Geology of the Hurley West Quadrangle Grant County New Mexico

By WALDEN P. PRATT

CONTRIBUTIONS TO GENERAL GEOLOGY

GEOLOGICAL SURVEY BULLETIN 1241-E

A study of part of the Silver City mining region, with emphasis on Paleozoic stratigraphy and on early Tertiary intrusion and faulting

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1967

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

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GEOLOGY OF THE HURLEY WEST QUADRANGLE, GRANT COUNTY, NEW MEXICO

By Walden P. Pratt

ABSTRACT

The Hurley West 7½-minute quadrangle is an area of about 63 square miles in the southern part of the Silver City mining region of New Mexico. Bedrock exposures underlie only about one-fifth of the area of the quadrangle, but they have furnished much information—on geologic structure, igneous geology, and especially Paleozoic stratigraphy—important to the study of the Silver City region as a whole. The quadrangle is dominated by Lone Mountain, a low inselberg in its north-central part; rising about 500 feet from the surrounding flats, Lone Mountain is a remnant of a cuesta, with the steep slope on the southwest side and the gentle dip slope on the northeast. Most of the remainder of the quadrangle is a partly dissected gently sloping plain; in the northeast corner of the quadrangle this flatland merges with a volcanic plateau.

Geologic formations exposed in the Hurley West quadrangle range in age from Precambrian to Recent. Most of the consolidated rocks are older than Cenozoic and are exposed in and around Lone Mountain. The oldest formation, Precambrian granite, crops out in a small area at the western base of Lone Mountain and comprises two varieties, a heterogeneous inequigranular granite and a homogeneous porphyritic biotite granite. The granite is overlain by some 4,000 feet of northeasterly dipping Paleozoic and Mesozoic sedimentary rocks, predominantly limestone and dolomite. The formations are as follows, from bottom to top: The Bliss Sandstone, hematitic and glauconitic sandstone, and dolomite, of Late Cambrian and Early Ordovician age; the El Paso Dolomite of Early Ordovician age; the Montoya Group of Middle and Late Ordovician age, consisting of the Cable Canyon Sandstone and Upham Dolomite Members of the Second Value Dolomite, Aleman Formation (distinctive interbedded dolomite and chert), and Cutter Dolomite; the Fusselman Dolomite of Silurian age; the Percha Shale of Late Devonian age, divisible into the Ready Pay Member (black fissile shale) below and the Box Member (gray shale with limestone nodules) above; the Lake Valley Limestone of Early Mississippian age, locally divisible into four members, the Andrecito, Alamogordo, Nunn, and Tierra Blanca, on the basis mainly of differences in bedding and amount of chert; the Magdalena Group of Pennsylvanian age, comprising the Oswaldo Limestone (massive light-gray aphanitic limestone with a red silty basal shale member) and the Syrena Formation (silty limestone and shale); the Abo(?) Formation of Permian age (mudstone);

the Beartooth Quartzite of Late(?) Cretaceous age; and the Colorado Formation of Late Cretaceous age (interbedded sandstone and shale). Thirty-five dikes, two sills, and a laccolith intrude the sedimentary rocks. The sills, the laccolith, and some of the dikes are of probable early Tertiary age; the rest of the dikes are presumed to be of the same age but could be Mesozoic. The sills and laccolith are composed of three varieties of latite porphyry, but the dikes range in composition from quartz latite to basalt. Interbedded volcanic and sedimentary rocks of Miocene(?) age occur in the northeast corner of the quadrangle. They are mapped as the Rubio Peak Formation (conglomerate, sandstone, and lithic tuffs), the Sugarlump Tuff (light-gray vitric tuffs overlain by tuffaceous sandstones), and the Kneeling Nun Tuff (distinctive grayish-red welded rhyolite crystal tuff).

The remaining formations in the quadrangle are relatively unconsolidated and owe their origin to erosion of the older rocks. The Gila Conglomerate, of Pliocene to early Pleistocene age, is a vast basin-fill deposit underlying nearly four-fifths of the quadrangle. Three facies of the Gila are recognized, and they reflect different lithologies of different source areas: (1) the volcanic facies, in the east and central parts of the quadrangle, contains abundant boulders of vesicular basalt and andesite and largely reflects erosion of the Pinos Altos Mountains to the north; (2) the silicic facies, in the southwest part of the quadrangle, was derived from the Burro Mountains to the west and consists of a relatively fine grained aggregate of silica-rich rock and mineral fragments including porphyritic and granitic rocks, quartzite, and small grains of quartz and feldspar; (3) the carbonate facies, in the west-central part of the quadrangle, was derived from the Silver City Range and contains limestone and dolomite clasts in excess of volcanic rocks. Quaternary colluvium forms masses large enough to be mapped along the base of the steeper slopes of Lone Mountain, and Quaternary alluvium fills the bottoms of the major stream channels.

The dominant geologic structure of the Silver City region is a broad northwest-trending syncline contained within a northwest-trending elongate block, some 15 miles wide and at least 20 miles long, whose bounding sides have dropped down (relatively) along major basin-and-range faults. Lone Mountain lies near the southwest side of this block, which is bounded by the Silver City fault. In the Lone Mountain area, where the northeasterly dipping strata represent the west limb of the syncline, the large block is broken into smaller ones by northeasterly trending cross faults. The principal cross fault, the Rio de Arenas fault, skirts the northwest side of Lone Mountain and has a displacement of about 1,600 feet vertically, the north side relatively down; this fault affects the entire sedimentary section from Paleozoic through Cretaceous. A complex history of faulting east of Lone Mountain is recorded by offsets of Paleozoic and Cretaceous strata and of the Chino Quarry sill: intrusion of the sill was preceded by minor faulting and was followed by major faulting; this in turn was followed by the emplacement of the Cameron Creek laccolith, in which the laccolith made room for itself by uplifting its roof like a trapdoor, from a pivot point to a maximum of about 1,100 feet along a new fault which the magma then engulfed. The precise geologic age of the faults is not known; most of the displacement probably occurred early in the Tertiary, between deposition of the Colorado Formation (early or middle Late Cretaceous) and emplacement of the Hurley sill and Cameron Creek laccolith, which are known only to predate the Rubio Peak Formation of Miocene(?) age. Younger faults in the volcanic rocks in the northeast corner of the quadrangle are of relatively insignificant displacement and represent the extremities of faults developed more extensively in adjacent areas.

The present land surface of the quadrangle comprises four geomorphic elements. Lone Mountain, the most prominent of these elements, is the remnant of an inselberg that stood above a pediment formed during the late Pliocene and early Pleistocene; the pediment is now buried under the Gila Conglomerate. A second geomorphic element, the Bayard surface, bevels the Gila Conglomerate and older rocks and is now partly preserved in nearly three-quarters of the quadrangle as a gently southward-sloping plain, dissected by the present drainage network. The other two geomorphic elements are formed respectively on volcanic rocks in the northeast corner of the quadrangle and on the alluvial fan of the Burro Mountains in the southwest corner of the quadrangle. Land forms within these four major elements depend largely upon the structure of the geologic formations and their relative resistance to erosion.

The principal metallic mineral resources of the Hurley West quadrangle have been ores of silver and manganese. Rich silver ore was mined at Lone Mountain in the early 1870's; it consisted of supergene minerals derived from narrow veins of argentiferous galena, most of which occupied fractures in the Fusselman Dolomite but some of which were in other formations. The silver ore appears to be largely exhausted. Manganese ore, produced intermittently from 1918 to 1959, occurs as both vertical and horizontal bodies of manganese oxides that replace the Lake Valley Limestone just beneath the basal shale member of the Oswaldo Limestone. The manganese ore is not yet exhausted but its apparent concentration and quantity are low and unpromising; one small area, however, seems favorable for prospecting for small bodies of manganese ore like those mined previously. Copper in solution in Whitewater Creek, derived from leaching of the vast dump of the Chino open-pit copper mine, is recovered in small-scale precipitation operations. Concentrations of detrital magnetic iron oxides occur as cobbles in streambeds; they were derived immediately from the Gila Conglomerate but had an ultimate source in contact-metamorphic magnetite deposits adjacent to the Hanover-Fierro stock in the Santa Rita quadrangle. If similar concentrations occur in buried channels in the Gila Conglomerate, they might be discoverable by geophysical methods and could be exploited on a small scale.

Known nonmetallic mineral resources of the quadrangle are metallurgical limestone and gravel. Oswaldo Limestone is quarried east of Lone Mountain and used as a flux in the copper smelter at Hurley; the probable reserves of limestone for this use, both in the Oswaldo Limestone and in the Lake Valley Limestone, are large and easily accessible.

INTRODUCTION

LOCATION AND GEOLOGIC SIGNIFICANCE OF AREA

The Hurley West quadrangle is in northeastern Grant County, N. Mex., in the southern part of the Silver City mining region. The quadrangle is bounded by parallels 32°37′30″ and 32°45′ N. and by meridians 108°07′30″ and 108°15′ W.; it contains an area of 62.8 square miles. Silver City is about 1 mile northwest of the quadrangle, and Santa Rita, site of the Chino open-pit copper mine, is about 4 miles northeast of the quadrangle (fig. 1). The village of Hurley and the small settlement of North Hurley lie at the east side of the quadrangle.

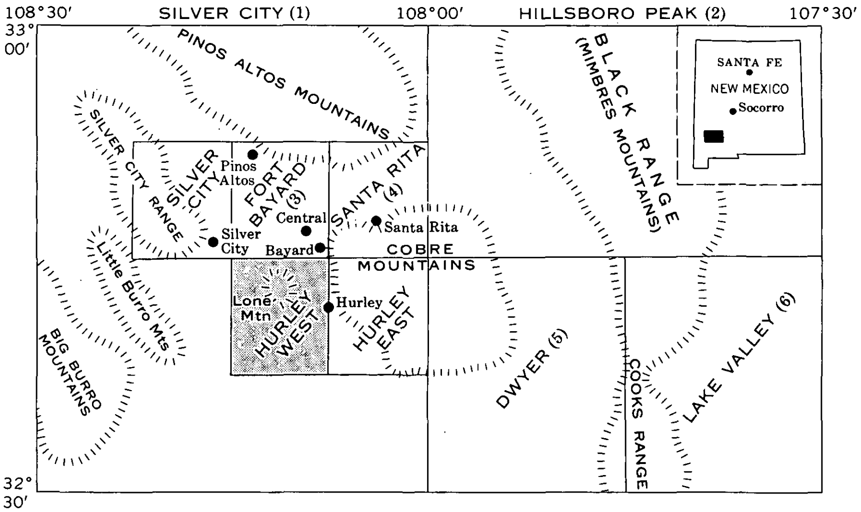

FIGURE 1.—Location of Hurley West quadrangle (shaded) and index to adjacent quadrangles. References to published geologic maps: (1) Paige (1916), (2) Kuellmer (1956), (3) Jones (1963), (4) Hernon, Jones, and Moore (1964), (5) Elston (1957), (6) Jicha (1954).

Although the Hurley West quadrangle is of minor importance in the mineral economics of the Silver City region, it is of major significance to an understanding of the regional geology, because Lone Mountain, an isolated fault block in the northern part of the quadrangle, offers for this region the best exposure of most of the local Paleozoic sedimentary section, from the Bliss Sandstone of Cambrian and Ordovician age through the Lake Valley Limestone of Mississippian age. The greatest mineral potential of the Hurley West quadrangle is in its nonmetallic resources. Oswaldo Limestone is at present being quarried for use as a flux in the copper smelter at Hurley; the reserves of limestone for such purposes are large and easily accessible. Gravel in the Gila Conglomerate has been quarried recently for road metal, and of this commodity the quadrangle contains an inexhaustible supply. The Gila Conglomerate may also contain, at depth, aquifers which could help greatly to satisfy the increasing local demand for water. The metallic resources of the quadrangle are largely depleted. Silver ore, produced in quantity from Lone Mountain in the 1870's, now appears to be exhausted. Manganese ore has been mined on a small scale just northwest of Lone Mountain as recently as 1959; although it is not yet exhausted, its apparent concentration and quantity are low, and extensive future development seems unlikely.

GEOGRAPHY

The most conspicuous geographic feature of the Hurley West quadrangle is Lone Mountain, a trio of hills whose rounded peaks stand 300–500 feet above the surrounding flats, rising steeply on their south and west sides and sloping off gently to the northeast (pl. 1). The three hills are referred to in this report as the west, central, and south peaks. The west peak, elongated slightly north of west, consists of three knobs; the middle knob, at 6,257 feet, is the highest point in the quadrangle. An elongate north-trending hill at the northeast foot of the central and south peaks is separated from these peaks by a small valley and forms a sort of rear guard to the main part of the mountain. Most of the ground surface in the remainder of the quadrangle is a gently southward-sloping gravel-covered plain that has been divided into low north-trending rounded ribs by a series of southward-flowing intermittent streams; from west to east, the principal streams are Pipe Line Draw, San Vicente Arroyo, Rio de Arenas, Cameron Creek, and Whitewater Creek. The lowest elevations in the quadrangle, less than 5,250 feet, are in the beds of San Vicente Arroyo and Cameron Creek at the south edge of the quadrangle.

One major paved route, U.S. Highway 260, traverses the eastern edge of the quadrangle, and several graded and ungraded roads provide access to other parts of the quadrangle, including Lone Mountain.

Vegetation in most of the quadrangle is sparse and consists largely of cacti, grasses, and scattered low scrubby trees; large broadleaf trees grow along several of the creeks. The climate is typical of moderate elevations in the southwest; it is semiarid, with frequent rains in the late spring and early summer, and moderate temperatures in the fall and early spring.

PURPOSE OF INVESTIGATION

The Hurley West quadrangle is one of several quadrangles mapped by the U.S. Geological Survey as part of a restudy of the Silver City mining region, which comprises the Silver City, Chloride Flat, Pinos Altos, Central, Santa Rita, Georgetown, and Lone Mountain mining districts. Several reports on this work have been published (Hernon, 1949; Hernon and others, 1953, 1964; Jones, 1963; Jones and others, 1961, 1964, 1967; Pratt and Jones, 1961a, b, 1965), and other reports are now in various stages of preparation. The principal objectives of mapping the Hurley West quadrangle were to establish the details of the Paleozoic stratigraphy and to clarify the geologic structure; less attention was given to the ore deposits in this quadrangle than in other quadrangles because they are of minor extent and are poorly exposed. Especially informative structural relations have been brought to light by the mapping of several intrusive igneous bodies that occur in the quadrangle (Pratt and Jones, 1961b, 1965). Finally, volcanic rocks of the west edge of the Cobre Mountains volcanic field crop out along the east side of the quadrangle, and, although these are more completely exposed farther east, this study provided the opportunity for a cursory examination of their local character.

PREVIOUS WORK

G. K. Gilbert visited the east side of Lone Mountain in 1873 and recognized it in general terms as an extension of the Silver City Range; he referred also to calcareous veins and argentiferous galena in the area (Gilbert, 1875, p. 516–517). A few other references to the Lone Mountain district are found in the literature of the late 1800's and early 1900's (for example, Jones, 1904), but apparently no one made any significant geologic observations before Graton (1910), who published general notes on the stratigraphy, structure, and what then remained of the silver ore deposits. Graton's report, however, did not include a map. In 1910, Paige (1916) mapped the entire Silver City 30-minute quadrangle. The present map of the Hurley West quadrangle (pl. 1) differs from Paige's smaller scale map in only a few matters other than subdivision of formations and details of fault patterns. Spencer and Paige (1935) and Lasky (1936) studied areas adjacent to the Hurley West quadrangle. In 1945, Manning W. Cox made a reconnaissance of the northeastern part of the quadrangle, northeast from the south peak of Lone Mountain; his map and brief report, in the files of the U.S. Geological Survey, were referred to during the fieldwork and preparation of the present report. At least one mining company has done some geologic mapping in the Lone Mountain area within recent years, and students from several colleges have mapped in the area in connection with summer field courses, but none of this work is published. Several recent studies have been made of Paleozoic formations in southern New Mexico and western Texas, whereas exposures in the Silver City region, even though they represent the western limit of most of these formations, have received little attention in the literature. The principal areas of study of Paleozoic formations are shown in figure 2. Other workers have discussed the stratigraphy of certain systems, or other units, for larger areas in southern New Mexico; these studies are:

Pre-Pennsylvanian—Flower (1958)
Ordovician (Montoya Group)—Howe (1959)
Silurian (Fusselman Dolomite)—Howe (1959)
Devonian—Stevenson (1945)

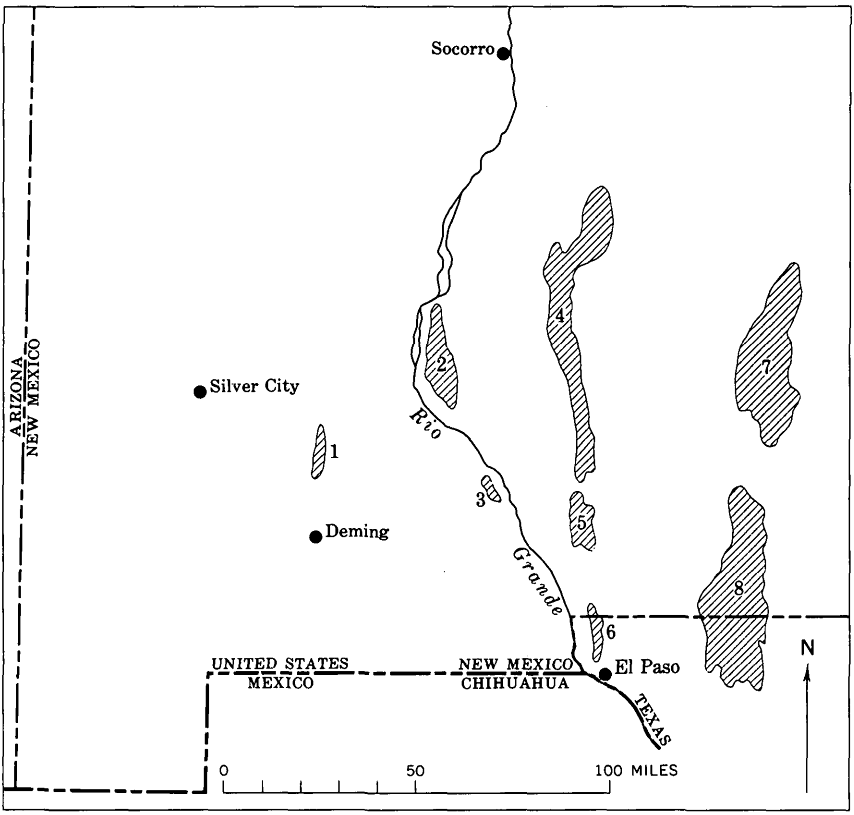

FIGURE 2.—Principal areas of published studies of Paleozoic formations in southern New Mexico and western Texas. 1. Cooks Range—Jicha (1954). 2. Caballo Mountains—Kelley and Silver (1952). 3. Robledo Mountains—Kottlowski (1960a). 4. San Andres Mountains—Kelley (1955); Kottlowski, Flower, Thompson, and Foster (1956). 5. Organ Mountains—Dunham (1935). 6. Franklin Mountains—no complete map since Richardson (1909). 7. Sacramento Mountains—Pray (1953; 1959). 8. Hueco Mountains—King, King, and Knight (1945).

Mississippian—Laudon and Bowsher (1941, 1949)
Pennsylvanian—Thompson (1942); Kottlowski (1960b)
Permian—Thompson and Kottlowski (1955); New Mexico Geological Society (1955).

Maps and reports covering parts of the nearby Black Range, Cooks Range, and Cobre Mountains (fig. 1), published by the New Mexico Bureau of Mines and Mineral Resources, have contributed much to the understanding of the Cenozoic geology of the region.

FIELDWORK AND ACKNOWLEDGMENTS

The fieldwork on which this report is based was done during a total of about 11 weeks in October and November 1958, April 1959, and April and May 1960. Contacts were mapped in the field on U.S. Geological Survey aerial photographs taken in 1945, enlarged to about 1:10,000. They were later transferred directly to the 1:24,000 topographic base with a Saltzman projector; most of the quadrangle has little relief, so that adjustments for distortion were necessary in general only on the steeper parts of Lone Mountain. Most of the Quaternary alluvium and colluvium was mapped from the aerial photographs. (See "Quaternary deposits.") Measured stratigraphic sections, except those of the Beartooth Quartzite and the Colorado Formation, were indicated in the field with yellow paint marks on the outcrop at the base and top of the section and at 100-foot intervals from the base up.

My greatest debt is to the late William R. Jones, who assisted me in the field in many ways, reviewed this report, and freely provided general counsel throughout the study; the conclusions presented here are largely my own, but the fieldwork and the report alike benefited from his helpful suggestions. Dr. Rousseau H. Flower of the New Mexico Bureau of Mines and Mineral Resources visited Lone Mountain and commented on the paleontology of the lower Paleozoic rocks; he also furnished lists of fossils in the Bliss Sandstone and El Paso Dolomite, which are greatly appreciated. Paul L. Williams provided a helpful discussion of the microscopic features of the welded tuffs. Among local residents who were helpful in one way or another are Messrs. Robert Mathis and Floyd Todd of Silver City, and Messrs. William Rockwell and E. A. Rockwell of Deming.

GEOLOGIC FORMATIONS

The geologic formations of the Hurley West quadrangle, shown on plate 1, range in age from Precambrian to Recent. Lone Mountain and a few low outliers are made up largely of Paleozoic sedimentary rocks which dip generally northeast and are broken by many normal faults, most of which trend northeastward. The oldest sedimentary formation, the Bliss Sandstone of Cambrian and Ordovician age, rests depositionally on Precambrian granite. The Paleozoic rocks are overlain by the Beartooth Quartzite and the Colorado Formation of Cretaceous age, and these in turn are overlain by several volcanic and interbedded sedimentary formations of Miocene(?) age, which occupy the northeastern corner of the quadrangle and represent the west edge of the Cobre Mountains volcanic field. The Paleozoic and Mesozoic sedimentary rocks are intruded by many dikes, two sills, and a laccolith, which are of Late Cretaceous to middle Tertiary age. The Gila Conglomerate of Pliocene to early Pleistocene age, an extensive basin-fill deposit, covers most of the quadrangle and is the youngest formation except for Quaternary colluvium and valley fill.

PRECAMBRIAN ROCKS

Rocks of Precambrian age are exposed in the quadrangle along Rio de Arenas just west of Lone Mountain, and along the western base of the west peak; they consist of two main varieties of granite and a few dikes of pegmatite and fine-grained granite.

One of the varieties of granite is a heterogeneous inequigranular phanerite composed dominantly of varying amounts of quartz and alkali feldspar, in crystals as much as half an inch across, set in a fine-grained light-colored matrix. Thin sections show that the rock contains a trace of muscovite but no ferromagnesian minerals, and almost no accessory minerals except for a few opaque grains (probably iron oxide), a little hematite, and a few grains of probable zircon. The feldspars are virtually unaltered, showing only a trace of clay and sericite. This granite makes up most exposures on both sides of Rio de Arenas in the NE¼ sec. 29, T. 18 S., R. 13 W., and is probably continuous with the granite along the base of Lone Mountain. It is cut by numerous fractures, which strike N. 40°–70° E. and dip 70° SE.; many of these are occupied by open veins, as much as 1 inch wide, lined with small quartz crystals. The age of this granite is inferred to be Precambrian because it is overlain depositionally by the Bliss Sandstone, the lower part of which is Late Cambrian.

The other variety of granite is exposed just south of the center of section 29. The rock is deeply weathered and crumbles readily when struck with a pick, but it appears to be a homogeneous porphyritic biotite granite containing abundant phenocrysts of pink alkali feldspar. It is cut by a few dikes of fine-grained leucogranite but lacks the abundant quartz veins that characterize the other variety. This granite is nowhere exposed in contact with any other rocks, but it is assumed to be Precambrian also. However, its lack of quartz veins suggests that it is younger than the other granite.

Pegmatite dikes are exposed at several places in both types of granite. They are no more than 2 feet wide, and are composed of massive quartz and coarsely crystalline pink feldspar. These dikes do not cut any of the other formations in the quadrangle and are therefore assumed also to be Precambrian.

PALEOZOIC ROCKS

Sedimentary rocks representing all systems of the Paleozoic are exposed in the Hurley West quadrangle; a composite stratigraphic section of the rocks of Cambrian through Mississippian ages is given in figure 3.

CAMBRIAN AND ORDOVICIAN SYSTEMS, BLISS SANDSTONE

DEFINITION

The Bliss Sandstone in the Silver City region was correlated by Paige (1916, p. 3), on the basis of its lithology and fossil content, with the Bliss Sandstone of the Franklin Mountains, El Paso County, Tex., where it was originally described by Richardson (1904). In the Silver City region the Bliss consists of impure sandstone, orthoquartzite, and dolomite, and it lies above the Precambrian granite and below the El Paso Dolomite of Early Ordovician age.

Kelley and Silver (1952, p. 33–34) proposed changing the name from Bliss Sandstone to Bliss Formation because of the diverse lithology of the unit in the Caballo Mountains. The name Bliss Sandstone is retained in this report because the sandstone—now generally indurated to quartzite—is not only the dominant lithology but is the formation's characteristic feature.

DISTRIBUTION AND LITHOLOGY

The Bliss Sandstone in the Hurley West quadrangle is exposed along the western base of Lone Mountain, and farther west across the Rio de Arenas. Impure orthoquartzite makes up about 60 percent of the Bliss, and dolomite the remainder; detailed descriptions are given in measured section 1. The quartzite is mostly dark gray, brown, or red, medium grained to coarse grained, locally hematitic or glauconitic or both, and locally oolitic. The dolomite occurs as two separate groups of beds, each about 40 feet thick, in the upper part of the formation. The dolomite in the upper group weathers light grayish brown and has a blocky outcrop; the lower group is sandy, forms a slabby outcrop, and contains nodules and thin layers of quartzite.

In thin section the Bliss appears as a fairly well rounded medium- to coarse-grained quartz sandstone. The quartzite of the Bliss consists almost entirely of quartz grains, with sparse feldspar grains and a little interstitial chlorite and hematite; the fabric is a tightly interlocking mosaic. The hematitic sandstone contains more interstitial hematite, which surrounds the quartz grains and preserves their original well-rounded shapes; the hematite, however, does not constitute more than a small percentage of the rock volume, except for a few seams in which subangular quartz grains are set in a hematite matrix that makes up as much as 40 percent of the volume. The glauconitic sandstone is similar texturally but contains about 30 percent rounded glauconite grains, 65 percent quartz, and 5 percent interstitial hematite and pale-brown carbonate.

The dark colors and impurity of most of the quartzite distinguish it from the Beartooth Quartzite of Cretaceous age, which in general is white and nearly pure.

THICKNESS

The Bliss is 188 feet thick where measured near the south end of the exposure west of Lone Mountain. There is no indication that it thickens or thins depositionally elsewhere in the vicinity. Its outcrop narrows, however, in the NE¼ sec. 29, where the formation appears to have been squeezed out along the North Slope fault.

CONTACTS

Bliss Sandstone and the underlying granite crop out within a few feet of each other at several places at Lone Mountain, but the contact is actually exposed in only one place, in a gully about 500 feet southwest of the NE cor. sec. 29, T. 18 S., R. 13 W. The surface of the contact here dips 17° N. 75° E., glauconitic quartzite lying (with the same dip) on the granite.

The contact of the Bliss with the overlying El Paso Dolomite of Early Ordovician age is placed at the top of the uppermost quartzite bed and appears conformable.

FOSSILS AND AGE

A few specimens of the Late Cambrian brachiopod *Eoorthis* were collected from the lower part of the Bliss during this study, but much more extensive collections have been made by Dr. R. H. Flower, of the New Mexico Bureau of Mines and Technology, who made available his observations on the fossils and age of the Bliss summarized in table 1. Flower placed the base of the Canadian (Lower Ordovician) approximately at the base of the upper group of dolomite beds and thus included the upper 56 feet of the Bliss of this area in the Lower Ordovician.

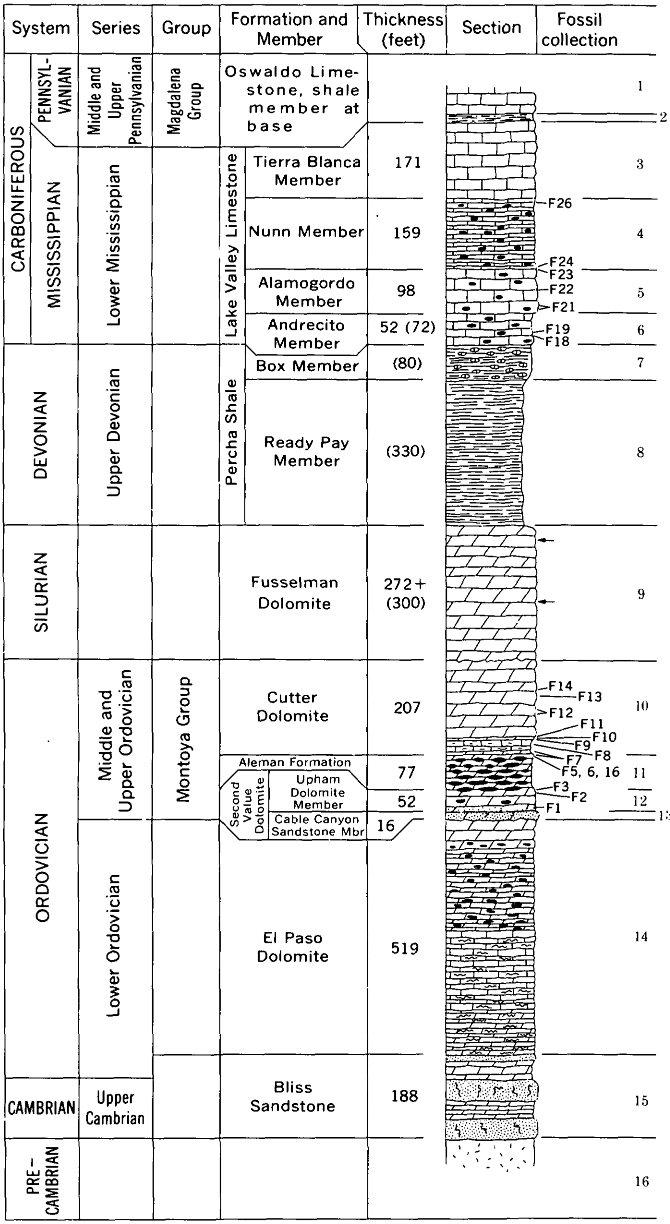

FIGURE 3.—Composite stratigraphic section of Cambrian through Mississippian rocks in the Hurley West quadrangle. Thickness figures in parentheses obtained from cross sections; all others measured in the field.

Unit	Key to lithology of numbered units in section
1	Bluish-gray aphanitic massive limestone containing a few thin shale partings.
2	Dark-brownish-red shale and siltstone.
3	Light-gray medium crystalline to coarsely crystalline blocky to massive limestone; abundant crinoids in many beds; sparse chert lenses.
4	Light-gray fine-grained limestone weathers pinkish locally, contains chert lenses; thin shaly partings more abundant in lower part; blocky in upper part, slabby in lower part; abundant bryozoans and crinoids.
5	Medium-gray aphanitic to coarsely crystalline limestone, mostly massive;common chert lenses; crinoids and corals locally in upper part.
6	Light-gray to light-reddish-gray blocky limestone; coarsely crystalline in upper part to finely crystalline in lower part; abundant chert lenses and layers; fossiliferous.
7	Light-gray shale containing abundant limestone nodules.
8	Black fissile shale.
9	Medium- to light-brownish gray aphanitic to finely crystalline massive dolomite; vugs common, filled with calcite in lower part; dark-brown pentameroid zones at horizons indicated by arrows.
10	Light-gray to light-brownish-gray very finely crystalline massive dolomite; muddy limestone near base, poor outcrop; a few irregular chert masses near base.
11	Interlayered light-gray very finely crystalline dolomite and discontinuous ¼- to 1-inch layers of dark-brown chert; chert layers become smaller and less abundant at top and bottom.
12	Medium-brownish-gray finely crystalline to medium crystalline massive dolomite; sandy in lower 5 feet; a few chert nodules near middle; abundant crinoid fragments; abundant brachiopods at top, a few brachiopods and cephalopods in lower part.
13	Brownish-gray to brown medium-grained to very coarse grained sandstone and sandy dolomite; massive; locally crossbedded; white ("opalescent") quartz grains common.
14	Light- to medium-gray finely crystalline to medium-crystalline slabby-weathering dolomite, and 177 feet of limestone at 100 feet above base; abundant fucoidal markings; chert nodules common in upper half.
15	Predominantly dark-gray or brown massive quartzite; locally hematitic or glauconitic and locally oolitic; includes two units of light-grayish-brown massive to slabby dolomite.
16	Light-gray granite and biotite granite, mostly porphyritic.

FIGURE 3.—Continued.

TABLE 1.—*Fossils and age of the Bliss Sandstone at Lone Mountain*

[From R. H. Flower, written commun., 1960. Lithology and thicknesses correspond to measured section]

Age	Lithology	Thickness (feet)	Fossils
Canadian (Early Ordovician)	Quartzite	12	*Symphysurina* in upper 11 feet.
	Dolomite	44	
Trempealeauan (Late Late Cambrian)	Quartzite	49	Fragments of Trempealeauan trilobites—*Illaenurus*, *Dikelocephalus*?, and Saukiidae—in upper 39 feet.
Probable upper Franconian (Middle Late Cambrian)	Dolomite	36	
	Quartzite	37	*Billingsella* (brachiopod).
Lower Franconian (Middle Late Cambrian)	Quartzite	10	*Eoorthis* (brachiopod) in lower 7 feet.

SECTION 1.—*Bliss Sandstone on the southwest side of the west peak of Lone Mountain (pl. 1)*

[Measured by W. P. Pratt and W. R. Jones, Oct. 7, 1958]

El Paso Dolomite.

Bliss Sandstone:

	Thickness (feet)
Quartzite, glauconitic or hematitic or both; medium gray or reddish gray; weathers dark gray; fine to medium grained, very thinbedded, massive; upper 2 ft very coarse grained and poorly sorted	11
Quartzite, medium-brownish-gray; weathers reddish brown; very fine to fine grained, laminated, massive	1
Dolomite, light-brownish-gray; weathers light grayish brown to dark brown; finely crystalline, laminated, locally very thin bedded, blocky; most weathered surfaces show abundant flat angular fragments ¼ to 1 in. long (edgewise conglomerate)	44
Quartzite, locally arkosic in upper part; light gray; weathers light grayish brown; medium to coarse grained, very thin bedded, massive, in places prominently crossbedded; locally less firmly cemented (sandstone), these portions indurated to quartzite along joint planes	39
Quartzite, locally hematitic; medium gray or brownish gray; weathers dark metallic gray to medium reddish brown; medium grained, very thin bedded, massive	10
Dolomite, sandy, light-gray; weathers light grayish brown; very thin bedded, slabby; contains nodules and layers of hematitic quartzite as much as 1 in. thick; locally contains scattered hematite oolites which stand out on weathered surface	36
Quartzite, mostly glauconitic and hematitic, glauconite increasing upward; dark gray to dark brownish gray both fresh and weathered; very coarse grained in lower part, grading upward to fine grained; very thin bedded, massive, locally crossbedded; contains coarse oolitic hematite in middle part	37
Quartzite, light gray both fresh and weathered; dominantly coarse grained, thick bedded, massive; very well indurated; forms ledge	3
Quartzite, light-reddish-brown; weathers dark reddish brown; poorly sorted, coarse grained to very coarse grained, thick bedded, massive; includes 1–2 ft of poorly sorted light-brown friable sandstone containing vertical tubes about ¼ by 2 in., probably worm burrows	7
Total Bliss Sandstone	188

Precambrian granite.

ORDOVICIAN SYSTEM

EL PASO DOLOMITE

The El Paso Dolomite consists of generally thin-bedded dolomite and limestone overlying the Bliss Sandstone of Late Cambrian and Early Ordovician age and underlying the Montoya Group of Middle and Late Ordovician age. The contact of the El Paso Dolomite with the overlying Cable Canyon Sandstone Member of the Second Value Dolomite of Middle Ordovician age appears conformable, but a hiatus corresponding to at least part of Middle Ordovician time indicates a disconformity. The El Paso in the Silver City region was correlated by Paige (1916, p. 4), on the basis of its lithology and fossil content, with the El Paso Limestone of the Franklin Mountains, Tex., near the city of El Paso. In this report the formation is referred to as the El Paso Dolomite to emphasize its dominantly magnesian composition.

DISTRIBUTION AND THICKNESS

A complete section of the El Paso Dolomite is exposed along the western base of the west peak of Lone Mountain. Other exposures, less complete because of burial or faulting, occur on the north and south flanks of the west peak, along the west base of the central and south peaks, and on the south side of the outlier west of Rio de Arenas. A thickness of 519 feet of El Paso Dolomite was measured on the west side of Lone Mountain; this compares favorably with Paige's measurement of 503 feet in the same locality.

LITHOLOGY

At Lone Mountain the El Paso consists of about 520 feet of light- to medium-gray dolomite and limestone. The formation may be divided into two parts for description, but it was found impracticable to use these two divisions as map units. The lower part is 277 feet thick and consists of 100 feet of dolomite overlain by 177 feet of limestone. It is characterized by numerous fucoidal markings, by a generally slabby appearance of the weathered outcrop, and by a lack of chert. The fucoidal markings are particularly distinctive; they are light-brown irregular amoeboid splotches, as much as several inches long, with long dimensions generally parallel to the bedding (fig. 4). The upper part of the El Paso, 242 feet thick where measured, differs from the lower part in the following characteristics: (1) It generally weathers to a darker color, a medium brownish gray, in contrast to the light grays of the lower part, (2) most of it weathers to a slabby outcrop like that below, but the uppermost 65 feet is massive, and (3) it does not contain fucoidal markings, but most of it does contain small distinctively irregular

FIGURE 4.—Fucoidal markings in the El Paso Dolomite, southwest side of west peak of Lone Mountain.

chert nodules, as shown in figure 5. In approximately the uppermost 45 feet of the El Paso Dolomite, the combination of massive outcrop and absence of chert or fucoidal markings makes the formation very difficult to distinguish from parts of the Upham, Cutter, and Fusselman.

In the Caballo Mountains, Kelley and Silver (1952) divided the El Paso into two mappable units, which they named the Sierrite Limestone (below) and the Bat Cave Formation (above). They stated (p. 42) that these two units "are not only mappable on lithologic grounds but are distinct enough to be locally identified in partial exposures and faulted segments. They also can be distinguished at a distance by the gross features of color, beddedness, and topographic expression." They correlated the Sierrite Limestone with the lower 134 feet of the section of the El Paso Limestone that Paige (1916, p. 4) measured at Lone Mountain. The section of the El Paso measured during the present study does indeed show a break at 134 feet above the base, but this break marks a transition upward from bluish-gray-weathering fucoidal limestone to an identical limestone with a few conglomerate masses; the distance of 134 feet is purely coincidental. If the El Paso at Lone Mountain were to be subdivided, by far the most easily recognizable break would be the one at 277 feet from the

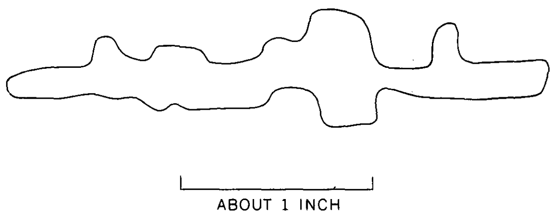

FIGURE 5.—Exposed face of irregular chert nodule in upper part of El Paso Dolomite.

base; but the lithologic differences that mark this break are not those described by Kelley and Silver. In short, Kelley and Silver's subdivisions of the El Paso cannot be made at Lone Mountain.

Masses of limestone or dolomite conglomerate, with cross-cutting boundaries, occur at several places in the El Paso. (See measured section 2.) Kelley and Silver (1952, p. 46) described similar conglomerate masses in the El Paso of the Caballo Mountains, where they are characteristically associated with stromatolites. A similar association is possible at Lone Mountain, but during this study no stromatolites were noted.

FOSSILS AND AGE

Many parts of the El Paso Dolomite at Lone Mountain are fossiliferous, but no fossils were collected during this study because of a concurrent investigation by R. H. Flower (written commun., 1960), whose observations are summarized in table 2.

TABLE 2.—*Fossils and age of the El Paso Dolomite at Lone Mountain*

[From R. H. Flower, written commun., 1960. Lithology and thicknesses correspond to measured section]

Age	Lithology	Thickness (feet)	Fossils
Jefferson City (upper Canadian)	Dolomite	233	Upper 103 ft constitute second piloceroid zone: short and mainly straight piloceroid siphuncles; "*Allopiloceras*" (new), "*Mcqueenoceras*" *franklinense;* also conspicuous sponges—*Archeoscyphia*.
Demingian (middle Canadian)	Dolomite	9	Gastropod—new genus and species; *Leiostegium* (trilobite).
	Limestone	177	Upper 72 ft constitute first piloceroid zone: large endoceroid and piloceroid siphuncles; *Piloceras, Bisonoceras* (ms.) aff. *Cyrtendoceras;* first abundant coiled cephalopods, cf. *Campbelloceras* and *Aphetoceras;* first conspicuous sponges—silicified fragments.
			First endoceroid zone at 44 ft above base: endoceroid siphuncles—*Kirkoceras, Proendoceras;* gastropod—new genus and species, aff. *Raphistoma trochiscus; Diaphelasma* (brachiopod); *Hystricurus* (trilobite).
Gasconade (lower Canadian)	Dolomite and limestone	5	*Lytospira gyrocera* (gastropod); *Symphysurina*.
	Dolomite	95	

SECTION 2.—*El Paso Dolomite on the southwest side of the west peak of Lone Mountain (pl. 1)*

[Measured by W. P. Pratt and W. R. Jones, Oct. 7, 1958]

	Thickness (feet)
Cable Canyon Sandstone Member of Second Value Dolomite.	
El Paso Dolomite:	
Dolomite, medium-gray; weathers light brownish gray; fine to medium crystalline, thick bedded, massive	45
Dolomite, like unit above; irregular nodules and wavy layers of chert, as much as 1 in. thick, common	20
Dolomite, medium-gray; weathers light brownish gray to grayish brown; fine to medium crystalline, thin bedded, slabby; irregular nodules and wavy layers of chert common; calcite veins fairly common	168
Dolomite, medium-dark-gray, medium-crystalline, granular, thick bedded, massive; locally conglomeratic with slabby ½- to 1-in. fragments of dolomite	9
Limestone, light-gray; weathers light bluish gray to medium gray; locally has abundant distinctive light-brown fucoidal markings; both crystalline and clastic; grain size variable but generally very fine to medium; generally very thin bedded, slabby; crosscutting masses of limestone conglomerate, consisting of limestone fragments less than an inch across in a medium-grained clastic limestone matrix, in upper 143 ft; two dolomite beds, each 3 ft thick, at 93 ft and 135 ft above base	177
Dolomite and limestone, interbedded	5
Dolomite, light- to medium-gray; weathers light brownish gray; fine to medium crystalline, very thin bedded, slabby; abundant fucoidal markings, especially in lower 60 ft	95
Total El Paso Dolomite	519
Bliss Sandstone.	

MONTOYA GROUP

The Montoya Group and the overlying Fusselman Dolomite in southern New Mexico and western Texas have been the subject of much study during the past decade or so. These studies were summarized in a paper by Pratt and Jones (1961a), to which the reader is referred for background information on the history of classification and nomenclature of the formations and for a discussion of their occurrence and subdivision in the Silver City region.

The Montoya Group comprises massive-weathering gray dolomite in part containing abundant chert; it lies over the El Paso Dolomite of Early Ordovician age and beneath the Fusselman Dolomite of Silurian age. The Montoya in the Silver City region was correlated by Paige (1916) with the Montoya Limestone near El Paso, Tex., on the basis of Late Ordovician (Richmond) fossils.

DISTRIBUTION

The formations of the Montoya Group underlie a large part of the west peak of Lone Mountain, as well as the west and south flanks of the central peak and south peak, and form the main part of the low outlier west of Lone Mountain. The small exposure south of this outlier is tentatively identified as Montoya on the basis of its lithology, which is typical of the Cutter and Upham, and the presence of conodonts including a large percentage of multiple cone types (R. J. Ross, Jr., written commun., Sept. 15, 1960).

SUBDIVISION

In the earlier report, we (Pratt and Jones, 1961a) established that the Montoya Dolomite in the Silver City region is divisible into the four conspicuous units defined by Kelley and Silver (1952) in the Caballo Mountains and now recognized by most workers throughout southern New Mexico and western Texas; from the base up these four units are the Cable Canyon Sandstone, Upham Dolomite, Aleman Formation, and Cutter Formation. Kelley and Silver considered these units as formations and therefore proposed that the Montoya be raised to group status, and nearly all subsequent workers have followed this proposal. The most recent exception was our discussion of the Montoya Dolomite in the Silver City region, in which we objected to formational status of the four units because in many places they are not mappable at the commonly used scale of 1:24,000. However, we did recognize that formational subdivision would be made in some areas where the formations can be depicted separately.

The three upper units of the Montoya are definitely mappable at 1:24,000 in the Lone Mountain area, but the Cable Canyon unit—otherwise a valid formation—simply is not thick enough (its normal outcrop is not wide enough) to be depicted separately at 1:24,000. Hence, whereas the upper three units of the Montoya can reasonably be accorded formational status, the Cable Canyon cannot, nor can it stand alone as a member without a parent formation. In this report, therefore, the Cutter and Aleman Members are considered as formations, and the Montoya Dolomite is elevated to group status. The Upham and Cable Canyon are mapped together as members of the Second Value Dolomite, retaining the name originally proposed for these beds by Entwistle (1944, p. 16–17) at their type locality on the Second Value claim at Boston Hill near Silver City and still used locally by Flower (1965). I would emphasize, however, that this retention of member rank for the Upham and Cable Canyon is done only with reluctance, for the Upham is as mappable a unit as ever graced the desert landscape, and so, but for its insufficient thickness, would be the Cable Canyon. In summary, the usage followed in this report is:

- Montoya Group
  - Cutter Dolomite
  - Aleman Formation
  - Second Value Dolomite
    - Upham Dolomite Member
    - Cable Canyon Sandstone Member

SECOND VALUE DOLOMITE

Cable Canyon Sandstone Member

At the base of the Montoya Group is the Cable Canyon Sandstone Member of the Second Value Dolomite, a medium- to coarse-grained quartz sandstone consisting of subrounded clear to whitish (opalescent) quartz grains cemented by dolomite or, in patches, by silica. In places the proportion of quartz grains decreases and the rock becomes a sandy dolomite. It is generally thick bedded and locally is crossbedded. The coarse sandy lithology and brown to brownish-gray massive outcrop make the Cable Canyon one of the most distinctive units in the entire Paleozoic succession of the region. No fossils have been observed in the Cable Canyon Sandstone Member at Lone Mountain or elsewhere in the Silver City region.

Flower (1958, p. 69–72) described a few feet of basal sandstone at the base of the Cable Canyon at several other places in southwestern New Mexico; he interpreted these sandstones as a separate depositional unit that corresponds to the Harding Sandstone (Middle Ordovician age) of Colorado and is distinct from the Cable Canyon of the type locality which he regarded as Red River (late Trenton and Eden) in age. There is no paleontologic evidence for this interpretation at Lone Mountain, but the lowermost 2½–4 feet of the Cable Canyon is lithologically slightly different from the overlying beds and is separated from them by an irregular surface with local relief of as much as 2 inches. Hence it is clear that there is lithologic evidence for Flower's separate depositional unit at Lone Mountain, even though there are no fossils to establish the duration of the hiatus. For mapping, however, this unit was included as part of the Cable Canyon Sandstone Member. The thickness of the Cable Canyon in the Lone Mountain area ranges from 2 to 16 feet.

The Cable Canyon lies in sharp contact on the El Paso Dolomite, but the contact shows less relief than the irregular surface within the Cable Canyon. The upper contact of the Cable Canyon is gradational.

Upham Dolomite Member

The Upham Dolomite Member of the Second Value Dolomite is a medium-brownish-gray massive dolomite that is finely to medium crystalline; the lowermost few feet is sandy, representing a transition from the Cable Canyon Sandstone Member. Most of the Upham is abundantly crinoidal, and chert nodules or lenses occur locally. The member is consistently thick bedded and weathers to a massive outcrop. A 3-foot bed at the top of the Upham weathers to a strikingly lighter shade of brown than the rest of the Upham; this bed is referred to by R. H. Flower (oral commun., 1958) as a "white calcarenite" and contains abundant brachiopods identified by him as *Zygospira* and *Dalmanella*(?), which he regards as evidence for inclusion of the bed in the overlying Aleman Formation. Lithologically, however, the bed is more like the rest of the Upham (see measured section 3) and is here considered part of it. Where measured at Lone Mountain, on the southwest side of the peak, the Upham Dolomite Member is 52 feet thick.

The light-brownish-gray beds at the top of the Upham Dolomite Member pass abruptly into the light-gray, more finely crystalline, more smoothly weathering, chert-bearing beds of the overlying Aleman Formation.

ALEMAN FORMATION

As distinctive as the Cable Canyon is the banded chert and dolomite of the Aleman Formation; the very finely crystalline dolomite weathers to a smooth, light-gray surface against which the layers and lenses of dark-reddish-brown chert, ¼–1 inch thick, stand out in bold contrast (fig. 6). On a fresh break, the dolomite is seen to be laminated, but it is not fissile; it breaks along the chert layers into 1- to 2-inch slabs. The chert constitutes an estimated 10–20 percent of the formation and occurs in discontinuous layers several feet across, with wavy boundaries, or in lenses; lenses or pods are the predominant form in the upper 10 feet of the formation and also near the bottom. The Aleman is 77 feet thick where measured at Lone Mountain.

The contact with the overlying Cutter Dolomite is conformable and is placed at a slight change in the color of the weathered dolomite (light gray below, light brownish gray above), which coincides with a decrease in the amount of chert. These features also coincide locally with a change in slope, the lower part of the Cutter forming a ledge 2–3 feet high, which stands out from the smooth slope formed on the Aleman.

FIGURE 6.—Outcrop of Aleman Formation near west end of summit of west peak, Lone Mountain. Photograph by W. R. Jones.

CUTTER DOLOMITE

The Cutter Dolomite consists largely of light-brownish-gray massive dolomite of lithographic or sublithographic texture. It looks much like the Upham Dolomite Member, which in isolated small outcrops is distinguishable only by its characteristic crinoid fragments. Although thin to laminar bedding is discernible in much of the Cutter, its outcrop is almost everywhere massive. Exceptions to the massive, dolomitic lithology are the two units of weakly resistant limestone and mudstone near the bottom of the formation, noted in the measured section. The Cutter Dolomite is 207 feet thick where measured at Lone Mountain.

The upper contact of the Cutter, and hence of the Montoya Group, is well defined at Lone Mountain and most other places in the Silver City region by contrasting lithologies: the Cutter is light gray and dense; the overlying Fusselman Dolomite is dark gray and vuggy (fig. 7). In some of the few places where these contrasts are not conspicuous, the contact may be defined by use of an additional criterion—namely, the Cutter is barren of fossils, whereas the Fusselman locally contains small cup corals within a few feet of the contact. At Lone Mountain the contact is well exposed as a sharp disconformity with

FIGURE 7.—Contact (at point of pick) between Fusselman Dolomite, above, and Cutter Dolomite, below, near summit of south peak, Lone Mountain. Photograph by W. R. Jones.

irregularities extending an inch or so above and below the normal surface (fig. 7).

FOSSILS AND AGE

Brachiopods collected at several horizons in the Montoya Group, although poorly preserved, appear similar to forms of Late Ordovician age (probably Richmond) occurring in the Montoya at Bear Mountain, 14 miles northwest (Pratt and Jones, 1961a, p. 499). All collections except F16 were taken from along or near the line of the measured section on Lone Mountain (fig. 3). The fossils identified are listed below. The corals, which make up collections F12, F13, and F14, were identified by W. A. Oliver, Jr., and all other fossils by R. J. Ross, Jr., both of the U.S. Geological Survey; their comments are included in the fossil lists.

On the basis of his own extensive work, Flower (1965) considered the age of the Montoya as Middle and Late Ordovician.

Cutter Dolomite:

- Collection F2–58 (upper 102 ft of Cutter):
  - *Favosites* sp.
  - Heliolitids (possibly *Protrochiscolithus* sp.)
    - Concerning the heliolitids, Oliver stated (written commun., Dec. 9, 1958): "These are poorly preserved but show the general characters of the Upper Ordovician genus *Protrochiscolithus* except for the remarkably large size of the corallites. These are 4 times as large as any previously described species of this genus or any closely allied genus and make identification and age assignment very uncertain. It is possible that these merely represent spectacularly large individuals of the genus (therefore Upper Ordovician) but they may just as likely represent Silurian derivatives of the Upper Ordovician forms."
- Collections F12 (89–102 ft above base of Cutter), F13 (133 ft above base of Cutter), and F14 (145–147 ft above base of Cutter):
  - *Palaeofavosites* sp. cf. *P. okulitchi* Hill (not Stearn)—almost certainly Late Ordovician.
- Collection F11 (41–43 ft above base of Cutter):
  - *Hebertella* cf. *H. sinuata*
  - Rhynchonellid, indeterminate
  - *Platystrophia*? sp.
  - Unidentifiable coral
  - Conodonts, abundant; all are multiple-cone compound forms.
- Collection F10 (38 ft above base of Cutter):
  - Large brachiopod shells—may be brachial valves of *Hebertella*
  - Conodonts, rare; include multiple-cone types.
- Collection F9 (34–35 ft above base of Cutter):
  - *Hebertella*? sp.
  - *Platystrophia*? sp.

Collection F8 (23–25 ft above base of Cutter):
- Brachiopods. Almost all are single species of *Diceromyonia*. Fragmentary specimens include:
  - Rhynchonellid, indeterminate
  - *Strophomena*? sp.
  - *Rafinesquina*? sp.

Collection F7 (basal 7 ft of Cutter):
- Bryozoans numerous and varied, but all are silicified casts of interiors.
- *Zygospira* sp.
- Unidentifiable fragments of other brachiopods
- Conodonts. Some simple cones, but several varieties of multiple-cone types present in fair numbers.

Aleman Formation:

Collection F16 (topmost 1 ft of Aleman, near south end of outlier in south-central part of sec. 34):
- Brachiopods:
  - *Strophomena* sp.
  - *Thaerodonta* sp.
  - *Hypsiptycha* sp. (most common fossil in this sample).
- Bryozoans: *Sceptropora*? sp.
- Conodonts, very rare, fragmentary

Collection F6 (topmost 1 ft of Aleman): Most of the insoluble residue of this sample is composed of "mats" of silicified shells of *Strophomena*, a resupinate convexo-concave brachiopod, suggesting that the bottom may have looked like a modern oyster bank. A species of *Paucicrura* is represented by a few (6) free shells.

Collection F5 (72 ft above base of Aleman):
- Brachiopods:
  - Large finely ribbed form, probably *Hebertella*
  - Finely pseudopunctate strophomenid
  - *Platystrophia*? sp.
- Bryozoans, possibly of the *Sceptropora* type
- Conodonts, rare; simple curved cones

Upham Dolomite Member of Second Value Dolomite:

Collection F3 (1 ft below top of Upham):
- Brachiopods:
  - *Zygospira* sp. (most common form)
  - *Paucicrura* sp.
  - *Onniella*? sp.
- A few conodonts were recovered.
- This may represent the so-called *Zygospira* zone of Flower, which he places in the base of the Aleman.

Collection F2 (6 ft below top of Upham):
- Conodonts, mostly simple curved cones; include rare compound types. Silicification of brachiopods very poor although fragments abundant. Recognizable types are dinorthid, rhynchonellid, and dalmanellid, but none identifiable to species or genus.

Collection F1 (24 ft above base of Upham and 8 ft above top of Cable Canyon Sandstone Member):
- Molds of brachiopods in dolomite. A rhynchonellid and an orthid recognizable but not identifiable to genus.

SECTION 3.—*Montoya Group on south side of south peak of Lone Mountain (pl. 1)*

[Measured by W. P. Pratt and W. R. Jones, Oct. 10, 1958]

Fusselman Dolomite.
Disconformity (fig. 7).
Montoya Group:

	Thickness (feet)
Cutter Dolomite:	
Dolomite, medium-brownish-gray; weathers light brownish gray to light gray; very finely crystalline, in places aphanitic; no bedding visible; massive	71
Dolomite, medium-dark-gray; weathers medium brownish gray; very finely crystalline; no bedding visible; massive	8
Dolomite, medium-light-gray; weathers light gray to medium brownish gray; very finely crystalline, laminated to very thin bedded, massive; several limestone conglomerate beds; a few thin chert lenses about 15 ft above base	85
Dolomite, medium-light-gray; weathers light brownish gray with brown streaks that represent abundant brachiopods; very finely crystalline, very thin bedded, massive	10
Mudstone, calcareous, with limestone lenses; mottled light olive gray both fresh and weathered; very thin bedded, slabby; very weakly resistant; poor outcrop	8
Dolomite, medium-brownish-gray; reddish streaks; weathers light brownish gray; very finely crystalline, thick bedded, massive; abundant small brachiopods	2
Limestone, muddy, light-pinkish-gray; weathers medium grayish brown to light gray; very finely crystalline; no bedding visible; very weakly resistant; no outcrop	16
Dolomite, medium-gray; weathers light gray to brownish gray; very finely crystalline, thick bedded, massive; a few irregular chert masses in lower part; abundant small pods (filled vugs) of coarsely crystalline dolomite weather to rough surface	7
Total Cutter Dolomite	207
Aleman Formation:	
Dolomite, medium-gray; weathers light gray; very finely to finely crystalline; no bedding visible; massive; common irregular veinlets of white coarsely crystalline dolomite; rounded irregular masses of chert, like that in unit below, becoming smaller and less abundant toward top; brachiopods, more abundant toward top	10
Dolomite and chert, interlayered. Dolomite is medium gray, weathers light gray with very smooth surface; very finely crystalline, laminated; massive within but breaks into 1- to 2-in. slabs because of chert. Chert constitutes roughly 10–20 percent of unit, as lenses and discontinuous layers generally ¼–1 in. thick; dark gray to brownish gray with alternating dark and light bands ⅟₁₆–¼ in. thick; weathers reddish brown; somewhat more discontinuous near bottom. Dolomite and chert unit grades into unit above	67
Total Aleman Formation	77

SECTION 3.—*Montoya Group on south side of peak of Lone Mountain*—Continued

	Thickness (feet)
Montoya Group—Continued	
Second Value Dolomite	
Upham Dolomite Member:	
Dolomite, medium-brownish-gray; weathers light brownish gray; fine to medium crystalline, locally coarsely crystalline; thick bedded, massive; abundant tiny cavities; abundant brachiopods in middle part weather to dark brown and stand out in relief on weathered surface	3
Dolomite, medium-dark-gray; weathers medium brownish gray; fine to medium crystalline, thick bedded, massive; abundant crinoid fragments; a few brachiopods at top	10
Dolomite, medium-dark-gray; brownish-red specks; weathers medium brownish gray; finely crystalline, thick bedded, massive; abundant small crinoid fragments; includes a few chert nodules as much as 1 ft long	6
Dolomite, medium-gray; weathers light brownish gray; finely crystalline, thick bedded, massive; a few large chert lenses	6
Dolomite, medium-dark-gray; small brownish-red streaks; weathers medium brownish gray; medium crystalline becoming finer upward; thick bedded, massive; small crinoid fragments fairly common; a few brachiopods and cephalopods	22
Dolomite, sandy, medium-dark-brownish-gray; weathers medium brownish gray; fine to medium crystalline, thick bedded, massive; in places a medium-grained dolomitic sandstone; sandy parts contain a few whitish (opalescent) quartz grains	5
Cable Canyon Sandstone Member:	
Sandstone and sandy dolomite, medium-gray; weathers medium brownish gray; generally coarse grained but ranges from fine to very coarse; thick bedded, massive; ranges irregularly from sandstone to sandy dolomite, weathered surface therefore patchy because of greater resistance of sandy parts	7
Quartzite and sandstone, light-gray; weathers dark brown; medium to very coarse grained, occasional pebbles as much as ¼ in. in diameter; very thin bedded, locally cross bedded, massive; contains characteristic whitish (opalescent) quartz grains	5
Dolomite, sandy, medium-gray; weathers light brownish gray; finely crystalline, thick bedded, massive; contains abundant coarse sand grains concentrated in rounded irregular masses, generally ¼–½ in. long but as much as 8 in. long, which stand out as knobs on weathered surface, some sufficiently indurated to be classified as quartzite; common large vugs filled with calcite	4
Total Second Value Dolomite	68
Total Montoya Group	352
El Paso Dolomite.	

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SILURIAN SYSTEM—FUSSELMAN DOLOMITE

Definition.—Light- to medium-gray massive dolomite, overlying the Montoya Group of Middle and Late Ordovician age and underlying the Percha Shale of Late Devonian age, constitutes the Fusselman Dolomite. In the Silver City region this formation was originally described by Paige (1916) as the Fusselman Limestone, on the basis of Silurian fossils and lithologic similarity to the Fusselman Limestone in the Franklin Mountains. The Fusselman Dolomite in the Silver City region has been described in a previous paper (Pratt and Jones, 1961a).

Distribution and lithology.—The Fusselman Dolomite forms the dip-slopes—that is, the eastern, gentle slopes—of the central and south peaks of Lone Mountain; it is also exposed in two outliers southeast of Lone Mountain and in the outlier west of the mountain. The formation is a monotonous succession of brownish-gray aphanitic to finely cystalline massive dolomites. Its only noticeable lithologic variations are the presence of calcite-filled vugs in many zones, and vertical changes in the shade of gray or brownish gray, particularly of the weathered rock. Several "memebers" might be distinguished on the basis of these color differences, but they would be of questionable significance and no attempt was made to map such units. Although laminar to thin bedding is visible on fresh breaks in much of the Fusselman, the outcrop is nearly everywhere massive.

Thickness.—No complete section of the Fusselman at Lone Mountain has been measured, but the thickness is known to be at least 272 feet and probably is about 300 feet. The thickness of at least 272 feet was obtained by putting together two partial sections. The partial section southeast of Lone Mountain (section 4), measured from the base of the formation up to a pentameroid zone, is 131 feet thick. The partial section on Cameron Creek (section 5) is 212 feet thick but includes neither the top nor the base of the formation. It does include, however, two pentameroid zones, the lower of which probably correlates with the pentameroid zone at the top of section 4. The thickness from the base of this zone to the top of the Cameron Creek section is 141 feet. These combined partial sections thus represent a total of 272 feet. A section constructed northeastward from the south peak of Lone Mountain gives a total thickness of 300 feet for the Fusselman; this is the closest approach to an accurate field measurement of the total section.

Contacts.—The apparently disconformable basal contact of the Fusselman has been described under the Cutter Dolomite and is shown in figure 7. The upper contact, with the Percha Shale, is rarely exposed because the shale weathers so easily to soil. At the one place on Lone Mountain where the contact was observed, it is a sharp break with dolomite below and black fissile shale above; and it shows no evidence of angular unconformity.

Fossils and age.—Fossils in several zones in the Fusselman Dolomite indicate a Silurian age for the formation. Pentameroid brachiopods occur abundantly and conspicuously at Lone Mountain in at least two zones near the middle of the formation; these were tentatively identified by C. W. Merriam (written commun., 1959) as ?*Conchidium* n. sp. and were believed by him to indicate a Silurian age, probably either Middle or Late Silurian. Fossils collected near the top and the base of the Fusselman elsewhere in the Silver City region, 12 miles northwest of Lone Mountain, are of definite or probable Silurian age (Pratt and Jones, 1961a, p. 499). Small streptelasmatoid horn corals from the basal 5 feet of the Fusselman at Lone Mountain apparently are indeterminate. According to W. A. Oliver, Jr. (written commun., 1960), they are suggestive of Silurian age, whereas R. H. Flower (written commun., 1959) regarded specimens he collected as being of Ordovician aspect.

Measured sections.—No complete section of the Fusselman Dolomite has been measured at Lone Mountain. The two partial sections measured include most of the formation from the base to within about 30 feet of the top. The uppermost part of the formation forms a dip slope everywhere and is partly covered by soil derived from the overlying Percha Shale, but it seems to consist of massive gray dolomites identical with those of the measured sections.

SECTION 4.—*Fusselman Dolomite (partial section), on low knob southeast of south peak of Lone Mountain, NE¼SW¼ sec. 34, T. 18 S., R. 13 W.*

[Measured by W. P. Pratt and W. R. Jones, May 1, 1959]

	Thickness (feet)
Fusselman Dolomite:	
Approximate base of lowest pentameroid zone.	
Dolomite, dark-gray, fine-grained, massive; silicified corals in upper 5 ft	88
Dolomite, light-gray, fine-grained, massive	2
Dolomite, medium- to dark-gray, fine-grained, massive, vuggy; small cup corals in all but lowermost 5 ft; chain corals at 32 ft above base	41
Measured partial thickness of Fusselman Dolomite	131
Cutter Dolomite: Dolomite, light-gray, fine-grained.	

SECTION 5.—*Fusselman Dolomite (partial section), on east bank of Cameron Creek, NE¼NE¼ sec. 3, T. 19 S., R. 13 W.*

[Measured by W. P. Pratt and W. R. Jones, Oct. 11, 1958]

	Thickness (feet)
Fusselman Dolomite:	
Upper part eroded.	
Dolomite, medium-dark-gray; weathers medium brownish gray with a few light-gray beds near top; very finely crystalline, laminated to very thin bedded, massive; vugs smaller than 2 mm common, especially in upper part; thin brown-weathering siliceous stringers in uppermost 2 ft; (fault with 5-ft throw at 5 ft above base)	42
Dolomite, medium-light-gray; weathers light gray and brownish gray; aphanitic; no bedding visible; massive	14
Dolomite, medium-gray; weathers medium brownish gray; finely to very finely crystalline; no bedding visible, massive; a few small calcite-filled vugs	4
Dolomite, medium-brownish-gray; weathers medium to light brownish gray; finely to very finely crystalline, laminated, massive; upper 22 ft and lower 33 ft contain common brachiopod-rich layers (pentameroids) as much as 2 in. thick, some converted to massive aphanitic silica, which stand out on weathered surfaces as dark-brown or gray ribs; scattered calcite pods; shear zone with 13-ft throw at about 40 ft above base	81
Dolomite, medium brownish gray both fresh and weathered; very finely crystalline, thick bedded, massive; common calcite pods as much as 2 in. long	71+
Base not exposed.	
Measured partial thickness of Fusselman Dolomite	212+

DEVONIAN SYSTEM—PERCHA SHALE

Definition.—The Percha Shale consists of fissile shale that lies above the Fusselman Dolomite of Silurian age and beneath the Lake Valley Limestone of Early Mississippian age. The Percha was correlated by Paige (1916), on the basis of its lithology and Late Devonian fossils collected from its upper part, with the Percha Shale in its type locality on Percha Creek near Hillsboro, Sierra County, N. Mex.

Subdivision.—In the Lone Mountain area the Percha Shale is divisible into a lower unit consisting of about 330 feet of black fissile shale and an upper unit consisting of about 80 feet of light-gray shale or mudstone with abundant limestone nodules. As Gordon and Graton (1906, 1907) failed to designate a specific type locality when they originally described and named the formation, Stevenson in 1945 (p. 241) proposed an excellent section of the Percha 2½ miles southeast of Hillsboro as the type section and divided the Percha into two members, the Ready Pay Member below and the Box Member above. According to Stevenson's descriptions, these two members are almost identical to the two units in the Lone Mountain area, and his names are therefore applied to them in this report.

Distribution.—The Percha Shale underlies the depression between the Fusselman dip slope and the cliff formed by the Lake Valley Limestone along the northeast side of Lone Mountain. Three small areas of Percha Shale are exposed just north of the Rio de Arenas fault in the vicinity of Rio de Arenas; and another small outcrop occurs about 200 feet south of the Rio de Arenas fault, in the SW¼ sec. 21, T. 18 S., R. 13 W.

Lithology.—The Ready Pay Member is almost entirely black fissile shale, which in a few places is bleached. The bleaching probably is an effect of alteration; it is not a result of weathering because many weathered outcrops are still black. The small, isolated outcrop in the SE¼ sec. 21 consists of red and white siltstones which are interpreted as Ready Pay of anomalous lithology, possibly altered, that has been faulted down or slumped into its present position.

The Box Member is a distinctive nodular shale. The nodules are composed of finely crystalline gray limestone and are about half an inch to several inches long and as much as 2 inches thick, but most commonly they are less than 1 inch thick and 2–4 inches long. The matrix is gray- to green-weathering slightly calcareous shale or mudstone with a semifissile to blocky fracture.

The contact between the two members of the Percha is gradational through a thickness of about 20 feet: the fissile black shale, which contains a few thin beds of limestone, gradually changes upward from black to grayish olive green, and the limestone beds become more abundant but less continuous, eventually remaining as abundant nodules in grayish-green shale, characteristic of the Box Member.

Thickness.—The total thickness of the Percha Shale in the Lone Mountain area is approximately 410 feet. As no complete section is exposed in the quadrangle, this figure is based on a cross section in sec. 27, T. 18 S., R. 13 W., on which the Ready Pay Member measures 330 feet thick and the Box Member 80 feet. Locally, however, the Percha appears thinner owing to faulting.

Contacts.—The basal contact of the Percha Shale is a sharp break, as described under "Fusselman Dolomite." The upper contact of the Percha, with the Lake Valley Limestone, is exposed at two places in the quadrangle; it is sharp at one place and gradational at the other. Where exposed on the east bank of Rio de Arenas, the contact is wavy, sharp, and apparently conformable; limestone of the Andrecito Member of the Lake Valley Limestone is "molded" against the undulating surface of the typical Box Member, as shown in figure 8. At the other exposure of the contact, about 1,500 feet west of the first, the Percha is apparently gradational into the Lake Valley; through a vertical distance of about 6 feet, the lithology changes upward from grayish-green shale with abundant limestone nodules, typical of the Box Member, to shale with thin wavy limestone beds and minor black chert, to slabby limestone with ½–1-inch shale partings and black chert nodules and layers, and finally to thick-bedded crinoidal limestone with thin (less than ½ inch) shale partings and minor black chert nodules, typical of the Andrecito Member of the Lake Valley Limestone. Arbitrarily the contact would be placed between the shale and the slabby limestone, but genetically this appears to be a conformable gradational contact. The variation in the nature of the upper contact of the Percha within such a short lateral distance suggests local pre-Lake Valley erosion. Jicha (1954, p. 16) found evidence of greater erosion than this in the Cooks Range, where the entire Box Member is missing in some sections.

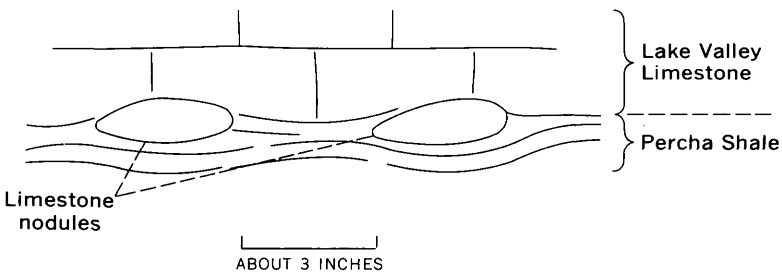


FIGURE 8.—Undulating upper contact of the Percha Shale, on the east bank of Rio de Arenas, SE¼SE¼ sec. 20, T. 18 S., R. 13 W.

Fossils and age.—Fossils are very sparse in the Percha Shale at Lone Mountain, and none were collected; but an abundant fauna has recently been collected by W. R. Jones from the Box Member near Georgetown, about 13 miles northeast of Lone Mountain, and its age has been determined as Late Devonian by J. T. Dutro, Jr., of the U.S. Geological Survey. This confirms a previous determination on fossils from an unspecified locality or localities in the Silver City region (Paige, 1916, p. 5).

MISSISSIPPIAN SYSTEM—LAKE VALLEY LIMESTONE

DEFINITION AND SUBDIVISION

The name Lake Valley Limestone was given by Cope (1882, p. 214) to calcareous beds lying conformably over the Percha Shale at Lake Valley, Sierra County, N. Mex. Paige (1916) grouped rocks of what was then considered the Carboniferous period in the Silver City region under the name Fierro Limestone, a name now abandoned; he correlated the lower part of the Fierro Limestone with the Lake Valley Limestone on the basis of Mississippian fossils. As now defined in the Silver City region, the Lake Valley Limestone consists of light-gray limestone, commonly containing abundant crinoids or bryozoans, that overlies the Percha Shale and underlies the Oswaldo Limestone of Pennsylvanian age.

Laudon and Bowsher (1941, 1949), after a comprehensive regional study of the Mississippian in southern New Mexico, subdivided the Lake Valley Limestone into six members, from youngest to oldest as follows:

Dona Ana Member—medium-bedded to massive gray to black very cherty crinoidal coquina.

Arcente Member—soft thin-bedded gray calcareous siltstone interbedded with thin laminations of soft gray shale.

Tierra Blanca Member—medium-bedded gray to brown crinoidal coquina beds containing light-colored chert nodules.

Nunn Member—soft blue-gray marls and nodular crinoidal limestones.

Alamogordo Member—massive black very cherty poorly fossiliferous cliff-forming limestone beds.

Andrecito Member—thin-bedded gray fossiliferous limestone grading upward into thin-bedded dark-gray somewhat cherty limestone; very thin bedded and noncherty in Lake Valley and Silver City areas.

The lowest four of these members are recognized at Lone Mountain. The Andrecito is atypical at Lone Mountain, for most of it contains abundant chert. These cherty beds are assigned to the Andrecito Member rather than to the Caballero Formation, which underlies the Lake Valley elsewhere, because they are lithologically unlike the Caballero and because their contact with the overlying massive beds typical of the Alamogordo Member appears conformable (Laudon and Bowsher, 1949, p. 9–10; Jicha, 1954, p. 16–18).

Schmitt (1935, p. 188) proposed the name Hanover limestone for the crinoidal limestone at the top of the Lake Valley Limestone in the Santa Rita area. This name is commonly used by geologists in the Silver City region but is little used elsewhere, and has been abandoned in favor of Laudon and Bowsher's Tierra Blanca, with which it is obviously equivalent.

DISTRIBUTION AND LITHOLOGY

The Lake Valley Limestone in the Lone Mountain area is best exposed in the cliffs along the east side of Lone Mountain, east of the

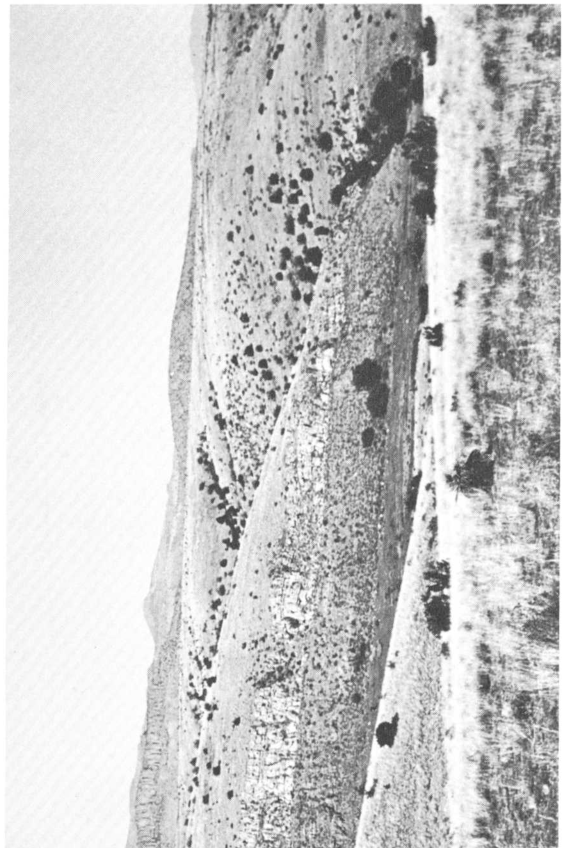


FIGURE 9.—Cliffs of Lake Valley Limestone along east bank of Cameron Creek, SE¼ sec. 27, T. 18 S., R. 13 W. Mlan, Andrecito Member; Mlal, Alamogordo Member.

small valley underlain by the Percha Shale (fig. 9). It is also exposed in three areas north of the Rio de Arenas fault and in a low isolated outlier 1½ miles west of Hurley.

The Lake Valley is most characteristically a light-gray crinoidal limestone in which chert lenses or layers are fairly common. The four members differentiated in the Lone Mountain area are described in detail in the measured sections; their general characteristics are as follows:

Tierra Blanca Member—massive light-gray crinoidal limestone.

Nunn Member—slabby to blocky light-gray limestone, locally weathering pinkish gray; has chert lenses, thin shaly partings, and abundant bryozoans and crinoids.

Alamogordo Member—massive medium-gray cliff-forming limestone containing common chert lenses (fig. 9).

Andrecito Member—light-gray to reddish-gray slabby limestone containing abundant chert lenses and layers.

In places where most of the formation is exposed, these members may be distinguished with little difficulty; but in small isolated outcrops, the lithologic similarities between the members and the variability in their thicknesses may make it difficult or impossible to distinguish them. The east-west elongate outcrop just north of the Rio de Arenas fault in the SE¼ sec. 20 and SW¼ sec. 21 is definitely Lake Valley, but the individual members were not mapped in that area. In the cliff exposures in the W½ sec. 22, faulting and probable thinning made it impossible to differentiate between the Andrecito and Alamogordo Members, and they were mapped together.

THICKNESS

Where measured near the south end of the cliff outcrop in secs. 27 and 34, the Lake Valley Limestone is about 500 feet thick. Less than 1 mile north, it is about 580 feet thick. Still farther north, just south of the north edge of sec. 27, the lower three members of the formation aggregate only about 230 feet, in contrast to 309+ feet in the measured section. West of Lone Moutain, in sec. 20, the Lake Valley is only about 430 feet thick. These variations in thickness probably are the result of plastic flow during local folding and faulting; similar thickness variations caused by plastic flow have been noted in the Lake Valley in the nearby Santa Rita quadrangle (W. R. Jones, written commun., 1960).

CONTACTS

The basal contact of the Lake Valley Limestone, with the underlying Box Member of the Percha Shale, has been described under "Percha Shale." The upper contact, with the basal shale member of the Oswaldo Limestone of Pennsylvanian age, appears conformable, although fossils indicate a hiatus corresponding to Late Mississippian time.

FOSSILS AND AGE

Fossils occur at many horizons in the Lake Valley Limestone; those reported below were collected from the three lower members of the Lake Valley along or close to the measured sections (fig. 3). The only fossils seen in the Tierra Blanca Member were fragments of crinoid stems, and these were not collected. The following report was prepared by J. T. Dutro, Jr., in consultation with W. J. Sando and Helen Duncan, all of the U.S. Geological Survey:

This report covers 7 collections from the Lake Valley formation; all indicate an Early Mississippian age—probably lower Osage equivalent. * * * The corals are all types that are encountered in early Osage assemblages. The small *Spirifer*, the *Imbrexia*? sp., and the productoids are brachiopods generally found in rocks of early Osage age. The bryozoan assemblage is characteristically early Mississippian and similar forms are found throughout the Lake Valley beds in many places.

Nunn Member:

Collection F26 (10 ft below top of Nunn):
- echinoderm debris, indet.
- *Cladochonus* sp.
- *Fenestella* spp.
- *Polypora* sp.
- rhomboporoid bryozoan, indet.
- *Punctospirifer* sp.

Collection F24 (basal 1 ft of Nunn):
- echinoderm debris, indet.
- *Cladochonus* sp.
- *Fenestella* spp.
- *Polypora* sp.
- *Cystodictya*? sp.
- rhomboporoid bryozoan, indet.

Alamogordo Member:

Collection F23 (1 ft below top of Alamogordo):
- *Imbrexia*? cf. *I.*? *forbesi* (Norwood and Pratten). This is a fairly common Lake Valley form that indicates an early Osage age.

Collection F22 (55 ft above base of Alamogordo):
- echinoderm debris, indet.
- *Zaphrentites* sp.
- fistuliporoid bryozoan, indet.
- *Fenestella* spp.
- *Polypora* sp.
- *Ptylopora* sp.
- *Penniretepora* sp.
- rhomboporoid bryozoan, indet.
- *Marginatia*? sp. (this represents the old "*Productus fernglenensis*" Weller group).

Collection F21 (10–15 ft above base of Alamogordo):
- *Orbinaria*? sp. (this is a productellid brachiopod).
- *Spirifer* sp. (small, perhaps same as in F18).

Andrecito Member:

Collection F19 (26 ft below top of Andrecito):
- echinoderm debris, indet.
- *Vesiculophyllum*? sp.

Collection F18 (48 ft below top of Andrecito):
- echinoderm debris, indet.
- *Zaphrentites* sp.
- horn coral, indet.
- *Camarotoechia* sp.
- *Spirifer* sp. (small, indet.)

MEASURED SECTIONS

Two partial sections of the Lake Valley Limestone were measured east of Cameron Creek, in the S½SE¼ sec. 27, and the N½NE¼ sec. 34, T. 18 S., R. 13 W. (pl. 1). The first section covered the span from near the unexposed base of the Andrecito Member to the top of the Nunn Member. The second partial section was measured from the base of the Nunn Member to the top of the Tierra Blanca Member, and this section seemingly included 310 feet of Nunn. However, the line of this section crossed two fracture zones of indeterminable displacement in the upper part of the Nunn Member, and the excessive thickness of Nunn—310 feet compared to 159 feet in the first section—is therefore probably due to repetition.

Thus the total thickness, in feet, of the Lake Valley is:

Tierra Blanca (from section 7)	171
Nunn (from section 6)	159
Alamogordo (from section 6)	98
Andrecito (from section 6)	72
Total Lake Valley Limestone	500±

SECTION 6.—*Lake Valley Limestone, cliff and slope on east side of Cameron Creek, SW¼SE¼SE¼ sec. 27, T. 18 S., R 13 W.*

[Measured by W. P. Pratt and W. R. Jones, Oct. 11, 1958]

	Thickness (feet)
Lake Valley Limestone:	
Tierra Blanca Member: Abundant low ribs of crinoidal limestone, no chert.	
Nunn Member:	
Limestone, medium-gray; weathers light gray; aphanitic or locally coarsely crystalline, very thin bedded; massive to blocky fracture; a few chert lenses concentrated in layers; lowermost 65 ft exposed as sporadic ribs; intervening inferred from float	154
Limestone, medium-brownish-gray; weathers light gray; aphanitic, very thin bedded; slabby fracture; abundant small chert pods	5
Total Nunn Member	159
Alamogordo Member:	
Limestone, medium-gray; weathers medium light gray to brownish gray; aphanitic to very coarse grained, thick bedded, massive; common chert lenses	29
Limestone, medium-dark-brownish-gray; weathers medium gray; aphanitic with a few very coarse crystals, and locally very coarsely crystalline; very thin bedded, slabby; abundant crinoids and corals, common chert lenses	13
Limestone, medium-dark-gray to brownish-gray; weathers medium gray; mostly aphanitic; no bedding visible; massive; large chert lenses and crinoids in upper part	46
Limestone, medium-gray; alternate beds weather to dark brown or medium gray; coarse grained (calcarenite), thick bedded, massive	7
Limestone, light-gray; weathers medium light gray; medium to coarsely crystalline, thick bedded, massive, crinoids in upper part	3
Total Alamogordo Member	98
Andrecito Member:	
Limestone, medium-gray; weathers medium light gray; very coarsely crystalline, very thin bedded, blocky; abundant chert lenses and layers; fossiliferous; upper 10 ft contains less chert and is more massive	29
Limestone, medium-gray; weathers medium light gray; very coarsely crystalline, very thin bedded, massive, abundant fossil fragments weather to brown masses	8
Limestone, medium-reddish-gray; weathers medium light reddish gray; finely crystalline, very thin bedded, blocky; abundant large lenses and discontinuous layers of chert, as much as 3 in. thick, constitute 10–15 percent of unit	15
Unexposed	20±
Total Andrecito Member	72±
Percha Shale.	

SECTION 7.—*Lake Valley Limestone (partial section), gully on east side of Cameron Creek, measured in N½NE¼NE¼ sec. 34 and S½SE¼SE¼ sec. 27, T. 18 S., R. 13 W.*

[Measured by W. P. Pratt and W. R. Jones, Oct. 14, 1958]

	Thickness (feet)
Oswaldo Limestone, basal shale member.	
Lake Valley Limestone:	
Tierra Blanca Member:	
Limestone, medium-gray; weathers medium light gray to brownish gray; generally medium to coarsely crystalline, thin to thick bedded, blocky to massive; sparse chert lenses, abundant crinoids in many beds; weathers to wide rounded ribs (on gentle slope)	171
Total Tierra Blanca Member	171
Nunn Member:	
Limestone, medium-brownish-gray; weathers light gray; aphanitic, thin bedded; rounded blocky fracture; a few chert lenses and thin shaly layers; several wavy layers of chert, 2–6 in. thick, in upper 30 ft; common bryozoans; grades into unit below; 3-ft fracture zone at 48 ft above base, fault at 90 ft above base	186
Limestone, medium-gray to pinkish-gray; weathers medium light gray; finely crystalline; common chert lenses; many shaly partings cause weathering to rounded slabs; abundant crinoids and bryozoans, and sporadic brachiopods and corals; a few 1- to 2-ft beds of medium-light-gray massive crinoidal limestone, increasing upward, form ledges	124
Total Nunn Member	310
Andrecito Member.	

PENNSYLVANIAN SYSTEM—MAGDALENA GROUP

DEFINITION AND SUBDIVISION

The name Magdalena Group was applied by Gordon (1907) to rocks of Pennsylvanian age in the Magdalena Mountains; he differentiated a lower unit of clastic rocks, the Sandia Formation, and an upper unit, the Madera Limestone. Spencer and Paige in 1935 correlated rocks of Pennsylvanian age in the Santa Rita district with the Magdalena Group, but (1935, p. 23) found the lithology

> so notably different that divisions corresponding with the Sandia and Madera formations have not been recognized. However, in course of the present study of the Santa Rita area it has been convenient to divide the section into two parts, which have been mapped as the Oswaldo formation below and the Syrena formation above, the names being those of patented mining claims about 1 mile south of Hanover post office.

As defined by Spencer and Paige, the Oswaldo Formation is dominantly limestone but contains about 15 percent shale, both as partings and as a unit 20–30 feet thick at the base of the formation. This basal unit, informally called the Parting shale by Schmitt (1935, p. 188), is referred to in this report as the basal shale member of the Oswaldo Limestone. The Syrena Formation also is composed of limestone and shale; its lower part is about 40 feet of black calcareous shale and mudstone, and this 40-foot unit is overlain by a succession of limestone and shale.

DISTRIBUTION

The Magdalena Group in the Hurley West quadrangle is represented entirely by the Oswaldo Limestone, with the exception of one small area of shale assigned to the Syrena. The group is exposed chiefly along Cameron Creek, in the lowlands east of Lone Mountain, and less extensively in sec. 20, north of the Rio de Arenas fault. The best exposures are in the Chino quarry in sec. 27 and on the flat to the south.

OSWALDO LIMESTONE

The Oswaldo Limestone consists mostly of light-weathering gray lithographic limestone, in thick beds separated by shaly partings. The only noteworthy exception to this lithology is about 30 feet of impure silty and shaly limestone lying beneath the Beartooth Quartzite along a gully in the SE¼ sec. 20. This 30-foot unit, about 200 feet above the base of the Oswaldo, includes both thin-bedded and massive rocks ranging from gray limestone with tan shaly reticulations to gray limestone nodules in a tan shaly, silty, or muddy matrix; it also contains a few beds of highly indurated mudstone. These rocks probably correspond to the so-called striped beds near the top of the Oswaldo in the Santa Rita quadrangle (W. R. Jones and R. M. Hernon, written commun., 1960). Fossils occurring in these rocks are suggestive of a Late Pennsylvanian age, which in turn would suggest that the rocks represent the Syrena Formation. However, these rocks are here considered not to represent the Syrena because of the absence of the black calcareous shale that characterizes the basal part of the Syrena elsewhere in this region, and because the fossil evidence is not definitive. (See under "Fossils and age".) A 2- to 3-foot bed of coarse-grained brown sandstone is exposed about 100 feet above the base of the Oswaldo near the center of sec. 35.

The basal shale member of the Oswaldo Limestone in the Lone Mountain area consists of distinctive dark-brownish-red shale and siltstone, 22 feet thick where measured above the measured section of the Lake Valley Limestone. Elsewhere in the quadrangle, the thickness is comparable to this, except in the SW¼ sec. 22, where the unit pinches out. In many exposures near the Cameron Creek laccolith, the basal shale is hardened and has a baked appearance; but thin sections of such specimens show only an aggregate of subangular quartz grains 0.05–0.1 mm in diameter, in a clay matrix, and show no evidence of metamorphism.

No stratigraphic section of the Oswaldo Limestone was measured during this study, and data are not sufficient to permit an accurate measurement of thickness from any cross sections. An approximate thickness of 850 feet is indicated by a cross section in sec. 35, where the Oswaldo may be complicated by faults or inflated by intrusion. Elsewhere in the quadrangle, the thickness of the Oswaldo appears to be extremely variable owing to pre-Beartooth erosion that largely removed the overlying Syrena and Abo formations and probably part of the Oswaldo too.

Neither the basal nor the upper contact of the Oswaldo Limestone is well enough exposed in the quadrangle to permit observations on their physical characteristics.

SYRENA FORMATION

Two small exposures, lying about 800 feet apart in the SE¼ sec. 23, are assigned to the Syrena Formation; they consist of fissile gray shale with very abundant nodules of slightly calcareous mudstone. The rocks are assigned to the Syrena because of their position above the Oswaldo Limestone and their lithologic similarity to the lower part of the Syrena in the Santa Rita quadrangle.

FOSSILS AND AGE

Three collections of fossils from the Oswaldo Limestone indicate a Middle and Late Pennsylvanian age. J. T. Dutro, Jr. (written commun., 1961), reported as follows on two collections from the impure silty and shaly limestone of the upper part of the Oswaldo in the NW¼SE¼ sec. 20. Collection F31 is from the topmost part of the Oswaldo, within about 10 feet of the base of the Beartooth Quartzite; collection F32 was made about 25 feet lower.

Collection F31 contains only a limited brachiopod assemblage that suggests late Pennsylvanian, perhaps Virgil, age.
The assemblage is:

Derbyia cf. *D. crassa* (Meek and Hayden)
Linoproductus cf. *L. magnispinus* Dunbar and Condra
Antiquatonia sp.
Juresania? sp.
phillipsid tribolite, indet.

Collection F32 contains a brachiopod assemblage that is suggestive of post-Des Moines, but not latest Pennsylvanian, age. I would suggest a correlation with the Missouri equivalents. The assemblage is:

echinoderm debris, indet.
Lissochonetes cf. *L. geinitzianus* (Waagen)
Antiquatonia cf. *A. coloradoensis* (Girty)

Spirifer cf. *S. occidentalis* (Girty)
Spirifer sp. (small)
Composita cf. *C. subtilita* (Hall)
ostracode fragments, indet.

The other collection consisted of a single block of limestone containing visible foraminifers, collected from the middle(?) part of the Oswaldo, a few hundred feet south of the quarry road in the SW¼SE¼SE¼ sec. 26, T. 18 S., R. 13 W. Lloyd G. Henbest of the U.S. Geological Survey reported on this sample as follows (written commun., 1960):

This sample contains an abundance of stony algae and of *Fusulinella devexa* (?) Thompson. The age indicated is the middle part of the Middle Pennsylvanian (i.e. late Atoka (= Bend) or possibly early Des Moines age).

PERMIAN SYSTEM—ABO(?) FORMATION

The name Abo Sandstone was applied by Lee in 1909 to coarse-grained dark-red to purple sandstone, containing variable amounts of shale, at the south end of the Manzano Range in central New Mexico (Lee and Girty, 1909, p. 12). A sequence of red shales and limestones exposed near Santa Rita, resting unconformably on the Syrena Formation and overlain by the Beartooth Quartzite of Cretaceous age, was correlated with the Abo by Spencer and Paige (1935). No fossils have been found in the Abo in the Santa Rita area. Farther east, the age of the Abo is considered to be Early Permian (Jicha and Lochman-Balk, 1958, p. 6–7).

A small exposure of light-reddish-brown and olive-green silty mudstone with uneven fracture, apparently overlying the westernmost of the two exposures of Syrena Formation in the SE¼ sec. 23, is questionably assigned to the Abo Formation on the basis of its stratigraphic position and its lithology, which is more like the typical Abo Formation of the Santa Rita quadrangle than like typical Syrena Formation (W. R. Jones, oral commun., 1960). Fragments of a linoproductid brachiopod collected from the formation indicate a marine origin but are not definitive in separating Late Pennsylvanian from Permian (J. T. Dutro, Jr., written commun., 1961).

MESOZOIC TO CENOZOIC ROCKS

CRETACEOUS SYSTEM

BEARTOOTH QUARTZITE

Definition and distribution.—The Beartooth Quartzite was named by Paige (1916, p. 5) for exposures on Beartooth Creek, about 9 miles east-northeast of Silver City. He defined the formation as quartzite and a little interbedded shale resting unconformably on Precambrian to Pennsylvanian rocks and overlain in apparent conformity by the

Colorado Shale of Late Cretaceous age. Paige found no fossils in the Beartooth but regarded its age tentatively as Late Cretaceous.

The Beartooth is generally resistant but is exposed in only four small areas in the Hurley West quadrangle: north of the Rio de Arenas fault in sec. 20; on both sides of Cameron Creek in sec. 23; north of the road in the center of sec. 26; and in two small patches just north of the Chino Quarry fault in sec. 27.

Lithology.—The most distinctive lithology of the Beartooth in the quadrangle, and the most frequently observed, is a light-gray fine-grained quartzite, which generally weathers to a massive outcrop and characteristically is stained light red and black on numerous fracture surfaces and bedding planes. Beds or lenses of conglomerate, consisting of subangular pebbles of siliceous rocks (mainly chert) in a quartzose matrix, occur in three of the four areas of exposure. Rocks other than quartzite occur in the Beartooth in the measured section, but in the other exposures the formation consists almost exclusively of quartzite and minor conglomerate. The larger of the two patches of Beartooth north of the Chino Quarry fault in sec. 27 consists of conglomerate overlain by dark-green siltstone, with very little typical quartzite.

SECTION 8.—*Beartooth Quartzite (partial section) on east bank of a southeast-flowing tributary to Rio de Arenas, NW¼SE¼ sec. 20, T. 18 S., R. 13 W.*

[Measured Apr. 29, 1960]

	Thickness (feet)
Gila Conglomerate (debris).	
Beartooth Quartzite:	
Quartzite, light-gray, medium-grained, thin-bedded, crossbedded; weathers to massive outcrop	30
Mudstone, light-greenish-gray; semiconchoidal fracture; alternating with gray siltstone	13
Siltstone, light-gray, thin-bedded; a few quartzite beds in upper 3 ft	12
Quartzite, gray, fine-grained, massive, highly indurated; black and red stains on weathered surfaces	10
Quartzite and sandstone, alternating massive and thin bedded, like lowest unit	18
Mudstone, silty, light-greenish-gray; semiconchoidal fracture	2
Quartzite, light-gray or white, fine-grained, generally massive; black and red stains on weathered surfaces; locally thin bedded, with clayey or tuffaceous(?) matrix; a few beds of aphanitic white quartzite (novaculite?), and some lenses of quartzose conglomerate	20
Measured partial thickness of Beartooth Quartzite	105
Oswaldo Limestone.	

Thickness.—The measured partial thickness of the Beartooth, 105 feet, is comparable with the 90–125-foot thickness in the Silver City region reported by Paige (1916), but is less than thicknesses of about 140 feet in Yellowdog Gulch, in the Santa Rita quadrangle (W. R.

Jones, written commun., 1961), and 280 feet southeast of Santa Rita (Elston, 1957, p. 9). The formation has not been measured elsewhere in the Hurley West quadrangle, but it is estimated to be as much as 190 feet thick northwest of the measured section. Neither the top nor the basal contact of the Beartooth is exposed anywhere in the quadrangle.

Age.—No fossils have been found in the Beartooth anywhere in the Silver City region. Darton (1928, p. 38) correlated the Beartooth Quartzite with the Sarten Sandstone in the Cooks Range, about 40 miles southeast of Silver City, on the basis of lithology and stratigraphic position. Fossils from the middle of the Sarten are of Early Cretaceous age. In the Santa Rita quadrangle, however, W. R. Jones and R. M. Hernon (written commun., 1960) gave more credence to the conformable position of the Beartooth beneath the Colorado Formation, which is of Late Cretaceous age; they suggested that deposition of the Beartooth and Colorado sediments may have been continuous, and that the Beartooth may be correlative with only the upper part of the Sarten; thus they regarded the age of of Beartooth as Late(?) Cretaceous. The upper contact of the Beartooth, with the Colorado Formation, is not exposed in the Hurley West quadrangle and therefore is not known to be conformable. But fossils in the lower part of the Colorado Formation in the quadrangle are of Greenhorn and in part possibly Carlile age, so there would seem to have been ample time (Dakota) for deposition of the Beartooth in the earlier part of the Late Cretaceous.

COLORADO FORMATION

DEFINITION

Rocks of early Late Cretaceous age along the east side of the Front Range in the Rocky Mountains were named the Colorado Group by Hayden in 1876. Paige (1916) correlated the sandy shales and sandstones overlying the Beartooth Quartzite in the Silver City region with the Benton Shale of the Colorado Group, and applied to these beds the name Colorado Shale. In the present report, these beds are referred to as the Colorado Formation in accordance with the usage of Hernon and others (1964) in the Santa Rita quadrangle, because the most characteristic feature of the formation in the Silver City region is its heterogeneity.

DISTRIBUTION AND LITHOLOGY

The Colorado Formation in the Hurley West quadrangle is exposed principally along the banks of a south-flowing tributary to Rio de Arenas, in sec. 20. A few other outcrops are in sec. 23, mainly in the bed of Cameron Creek. The formation consists mainly of impure sandstones, siltstones, shales, and mudstones. It is characterized by mixed lithologies, either in a single bed (for example, shaly sandstone and silty shale) or as alternating beds (for example, alternating sandstone and mudstone), and by predominantly dull colors—olive green, brown, or dark gray. The greatest thickness of the formation is exposed along the west bank of the south-flowing tributary of the Rio de Arenas; much of the formation here is covered, and it was not measured, but the estimated thicknesses are as follows:

	Estimated thickness (feet)
Gila Conglomerate (debris).	
Colorado Formation (generalized):	
Mudstone, olive-green; conchoidal fracture	400
Sandstone, white; stained reddish	250
Sandstone, greenish-brown, impure; pelecypods in upper part	1, 000
Total	1, 650
Beartooth Quartzite.	

The following better exposed but less complete section occurs in the channel of Cameron Creek. The general lithology of this section and the pelecypods in its upper part suggest that it corresponds to the upper part of the lowermost unit in the generalized section given above.

SECTION 9.—*Colorado Formation (partial section), in channel of Cameron Creek, in NE¼SE¼ sec. 23, T. 18 S., R. 13 W.*

[Measured by W. P. Pratt and W. R. Jones, Apr. 23, 1960]

	Thickness (feet)
Alluvium.	
Colorado Formation:	
Sandstone, silty and shaly; weathers light brown and purplish brown; contains a few thick beds of sandstone	10
Sandstone, silty; weathers light purplish gray; thin bedded	12
Sandstone, fine-grained, and siltstone; brown, massive, cemented by calcite; occurs as lenticular beds 1–3 ft thick; interbedded with brown sandy mudstone having imperfect conchoidal fracture. Unit contains pelecypods: fossil collection F30–60 at 5 ft from top, collection F29–60 at 43 ft from top	63
Shale, silty; weathers dark gray or brown; conchoidal fracture; alternates with light-gray-weathering siltstone beds generally 1–2 in. thick and spaced 4–6 in. apart	48
Not exposed; probably shale	63
Sandstone, dark-gray, thin bedded; alternates with silty mudstone	10
Mudstone, dark-gray; irregular conchoidal fracture; slightly calcareous; several beds of brown or dark-gray impure sandstone	49
Base not exposed.	
Measured partial thickness of Colorado Formation	255

CONTACTS

In the few places where the base of the Colorado Formation is mapped, the contact surface is covered by debris. The next younger sedimentary formation, the Rubio Peak Formation, is not exposed in contact with the Colorado Formation in this quadrangle.

FOSSILS AND AGE

The two suites of fossils collected in the channel of Cameron Creek, at the horizons indicated in the measured section above, were examined by W. A. Cobban of the U.S. Geological Survey, who reported on them as follows (written commun., 1960):

Collection F29–60:
Pelecypods:
Pseudoptera sp.
Ostrea sp.
Cardium pauperculum Meek?
Parmicorbula sp.
A shallow-water marine assemblage. Possibly from a near-shore equivalent of the Greenhorn limestone.
Collection F30–60:
Pelecypod: *Ostrea* sp.
Gastropod: *Rostellites gracilis* Stanton?
These marine fossils are either Greenhorn or Carlile in age.

Thus the lower part of the Colorado Formation in this area is early or middle Late Cretaceous in age.

UPPER CRETACEOUS TO LOWER TERTIARY INTRUSIVE ROCKS

Intrusive igneous rocks, ranging in form from sills and a laccolith to dikes, and in mineralogic composition from quartz latite to basalt, occur in the northern part of the Hurley West quadrangle. The sills and laccolith are in the upper Paleozoic and younger rocks northeast of Lone Mountain, whereas most of the dikes are in Paleozoic rocks and are exposed in the main Lone Mountain mass and its outliers. These intrusions postdate the Colorado Formation of Late Cretaceous age and predate the Rubio Peak Formation of Miocene(?) age; they are therefore considered as Late Cretaceous to early Tertiary in age. Their age relations are discussed more specifically at the end of this section. Contact-metamorphic effects of the intrusive rocks are only slight, and are described under individual intrusions where applicable.

SILLS AND LACCOLITH

The laccolith and two sills exposed in the Hurley West quadrangle are composed of latites; they are here named the Chino Quarry sill, the Hurley sill, and the Cameron Creek laccolith (pl. 1), in the inferred order of their emplacement.

CHINO QUARRY SILL

The Chino Quarry sill, so named because its main exposure is near the limestone quarry operated by Chino Mines Division of Kennecott Copper Corp., is exposed discontinuously over a total length of about a mile in secs. 26 and 23. The four outcrop areas of the sill are interpreted as belonging to three faulted segments; two other small outcrops shown on plate 1 in the Chino Quarry fault zone probably represent the feeder dike of the sill; and an additional faulted segment of the sill does not now crop out, but its existence is inferred. The relationships of the present outcrop areas to the inferred overall form of the sill are shown in figure 17.

Form.—The Chino Quarry sill appears to have been, before its deformation, a conformable body generally 100–150 feet thick but bulged to a maximum thickness of about 200 feet near its south end. The sill dips gently eastward within the Oswaldo Limestone; north of the Chino Quarry fault the sill is near the base of the Oswaldo, but south of the fault it is about 400 feet above the base.

Petrography.—The rock of the Chino Quarry sill is a biotite latite; it contains about 50 percent small phenocrysts, which are mostly smaller than 2 mm and consist of white plagioclase and minor biotite, in an aphanitic matrix that appears medium grayish green to the naked eye but speckled green and white under the hand lens. The rock appears relatively fresh in hand specimen, but thin sections show moderate alteration: the plagioclase phenocrysts are altered to carbonate and a little kaolinite, the biotite phenocrysts are altered to chlorite and a little epidote, and the matrix, a mixture of feldspars and quartz, is partly altered to epidote, chlorite, carbonate, and magnetite. The rock of the dike in the Chino Quarry fault zone is a dull dark green in hand specimen; in thin section it is texturally identical with rock from the main part of the sill but is more intensely altered to montmorillonite and chlorite.

HURLEY SILL

The Hurley sill is exposed intermittently in the northeastern part of the quadrangle. The two main areas shown as the Hurley sill on plate 1 represent inferred outcrop limits of the sill; actual outcrops make up about a third of these areas, the remainder being alluvium and colluvium. Igneous rock presumed to be an extension of the Hurley sill was penetrated at a depth of 310 feet (elevation 5,610 ft) in a drilled well in the SW¼SE¼ sec. 15.

Form

The Hurley sill appears to be a gently eastward-dipping body intruded partly at about the top of the Beartooth Quartzite and partly somewhat higher, within the Colorado Formation. The floor of the sill is at an elevation of about 5,750 feet at the west side of the outcrop area and must be below 5,665 feet at the east side (pl. 1). These elevations indicate a minimum dip of about 3° E.; however, it is more likely that the sill is virtually concordant and has the same dip as the enclosing sedimentary rocks—about 15°. The present (uneroded) thickness of the sill is at least 190 feet, based on the minimum dip of 3°; if the sill is concordant, its thickness is as much as several hundred feet greater. The original thickness of the sill cannot be determined, because the roof rocks of the sill and probably part of the sill itself were eroded before deposition of the Rubio Peak Formation; and a later period of erosion probably removed some of the Rubio Peak Formation and more of the sill before deposition of the Gila Conglomerate.

The Hurley sill is probably an extension of the Fort Bayard laccolith of Spencer and Paige (1935, p. 33–34), which is exposed farther north in the Fort Bayard and Santa Rita quadrangles. The Fort Bayard laccolith ranges in thickness from 0 to about 1,200 feet in the Vanadium area (W. R. Jones and R. M. Hernon, written commun., 1960).

Petrography

The rock of the Hurley sill is a porphyritic hornblende latite. Outstanding in hand specimen is the abundance of greenish-black lustrous prisms of hornblende, which are as much as 3 mm long and in some places show a rude alinement. These are set among indistinct glassy white plagioclase phenocrysts, in a fine-grained light-gray matrix that consists of quartz, indistinguishable feldspars, and accessory magnetite, apatite, and sphene; the phenocrysts constitute 50 percent or more of the rock.

Thin sections show only slight alteration: the plagioclase phenocrysts are slightly altered to sericite and a little kaolinite; a few hornblende phenocrysts are slightly altered to carbonate; and in the matrix, the feldspars are slightly altered to kaolinite. In its easternmost exposure, in a gully in the NW cor. sec. 30, T. 18 S., R. 12 W., the sill rock is more altered, probably owing to pre-Miocene(?) weathering.

CAMERON CREEK LACCOLITH

The Cameron Creek laccolith, best exposed of the three major intrusives, crops out in and near the valley of Cameron Creek along the northeast side of Lone Mountain. The laccolith presents an ideal student problem in mapping and structural interpretation, and for this purpose an integrated account of its geology and structural history has recently been published (Pratt and Jones, 1965).

Form

Although Graton (1910, p. 320) had referred to this intrusion as a sill, Paige (1916, structure sections) interpreted the mass as a stock—an interpretation that is quite understandable in view of the scarcity of outcrops showing the contact surfaces of the body, and the short time that was available to Paige for mapping the entire 30-minute quadrangle. Recognition once more of the conformable nature of the intrusion is recorded in the unpublished notes of M. W. Cox, who made a reconnaissance of the Cameron Creek area in 1945. The laccolith dips rather gently to the northeast and is generally conformable with the enclosing sedimentary rocks.

The exposed part of the laccolith is nearly 1¼ miles long at the base and has a maximum thickness of about 1,500 feet. The floor is virtually flat and strikes about N. 30° W.; where the actual surface of the floor is exposed, near the center of the south edge of sec. 22, it is approximately parallel to the dip of bedding in the underlying limestone. The roof is arcuate in plan view, convex to the east, but as a whole it is approximately parallel to the strike of bedding in the overlying rocks. To the north, the roof appears to be converging on the floor, and probably the laccolith does not extend much beyond the center of sec. 22. On the south, the lower part of the laccolith terminates abruptly against the Chino Quarry fault, and the upper part interfingers irregularly with the host strata. Presumably the laccolith extends beneath the Gila Conglomerate to the center of sec. 26, where identical rock is exposed. The readily visible conformability of the floor and arching of the roof are the reasons for which the intrusion is here considered not merely an irregular sill but a true laccolith.

The dike along the Chino Quarry fault southwest of the laccolith is lithologically so similar to the laccolith that the two may well have solidified from the same magma. For this reason the dike is interpreted as a feeder of the laccolith, even though the two masses are not now visibly connected.

Petrography

The rock of the laccolith, a biotite-quartz latite, is a homogeneous porphyry composed of 10–15 percent phenocrysts, most of which are plagioclase (sodic andesine) but a few of which are biotite and quartz, in a medium-gray aphanitic matrix. The plagioclase phenocrysts are as much as 1 cm long and are milky white, being slightly but pervasively altered to sericite and carbonate. Quartz phenocrysts are uncommon and are generally large, measuring ½–1 cm; they are anhedral to subhedral, and unaltered. Biotite phenocrysts are small, less than 5 mm across and generally less than 2 mm thick, but readily visible in hand specimen; thin sections show them to be bleached and in part altered to chlorite, carbonate, and magnetite. The matrix has an average grain size of 0.05–0.1 mm and consists of fresh quartz, plagioclase and probable potassic feldspar altered to montmorillonite and carbonate, minor biotite altered to chlorite, minor magnetite, and a trace of sphene. The argillic alteration is only slight in volume but is manifested as dense tiny grains that permeate the matrix (as montmorillonite) and the phenocrysts (as sericite), so that the phenocrysts are almost indistinguishable in plane polarized light.

Metamorphic effects

The Cameron Creek laccolith has had the following slight contact-metamorphic effects on the invaded rocks within a few feet of the contact:

1. Whitening and recrystallization of limestone ("marmorization") is common.[1]
2. Formation of contact-metamorphic minerals in limestone: grossularite is fairly common, as fine-grained pale-green aggregates sporadically replacing limestone and in places preferentially replacing fossil fragments; prehnite occurs sparsely, as fine-grained radiating fibers recognized only in thin section; and wollastonite is also sparse, as fine-grained prismatic aggregates recognized only in thin section.
3. Local silicification, apparent partial or total replacement of limestone by fine-grained quartz. In one place, quartz forms small (1 mm long) doubly tapered hexagonal spindles with radial internal structure, their size and shape suggesting that they may be silicified fusulines.
4. In places the siltstone of the basal shale member of the Oswaldo Limestone is hardened and has a baked appearance for a few feet from the laccolith, but thin sections show no evidence of metamorphism, either as recrystallization or as introduction of new minerals.

DIKES

Thirty-five dikes, ranging from quartz latite to basalt, have been mapped in the Hurley West quadrangle. Most are only a few feet wide, but their exposed or inferred lengths range from a few feet to three-quarters of a mile. The dikes are assignable to two general compositional groups—silicic to intermediate, and mafic; most of

[1] Yellowish coatings that occur on the limestone within a few feet of the contact in the NW¼NE¼SW¼ sec. 22, which fluoresce greenish yellow under short-wave ultraviolet light and pale green under long-wave ultraviolet light, proved to be calcite; the cause of the fluorescence was not determined, but the coatings give a negative uranium-flux test and have no measurable radioactivity (E. J. Young, written commun., 1959).

them can be identified as to group in the field, though a few of the latites are dark green, their feldspar phenocrysts are plagioclase only, and they look like andesites or basalts. The silicic-to-intermediate dike group comprises 10 dikes of latite or quartz latite and has by far the greater areal extent of the two groups. The mafic dike group comprises 25 generally small dikes of andesite, microgabbro, and basalt. The dikes have had no contact-metamorphic effects on the invaded rocks except for slight recrystallization of limestone or dolomite in a few places, and local formation of garnet.

EMPLACEMENT

Most of the dikes appear to have been emplaced either by creating new fractures or by injection along already existing fractures on which there had been no displacement; only a few dikes occupy obvious faults. The irregular dike along the Rio de Arenas fault seems to represent a combination of permissive and forcible intrusion; the fault probably offered an original zone of weakness, but once the intrusion was begun, it apparently continued by the best means available—magmatic stoping. This is shown not only by the irregularity of its overall pattern and by its divergence to the northwest, away from the Rio de Arenas fault, but also by the following relationships near the northwest end of the dike, at its contact with the Percha Shale:

1. The contact, where visible, is vertical or nearly so, but the bedding of the shale dips 25° NE.
2. In plan, the contact is irregular; at one place it nearly engulfs a peninsula of brecciated shale about a foot long (fig. 10).
3. The shale is severely brecciated as far as 6 feet away from the contact; beyond this it is wrinkled for about another 15 feet.

In summary, some of the dikes were intruded along older faults or fractures, but most of them apparently were emplaced either by pushing the country rocks aside without offsetting them, or in some places by stoping their way into them, or by both of these processes.

PETROGRAPHY

Silicic to intermediate rocks.—Latites and quartz latites constitute 10 of the dikes in the quadrangle. In general they are porphyritic rocks containing less than 40 percent phenocrysts of plagioclase, in some places quartz, and biotite, hornblende, or muscovite, in a light-to-medium-gray aphanitic matrix of plagioclase, potassic feldspar, quartz, and minor ferromagnesian minerals. Plagioclase phenocrysts are at least slightly altered, and in some dikes are intensely altered, to various combinations of sericite, carbonate, and clays. The hornblende and mica phenocrysts are fresh in some dikes, and

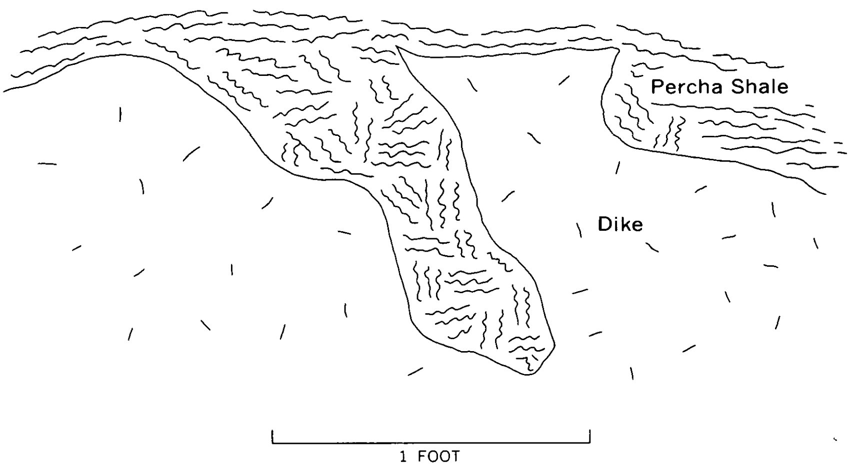


FIGURE 10.—Intrusive contact between quartz latite dike and Box Member of Percha Shale, showing brecciation of shale, NW¼SE¼SW¼ sec. 20, T. 18 S., R. 13 W.

in others they are partly or completely altered to chlorite or to mixtures of chlorite, carbonate, epidote, sericite, and an opaque mineral or minerals. As a rule, the minerals of the matrix are altered to the same degree as the phenocrysts; quartz in the matrix is unaffected, but the feldspars and ferromagnesian minerals are altered to clays, carbonate, sericite, and chlorite.

Mafic rocks.—The mafic dike rocks are dark green in hand specimen and consist of basalts, andesites, and microgabbros. Some have phenocrysts of palagioclase and ferromagnesian minerals—pyroxene or hornblende or both—set in a dark-green fine-grained matrix, whereas others have no recognizable phenocrysts but are sufficiently coarse grained that the plagioclase laths can be distinguished with a hand lens. Microscopic study shows that almost all the mafic rocks are altered; the plagioclase is altered to carbonate and to chlorite or epidote or both; the ferromagnesian minerals are altered to chlorite, epidote, carbonate, and opaque minerals.

DESCRIPTIONS OF SELECTED DIKES

Quartz latite dike along Rio de Arenas fault.—The largest dike in the quadrangle is a quartz latite porphyry dike that appears to have been localized in part by the Rio de Arenas fault; it intrudes the fault zone in the SE¼ sec. 20, and then apparently swerves to the northwest and intrudes the Percha Shale. The dike is not exposed continuously, but the several outcrops over a distance of three-fourths of a mile are correlated on the basis of their distinct lithology—a very light green rock containing phenocrysts of quartz, plagioclase, and potassic feldspar. The quartz phenocrysts are distinctive euhedral bipyramids as much as one-fourth inch long and stand out from the easily weathered matrix. Except in the westernmost outcrop, the potassic feldspar phenocrysts are large and also weather out easily. They occur both as individuals and as Carlsbad twins, or less commonly as Baveno twins, and range in size from a fraction of an inch to 2½ inches.

The dike locally has metamorphosed the Box Member of the Percha Shale. The Percha shows no obvious metamorphic effects in hand specimen other than hardening and some recrystallization, but a thin section of a specimen from within a few inches of the dike shows abundant subhedral poikiloblasts of carbonate, mostly about 0.5 mm across, in a fine-grained (0.05 mm) mosaic of quartz; both minerals contain euhedra of garnet.

Quartz-biotite latite dike along Chino Quarry fault.—The dike along the Chino Quarry fault, in the SE¼ sec. 27, is a porphyry with about 20–25 percent phenocrysts of white plagioclase, minor biotite, and a little quartz, set in a medium-greenish-gray aphanitic matrix. Under the microscope the plagioclase phenocrysts are seen to be slightly altered to sericite; the biotite is completely altered to chlorite and magnetite; and the matrix consists of slightly altered plagioclase and lesser amounts of quartz and potassic feldspar. The similarity to the rock of the Cameron Creek laccolith is conspicuous in both hand specimen and thin section; this lithologic similarity, and the location of the dike along the fault against which the laccolith terminates, suggest that the dike represents a conduit through which magma rose to form the laccolith.

Hornblende-quartz latite dike on west peak of Lone Mountain.—The dike that cuts across the west peak of Lone Mountain characterizes the basaltic-looking latites: its very dark green color in hand specimen gives it the appearance of a basalt, but in thin section it is seen to consist of phenocrysts of plagioclase, hornblende, and a little quartz, in a matrix of quartz, plagioclase, minor biotite, carbonate (from potassic feldspar?), and magnetite. All minerals but the quartz are moderately altered to carbonate; some of the feldspar phenocrysts are completely altered to carbonate, and others, definitely plagioclase, are altered to sericite and carbonate, but only on their rims. Hornblende phenocrysts are fairly abundant and are completely altered to carbonate and dense opaque dust.

AGE AND REGIONAL CORRELATION

The intrusive rocks penetrate the Colorado Formation of early or middle Late Cretaceous age and underlie the Rubio Peak Formation of Miocene(?) age; they are therefore considered as Late Cretaceous to early Tertiary in age. The Chino Quarry sill was the earliest intrusive body, and was probably followed by the Hurley sill and then by the Cameron Creek laccolith and some, perhaps most, of the dikes. None of the intrusions, however, can be assigned to a specific epoch.

The facts pertinent to the age relations among dikes, sills, laccolith, and faults are as follows:

1. The Chino Quarry sill postdates some minor faults in the Oswaldo Limestone but is offset by the Chino Quarry and Indian Village faults.
2. The Indian Village fault is partly engulfed by the Cameron Creek laccolith and fails to offset the Hurley sill.
3. The Cameron Creek laccolith intrudes rock in the Chino Quarry fault zone, and the dike that occupies the Chino Quarry fault is probably a feeder of the laccolith.
4. The Hurley sill is cut by a latite dike.
5. Several dikes occupy faults, lie along fault trends, or cut across faults, and therefore postdate them; the most noteworthy are the large dike along the Rio de Arenas fault and the dike on the west peak of Lone Mountain, which closely follows one fault and cuts across another (North Slope fault). Only one dike, the large one in the NE¼ sec. 30, is offset by a fault.
6. The Hurley sill and several dikes cut the Colorado Formation, and the Hurley sill is overlain by the Rubio Peak Formation.

From these observations may be inferred the following general sequence: (1) deposition of the Colorado Formation in early or middle Late Cretaceous time, (2) minor faulting, (3) intrusion of the Chino Quarry sill, (4) major faulting, (5) intrusion of the Hurley sill, (6) intrusion of the Cameron Creek laccolith and some, perhaps most, of the dikes, and simultaneous movement on Cameron Creek fault, (7) deep erosion, exposing the Hurley sill, and (8) alternating deposition of gravels and volcanics in Miocene(?) time.

Several of the mafic dikes are intruded into the Precambrian granite and could be of Precambrian age themselves, but are considered younger because they are petrographically similar to the mafic dikes that cut younger rocks.

The sills and dikes in the Hurley West quadrangle are part of a vast array of igneous rocks intruded during Late Cretaceous to early Tertiary time throughout the Silver City region. These intrusions include several stocks, numerous sills and laccoliths, and an infinitude of dikes and small plugs; the dikes are clustered most densely in the Fort Bayard quadrangle, where they have intruded the Cretaceous sedimentary rocks and volcanic breccia so pervasively that in places there is very little country rock left. The intrusive rocks in the Hurley West quadrangle make up such a small part of this extensive series that their petrogenesis cannot be considered independently, and it is for this reason that no comprehensive petrologic study was attempted for this report. The only specific correlation between the intrusions in the Hurley West quadrangle and those in the adjacent areas is that the Fort Bayard laccolith of Spencer and Paige (1935, p. 33–34) correlates with the Hurley sill. The two masses are both intruded near the base of the Colorado Formation and appear petrographically identical both in hand specimen and under the microscope; they are therefore considered to be separate exposures of the same sill. Other specific correlations between intrusions in the Hurley West quadrangle and in the adjacent areas are impracticable at the present time, but there is little doubt that they are all related to the same major epoch of igneous intrusion.

CENOZOIC ROCKS AND SEDIMENTS

MIOCENE(?) VOLCANIC AND INTERBEDDED SEDIMENTARY ROCKS

The Hurley West quadrangle is at the western edge of an expanse of gently dipping interbedded volcanic and sedimentary rocks that extends some 20 miles to the east and southeast (Paige, 1916; Kuellmer, 1956); this expanse is referred to here as the Cobre Mountains volcanic field. Because of the restricted occurrence of these rocks in the Hurley West quadrangle, no definitive work on their stratigraphy has been done for this report. They have, however, been divided for convenience of mapping into three formations, which correspond to those defined farther east, in the Dwyer quadrangle (Elston, 1953, 1957) and the Lake Valley quadrangle (Jicha, 1954), and recognized also in the Santa Rita quadrangle (Hernon and others, 1964). These three formations are the Rubio Peak Formation, the Sugarlump Tuff, and the Kneeling Nun Tuff. In the Hurley West quadrangle they are exposed almost exclusively in the bluffs and low hills of the northeastern corner of the quadrangle. This north-south elongate area, about 1 mile wide and 3 miles long (pl. 1), is referred to in this section as the volcanic area.

RUBIO PEAK FORMATION

The Rubio Peak Formation in the Hurley West quadrangle consists of gray to dark-reddish-brown conglomerates and in places red and pink lithic tuffs; the formation overlies the Hurley sill and underlies the Sugarlump Tuff. At its type locality in the Dwyer quadrangle, the Rubio Peak Formation, according to Elston (1957, p. 18–19),

> includes andesite and latite flows, agglomerates, tuffs, breccias, tuffaceous sandstones, and conglomerates. The most common colors are dark gray, brown, purple, or black, but some tuffs are light cream or green. Individual flows or tuff beds have limited extent, and no attempt has been made to map them separately.

Although the conglomerates and interbedded tuffs assigned to the Rubio Peak Formation in the Hurley West quadrangle lack the andesite and latite flows apparently characteristic of the formation in the adjacent quadrangles, they are here considered equivalent to the Rubio Peak Formation mainly because of the conglomerates, which are absent from the typical Sugarlump Tuff but are present in the Rubio Peak Formation, especially in the Santa Rita quadrangle (Hernon and others, 1964).

Three principal rock types make up the Rubio Peak Formation in the Hurley West quadrangle; they are a conglomerate with silicic volcanic debris, an older conglomerate without such debris, and a pink to reddish crystal-lithic rhyolite tuff. The conglomerate without silicic volcanic debris is the oldest of the three rock types and is of sufficient thickness and areal distribution to be mapped separately (pl. 1). The volcanic conglomerate and the rhyolite tuff are interbedded and have been grouped together as a single map unit. The relations between the two map units may be complex, but the older conglomerate appears to be thickest in the northern part of the volcanic area, whereas the volcanic conglomerate and interbedded tuff are thickest in the southern part of the volcanic area; in the northern part, the conglomerate-tuff unit either was never deposited or has been largely eroded.

The older conglomerate is light greenish gray or light brown and poorly sorted; it consists of generally angular or subangular rock fragments, of all sizes from sand grains to boulders, in a slightly calcareous clayey matrix. The fragments represent a variety of rock types—mostly fine-grained porphyries typical of the many dike rocks and older (Cretaceous?) volcanic rocks of the Santa Rita and Fort Bayard quadrangles, but also some sedimentary rocks. The fragments do not, however, include the typical Miocene(?) extrusive rhyolites and silicic tuffs, and the conglomerate therefore was probably deposited just prior to this period of volcanism. A crude bedding is imparted by the greater abundance or greater size of fragments in some beds (fig. 11); the dip of the bedding varies but is locally as great as 20° near the center of sec. 18 (beyond the Hurley West quadrangle). This conglomerate is best exposed along the east bank of Whitewater Creek in sec. 18 and in two northeast-draining gullies west of the highway in the NE¼ sec. 13. Elsewhere, exposures of the conglomerate are few, and its distribution was mapped on the basis of float, a few roadcuts, and a distinctive appearance on the aerial photographs.

The lithology of the volcanic conglomerates and interbedded tuffs forming the upper part of the Rubio Peak Formation is described in section 10.

SECTION 10.—*Upper part of Rubio Peak Formation (partial section)*

[Upper four units exposed in bluff in S½ sec. 19, T. 18 S., R. 12 W., a few hundred yards east of Hurley West quadrangle. Lowest unit exposed in low mesa north of Hurley, in NW¼ sec. 30, T. 18 S., R. 12 W. Measured by W. P. Pratt, Apr. 16, 1959]

	Estimated thickness (feet)
Sugarlump Tuff.	
Rubio Peak Formation:	
Conglomerate containing fragments of silicic volcanic rocks; very poorly exposed	50
Rhyolite tuff, light-pink to medium-brownish-red; both lithic and crystal fragments, including some pumice; maximum size of lithic fragments about 1 in. Parallelism of platy crystals or fragments and abundant tiny flattened vesicles indicates some compaction, but pumice fragments are not noticeably compacted. Forms lowest ledge near base of cliff	25
Conglomerate, volcanic, dark-reddish-brown. Abundant lithic fragments (mostly aphanitic red volcanic rocks) and some mafic crystal fragments, notably euhedral hornblende crystals, also some biotite; calcite cement constitutes about 5 percent of rock. Fairly good stratification owing to some beds having an abundance of large subangular fragments as much as about 4 in. long	6
Rhyolite tuff, pink, crystal-lithic; abundant fragments of biotite, quartz and (or) feldspar, and assorted volcanic rocks, in pink aphanitic matrix. No noticeable compaction; otherwise similar to rhyolite tuff above	50
Conglomerate, volcanic, dark-reddish-brown; like that above	20+
Base covered by alluvium.	
Measured partial thickness of Rubio Peak Formation	151+

SUGARLUMP TUFF

The Sugarlump Tuffs were named by Elston (1957, p. 23) after a hill in the Dwyer quadrangle, where they

> consist of many units, some local and others widespread. They include both massive and bedded pyroclastics of latitic or rhyolitic composition. * * * Many tuffs are conglomeratic or sandy. Colors are strikingly bright, usually green or white, with occasional pink or brown layers. Several beds of massive vitric crystal tuffs 20–50 feet thick are intercalated with bedded tuffs. These beds are interpreted as ignimbrites * * *.

Rocks in the Hurley West quadrangle assigned to the Sugarlump are generally light- to medium-gray rhyolite tuffs, some light and porous and others dense, and interbedded tuffaceous sandstones and conglomerates. They lie above the Rubio Peak Formation and beneath medium-pink rhyolite of the Kneeling Nun Tuff. These gray tuffs and interbedded sedimentary rocks are similar in lithology and stratigraphic position to rocks in the Santa Rita quadrangle correlated with the Sugarlump Tuffs (Hernon and others, 1964); that correlation is followed in this report, but the singular form, Sugarlump Tuff, is used here.

As exposed in the Hurley West quadrangle, the Sugarlump Tuff consists in general of two thick units of light-gray vitric tuffs, each

FIGURE 11.—Older conglomerate of Rubio Peak Formation, east bank of Whitewater Creek, west of center of sec. 18, T. 18 S., R. 12 W.

about 200 feet thick, separated by about 100 feet of tuffaceous sandstones and minor dark conglomerate. The tuffs are distinctive in their light- to medium-gray color and low content of crystal fragments, though some contain numerous fragments of pumice. They are variable in that they range from very light weight porous rocks to heavier, dense, glassy rocks that appear to be welded. The "welded" tuffs, however, are seen under the microscope to contain abundant excellently preserved shards that are devitrified but show none of the compaction that characterizes true welded tuffs (fig. 12), and their welding is therefore the result of devitrification and silicification rather than fusion by their own original heat.

The tuffaceous sandstone unit in the Sugarlump Tuff comprises both poorly bedded and well-bedded materials of light to dark colors and includes a few layers of pink crystal-lithic tuff similar to that in the Rubio Peak Formation.

Details of the lithology of the Sugarlump Tuff are given in section 11.

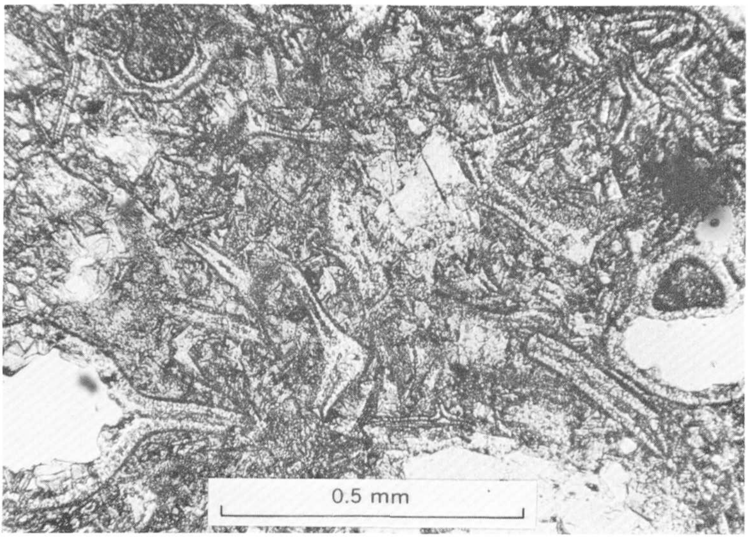


FIGURE 12.—Photomicrograph of vitric tuff of Sugarlump Tuff. × 80, ordinary light. Specimen PC–13A–59.

SECTION 11.—*Composite section of Sugarlump Tuff exposed in sec. 19, T. 18 S., R. 12 W., just east of Hurley West quadrangle, and in extreme northeast corner of the quadrangle*

[Measured by W. P. Pratt, Apr. 16, 1959]

	Estimated thickness (feet)
Kneeling Nun Tuff.	
Sugarlump Tuff:	
Tuff, light-gray; common fragments of quartz, plagioclase, sanidine, and minor biotite, in very light gray or pinkish-gray porous aphanitic matrix (not devitrified)	215
Tuffaceous sandstones, mostly cream colored or light gray, some darker; poorly bedded to well bedded; mostly poorly sorted with fine-grained tuffaceous matrix; gravels locally in upper part; dark-bluish-green sandy bed near base, green color caused by clinoptilolite (W. R. Jones, oral commun., 1960); unit includes a little pink crystal-lithic tuff	110
Conglomerate, dark	5
Tuffs, light-gray; a few pumice fragments, scattered fragments of sanidine, plagioclase, quartz, and biotite, and abundant cavities less than ½ mm across; matrix aphanitic and generally porous but in some places dense and glassy and containing easily visible shards	200
Total estimated thickness of Sugarlump Tuff	530
Rubio Peak Formation.	

At two places in the quadrangle, rocks of the Sugarlump Tuff are almost wholly altered to a bright-pink clay of the montmorillonite group; nothing of the original rock remains other than a few quartz and biotite crystals and faint outlines of the original tuffaceous texture. The best example of this alteration is exposed in a roadcut on U.S. Route 260 about a quarter mile south of the north edge of the quadrangle. Two faults cut the volcanic section here; one of them abuts against a mass of pink clay, but the other fault is inferred and its relation to the clay is not evident. The other exposure of pink clay is 600 feet southwest of the northeast corner of the quadrangle and is also near a fault. In the absence of further evidence, the clay alteration is interpreted as a local result of hydrothermal activity along faults.

KNEELING NUN TUFF

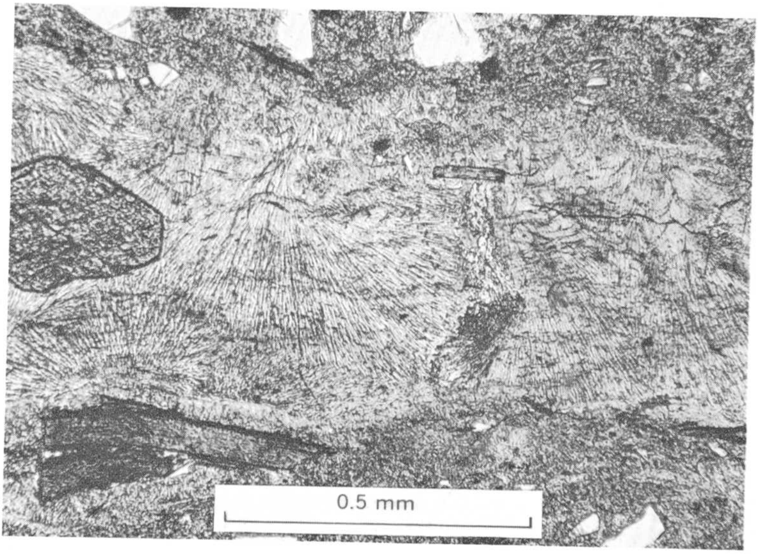
The Kneeling Nun Tuff was named by Elston (1953) for the Kneeling Nun, a prominent landmark in the Santa Rita quadrangle. The name given by Elston was Kneeling Nun Rhyolite Tuff; in the present report the name Kneeling Nun Tuff is preferred, not only because it is less cumbersome but also because the rock is not everywhere a rhyolite (Hernon and others, 1964). As described by Elston (1953, 1957) and Jicha (1954), the Kneeling Nun Tuff is lithologically the most consistent of these three volcanic formations of the Cobre Mountains volcanic field; it is, according to Jicha (1954, p. 44–45), "pinkish gray to reddish brown, medium-grained, highly porphyritic with numerous phenocrysts of quartz as much as 3 mm in diameter, less sanidine and plagioclase of similar size, and minor biotite in a fine-grained matrix."

Rhyolite of the Kneeling Nun Tuff is exposed in a few areas near the north edge of the quadrangle, but the rock in these exposures may not be in place. At least one of them is underlain by conglomerate containing fragments of typical Kneeling Nun Tuff; this "outcrop," therefore, must be a residual block, which casts doubt on the validity of the other outcrops. The adjacent quadrangles contain numerous examples of large blocks of Kneeling Nun Tuff, some as much as several hundred feet long, that have arrived at their present position by landsliding from the face of the retreating cliff. Most of these blocks are sufficiently intact that if they were surrounded by soil or talus, and were isolated enough that their structural relation were not so obvious, they could easily be taken for authentic outcrops of Kneeling Nun Tuff in place. The exposures of Kneeling Nun Tuff in the Hurley West quadrangle may also be residual blocks and as such would belong more properly in the Gila Conglomerate, perhaps as a distinct facies of the conglomerate. They are, however, shown on plate 1 because of their size and their certain source in the Kneeling Nun.

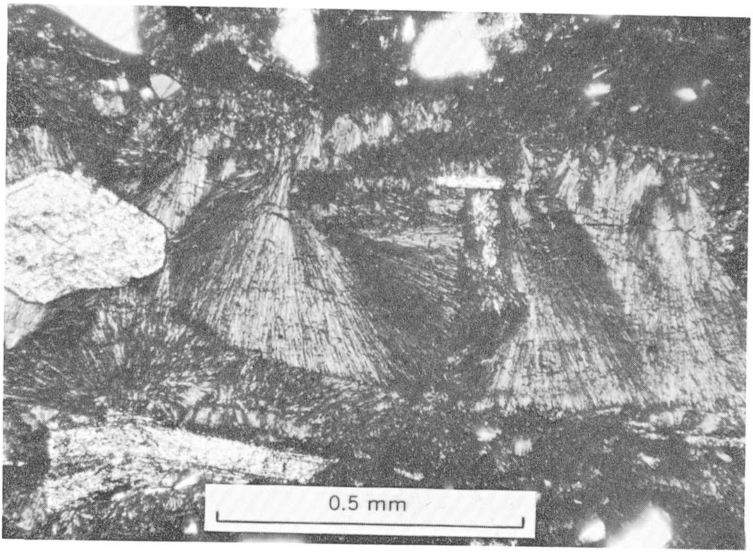
The Kneeling Nun Tuff exposed in the Hurley West quadrangle is a pinkish- or reddish-gray vitrophyre containing abundant crystal fragments of quartz, sanidine, plagioclase, and biotite, and a few lithic fragments, in a pale-red to pale-grayish-red glassy matrix. The matrix appears structureless except for a pronounced but irregular color streaking in some specimens. Under the microscope, the glass appears generally homogeneous but contains many crystallites, and under crossed nicols shows vague radial or sheaflike aggregates of low birefringence, which indicate the beginning of devitrification (fig. 13). Some thin sections show conspicuous light and dark streaks generally parallel but locally very wavy and wrapped around crystal fragments (fig. 14). These streaks are presumed to be shards that have been fused together and wrapped around the crystals under the influence of their own heat and under pressure of the overlying rock; they thus confirm the origin of the Kneeling Nun as a welded tuff, as previously interpreted by Elston and Jicha.

AGE OF VOLCANIC ROCKS

Two lines of evidence, both indirect, suggest middle or late Tertiary ages for these three volcanic formations. The three formations are correlative, both lithologically and stratigraphically, with the Rubio Peak Formation, the Sugarlump Tuff, and the Kneeling Nun Tuff of the Dwyer quadrangle (Elston, 1957) and the Lake Valley quadrangle (Jicha, 1954). (See fig. 1 of this report.) Kuellmer traced probable equivalents of these three formations to an area north of the Hillsboro Peak quadrangle, where the equivalents of the Sugarlump Tuff and the Kneeling Nun Tuff are bracketed by two virtually identical fossil plant assemblages of probable late Miocene or early Pliocene age; the lower of the two assemblages is in strata believed to be correlative with the Rubio Peak Formation (Kuellmer, 1956; Jahns and others, 1955, p. 94; Kuellmer, written commun., 1960). On this basis, all three formations would be late Miocene or early Pliocene in age—if the correlations of the volcanic units were valid. However, rhyolitic volcanics of the Datil Formation near Mogollon and Reserve have recently been dated by the potassium-argon method as 26.7–28.7 m.y. (million years) old—late Oligocene (Weber and Bassett, 1963). The volcanic rocks of the Silver City region have not been traced into the Mogollon area except in a very general way (Dane and Bachman, 1961), but it is almost certain that they all represent the same grand epoch of regional volcanism. Hence the age of the volcanic formations could be anything from late Oligocene to early Pliocene, but in view



A



B

FIGURE 13.—Photomicrograph of devitrified glass in Kneeling Nun Tuff. × 80. *A*, Ordinary light. *B*, Crossed nicols. Specimen PC–11–59.

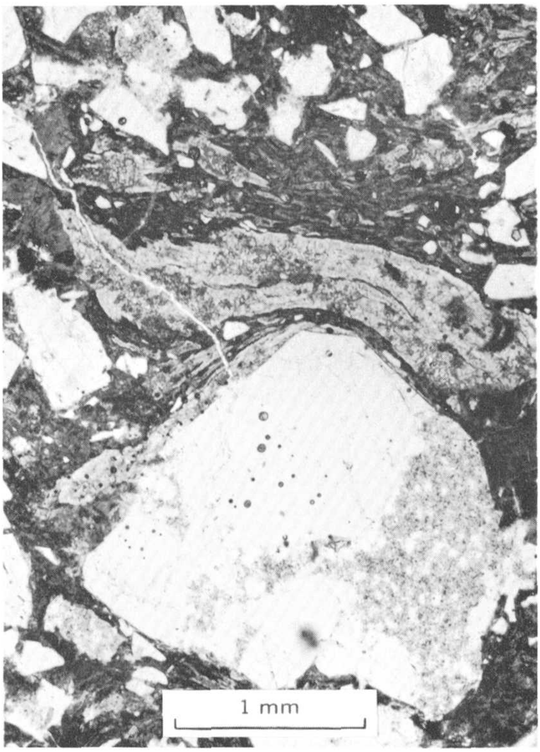


FIGURE 14.—Photomicrograph of welded shards in Kneeling Nun Tuff. × 25, ordinary light. Specimen PC-11-59.

of the inconclusive and possibly conflicting evidence it is here considered simply as Miocene(?).

GILA CONGLOMERATE

Gravels that are poorly to well consolidated and contain fragments of nearly all the rock types in the region underlie about four-fifths of the Hurley West quadrangle and much of the remainder of the Silver City region. Paige (1916, p. 7) noted the probable equivalence of these deposits with the Gila Conglomerate of eastern Arizona, and that name is applied to them here. Probably they are also equivalent with the Santa Fe Group of the Rio Grande drainage, but the Gila correlation is followed here in keeping with a recent proposal (Elston and Netelbeek, 1965, p. 36) that the two units be separated arbitrarily on the basis of drainage basins, the Santa Fe Group being

restricted to all regions where the surface drainage is to the Rio Grande and to closed basins east of the Rio Grande. The Gila Conglomerate * * * [is] restricted to use in all areas where the surface drainage is to the Colorado River and its tributaries, or to closed basins west of the Rio Grande * * * .

Paige's description (1916, p. 6) of the conglomerate may be aptly quoted here:

The material of the deposits is derived from the neighboring mountains and consists of fragments of lava or of pre-Cambrian igneous rocks or younger sediments, its character depending upon the kind of rock that is exposed in the neighboring uplands. The fragments range in size from fine dust to blocks several feet in diameter. In some places large boulders form a part of the deposits. Most of the fragments are subangular, as would be expected in view of the proximity of their source and the mechanical nature of the rock disintegration by which erosion was aided in Pleistocene time, as it is at present.

* * * A description of individual specimens * * * can have but very local application, for the debris was deposited rapidly from areas that contributed abundant supplies, and the deposits formed were various; indeed, they are characterized by lack of homogeneity. The bedding, though discernible, lacks the continuity that is generally characteristic of sediments deposited in bodies of water but illustrates admirably the features that mark rapid continental deposition. * * *

Calcite, silica, and iron oxide, each—or a combination of each—in differing proportions, are the cementing materials which in places bind together the otherwise loosely collected fragments and make of them a resistant conglomerate.

Nearly all the areas shown on the geologic map as Gila Conglomerate represent surficial débris rather than actual outcrops. The conglomerate is well exposed only in the banks of the deeper gullies and stream valleys, especially in the steep walls of San Vicente Arroyo in the southwest part of the quadrangle and along the east bank of Cameron Creek west of the Silver City airport. The boulders of volcanic rocks that are characteristic of much of the conglomerate litter the surface over most of the quadrangle.

Facies.—Three general lithologic facies of the Gila Conglomerate can be recognized in the quadrangle; they are here referred to as the volcanic, carbonate, and silicic facies, on the basis of the dominant constituent. The lithologies and the distribution of the three facies reflect not only the lithologies of the source areas but also the depositional pattern of debris from these source areas (fig. 15). The volcanic facies covers all but the southwestern part of the quadrangle; it represents the alluvial fan of the Pinos Altos Mountains to the north and, to a lesser extent, that of the Cobre Mountains to the east. It is characterized by boulders of vesicular basalt and andesite, derived from flows that overlie the Kneeling Nun Tuff. The silicic facies occurs in the southwestern part of the quadrangle and forms the alluvial fan of the Little Burro Mountains, from whose dominantly silicic igneous and metamorphic rocks it was derived. Its fragments consist chiefly of light-colored aphanitic porphyries, granitic rocks, pink and light-gray quartzite, and fairly

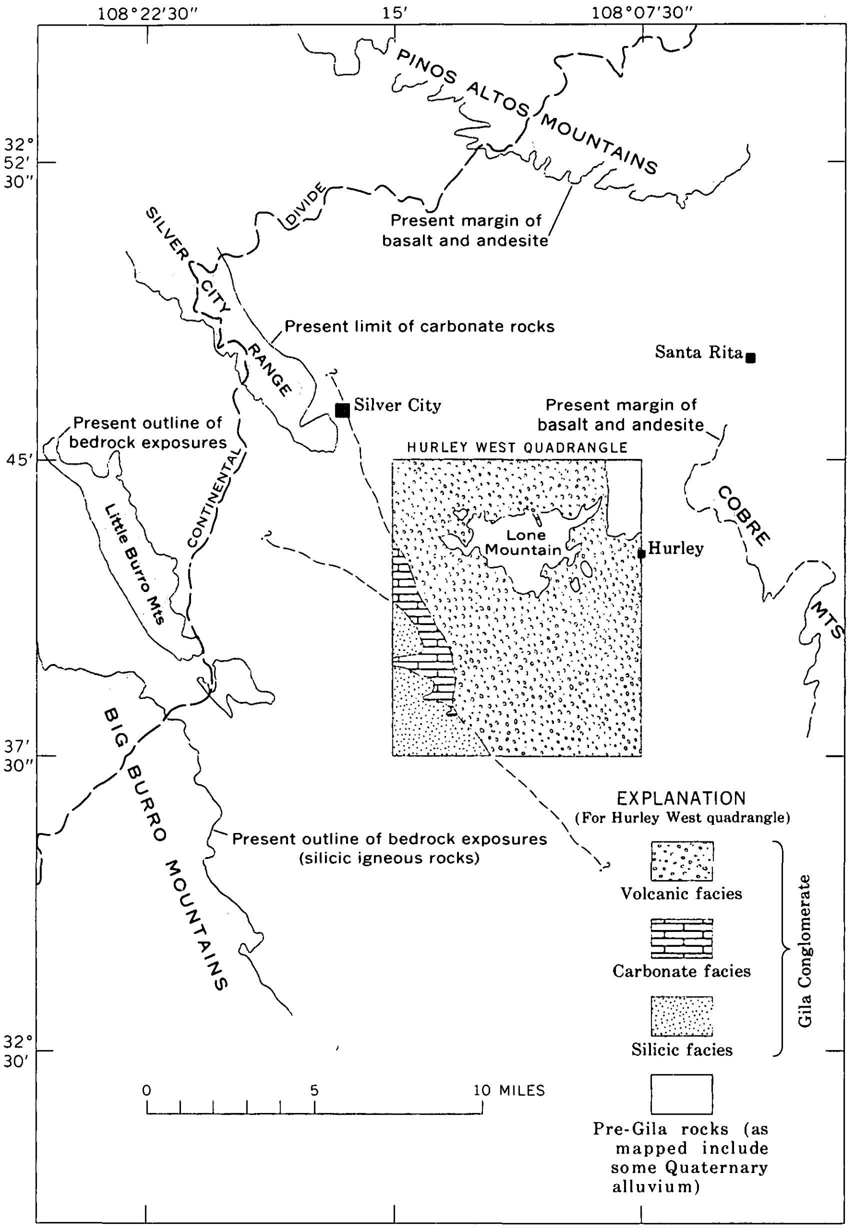


FIGURE 15.—Lithologic facies of Gila Conglomerate in the Hurley West quadrangle, in relation to their respective source areas.

abundant small grains of feldspar. This facies is distinguished from the other two by the abundance of these silicic rocks, the absence of limestone or basaltic volcanic rocks, and the generally pink color of the silty or clayey matrix. The carbonate facies, which contains common limestone and dolomite fragments in addition to those of volcanics and other rocks, occurs in a narrow strip along the west side of San Vicente Arroyo; this strip is a part of the alluvial fan of the Silver City Range. The outlines of the three facies shown in figure 15 are generalized; actually there is some interlayering of the silicic and carbonate facies, and this is interpreted as being a result of the alternate overlapping of the two fans as they grew and coalesced.

Age.—The Gila Conglomerate postdates the Kneeling Nun Tuff, which in this report is considered as Miocene(?) in age. Paige (1916, p. 6–7), in correlating these rocks with the Gila Conglomerate, followed Gilbert's original assignment of an early Quaternary age. Near Silver City, however, the formation is overlain by semiunconsolidated alluvium considered at least as old as fairly early Pleistocene (W. R. Jones and R. M. Hernon, written commun., 1960). The age of the Gila Conglomerate in this area is therefore inferred to be Pliocene to early Pleistocene. This accords with the age of the Gila in southeastern Arizona as established by vertebrate fossils (Heindl, 1952, p. 114).

QUATERNARY DEPOSITS

Colluvium covering an area about 2 miles long and as much as a mile wide along the southwest side of Lone Mountain was mapped separately to distinguish it from Gila Conglomerate. The colluvium, derived from the steep southwest slopes of Lone Mountain, consists mostly of coarse limestone and dolomite debris cemented by caliche; its extent was mapped almost solely on the basis of the light-gray color of the caliche as interpreted on aerial photographs and may be in error locally. Smaller masses of colluvium, including talus, are common, especially along the east side of the ridge of Gila Conglomerate that caps the Hurley sill and around the mesas formed by the Rubio Peak Formation north of Hurley. These masses were not mapped separately but were included in the Quaternary alluvium.

Alluvium in the Hurley West quadrangle consists of unconsolidated to moderately cemented gravel, sand, and silt, and occupies nearly all the major and intermediate stream courses of the quadrangle. Locally—as in the upper parts of Cameron Creek, its tributary to the west, and the Rio de Arenas—the silts have given rise to soil that is irrigated and used for pasture. Recent streamwash, where of significant extent, is shown on plate 1 by the dotted pattern of the topographic base map. The Quaternary alluvium was mapped in most places from aerial photographs, on the basis of a slight change in slope across the streambank, which marks the contact between alluvium and Gila Conglomerate. The change in slope is more pronounced in the larger valleys—San Vicente Arroyo, Rio de Arenas, and Cameron Creek. In many of the smaller drainages, the alluvium constitutes only a thin veneer in the stream bottom, and the change in slope at its edge is very slight. Hence the mapped extent of Quaternary alluvium may be characterized by the generalization that the smaller the gully, the less exact is the outline of its alluvial fill.

The thickness of the alluvium ranges from less than 1 foot in the narrowest gullies to about 30 feet in the lower part of San Vicente Arroyo. In many places it has been trenched by recent gullying, much of which has occurred since the middle of the 19th century, according to longtime residents. There is no internal evidence of the maximum age of the alluvium and no indication that it includes a significant stratigraphic break. The alluvium is younger than the Gila Conglomerate and may be presumed to represent continuous erosion of the Gila since some time during the Pleistocene.

GEOLOGIC STRUCTURE

REGIONAL SETTING AND MAJOR STRUCTURAL UNITS

The Hurley West quadrangle is in the Basin and Range province a few miles south of its boundary with the Datil section of the Colorado Plateaus (fig. 16). The gross structural grain in this region strikes northwest, and is characterized by broad open folds broken by steep northwest-trending normal faults that define the dominant structural units, a series of elongate blocks. Lone Mountain lies in one of these blocks, which extends northwest to include the Silver City Range. The block is bounded on the southwest by a major fault, the Silver City fault, whose southwest side has moved relatively down, and on the northeast by the Mimbres fault, whose northeast side has moved relatively down. In the Lone Mountain area this large block has been broken into smaller ones by cross faults that trend northeast (pl. 1); the principal cross faults are here named, from northwest to southeast, the Rio de Arenas, North Slope, West Peak, Percha Valley, and Chino Quarry faults. Two other faults, not cross faults in the same sense as those listed here but important in connection with intrusion of the Cameron Creek laccolith, are here named the Indian Village fault[2] and the Cameron Creek fault.

[2] So named in allusion to its location near the site of the "Cameron Creek Village" of the Mimbres Indians, excavation of which was described by Bradfield (1929). The site is along the top of the short ridge that projects into Cameron Creek valley in the SE¼NE¼ sec. 23, T. 18 S., R. 13 W. (erroneously reported as sec. 33 by Bradfield, 1929, p. 9).

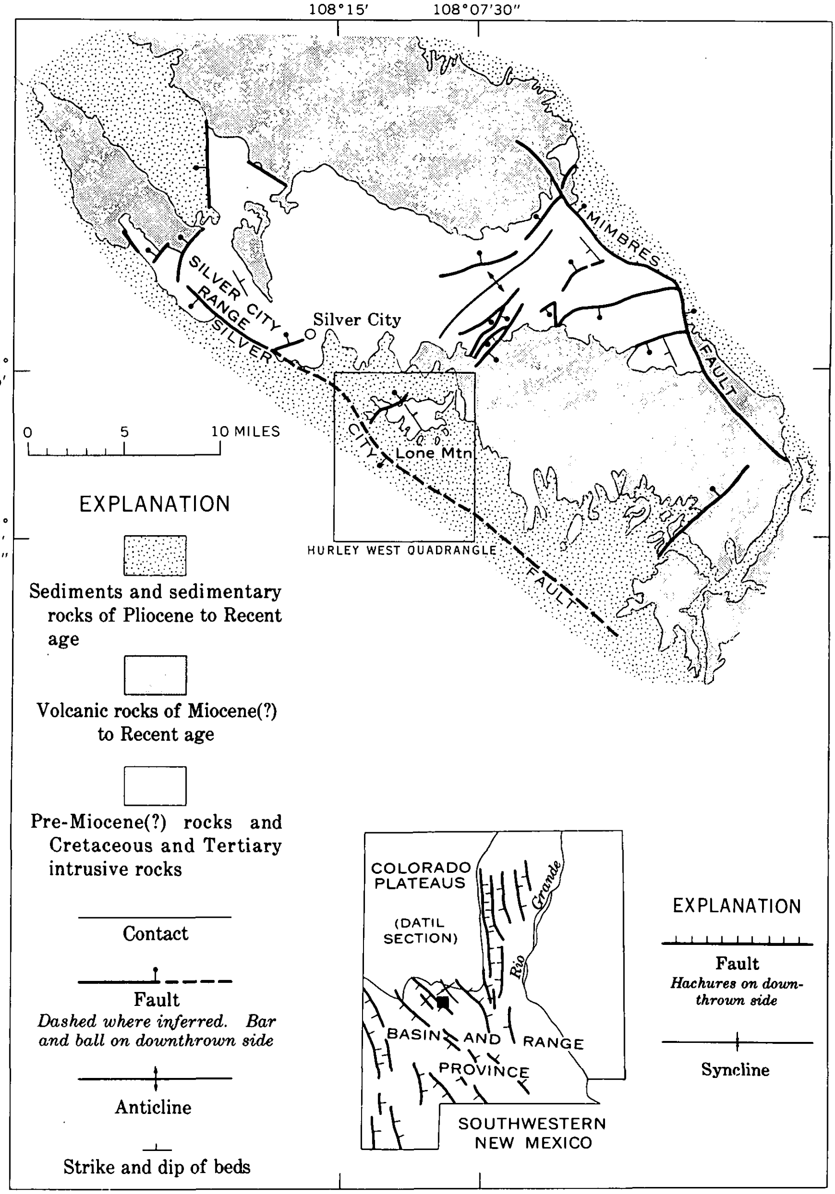


FIGURE 16.—Principal structural features of the Silver City region. Modified from Jones, Hernon, and Pratt (1961), Dane and Bachman (1961), and Kelley and Silver (1952).

The faults in the volcanic rocks in the northeast corner of the quadrangle are significantly younger than the Lone Mountain faults—Pliocene(?) rather than early Tertiary(?)—but probably represent renewed movements on older faults that may be extensions of the cross-fault pattern in the Lone Mountain area. They are not considered in detail in this report, because their displacement in this quadrangle is relatively insignificant.

FOLDS

The gently northeasterly dipping Lone Mountain strata, characterized by Paige (1916, p. 10–11, fig. 8) as the Lone Mountain monocline, appear regionally as the southwest limb of a broad syncline whose opposite limb is exposed in the Santa Rita quadrangle; the axis of this syncline trends northwest and passes about 7 miles northeast of Lone Mountain. The Lone Mountain "monocline" is the southern extension of a similar synclinal limb in the Silver City Range.

Most folds recognized within the Hurley West quadrangle are either too small and local or too broad and subtle for their axes to be depicted on plate 1. A few small folds are associated with faults, as along the south edge of sec. 22, and are indicated by the map pattern. A long low dome in the northeastern part of the quadrangle is indicated by the outcrop pattern of the gray vitric tuffs of the Sugarlump Tuff (principally along the base of the cliff in the Hurley East quadrangle), and by dips in the conglomerates of the Rubio Peak Formation; the approximate location of the domal axis is shown on plate 1. The dome is thought to be related to movements on the Groundhog fault of the adjacent Fort Bayard and Santa Rita quadrangles (W. R. Jones, oral commun., 1960). Another small dome, outlined by the contact of the Bliss Sandstone against the Precambrian granite in sec. 29, appears to be little more than a local irregularity on the synclinal limb of Lone Mountain and in fact may be only a result of drag along the Rio de Arenas fault.

The age of the regional folds is not known, but they are thought to have been formed during the same period of deformation that produced the major faults—early in the Tertiary. No major folding is known to have affected the area prior to that time. Regional warping, however, at some time between the Permian and the Late Cretaceous, is indicated by the unconformity at the base of the Beartooth Quartzite.

FAULTS AND FRACTURES

Faults in the Hurley West quadrangle are all normal and are vertical or steeply dipping; most of them strike roughly northeast, but a few strike almost due north or in the northwest quadrant. Neither the direction of movement (whether vertical or horizontal) nor the absolute movement (which block moved) is known for any faults except the Rio de Arenas fault, on which movement appears to have been vertical. Presumably movement on the other faults also was dominantly vertical.

Most of the faults are manifested in the field by single silicified fractures or by zones of silicified fractures or breccia no more than a few feet wide, as well as by obvious offset of beds; some faults, such as the northwest-trending echelon faults in the SW¼ sec. 22, are also expressed in the topography. A few faults are indicated by offset of beds even though no fractures are apparent, as in two segments of the North Slope fault. Faults in the northeastern part of the quadrangle are recognized by their obvious offset of volcanic rocks but generally show no distinct fracture zone. A few other faults are shown on plate 1 where fractures occur, without visible offset, along strike from faults that do have offset, as in the Fusselman Dolomite in the outlier west of Cameron Creek, near the center of sec. 34; in most places, however, fractures such as these are parts of broader fracture zones and are so indicated on plate 1. Faults of little displacement within the Fusselman Dolomite, and possibly within the Cutter Dolomite and the Lake Valley Limestone, may well have been passed over because they are healed by recrystallization and do not offset marker beds.

Only five faults are discussed individually in this report, the first two because of their importance as major structural breaks and the other three because of their complex mutual history. The remaining faults mostly fit the generalities just given.

SILVER CITY FAULT

The Silver City fault is the major fault that marks the southwest side of the regional Silver City horst (Ordonez and others, 1955, p. 10).[3] The fault is presumed to exist west of Lone Mountain to account for repetition of part of the section farther west in the Little Burro Mountains. The fault must trend approximately northwest; it thus defines the southwest side of the Lone Mountain "monocline" and connects with the unnamed fault mapped by Paige along the east side of Treasure Mountain, which marks the southwest side of the Silver City Range (fig. 16; see also Paige, 1916, fig. 8). Its inferred existence west of Lone Mountain is confirmed by an aeromagnetic survey made by a private mining company, which shows a linear magnetic anomaly trending approximately northwest across the quadrangle from the north center of sec. 9, T. 19 S., R. 13 W., to the south center of sec. 13, T. 18 S., R. 14 W. The fault appears to be a typical basin-range mountain-block fault, whose west side presumably was dropped down. The Silver City fault is the primary

[3] The recent application to this fault of a new name, "Treasure Mountain fault" (Jones and others, 1964, fig. 1 and p. 4), was the inadvertent error of the present author and is hereby recanted.

structural reason for the existence of Lone Mountain and the Silver City Range.

RIO DE ARENAS FAULT

Another major fault, the Rio de Arenas fault, marks the northwest side of the North Slope block. As measured on section *B–B′*, plate 1, the net vertical separation on the two branches of the fault is about 2,300 feet, north side down; the net left-lateral separation is about a mile. Both the sinuous trace of the fault, and vertical slickensides on the fault surface in the SW¼ sec. 21, suggest that the movement was dominantly vertical.

Although the presence of the fault is clearly indicated by the visible offset of formations, the fault itself is not well exposed. A smooth, linear, vertical surface along the outcrop of Precambrian granite in the NW¼ sec. 29 is the best exposure of the actual fault surface. A major irregular dike has intruded the fault for a distance of about half a mile in and near the SE cor. sec. 20. At several places in the SW¼ sec. 21, the fault is a zone of silicified breccia several feet wide; in addition to massive dolomite that might have come from any of several formations, the breccia contains a few blocks of the distinctive cherty dolomite of the Aleman Formation. Although most of the displacement appears to have been along the single fault that is marked by this breccia zone, an anomalous pattern of outcrops between the main fault and a branch fault just to the south, in the same area, suggests that the Rio de Arenas fault at least locally is not a simple one but may have involved one or more slivers as much as half a mile long.

The Rio de Arenas fault is inferred to extend beneath the Gila Conglomerate both to the southwest and to the northeast, for unknown distances. Two plugs of quartz latite porphyry, like the quartz latite porphyry of the irregular dike along the fault in secs. 20 and 29, lie about 4½ miles N. 25° E. from the east end of the dike, in the Fort Bayard quadrangle (for their approximate location, see areal geologic map in Paige, 1916). W. R. Jones observed (oral commun., 1961) that these plugs are suggestive of a north-northeast extension of the Rio de Arenas fault.

INDIAN VILLAGE FAULT, CAMERON CREEK FAULT, AND CHINO QUARRY FAULT

The peculiar distribution of the formations surrounding the Cameron Creek laccolith, and their relations to it, indicate that the laccolith at its thickest point uplifted its roof about 1,100 feet along a trapdoor fault and then engulfed the rocks on either side of the fault. The emplacement of the laccolith culminated a rather complicated series of structural events (Pratt and Jones, 1961b, 1965), interpreted as follows (see fig. 17):

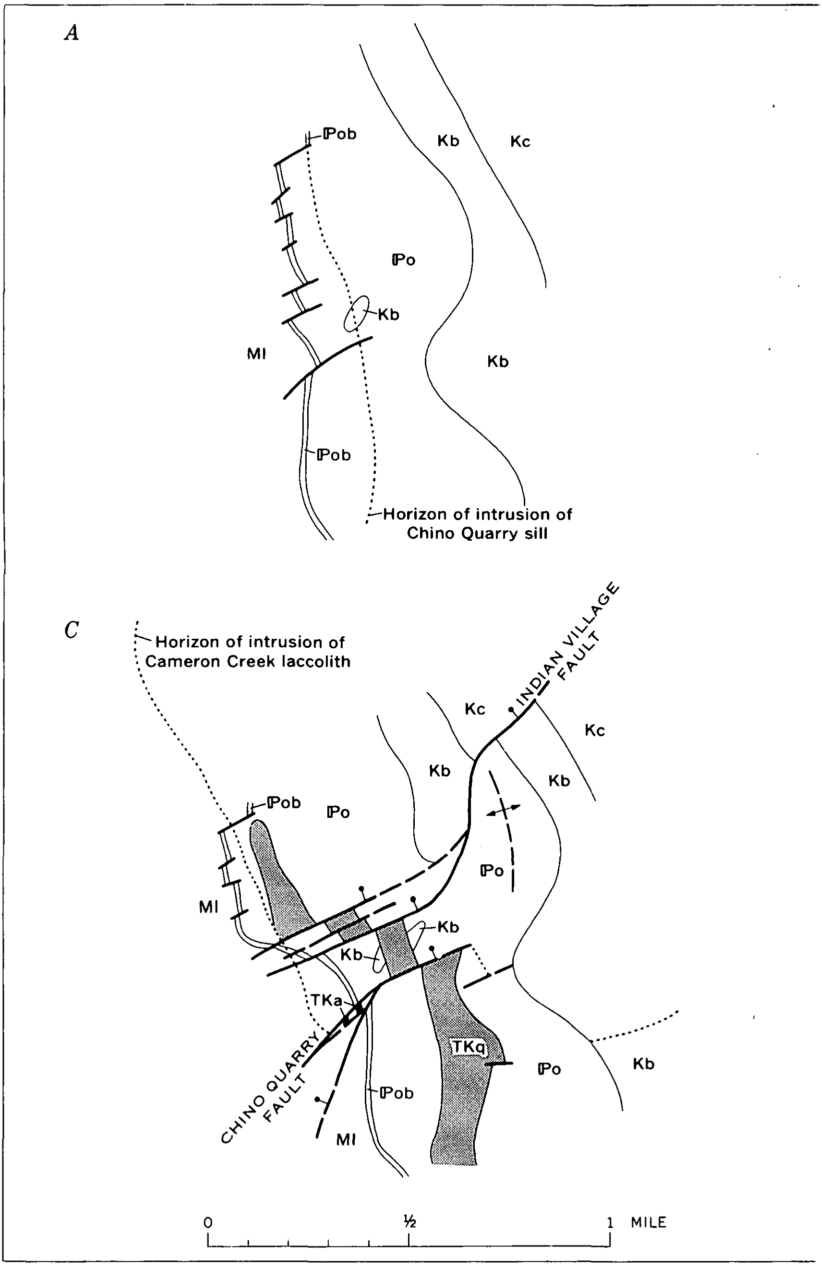
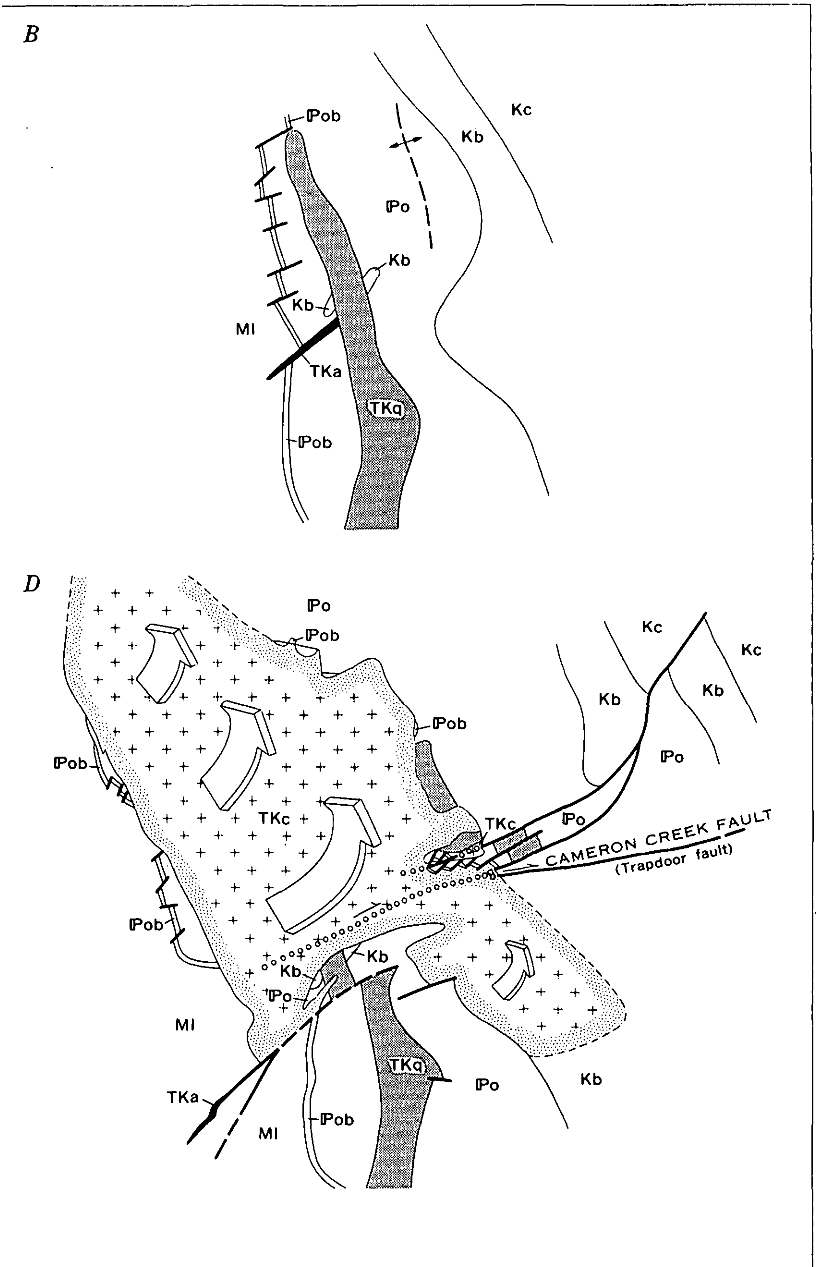


FIGURE 17.—Inferred history of deformation in the vicinity of the Cameron Creek laccolith, shown as successive maps at level of present ground surface. TKa, dikes; TKc, Cameron Creek laccolith; TKg, Chino Quarry sill; Kc, Colorado Formation; Kb, Beartooth Quartzite; Po, Oswaldo Lime-



stone; Pob, basal shale member of Oswaldo Limestone; Ml, Lake Valley Limestone. In *C*, bar and ball on downthrown side of faults. Small circles in *D* represent postulated preintrusion positions of faults.

1. Pre-Late Cretaceous tilting and normal faulting of the Oswaldo Limestone, with dominantly right-lateral apparent offset. Erosion to an irregular surface, followed by deposition of Beartooth Quartzite and Colorado Formation in Late Cretaceous time (fig. 17*A*).
2. Emplacement of Chino Quarry sill in the Oswaldo Limestone, at different distances above the base because of the earlier faulting. Southernmost of earlier faults is locus of feeder channel (fig. 17*B*).
3. Renewed faulting, with left-lateral apparent offset. Principal movement on the Indian Village fault, which split westward into two (or more) faults, southernmost of which later coincided with part of the Cameron Creek fault (fig. 17*C*).
4. Emplacement of Hurley sill in Colorado Formation north of Indian Village fault but mostly in Beartooth Quartzite south of fault.
5. Intrusion of Cameron Creek laccolith along surface indicated by dotted line in figure 17*C*. Room for laccolith created by vertical uplift of roof rocks along a new fault, the Cameron Creek fault (which represents the open side of the trapdoor), the entire block north of fault being apparently offset to east (fig. 17*D*). (Hinge of trapdoor is represented by point where laccolith wedges out to north—now concealed under Gila Conglomerate.) Laccolith magma then partly engulfing rocks south of fault, obliterating western part of fault. Rocks within the Indian Village fault zone severely faulted by drag along the Cameron Creek fault.
6. Erosion; deposition of volcanic rocks and Gila Conglomerate; and later erosion to present surface (pl. 1).

Evidence that the Chino Quarry fault preceded, and in part limited, emplacement of the Cameron Creek laccolith is found in the fault zone in the NE¼SE¼ sec. 27, where the laccolith intrudes the rock of the fault zone; these relations are shown in figure 18. The presence in the fault zone of dark-green latite like that of the Chino Quarry sill suggests that the original fault acted as a feeder channel for the sill—as it did later for the Cameron Creek laccolith. According to this interpretation, renewed movement on the fault after emplacement of the Chino Quarry sill (fig. 17*C*) deformed the feeder dike and left the isolated remnants now exposed.

Other interpretations of the field relations are possible. One alternative interpretation would account for the two small outcrops of Beartooth Quartzite near the east edge of sec. 27 as a result of faulting, rather than deposition on an undulating erosion surface on the Oswaldo Limestone; however, a fault of the required throw and trend would almost certainly have continued into the Lake Valley Limestone below, and no such fault now appears there. Other possible inter-

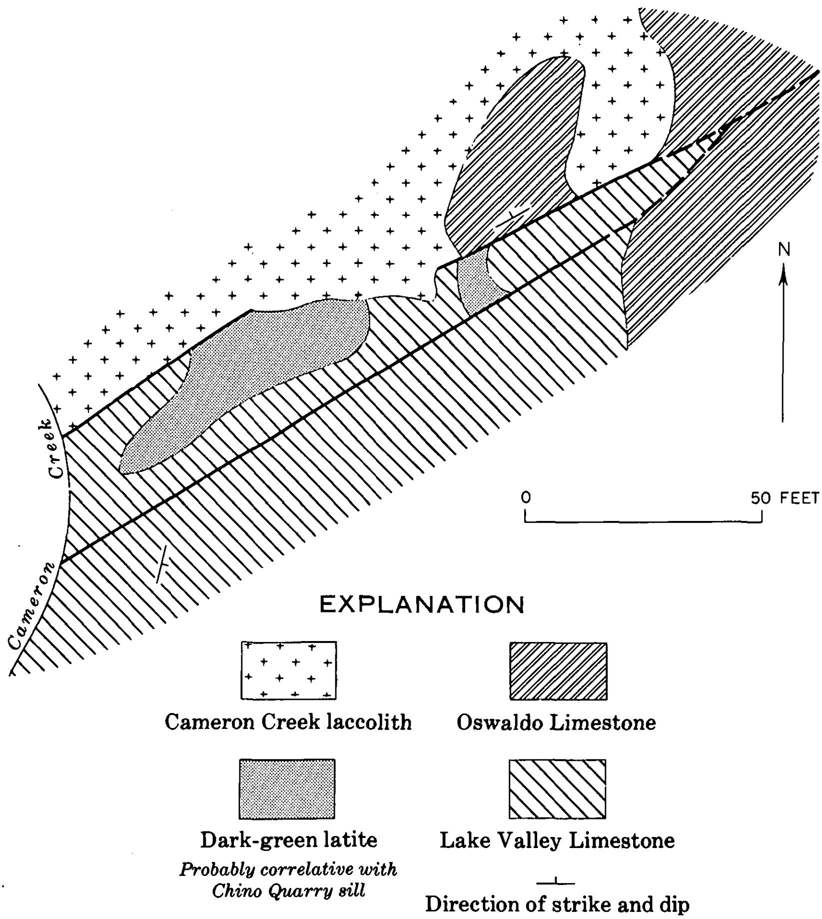


FIGURE 18.—Chino Quarry fault zone in NE¼SE¼ sec. 27, T. 18 S., R. 13 W.

pretations would differ from that presented here mainly in assuming that the Chino Quarry sill preceded faulting of the Oswaldo Limestone and was originally intruded at different horizons in the Oswaldo on opposite sides of joints—as is typical of diabase sills in the Arizona asbestos region. Each interpretation has its own difficulties; the one presented here is preferred because in spite of its difficulties—such as the assumed obliteration of some of the evidence (engulfment of the Cameron Creek fault)—it appears to be the simplest explanation of all the observed facts.

GEOLOGIC AGE OF FAULTS

The faults at Lone Mountain are inferred to have formed during three main periods of faulting: (1) minor faulting prior to deposition of the Beartooth Quartzite; (2) minor faulting after deposition of the

Colorado Formation and before intrusion of the Chino Quarry sill, and (3) major faulting that postdated this sill but predated the Hurley sill, the Cameron Creek laccolith, and many dikes. (The specific evidence of these age relations has been listed in the section entitled "Age and regional correlation," p. E53, and need not be repeated here.) The third episode, major faulting, included the principal movements on the Rio de Arenas fault and other cross faults of similar trends. This major faulting has not been dated in terms of Tertiary epochs; but in the complex sequence of tectonic events that occurred between the Late Cretaceous and the Miocene(?), the major faulting was early (Jones and others, 1961).

The Rio de Arenas fault is the only cross fault that is fairly well dated; it postdates the Colorado Formation of Late Cretaceous age and predates a major dike. (The presence of Gila Conglomerate against the surface of the Rio de Arenas fault in two places is suggestive of some minor post-Gila movement on this fault, but the exposures are not conclusive.)

The faults in the Miocene(?) volcanic rocks, even though they may express deeper faults that were initiated earlier, have obviously been active since the Miocene(?); these faults do not, however, extend into the exposed parts of the Gila Conglomerate—that is, the uppermost parts, which are of Pleistocene(?) age. The age of these faults is therefore inferred to be Pliocene(?).

GEOMORPHOLOGY

The present land surface of the Hurley West quadrangle is inherited largely from two older surfaces that were developed at various stages from the early Tertiary to the Pleistocene(?). The older of these surfaces is now either buried or eroded, and its traces are exposed only locally. The younger of the surfaces, the Bayard surface, is partly preserved in nearly three-quarters of the quadrangle.[4]

PEDIMENT AT BASE OF GILA CONGLOMERATE

With the uplift of the regional block bounded by the Silver City and Mimbres faults (fig. 16) at some time prior to the Miocene(?), erosion proceeded to cut back into the mountain block; on the southwest side of the mountain block a pediment was formed, across which the erosional debris was transported en route to its deposition in the structural basin south of the Silver City fault. As the highland wore down and the basin was filled in, the level of the basin fill rose and its margin advanced northward across the pediment,

[4] I am indebted to the late Robert M. Hernon for an enlightening discussion of the pre-Gila pediment and the Bayard surface. In addition, much of this material is drawn from a report by Jones, Hernon, and Moore (1967) on the Santa Rita quadrangle.

gradually burying the beveled mountain block under its own debris—the Gila Conglomerate. The pediment itself is now exposed only as a trace. Where the Gila Conglomerate remains, the pediment is buried beneath it, as in most of the Hurley West quadrangle; in areas to the north the original pediment has been removed and replaced by another pediment, slightly lower, which forms part of the Bayard surface. The only parts of the pre-Gila surface now exposed in the quadrangle are the inselbergs, such as Lone Mountain and its outliers, that were never worn down to the general pediment level. The present ground surface at these places corresponds closely to the pre-Gila surface but is slightly lower because of post-Gila erosion.

BAYARD SURFACE

Bayard surface is the name given by Jones, Hernon, and Moore (1967) to a gently southward sloping erosional surface that bevels the Gila Conglomerate and older rocks. The Bayard surface extends from the steep flank of the Pinos Altos mountains southward into the Deming basin; it slopes uniformly at about 80 feet per mile, being interrupted only by Lone Mountain and some of its outliers, which project up through the surface, and by the drainage network that cuts into it. The surface was named from its conspicuousness near the town of Bayard, which is just off the northeast corner of the Hurley West quadrangle.

The Bayard surface is in essence a second pediment on the regional mountain block. North of the Hurley West quadrangle, the surface is cut on bedrock and is clearly a surface of erosion. It is also an erosional surface in the Hurley West quadrangle, but here it is cut mainly on the Gila Conglomerate. In a strict sense the Bayard surface is a pediment only as far southwest as the Silver City fault; in a broader sense it is a pediment as far south as it is preserved—that is, to the edge of the alluvium derived from erosion of the Gila Conglomerate. The relation of the Bayard surface to the Gila Conglomerate and to the earlier pediment is shown diagrammatically in figure 19. As is evident from the diagram, the Bayard surface largely reflects the original surface (top) of the Gila Conglomerate.

PRESENT LAND SURFACE

The present land surface of the Hurley West quadrangle is composed of four geomorphic or physiographic elements. The most conspicuous of these is Lone Mountain. The second most conspicuous is the dissected Bayard surface, against whose extensive flatness Lone Mountain stands out in such contrast. The other two elements are parts of physiographic units best developed elsewhere: in the southwest corner the dissected fan of the Little Burro Mountains,

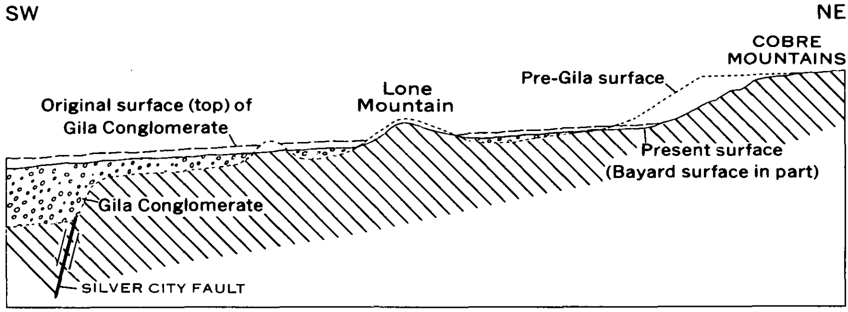


FIGURE 19.—Relation of Bayard surface to Gila Conglomerate. Vertical scale exaggerated.

and in the northeast corner the irregular topography of the west edge of the Cobre Mountains volcanic field.

LONE MOUNTAIN

Like mountains in almost any moderately arid region, Lone Mountain owes both its major form and its minor topographic details largely to two factors: its geologic structure, and the relative resistance of its component formations to erosion. Lone Mountain is a remnant of a cuesta formed on rocks that dip gently to the northeast. The existence of the mountain as an isolated unit is the result of (relative) uplift of the Lone Mountain-Silver City block along the Silver City fault; its isolation from the Silver City Range is due to its (relative) uplift along the Rio de Arenas fault. The lithology of the Percha Shale has been the next greatest control: the Percha is easily eroded in contrast to the limestone and dolomite above and below it, and in most places it has been stripped back and has left a dip slope on the underlying Fusselman Dolomite. The Percha is now marked by a valley, which at Lone Mountain is bounded on the west by the gentle dip slope of the Fusselman and on the east by a steeper slope eroded across the beds of the Lake Valley Limestone. The lowland east of the Lake Valley hill reflects lower resistance of the Cameron Creek laccolith. Many smaller details of form in and around Lone Mountain are related to several factors, particularly the following three: (1) Differences in resistance of individual beds or groups of beds (in the Bliss Sandstone, for example, the quartzite beds weather to steeper slopes than the dolomite beds), (2) juxtaposition of formations of different resistance along faults, and (3) generally lower resistance of dikes. Most of these details can be seen in the field but are too small to be shown on the topographic map.

DISSECTED BAYARD SURFACE

The Bayard surface, modified by incised stream valleys, constitutes the present surface of nearly three-quarters of the quadrangle. Alluvial terraces in many places show that the present drainage network has undergone two periods of downcutting. During the first period the main wide channels were cut—Pipe Line Draw, San Vicente Arroyo, Maudes Canyon, Rio de Arenas, Cameron Creek, and Whitewater Creek. This period was followed by a period of deposition during which the valleys were partly refilled with alluvium. During recent rejuvenation the streams have incised the valley fill, reaching its base almost everywhere. Many of the resulting paired terraces are only a few feet across and a foot or so high, but others are as much as half a mile across and about 30 feet high. The best displayed terrace is in San Vicente Arroyo near the center of sec. 20, T. 19 S., R. 13 W., where the present stream channel exposes excellently the unconformity between valley fill and Gila Conglomerate.

DISSECTED FAN OF THE BURRO MOUNTAINS

The southwestern part of the quadrangle, specifically the part west of Pipe Line Draw, lies on the outermost flanks of the alluvial fan of the Little Burro Mountains. The area is characterized by topography notably different from that of the adjacent Bayard surface; it slopes eastward rather than southward, and it is much more intricately dissected than the Bayard surface. (See pl. 1 and fig. 20.) This area is underlain chiefly by the finer gravels of the silicic facies of the Gila Conglomerate; the mergence, and possible interfingering, of this facies with the volcanic and limestone facies of the Gila is approximately coincident with Pipe Line Draw.

The more intricate dissection of the surface is probably a result of the different lithology of this facies of the Gila. R. M. Hernon pointed out (oral commun., 1961) that the presence of limestone and basalt in the two facies underlying the Bayard surface favors the development of caliche, visible in some roadcuts, which would tend to resist erosion, whereas the silicic facies lacks these calcium-rich rocks and does not give rise to caliche. Another possible explanation is that the erodability is a simple function of grain size, the sands and fine gravels of the silicic facies being reflected in a finer grained, more intricate dissection pattern than the coarser gravels of the volcanic and limestone facies.

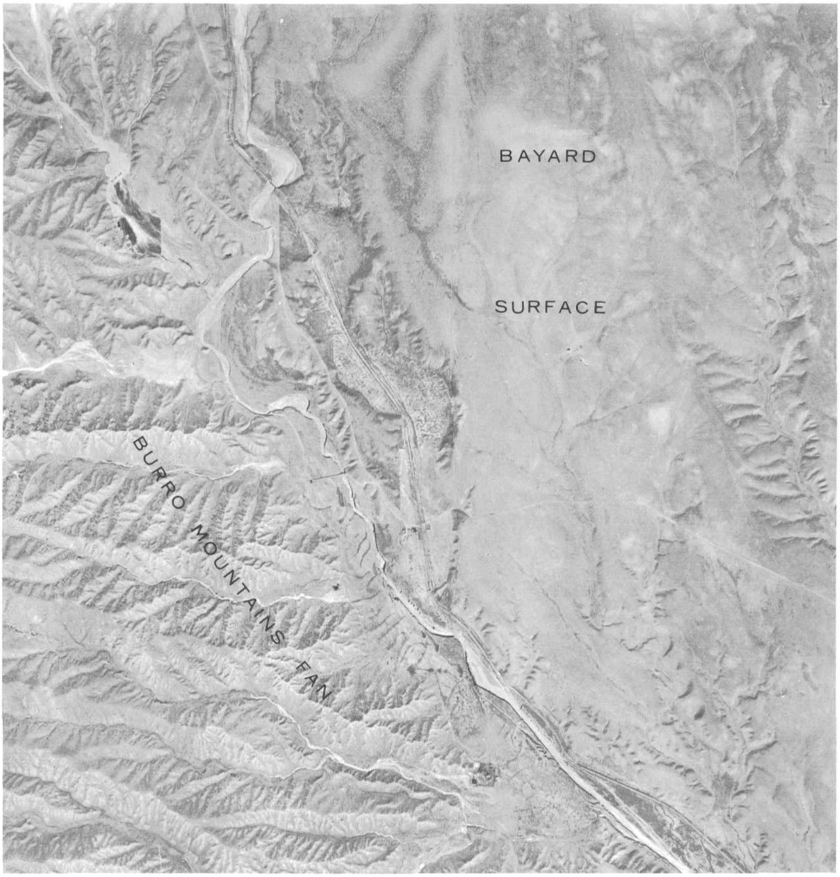


FIGURE 20.—Aerial photomosaic showing topographic contrast between Bayard surface, east of Pipe Line Draw, and Burro Mountains fan to west. From Geological Survey photographs GS–BX 2–14 and 2–15.

WEST EDGE OF COBRE MOUNTAINS VOLCANIC FIELD

The landforms in the northeast part of the quadrangle represent a transition between the Bayard surface and the Cobre Mountains volcanic field. The volcanic rocks are flat lying and generally erode to cliff-and-bench topography, such as that extending about a mile north from Hurley. Farther north in the quadrangle, where the volcanic rocks have been faulted and are thinner than elsewhere, the topography is irregular, and its details are largely dependent on different degrees of resistance of different lithologies.

GEOLOGIC HISTORY

A résumé of the major Cenozoic events in the Hurley West quadrangle is presented in table 3. Events of the Paleozoic and Mesozoic

TABLE 3.—*Geologic events of the Cenozoic Era in the Hurley West quadrangle*

ERA	PERIOD	EPOCH	EVENT: Magmatism: Intrusion	EVENT: Magmatism: Extrusion	EVENT: Tectonism	EVENT: Erosion	EVENT: Deposition
CENOZOIC	QUATERNARY	Recent			? Rejuvenation	Incision of valley fill and general erosion throughout quadrangle	
		Pleistocene			? Rejuvenation	Original dissection of Bayard surface Formation of Bayard surface	Refilling of valleys
	TERTIARY	Pliocene(?)			Faulting of volcanic rocks (reactivation of older faults?)		Gila gravels
		Miocene(?)		Kneeling Nun Tuff Sugarlump Tuff Rubio Peak Formation			Sediments in Sugarlump Tuff and Rubio Peak Formation
		Pre-Miocene(?), postmiddle Late Cretaceous	Cameron Creek laccolith and most dikes Hurley sill Chino Quarry sill		Trapdoor faulting Major faulting Minor faulting	Beginning of pedimentation	

consisted entirely of marine sedimentation interrupted by occasional periods of emergence—nondeposition or erosion. For more complete discussions, particularly of the Paleozoic record, the reader is referred to Paige's lucid reconstruction of events in the Silver City region (1916, p. 12) and to Flower's comprehensive interpretation of Cambrian to Mississippian history throughout southern New Mexico (1958, p. 63–65). As for events of the Precambrian, the small outcrops of granite permit only the unenlightening inference that at some time in the Precambrian, granite was emplaced.

ECONOMIC GEOLOGY

Rich silver ore was discovered at Lone Mountain in 1871. Mining was excitedly active for about 3 years after this, and during that time Lone Mountain became a district in its own right; but the excitement dwindled as the high-grade ores near the surface were mined out, and by 1884 the Lone Mountain district was virtually inactive. No more production was reported until 1920, when activity was spurred by new discoveries of silver ore southeast of Lone Mountain, about 2 miles west of Hurley. The new deposits were worked sporadically in the early 1920's and in the late 1930's and late 1940's. No silver production has been reported since 1950, but claims have been staked on the east slope of the central peak as recently as March 1960.

Other mineral resources that have been exploited in the Hurley West quadrangle include manganese oxide deposits in limestone, copper in solution in Whitewater Creek, limestone quarried for use as a flux in the copper smelter at Hurley, and gravel quarried for road metal.

METALLIC MINERAL RESOURCES

Any attempt to synthesize a general description of the Lone Mountain silver and manganese ore meets with several frustrations. The first and most obvious is that they are mostly mined out. Second, direct observations of ore minerals are limited to a few shallow pits and to material found on the dumps; nearly all the shafts are caved or unsafe. Finally, reports in the various mineral-resource volumes of the 1870's and 1880's are informative in a general way as to mineralogy and form, but their references to specific veins are in terms of claims whose locations are no longer known. Manganese ores have been produced intermittently since 1918, some of them apparently from the same mines that formerly produced silver; but there is little evidence now as to whether the silver deposits should be classed as silver-manganese deposits or whether some of them were free of manganese. Consequently the distinction between silver ores and manganese ores in this report is only a convenient means of organizing the available data and carries no genetic implication.

DEPOSITS OF SILVER ORE

OCCURRENCE

The most extensive of the silver mines at Lone Mountain were reached through shafts in the north-northwest-trending valley underlain by Percha Shale, in sec. 27. A few shafts also were sunk along the North Slope fault in the NE¼ sec. 29. An adit near the top of the west peak extends about 100 feet N. 80° E. along a fracture zone.

These ores occurred mainly in crosscutting fractures and did not show the obvious stratigraphic control that characterized the silver ores elsewhere in the region, most of which were in the Fusselman Dolomite immediately beneath the Percha Shale (Graton, 1910, p. 320). Although many of the veins at Lone Mountain were in the upper part of the Fusselman, others lay deeper in the Fusselman. At least one vein, on the west peak, is in a vertical fracture in the Upham Dolomite Member and Aleman Formation; and shafts and dumps indicate that a considerable amount of ore—presumably silver ore—was mined from along the west end of the North Slope fault, where the fault separates Precambrian granite from Bliss Sandstone and El Paso Dolomite.

The ores discovered in 1920 were mined from a few open cuts and shafts in the Lake Valley Limestone, mostly in the SW¼ sec. 35. The shafts are now inaccessible, but a long pit near the center of sec. 35, in the Lake Valley Limestone and just beneath the Oswaldo Limestone, follows a zone of fractures trending N. 65° W. Another group of shafts and pits in the Lake Valley, mostly in the S½ sec. 20, probably was worked primarily for manganese, but may also have produced some silver.

MINERALOGY

The silver ore mined at Lone Mountain in the last century was described by Graton (1910) as follows:

> Silver chloride was the most common ore mineral, but the richest ores carried curved bundles of native silver wires and, it is said, argentite also. * * * The veins are narrow and the values not persistent. * * * Thorough oxidation has destroyed evidence of the character of the original ore minerals. The absence of much lead and the richness of the narrow veins, together with the reported presence of argentite, make it seem possible that that mineral may have been the principal silver carrier in the unoxidized ore.

This information is supplemented by reports published in the 1870's and 1880's, which indicate that most of the veins were 2–5 feet thick; one report mentions a vein nearly 8 feet thick. Another report refers to "a well defined vein of sulphurets [sulfides] and native sheet copper" (U.S. Bureau of the Mint, 1883, p. 581), the only mention of ore minerals other than the three listed by Graton.

Little is known of the primary ore mineralogy beyond Graton's mention of reported argentite. The only sulfide observed at Lone Mountain during the present study is galena: it occurs with barite in a narrow vein explored by means of an adit near the top of the west peak, and much more sparsely, again with barite, in small workings along the valley in sec. 27. Other minerals occurring in fractures exposed in small workings, or in specimens collected on the dumps, include quartz, calcite, dolomite, and small amounts of anglesite, cerussite, willemite, and malachite.

Even less is known about the occurrence of the silver-manganese ores discovered in 1920 in sec. 35, southeast of Lone Mountain. The shafts, which are in the Tierra Blanca Member of the Lake Valley Limestone, are now inaccessible, and the only vein mineral seen on their dumps is dark brown coarsely crystalline calcite. A pit near the center of sec. 35 follows a zone of fractures filled with botryoidal and fibrous manganese oxide together with calcite, quartz, and barite. Some of the calcite is dark brown or nearly black; a sample of this calcite analyzed colorimetrically contained 1.51 percent manganese, but spectrographic analysis showed a content of only 0.0003 percent silver.

ORIGIN

The origin of the silver ores is unknown. Graton (1910, p. 321), reflecting the then current trend of thought to relate ore deposits to nearby intrusions merely on the basis of proximity, wrote "the ore deposition at Lone Mountain was probably related both in time and origin to the porphyry intrusion [presumably the Cameron Creek laccolith]." It is noteworthy, however, that the known metamorphic effects of the laccolith on its host rocks are only slight and do not include metallization. There is, in short, no evidence that the ores are spatially or genetically related to intrusive bodies recognized during this study.

MANGANESE OXIDE DEPOSITS

ORE BODIES WEST OF LONE MOUNTAIN

Small bodies of manganese ore in the Lake Valley Limestone west of Lone Mountain have been worked intermittently from 1918 to as recently as May 1959. Small workings and prospects are centered about three localities west and northwest of Lone Mountain: (1) In the SE¼SW¼SE¼ sec. 20 are the most recently worked ore bodies, in a 150- by 500-foot zone of minor fractures in the Nunn and Tierra Blanca Members of the Lake Valley Limestone. The zone trends north-northwest, generally parallel to several larger faults in the SE¼ sec. 20 (pl. 1). (2) About half a mile to the northwest, in the SW¼NW¼ sec. 20, are fairly extensive but older workings which consist of several shafts that are now inaccessible and a few shallow pits in the Tierra Blanca Member and in the Oswaldo Limestone. Minor fractures are exposed in some of these workings, but no mappable faults were seen in this area. (3) In the NE¼ sec. 30 and NW¼ sec. 29, a few pits were dug, apparently to develop small amounts of manganese oxide in the El Paso Dolomite. Wells' description (1918, p. 43) of the location of the "Causland property" seems best to fit this locality, but his description of the geology mentioned nearby dikes and is therefore thought to refer to the ore bodies in locality 1.

The manganese ore, which occurs chiefly as replacement bodies in Lake Valley Limestone, apparently was subject to both structural and stratigraphic controls. All but one of the ore bodies now exposed are irregular vertical masses that appear to have replaced the limestone outward from vertical fractures, which the ore now fills. At the north end of the recent workings, a tabular body of ore, averaging about 8 inches in thickness, lies parallel to the bedding immediately below the basal shale member of the Oswaldo Limestone. The few shafts that start in the Oswaldo Limestone appear to have gone through the basal shale member into the Lake Valley Limestone, because shale and mineralized limestone are found on the shaft dumps although no manganese minerals are visible in the Oswaldo exposed in their walls; the inference is that the shafts were sunk in order to reach potentially mineralized Lake Valley Limestone beneath the shale.

The ore consists of fibrous and massive black manganese oxide(s), either in relatively pure masses or in combination with iron oxides and silica. Some of the mineralized rock is highly siliceous, resembling jasperoid, and it is not known how much of this siliceous rock was considered "ore"; only handpicked fibrous oxides were recovered in 1959. Quartz and calcite constitute the gangue. The fibrous oxide appears to be free of iron, but the ore mined in 1918 was not; according to Wells (1918, p. 43), a mixed sample from several exposures assayed 18.8 percent manganese and 35.4 percent iron. Handpicked ore shipped in 1959 assayed 36–37 percent manganese (William Rockwell, oral commun., 1959).

MANGANESE-BEARING CALCITE VEINS IN HURLEY SILL

Veins as much as 6 feet thick, consisting of brown to black coarsely crystalline calcite and a little fibrous manganese oxide, occur at several places in the Hurley sill (pl. 1). The calcite is megascopically similar to the dark calcite southeast of Lone Mountain, which contains about 1.5 percent manganese. Two pits have been dug on the thickest of these veins, near the center of the north edge of sec. 24, to depths of about 10 feet and 25 feet; it is not known whether the pits were dug to extract the manganese oxide as ore, or merely to explore the vein.

ORIGIN

The association of manganese oxides with manganese-bearing calcite veins in several places suggests that the oxides were formed by oxidation of the calcite, as outlined by Emmons (1917, p. 440). Hewett and Fleischer (1960, p. 24), however, considered that in certain deposits of this type, both the calcite and the manganese oxides are hypogene. In the deposit southeast of Lone Mountain, manganese oxide coats quartz, calcite, and other minerals; hence it must have been the last mineral to form, but this does not indicate whether it was hypogene or supergene.

POSSIBLE UNDISCOVERED MANGANESE ORE BODIES

Most of the areas of high potential for discovery of new silver and (or) manganese deposits, or extensions of known deposits, seem to have been adequately prospected, but one area northwest of Lone Mountain appears to merit exploration for manganese at some future time when the demand justifies exploration for one or more small ore bodies like those mined in the past. This area is in the NE¼ SW¼ sec. 20 where an inferred fault in the Lake Valley Limestone is concealed beneath an apparently thin veneer of Gila Conglomerate. Shafts, pits, and dumps in the outcrop area to the west indicate significant past production of ore from the Lake Valley Limestone. The specific area probably most favorable for subsurface prospecting is a narrow northwest-trending zone that represents the continuation of the base of the Oswaldo Limestone beneath the conglomerate—particularly the area where this zone would be intersected by the projection of the inferred fault.

COPPER IN WHITEWATER CREEK

Whitewater Creek, a stream that flows southward through the northeast corner of the quadrangle, is fed principally by waters that start farther northeast in Hanover and Santa Rita Creeks and are diverted by Kennecott Copper Corp. to leach the vast dump of waste rock from the Chino open-pit copper mine.

Copper is precipitated from these waters and most of the residual solution is recycled over the dump, but a small amount—still containing a little copper—escapes downstream along Whitewater Creek. Independent operators channel this weak solution into small vats or troughs containing scrap iron, thus repeating the precipitation operation on a much smaller and slower scale. In the spring of 1960 there were some half-dozen independent operations of this type in the Hurley West quadrangle.

CONCENTRATIONS OF DETRITAL IRON OXIDES

Rounded magnetic cobbles of iron oxides, as much as several inches across, occur in the present streambeds and locally are concentrated at stream bends and elsewhere. The cobbles consist of a fine-grained intergrowth of magnetite, ilmenite, and minor hematite (T. G. Lovering, written commun., 1960); their immediate source is the Gila Conglomerate, but they are presumed to have been derived ultimately from the contact-metamorphic magnetite deposits adjacent to the Hanover-Fierro stock in the Santa Rita quadrangle. The concentrations of cobbles have been exploited on a small scale. Similar concentrations may be present in buried channels in the Gila Conglomerate; the magnetite content of such concentrations, if they are not buried deeply beneath the present surface, should make them detectable by continuous ground traverses with a magnetometer sensitive to 1 gamma (J. E. Case, oral commun., 1965).

A Geological Survey aeromagnetic survey made in 1946 (Jones and others, 1964) shows a small anomaly of about 200 gammas at the center of the NE¼ sec. 20, T. 18 S., R. 13 W. There is no indication of a fault or other potentially mineralized zone extending into this area beneath the Gila Conglomerate, and conceivably the anomaly is due to a large concentration of magnetite cobbles in the conglomerate.

NONMETALLIC MINERAL RESOURCES

LIMESTONE FOR METALLURGICAL USE

Oswaldo Limestone is extracted from a large quarry just west of the Chino Quarry sill and hauled by truck to Hurley, where it is used as a flux in the smelting of copper ore. The same formation is exposed farther east along the road now used for haulage; the only apparent reason for location of the quarry where it is, a mile farther from Hurley, is that the stratigraphic part of the Oswaldo Limestone being quarried there is chemically more suitable for use at the smelter. A small quarry in the Tierra Blanca Member of the Lake Valley Limestone, just south of the draw in the NW¼NE¼ sec. 27, is now abandoned; its original purpose is not known, but it too may have provided limestone for the smelter. As can be seen from the geologic map and sections, the reserves of Lake Valley and Oswaldo Limestones, probably as pure as that now being quarried, are large and easily accessible.

GRAVEL

Construction projects in the vicinity of the Hurley West quadrangle will never suffer for want of gravel; the Gila Conglomerate underlies more than three-quarters of the quadrangle, and much of it is so poorly consolidated that it could be easily quarried as gravel. The conglomerate has been quarried in at least one place, in the NE¼ NW¼ sec. 25, for use as road ballast; in 1959 the gravel was used in the widening of U.S. Highway 260 between Silver City and Central.

Gila Conglomerate probably has been quarried in small quantities elsewhere in the quadrangle, as it is almost everywhere easily accessible from the roads. The silicic facies, in the southwest part of the quadrangle, would probably be adaptable to different uses from those of the volcanic and limestone facies because of its finer grain size.

AMETHYST

A small pit in the NW¼SE¼ sec. 21 was opened some years ago to develop a showing of amethyst, but the material proved too poor to exploit profitably. The amethyst occurred in a silicified zone, in the Fusselman Dolomite, which is now partly covered by rubble but appears to trend about N. 10° E. The pit extends about 20 feet along this trend and has a maximum width of about 10 feet and a maximum accessible depth of 6 feet. The silicified zone narrows and continues northward at the surface for about 50 feet, but shows no amethyst; it does not visibly continue to the south. A few specimens on the dump contain slightly cloudy pale-violet terminated crystals a few inches long; others contain intergrowths of larger crystals with pyramidal faces indicating a diameter of nearly 2 inches, but these also are variably pale violet to white. No crystals approaching gem quality were seen.

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