockingbird Gap Hills confirmed their conclusion within this local area.

Local thinning of the Bliss Sandstone is due to relief on the underlying Precambrian surface. Where the Bliss is overlain unconformably by Pennsylvanian strata, thinning is due to truncation and to channeling by overlying strata. Where overlain by the El Paso Dolomite, the northwestward thinning of the Bliss Sandstone may be attributed to regional onlap by the El Paso, but field observations have so far failed to substantiate this hypothesis. The writer suggests, therefore that the regional thinning of the Bliss to the north and the northwest may be the result of either a gentle rise in the Precambrian surface or a lesser amount of source material in that direction.

Age and correlation

Fossils were not observed in the Bliss Sandstone in the Mockingbird Gap quadrangle, and the age of the Bliss in the quadrangle is indicated by fossils collected by geologists in other areas. Flower (1953) cited evidence that the Bliss contains both Late Cambrian and Early Ordovician fossils; he stated (p. 2055) that "the base of the Bliss Sandstone may be as old as the middle of the Franconia, and its top may extend into the basal Ordovician." In the San Andres Mountains Kottlowski, Flower, Thompson, and Foster (1956, p. 16) collected fossils of Early Ordovician age from the upper beds of the Bliss. Owing to the lack of definite faunal evidence in the Mockingbird Gap area, however, the Bliss Sandstone is assigned a Late Cambrian and Early Ordovician age.

FIGURE 3.—Primary sedimentary structures in lower Paleozoic rocks. Scale is 77 inches long. *A*, Crossbedding (diagonally inclined bedding) in upper part of Bliss Sandstone, Mockingbird Gap Hills. *B*, El Paso Dolomite about 6 feet above base of formation showing a lower, thinly laminated zone, a middle zone of intraformational conglomerate, and an upper zone of diagonally inclined bedding, southern Oscura Mountains.

LOWER ORDOVICIAN ROCKS—EL PASO DOLOMITE

Definition

Originally, Richardson (1904, p. 29) defined the El Paso Limestone to include all rocks of Ordovician age in the Franklin Mountains near El Paso, Tex. Later, on the basis of lithology and fauna, he restricted the El Paso Limestone to the basal rocks and named the upper rocks the Montoya Limestone (Richardson, 1908, p. 478–479; 1909, p. 4). Darton first extended the usage of El Paso Limestone into southern New Mexico, including the San Andres Mountains (Darton, 1917, p. 34–36) and Oscura Mountains (Darton, 1928, p. 194).

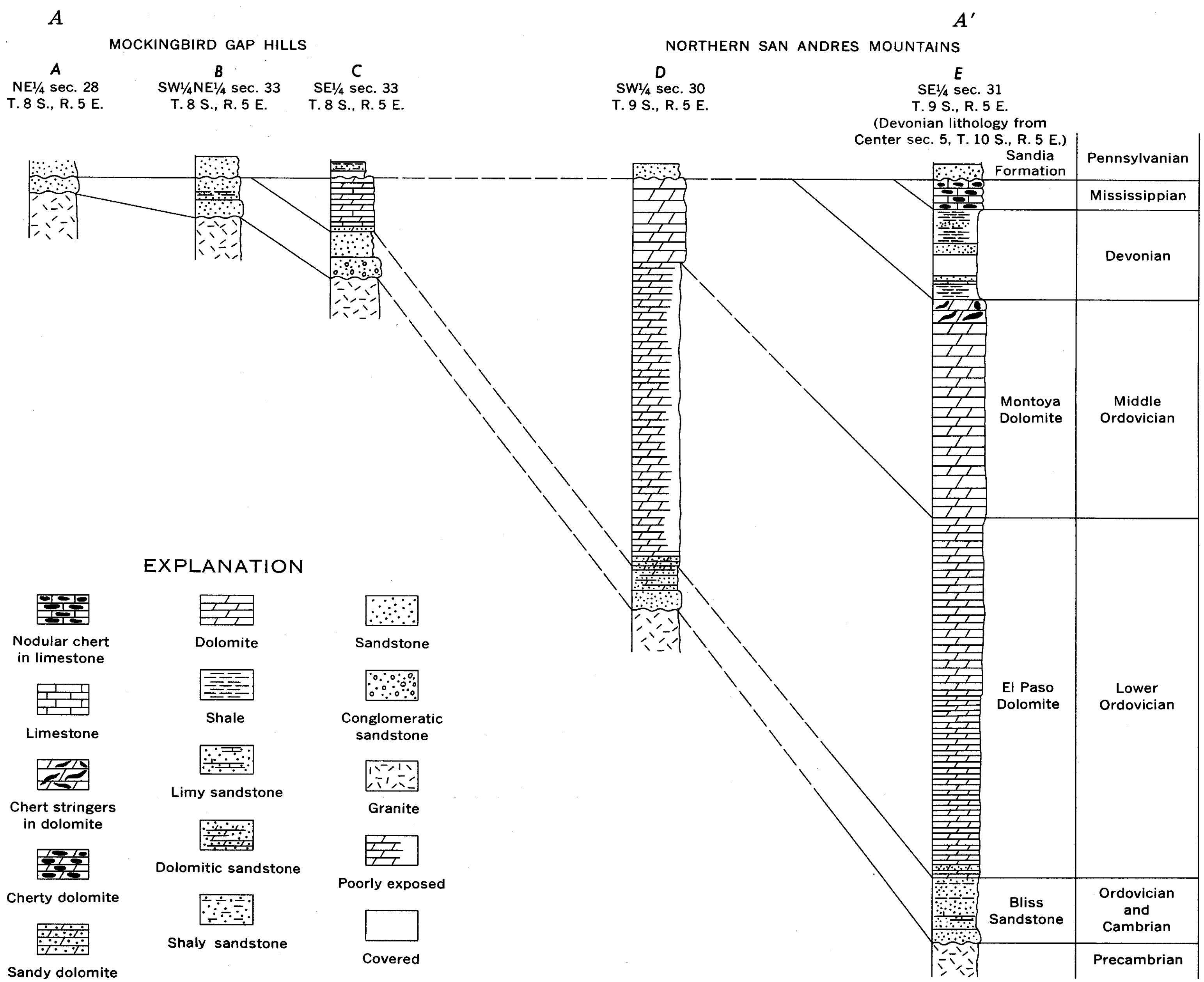
Other geologists have variously referred to the rocks of Early Ordovician age in the Franklin Mountains and in southern New Mexico as the El Paso Dolomite (Dunham, 1935, p. 42) or the El Paso Formation (Dunham, 1935, p. 164; Cloud and Barnes, 1948, p. 74). Kelley and Silver (1952, p. 40–56) proposed that the El Paso in the Caballo Mountains be raised to group status and include two formations that were named, in ascending order, the Sierrite Limestone and the Bat Cave Formation. Kottlowski, Flower, Thompson, and Foster (1956, p. 16) could not recognize the Sierrite Limestone and Bat Cave Formations in the San Andres Mountains but accepted the group status of the El Paso on the basis of a "distinct succession of faunas and lithic units." In the Mockingbird Gap quadrangle the El Paso is mappable only as a single unit at standard map scales; it is regarded in this report as a formation, although lithologic members may be recognizable in adjacent areas.

Distribution

In the Mockingbird Gap quadrangle the El Paso Dolomite has essentially the same distribution as the Bliss Sandstone. It forms prominent ledges along the west-facing scarp of the southern Oscura Mountains. It thins northward and is absent north of the middle part of the southern Oscura Mountains (fig. 4, col. ***F***). It is present in the southern part of the Mockingbird Gap Hills (fig. 4, cols. ***A, B***) but is absent in the northern part (fig. 4). In the southwestern part of the quadrangle the El Paso is present but poorly exposed.

Lithology

In the Mockingbird Gap quadrangle, the El Paso is predominantly sandy dolomite. Some beds are sandy, especially near the base of the formation. On fresh surfaces the El Paso is light to medium gray and finely crystalline. It weathers to a smooth or hackly light-olive


A
A′
MOCKINGBIRD GAP HILLS
NORTHERN SAN ANDRES MOUNTAINS
A
NE¼ sec. 28
T. 8 S., R. 5 E.
B
SW¼NE¼ sec. 33
T. 8 S., R. 5 E.
C
SE¼ sec. 33
T. 8 S., R. 5 E.
D
SW¼ sec. 30
T. 9 S., R. 5 E.
E
SE¼ sec. 31
T. 9 S., R. 5 E.
(Devonian lithology from
Center sec. 5, T. 10 S., R. 5 E.)
Sandia
Formation
Pennsylvanian
Mississippian
Devonian
Montoya
Dolomite
Middle
Ordovician
El Paso
Dolomite
Lower
Ordovician
Bliss
Sandstone
Ordovician
and
Cambrian
Precambrian
EXPLANATION
Nodular chert
in limestone
Limestone
Chert stringers
in dolomite
Cherty dolomite
Sandy dolomite
Dolomite
Shale
Limy sandstone
Dolomitic sandstone
Shaly sandstone
Sandstone
Conglomeratic
sandstone
Granite
Poorly exposed
Covered

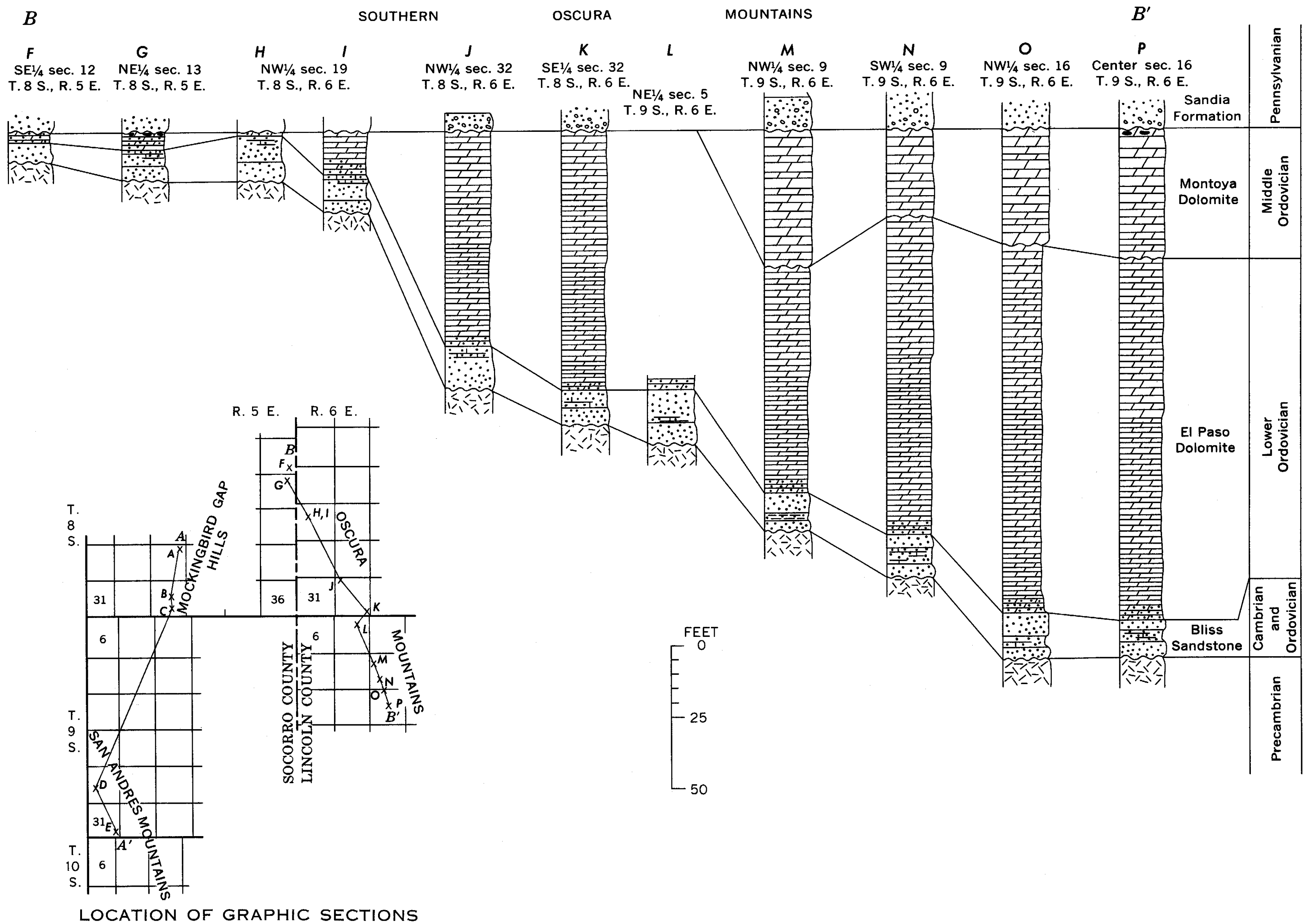


Figure 4.—Graphic sections of pre-Pennsylvanian Paleozoic formations.

to yellowish-gray surface. Beds range in thickness from 2 to about 18 inches, averaging about 6 inches thick. In the southern part of the Oscura Mountains, bedding is relatively thicker in the upper part of the El Paso Dolomite than near the base. The thicker bedded part reaches a maximum thickness of about 55 feet in the southern part of the Oscura Mountains (sec. 16, T. 9 S., R. 6 E.), and it thins progressively northward in the range. The basal, thinner bedded part of the El Paso weathers to a series of weak ledges or a rubble-covered slope. Beds are very thinly laminated near the base, where 12–16 lamellae per inch are not uncommon. Intraformational edgewise conglomerate that contains clasts as much as about 2 inches in longest dimension are very common in the basal 10 feet of the formation (fig. 3*B*).

Glauconite is common near the base but is much less abundant than in the underlying Bliss Sandstone. At one locality (NW¼ sec. 16, T. 9 S., R. 6 E.), scattered well-rounded medium grains of hematite are present near the basal contact of the El Paso. Chert is sparse, and at the few places it was observed, it occurs as gray nodules and stringers or as finely disseminated chert on weathered surfaces near the base of the formation. The irregular chert laminations and "embossed reticulations on bedding planes" observed by Kelley and Silver (1952, p. 43) in the basal part of the El Paso in the Caballo Mountains are not conspicuous in the Mockingbird Gap quadrangle.

The El Paso Formation is a mosaic of fine anhedral to subhedral carbonate crystals and variable amounts of intermixed quartz grains. Most of the carbonates are dolomite, but selective stains on individual scattered crystals indicate that calcite, although not a distinctive portion of the rock, probably does occur in those crystals. Fracture fillings, however, consist entirely of calcite in the thin sections examined.

Dolomite crystals range from about 0.15 to 0.3 mm in diameter. Fractures do not appear to control the size of crystals, but in some thin sections there is a zoning and an abrupt change in the size of crystals along an irregular contact. Such an example was noted where the average crystal size changed abruptly from 0.15 to 0.05 mm in diameter.

In several thin sections dolomite crystals of bladed habit were observed. These elongate crystals are about 0.15–0.25 mm long and 0.08–0.10 mm wide, are randomly oriented, and exhibit parallel extinction. They are scattered among larger rhombs of dolomite, which average about 0.55 mm in diameter. Many of the rhombs are deeply etched and replaced by the elongate crystals, which indicates that the elongate crystals are of a later, and probably distinct, stage of crystallization. The rhombs are very similar in appearance and size to the elongate prisms in dolomite of Devonian age on the east side of the Central Russian Highlands, U.S.S.R., as described by Makhlaev (1961).

Some quartz grains occur in all thin sections of the El Paso examined, but quartz is most abundant in sections from near the base of the unit. The quartz grains are 0.1–0.15 mm in diameter but possibly decrease slightly in diameter upward in the stratigraphic section. The quartz is subangular to round and frequently etched and partially replaced by dolomite. Glauconite occurs near the base of the formation as pellets. Scattered grains of well-rounded leucoxene, slightly altered to red hematite and averaging about 0.1 mm in diameter, were observed in one thin section of material taken from about 6 feet above the base of the El Paso.

During the present study, six representative samples of the El Paso Dolomite were analyzed for calcium and magnesium ratios. The ratios of calcium and magnesium range from 1.14 (dolomite) to 1.41 (calcitic dolomite) (Guerrero and Kenner, 1955). Five of the samples were from various localities in the southern Oscura Mountains and have calcium-magnesium molal ratios ranging from 1.14 to 1.20 (dolomite). The sixth sample, consisting of calcitic dolomite, was collected from the Capital Peak quadrangle to the south (center of sec. 5, T. 10 S., R. 5 E.).

Insoluble residues of 10 samples of the El Paso Dolomite from the southern Oscura Mountains range from 5 to 31.9 percent (by weight) of the rock. Insoluble residues from samples collected within the basal 10 feet of the El Paso range from 18 to 31.9 percent of the rock, and samples collected from above the basal 10 feet of the formation contain from 5 to 12 percent insoluble residues. Quartzs and grains are distributed throughout the El Paso Dolomite in the quadrangle, but near the base insoluble residues consist largely of fine quartz-sand grains and some glauconite, and in the upper part the insoluble residues consist of finely crystalline drusy and spicular quartz. A small percentage (less than 10 percent of the total residue) of light-gray clay was observed in some residues.

Thickness

The thickness of the El Paso Dolomite ranges from 0 to 128 feet in the Mockingbird Gap quadrangle. It is greatest at the southernmost exposures in the Oscura Mountains (fig. 4, col. **P**). From that point northward in the Oscura Mountains, the thickness decreases rather uniformly to 4 feet at the northernmost stratigraphic section measured (fig. 4, col. **F**). The El Paso was not observed north of that section. Locally, for about 1 mile south of this point, the El Paso has an irregular thickness, and at one place it is absent (fig. 4, col. **G**). This irregularity in thickness is the result of local channels cut before (or during) deposition of the Sandia Formation of Pennsylvanian age.

Progressive northward thinning of the El Paso Dolomite in the quadrangle is observed both where the El Paso is overlain by the Upham Dolomite Member of the Montoya Dolomite of Ordovician age and by the Sandia Formation of Pennsylvanian age. Thus, there is some evidence of regional beveling of the El Paso in Ordovician as well as other periods of Paleozoic time. Beveling of the El Paso is discussed more fully on pages 17 and 19 of this paper.

The El Paso Dolomite is 10–12 feet thick in the southern part of the Mockingbird Gap Hills and is absent in the northern part (fig. 4). It is about 100 feet thick in the northern part of the San Andres Mountains (fig. 4), and it thickens to 760 feet in Ash Canyon, about 60 miles to the south (Kottlowski and others, 1956, p. 18).

Contact with overlying formations

In the mapped area the El Paso Dolomite is overlain by the Upham Dolomite Member of the Montoya Dolomite of Middle Ordovician age, or, where the Montoya is absent, by strata of Pennsylvanian age (fig. 4). Where the Upham overlies the El Paso, the contact between the two units is sharp, although in any individual outcrop there is little evidence of the regional unconformity that separates them.

The criteria used in the field during the present work to distinguish the El Paso from the Upham Dolomite Member of the Montoya are as follows:

Color.—The El Paso is light to medium gray and weathers to various hues of olive or yellow, whereas the Upham is medium to medium dark gray. Weathering produces little change in the color of the Montoya, but in some places the Montoya is a pale-olive hue on the surface.

Weathering.—The El Paso weathers smooth to hackly. On a weathered surface the Upham is commonly pitted deeply.

Bedding.—Beds in the El Paso are generally not more than 18 inches thick. Beds in the Upham are generally 1–6 feet thick and average about 3 feet thick.

Topographic expression.—The El Paso forms steep slopes or prominent ledges, whereas the Upham forms a massive rounded ledge.

At places where the Montoya Dolomite is absent, the contact of the El Paso with overlying strata of Pennsylvanian age is irregular and sharp. Discontinuous beds of sandstone at the base of the Pennsylvanian fill broad channels in the El Paso and at places cut through the El Paso into the underlying Bliss Sandstone. Coarse, slightly conglomeratic sandstone is the most common rock type in the Pennsylvanian directly overlying the El Paso, but siltstone and shale of Pennsylvanian age rest on the El Paso at some localities.

Age and correlation

Extensive dolomitization has destroyed most fossils in the El Paso Dolomite in the Mockingbird Gap quadrangle. On weathered surfaces, fragments of fossils, particularly very small crinoid columnals, are abundant in some places, but diagnostic fossils are sparse. Ghost of shells and crinoid columnals in thin sections indicate that organisms were abundant in many parts of the El Paso before they were destroyed by processes of dolomitization and recrystallization.

The only identifiable fossils collected from the El Paso during the present study were the following brachiopods, which were identified by Reuben J. Ross, Jr., of the Geological Survey:

Finkelnburgia cf. *F. bellatula* Ulrich and Cooper
Diaphelasma cf. *D. pennsylvanicum* Ulrich and Cooper

These brachiopods were collected 75 feet above the base of the El Paso in the southern part of the Oscura Mountains (fig. 4, col. **P**). Ross (written commun., 1960) stated that—

> Identification of both these forms is hampered by poor preservation of details of exterior ornamentation. Because interior details are not clearly defined, this may be the result of poor silicification. However, the possibility exists that abrasion on the sea floor prior to burial may have contributed to wearing ornamentation down.
>
> Conodonts are abundant, all being the long curved tusk or simple cone type found in Lower Ordovician units. These are very much like those in the lower part of the Manitou Formation of Colorado.
>
> All these forms indicate an age equivalent to that of units A of the El Paso (Cloud and Barnes, 1948, p. 74) in the Franklin Mountains. I see no indication of an environmental difference between the El Paso of the Oscura Mountains and unit A (the basal part of the El Paso) of the Franklin Mountains.

In color, bedding, and sand content, the El Paso closely resembles the basal part of the El Paso in the southern San Andres Mountains and the Franklin Mountains, where the total thickness of the El Paso is much greater. It resembles the Sierrite Limestone of Kelley and Silver (1952, p. 42–45) at the base of the El Paso in the Caballo Mountains and is here correlated with the Sierrite. Kottlowski, Flower, Thompson, and Foster (1956, p. 16) did not recognize the Sierrite Limestone in the San Andres Mountains, as the contact of the Sierrite with overlying units is apparently vague in that area. Instead, they divided the "El Paso group" into seven informal lithologic divisions, which are numbered I–VII in ascending order. Only the basal division seems to occur near the wedge edge of the El Paso in the Oscura Mountains. Lithologic equivalents of division I and the basal part of division II of Kottlowski, Flower, Thompson, and Foster (1956, p. 17) may be in the southernmost part of the Oscura Mountains (fig. 4, cols. ***M–P***) and the northern part of the San Andres Mountains (fig. 4). However, these informal divisions are difficult to trace laterally in those areas.

MIDDLE ORDOVICIAN ROCKS—UPHAM DOLOMITE MEMBER OF THE MONTOYA DOLOMITE

Definition

The name Montoya was introduced by Richardson (1908, p. 478–479) for a unit he later described (1909, p. 4) as "about 250 feet of limestone lying between the El Paso and Fusselman limestones and containing Richmond and Galena faunas." The name was derived "from a station on the Santa Fe Railway in the Rio Grande Valley about 10 miles above El Paso," (1909, p. 4), but a type locality was not designated. Pray (1958, p. 30) proposed that a stratigraphic section in the northern Franklin Mountains, El Paso County, Tex., be adopted as the type section of the Montoya. At that locality the Montoya is 429 feet thick and consists chiefly of dolomite, cherty dolomite, and dolomitic limestone (Pray, 1958, p. 38–39). Darton extended the usage of "Montoya" into southern New Mexico, including the San Andres Mountains (Darton, 1917, p. 39) and the Oscura Mountains (1928, p. 194).

Different workers have variously and interchangeably used "Montoya Limestone" (Richardson, 1908, 1909; Darton, 1917; 1928), "Montoya Formation" (Dunham, 1935, p. 164; Pray, 1959), and "Montoya Dolomite" (Dunham, 1935, p. 42).

In southern New Mexico, Darton (1917, p. 38–39) recognized a local sandstone at the base of the Montoya, an overlying massive, dark-colored "limestone," and an upper, cherty member. Kelley and Silver (1952, p. 56–64) proposed that the Montoya be raised to group status in the Caballo Mountains and that it include, in ascending order: the Cable Canyon Sandstone, Upham Dolomite, Aleman Formation, and Cutter Formation. The lower three formations are equivalent to the subdivisions recognized by Darton, whereas the Cutter Formation was previously regarded as a lower part of the Fusselman Limestone of Silurian age. Pray (1953) recognized the Ordovician age of the lower part of the "Fusselman" in the Sacramento Mountains and there named it the Valmont Dolomite. Only a thin erosional remnant of the Montoya Dolomite, the Upham, crops out in the Mockingbird Gap quadrangle. In the present report this unit is regarded as a member of the Montoya Dolomite.

Distribution

In the Mockingbird Gap quadrangle the Upham Dolomite Member of the Montoya Dolomite is more restricted in extent than either the Bliss Sandstone or the El Paso Dolomite. The Upham is exposed in the southern Oscura Mountains as far north as the SE¼ sec. 5, T. 9. S., R. 6 E. The Upham is absent in the Mockingbird Gap Hills but is present in the northern part of the San Andres Mountains south of Little Burro Peak (sec. 30, T. 9 S., R. 5 E.).

Lithology

The Upham Dolomite Member of the Montoya consists of medium-dark-gray to olive-gray dolomite, which weathers with little change in color. Pink and dark-red streaks are associated with some fractures, but this coloration does not appear to be a major or persistent feature. Weathering results in a deepy pitted and rough surface, which, with the relatively dark color, is a characteristic feature of the Upham surface exposures. Bedding is even and generally thick (1–6 ft.), and the unit is exposed as a rounded ledge (fig. 5).

Chert is present only at scattered localities in the southern Oscura and northernmost San Andres Mountains, where it occurs sparsely as medium-gray nodules and stringers near the top of the formation. It is probably this part of the Upham that Darton (1928 p. 194) regarded as the cherty member (the Aleman Formation of Kelley and Silver, 1952) of the Montoya in southern New Mexico. However, the writer believes that the Aleman is absent in the Mockingbird Gap quadrangle.

The Upham Dolomite Member is a microcrystalline to cryptocrystalline mass of dolomite that contains

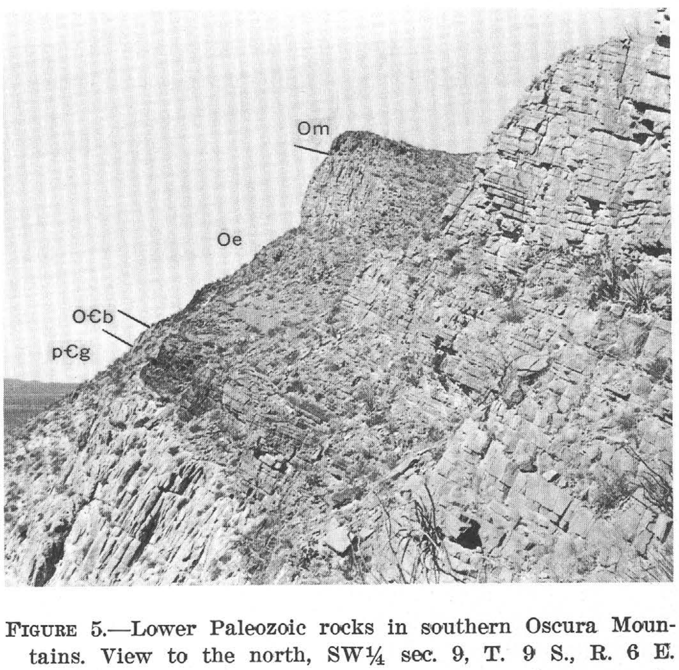


FIGURE 5.—Lower Paleozoic rocks in southern Oscura Mountains. View to the north, SW¼ sec. 9, T. 9 S., R. 6 E. Stratigraphic section ***M*** (fig. 4) was measured on spur in background where Precambrian granite (p€g), Bliss Sandstone (O€b), El Paso Dolomite (Oe), and Montoya Dolomite (Om) are visible.

scattered irregular, anhedral grains. Quartz sand grains which are subangular to subround and which average about 0.30 mm in diameter, are scattered throughout but do not form more than 1 percent of the rock. Some of the grains are deeply etched by dolomite, and etching may account for their angularity. Insoluble residues range from 2.6 to 4.4 percent by weight and consist of yellowish-brown clay and sparse grains of quartz. Versenate analysis of a representative sample from the southern Oscura Mountains yielded a calcium-magnesium molal ratio of 1.11 and indicates that the sample is relatively pure dolomite (Guerrero and Kenner, 1955, p. 46). This analysis conforms closely with the numerous analyses of the Montoya (Upham Dolomite) from other parts of southern New Mexico recorded by Kottlowski (1957).

H. A. Tourtelot, of the U.S. Geological Survey (written commun., 1962), made X-ray analyses of the insoluble residues from four samples of the Montoya from the southern Oscura Mountains. The samples were collected from a measured section in the SW¼ sec. 9, T. 9 S., R. 6 E., and are from the base of the formation and at approximately 12-foot intervals up the section. The X-ray analyses showed the following results:

1. Quartz and clay are the dominant insoluble residues in the basal half of the Montoya at the sampled locality.
2. The clay consists entirely of illite.
3. Goethite forms part of the insoluble residues of samples from the upper half of the Montoya, and the goethite content apparently increases upward in the section. Goethite is so abundant in the sample from the top of the unit that it masks the presence of any clay minerals which might otherwise appear on the X-ray traces.

Tourtelot stated that the goethite "may occur as such in the original carbonate rock as a primary constituent, as a near-surface weathering product of other iron minerals such as siderite, or as an alteration product of other iron oxides." The relatively high content of iron in the upper part of the Montoya at this locality may be related to pre-Pennsylvanian weathering of the Montoya.

Thickness

In the southern Oscura Mountains the Upham Dolomite Member ranges in thickness from 0 to 43 feet. The Upham thins northward in the Oscura Mountains, and the termination of continuous exposures is in the NW¼ sec. 9, T. 9 S., R. 6 E. One small outlier of Montoya that overlies the El Paso Dolomite and is overlain by Pennsylvanian rocks is exposed in the SE¼ sec. 5, T. 9 S., R. 6 E. At this exposure the Montoya has a maximum thickness of about 10 feet. Although the northward thinning of the Montoya is generally progressive, there is much variation in thickness locally due to pre-Pennsylvanian channeling. In the southwestern part of the quadrangle (sec. 30, T. 9 S., R. 5 E.) the Upham Dolomite Member of the Montoya is 30 feet thick. It is absent in the Mockingbird Gap Hills.

Upper contact

Everywhere within the Mockingbird Gap quadrangle the Upham is overlain by the Sandia Formation of Middle Pennsylvanian age. The contact with the Sandia Formation is sharp and irregular, and some channels into the Montoya are filled by sandstone of the basal part of the Sandia. Both the sandstone, including quartz granule conglomerate beds, and the greenish-gray shale occur at the base of the Sandia, and either rock type may rest on the Upham.

Darton (1928, p. 194) noted "red shale" in contact with the Upham in the southern Oscura Mountains. The Upham-Sandia contact was traced carefully in that area, and at one place (center of sec. 16, T. 9 S., R. 8 E.) reddish sandstone and angular chert fragments were found at the base of the Pennsylvanian, but red shale was not observed at that horizon.

Age and correlation

Fossils are very sparse in the Upham Dolomite Member in the Mockingbird Gap quadrangle, and none were collected during the present study. Only one fragment of *Receptaculites* was observed in rock debris on an exposure of the Upham in the southern Oscura Mountains.

Darton (1928, p. 194) observed the chert in the upper part of the Montoya in the southern Oscura Mountains and assumed that the cherty member—the Aleman Formation of Kelly and Silver (1952)—was present in that area. However, this chert occurs as stringers and pods that cut across bedding, and it bears little resemblance to the bedded chert of the cherty member of the Montoya farther south in the San Andres Mountains. Chert at the top of the Upham is here regarded as replacement and filling along fractures which developed beneath the major unconformity that overlies the Upham. Only the dark massive dolomite, the Upham Dolomite of Kelley and Silver (1952), is present in the Mockingbird Gap quadrangle.

Kelly and Silver (1952, p. 65, fig. 25, and p. 228) stated that the "Upham dolomite appears to be overlapped northward by the Aleman formation in the north end of the San Andres Mountains." Evidence for this relationship has not been found in the Oscura Mountains nor in the San Andres Mountains north of Capitol Peak, which is south of the Mockingbird Gap quadrangle.

Kottlowski, Flower, Thompson, and Foster (1956, p. 24–25) correlated the Upham Dolomite of Kelley and

Silver (1952) with the upper part of the Trenton Group of late Middle Ordovician age in the Eastern United States. Only the Upham is present in the Mockingbird Gap quadrangle. The Aleman cherty and Cutter Members of the Montoya in the San Andres Mountains to the south of the mapped area are of Late Ordovician age (Kottlowski and others, 1956, p. 7).

DEVONIAN AND MISSISSIPPIAN ROCKS

Rocks of Devonian and Mississippian ages were not observed in the Mockingbird Gap quadrangle, but about 1 mile south of the south boundary of the quadrangle, they are exposed in the northern San Andres Mountains. Darton (1928, p. 194) discussed a "red shale" in the Oscura Mountains overlying the Montoya Dolomite, which he thought was "possibly Percha." In exposures near the south end of the Oscura Mountains (center of sec. 16, T. 9 S., R. 6 E.), reddish sandstone and angular chert fragments are present in the basal bed of the Pennsylvanian, which rests on the Montoya at that place; but neither red shale nor other strata which could be assigned to the Devonian were observed.

Kottlowski, Flower, Thompson, and Foster (1956, pl. 1) labeled a "Mockingbird Gap" columnar section which indicates 15 feet of Devonian strata resting on the El Paso Dolomite. Exact location of their stratigraphic section is not indicated on that section, but such relationships were not observed in the quadrangle during the present work. Where observed immediately south of the quadrangle, the Devonian rests on the Upham Dolomite Member of the Montoya Dolomite.

The Devonian rocks at Hays Gap, about 2 miles south of the mapped area (center of sec. 5, T. 10 S., R. 5 E.), are poorly exposed. Where observed the rocks consist of yellowish-gray shale, mudstone, fine-grained sandstone, and limestone. A bed of gray fossiliferous limestone 6 inches thick occurs 5 feet above the base of the formation. At Hays Gap the Devonian is 32 feet thick.

In a northern tributary to Johnson Park Canyon south of the mapped area and about 5 miles northwest of Hays Gap (SE¼ sec. 31, T. 9 S., R. 5 E.), the upper part of the Devonian is very well exposed and consists of 23 feet of interbedded yellowish-brown mudstone and fine-grained sandstone. Corals and gastropods are common in a zone about 22 feet below the top. The basal 5–10 feet of the Devonian, as well as the contact with the underlying Montoya Dolomite, is covered at that locality, and a complete stratigraphic section could not be measured.

A limestone bed correlated on the basis of lithology with the Mississippian Alamogordo Limestone Member of the Lake Valley Formation rests on the Devonian in Hays Gap and in Johnson Park Canyon. The limestone is dark gray and thin bedded (1–3 ft thick); in some places it contains numerous chert nodules more than 1 foot in diameter. The chert is very dark gray to nearly black and is banded concentrically. At Hays Gap this limestone is 15 feet thick, and in Johnson Park Canyon it is 10 feet thick.

Northward from Johnson Park Canyon the Devonian and Mississippian beds were traced for about half a mile to their wedge edge. At the wedge edge, exposures are fair to poor, but within about 300 yards (NE¼ sec. 31, T. 9 S., R. 5 E.) a basal sandstone of the Sandia Formation fills a broad channel which cuts northward through the Devonian and Mississippian (Bachman, 1961). North of the wedge edge, Pennsylvanian strata rest on the Upham Dolomite Member of the Montoya Dolomite.

INTERPRETATION OF PRE-PENNSYLVANIAN PALEOZOIC STRATIGRAPHY AND SEDIMENTATION

Kelley and Silver (1952) discussed the implications of the northward thinning of pre-Pennsylvanian Paleozoic strata in New Mexico and presented two hypotheses which are of regional, as well as local, paleogeographic significance. They suggested (1952, p. 81) that during parts of Cambrian, Ordovician, Silurian, and Devonian times, depositional areas in New Mexico extended beyond the present limits of distribution of these rocks. They also suggested (1952, p. 132–134) that an east-west hinge line existed a short distance north of the Caballo Mountains and that the region north of the hinge line was recurrently uplifted during early Paleozoic time. Observations during the present work are in agreement with these hypotheses.

If the wedge edges of the Bliss, El Paso, and Montoya Formations in the southern Oscura Mountains represent shorelines and boundaries of basins of deposition, correlative horizons within the formations should reflect landward transitions in lithology. However, such facies changes within these formations are not apparent. In the southern Oscura Mountain, the Bliss, El Paso, and Montoya are not more clastic than rocks of correlative horizons within these formations farther to the south. Sizes of sand in the Bliss Sandstone are comparable to those in the Bliss in the southern San Andres Mountains and the Caballo Mountains. Both the gross lithology and insoluble residues of the El Paso and Montoya are comparable to correlative units in those formations to the south.

Insoluble residues in the basal part of the El Paso in the Oscura Mountains contain abundant quartz sand (about 18–32 percent), but the basal part of the El Paso is also very sandy in the San Andres Mountains to the south (Kottlowski and others, 1956, p. 17). Insoluble residues of the basal part of the El Paso in the San Andres Mountains are estimated to average 33 percent glauconitic quartz sand (Kottlowski and others, 1956, p. 83). Cloud and Barnes (1948, p. 368) observed porphyry, granite, and quartzite pebbles and described "arenaceous dolomite grading to dolomitic sandstone in the basal 1 to 3 feet" at the base of the El Paso in the Franklin Mountains in western Texas. This indicates that regionally the basal part of the El Paso is arenaceous and contains a variety of clastic debris.

The gross lithology of the Upham Dolomite Member of the Montoya Dolomite in the Oscura Mountains is very similar to the Upham in the San Andres Mountains to the south. Insoluble residues in the Montoya of the Oscura Mountains consist predominantly of clay and constitute 2.6–4.4 percent of the rock by weight. This proportion is comparable to that in the Upham in the San Andres Mountains (Kottlowski and others, 1956, p. 83–84). Kottlowski (1957, p. 12–13) described the constituents of the Upham over a broad area in south-central New Mexico and noted that in the 17 samples analyzed, insoluble residues range from 0.2 to 9.7 percent. He also stated that "insolubles are 1.5 percent or less in 13 of the samples, and in only two samples exceed 3 percent."

Rocks of Devonian and Mississippian ages wedge out south of the Mockingbird Gap quadrangle (fig. 4). The general sequence of Devonian strata near its wedge edge is lithologically similar to the sequence observed in the southern San Andres Mountains. Mississippian strata at their wedge edge do not represent the entire lithologic sequence of Mississippian rocks in the southern San Andres Mountains; but the one member at the wedge edge, the Alamogordo Member of the Lake Valley Formation, is lithologically similar to the Alamogordo Member at exposures in the southern San Andres Mountains. Rocks that are time equivalents of the Devonian and Mississippian of the northern San Andres Mountains have not been identified in north-central New Mexico. However, rocks of Mississippian age are present in the Ladron Mountains (Kelley and Silver, 1952, p. 86; Armstrong, 1958, p. 5) about 70 miles northwest of the Oscura Mountains, and 90 miles farther north in the Nacimiento Mountains (Fitzsimmons and others, 1956). Rocks of Mississippian and questionable Devonian ages have been identified in the Sangre de Cristo Mountains (Baltz and Read, 1960) in northern New Mexico. No direct evidence has been found to indicate that seaways from southern to northern New Mexico were connected during any part of Devonian and Mississippian time, nor does present evidence suggest that an extensive highland existed in central New Mexico during that time. In the discussion of the Mississippian rocks of the Ladron Mountains, Armstrong (1958, p. 6) stated that "it appears that the Mississippian setting was far from shore or that New Mexico had little relief at that time."

Because of the lack of lithologic evidence of shorelines in the vicinity of the Oscura Mountains, the writer concludes that rocks of Ordovician, Devonian, and Mississippian ages extended farther northward in New Mexico than the present exposures indicate, and that rocks of Silurian age possibly extended farther north. However, periodic epeirogenic uplifts resulted in beveling of pre-Pennsylvanian strata, and the northward extent of these pre-Pennsylvania seas must remain speculative at present. The times at which periodic uplift occurred in the Paleozoic Era in southern New Mexico and the problem of the "hinge line" are discussed below.

Hinge line

The northward thinning of pre-Pennsylvanian rocks is an outstanding regional feature in south-central New Mexico. The thinning is the result of periodic uplifts which occurred north of a broad easterly trending hinge line that extended from the vicinity of the Caballo Mountains (Kelley and Silver, 1952, p. 132–134) northeastward at least as far as the Oscura Mountains. In addition to Middle Ordovician and Late Silurian or Early Devonian uplift discussed by Kelley and Silver (1952 p. 78–80, 134), there is regional evidence for uplift during Late Ordovician or Early Silurian and probably during both Early and Late Mississippian time. Late Ordovician or Early Silurian uplift is indicated by erratic thicknesses of the Montoya Dolomite where it underlies the Fusselman Dolomite of Middle Silurian age to the south in the San Andres Mountains, and early Mississippian uplift is indicated by the northward pinchout of pre-Alamogordo Mississippian rocks (Laudon and Bowsher, 1949). Mississippian uplift may not have resulted in significant erosion of pre-Mississippian strata but did result in nondeposition in this area while Mississippian sediments were being deposited elsewhere in south-central New Mexico.

Southward from the hinge line no appreciable amount of clastic rocks accumulated in the pre-Pennsylvanian stratigraphic sequence. Such accumulations of clastic debris should be expected in the vicinity of areas of major uplift. Owing to the absence of clastic debris, it is thought that uplift was epeirogenic and measurable in no more than tens of feet per mile. Processes of chemical weathering could have been dominant over those of rapid erosion.

Dolomitization

Sufficient data are not available to evaluate the process of dolomitization of the Paleozoic strata of southern New Mexico. The widespread dolomitization of early Paleozoic formations of southern New Mexico was discussed briefly by Dunham (1935, p. 44–45), and the occurrence of these dolomites was studied by Kottlowski (1957). The two main problems relate to the process and the time of dolomitization.

The following relationships are apparent from a study of available information:

1. Carbonate parts of the Bliss Sandstone in the Oscura Mountains and adjacent areas consist largely of calcium carbonate.
2. The El Paso Dolomite appears to be more highly dolomitized in the Mockingbird Gap quadrangle than in adjacent areas. In the San Andres Mountains, the dolomitization of the El Paso is "erratic and irregular," as recorded by Kottlowski, Flower, Thompson, and Foster (1956, p. 17).
3. The Upham Dolomite Member of the Montoya Dolomite in the Oscura Mountains and adjacent areas is widely and uniformly dolomitized. This is apparent from analyses of the Upham Dolomite presented by Kottlowski (1957).
4. In the Oscura and San Andres Mountains there is no extensive dolomitization of rocks younger than the Silurian except for some dolomitization of limestone in the Yeso Formation of Permian age. This is generally true in south-central New Mexico, except for some Permian strata (King, 1948, p. 17, 36, 37, 40, 62, 66).

The study of thin sections during the present work indicates that the El Paso Dolomite in the Mockingbird Gap quadrangle is largely a dolomitized organic limestone, or calcarenite, and that the Upham Dolomite Member of the Montoya Dolomite is largely a dolomitized lime mudstone, or micrite. Evidence for several stages of crystallization, any of which, except the last, may have been associated with extensive metasomatic replacement by dolomite was particularly distinct in the El Paso. In order of occurrence these stages include:

1. Development of scattered rhombohedrons of dolomite in limestone. (This stage was not observed in thin sections from the Oscura Mountains but is present in some thin sections of the El Paso from the southern San Andres Mountains.)
2. Development of finely crystalline mosaic of anhedral to subhedral dolomite crystals and ultimate complete metasomatic replacement of calcite by dolomite.
3. Recrystallization of fine mosaic to a relatively coarse mosaic. Secondary silicification in veinlets and drusy masses may have occurred concurrently. The abrupt contact between the fine and coarse mosaic is explained more fully by Bathurst (1958, p. 24–25) as grain growth and is a process distinct from secondary recrystallization.
4. Filling of fine veinlets and fractures with calcite.

The presence of calcite in the last stage of crystallization, as indicated by stains, indicates that introduction of magnesium carbonate in large quantities ceased before stage 4. Stage 4 is probably related to Tertiary tectonic activity and consequent movement of calcareous solutions and probably is not related to a process of dedolomitization.

Of particular interest is the presence of a unique microscopic texture observed in three or four thin sections of the El Paso. In these thin sections, scattered grains of dolomite are elongate and under crossed nicols extinguish parallel to the long axis of the grain. The grains average about 0.10 mm in width and 0.25 mm in length.

These are very similar to elongate crystals from Devonian dolomite along the east side of the Central Russian Uplands which Makhlaev (1961, p. 473–477) illustrated and described. He noted that the elongate grains, or prisms, are oriented at random, but that they give a false impression of preferred orientation under crossed nicols, for they extinguish parallel to the cross hairs of the microscope. He also observed that these prisms are subject to replacement by both authigenic quartz and calcite. The calcite, which forms mainly in the central part of the grains, apparently was regarded by Makhlaev to be the result of dedolomitization.

Makhlaev noted that prismatic texture develops from microcrystalline dolomite concurrently with grain growth of dolomite. He suggested that at times during diagenesis some of the prisms may develop slightly earlier than the granular texture, but he regarded most prisms as having filled voids and considered them as druses which formed during recrystallization. He did not observe prisms on fossils.

The prismatic dolomite described by Makhlaev is apparently similar to that in the El Paso Dolomite. However, close examination of the El Paso also reveals significant dissimilarities such as absence of replacement of prisms by calcite and absence of authigenic quartz. In the El Paso Dolomite crystals of prismatic crystals intrude, or are surrounded by, a dolomitic matrix. Only in gross aspect are these prisms similar to those described by Makhlaev. The prismatic crystals in the El Paso may have resulted from selective dolomite replacement of original organic fragments. Minute fragments of crinoidal debris were observed on some weathered surfaces of El Paso strata. However, the process of the formation of dolomite prisms in the El Paso is not readily apparent.

Distribution of quartz sand

Quartz sand composes more than 50 percent of the Bliss Sandstone and may compose as much as 25–30 percent of the lower part of the El Paso Dolomite. It is scattered and probably forms less than 5 percent of the upper part of the El Paso and less than 1 percent of the Montoya Dolomite in the Mockingbird Gap quadrangle.

The quartz sand in the Bliss was probably derived from the underlying Precambrian granite, because it commonly contains clouds of inclusions similar to those observed in quartz in the granite. Transportation of individual grains apparently was limited to short distances. The general absence of both feldspars (except for a very few scattered grains) and products of feldspar weathering (except those in the upper part of the Bliss) indicates that a long period of weathering occurred on the granite terrain before the Bliss was deposited. The Bliss Sandstone is presumed to represent a deposit of sand repeatedly reworked by an advancing sea.

The quartz sand in the El Paso Dolomite may be similarly derived in part from the Precambrian terrain, but scattered quartz sand in the dolomites of the upper part of the El Paso and the Montoya may have been derived from reworking of underlying beds during periods of uplift. Cloud and Barnes (1948, p. 96) presented evidence that quartz sand in the Ordovician Ellenburger Group of Texas "was brought to its present position by the wind." This interpretation could be applied to the El Paso Dolomite in part, particularly to the Upham Dolomite member of the Montoya Dolomite in the quadrangle.

Etching and replacement of both quartz and glauconite grains by carbonate minerals (and hematite) is common in the Bliss Sandstone, and replacement of quartz sand by carbonate minerals is common in the El Paso and Montoya. Other geologists have also observed this latter phenomenon (Bourcart and others, 1933; Alimen, 1944), which results in the apparent frosting of sand in some carbonate rocks (Walker, 1957).

Environment of deposition

The widespread distribution of relatively similar rock units within the pre-Pennsylvanian Paleozoic indicates uniform conditions of deposition for each unit in south-central New Mexico. Apart from the periodic epeirogenic uplift along the generally east-trending Paleozoic hinge line, there were probably few, if any, major barriers to transgressions of seas. The pre-Pennsylvanian seas probably transgressed from the west (Kelley and Silver, 1952, p. 55).

The Bliss Sandstone is a transgressive deposit and represents the first phase of deposition in the El Paso sea. Weathered granite probably in relatively nearby areas was the source of sediments. The sand was reworked by minor currents as it was deposited.

The El Paso sea supported an abundant fauna and was probably relatively shallow—less than 100 fathoms—although very widespread. Dolomitization and recrystallization have altered many of the original constituents, but fragments and "ghosts" of organic debris are commonly observed in thin section. Much of the organic debris is apparently of calcarenite size and may represent deposition in seas of moderate turbulence.

The Montoya sea may also have supported an abundant fauna, as many fossils occur in the Montoya farther south in the San Andres Mountains. Although dolomitized rock is even more widespread in the Montoya Dolomite in the Mockingbird Gap quadrangle than in the El Paso Dolomite, and original fabric is obscure, the Montoya was probably deposited originally as a lime mud, or micrite. The sea may have been less turbulent than the El Paso sea.

PENNSYLVANIAN ROCKS

The nomenclature of Pennsylvanian rocks in New Mexico has had a complex history and will probably continue to be the source of much debate in the future. Relatively few of the stratigraphic units named in the literature have been indicated on published maps, and it remains for more detailed tracing and mapping of rock units in mountain uplifts to establish a satisfactory basis for synthesis of the nomenclature. However, the depositional history of Pennsylvanian rocks in New Mexico is complex, and mapping, by different geologists, of rock units in separate mountain ranges may result in apparent inconsistencies.

Herrick and Bendrat (1900) used the term "Sandia" for the basal beds of the Pennsylvanian in the Sandia Mountains, east of Albuquerque, and Keyes (1903) named the overlying limestone Madera. Gordon (1907) defined the Magdalena Group to include the "Sandia beds" at the base and an overlying Madera Limestone in the Magdalena Mountains, west of Socorro. Read, Wilpolt, Andrews, Summerson, and Wood (1944) accepted the Magdalena Group, including the Sandia Formation and Madera Limestone, in central New Mexico. They divided the Sandia Formation into a lower, discontinuous limestone member, which they recognized might include rocks of pre-Pennsylvanian age, and an upper, clastic member. They also divided the Madera Limestone into a lower, gray limestone member and an upper, arkosic limestone member.

Kelley and Wood (1946) used a similar nomenclature on the Lucero uplift along the west side of the Rio Grande valley. However, they named the members of the Madera Limestone, in ascending order, the Gray Mesa Member and the Atrasado Member, and at the top of the Madera Limestone included a transitional zone of marine and continental beds which they named the Red Tanks Member. Wilpolt, MacAlpin, Bates, and Vorbe (1946) mapped a transitional zone similar to the Red Tanks Member, recognized its Permian age in south-central New Mexico, and named it the Bursum Formation. Wilpolt and Wanek (1951) included the Bursum Formation in the Magdalena Group. Although the term Magdalena Group is useful in some parts of New Mexico, it is not used in the present report.

Thompson (1942) measured numerous stratigraphic sections of Pennsylvanian rocks in New Mexico and divided them into series, groups, formations, and members largely on the basis of fusulinid zones. Kottlowski, Flower, Thompson, and Foster (1956, p. 35) used Thompson's series names in the San Andres Mountains and established divisions of the Pennsylvanian "based on lithology and zonation of * * * fusulinids." They named the upper part of the Pennsylvanian sequence the "Panther Seep Formation" on the basis of its "distinct lithology and the possibility that the upper part of the formation may be of Wolfcamp age"; however, they assigned the Panther Seep Formation to the Virgil Series (Kottlowski and others, 1956, p. 42).

The type locality of the Panther Seep Formation is in the vicinity of Rhodes Canyon in the San Andres Mountains, about 20 miles south of the Mockingbird Gap quadrangle. In the San Andres Mountains the Panther Seep Formation appears to be a logical cartographic unit. However, the stratigraphic relation of the Panther Seep Formation to strata in the Oscura Mountains is not understood, and the Panther Seep Formation is restricted to the San Andres Mountains in the present report.

Much of the apparent confusion in nomenclature of Pennsylvanian and Lower Permian rocks in southern New Mexico results from the fact that facies changes are abrupt. Numerous changes in facies within relatively short distances can be observed by physical tracing of the individual beds in the Oscura, San Andres, and Sacramento Mountains. A distinctive sequence of rocks in one area may change laterally in either age or lithology.

At the beginning of the present work, divisions of the Pennsylvanian rocks were made following those of Wilpolt and Wanek (1951). These divisions include the Sandia Formation, a dominantly clastic sequence at the base, and the Madera Formation. The Madera was subdivided into two members: the "lower gray limestone member" at the base and the overlying "arkosic limestone member," which are here called lower and upper members, respectively. Mapping of these members revealed both the facies changes in the Oscura Mountains and the arbitrary nature of the contacts used. During mapping, fusulinids were collected systematically from map units in various parts of the area and were later studied to determine the faunal content and the relative age of the rocks.

SANDIA FORMATION

Distribution and lithology

The Sandia Formation crops out along the western front of the Oscura Mountains, in the Mockingbird Gap Hills, and in the San Andres Mountains. The Sandia commonly underlies a gentle slope and is one of the most poorly exposed map units in the quadrangle.

The sandstone beds of the Sandia Formation are coarse grained to conglomeratic and contain pebbles as much as one-half inch in diameter in places near the base of the formation. The sandstone is light gray to brown and in some places weathers pink or light red. Generally, it is composed of angular quartz fragments and lesser amounts of biotite and fragmental chert. Fragments of recognizable pre-Pennsylvanian Paleozoic rocks were not observed, but some of the chert fragments near the base may have been derived from rocks of Mississippian age. Sandstone beds range in thickness from a few inches to about 50 feet and are lenticular. One of the most persistent sandstone beds at the base of the formation was traced for about 1 mile in the southern part of the Oscura Mountains (SW¼ sec. 9, T. 9 S., R. 6 E., to SW¼ sec. 4, T. 9 S., R. 6 E.). It ranges in thickness from a knife edge to about 45 feet and is interpreted as a channel filling. At another place along the western front of the Oscura Mountains, sandstone lenses are local and terminate abruptly along the line of outcrop. Here a basal sandstone lens occupies a channel cut through the El Paso and into the top of the Bliss Sandstone.

Shale beds in the Sandia Formation are poorly exposed, but those observed are gray to greenish gray, are commonly sandy and micaceous, and are even and thin to fissile bedded. Silt was not observed, but supposedly it makes up part of the formation in covered shaly intervals.

Limestone beds, which compose about 5–8 percent of the Sandia Formation in the quadrangle, are mostly gray to dark brown and weather gray to yellowish brown. Bedding thickness ranges from a few inches to about 5 feet and is commonly 1–2 feet. Successions of limestone beds form layers that range from a few inches to 15 feet in thickness. The limestone commonly is calcarenite and is composed of crinoid columnals and other fossil fragments; rarely, it is finely crystalline "lime mudstone"; or, very rarely, it is cherty. The beds are relatively impure and are commonly sandy or shaly.

Thickness

The Sandia Formation thins toward toward the north and northeast in the mapped area. Its thickness is about 250 feet at the south end of the Oscura Mountains (pl. 2), 253 feet in the Mockingbird Gap Hills, 68 feet in the central part of the southern Oscura Mountains (SW$\frac{1}{4}$ sec. 12, T. 8 S., R. 5 E.), and 16 feet at the north edge of the quadrangle. Wilpolt and Wanek (1951) measured 15 feet of Sandia in the northern Oscura Mountains.

Contacts

The basal contact of the Sandia Formation is irregular, and the formation rests on a major erosional unconformity in both the Oscura and the San Andres Mountains. Depth of erosion appears to increase in magnitude from south to north in the Mockingbird Gap quadrangle (pl. 2, fig. 8). Lenticular beds of sandstone at the base, within the formation, are believed to represent channel deposits (fig. 8). In places, shale and sandy shale make up the basal rocks of the unit.

The contact of the Sandia with the overlying Madera Formation is gradational and locally difficult to map. The following criteria were used during the present study to differentiate the Sandia Formation from the lower member of the Madera Formation:

1. The Sandia Formation consists dominantly of quartzose sandstone and shale, whereas the lower member of the Madera Formation is dominantly limestone.
2. Where present in the Sandia Formation, limestone is generally sandy or shaly and crinoidal as compared with the dominantly dense "lime mudstone," or micrite, of the lower member of the Madera Formation.
3. Nodular chert is sparse in limestone beds of the Sandia Formation but common in limestone of the lower member of the Madera.
4. The contact between the Sandia Formation and the lower member of the Madera Formation was drawn at the top of the dominantly clastic sequence and at the base of the sequence of thick-bedded limestone. As drawn, no sandstone beds and only occasional interbeds of shale were included in the lower member of the Madera.

These criteria appear to be valid for the separation of the Sandia and lower member of the Madera Formation throughout the Oscura Mountains.

The Sandia-Madera contact, however, is not a planar surface. Small-scale interfingering of the upper part of the Sandia Formation with the Madera Formation probably occurs in both the Oscura Mountains and the Mockingbird Gap Hills. South of the Mockingbird Gap quadrangle, in the vicinity of Capitol Peak, massive beds of limestone occur locally within the clastic Sandia Formation, and the Sandia and lower part of the Madera interfinger.

Age and correlation

No diagnostic dating fossils were found in the Sandia Formation in the Mockingbird Gap quadrangle, but fusulinids are abundant in some places in the basal beds of the overlying Madera Formation. On the basis of the Madera fauna, the Sandia Formation in this area is placed within the "Zone of *Fusulinella*" of Middle Pennsylvanian age.

The Sandia Formation in the Mockingbird Gap quadrangle is lithologically distinct from the type "Derry series" of Thompson (1942) in the Derry Hills, about 80 miles southwest of the Oscura Mountains. On the basis of the fusulinids from the overlying Madera Formation, however, the Sandia Formation may be equivalent to some part of Thompson's "Derry series" and is equivalent to at least a part of the Atoka Series of the midcontinent region.

MADERA FORMATION

LOWER MEMBER

Character

The lower member of the Madera Formation forms a prominent series of ledges or cliffs along the west-facing scarp of the Oscura Mountains, in the Mockingbird Gap Hills, and in the northern part of the San Andres Mountains. The member consists predominantly of limestone and contains a few relatively thin beds of gray calcareous shale locally.

In profile, exposures of the lower member of the Madera Formation in the southern Oscura Mountains and in the Mockingbird Gap Hills appear to form three major ledges and two intervening slopes. The lower of the two slopes is on the upper part of the lower half of the member and is underlain by a less resistant monzonite sill of probable Tertiary age. The thickness of the sill varies considerably throughout the quadrangle but ranges from about 25 to more than 50 feet where measured. The explanation for the upper of the two slopes is less apparent at most outcrops because the limestone sequence is generally continuous in that interval. The upper slope may be the result of weathering of a relatively more argillaceous limestone interval, for it locally contains shale (fig. 4, cols. **E, G**).

The limestone beds of the lower member are generally medium gray and weather light medium gray, olive gray, or, locally, dusky yellow to brown. Beds are a few inches to more than 10 feet thick and are generally even and relatively parallel, but some are broadly wedge or lens shaped in cross section. At both the base and the top of the member, some individual beds grade laterally into calcareous shale.

Chert is a major and conspicuous constituent of some limestone beds and occurs both as nodules and as stringers parallel to the bedding. Nodules of chert range from less than 1 inch to more than 1 foot in diameter and in places coalesce to form stringers. Some of these stringers and lenses of chert can be traced for several hundred feet. Chert is not a consistent constituent of individual beds, however; the cherty limestone beds traced along exposed faces grade laterally into noncherty limestone. This random distribution of chert in the lower member of the Madera Formation is apparent in the graphic sections (pl. 2).

Shale is present locally but composes only a minor part of the lower member; it is light gray to gray and calcareous. The thickest shaly unit observed is a shaly limestone nearly 50 feet thick (pl. 2, col. **E**) that occurs about 75 feet below the top of the member in the Mockingbird Gap Hills. Neither quartz sandstone nor sandy beds were observed in the lower member in the quadrangle.

Thickness

The lower member of the Madera Foundation thickens southward and southwestward from the north edge of the quadrangle. Excluding sills, it is 268 feet thick in the Oscura Mountains at the north edge of the quadrangle and 407 feet thick in the southern part of the Mockingbird Gap Hills (pl. 2).

Wilpolt and Wanek (1951) stated that "in the northern Oscura Mountains, this member is 370 feet thick but it thickens rapidly southward to 700 feet thick in the central Oscura Mountains." Locally, carbonate rocks are very abundant in the upper part of the Madera in the central Oscura Mountains, and Wilpolt and Wanek may have included some limestone from the upper part of the Madera in their lower member.

Age and correlation

The lower member of the Madera Formation is abundantly fossiliferous in the Mockingbird Gap quadrangle. Many macrofossils are embedded in the limestone, and they are difficult to collect. Brachiopods and corals appear to be the most abundant.

Fusulinids are common to abundant in many beds in the lower member. Commonly, fusulinids are concentrated near the tops of individual beds. Fusulinids found in the lower member include *Fusulinella*, which occurs near the base of the member, and *Fusulina* associated with *Wedekindellina* in the upper part of the member. *Pseudostaffella* was observed in one collection.

On the basis of fusulinids, the top of the Zone of *Fusulinella* (Thompson, 1948, p. 22) is about 50 feet above the base of the lower member. No apparent lithologic change marks the top of that zone. The remainder of the member is in the lower part of the Zone of *Fusulina*. Since the most common occurrence of the fusulinid *Wedekindellina* is in the lower part of the Zone of *Fusulina* in the midcontinent region (Thompson, 1948, p. 22), a similar association is assumed in the Oscura Mountains. Specimens of *Wedekindellina* are present to the top of the lower member of the Madera Formation in the southern Oscura Mountains (pl. 2, col. **F**), whereas *Triticites ohioensis* is present near the base of the overlying upper member (pl. 2, col. **A**). This implies a local faunal hiatus between the lower and upper members. The lower member of the Madera Formation in the Mockingbird Gap quadrangle is correlated with the upper part of the Atoka Series and the lower part of the Des Moines Series of the midcontinent region.

UPPER MEMBER

Wilpolt and Wanek (1951) assigned the upper part of the Madera Formation in the northern part of the Oscura Mountains to an "arkosic limestone member" following the usage by other geologists in central New Mexico (Read and others, 1944; Bates and others, 1947). During the present work the upper, dominantly clastic part of the Madera Formation was likewise assigned to an informal member. The term "arkosic limestone" is not used here, however, because the limestones are not arkosic and because complexities of the stratigraphy of the upper part of the Madera within the Mockingbird Gap quadrangle indicate that reference to the "arkosic limestone member" may be a milseading suggestion of precise correlation with rocks of other areas. Few, if, any, individual beds of limestone in the upper part of the Madera Formation are continuous for great distances in this area. Therefore, correlation of a sequence of beds within the Pennsylvanian of south-central New Mexico should be made with great care and with consideration of all available information.

Distribution

The upper member of the Madera Formation is exposed on the back slopes of the southern Oscura Mountains, in the Mockingbird Gap Hills, and in faulted blocks in the northern part of the San Andres Mountains. It is partly exposed in the southern Hansonburg Hills and in small inliers west of the Oscura Mountains. Exposures are very good along the dip slope of the Oscura Mountains in the northern and southern parts of the Mockingbird Gap quadrangle but are only fair to poor in the central part of the quadrangle, where small trees and undergrowth cover much of the dip slope. In the Mockingbird Gap Hills the exposures are very good, but detailed study of the member there is complicated by numerous small faults (some of which are obscure) that offset beds and make tracing the beds both difficult and time consuming.

Lithology

The upper member of the Madera Formation consists of interbedded limestone, shale, siltstone, quartz sandstone, graywacke, and arkose. Lenticular conglomeratic beds are present in the southern part of the quadrangle throughout the stratigraphic range of the member. These may be composed of limestone granules and pebbles or quartzitic granules in an arkosic matrix. The proportion of conglomeratic lenses increases upward in the stratigraphic section. The coarse beds (sandstone and conglomerate) are most abundant in the southern part of the quadrangle and interfinger with shale and limestone northward.

Limestone is the dominant rock in the northern part of the quadrangle but is less abundant in the southern part. The limestone beds generally form thin steplike ledges, but some beds are massive and form cliffs. Fresh limestone surfaces range from medium light gray to medium dark gray. Some beds weather medium gray, but most beds weather light olive gray with subtle hues of yellow to light brown. Individual units are generally parallel bedded and range in thickness from less than 1 inch to more than 5 feet. Locally, the more coarsely textured limestones are crossbedded.

Shale forms a large part of the upper member of the Madera Formation throughout the quadrangle. In the southern part of the Oscura Mountains, however, the shale beds are more silty and sandy than in the northern part. The shale is mostly light to medium gray, and locally it is very calcareous. Some calcareous beds contain abundant marine fossils. Some shale beds are olive gray, and most of the silty and sandy beds are yellow or brown. Bedding is thinly laminated to fissile.

In the Mockingbird Gap Hills a dark-gray fissile carbonaceous shale occurs in the basal part of the upper member. This shale bed is at least 50 feet thick and contains stumps of fossil wood which R. A. Scott, of the U.S. Geological Survey, assigned to the genus *Dadoxylon* (written commun., 1962). A coal bed slightly more than 1 foot thick was reported in the Mockingbird Gap Hills by Meinzer and Hare (1915, p. 59), but it was not observed during the present investigation. In the northern part of the quadrangle along Workman Ridge, three beds of dark-red to variegated gray and dark-red shale were observed in the upper member.

Conglomerate, arkose, graywacke, and quartzitic sandstone are abundant in the upper member of the Madera in the southern part of the quadrangle, are less abundant in the central part, and are virtually absent in the northern part. The clastic rocks are commonly composed of angular poorly sorted quartz, feldspar, and mica grains and rock fragments. The limestone granule to pebble conglomerate is cemented by argillaceous limestone. The clastic rocks are gray, greenish gray, or dark green near the base of the member and brown to reddish brown in the upper part of the member. These beds are cross-laminated and lenticular in cross section, and they wedge out laterally within 200 feet to 1 mile along their exposure. The lenses have random geographic and stratigraphic distribution, and the coarser textured lenses do not indicate extensive horizons of disconformities. They are interpreted as fluviatile channel fillings; some may be continuous in sinuous patterns which follow Pennsylvanian stream beds, and they may represent local diastems.

The texture of the limestone beds of the upper member ranges from very fine grained micrites to coarse-grained calcarenites. Fossils occur in most of the limestone beds observed and range from fragments in the coarser grained limestones to complete fossils. Where the fossils are complete, the brachiopods, pelecypods, and other fossils with body cavities contain small percentages of very fine grained lime mudstone in the basal parts of the cavities, as the individuals are oriented in the limestone bed; whereas the upper parts of the body cavities are filled with fine mosaics of sparry calcite. This type of preservation indicates that the fossil was moved very little before complete burial. Other coarsely crystalline limestones consist chiefly of fossil fragments interbedded in lime mudstone. Quartz grains, feldspars, and other detrital minerals were not observed in the limestone thin sections.

Twenty-seven samples from the quadrangle were analyzed for calcium and magnesium to determine the extent of dolomitization of carbonate rocks in the upper member of the Madera Formation. Of these, only five contain more than a trace of magnesia (0.6–0.7 percent), and in four of these the calcium-magnesium molal ratio is between 29.98 and 35.3. These four are classified as magnesian limestone. The molal ratio of the fifth sample is 38.73. The ratio of the other 22 samples is 100, all being relatively pure calcium carbonate. Many of these samples contain large amounts of argillaceous insoluble residue and thus do not indicate potentially commercial deposits of limestone. Not enough limestone analyses are available to determine whether the five samples containing more than a trace of magnesia are of stratigraphic or paleogeographic significance.

The sandstones of the upper member of the Madera Formation received only cursory microscopic examination. They are fine grained and poorly sorted and contain abundant fragments of feldspar. The quartz grains are angular, and some grains contain "clouds" of inclusions similar to those observed in quartz grains in the Precambrian granite and the Bliss Sandstone. There is some evidence that the long axes of the feldspars may have a preferred orientation generally parallel to the bedding planes. The feldspars appear relatively "fresh" but are sericitized in places.

One representative thin section and sample from a lenticular sandstone bed at the south end of the Oscura Mountains (SW¼ sec. 11, T. 9 S., R. 6 E.) was examined in detail by R. A. Cadigan, of the Geological Survey. This sample was collected about 375 feet above the base of the upper member and is considered to be typical of sandstone beds in the upper member, although relative percentages of minerals are variable from bed to bed and even at various localities within an individual bed. Cadigan (written commun., 1962) reported as follows:

This is a very fine grained sandstone. Detrital grains which compose 70 percent of the area of the thin section consist of quartz, albite, fragments of quartzite, mica, and perthite. The clay fraction, 25 percent of the area of the thin section, is almost exclusively chlorite (pennine). Cement, 5 percent of the area of the thin section, includes calcite and unidentified opaque interstitial material. Heavy minerals include:

Apatite, some rounded, some hexagonal;
Tourmaline, pink, rounded;
Chlorite, green, ragged;
Glauconite(?), green, rounded;
Leucoxene.

The clay matrix has characteristics of an altered ash. There is much mica, and there are many interstitial quartz overgrowths. The rock may be slightly metamorphosed. Interstitial calcite replaces albite(?). Fragments of crystal (sodic?) tuff have altered to chlorite (pennine), and some albite(?) has altered to chlorite. Kaolinite and fragments of crystal or rhyolite tuff form a small portion, 1 percent or less, of the thin section. This rock may be classified as a graywacke, or as a chloritic feldspathic tuff if the probable extrusive igneous origin of the clay matrix is considered in the classification.

Contacts

The basal contact of the upper member of the Madera Formation is drawn at the top of the sequence of massive cherty limestone beds (lower member) and the base of the sequence of interbedded shale, sandstone, and limestone. In both the northern and southern parts of the Mockingbird Gap quadrangle the basal contact is comparatively sharp, whereas in the central part of the quadrangle—in the Oscura Mountains—it is less definite. Near South Oscura Peak, numerous beds of limestone occur in the upper member. In that area the contact between the lower and upper members of the Madera is less definite and is best determined by lateral tracing and projection of the contact from either the northern or the southern part of the quadrangle.

In the northern part of the quadrangle, and particularly in the Hansonburg Hills, the upper contact of the upper member of the Madera is drawn at the top of the dominantly gray lithologic sequence and at the base of interbedded limestone and red beds of the overlying Bursum Formation. In the Hansonburg Hills the basal bed of the Bursum Formation is a distinctive red shale interbedded with arkosic sandstone (the "Abo tongue" as mapped by Wilpolt and Wanek, 1951). In the extreme southern part of the Oscura Mountains the upper contact of the upper member of the Madera would be practically impossible to determine unless it were physically traced from the northern part of the mountains, for in that area the lithology of the basal part of the Bursum Formation closely resembles that of the upper member of the Madera. A horizon on the upper limestone bed of the Madera Formation, as mapped by Wilpolt and Wanek (1951), was traced and used to define the basal contact of the Bursum Formation. Because of facies changes within the Bursum Formation and the lithologic resemblance of the Bursum to the Madera in places, the contact between the two formations is an arbitrary one.

Thickness

It is difficult to measure a complete stratigraphic section of the upper member of the Madera Formation in a continuous sequence; therefore, measurements of it were made from a composite section. This method does not permit the representation of an accurate thickness for any single geographic locality within the quadrangle, but it does represent a general order of magnitude.

In the northern part of the quadrangle the upper member ranges in thickness from 500 to about 825 feet (pl. 2, cols. **A–D**). In the Oscura Mountains, toward the southern part of the quadrangle, the upper member has a maximum thickness of about 1,575 feet (pl. 2, cols. **G, H**).

Age and correlation

In the mapped area the upper member of the Madera Formation is entirely within the "zone of *Triticites*" and includes representatives of the *Triticites* subzones. Collections from the basal part of the upper member include *T. ohioensis*, *T. nebraskensis*, and *T.* cf. *T. irregularis*. In the southern part of the Oscura Mountains, *Kansanella cuchilloensis* occurs about 650 feet above the base of the member (pl. 2, col. **G**). The assemblage of *Triticites ohioensis* occurs throughout a basal interval about 250–300 feet thick in the northern part of the quadrangle and in a basal interval about 650 feet thick in the southern part. This faunal assemblage is correlative with the Missouri Series of the midcontinent region.

Above the *Triticites ohioensis* assemblage, *T. plummeri* and associated species are present. In the northern part of the quadrangle, the zone of this faunal assemblage is relatively thin and does not exceed 350 feet. In the southern part it may extend through about 950 feet (pl. 2, col. **H**), but fusulinids are rare or poorly preserved in the upper part of the upper member in that area. This faunal assemblage is correlative with the Virgil Series of the midcontinent region. Thus, both Missouri and Virgil faunal equivalents are represented in the upper member of the Madera Formation in the Mockingbird Gap quadrangle.

In the northern part of the quadrangle (pl. 2, col. **D**) fusulinids were collected from a limestone bed about 150 feet below the top of the upper member of the Madera Formation. These fusulinids show affinities to both Pennsylvanian and Permian forms. D.A. Myers first examined this collection and regarded the fusulinids as questionably Early Permian in age. Myers (written commun., 1962) identified one species as *Triticites creekensis* and noted another species which "belongs to the clan of *T. ventricosus*." As the fusulinids were collected from a horizon definitely below the Permian Bursum Formation, as defined and mapped by Wilpolt and Wanek (1951), this collection was reexamined several times. Also, L.G. Henbest, of the U.S. Geological Survey, examined 18 selected thin sections from this collection. He stated (written commun., 1962):

> The 18 thin sections were carefully surveyed. Each section contains one or more specimens of *Triticites* closely resembling *T. cellimagnus* Thompson, and in one or two sections a species resembling *T. creekensis* Thompson. A highly evolved species of *Globivalvulina* is present. My first impression agreed with the sender's determination of these as of very early Wolfcamp or of Bursum age, but there are two things about the foraminifer assemblage that call for caution. The first is that *Schubertella kingi* Dunbar and Skinner, *Geinitzina postcarbonaria*, and spandelinids, which are so abundant in earliest Permian environments like the one represented here, are missing. The second is that the stage of evolution represented by *Triticites plummeri* Dunbar and Condra makes me suspect that forms resembling *T. cellimagnus* and *T. creekensis* may have existed in very late Cisco and Virgil time. Microspheric juvenaria of a form resembling *Schubertella* are present. Such are common in the upper Cisco rocks.
>
> Late Virgil (Cisco) or more likely very early Wolfcamp age is indicated. Inasmuch as this seems to be an important issue, it is suggested that other collections be obtained and that larger areas of matrix be included in the sections to obtain as much corollary evidence as possible and to check on the above determination.

Study of other samples of these rocks and the evidence provided by tracing of beds in the field indicate that this fauna is from rocks equivalent to very late Virgil or Cisco age and that the fauna is transitional between Pennsylvanian and Permian. Also, in accord with the statement by Henbest quoted above, forms resembling *Triticites cellimagnus* and *T. creekensis* probably existed in very late Cisco and Virgil time in the Oscura Mountains area.

Megafossils are common in the upper member of the Madera Formation and consist of long-ranging Pennsylvanian forms. A particularly well preserved, dominantly coral, fauna was collected about 800 feet below the top of the member in calcareous shale and the basal, nodular part of an overlying limestone bed (pl. 2, col. **H**). It consists of the following species, which were identified by W. J. Sando and J. T. Dutro, Jr. (written commun. 1961):

Caninia cf. *C. torquia* (Owen)
Multilithecopora aff. *M. paucitabulata* Moore and Jeffords
Wellerella cf. W. osagensis (Swallow)
"*Ambocoelia*" cf. "*A*" *planoconvexa* (Shumard)
Neospirifer aff. *N. triplicatus* (Hall).

One specimen of a rhizomorine lithistid demosponge was collected from a cherty limestone bed about 75 feet above the base of the upper member (pl. 2, col. **C**). It was identified as *Haplistion sphaericum* Finks by R. M. Finks (written commun. 1962). Finks stated that the type specimens of this species were collected in the Sacramento Mountains, southeast of the Mockingbird Gap quadrangle, and that they were from rocks considered to be a Des Moines equivalent. He further stated that "species of the genus *Haplistion* * * * seem to be long ranging for the most part, and a very similar species to the present one * * * occurs in the middle or upper Permian of Spitzbergen."

PERMIAN ROCKS

BURSUM FORMATION

The Bursum Formation was defined by Wilpolt, MacAlpin, Bates, and Vorbe (1946) from exposures west of Bursum triangulation point (SE¼ sec. 1, T. 6 S., R. 4 E.) in the Hansonburg Hills, Socorro County, N. Mex. The type stratigraphic section, about 5 miles north of the Mockingbird Gap quadrangle, was examined during the present investigation. Both at the type locality and in the northern and central part of the Oscura Mountains, the Bursum Formation is a well-defined lithologic unit. At some localities in the southern Oscura Mountains, facies changes occur in the Bursum Formation, and the contacts are therefore difficult to trace.

The Bursum Formation is transitional between the dominantly gray strata of marine origin in the Madera Formation and the red strata of continental origin in the overlying Abo Formation. This "transitional zone" has been named by several geologists. In the Los Pinos Mountains about 35 miles northwest of Mockingbird Gap, Stark and Dapples (1946, p. 1154) proposed the name Aqua Torres Formation for a similar zone. In the northern Sacramento Mountains, about 40 miles southeast of Mockingbird Gap, Otte (1959, p. 25) gave the name Laborcita Formation to the "transition beds" that are dominantly marine. The intertonguing nature of the "transition zone" makes it difficult to map as a logical cartographic unit. It is here proposed that the name Bursum Formation be restricted geographically to the vicinity of the Oscura Mountains.

Distribution

The Bursum Formation is well exposed and readily mappable in the Hansonburg Hills. It is exposed in the northeastern part of the Mockingbird Gap quadrangle, where it is lithologically similar to the formation at the type section. To the south, in the Oscura Mountains and in the Mockingbird Gap Hills, the Bursum is well exposed; but facies changes occur in the southern part of the quadrangle, and limestone and gray shale replace the basal red beds interval found in the exposures to the north.

Lithology

At the type locality and in the Mockingbird Gap quadrangle, the Bursum Formation is composed dominantly of dark-red to reddish-brown conglomerate, arkose, and shale with interbeds of gray to yellowish- or brownish-gray limestone. In the southern part of the quadrangle calcareous shale and limestone beds are the dominant rocks in the basal part of the formation, and interbedded red beds and limestone compose the upper part.

The red beds of the Bursum Formation include dark-red to reddish-brown conglomerate, arkose, sandstone, and some siltstone and shale. Shale and siltstone are poorly exposed and occur in slopes, whereas most conglomeratic and arkosic beds are well consolidated and form rounded to angular ledges. The beds of conglomerate and arkose are lenticular in cross section and are mostly crossbedded and poorly sorted. They contain fragments of a variety of rock types and feldspar, mica, and other minerals. Conglomeratic lenses occur at random stratigraphically, although some field evidence suggests that the depositional axes of the lenses trend generally northeast to east.

The limestone is mostly medium gray and weathers to mottled hues of olive, yellowish gray, or dark red. Some of the red stain on weathered surfaces may be attributed to leaching of superjacent red beds. Most of the limestone is finely crystalline micrite, but some is calcarenite or consolidated limestone conglomerate. The limestone conglomerate appears to be intraformational and is composed of rounded fragments which range in size from coarse sand to cobbles. Some of these calcarenites or limestone conglomerates are completely cemented by "lime mud" so similar to that of the conglomeratic fragments that the rounded constituents are not apparent on a fresh surface and can be seen only microscopically or on some weathered surfaces.

Texturally, the limestone beds are chiefly micrites. They contain sparry calcite in filamentous to irregular small sporadic masses. Sparse scattered rhombohedrons of dolomite were noted in one thin section. The "mud" matrix is dark, cloudy, and cryptocrystalline. In thin section, algal masses appear as laminated filamentous sparry calcite embedded in micrite. Sparry calcite occurs both as isolated crystals, which appear to "float" in the micrite matrix, and as drusy fillings in body cavities of fossils.

Eleven samples of limestone from the Bursum Formation were analyzed, by J. A. Thomas, U.S. Geological Survey, for calcium and magnesium. Of these, seven were limestone with no more than 0.7 percent magnesium, three were magnesium limestone, and one bulk sample of pebble conglomerate was calcitic dolomite. The conglomerate may have been deposited in an intertidal zone where dolomite was concentrated, or, possibly, some of the magnesium is in a chloritic clay fraction of the rock and the carbonate material is primarily calcium carbonate.

About 1 mile southwest of the abandoned town of Estey City (SW¼ sec. 36, T. 8 S., R. 6 E.) is a sequence of interbedded medium-dark fine-grained limestone and shale at least 50 feet thick. Because the base of the sequence is covered, its true thickness could not be measured. The beds of limestone and shale have an average thickness of about 3–4 inches. The shale beds are fissile, and all bedding is parallel. In the Mockingbird Gap quadrangle, such fine-grained thin even-bedded rocks are sparse in the Bursum Formation. Apparently they were deposited in a relatively low-velocity marine environment—probably in a lagoon or bay. Fossils are rare in the sequence, which may indicate a restricted environment; and only two specimens of brachiopods (*Composita sp.* and *Chonetes sp.*), scattered fragments of bryozoans, and a fragment of a small horn coral were observed in the field. Farther north this sequence becomes thinner, and within 1 mile grades laterally into interbedded coarse clastic rocks and lenticular beds of limestone.

Beds of algal limestone are present in the Bursum Formation in the southeastern part of the quadrangle west of Estey City (fig. 6). The algal colonies are concentrated on the upper surface of the beds and weather to rounded mounds from 1 to 6 inches in diameter. Some of the colonies were apparently broken up before complete consolidation of the rock.

The arkose is composed dominantly of sodic feldspar, which is unusually fresh and shows little alteration to sericite or clay minerals. Quartz grains, like the feldspar constituents, are angular to subangular. Some thin sections contain calcite cement, which has partly or completely replaced some feldspar grains. R. A. Cadi-

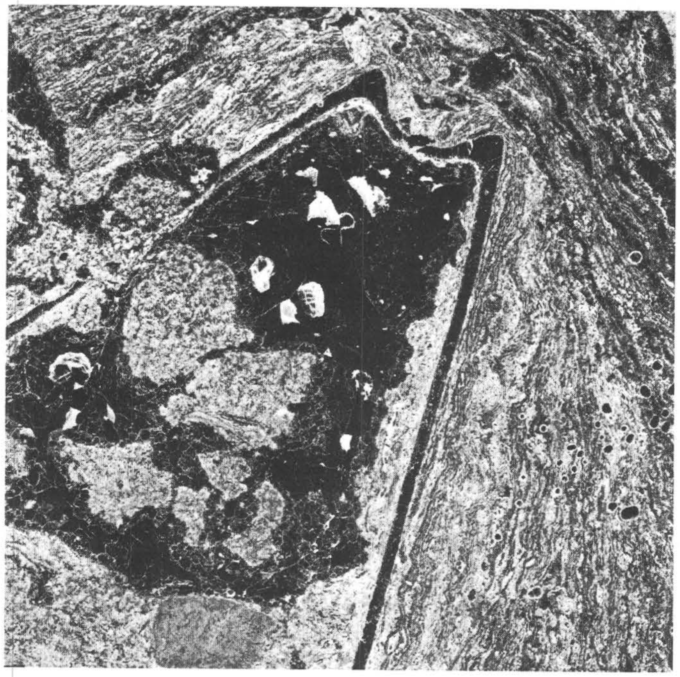


FIGURE 6.—Colonial algae in the Bursum Formation. Acetate peel × 5.

gan, of the U.S. Geological Survey (written commun., 1962), examined two representative thin sections and bulk samples of arkose from the Bursum Formation:

> Based on the thin-section study, the first sample consists of 65 percent albite, sodic oligoclase, altered tuff fragments, mica, quartz, unidentified rock fragments, and opaque grains; 25 percent clay minerals including chlorite (pennine and possibly another variety), montmorillonite, hydrous mica-montmorillonite, and mica; and 10 percent cement including carbonates (calcite and possibly dolomite), iron oxides, and unidentified opaque minerals.

Cadigan classified this sample as either a graywacke or an arkosic tuff, depending on the origin and classification of the chlorite in the clay fraction of the sample. In the same sample he found the following heavy minerals: apatite, leucoxene, anatase, rutile, hematite, and magnetite. Cadigan (written commun., 1962) interpreted this rock as having been derived from "sodic igneous intrusive and extrusive rocks" and considered that "the original detrital material (before diagenesis) was probably sodic feldspar and sodic volcanic debris including tuff fragments and ash, quartz grains, books and flakes of biotite, opaque oxides, and silicate minerals. Diagenesis started with the glassy ash, which altered to montmorillonite, which in turn altered to chlorite in the absence of potassium and in the presence of abundant magnesium from the glass."

The second sample examined by Cadigan was similar to the first except that it contained visible copper carbonate minerals. In it he noted the following heavy minerals: Coarse apatite, barite, angular zircon (pink), chlorite, magnetite, leucoxene (pale yellow), purple ilmenite, and malachite. He also interpreted this sample as tuffaceous but stated that the "tuff characteristic was good to poor because of chloritization and possible albitization of 'glassy' material." He stated that the "angular to subangular grains suggest that the sediment is quite close to the source (within 100 miles)."

Contacts

The physical stratigraphy and the fusulinid faunas indicate that deposition of sediments continued in the mapped area without appreciable interruption from Pennsylvanian into earliest Permian time. Both the upper and lower contacts of the Bursum Formation are gradational or intertongue with adjacent strata. There is evidence that some beds in the Bursum have been reworked, as limestone conglomerate is common in the formation. However, these conglomerate beds are here regarded as intraformational and are not related to a regional unconformity. Similar intraformational limestone conglomerate is present in the upper member of the Madera Formation.

At one locality about 300 yards northwest of Schollewell (SE¼ sec. 2, T. 9 S., R. 6 E.) on the eastern flank of the Oscura Mountains, a limestone pebble and cobble conglomerate occurs at the base of the Bursum Formation. This bed is lenticular but no evidence was found to indicate that it is a so-called "basal" conglomerate or that it marks an unconformity. There is no evidence that the conglomerate is of more significance than other local conglomeratic lenses in the upper member of the Madera Formation or the Bursum Formation.

Facies changes in the basal part of the Bursum and the upper part of the Madera Formations obliterate the marked lithologic contact that is traceable in the northern part of the quadrangle. For this reason, the contact as mapped in the southern part of the guadrangle is an approximate horizon that was traced from the northern part of the Oscura Mountains southward (pl. 3). The main distinctions of the Bursum Formation from the upper member of the Madera Formation in the area of facies changes are as follows:

1. Dark-red and gray shale interfinger, and red shale is sporadically present in the Bursum Formation; whereas gray shale is predominant in the upper part of the Madera Formation.
2. Sandstone and conglomerate beds in the Bursum Formation are generally dark reddish brown as compared with the more grayish to greenish-gray tones in the upper member of the Madera.

Age and correlation

The Bursum Formation is of Early Permian, Wolfcamp, age. It is apparently somewhat older than the basal part of the type stratigraphic section of the Wolfcamp in southwestern Texas (Ross, 1963, p. 46).

Fusulinids collected from the Bursum Formation in the Mockingbird Gap quadrangle during the present study include the following species: *Schwagerina* sp., "*Triticites*" sp. (a very advanced form transitional between *Triticites ss.* and *Schwagerina*), other advanced forms of *Triticites*, *Triticites* cf. *T. creekensis* Thompson, and *Schubertella* (?) sp.

Macrofossils are common in the limestone beds of the Bursum Formation but are rarely silicified and are generally too poorly preserved to be identified. In the parts of individual limestone beds deposited near shore, fossil fragments are common but broken and abraded. Various types of algae are common in limestones of the Bursum and consist chiefly of filamentous types (fig. 6) or algal encrusted pellets.

Thickness

The Bursum Formation ranges in thickness from about 65 to at least 450 feet in the Mockingbird Gap quadrangle. The minimum thickness was measured where a channel filled by the Abo Formation cuts into the Bursum in the northeastern part of the quadrangle (pl. 3, col ***A***). In the southern part of the Oscura Mountains the Bursum is at least 450 feet thick (pl. 3, col ***I***), but the upper part of the stratigraphic section is faulted and poorly exposed and cannot be measured accurately.

ABO FORMATION

The Abo Formation was originally named by Lee (Lee and Girty, 1909, p. 12) for Abo Canyon at the south end of the Manzano Mountains about 50 miles northwest of the Mockingbird Gap quadrangle. As Lee did not establish an adequate type locality for the formation, Needham and Bates (1943, p. 1654–1657) redescribed the formation and established a type locality in Abo Canyon. The Abo Formation has been discussed extensively in the geologic literature, but many problems pertaining to its age and stratigraphic relations are still open to debate.

Distribution

The Abo Formation is well exposed in the northeastern part of the Mockingbird Gap quadrangle, on the dip slope of the southern Oscura Mountains, and in the Mockingbird Gap Hills. It is partly exposed at numerous localities in the quadrangle as inliers in the alluvial fans. The formation crops out continuously in the Oscura Mountains to the north of the quadrangle and southward in the San Andres Mountains.

Lithology

The term Abo Formation as used in this report includes poorly sorted ledge-forming crossbedded conglomerate, arkose, and shaly siltstone or feldspathic sandstone which overlies and interfingers with the Bursum Formation. The Abo, particularly the lower part, is chiefly dark reddish brown to dusky red but may include some greenish-gray to light-gray rocks. The Abo Formation as mapped during the present investigation includes some strata in the upper 200–300 feet which are moderately red and are more like the lighter red strata of the overlying Yeso formation than the darker hued lower strata of the Abo. The upper strata are generally fine- to medium-grained well-sorted sandstone containing erratically distributed lenses of pebble conglomerate.

Constituents of conglomerate beds range in size from granules to cobbles and include quartzite, granite, limestone, and other rock fragments. About 1½ miles south of Estey City, subangular pebbles of a distinctive rhyolite are present in lenticular conglomerate beds about 200 feet below the top of the Abo Formation. This rhyolite is porphyritic and contains feldspar phenocrysts. The feldspars are highly altered but appear to be orthoclase. The rhyolite pebbles are very similar both megascopically and microscropically to rhyolite granules and pebbles observed in the Abo Formation in the southern Sacramento Mountains (Bachman and Hayes, 1958, p. 692) and to pebbles and cobbles in the northern part of the Sacramento Mountains (Otte, 1959, p. 63: Bachman, 1960, p. B239).

Most of the beds in the Abo Formation are very feldspathic. Angular grains of feldspar are commonly visible to the naked eye. Microscopically, feldspar is the dominant mineral constituent, and quartz occurs in only minor amounts. Opaque minerals are common. Some of these, probably magnetite, are fairly well rounded. Copper minerals are not uncommon in the arkose, as well as in other beds in the Bursum and Abo interval, but they appear to be secondary. Some copper minerals invade, and replace, feldspar grains. The geologic relationship of copper mineralization in the Mockingbird Gap area is discussed more fully on page 38.

R. A. Cadigan (written commun., 1962) examined representative thin sections of arkose from the Abo Formation in the Mockingbird Gap quadrangle. He observed albite grains, biotite flakes slightly altered to chlorite, anomalously violet-purple chlorite crystals (between crossed nicols), interstitial chert cement, some microcline grains, and some fragments of lithic tuff.

Thickness

The Abo Formation is about 525 feet thick in the Mockingbird Gap quadrangle. Complete stratigraphic sections are uncommon, and only two such sections were measured in the quadrangle (pl. 3, cols. ***B***, ***F***). Locally, the Abo Formation may be more than 525 feet thick, where it fills channels in the Bursum Formation in the northeastern part of the quadrangle (pl. 3, col. *A*); but it is thinner in the southeastern part of the quadrangle (pl. 3, col. *I*), where the Bursum Formation interfingers relatively high into the normal stratigraphic position of the Abo Formation. Differences in thickness of the Abo Formation are therefore dependent upon the stratigraphic relations of the Abo and Bursum Formations.

Contacts

The basal contact of the Abo Formation has been regarded as a regional unconformity (Lloyd, 1949), and the unconformable nature of the basal contact in many areas is well documented. This unconformity is particularly well displayed in parts of the Sacramento Mountains (Pray, 1949, 1961; Bachman and Hayes, 1958; Otte, 1959), and along other parts of the ancient Pedernal landmass (Thompson, 1942, p 12–14). In the Mockingbird Gap quadrangle, however, the basal contact varies from erosional to gradational. Channels in the Bursum are filled with Abo strata, and elsewhere Abo strata interfinger with the Bursum Formation. Interfingering of the nonmarine strata of the Abo Formation with marine strata of Early Permian age has been observed in other areas, where exposures are available along the edges of marine depositional basins (Otte, 1959, p. 54), Thus, the basal contact of the Abo Formation is not a regional unconformity but is unconformable along the edges of later Pennsylvanian and Permian orogenic uplifts and conformable near the axes of depositional basins.

The upper contact of the Abo Formation, with the overlying Yeso Formation, is gradational in the Mockingbird Gap quadrangle. In other parts of New Mexico this contact is placed at the top of beds of dark-red angular feldspathic sandstone or arkose and at the base of light-red well-sorted fairly well rounded dominantly quartzose sandstone. Commonly there is also a marked change in color from hues of dark red in the Abo Formation to light red, pink, yellowish gray, or even white in the Yeso Formation. In the northern Oscura Mountains, Wilpolt and Wanek (1951) placed the contact between the two formations in a slope, apparently on the basis of topography. However, Kottlowski, Flower, Thompson, and Foster (1956, p. 53) noted that the contact between the Abo and Yeso Formations is "gradational, although relatively sharp" in the San Andres Mountains. Rocks resembling the basal part of the Yeso Formation are well exposed, although slope forming, in the upper part of the Abo Formation in the Mockingbird Gap quadrangle. However, dark-red pebble conglomerate lenses are interbedded in these beds that are similar to the Yeso. Consequently, the top of the Abo Formation was drawn to include the conglomeratic lenses and at the base of a prominent light-red to orange-red fine-grained cross-laminated ledge. This ledge was assigned to the Meseta Blanca Sandstone Member of the Yeso Formation. The Abo-Yeso contact as thus drawn may be at least 75 feet higher stratigraphically than that drawn by Wilpolt and Wanek (1951).

Age and correlation

Interfingering of the Abo with fusulinid-bearing beds of the Bursum Formation in the Mockingbird Gap quadrangle and with marine formations in other areas (Kottlowski and others, 1956; Otte, 1959) indicates that at least the basal part of the Abo is equivalent to rocks of Wolfcamp age. The Abo Formation interfingers with the Lower Permian Hueco Formation in the southern Sacramento Mountains (Pray, 1954, 1961; Bachman and Hayes, 1958) and in the southern San Andres Mountains (Kottlowski and others, 1956; Bachman and Myers, 1963). It is possible, but not proved, that the "upper tongue of the Abo Formation" mapped by Bachman and Myers in the southern San Andres Mountains is equivalent to the Meseta Blanca Member of the Yeso Formation of the Mockingbird Gap area.

YESO FORMATION

The Yeso Formation of Permian age is the youngest Paleozoic formation exposed in the Mockingbird Gap quadrangle and is represented only by the lower part of the formation. The Yeso Formation was named originally by Lee (Lee and Girty, 1909, p. 12) for Mesa del Yeso, about 12 miles northeast of Socorro, N. Mex. As Lee did not define an adequate type locality or describe an adequate type stratigraphic section, Needham and Bates (1943, p. 1657–1661) redescribed the formation and designated a type locality 2¼ miles southeast of Mesa del Yeso. They divided the formation into four units, the upper two of which were assigned formal member status. Wood and Northrop (1946) named the basal, clastic member of the Yeso Formation in the Nacimiento Mountains, about 150 miles northwest of Mockingbird Gap, the Meseta Blanca Sandstone Member. This member name has been extended as far south as the northern Oscura Mountains (Wilpolt and Wanek, 1951) and is used in the present work, although in a somewhat more restricted sense than used in the northern Oscura Mountains. In the Mockingbird Gap quadrangle the Meseta Blanca is overlain by thin beds of fine-grained sandstone, shale, limestone, and gypsum that are not well enough exposed for division into members. Wilpolt and Wanek (1951) were able, however, to divide the Yeso Formation into the Meseta Blanca Sandstone Member and the overlying Torres, Canas Gypsum, and Joyita Sandstone Members.

MESETA BLANCA SANDSTONE MEMBER

Distribution, lithology, and thickness

In the Mockingbird Gap quadrangle, the Meseta Blanca Sandstone Member of the Yeso Formation is present on the eastern dip slope of the Oscura Mountains and in faulted blocks east of the Oscura Mountains. It is also exposed prominently along the eastern slope of the Mockingbird Gap Hills and in smaller fault blocks in that area.

The Meseta Blanca consists of light-red fine-grained sandstone, siltstone, and shale. Ledges of sandstone are a prominent feature of the member at its base, but this sandstone grades upward into shaly to silty platy beds which average about 1 inch in thickness. Light-red shale forms much of the upper part of the member. Above the basal ledges the member forms slopes. All beds are intricately cross-laminated.

As restricted during the present work, the Meseta Blanca Sandstone Member has an average thickness of about 185 feet in the Mockingbird Gap quadrangle. It is about 170 feet thick in the southern part of the Oscura Mountains and about 260 feet thick in the northern part of the quadrangle.

Contacts

As drawn by Wilpolt and Wanek (1951) the lower part of the Meseta Blanca Sandstone Member "usually forms a valley on the gently dipping back slope of the Abo Formation; and the upper part forms a slope leading up to the rim of a cuesta capped by the lowest limestone ledge of the Torres Member." During the present work, lenticular deposits of conglomerate which are considered to be related more closely to the Abo Formation were observed in the slope immediately overlying the main body of the coarse-grained Abo Formation. For this reason, the basal contact of the Yeso Formation—that is, the base of the Meseta Blanca Sandstone Member—was placed at the base of a massive sandstone ledge well above the basal slope of the Meseta Blanca as mapped by Wilpolt and Wanek. The contact between the Abo and Yeso is gradational in the Mockingbird Gap quadrangle, rather than disconformable as postulated by Needham and Bates (1943, p. 1661) for other parts of New Mexico. The contact between the Yeso and Abo Formations is thus arbitrary, and during the present work it was placed at the base of the cuesta-forming ledge chiefly as a matter of convenience in mapping. This contact, based on surface observations, would be very difficult to determine in the subsurface in the mapped area.

The upper contact of the Meseta Blanca Sandstone Member is placed at the top of the dominantly pink to light-red clastic unit. The base of the overlying undifferentiated Yeso Formation consists of dolomitic limestone or yellowish-green shale and is gypsiferous in places.

Age and correlation

The age assignment of the Yeso by Wilpolt and Wanek (1951) is followed here because no new fossil evidence was found during the present work. They assigned the Yeso Formation to Leonard equivalence.

The Meseta Blanca Sandstone Member has been mapped and correlated in many areas north of Mockingbird Gap, but southward its equivalents are not certainly identified. It is very similar lithologically to the Otero Mesa Member of the Yeso Formation as defined by Bachman and Hayes (1958) immediately south of the Sacramento Mountains. It is also similar to the "upper tongue of the Abo Formation" as mapped by Bachman and Myers (1963) in the southern part of the San Andres Mountains.

The stratigraphic relations of the upper part of the Abo Formation and the basal part of the Yeso Formation in south-central New Mexico will be understood only after further detailed mapping in several key areas. Many exposures of so-called "Abo Formation" in south-central New Mexico might be more accurately assigned to the basal part of the Yeso Formation. The Abo-Yeso contact is of considerable importance southward in New Mexico as both formations grade into a carbonate-rock sequence. An understanding of these gradational relations could affect correlations of the various surface and subsurface rock units in southern New Mexico.

UPPER PART OF THE YESO FORMATION

The part of the Yeso Formation that overlies the Meseta Blanca Sandstone Member was not divided into members in the present study. It consists of gypsum, dense gray dolomitic limestone, gray to light-red variegated shale, light-red siltstone, and fine-grained light-yellowish-brown sandstone. It is exposed in slopes and hills along the east edge of the quadrangle and as inliers in alluvium in the vicinity of Mockingbird Gap and north of the Mockingbird Gap Hills.

R. A. Cadigan (written commun., 1962) examined a sample of typical sandstone from the southern part of the Oscura Mountains. He determined that detrital grains compose about 75 percent of the rock and that calcite (and dolomite?) and optically continuous overgrowths on the quartz grains form the cement and compose about 25 percent of the rock. The detrital minerals consist chiefly of quartz and some sodic feldspar. Clay is not visible. Cadigan stated that "the detrital grains appear to have been subjected to much weathering and reworking prior to final deposition." He separated heavy minerals from the rock and found etched colorless garnet, leucoxene, and magnetite.

Two representative samples of limestone from the Yeso Formation were analyzed for calcium and magnesium by J. A. Thomas, of the U.S. Geological Survey. These were determined to have molal ratios of 2.04 and 2.32, which places the rocks in the category of dolomitic limestone.

Wilpolt and Wanek (1951, strat. section 5) determined that the total Yeso Formation, including the Meseta Blanca Sandstone Member as mapped by them, is about 1,675 feet thick in the Oscura Mountains. During the present work the Abo-Yeso contact was mapped approximately 75 feet higher than that mapped by Wilpolt and Wanek, and the total Yeso Formation is thus believed to be about 1,600 feet thick.

INTERPRETATION OF SEDIMENTATION AND STRATIGRAPHY OF PENNSYLVANIAN AND EARLY PERMIAN AGE

The Pennsylvanian and Lower Permian rocks in south-central New Mexico reflect the major cycle of sedimentation recognized previously by Read and Wood (1947, p. 223) in northern New Mexico. Read and Wood characterized the cycle by two parts, one marine and the other continental. They stated that the marine part consists of "(1) a suite of transgressive sediments; (2) evenly and widely distributed marine sediments that were deposited during a period of maximum marine transgression; and (3) evenly distributed and restricted alternating marine and continental sediments that represent a period of offlap or marine regression." In the Mockingbird Gap area the transgressive marine phase of the cycle is represented by clastic debris and thin beds of marine limestone in the Sandia Formation. The period of maximum marine transgression is represented by the thick limestone sequence in the lower member of the Madera Formation, and the period of alternating marine and continental conditions, or regressive phase of the cycle, is represented by the upper member of the Madera Formation and the Bursum and Abo Formations.

The depositional environment in the Mockingbird Gap quadrangle was exclusively marine throughout the range of *Fusulina* (Des Moines of the midcontinent region). Depth of the sea at that time is conjectural but probably did not exceed 100 fathoms. The presence of numerous corals indicates that the water was relatively clear, and the common occurrence of complete articulated brachiopods and other bivalves embedded in the rock indicates that wave and current action was minor. An undescribed form of hexactinellid sponge was collected from the lower member of the Madera Formation in the Mockingbird Gap Hills. R. M. Finks (written commun. 1962) stated that "sponges of any kind indicate clear waters and a generally low rate sedimentation. Very symmetrical stalked sponges, such as the present one, suggest particularly quiet water environment."

During the span of time indicated by *Triticites* (Missouri and Virgil of the midcontinent region) however, the depositional environment in the southern Oscura Mountains was near wave base, and frequently may have been above sea level. Alluvial deposition and local swampy conditions prevailed in that area during times of uplift. In the northern and central parts of the Oscura Mountains, marine conditions prevailed during late Madera time, and the deposition of marine limestone was the dominant sedimentary process. This distribution of rock types in the Oscura Mountains is believed to indicate the presence of a lagoon, or marine embayment, in the central and northern Oscura Mountains during Late Pennsylvanian time and a concurrent deltaic complex in the southern part of the mountain range.

No physical evidence was found of an extensive hiatus during any part of Pennsylvanian or Permian time, but there is evidence for a faunal hiatus in the southern Oscura Mountains during time equivalent to the late Des Moines of the midcontinent region. In the midcontinent region the fusulinid genus *Wedekindellina* is characteristic of the lower part of the Des Moines Series and is associated with early forms of *Fusulina*. There the genus *Fusulina* is highly evolved in the upper part of the Des Moines Series and *Wedekindellina* is not represented. In the southern part of the Oscura Mountains, beds containing early forms of *Triticites* rest directly on beds containing *Wedekindellina* and early forms of *Fusulina* (pl. 2). Locally, the fauna present in the upper part of the Des Moines of the midcontinent region is absent in the southern Oscura Mountains. This faunal hiatus may be related to local uplift. Other local diastems are indicated by the numerous channel deposits in the upper member of the Madera Formation and in the Bursum and Abo Formations.

During Pennsylvanian time sedimentary basins formed in south-central New Mexico along regional trends different from those of previous basins in that area. Tectonic activity during Pennsylvanian and Wolfcamp time was orogenic as contrasted with the epeirogenic activity of pre-Pennsylvanian Paleozoic time. The mountain systems trended generally north, and the axes of depositional basins trended closely parallel to the mountain systems. One such mountain system was the Pedernal landmass (Thompson, 1942, p. 12–14), whose axis was several tens of miles east of the present Oscura Mountains and trended generally north-south.

The Mockingbird Gap quadrangle is northeast of the northern extension of the axis of the Orogrande basin (fig. 7; Kottlowski, 1959). The deepest part of the Oro-

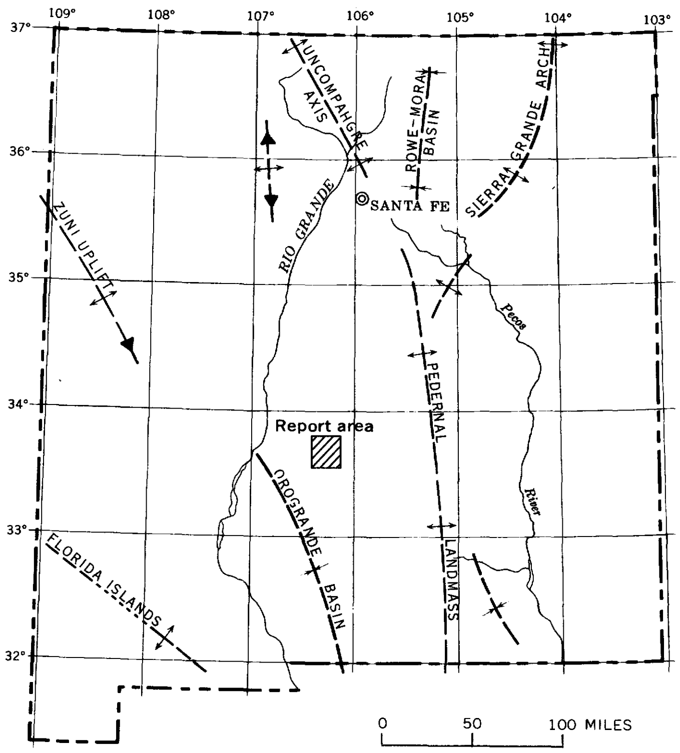


FIGURE 7.—Index map of New Mexico showing relative positions of major tectonic elements during Pennsylvanian and Early Permian time. (Modified from Read and Wood, 1947; Kottlowski, 1960).

grande basin is south of the quadrangle, in eastern Dona Ana and western Otero Counties, N. Mex. The depositional basin may have extended farther to the east during parts of Pennsylvanian time, but post-Pennsylvanian erosion on the Pedernal landmass removed strata down to rocks of Precambrian age. The main orogenic uplift during Pennsylvanian and Early Permian time trended generally north-south, but the southward thickening of Pennsylvanian strata indicates that there was a southward component of tilting in the Mockingbird Gap area during that time (fig. 8). The southward regional tilting may have resulted from continued activity along the early Paleozoic hinge line described previously.

The time of maximum marine invasion in the Oscura Mountain area extended from the latest part of the Zone of *Fusulinella* through part of the zone of *Fusulina*. The Orogrande basin began to form at this time. In the Oscura Mountain area, the first appearance of coarse clastic sediments after the maximum marine transgression coincides approximately with the first appearance of *Triticites*. The advent of clastic rocks does not necessarily indicate the existence of an extensive landmass high above the surrounding country, but it does indicate uplift which was probably the first stage of development of the Pedernal landmass to the east. The presence of lenticular channel deposits, plants, and coaly shale associated and interbedded with marine limestone in the upper member of the Madera Formation is evidence for a period of intermittent subaerial conditions near sea level. Subsidence of the depositional basin continued during this interval, but frequently it did not keep pace with the uplift and consequent flood of sediments from the adjoining landmass. It was at this time that the Orogrande basin reached its maximum development and was more or less confined on its eastern and northeastern margins by the developing Pedernal landmass.

The lowermost red beds in the stratigraphic section appear near the zone of *Triticites ohioensis* of Missouri age (Zone of fusulinids of Missouri age, fig. 8) but are not prominent from there upward through the remainder of the Pennsylvanian strata. Sediments deposited during earliest Wolfcamp time formed rocks that are dominantly red. Deposition occurred near sea level in the quadrangle area. During Wolfcamp time, the Orogrande basin became filled in places along its margins with sediments from the fully developed Pedernal landmass to the east, but there were probably channels and lagoons which connected with the open sea to the south.

The numerous channel deposits in the upper member of the Madera Formation and in the Bursum and Abo Formations indicate that a series of streams, probably westward flowing from the Pedernal landmass, existed at that time. During Missouri time and most of Virgil time, the depositional environment was probably one of chemical reduction, as indicated by the presence of gray and greenish-gray rocks. The depositional environment changed gradually from one of chemical reduction to oxidation during latest Pennsylvanian and Early Permian time, as indicated by the fact that red beds become progressively more dominant in the younger strata.

From the evidence previously cited (commun. from R. A. Cadigan, p. 24, 27), some volcanism possibly occurred on the Pedernal landmass during Late Pennsylvanian and Early Permian time. Such volcanic activity is suggested by the presence of altered tuffaceous fragments, but the extent of the volcanic activity is not known. Also, the previously mentioned rhyolite fragments in the Abo Formation in the Oscura and Sacramento Mountains may have been derived from Lower Permian volcanic rocks rather than Precambrian volcanic rocks.

Deposition of the Abo Formation was followed by an extensive transgression of the sea during Yeso time. The Yeso sea was probably shallow and, at times, hyper-

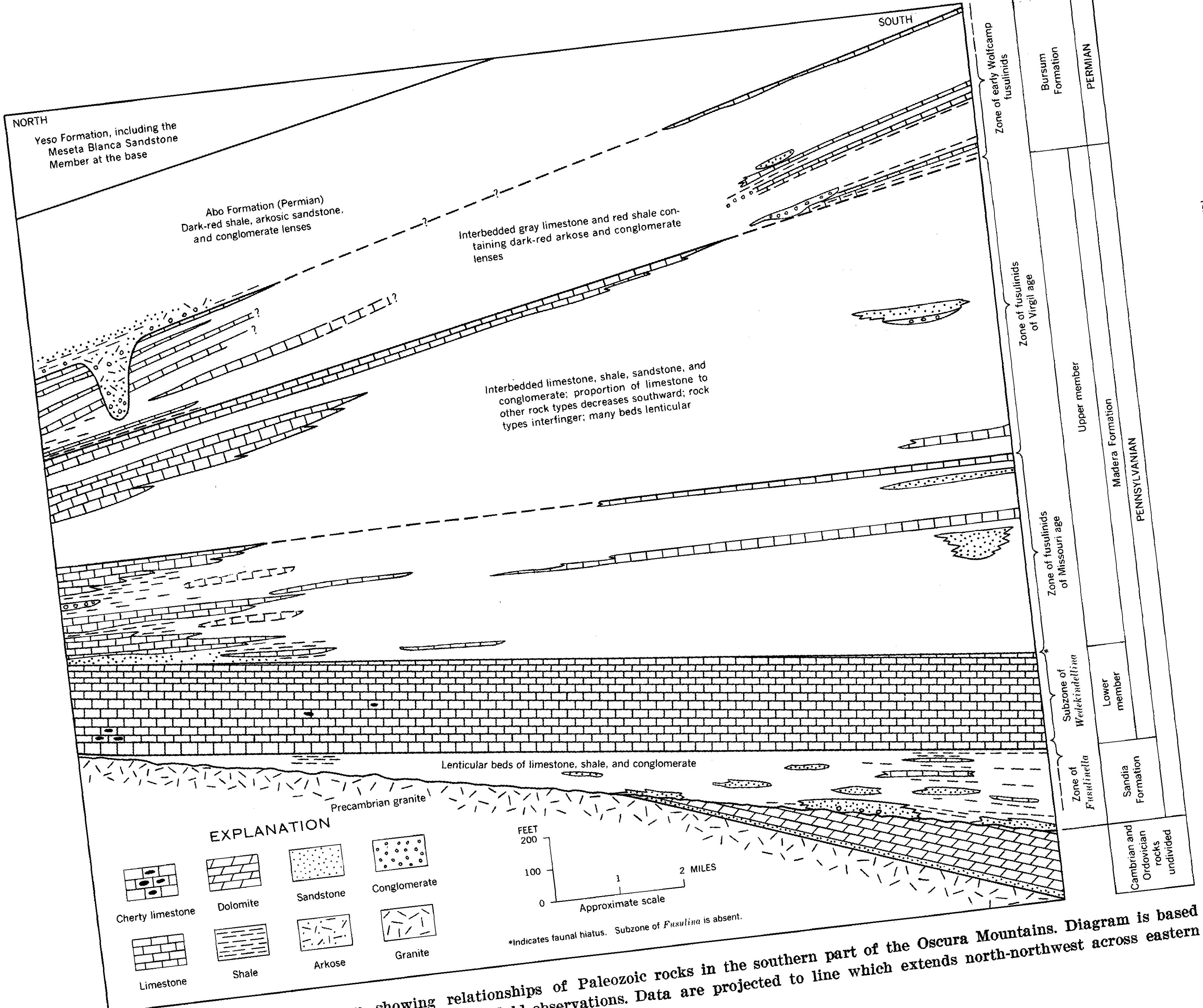


FIGURE 8.—Interpretive diagram showing relationships of Paleozoic rocks in the southern part of the Oscura Mountains. Diagram is based on measured stratigraphic sections and other field observations. Data are projected to line which extends north-northwest across eastern part of Mockingbird Gap quadrangle.

saline, as gypsum forms a significant part of the sedimentary deposits.

In the Mockingbird Gap quadrangle, red beds are apparently of two distinct types. The first type includes the dark-red to reddish-brown sediments of the Abo and Bursum Formations. The color resulted partly from oxidation and partly from the abundance of red feldspars in the rocks. These red beds probably formed subaerially. The second type of red beds is comprised of the light-red sandstone, siltstone, and shale in the Yeso Formation. These beds are associated with gypsum and dolomitic limestone, and they probably formed in shallow lagoonal basins.

CRETACEOUS ROCKS

Darton (1928, pl. 42 and p. 197) discussed and indicated two outcrops of rocks of Cretaceous age which, according to his description, should be within the Mockingbird Gap quadrangle. He stated that one outcrop, in the southwestern part of the quadrangle (T. 8 S., R. 4 E.), consisted of "Cretaceous sandstone of Colorado age"; the second outcrop was "reported in the western parts of Tps. 6 and 7 S., R. 5 E., 18 miles southeast of Carthage." During the present investigation the alluvial fans and arroyos of these two areas were carefully searched, but neither exposure was found.

IGNEOUS ROCKS OF PROBABLE TERTIARY AGE

Igneous rocks of probable Tertiary age form a minor part of the terrain in the Mockingbird Gap quadrangle and occur as dikes and sills. The most conspicuous of these igneous rocks are the monzonite sills along the western scarp of the Oscura Mountains and in the Mockingbird Gas Hills. They occupy a fairly uniform stratigraphic horizon near the middle part of the lower member of the Madera Formation (fig. 4). Slopes are formed where the sills are present, and exposures are only fair to poor. The individual sills generally range in thickness from 5 to 50 feet, but at scattered localities in the quadrangle a few sills are less than 2 feet thick.

Rock in the sills is medium gray, finely crystalline, and deeply weathered. Microscopically, feldspars appear to form about 75 percent of the rock mass. Staining indicates that about 45 percent of the feldspars contain potassium. Albite twinning is rare, but the few plagioclase feldspars examined appear to be andesine. Quartz was not observed. The alteration products consist of chlorite, clay, and calcite.

Three monzonite dikes, very similar lithologically to the sills, were mapped. All three strike northeastward and appear to be vertical. The dikes generally range from 1 inch to 10 feet in thickness. They are deeply weathered and are not conspicuous topographic features.

No alteration of the country rock was observed at the contacts with the intrusive rocks. Kottlowski (1953, p. 6) reported, however, that altered strata occur adjacent to a "hornblende sodaclase diorite" sill about 9 miles north of the quadrangle. Dikes have been prospected at several localities in the Mockingbird Gap quadrangle, but no mineralized rock has been observed.

Very little can be determined from field relations in the mapped area as to the age of the dikes and sills. However, the intrusions are known to be post-Early Permian, as they intrude rocks at least as young as the Yeso Formation. In addition they are displaced by faults of probable Tertiary age. Igneous rocks of south-central New Mexico, with the exception of definite Precambrian igneous rocks, are generally regarded as Cenozoic in age. Wilpolt and Wanek (1951) stated that "along the margin of the Rio Grande Basin dikes * * * intrude rocks of the Baca and Datil formations but do not intrude the Santa Fe formation. They may be related in age to the Tertiary(?) stocks of monzonite and granite in the Magdalena mining district and the monzonite batholith of the Organ Mountains." Owing to the lack of other information, this reasoning is followed in the present work, and the intrusions in the Mockingbird Gap quadrangle are assumed to be post-Baca Formation (Eocene?) and pre-Santa Fe Formation (middle? Miocene to Pleistocene?).

QUATERNARY DEPOSITS

Quaternary deposits consist chiefly of alluvium which blankets the intermontane areas in the quadrangle. They include crudely stratified lenses of cobbles and gravel that are interbedded with friable finer grained sediments. In Mockingbird and Oscura Gaps the alluvial deposits merge into slopes and form alluvial fans adjacent to the uplifts. In general the beds of alluvium dip away from the mountains, and the sediments are apparently derived from the local uplifts.

As fossils have not been found in the alluvial deposits in the quadrangle and details of deposition have not been studied, age of the alluvium in the area could not be determined. Probably some of the deeper trenches in the area have exposed alluvium of Pleistocene age. Deposition of some of the alluvium may have begun in Tertiary time. The sporadic exposures of bedrock in channel trenches indicate that the surface upon which the alluvium was deposited is highly irregular.

Caliche and gravels cemented by compact travertine are not as common in the quadrangle as in some adjacent areas. However, one notable example of a travertine-cemented gravel in the quadrangle was observed in the southern Oscura Mountains, in a channel trench near the abandoned Old Mills well (NE¼ sec. 24, T. 9 S., R. 6 E.). Here, a well-cemented Recent conglomerate floors the channel trench. The carbonate cement is hard under the hammer, and the conglomerate might be interpreted as a relatively old deposit if such conglomerates were not so widespread in Recent trenches in the arid Southwest. The compact travertine forms during intermittent runoff of ground water that carries calcium carbonate in solution.

GEOMORPHOLOGY

PEDIMENTS

Pediments and pediment deposits (Childs, 1948, p. 369–370; Tuan, 1959, p. 3) were observed in the Mockingbird Gap quadrangle in only three places. One possible pediment that is covered with gravel was mapped near Estey City (Sec. 25, T. 8 S., R. 6 E.; sec. 30, T. 8 S., R. 7 E.). Another pediment, along the southwest edge of the Oscura Mountains, is largely concealed by pediment deposits that merge laterally with alluvial fan deposits and was not mapped separately. The third probable pediment is expressed by scattered boulders on the northwestern part of the quadrangle (E½ sec. 7, T. 7 S., R. 5 E.); these boulders were not differentiated on the map, for they merge gradationally with the underlying alluvium.

The possible pediment deposit near Estey City rests on an inclined surface that slopes gently eastward across beveled edges of the dip slope of the Oscura Mountains. This deposit consists of uncemented poorly sorted gravel that includes pebbles, cobbles, and boulders of dark-red arkose and limestone in a matrix of dark-red sandy clay. The deposit is as much as 20 feet thick and rests in places at least 50 feet above adjacent valleys.

The pediment along the base of the western scarp of the Oscura Mountains is only locally exposed and is best observed along the extreme southern part of the range (NW¼ sec. 16, T. 9 S., R. 6 E.). The pediment is narrow and parallel to the mountain scarp and may not extend farther west than the structural lineament indicated on the map. It is probably a concave surface which was cut during retreat of the mountain front after faulting.

ALLUVIAL FANS

Alluvial fans consisting of sand, gravel, and boulders derived from adjacent mountains are the most extensive surficial deposits in the quadrangle. Most coalesce laterally with other fans. Away from the mountains the fans are inseparable from plains to the south in the Tularosa Valley and to the west in the Jornada del Muerto. Fan aprons occur locally.

The alluvial fans are composed of crudely stratified lenses of gravel and cobbles interbedded with poorly consolidated finer grained sediments. Beds dip away from the mountains and have upper surfaces that are smooth to slightly undulatory except where cut by local channels. Gradients reach a maximum of 500 feet per mile on the southeast side of Little Burro Peak, 375 feet per mile along the west side of Little Burro Peak, and about 400 feet per mile on the west side of the Oscura Mountains. The alluvial fans are assumed to be of Quaternary age, although some sedimentary debris may have been derived from the mountain uplifts during parts of Tertiary time.

ARROYOS (CHANNEL TRENCHES)

As in most of the arid Southwest, arroyos are conspicuous in the Mockingbird Gap quadrangle, and in places they dissect the alluvial fans into intricate patterns. Generally they are not as large as some arroyos in northwestern New Mexico, northeastern Arizona (Gregory, 1917, p. 130–131), and southern Utah, but they are well developed and have worked headward to the vicinity of the mountain fronts.

At least two periods of arroyo cutting are evident. The older arroyos are 200–300 feet wide and have sloping banks 20–30 feet deep, and the arroyo floors are covered with a thick layer of fine sand and silt. Aggradation may have followed this stage of arroyo cutting. The younger arroyos occupy the bottoms of the older arroyos. They are only 15–30 feet wide, and their banks, which are mostly vertical, are only 5–15 feet high and are strewn with pebbly and bouldery debris.

On the alluvial fans above the grade of the arroyos are small rills 1–2 feet wide and not more than 1 foot deep. Only annual plants and grasses grow in the rills, for the rills are evidently eroding at rates sufficient to deter the growth of perennial plants.

The dates of arroyo cutting are not known, but the older stage would be measured in hundreds of years. The present stage of arroyo cutting in this region is dated from about 1880 on the basis of historical documents (Bryan, 1925, p. 341–343). At least three stages of arroyo cutting are recognized in northwestern New Mexico (Bryan, 1941) and northeastern Arizona (Hack, 1942). The earliest is dated about 4000–6000 B.C. the second about A.D. 1100–1300 (Hack, 1942, p. 63 and table 2), and the third stage since about A.D. 1880. The present arroyo cutting may have begun in some areas of northwestern New Mexico as early as A.D. 1840 (Bryan, 1925). In the Davis Mountains of trans-Pecos Texas, two ancient stages of dissection are recognized (Albritton and Bryan, 1939), and a cycle of erosion is in progress.

No attempt is made here to correlate the two cycles of erosion observed in the mapped area with those cycles recorded in other areas. The younger arroyos in the Mockingbird Gap quadrangle are assumed to be contemporaneous with those now forming elsewhere in the Southwestern United States.

GEOLOGIC STRUCTURE

The east-dipping block-faulted Oscura Mountains along the east half of the Mockingbird Gap quadrangle are the dominant structural feature in the mapped area. The main faults in the Oscura Mountains strike northwestward, and observable fault planes are nearly vertical. The west-facing scarp of the Oscura Mountains has topographic relief of about 3,000 feet, which indicates that a major fault system is present in the valley immediately west of the mountain scarp.

Some generalizations can be made with regard to the faults in the Oscura Mountains:

1. Faults appear in plan to be systems of northwesterly striking, branching faults whose displacement is cumulative, rather than single faults of large displacement.
2. Relative cumulative movement is down on the west side of fault systems.
3. Except locally along the frontal scarp, gouge, or alteration, along fault planes is rare to nonexistent. However, most faults that persist for more than 2–3 miles are associated with minor synclines on their downthrown sides. Evidence of drag, other than the synclines, was not observed in the fault systems.

The Mockingbird Gap Hills, immediately west of the Oscura Mountains, are formed by an intricately faulted anticline. Most of the faults in this small area are high-angle normal faults, but low-angle gravity faults were also mapped (secs. 21 and 28, T. 8 S., R. 5 E.; fig. 10).

Faults in the Mockingbird Gap Hills, in some inliers west of the Oscura Mountains, and in Little Burro Peak can be characterized as follows:

1. Silicified fault gouge and some copper carbonate minerals may occur in the faults. Drag is associated locally with these faults.
2. Faulting is normal, but fault planes may range from nearly flat lying to vertical.

Little Burro Peak, in the southwestern part of the quadrangle, is physiographically a northward extension of the San Andres Mountains. It is an isolated uplifted block of Precambrian granite and is essentially a horst. An apparently continuous normal fault system, which is U-shaped in plan, passes along the east, north, and west sides of the mountain. On the northeast and northwest sides of the mountain uplift the fault plane is nearly vertical; but on the north, where the fault appears to encircle the granitic mass, the fault plane may dip as low as 30° N. Southward from the Mockingbird Gap quadrangle and near Capitol Peak, the Bliss, El Paso, and Montoya Formations and the upper member of the Madera Formation have been observed to rest with a low-angle fault contact on Precambrian granite.

The geologic structure of the Mockingbird Gap quadrangle is closely related to the structure of the Tularosa Valley. The Tularosa Valley (fig. 9) was regarded by Herrick (1904, p. 179, 181–182) as a collapsed anticline, the west limb of which was formed by the west-dipping San Andres Mountains. Darton (1928, p. 216) regarded the Tularosa Valley as a syncline and noted that "probably there is considerable faulting." However, he also observed that "an anticlinal arch crosses the basin southwest of Carrizozo and, passing west of Oscura, extends under the eastern part of Alamogordo, rises in the west face of the Sacramento Mountains, and continues southward into the Hueco Mountains." Kottlowski, Flower, Thompson, and Foster (1956, p. 73), although they did not make a special study of the geologic structure of the San Andres Mountains or adjacent area, interpreted the Tularosa Valley as a faulted anticlinal structure (similar to the interpretation of Herrick) which they described as follows:

> In general, the San Andres Mountains may be considered as the westward dipping limb of a broadly anticlinal structure whose axis follows the Tularosa Valley, converging in Mockingbird Gap between the San Andres Mountains and the eastward dipping rocks of the Oscura Mountains. The main eastward dipping limb of this structure is the Sacramento Mountains and the long, gentle solpe into the Pecos River Valley. The sedimentary rocks of the San Andres Mountains dip westward beneath the younger rocks and valley fill of the broadly synclinal Jornada del Muerto. The Tularosa Valley can be interpreted as a depressed or collapsed crest of the anticlinal structure between two major fault zones which follow the margins of the valley at either side.

The Mockingbird Gap Hills may represent the northern structural termination of the Tularosa Valley. The geologic structure of these hills suggests that the Tularosa Valley is a collapsed faulted anticline. The east structural boundary of the Mockingbird Gap Hills lies along the western frontal scarp of the Oscura Mountains and trends southeastward toward the Sacramento Mountain scarp. The western structural boundary of the Mockingbird Gap Hills trends southward along the frontal scarp of the San Andres Mountains (fig. 9). The geologic structure of the Mockingbird Gap Hills and the distribution of the few bedrock exposures in the Tularosa Valley suggest that bedrock in the Tularosa Valley may be intricately faulted.

The anticlinal structure of the Mockingbird Gap Hills probably represents the earliest stage of Tertiary tectonic activity in the Mockingbird Gap quadrangle and in the northern part of the San Andres Mountains. This tectonic activity is also indicated by the numerous

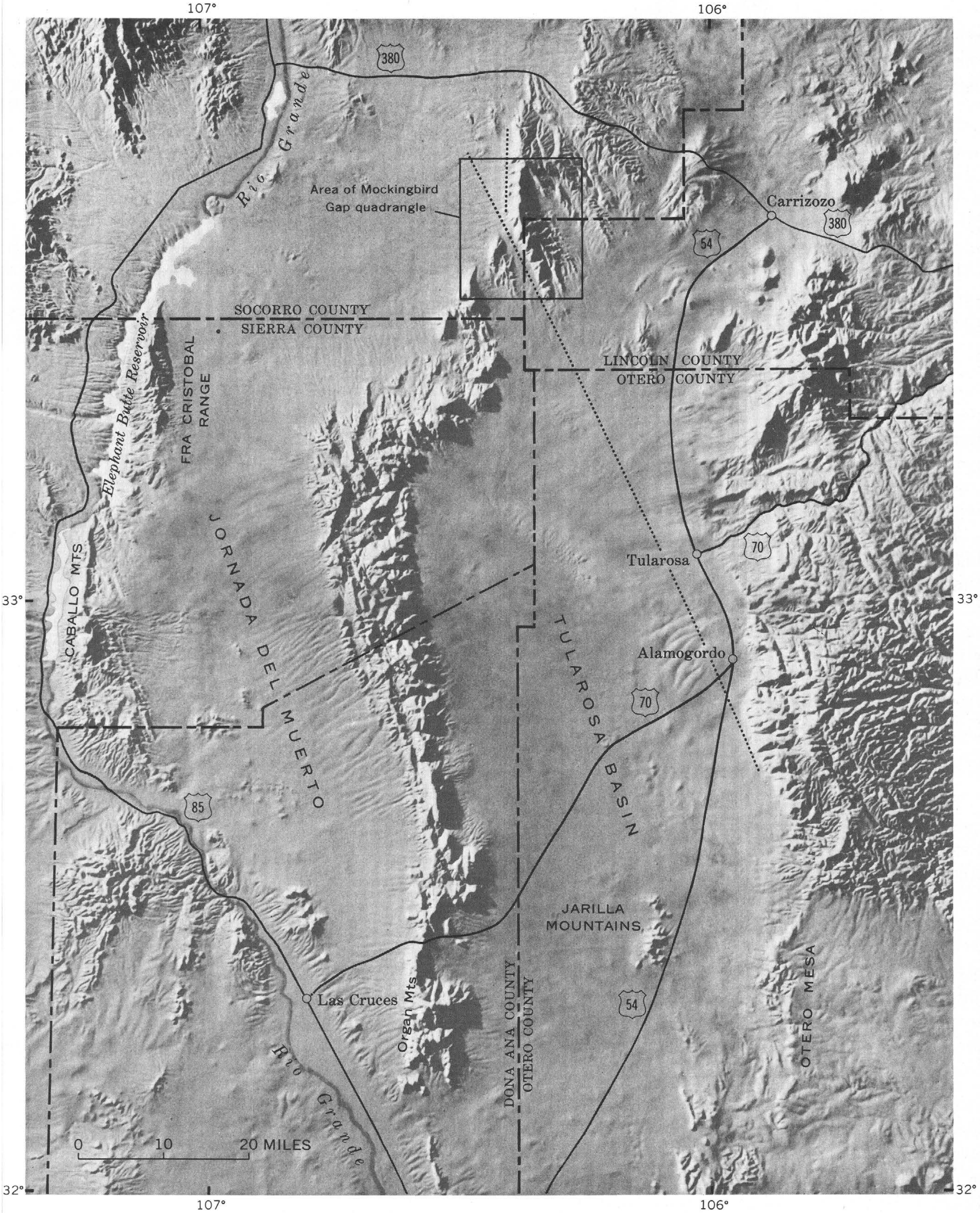


FIGURE 9.—Relief map of south-central New Mexico showing location of geographic features. Dotted line indicates hypothetical Oscura-Sacramento fault zone. Base map modified from Army Map Service plastic relief maps.

faults that displace the fold. Concurrently with, or subsequent to, the folding, low-angle gravity faults developed. One such gravity fault, which is intersected by later high-angle normal faults, is in the northern part of the Mockingbird Gap Hills (fig. 10(A)). A system of low-angle gravity faults has been traced along the western front of the northern part of the San Andres Mountains as far south as the vicinity of Capitol Peak. In the latter area, however, some low-angle faults are related to recent topography and are younger than those in the Mockingbird Gap Hills.

Earliest folding and faulting may have been during early Tertiary time. This activity was followed by a period of tectonic stability. The uplift of present mountain systems began during Pliocene and probably continued into Quaternary time. In the San Andres Mountains just south of the mapped area, modern topography appears to be related directly to faults in some places. Similarly, "the main Caballo Mountains block probably began its uplift no later than the end of the Miocene and gradually rose through much of Pliocene time and even into Quaternary time." (Kelly and Silver, 1952, p. 167.)

The time of faulting in the mapped area is not known, but is assumed to have been during the Tertiary. As noted previously, several stages of faulting have occurred in the mapped area. Modern topography in the mountains immediately south of the mapped area appears in places to be related directly to faults. Therefore, faulting in this region may range in age from early Tertiary to Recent.

ECONOMIC GEOLOGY

COPPER DEPOSITS

Two general types of copper deposits occur in the quadrangle. The first type, the red-bed deposits of the Estey district, has been discussed in the literature. The second type of deposit occurs in fault gouge, or in proximity to faults, in Precambrian granite, the Bliss Sandstone, and the El Paso Formation and apparently is not directly related to the red-bed deposits. Probably the two types of deposits have not been distinguished by some workers, and this has contributed to some of the debate in the literature on the origin of the deposits in the Estey district.

ESTEY DISTRICT

The red-bed copper deposits of the Estey district have been known since the latter part of the last century. The occurrence of copper in the Oscura Mountains was noted briefly by Silliman (1882, p. 427). Peters (1882) visited the deposits and briefly described their occurrence. The deposits and their mineralogy and origin were described in more detail by Turner (1903), Graton (Lindgren and others, 1910), and Rogers (1916).

During the present investigation the Estey district was not studied in detail because most of the old workings and prospects are caved, and the dump material is badly weathered. The observations of previous workers are summarized in the following paragraphs, and a few additional observations are made which are intended to orient the occurrences with the geologic setting as it is now understood.

The Estey district as defined by Graton (Lindgren and others, 1910, p. 201) comprises an indefinite area on the lower eastern slope of the Oscura Mountains. The site of the former town of Estey City is in the NE¼ SE¼ sec. 36, T. 8 S., R. 6 E. Only the foundations of a few buildings and the ruins of the mill are now visible. Access roads to the townsite are eroded and impassable.

In the Estey district various copper minerals occur in association with arkose, argillaceous siltstone, and limestone in the Bursum Formation and with conglomeratic channel deposits in the Abo Formation. The copper occurs in malachite and azurite stain and in some sulfide-oxide nodules as much as 2 inches in diameter. The nodules appear to be most common in the fine-grained rocks. The most conspicuous copper mineral is malachite, which Graton (Lindgren and others 1910, p. 202) indicated was the principal ore mineral.

Lasky and Wootton (1933, p. 76) stated that "ore is found at three horizons, the most important of which is the arkose at the base of the 'Red Beds'. The copper-bearing layers are thin; for the most part a few inches to 3 feet thick. Ore also occurs in cross fractures and prominent joints." The present writer did not observe that copper-bearing minerals are restricted to "three horizons." Such minerals occur at many places in the Bursum and Abo sequence but appear to be most abundant in, and adjacent to, arkosic channel deposits. Malachite and azurite form thin crusts on fracture surfaces, fill voids, and coat detrital grains.

Rogers (1916) studied samples of copper minerals from the district and recognized two kinds of concentrations: plant replacements, and nodules or concretions about 1 inch in diameter. Both types have the same minerals, which Rogers (1916, p. 373) stated were deposited in the following succession:

1. Hematite,
2. Pyrite,
3. Bornite,
4. Chalcocite, covellite, and chalcopyrite,
5. Melaconite,
6. Hematite of the second generation, limonite, and quartz, and
7. Azurite and malachite.

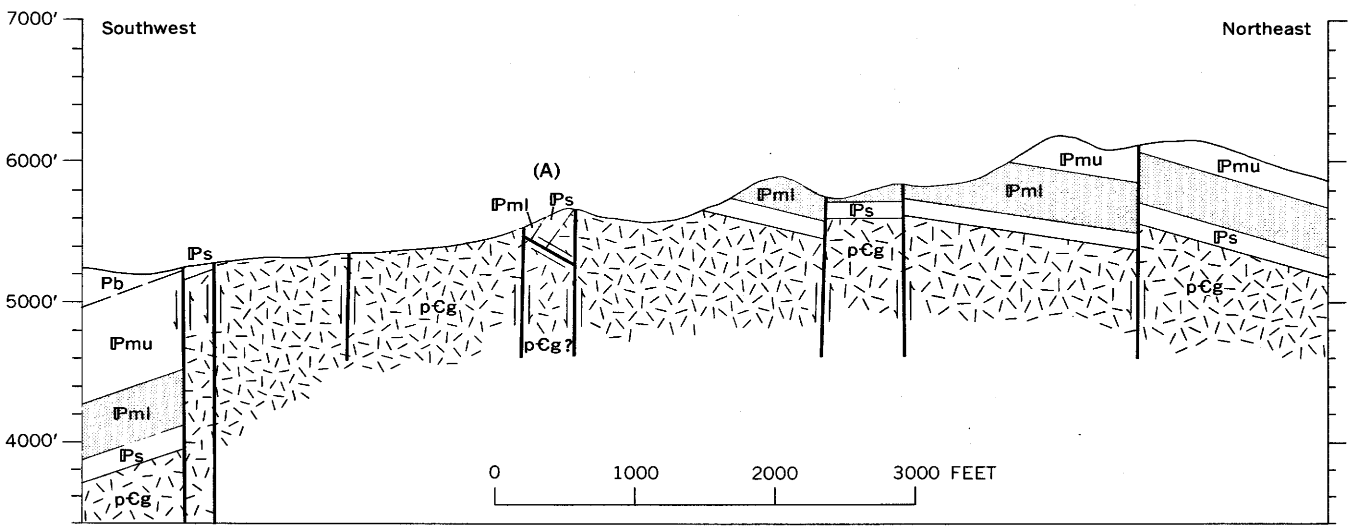


FIGURE 10.—Section in Mockingbird Gap Hills (SE¼ sec. 21, T. 8 S., R. 5 E.) showing anticlinal structure and early Tertiary gravity fault block (A) transected by high-angle normal faults.

Melaconite was observed in the polished surfaces examined during the present study and appears to be more common in nodules than the sulfides.

Little evidence was found to suggest that copper mineralization in the red beds of the Estey district proper is controlled by structural features. Some azurite and malachite stain is present along joint planes, but mineralization does not appear to be any more concentrated along zones of faulting than in unfaulted rock. Although numerous pits were opened along faults by the early prospectors, there is little to indicate that these pits were productive.

In the Estey district there is no apparent relationship between igneous intrusive rocks and the concentration of copper minerals. The monzonite dike near Estey City (NE¼ sec. 1, T. 9 S., R. 6 E.) has been prospected, but no copper minerals were observed in or around the pits. The monzonite dike in the SW¼ sec. 6, T. 8 S., R. 7 E., has also been prospected, but the results were apparently negative.

OTHER COPPER PROSPECTS

Early prospecting was done along fault zones on the western front of the Oscura Mountains and in the Mockingbird Gap Hills. Copper minerals were observed in prospect pits along faults in Precambrian granite (E½ sec. 16, T. 9 S., R. 6 E., and sec. 26, T. 8 S., R. 5 E.), the Bliss Sandstone (E½ sec. 5, T. 9 S., R. 6 E.), and the El Paso Dolomite (E½ sec. 16, T. 9 S., R. 6 E.). Copper mineralization along these faults is not extensive, however; azurite and some malachite occur as scales on fracture walls and planes and as small drusy fillings. Sulfides and oxides of copper were not observed at these occurrences.

ORIGIN OF RED-BED COPPER MINERALS

Little can be added in the present work to the classic debate on the origin of red-bed copper deposits. Significantly, however, two types of copper deposits occur within a limited area in the southern Oscura Mountains. Thus, the red-bed deposits of the Estey district appear to have had a geologic history different from that of the copper minerals along the fault zones in the western Oscura Mountains and in the Mockingbird Gap Hills. The copper minerals in the Mockingbird Gap Hills and the western part of the Oscura Mountains area are probably of hydrothermal origin, whereas the deposits in the Estey district were probably concentrated by ground or connate water.

The debate on the origin of red-bed copper deposits has centered around two contrasting concepts: (1) The copper is considered to be of hydrothermal, or magmatic, origin and derived from ascending solutions; and (2) the copper is derived from meteoric or connate water circulating within the enclosing strata. The latter theory has been further debated as to ultimate origin of the copper-bearing solutions and time and agents of mineral concentration.

Turner (1903, p. 681; 1916, p. 596–597) believed that the red-bed copper minerals in the Estey district are syngenetic and were "deposited from the waters which deposited the enclosing sediments." He speculated, however, that meteoric waters percolating along the cupriferous layers may have "re-arranged the copper salts without transferring the metallic contents any great distance." Rogers (1916, p. 380) believed that the copper deposits of the Estey district are epigenetic and "were formed by meteoric waters without the agency of igneous rocks. The ores were formed by circulating solutions, which may have been locally ascending, during a long-continued period of time." On the other hand, Graton (Lindgren and others, 1910, p. 203) believed that "the main faults antedated the deposition of the copper, which was brought in sulphide form by solutions ascending along the fault channels and, spreading out in the adjoining rocks, was deposited mainly as chalcocite, but also as bornite and chalcopyrite, at such places and in such beds as favored deposition."

During the present work the only definite evidence for ascending copper-bearing solutions was observed along fault zones outside the Estey red beds district proper. Copper mineralization along those fault zones was preferential toward porosity and has no apparent preferential relationship toward rock type. On the other hand, red-bed copper deposits in the Estey district are concentrated in and adjacent to arkosic and conglomeratic rocks. Part of the interpretation of the origin of the red-bed copper in the Coyote district in northern New Mexico, as outlined by Zeller and Baltz (1954), may apply to the copper minerals of the Estey district. In summary, the Coyote district copper-bearing minerals and solutions are believed to have been derived from Precambrian terrane in ancient highlands. The copper-bearing minerals and solutions were present in the connate waters of the sediments and were deposited syngenetically in the vicinity of plant debris before cell structure of the plants was crushed and destroyed. Further diagenetic concentration occurred by migration of connate water during compaction of the sediments (Zeller and Baltz, 1954, p. 6–8).

Plant debris is common on polished surfaces of copper-bearing nodules. It consists of twigs and woody fragments in which cell structure was not destroyed or crushed but was replaced by copper oxides, sulfides, and carbonates. This indicates that plant structure was replaced and preserved at an early stage of rock compaction.

Copper deposits of the Estey district and adjoining areas have no apparent economic potential. The great number of prospect pits and adits in the southern Oscura Mountains is an indication of the vast amount of unprofitable prospecting that took place during the late 1800's and early 1900's. Copper minerals are widely disseminated, occurring in small pockets or lenses of rocks, and even with modern methods for moving large amounts of earth and rock, the cost of copper recovery would be greater than the value of the ore. Griswold (1959, p. 106) stated that a "few carloads of ore was produced" from the Estey district but that "the spotty occurrences of the ore and its refractory nature (mostly oxide copper) prevented profitable exploitation."

OIL AND GAS POSSIBILITIES

Owing to the complex geologic structure of the Mockingbird Gap quadrangle, the possibility of finding oil or gas appears to be negligible. The block-faulted mountains and the covered faults, which surface evidence indicates must be present in the alluvial valleys, are not considered to be favorable for the accumulation of oil and gas. No test wells have been drilled in the area, and the nearest recent test well was drilled about 8 miles north of the quadrangle's north boundary (Sun Oil Co. Bingham State, sec. 2, T. 5 S., R. 5 E). That test penetrated to Precambrian rocks and was dry and abandoned.

CONSTRUCTION MATERIALS

Building stone, including granite and limestone, is present in the mountain uplifts. Some of the beds of Pennsylvanian limestone, if carefully prospected, might yield limestone of sufficient purity for the manufacture of cement. The granite is mostly jointed and in many places is brecciated; determination of the quantity of rock suitable for construction material would also require careful prospecting. Abundant deposits of sand and gravel are available on the fans and in the alluvial valleys. At present all materials are too far from both transportation routes and markets to be considered of economic value.

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